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**LOW COST AND FLEXIBLE TERMINAL NODE  
CONTROLLER DESIGN**

**M.Sc. THESIS  
IN  
ELECTRICAL AND ELECTRONICS ENGINEERING**

**BY  
YUSUF ELŞEYH VEYS  
MAY 2022**

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**M.Sc. Thesis  
in  
Electrical and Electronics Engineering  
Gaziantep University**

**Supervisor  
Assist. Prof. Dr. Serkan ÖZBAY**

**by  
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May 2022**



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# **LOW COST AND FLEXIBLE TERMINAL NODE CONTROLLER DESIGN**

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**Yusuf ELŞEYH VEYS**

## **ABSTRACT**

### **LOW COST AND FLEXIBLE TERMINAL NODE CONTROLLER DESIGN**

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**M.Sc. in Electrical and Electronics Engineering**  
**Supervisor: Assist. Prof. Dr. Serkan ÖZBAY**  
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With the spread of chaos and instability in conflict areas, the need for a tracking system has increased. In this thesis, a design and implementation of a low-cost communication network is introduced. The designed system uses UHF/VHF for vehicle localization using custom APRS hardware built with off-the-shelf electronic components and registration of acquired location using local database service. The proposed system also takes into account the financial aspect and accessibility of equipment as a prerequisite for the success of the network.

**Key Words:** Geolocation, Geo-registration, Radio Beacon, Arduino, Raspberry Pi,  
UHF, VHF, TNC, AFSK, APRS.

## ÖZET

### DÜŞÜK MALİYETLİ VE ESNEK TERMİNAL DÜĞÜM DENETLEYİCİSİ TASARIMI

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Çatışma bölgelerinde kaosun ve istikrarsızlığın yaygınlaşmasıyla birlikte bir takip sistemine olan ihtiyaç artmıştır. Bu tezde, düşük maliyetli bir iletişim ağının tasarımı ve uygulaması tanıtılmaktadır. Tasarlanan sistem, kullanıma hazır elektronik bileşenlerle oluşturulmuş özel APRS donanımını kullanarak araç lokalizasyonu için ve yerel veritabanı hizmeti kullanılarak edinilen konumun kaydı için UHF/VHF kullanır. Önerilen sistem ayrıca, ağın başarısı için bir ön koşul olarak ekipmanın finansal yönünü ve erişilebilirliğini de dikkate almaktadır.

**Anahtar Kelimeler:** Konum Belirleme, Coğrafi Kayıt, Radyo İşaretçisi, Arduino,

Raspberry Pi, UHF, VHF, TNC, AFSK, APRS.



*"Dedicated to my family"*

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(84) So, fight, [O Muḥammad], in the cause of Allah; you are not held responsible except for yourself. And encourage the believers [to join you] that perhaps Allāh will restrain the [military] might of those who disbelieve. And Allāh is greater in might and stronger in [exemplary] punishment.

To the soul of my mujahid immigrant father... My first impulsion to science and morals... He was waiting for this dissertation a lot, but the fate has been written for all of us faster.

To my patient and self-sacrificing mother, who has been away from her children and family for decades.

To my sister and brothers who I hope to meet soon.

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I dedicate this thesis

Youssef Abdullah Omar Sheikh Weiss

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## LIST OF ABBREVIATIONS

|              |                                                     |
|--------------|-----------------------------------------------------|
| <b>TNC</b>   | A Terminal Node Controller                          |
| <b>AFSK</b>  | Audio Frequency-Shift Keying                        |
| <b>APRS</b>  | Automatic Packet Reporting System                   |
| <b>AX.25</b> | A data link layer protocol                          |
| <b>GPS</b>   | Global Positioning System                           |
| <b>PTT</b>   | Push-To-Talk                                        |
| <b>XOR</b>   | XOR is a logical operation, pronounced exclusive OR |
| <b>AES</b>   | Advanced Encryption Standard                        |
| <b>UHF</b>   | Ultra-High Frequency                                |
| <b>VHF</b>   | Very High Frequency                                 |

## **CHAPTER I**

### **INTRODUCTION**

#### **1.1 Background and Problem**

Building traditional communication networks is impractical in conflict zones, for example (Syria, Iraq, Yemen, etc.), due to conditions of instability the management of the central regions will disappear, which makes them in a state of chaos, in which robberies and crimes abound, and it is difficult to control the security and administrative with traditional capabilities. They need expensive networks and a long time to build communication networks and fixed telephone exchanges and optical fibres, and all the above will not happen before political stability, which is a far-reaching reconstruction project in the current perspective. This increases the mentioned problems on the local administration and the people. The development of this technology helps local administrations and institutions to adjust the various processes according to the required application.

#### **1.2 Research Questions**

- 1.2.1 How to create a fast (transmitting and receiving) network, which does not depend on expensive traditional government infrastructure, as it can be used separately and reduced according to the required application?
- 1.2.2 The type of terminal used to load the received signal from the sensor (analog or digital).
- 1.2.3 Slowing update of data received from several sources separated in the system.
- 1.2.4 Weak encryption algorithm (xor algorithm).

1.2.5 Providing relatively inexpensive equipment for the network to be installed on the ground.

1.2.6 Terminal only sends the signal (we try to make it receive too).

### **1.3 Research Solutions**

The scopes are varied and different according to the nature of the available materials in the target area, the ranges are as follows:

1.3.1 Using an analog to digital converter or using direct digital transmitters Diversifying the microprocessors used to obtain the best control (Pic, Arduino ...) [1-3].

1.3.2 Experimenting with several protocols to reconfigure data as packets for transmission and reception [1-3].

1.3.3 Using an appropriate mechanism to compress the analog signal (for example, speech) when using the audio signal to transfer data [1-3].

1.3.4 Looking for a software library suitable for the network communication layers [4-5] [10-11].

1.3.5 Experimenting with theories of signal division TDMA, FDMA, CDMA, SDMA.... to get the best speed in updating the data received on the system [4][6].

1.3.6 Reducing the size of the data sent and limiting it to the necessary data and obtaining a brief message for transmission [7].

1.3.7 Using UHF networks to send data or part of GSM networks [8].

1.3.8 Using multiple encoding networks to obtain the highest possible encryption [4-6].

1.3.9 Finding a solution so that the terminal is for transmission and reception.

### **1.4 Research Scope**

Packet radio network may be considered as a simple wireless wide area network which does not depend on the traditional costly government infrastructure.

Terminal Node Controllers (TNCs) are used to interface a digital data source with radio transmitters in the VHF or UHF bands. Terminal Node Controller (TNC) is a

microprocessor-based on circuit that provides for connection of Data Terminal Equipment (DTE) device (e.g., personal computer) to packet radio network.

In other words, TNC is an autonomous microprocessor system with a modem that allows the control radio transceiver directly from TNC. TNC controller consists of two parts. The first one is digital by which data format processing runs according to the requirements of the packet radio network and operating rules such as the AX.25 protocol while the second one is analog part that plays a role of a modem and provides for a control over the radio transceiver directly from TNC.

The main tasks of this thesis are firstly to study packet radio networks in detail then to design Terminal Node Controller as low cost by a new produced microprocessor and flexible by the use of new software. The design is tested and the performance is evaluated on a packet radio network.

### **1.5 Research Benefits**

That project achieves its goal by building a network to track vehicles with ready-made components capable of covering an area of 300 km in diameter in a politically and security volatile region, and that the project is an important point for raising the technical and security infrastructure and moving towards stability.

### **1.6 Definitions**

1.6.1 Geolocation: It is a technology that uses data acquired from an individual's computer or mobile device to identify or describe the user's actual physical location [1-3].

1.6.2 Radio beacon: It is a device that transmits periodic radio signals with limited information (e.g., its identification or location) on a specific radio frequency [1-3].

1.6.3 Terminal Node Controller (TNC): It is a piece of equipment amateur radio operators use to send and receive data on their computers through radiofrequency [1-3].

1.6.4 Audio Frequency-Shift Keying (AFSK): It is a way to convert the digital data to an analog signal by modulating the frequency of the audio,

which makes it suitable to transmit over radio or telephone or even record it using audio recorders [4][6].

1.6.5 Automatic Packet Reporting System (APRS): It is a two-way tactical real-time radio-based digital communication system between all assets in a network for sharing information about everything going on in the local area at a specific frequency [10-11].

1.6.6 AX.25: It is a data link layer protocol derived from the X.25 protocol suite and designed for use by amateur radio operators [10-11].

1.6.7 Walkie talkie: It is handheld portable radio that use radio waves to communicate wirelessly on a single frequency band [3].

1.6.8 (GPS) Global Positioning System: It is a satellite-based navigation system made up of at least 24 satellites. GPS works in any weather conditions, anywhere in the world, 24 hours a day, with no subscription fees or setup charges [1-3].

1.6.9 Microcontroller: It is a compact integrated circuit designed to govern a specific operation in an embedded system. A typical microcontroller includes a processor, memory, and input/output (I/O) peripherals on a single chip [1-3].

1.6.10 Voltage Regulator: It is an electrical or electronic device that maintains the voltage of a power source within acceptable limits [9].

1.6.11 Push-to-talk or press-to-transmit (PTT): It is a method of having conversations or talking on half-duplex communication lines, including two-way radio, using a momentary button to switch from voice reception mode to transmit mode [3].

1.6.12 Ladder resistors: They are a combination of resistors connected in parallel and they are a simple and inexpensive way to perform the digital-to-analog conversion [9].

1.6.13 Dipole antenna: This is the simplest type of radio antenna, consisting of a conductive wire rod that is half the length of the maximum wavelength that the antenna produces [6].

1.6.14 OsmAnd: It is a map and navigation app for Android and IOS and suitable to our work with a little modification in the opensource version.

1.6.15 XOR cipher: It is a logical operation, pronounced exclusive or. It can be used to cipher messages simply and fast [4][6].

1.6.16: Advanced Encryption Standard (AES): It is a symmetric block cipher chosen by the U.S. government to protect classified information. AES is implemented in software and hardware throughout the world to encrypt sensitive data. It is essential for government computer security, cybersecurity, and electronic data protection [5].

1.6.17 Raspberry Pi: It is a tiny computer about the size of a deck of cards. It uses what's called a system on a chip, which integrates the CPU and GPU in a single integrated circuit, with the RAM, USB ports, and other components soldered onto the board for an all-in-one package [7].



## **CHAPTER II**

### **THEORY AND LITERATURE REVIEW**

#### **2.1 Research Methodology**

The research was done step by step as an architectural construction, so was reading into common theoretical principles, namely circuit design, data, computer communications, cellular communication systems, antenna design, hobbyist systems, and their projects.

After that the project topic was searched, in several master theses with the same title, then the thesis title was considered in detail and divided into four axes (low cost, flexible, terminal node controller, design) and then each term was searched individually, the principles of microcontrollers to reach the model that achieves the required efficiency, the cheapest price, the easiest way to access the field of implementation and the appropriate and related parts (this is the main goal of the thesis). Then the areas of future network development were searched and some comparisons were made with the implemented network (balloon connection, cubic satellite connection, GSM network).

#### **2.2 Basic Theory of Cellular Network**

The network is distributed over geophysical areas called "cells", each served by at least one fixed-location transceiver (usually three cellular segments or base transceiver stations). These cellular base stations provide network coverage that can be used to transmit voice, images, video, data, and other types of content. A cell typically uses a different set of frequencies from neighboring cells, to avoid interference and to provide a guaranteed QoS within each cell [5-6].

These cells, when linked together, provide radio coverage across a wide geographic area. This allows multiple mobile transceivers (e.g., mobile phones, tablets, laptops equipped with mobile broadband modems, pagers, smartwatches, IoT products, etc.) to communicate with each other and with transceivers and telephones fixed anywhere in the network, across base terminals, even if some transceivers move across more than one cell during transmission [6].

**Cellular networks offer many features:**

2.2.1 Larger capacity than a single large transmitter, since the same frequency can be used with multiple links if they are in different cells.

2.2.2 The energy used between mobile devices and the towers is low because of their proximity and is not as far away as the satellites.

2.2.3 The geographical area that provides services can be expanded indefinitely by planting more coverage towers.

Since the invention of the phone, many developments have taken place intending to deliver it to the largest number of beneficiaries in the world, and it does not remain confined to a certain class. Therefore, service operators deploy coverage towers in separate areas that form a large communication network that enables the user to access it everywhere [6].

The major geographic areas were divided into small hexagonal cells, because the hexagonal shape covers all areas without spaces like the case of a circular or square shape. A technology that allows the use of frequency in more than one cell has been relied upon, provided that the cells that use the same frequency are not adjacent, but rather there must be a separating cell with a different frequency FDMA [6].

The time division multiple access technologies have also been developed to solve the problem from another point of view, which is to identify and divide time between subscribers, and this technology is adopted in the APRS system [6].

## **2.3 Terms and Conditions of Research**

The basic function of any communication system lies in monitoring the user's data in the transmitting unit and transmitting it through the communication channel using the available physical resources, then regenerating it in the receiving unit with the best possible degree of accuracy. The efficiency of the communication system - in the general sense - is determined by several factors, including:

2.3.1.1 Effective investment of the available resources, the most important of which is the licensed frequency band and the energy required to complete the steps of information transfer and extraction again [6].

2.3.1.2 The ability of the system to overcome the negative effects of interference and distortion, which are imposed by the transmitting and receiving circuits on the one hand, and the communication channel on the other [6].

Achieving the greatest possible degree of efficiency requires a multi-step signal processing that considers the former efficiency factors and leads to a signal that is immune to jamming beams and has focused energy within the narrowest possible frequency range, this requirement leads to a simplified modular architecture of signal processing steps [6].

**Here two important topics are highlighted:**

The first is the tremendous effort that is being exerted to reach standard specifications that achieve or guarantee high performance for communication systems and the extent of cooperation required between different research bodies and groups to reach a system suitable for marketing and wide dissemination [6].

The second is the variety of challenges posed by the radio link or port in the design and development of communication systems in this thesis, such as preparing the audio signal to be suitable for transmission through this port, raising the investment of the available frequency channels, and the need to overcome the negative effects imposed by this port on the radio signal [6].

**The following stages have been passed to obtain the main objective of the thesis:**

2.3.2.1 In the first step, analogue signals are converted into digital signals, which is called modulation. This procedure includes the speech signal, as other signals, the data signal, and control signals are available in digital form [6].

2.3.2.2 The source coding step leads to a reduction of the original signal so that it can be represented with the least number of bits possible, which increases the efficiency of investing system resources [6].

2.3.2.3 This is followed by a step that leads to immunizing the signal from interference beams, known as channel coding. This step includes - in principle - modifying the information stream according to suitable algorithms, which allows for detecting errors and correcting them in the future. This step can be interpreted as making the signal more suitable for the available transmission channel and this permitting and simplicity is provided in the APRS communication protocol [6].

2.3.2.4 The interleaving step aims to provide the signal with additional immunity from the distortions caused by its transmission over the radio link, especially those that lead to distortion of successive groups of bits and this is a feature available in the chosen communication protocol APRS and AFSK type [10][11].

2.3.2.5 The procedure of interleaving is followed by a step encryption, which includes a modification to the information structure only that preserves its privacy, and protects it from the curiosity of eavesdroppers who are not authorized to know its content [10][11].

2.3.2.6 After preparing the data stream representing the subscriber's information, this stream is provided with the control bits that the network needs to coordinate the provision of the service to a large number of subscribers at the same time. That is, this step leads to the final structure of the packets carried by the physical channels, so it is conventionally referred to as a step formation of packets. In addition, within this step, multiple frameworks are configured according to the patterns provided by the system [10][11].

2.3.2.7 The digital modulation or modulation step leads to the radio analogue signal which is transmitted over the communication channel [10][11].

## 2.4 Signal Modulation

The different modulation methods provide multiple options for developers of communication systems, so the real challenge lies in designing a system in choosing the most appropriate modulation style or method to achieve the required technical conditions and specifications in the best possible way. The conditions through which AFSK was selected in this thesis, in addition to the general determinants explained in the previous paragraph, are:

2.4.1 Spectrum efficiency: Since modulation is what converts the signal from a digital signal that occupies a limited space of the baseband to an analog signal that occupies a certain field of the frequency spectrum assigned to the RF-Band system, the spectral efficiency plays a very important role in choosing the modulation method.

The spectral efficiency  $\eta_{Mod}$  of any modulation type is defined as the ratio of the rate of flow or transmission of information carried on a radio signal  $R_b$  measured in units *bits/s* (*bps*) to the frequency domain or spectral range occupied by the signal  $B_c$  measured  $H_z$

$$\eta_{Mod} = \frac{R_b}{B_c} \quad (2.1)$$

The higher the efficiency, the greater the amount of information that the modulation pattern allows to transmit within each frequency unit within its 1  $H_z$  bandwidth, which means that the necessary field width to meet or provide communication services is narrower, which in turn leads to an increase in the network capacity, measured either by the number of subscribers that can be provided services to them, or the amount of data that the network allows exchange [10][11].

This increase in capacity helps to achieve the most important objectives of the design step and reduce the costs of establishing and operating the network in this thesis.

On the other hand, the high spectral efficiency leads to easy-to-achieve specifications in terms of filter circuits in the transmitter and receiver, which also leads to an additional reduction in construction and implementation costs, which is the essence of this thesis [10][11].

2.4.2 Power efficiency: This average indicates the amount of power needed to transmit information at an error rate that does not exceed a specified threshold. The different modulation patterns can be compared in terms of efficiency by calculating the error rate, by calculating the BER error rate in terms of  $E_b/N_0$  the smaller the amount of this power, system efficiency increased [10][11].

2.4.3 Modulation noise protection: modulation immunity can be calculated by the vectorial component of the wave amplitude, phase, and the carrier signal [10][11].

The greater the spectral efficiency of representing a greater number of bits with a specific amplitude and phase of the modulated signal, the closer the points representing the radial values are to each other, and it is easier to appear ambiguous values between them. On the contrary, the greater the distance between the radial values, the greater the immunity of the system against noise [10][11]. It is clear from this that there is a conflict between the spectral efficiency and immunity against noise. Achieving high efficiency is positive in terms of investing the frequency field, but it is costly on the other hand, as it requires the use of advanced methods for channel coding, which in turn means a higher computational burden within the signal processing steps, which leads to increasing the cost of devices and peripherals, which is not desirable in the case of this thesis, in addition to the lack of equipment that fulfills this requirement [6][11].

2.4.4 Immunity from selective fading: If the bandwidth  $B_c$  that the signal occupies is greater than the channel interconnection range, then the dominant fading is selective, and then the sensitivity of the signal to interference between symbols is high, so the previous two media must be compared  $B_{coh}$ ,  $B_c$  and analyze their relationship to each other when choosing an embedding style, for example, if the design data necessitate acceptance of an embedding style that leads to a relatively large value for  $B_c$  they should also focus on effective methods of signal leveling or other techniques to bypass the downsides of fading [6][11].

2.4.5 Modified radio signal amplitude change: Power amplification circuits are one of the most expensive components of electronic devices. It has a limited amplitude of variability, and it ranges within a relatively small range as is the case and in this study an efficient and effective way to reduce the costs associated with the devices. In addition to the above, the modulation system

that leads to a signal of almost constant amplitude allows the use of non-linear amplifiers with high yield, which means that the life of the batteries and power banks in this case is significantly longer and this is very useful in the case of this project built in a state without power sources available or on-going [6][11].

2.4.6 Interference with neighboring frequency channels: The spectrum of the modified signal is often wider than the available frequency channel range, which leads to interference on the adjacent frequency channels, and this increases the cost of filtering circuits in the future and governs the use of advanced methods of signal processing. Therefore, the need is urgent. To a modulation pattern that leads to a large concentration of energy within the narrowest possible range, and to a signal envelope - in the spectral range - with a very sharp side slope. This also facilitates adherence to standard spectrum masks specifications and allows for the use of affordable filters.

In the case of this thesis, the frequency domain is very crowded, and we are basically working on a field that is not intended for civil and service uses and is constantly being disrupted due to the different war conditions and the multiplicity of parties to the conflict, as well as the high costs associated with the lack of devices and the diverse spectrum [6][11].

## **2.5 AFSK Technology**

AFSK, is an acronym for Audio Frequency Shift Keying.

We know that in the analog radio equipment that is used to send and receive audio messages, the process of modulation takes place in the traditional FM frequency, this equipment is designed according to this standard and can only perform this type of modulation. So, we are going to use it to transmit digital data at a low data rate by converting these digital bits into audio tones, at frequencies in the range of human voices that conventional radios can transmit. That is, we send two audio tones for bit coding, one for logic zero which is 2200 Hz, and another tone for logic one which is 1200 Hz. This technology is called AFSK, because it performs FSK digital modulation based on audible audio tones [12] as shown in Figure 2.1.

FSK is a modulation where the instantaneous frequency corresponds to a binary baseband signal. Given:

$xm(t)$  is the baseband signal, perhaps a binary square wave taking values of -1 and 1,

$fc$  is the carrier frequency

$f\Delta$  is the deviation,

then the modulated signal  $y(t)$  as a function of time is:

$$y(t) = \cos(2\pi fct + 2\pi f\Delta \int t_0 xm(\tau) d\tau) \quad (2.2)$$

Not by accident, this is the same definition for analog FM.

The only difference being the baseband signal  $xm(t)$  is analog, instead of digital.

That is, FM and FSK are the same modulation, just with different baseband signals.

For AFSK, the same equation applies, only the carrier frequency is something in the audio range. Then, it is fed into an FM modulator, which applies the modulation a second time. Even without doing the math you can imagine applying this modulation function a second time results in a very different transmission [12].

AFSK is a modulation technology for digital communication and modulation method.

AFSK technology was chosen because it modifies the AM or FM wave into a simple carrier wave that allows for pass-through coding algorithms, and was originally designed for modifications and applications of human voices and musical instruments.

It is used in many countries in the ambulance, fire, and police systems and applications that need alerting and dissemination of the information received to more than one caller [6]. The resulting signal in the time domain is shown in the Figure 2.1 below in red with the corresponding bitstream in green. Phase discontinuities are undesirable because they generate a very wide spectrum, shown in the Figure 2.2.

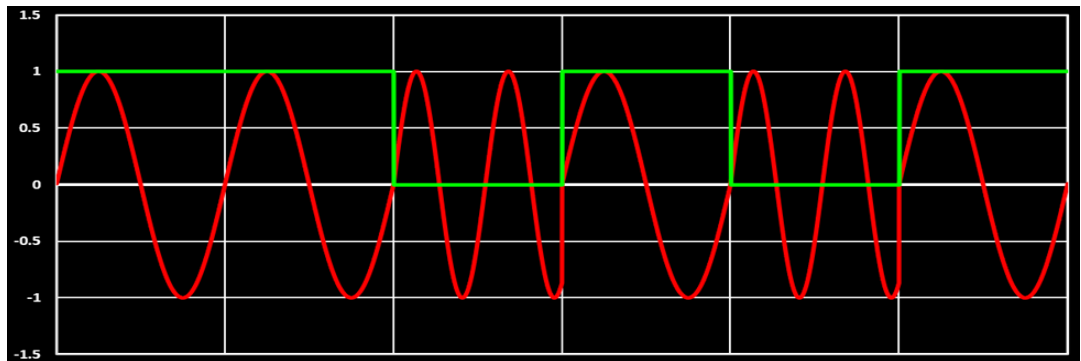


**Figure 2.1** Resulting signal in the time domain [12]

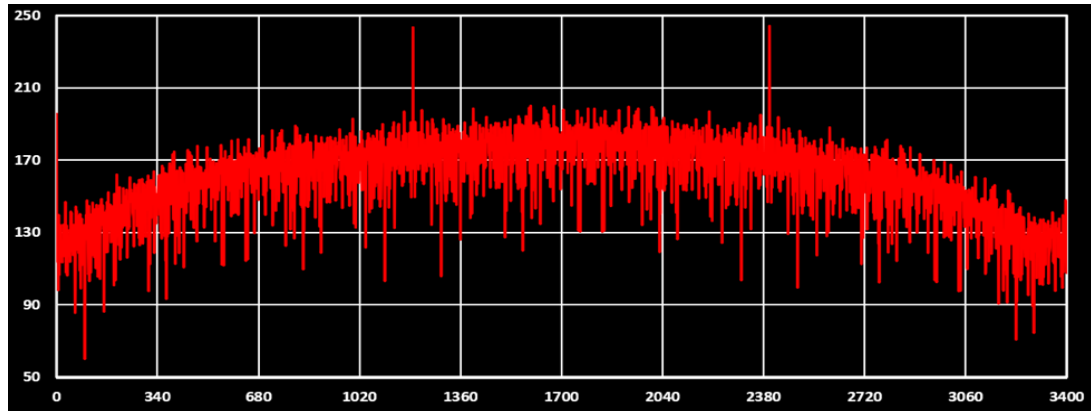


**Figure 2.2** Phase discontinuities [12]

In addition to the previous reasons, this technique has been used for several additional reasons, as follows:

2.5.1 Reducing the cost of building the system by relying on low-cost equipment, we used traditional radios walkie-talkies, which only accomplish the process of FM frequency modulation, so we converted its work from traditional FM to AFSK [12].

2.5.2 Other technologies such as PSK were used but the bit coding process is very complicated with the low-cost processors we used Atmega328. It is also difficult to detect in the future [12].

2.5.3 It is a famous and highly feasible technique when the data rate is low like in our case. Since we use low-cost equipment, we can compare the modulation techniques in our equipment according to the following Table 2.1.

**Table 2.1** Comparison the modulation techniques

| Modulation type | application on the walkie-talkie | Modulation in Atmega328 | Demodulation in Atmega328 |
|-----------------|----------------------------------|-------------------------|---------------------------|
| ASK             | No                               | Yes-Easy                | Yes-Easy                  |
| FSK             | Yes                              | Yes-Medium              | Yes-Difficult             |
| PSK             | Yes                              | Yes-Very Difficult      | No                        |

## **2.6 System Principle of Packet Radio by Using APRS Protocol**

APRS has been relied on as the primary medium for transmitting data between TNC and receiving stations or between TNCs itself.

APRS is short for Automatic Position Reporting System, which was designed by Bob Bruninga, WB4APR, and introduced by him at the 1992 TAPR/ ARRL Digital Communications Conference [10-11].

Fundamentally, APRS is a packet communications protocol for disseminating live data to everyone on a network in real-time. Its most visual feature is the combination of packet radio with the Global Positioning System (GPS) satellite network, enabling radio amateurs to automatically display the positions of radio stations and other objects on maps on a PC.

Other features not directly related to position reporting are supported, such as weather station reporting, direction-finding, and messaging [10-11].

### **APRS is different from the regular packet in several ways:**

2.6.1 It provides maps and other data displays, for vehicle/personnel location and weather reporting in real-time.

2.6.2 It performs all communications using a one-to-many protocol, so that everyone is updated immediately.

2.6.3 It uses generic digipeating, with well-known callsign aliases, so that prior knowledge of network topology is not required.

2.6.4 It supports intelligent digipeating, with callsign substitution to reduce network flooding.

2.6.5 Using AX.25 UI-frames, it supports two-way messaging and distribution of bulletins and announcements, leading to fast dissemination of text information.

2.6.6 It supports communications with the Kenwood TH-D7 and TM-D700 radios, which have built-in TNC and APRS firmware. Conventional packet radio is only useful for passing bulk message traffic from point to point, and has traditionally been difficult to apply to real-time events where information has a very short lifetime.

APRS turns packet radio into a real-time tactical communications and display system for emergencies and public service applications.

APRS provides universal connectivity to all stations, but avoids the complexity, time delays, and limitations of a connected network. It permits any number of stations to exchange data just like voice users would on a voice net. Any station that has information to contribute simply sends it, and all stations receive it and log it.

APRS recognizes that one of the greatest real-time needs at any special event or emergency is the tracking of key assets. Where is the marathon leader? Where are the emergency vehicles? What's the weather at various points in the county? Where are the power lines down? Where is the head of the parade? Where is the mobile ATV camera? Where is the storm? To address these questions, APRS provides a fully-featured automatic vehicle location and status reporting system. It can be used over any two-way radio system including amateur radio, marine band, and cellular phone. There is even an international live APRS tracking network on the Internet [10][11].

## **2.7 AX.25 Link Access Protocol for Amateur Packet Radio**

The idea of relying on the AX25 protocol can be summarized in the following points:

2.7.1 The nature of open-source software and protocols allowed developers and implementers to make extensive modifications without financial or governmental conditions without legal penetration, and this is what we need in this thesis [10][11].

2.7.2 The radio packet based on the X25 protocol and the developed model of it AX25 linked several thousand stations and terminals together directly and through the packet network, which is a series of digital control devices and then progressed to become a global network consisting of a different number of nodes, with different technologies and services, including gates, Internet ports, and connections satellites [10][11].

2.7.3 The dependence of APRS on AX25, which was originally developed by X25, is the reason for adopting this thesis [10][11].

2.7.4 AFSK relationship with APRS studies have indicated that the advantage of AFSK is that the audio signal can be fed to any radio microphone input. But if we ignore this, and assume a transmitter where the frequency can be directly

controlled, can this be done? The answer is yes, and this is sometimes done for APRS on a higher frequency. This is still in the case of microphone access, but the radio works Single sideband (SSB) instead of FM [10][11].

2.7.5 From a communication theory perspective, the previous step is not much different from Amateur Radio Teletype (RTTY). However, it would be better to use more efficient digital coding and error correction coding so AFSK was chosen for greater compatibility with APRS and with AX25 [10][11].

2.7.6 If signal modulation patterns other than AFSK are used, the signal will not be intelligible to other APRS stations, because the working philosophy is AFSK-on-FM APRS [10][11].

2.7.7 It was considered that the FM output with the FSK receiver is of varying frequency, in contrast, the square signal is received and we can receive alternating polar square waves or high-pass square waves, but in the case of this thesis TNC cannot do that because it expects to extract Conventionally twice by APRS because FM and FSK carry the same modulation concept with different wave type, bitstream, and radio wave [10][11].

2.7.8 It is noticeable that FSK over FM is not the same as FSK when we look at its waveform in the air. The spectrum is no longer two tones that bounce back and forth [10][11].

2.7.9 In the case of this thesis, the FSK modulator takes 0 and 1 as input, we could not generate the same signal as AFSK via FM, so an FM transmitter was adopted that modifies the radio frequency based on the level of the input signal, so the FSK modulation program was run and AFSK was generated via FM This is one of the features of the link to APRS and AX25 [10][11].

2.7.10 The AFSK signal can be generated in the software and used for software-based FM modulation, converting this whole signal to RF using generalized SSB mode with sufficient bandwidth as SDR HackRF but it is undesirable in the case of this thesis because it causes a physical burden and additional processing time unnecessarily [10][11].

## **2.8 Cube Satellite Tracking with APRS**

CubeSats enable low-cost experiments and assignments by universities. It is a good option for self-reliance to obtain advanced technology such as satellites and their

benefits. CubeSats are used to research UHF and VHF communications for tracking and telemetry applications. The current practice of CubeSat communications is the modification of the TNC to enable reception of data in the ground station. But we have not been able to implement this technology because of the severe security restrictions on the areas of instability and some of the advanced logistical technology that needs them, and this is not available to us [1-3][7].



## CHAPTER III

### DESIGN APPROACH

#### 3.1 Design and Simulation Requirements

The main objective of the GPS/telemetry beacon is to decode and forward GPS coordinates and telemetry information to nearby receiving stations to satisfy the mission objective, the following requirements needed to be met [2-3]:

3.1.1 The device would interface with GPS receivers.

3.1.2 The device would operate at a baud rate of 1200 so that it could be built and tested within the specified time frames. Further enhancement could be made to increase the baud rate up to 9600.

3.1.3 Each radio channel must withstand 60 transmitting units.

3.1.4 It must withstand a temperature range of -40 degrees to +85 degrees C.

3.1.5 It must be compact and easy to hide inside a vehicle.

3.1.6 It must be made of off-the-shelf components.

3.1.7 It must be low cost and easy to manufacture.

#### 3.2 System Layout

A block diagram for the system layout is shown in Figure 3.1 [2-3][7]:

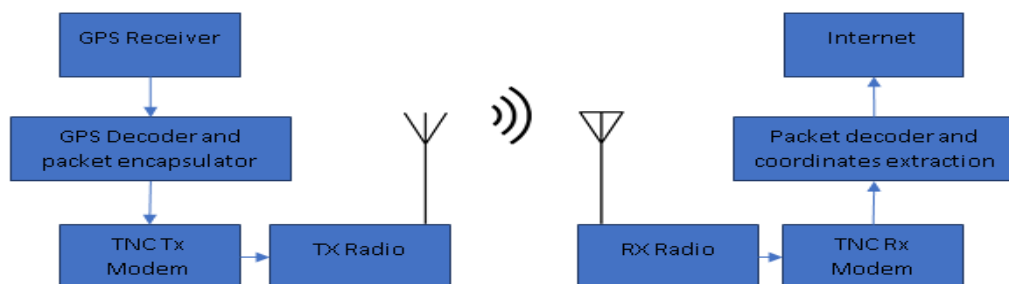


**Figure 3.1** A block diagram for the system layout

3.2.1 GPS Receiver: The GPS receiver acquires signals from the GPS satellite constellation and calculates its location and time. It then sends this information to the packet encapsulator in the form of NMEA sentences where it is packetized.

3.2.2 GPS Decoder and packet encapsulator: This device consists of a single microcontroller that takes the GPS data and time from the GPS receiver and decides the specified time to transmit for this unit to send the packet then convert the GPS coordinates into custom packets from these packets are sent to modem where they are converted into audible tones and sent to TX radio.

3.2.3 TNC Tx Modem: It consists of a single microcontroller that takes input data from UART serial pins and converts it into AFSK audio output.

3.2.4 TX radio: It consists of a walkie-talkie device with PTT and audio input channel connected to the TNC Tx Modem and it acts as an analog voice transmitter.

3.2.5 RX Radio: It consists of receiving talkie walkie device that receives audio from GPS beacon and passes the received signal to TNC Rx Modem.

3.2.6 TNC Rx Modem: It demodulates received AFSK signal to digital data.

3.2.7 Packet decoder and coordinates extractor: It consists of SoC computer which it takes input from TNC Rx Modem then detects and extracts GPS coordinates from valid received packets and sends them into internet database service.

### **3.3 Walkie Talkie Concept**

Walkie-talkie is an application of single-sideband communication technology, where the channel is busy by one speaker only and the other speaker is a listener and cannot participate in the conversation. With the development of mobile phones, however, this technology is still used for appropriate applications such as armies, police, and radio amateurs, prompting many companies to design advanced devices that use this mechanism and its technologies.

A hobbyist's device often has a tool to scan for and listen to other frequencies.

The devices contain VFO technology which only allows the user to tune in to authorized frequencies. Some radio amateurs on their devices have other inclusion methods such as FM, AM, SSB, and CW that enable them to communicate with wider amateur networks and add other features such as geolocation, messaging, and calling [5]. Figure 3.2 shows the Walkie talkie block diagram.

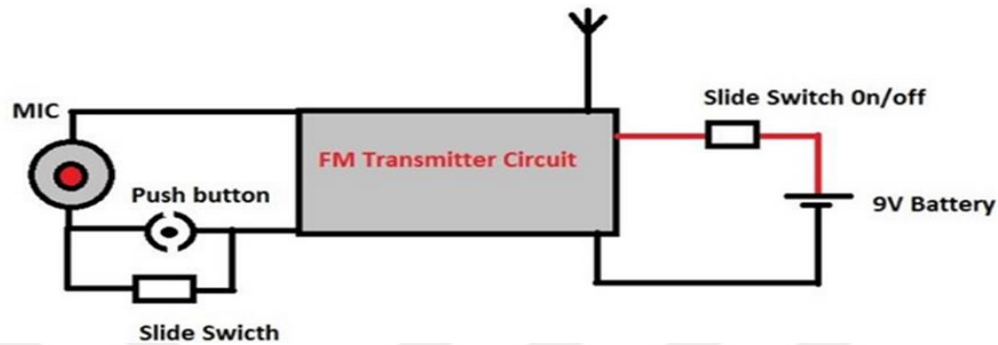


**Figure 3.2** Walkie talkie block diagram [16]

### 3.4 PTT Cconcept

PTT refers to "push-to-talk or press-to-talk". When an operator pushes the button on a hand-held microphone or "walkie talkie" as shown in Figure 3.3, the transceiver switches from receive to transmit. The button is referred to as a PTT button.

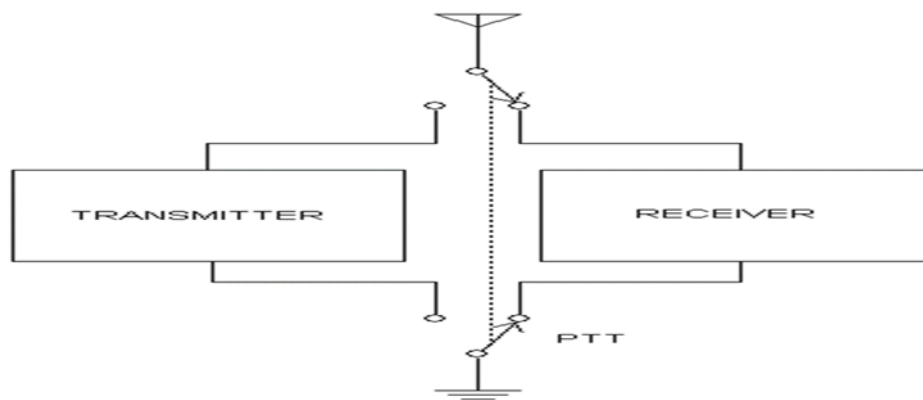


**Figure 3.3** PTT mechanism [17]

Figure 3.4 shows the concept of PTT, when the PTT button is activated, one or two relays close. One relay mutes the receiver and enables the transmitter. A second relay switches the antenna from the receiver to the transmitter. The reason why there are two relays is that one switches power and the other switches the antenna from the receiver

to the transmitter. Microphone audio is applied to the transmitter as modulation. Note: In modern radios, the relays have been eliminated and diodes do the antenna switching and transistors switch the transmitter and receiver on and off [6][8].

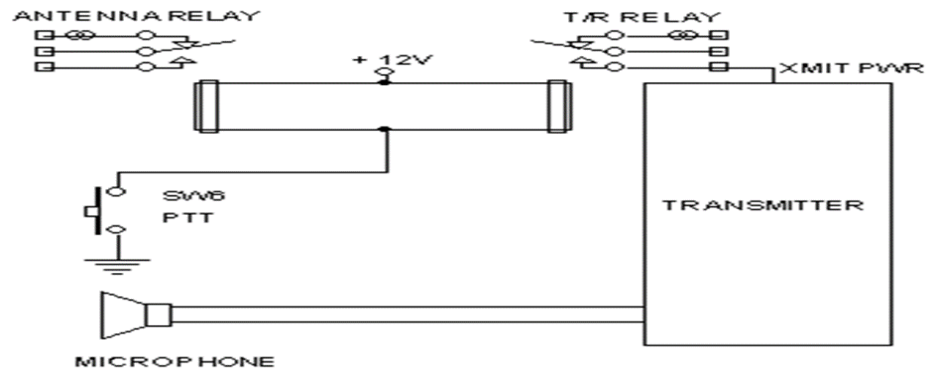


**Figure 3.4** PTT circuit diagram [17]

### 3.5 GPS/Telemetry Beacon Hardware Design (Transmitter Circuit)

Figure 3.5 shows the transmitter electronic circuit diagram:

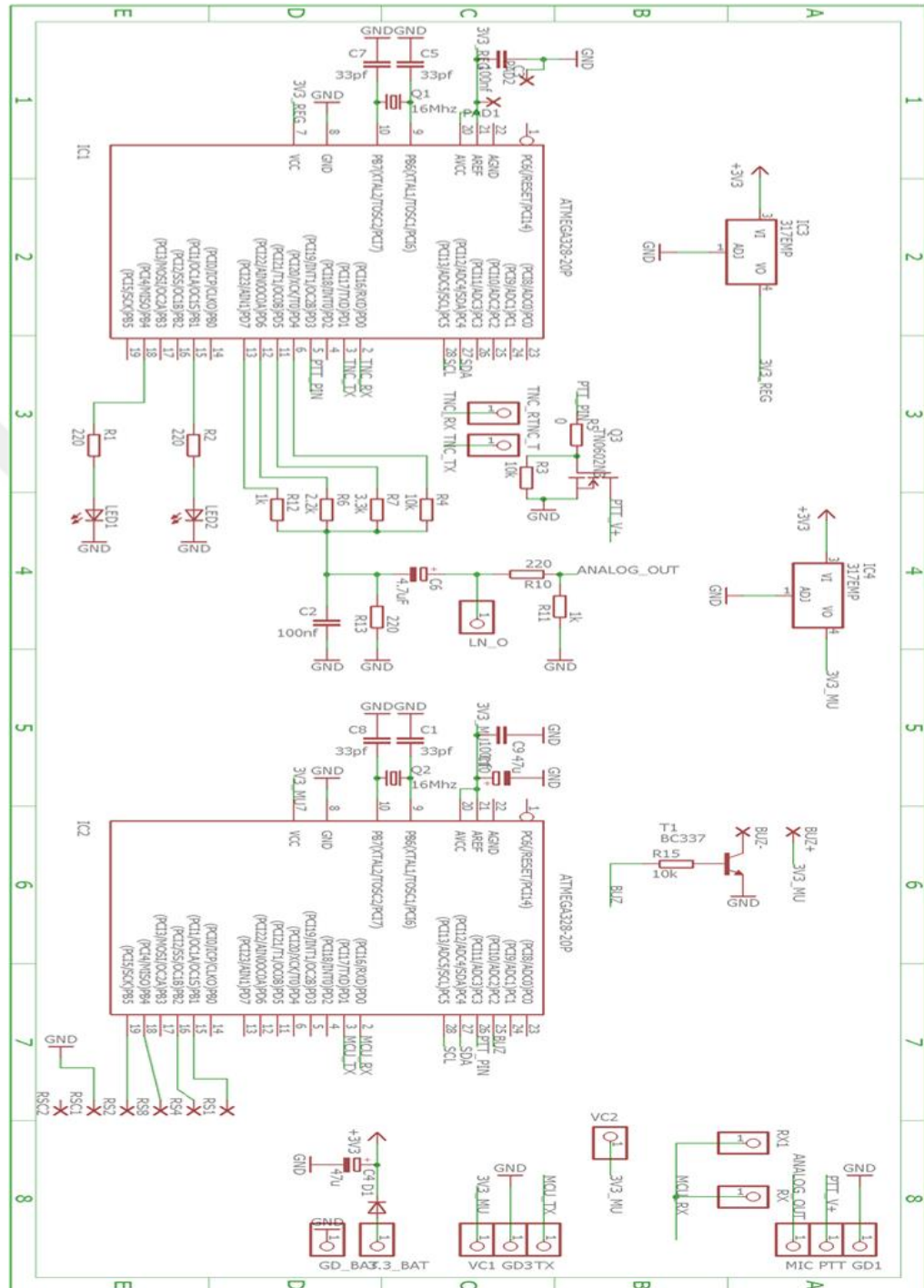


**Figure 3.5** Transmitter electronic circuit diagram

To achieve analog-to-digital conversion and modulation, the transmission circuit consists of two ATmega328P single-chip microcontroller, two 3.3V LDO (IC 317EMP) and a bunch of basic electronic components.

The block diagram which is shown in Figure 3.6 describes the electronic components used in electrical design and how it works.

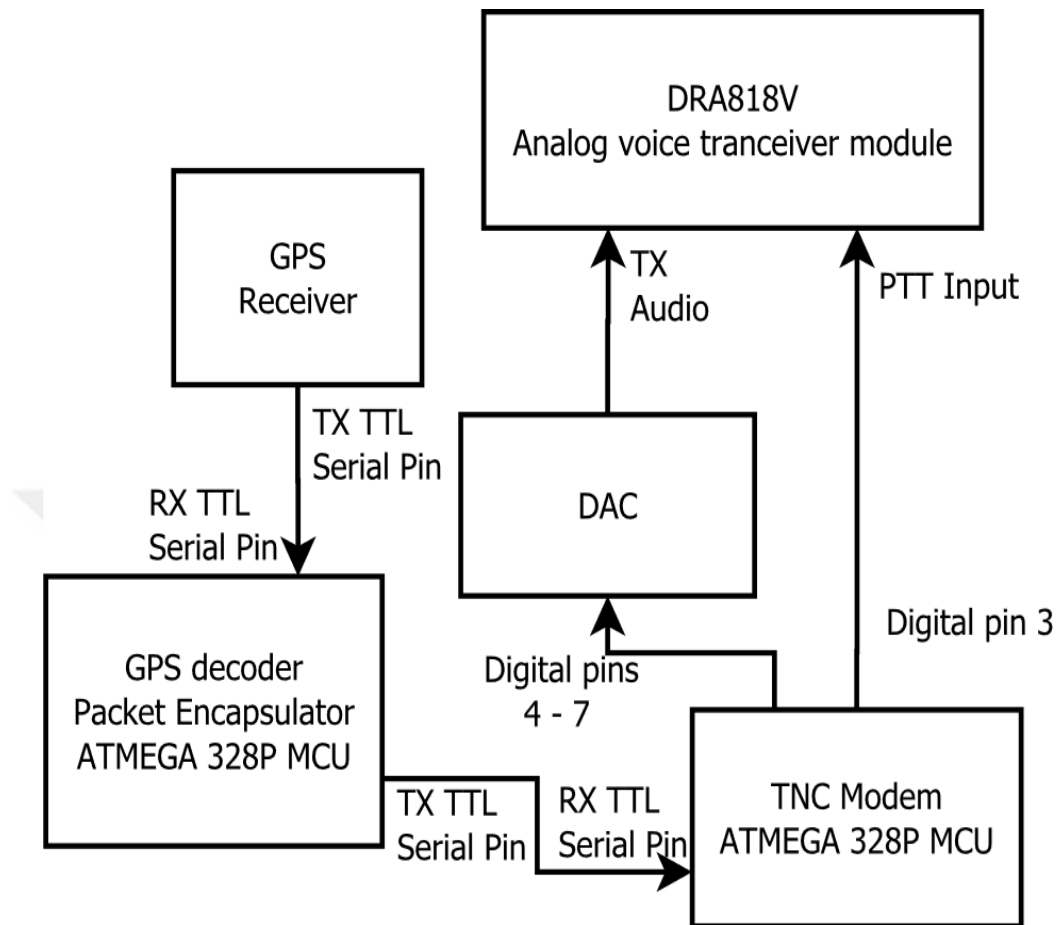


**Figure 3.6** Transmitter beacon block diagrams

### 3.6 Receiving Station Hardware Design

Figure 3.7 shows the receiving station circuit diagram:

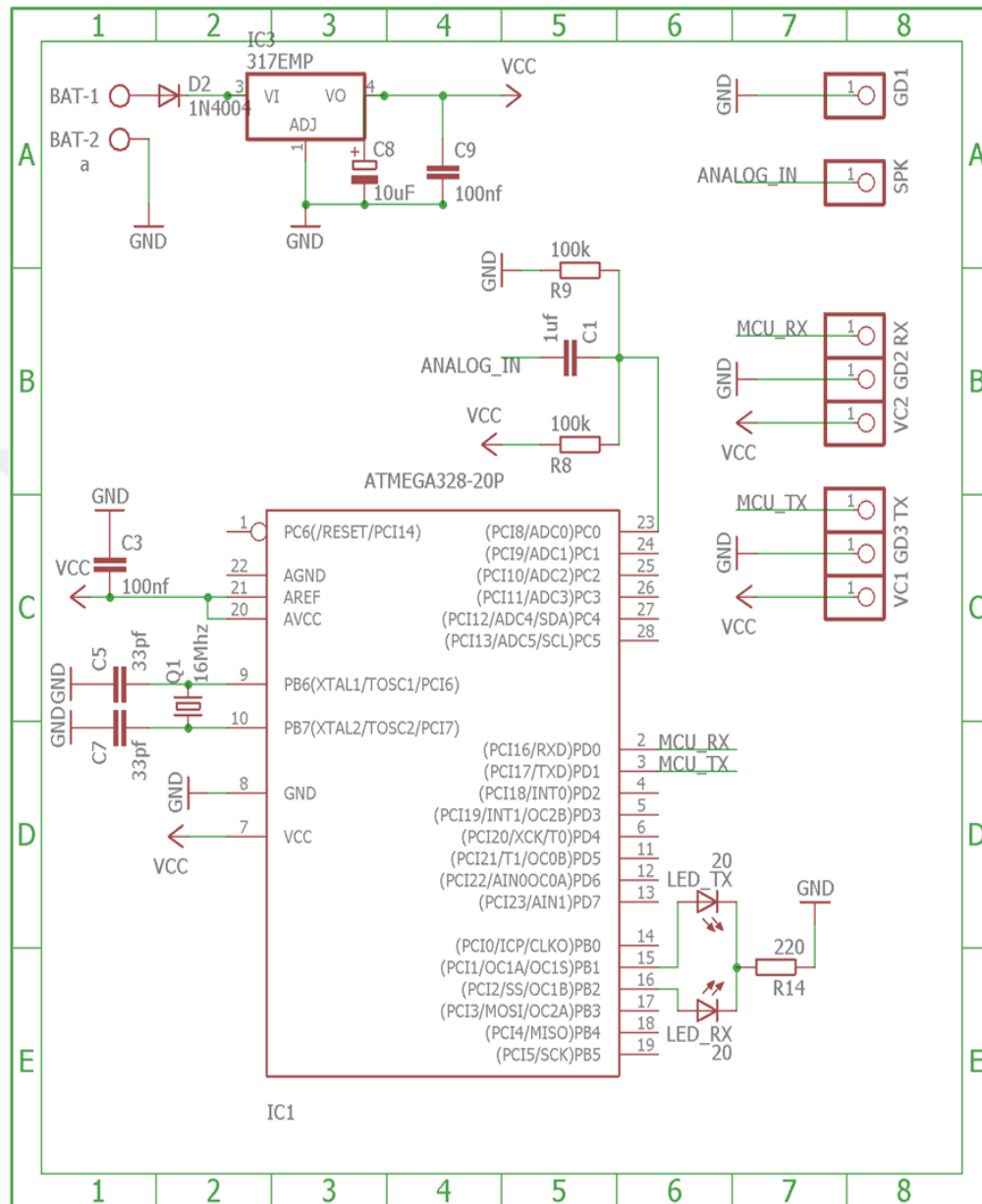


**Figure 3.7** Receiving station electronic circuit diagram

To convert from the analog system to the digital system and the modulation process the receiving circuit consists of ATmega328P single-chip microcontroller, 3.3V LDO (IC 317EMP) and a bunch of basic electronic components.

The block diagram which is shown in Figure 3.8 describes the electronic components used in electrical design and how it works.

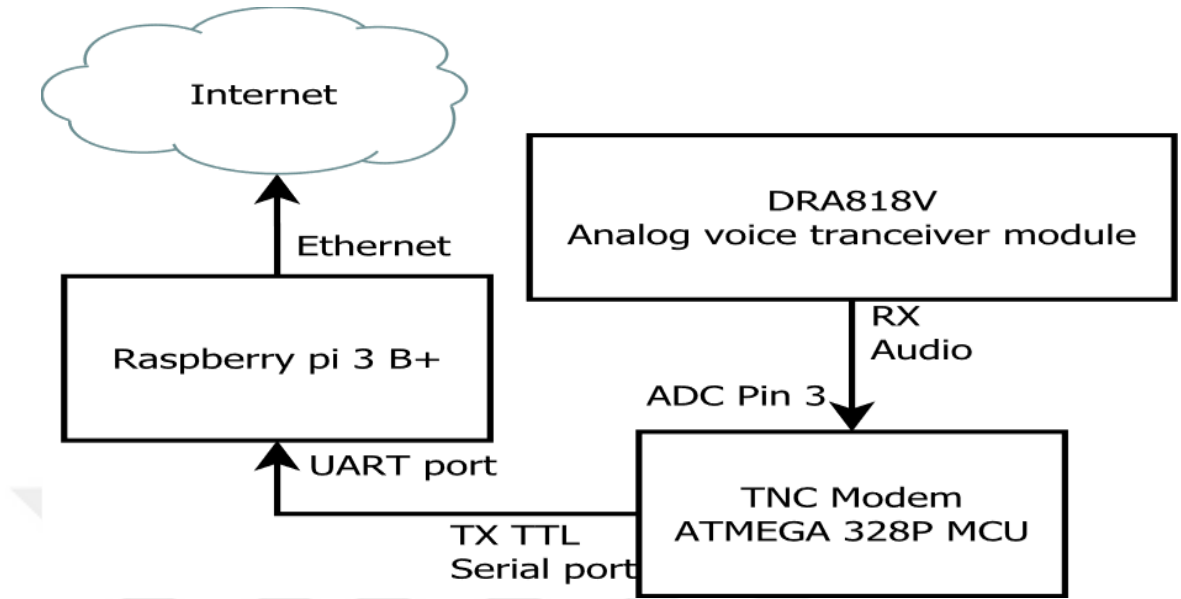


**Figure 3.8** Block diagram of the receiving station

### 3.7 Antenna Design and Simulation

The antenna is one of the important elements in the wireless communication system. No matter how accurate the transmitting and receiving devices are, the antenna has an essential and indispensable role [13].

An antenna is defined as a conductive device that radiates or captures electromagnetic energy. In general, the antenna system consists of:

3.7.1.1 Transmitting antenna: It is the tool that enables us to radiate electrical power from the transmitter to the atmosphere in the form of electromagnetic waves.

3.7.1.2 The receiving antenna: It is the tool that enables us to convert electromagnetic waves scattered in the atmosphere into electrical power that is directed to the receiver. It is useful to know that the specifications of the transmitting antenna apply to the receiving antenna as well, as the antenna can be used in transmitting and receiving operations, as is the case in many antennas of microwave systems and antennas of cellular communication systems or as the case of this thesis [13].

It is known that radiation always results from accelerating charges, and scientifically the radiation is attributed to accelerating electronics, and to increase the radiation from the antenna it is necessary to use one or more of the following methods [13]:

3.7.2.1 Increasing the frequency of the current in the antenna.

3.7.2.2 Increase the electrical power of the antenna.

3.7.2.3 Designing the antenna with a length equal to half the length of the wave to be radiated ( $\frac{1}{2}\lambda$ ) before addressing the method followed in designing the antennas of this thesis and its scientific specifications, a simplified explanation of the standard antenna isotropic must be provided in addition to the commonly used decibel unit.

An isotropic antenna is defined as a theoretical antenna that operates with the same efficiency in all directions, a radiation model of a spherical shape, and the field strength around the antenna is equal [13].

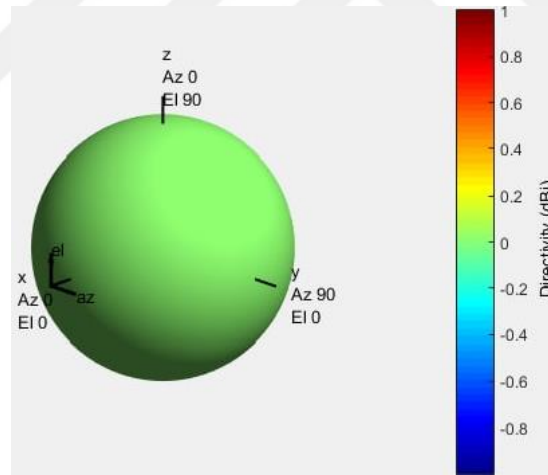


**Figure 3.9** Isotropic antenna [18]

Practically: It is impossible to construct a standard antenna with these specifications, but it is used as a theoretical reference for comparison with antenna systems, especially when calculating the antenna gain in decibels [13].

As for the decibel, it is a standard unit used to calculate the gain, and it is expressed mathematically as the decibel: the logarithmic measure of the ratio between two values, and written as an abbreviation (dB). For example, the power gain of an amplifier can be expressed in decibels as follows [13]:

$$dB = 10 \text{ Log}(\frac{P_{out}}{P_{in}}) \quad (3.1)$$

### 3.8 Antenna properties

Each antenna has several important characteristics that distinguish it, determining its field of work. In general, most of your antennas share these characteristics, whether they are transmitting or receiving antennas. What follows [13]:

3.8.1 Gain is defined as the ratio between the energy density emitted by the antenna in a specific direction to the energy density emitted by the standard antenna at the same point, assuming that the internal energy to them is equal. Antenna gain is measured in decibels (dB).

3.8.2 The antenna input impedance is defined as the ratio between the voltage value and the current value at the antenna input ends. Its knowledge is used in determining the necessary circuits to achieve a match between the antenna impedance and the transmission line impedance it is connected to when the antenna impedance differs from the transmission line impedance. Matching the two impedances between two electrical circuits means that the output impedance of the first circuit is equal to the input impedance of the second circuit, to ensure the transfer of the largest possible amount of energy between them.

3.8.3 Directivity means the ability of the antenna to focus the energy emitted from it in a specific direction more than the rest of the directions. The antenna that enjoys this characteristic is called the energy-directed antenna, as is the case in this thesis, and some antennas are not directed to energy, as is used in some radio broadcasting stations.

3.8.4 The radiation pattern is a diagram showing how the energy from the antenna to the atmosphere is distributed to the surrounding atmosphere. The benefit of knowing the radiation pattern of the antenna lies in determining the scientific applications of this antenna and how to direct it.

3.8.5 Antenna efficiency is defined as the percentage of the power emitted by the antenna  $P_r$  to the power entering it  $P_{in}$ .

$$\eta = (\frac{P_r}{P_{in}}) \times 100 \% \quad (3.2)$$

Where:  $\eta$  the antenna efficiency.

$P_{in}$  Input power of the antenna in watts.

$P_r$  The power emitted by the antenna in watts [6].

### 3.9 Antenna Dimension

The length of the antenna depends on the wavelength that it will radiate or receive and thus on its frequency it can be said that the higher the frequency of the signal that the antenna deals with, the smaller the antenna dimensions and vice versa.

To build an antenna with high efficiency in radiating electromagnetic waves, its length must be multiples of quarters or half of the wavelength ( $\lambda$ ) of the signal to be radiated.

Usually, the minimum possible length (without the use of auxiliary elements) is a quarter of the wavelength ( $0.25 \lambda$ ), and the half-wave antenna ( $0.5 \lambda$ ) is one of the very common antennas as it is the basis from which it arose and most other types of antennas developed [13].

The wavelength used in calculating the lengths of the antenna elements is called the effective length ( $\lambda$ ) and is equal to ( $0.95 \lambda$ )

where  $\lambda$  the wavelength inside the antenna (effective length).

$\lambda$  The wavelength in free space.

The reason for this decrease in the length of the wave inside the antenna is that its speed inside the antenna is about 5% less than its speed in free space [13].

### 3.10 Half Wave Dipole Antenna

In its simplest form as in this thesis, a dipole antenna in Figure 3.10 consists of a metal wire half the wavelength it radiates. This type of antenna is the main one from which most other antennas were launched [13].

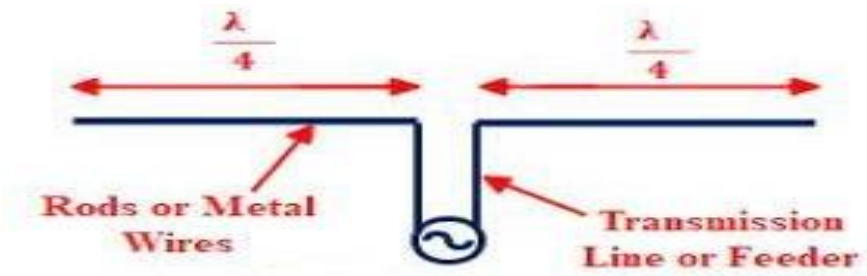


**Figure 3.10** Half wave dipole antenna [19]

3.10.1 Frequency range: (3-10000) MHz

3.10.2 Gain: Approx. 2.5dB depending on the height above the ground.

Polarization: Linear.

Radiation pattern: non-directional.

Scientific use: it is the basis on which many types of antennas are built, especially in the field of television reception, and the use of this thesis.

The introduction of simulation programs led to the design of high-accuracy antennas. S parameters and VSWR are the most important criteria to be taken when designing and implementing the antenna from programs such as ANSYS and CTC.

To receive the modulated signal (radio audio) from space and coming towards the receiving system I designed a 50cm T-shaped dipole antenna. The antenna design is based on the ANSI 2020 program as shown in Figure 3.11.

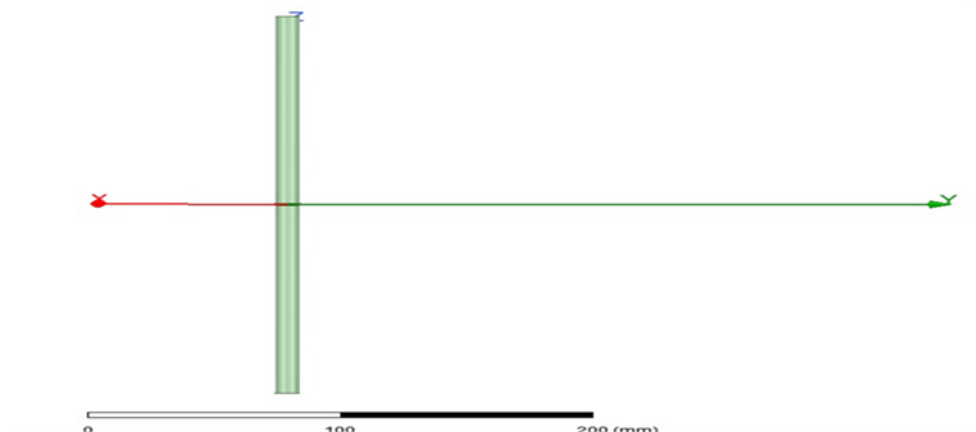


**Figure 3.11** 433 MHz dipole antenna for receiving signals

### 3.11 S Parameter Plot

In the first reading of the simulation, the phase plot of the parameter S displays the phase in degrees concerning frequency. Note that in Figure 3.12 when displaying the phase of parameter S, in some cases the phase delay is plotted. For example, it is clear from reading that the design is ideal for the band from 400 to 450 MHz, which is the band used in the thesis.

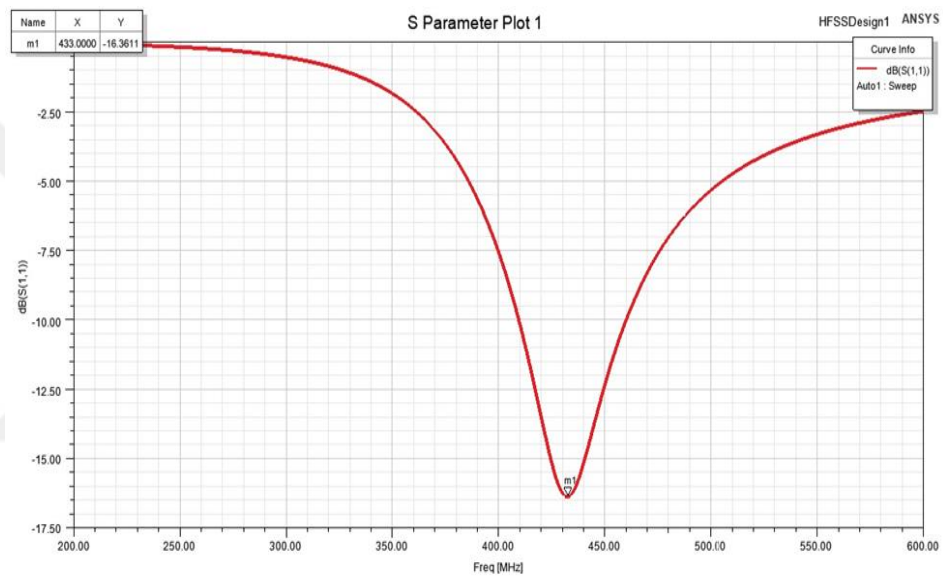


**Figure 3.12** S parameter plot

### 3.12 VSWR Plot

The following diagram Figure 3.13 is to find the VSWR (Voltage Standing Wave Ratio) which is an indication of the amount of mismatch between the antenna and its feed line connected to it. The range of VSWR values is from 1 to  $\infty$ . A VSWR value of less than 2 is suitable for most antenna applications. The antenna can be described as a "good match". The antenna is in the appropriate area for work.

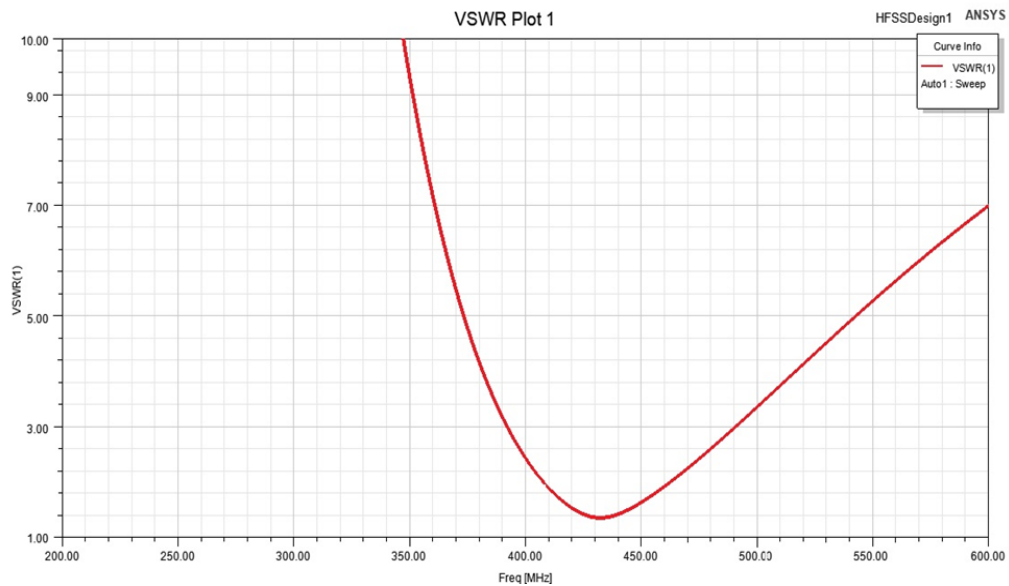


**Figure 3.13** VSWR plot

### 3.13 Antenna Gain

In electromagnetics, an antenna's power gain or simply gain is a key performance number that combines the antenna's directivity and electrical efficiency. In a transmitting antenna, the gain describes how well the antenna converts input power into radio waves headed in a specified direction. In a receiving antenna, the gain describes how well the antenna converts radio waves arriving from a specified direction into electrical power. When no direction is specified, the gain is understood to refer to the peak value of the gain, the gain in the direction of the antenna's main lobe. A plot of the gain as a function of direction is called the gain pattern or radiation pattern [6].

In Figure 3.14 the antenna gain is usually defined as the ratio of the power produced by the antenna from a far-field source on the antenna's beam axis to the power produced by a hypothetical lossless isotropic antenna, which is equally sensitive to signals from all directions. Usually, this ratio is expressed in decibels, and these units are referred to as decibels-isotropic (dBi). An alternative definition compares the received power to the power received by a lossless half-wave dipole antenna, in which case the units are written as dB [6].

Directivity: the antenna can receive a specific signal from a specific direction and neglect the rest of the signals from other directions [6].

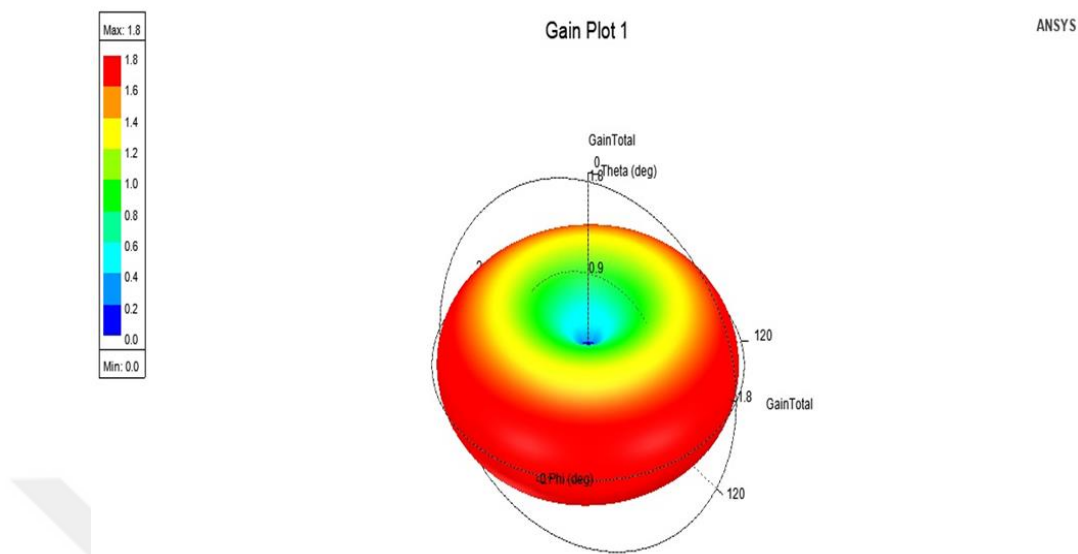


**Figure 3.14** Antenna gain plot

### 3.14 Protocol and Libraries

Since the APRS Protocol is open source, we found a lot of modifications to it, but we approved the library (libaprs) from (GitHub), [https://github.com/barisdinc/LibAPRS\\_Tracker](https://github.com/barisdinc/LibAPRS_Tracker)

APRS Protocol Reference It relied on reviewing it is terminology and details on the reference (Protocol Version 1.0 by the APRS Working Group Edited by Ian Wade)

This is nano minimal version of LibAPRS for tracker devices. This library is based on <https://github.com/markqvist/LibAPRS> Originally. I tried to use LibAPRS, when used in conjunction with Adafruit\_GPS or Tiny GPS it takes the whole global memory leaving no space for APRS Tracker functions (e.g.: serial configuration). So, I decided to sanitize the LibAPRS for those who will use it for mini tracker devices to send APRS packets. LibAPRS\_Tracker is a library for the Arduino IDE, that makes it easy to design and implement your own APRS Tracker devices for sending out your location, telemetry, etc. The hardware is Micro modem compliant using resistor ladder on pins D4,5,6,7. The PTT pin is D3. All the AFSK modulation, AX.25 packing, and such are running transparently in the “background” in interrupts [10][11].

Note that the sources file contains 13 sub-files:

3.14.1 AFSK.cpp and AFSK.h are responsible for implementing and relating to Audio frequency-shift keying (AFSK). Fixed telephones use AFSK modulation technology to transmit at a data rate of approximately 1200 bits per second.

3.14.2 AX25.cpp and the fourth, AX25.h, are responsible for implementing the protocol AX.25, where I reviewed the two files based on the reference (AX.25 Link Access Protocol for Amateur Packet Radio, Version 2.2 Revision: July 1998). Relying on the OSI system, specifically the second layer of it, the AX.25 protocol was derived, originally developed from X.25, which works to transfer encapsulated data and troubleshoot errors that may occur during messaging, whether in the channel or in the transmitted data packet..

3.14.3 CRC-CCIT.c and the sixth CRC-CCIT.h are responsible for detecting errors in data frames.

3.14.4 FIFO.h, is responsible for achieving synchronization.

3.14.5 HDLC.h is responsible for High-Level Data Link Control (HDLC) which is a bit-oriented code-transparent synchronous data link layer protocol developed by the International Organization for Standardization (ISO).

3.14.6 LibAPRS.cpp and the tenth, LibAPRS.h are the most important files and are responsible for implementing the APRS protocol.

3.14.7 constants.h contains all the transmission constants.

3.14.8 device.h file is responsible for defining the associated devices and ports.

3.14.9 src.ino is an empty file designed to make the protocol easier to write on the Arduino.

### **3.15 APRS ++**

In the LibAPRS library there is a lot of data in excess of the need to implement this thesis. This extra data in frame affects the speed of the data, and this slowdown occurred in the first, second and third models, noting that the maximum speed of (AFSK) is 1200 Bits per second [10][11].

In normal mode to create TNC using the LibAPRS library, the ax25\_sendVia function creates the frame to be sent, and the resulting frame structure is as follows:

- HDLC FLAG - 1 byte.
- SRC\_CALL - 8 bytes.
- DST\_CALL - 8 bytes.
- PATH1 - 8 bytes.
- PATH2 - 8 bytes.

AX25\_CTRL\_UI - 2 bytes.

- AX25\_PID\_NOLAYER - 2 bytes.

Buffer - 5 to MAX\_LN bytes.

- CRCL - 1 byte.
- CRCH - 1 byte.
- HDLC FLAG - 1 byte.

We notice the presence of a large amount of unnecessary data, namely: AX25\_PID\_NOLAYER, AX25\_CTRL\_UI, PATH2, PATH1, DST\_CALL, SRC\_CALL

The sender address will be added to the Buffer data. That is, we will only send the raw information without any additional charges.

Therefore, the ax25\_sendVia will be replaced by another function (ax25\_sendRaw) that reduces unnecessary data overload and sends the raw information as follows:

- HDLC FLAG - 1 byte.
- Buffer - to MAX\_LN 5 bytes.
- CRCL - 1 byte.
- CRCH - 1 byte.
- HDLC FLAG - 1 byte.

The speed of the data was verified in the fourth and fifth models. The modification was named APRS ++ for excellence in the thesis.

As for the programming commands, they are as follows:

define AX25\_MIN\_FRAME\_LEN 6 update

define CUSTOM\_FRAME\_SIZE 100 update

ax25\_ndecode () added

Iam\_sending added()

APRS\_sendPkt () updated

By using ax25\_sendRaw () we have this header:

HDLC\_FLAG(1byte) + buffer(1-max) + CRCL (1 byte) + CRCH (1 byte)  
+HDLC\_FLAG(1byte)

A GPS packet (NEMA protocol) string at 9600 baud enters the GPS decoder and packet encapsulator MCU as an TTL UART signal within this microcontroller the software decodes the NEMA packets and extracts the GPS coordinates and time then the MCU internal clock sync with the received time, the GPS coordinate encapsulates inside a new packet using a simple asynchronous HDLC standard. Figure 3.15 explains the Packet description.

| HDLC<br>Flag | SSID     | LAM:<br>LOM | LAPH     | LAPL     | LOPH     | LOPL     | CRC16        |
|--------------|----------|-------------|----------|----------|----------|----------|--------------|
| <b>0</b>     | <b>1</b> | <b>2</b>    | <b>3</b> | <b>4</b> | <b>5</b> | <b>6</b> | <b>7 - 8</b> |

**Figure 3.15** Packet description

- HDLC Flag: the flag to detect the beginning of the packet.
- SSID: the ID of transmitting unit.
- LAM: LOM: the decimal side of WGS84 coordinates (4-bit Lat) (4-bit Lon) taking in considering that the beginning of the latitude and longitude is 35.
- LAPH, LOPH: the first 2 digits after the floating point of the latitude, longitude coordinates.
- LAPL, LOPL: the 4 and 5 digits of the floating-point of the latitude, longitude coordinates.
- CRC16: 16-bit cyclic redundancy check of the packet bytes computed using CCITT algorithm.

Latitude and longitude can be extracted from packet as follows:

$$\text{Latitude} = (\text{LAM} + 35) + \frac{(\text{LAPH} \times 10^2) + \text{LAPL}}{10^4} \quad (3.3)$$

$$\text{Longitude} = (\text{LOM} + 35) + \frac{(\text{LOPH} \times 10^2) + \text{LOPL}}{10^4} \quad (3.4)$$

### 3.16 TCP / IP ++

The TCP/IP protocol is used to communicate between scattered receiving stations and the database. OSI is a set of protocol rules and regulations that regulate the work of global communications on the Internet, and the most important for this thesis is the TCP / IP protocol, which, with the transport layer, the handling communication layer, the application layer, and the host-to-host layer, provides communication between TNCs according to the standards of an engineering team. The Internet IETF is the most comprehensive legal framework for public networks [5].

In the experiments of the fourth and fifth models, the problem of delay or interruption of the Internet appeared due to the blind geographical spots and the weakness of the structure of the local Internet service operator.

To overcome this problem, I made the following modification Car Logger (Raspberry) and named it TCP / IP ++ to distinguish in the thesis.

Problem: Some coordinates are being received but are not sent to the database. The reason for this problem was that both the listening operation and the sending operation were going on the same thread (the main thread of the app).

Solution: Using multi-threading, the main thread of the app is responsible for only listening for the data from the cars. Sending the coordinates to the DB will be in a new thread.

### 3.17 Packet Decoder and Position Logger (Raspberry pi) – Diagram

The following chart Figure 3.16 shows the receiving station position decoder and logger.

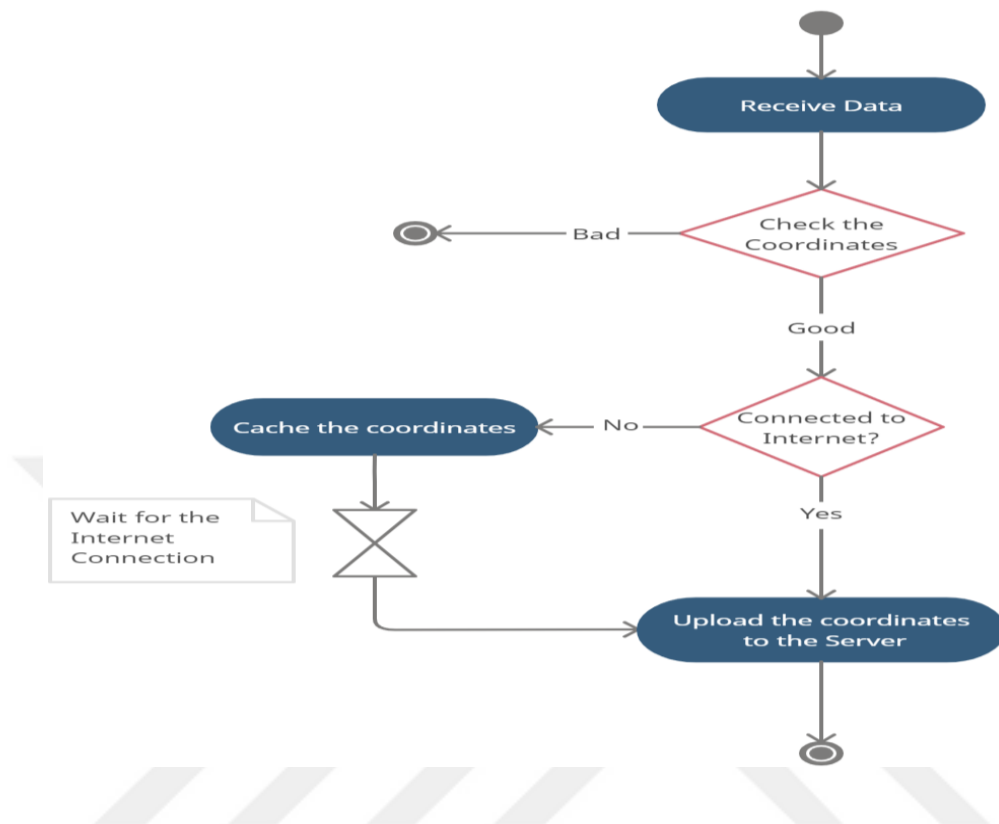


**Figure 3.16** Packet decoder and position logger (raspberry pi)

The software is written in C++ programming language and compiled in Linux Operating system considering the receiver TNC is connected to Raspberry pi computer via onboard Serial port (Pin 14-15) in the Raspberry pi's GPIO.

How it works:

3.17.1 The user should select this port from the ports list as in

Figure 3.17.

3.17.2 When the user presses the start button, the software will listen to this port.

3.17.3 When data is arrived, the software will parse this data and check if it is a valid data.

3.17.3.1 The data is considered valid when it has three parameters:

ID: the identifier number of the car.

Longitude: the longitude value of the coordinate.

Latitude: the latitude value of the coordinate.

3.17.4 After making sure the data is valid, this data will be encrypted by AES algorithm and pushed to the queue.

3.17.5 When the internet connection exists, it will send the coordinates to the database which consists of MySQL hosted database.

3.17.6 Separate web server that requests vehicle history from the database and presents it to each user with a great interface.

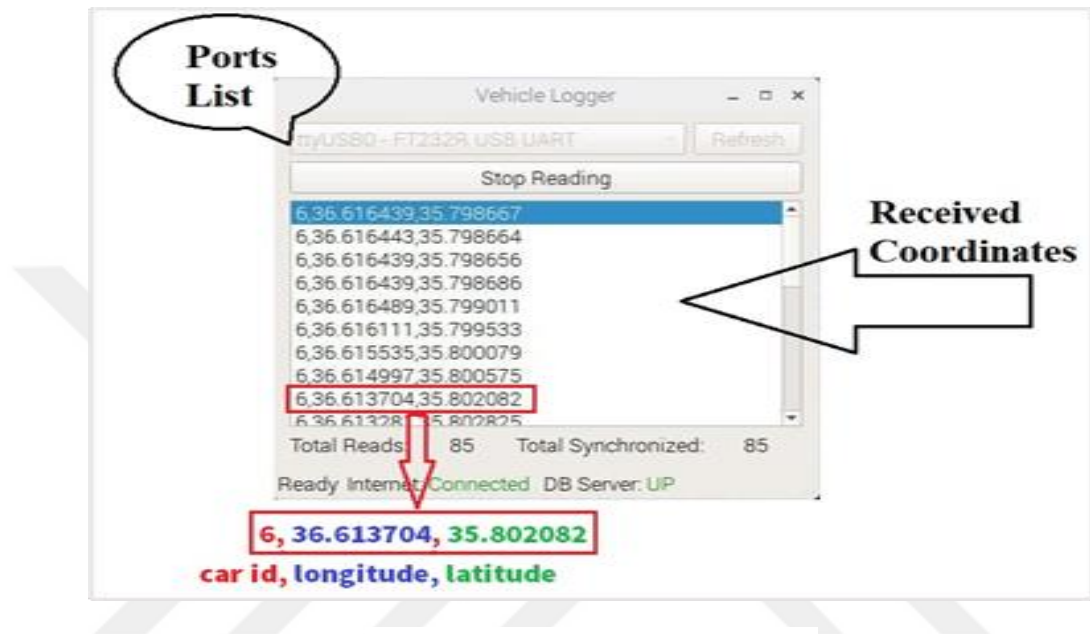


Figure 3.17 User select port

### 3.18 Tracker (web)

The following Figure 3.18 shows Tracker website.

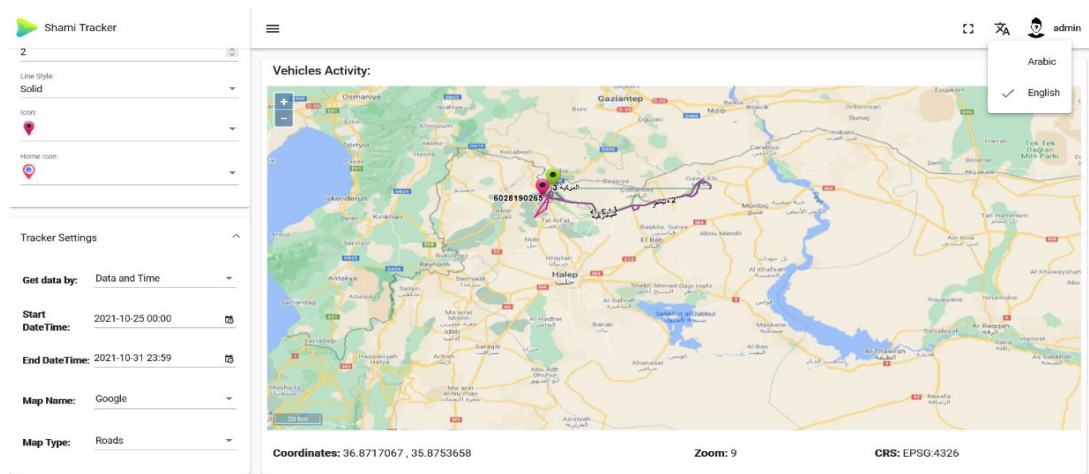


Figure 3.18 Tracker (web) – activity diagram

The website is written by Angular 7, an open-source JavaScript-based framework for creating dynamic web apps for both desktop and mobile devices.

How it works:

3.18.1 After a user successfully logs in the website, the user will get his car history from the database and display it on the map.

3.18.2 The user can see only his car.

3.18.3 The cars are displayed in a hierarchal form, each car is belonging to a group, and each group is belonging to a site. For example: site like “Aleppo”, group like “Emergency” and car like “Ahmad Car” as in Figure 3.19.

3.18.4 The paths of the cars are displayed on a map; the map library is open layers version 5.

3.18.5 The path can be displayed in two ways:

3.18.5.1 By number of coordinates: this will get the latest number of coordinates for each car as in Figure 3.20.

3.18.5.2 By date: this will get the coordinates between start and end date for each car as in Figure 3.21.

The user can show/hide the cars, change the map style (roads – satellite).

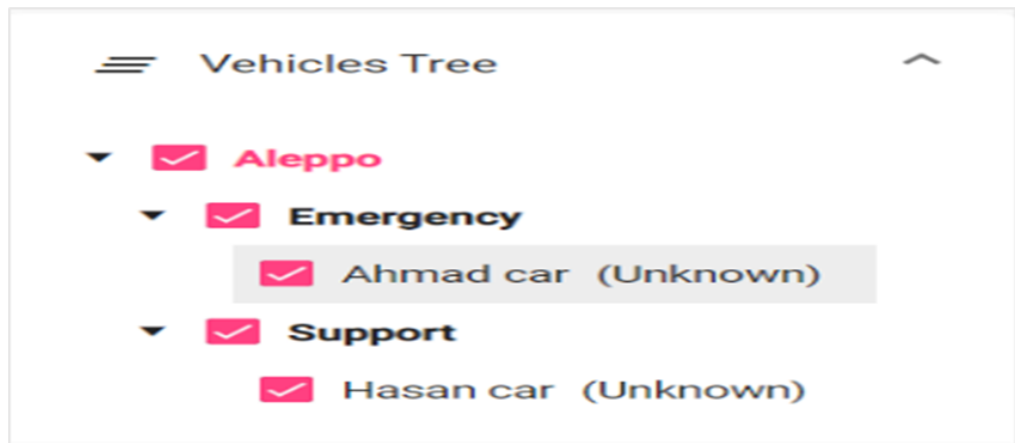


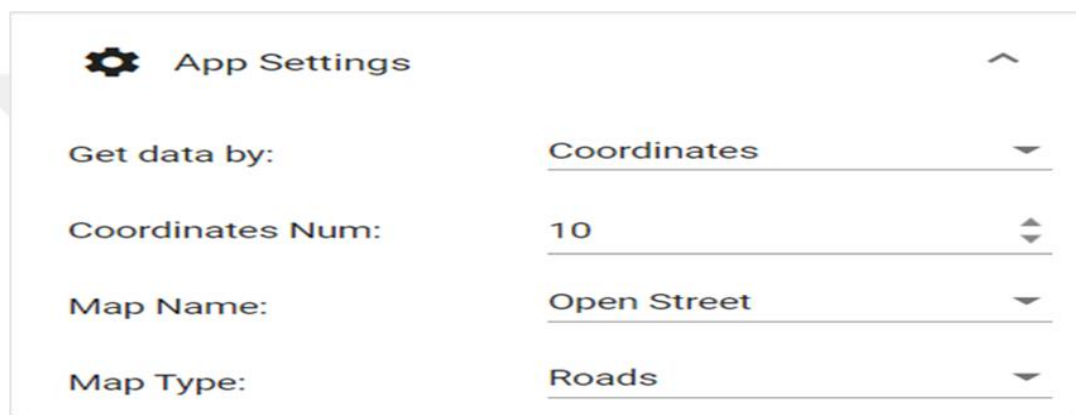
**Figure 3.19** Vehicles tree



The screenshot shows the 'App Settings' interface. At the top, there is a gear icon and the text 'App Settings' with an upward arrow. Below this, there are five settings rows:

- 'Get data by:' is set to 'Data and Time' with a dropdown arrow.
- 'Start DateTime:' is set to '01-02-2021 19:59' with a calendar icon.
- 'End DateTime:' is set to '08-02-2021 21:59' with a calendar icon.
- 'Map Name:' is set to 'Open Street' with a dropdown arrow.
- 'Map Type:' is set to 'Roads' with a dropdown arrow.

**Figure 3.20** Latest number of coordinates for each car



The screenshot shows the 'App Settings' interface. At the top, there is a gear icon and the text 'App Settings' with an upward arrow. Below this, there are four settings rows:

- 'Get data by:' is set to 'Coordinates' with a dropdown arrow.
- 'Coordinates Num:' is set to '10' with up and down arrow icons.
- 'Map Name:' is set to 'Open Street' with a dropdown arrow.
- 'Map Type:' is set to 'Roads' with a dropdown arrow.

**Figure 3.21** Coordinates between start and end date for each car

### 3.19 Cipherring and Encryption

Cipherring aims at a secure exchange of information between the two parties to the communication, ensuring the preservation of its privacy. Encryption is used in cellular communication systems, in other words, cipherring represents a goal that can be accessed through encryption. Cipherring leads to a change in the structure of the exchanged information, by using the cipherring key or encryption that is known only to the two parties concerned with its content. We note here that decryption is concerned with protecting information within the domain that is vulnerable to capture by third parties, without the ability of the network operator to prevent this. This thesis is the port or radio link of the mobile unit and the fixed station that feeds it, which represents an open part within the information path that the network operator cannot control who tries to access it. Therefore, the term cipherring in the context of our discussion denotes

the provision of information security exclusively within the radio port. Ciphering algorithms do not add any new bits to the chain of information being processed, which means that the rate of the information flow before and after the encryption does not change. The type of algorithm used in the thesis was determined based on the realistic determinants explained in the second chapter [6].

Advanced encryption standard AES is an official encryption method adopted by NIST national center for standards and technology, a branch of the United States government. This algorithm is widely required and accepted in the world because it is considered a secure method of encryption due to the length of the encryption key. This algorithm is a development of ideas featured in DES [13].

In 1997, NIST began searching for an alternative to DES, because DES was widely considered unsafe at the time, due to the development of advanced methods to break this method. In just 3.5 hours! All this basically contributed to the announcement of the issuance of a stronger encryption standard, and one of the objectives of this research was to announce an alternative that is used in general and not limited to the military, and for this reason, all specialists in cryptography were invited to submit their suggestions, and the conditions were as follows [13]:

3.19.1.1 AES must be publicly defined.

3.19.1.2 AES should be a symmetric block cipher algorithm.

3.19.1.3 AES should be designed so that the key length can be extended.

3.19.1.4 AES can be programmed using computer hardware and software.

3.19.1.5 AES shall be freely available or otherwise available in accordance with ANSI patent policy.

Algorithms that are in line with the previous points will be tested based on the following criteria [14]:

3.19.2.1 Security: how resistant it is to known methods for cracking encryption algorithms.

3.19.2.2 The quality of the computation: that is, the measurement of the time required for encoding, and the less it is, the better the algorithm will be.

3.19.2.3 Memory requirements: the capacity of the electronic memory used to implement the algorithm.

3.19.2.4 Algorithm suitability for computer hardware and software.

3.19.2.5 The simplicity of the algorithm.

3.19.2.6 Algorithm flexibility.

3.19.2.7 Licensing requirements.

3.19.2.8 Later, the length (key, block) that AES is supposed to provide was determined: (256,128), (192,128), (128,128).

The competition was in two stages. In the first stage, 15 algorithms were submitted. In 1999, 5 algorithms were selected for the qualifiers:

MARS, RC6, RIJNDEAL, SERPENT and TWOFISH.

In October 2000, RIJNDEAL was chosen to replace DES, and its name was changed to AES, and in November 2001 it became an official standard FIPS 197. The inventors of this standard are Daemen and Rijmen [13].

Rindol is a block cipher algorithm that supports multiple key lengths and text lengths. The encryption key  $k$  is an array of dimensions  $4 \times N_k$  (that is, the length of the key is  $4 \times N_k$  bytes) [13].

$$\underline{k} = \begin{pmatrix} k_{0,0} & k_{0,1} & \cdots & k_{0,N_k-1} \\ k_{1,0} & k_{1,1} & \cdots & k_{1,N_k-1} \\ k_{2,0} & k_{2,1} & \cdots & k_{2,N_k-1} \\ k_{3,0} & k_{3,1} & \cdots & k_{3,N_k-1} \end{pmatrix} \quad (3.5)$$

where each  $K_i, j$  can be taken as: 8 bits or 1 byte is a number in the set  $Z_{2.8}$ .

An integer in the set  $Z_{256}$ .

Key length in Rindal's algorithm can be  $N_k = 4.6.8$  (128.192.256) bytes.

Reading the encryption key from the array is according to each column from left to right:

$$\underline{k} = (k_{0,0}, k_{1,0}, k_{2,0}, k_{3,0}, \cdots, k_{0,N_k-1}, k_{1,N_k-1}, k_{2,N_k-1}, k_{3,N_k-1}) \quad (3.6)$$

The block or text we want to encode  $x$  is an array of lengths  $4 \times N_b$  (that is, the length of the key is  $4 \cdot N_b$  bytes):

$$\underline{x} = \begin{pmatrix} x_{0,0} & x_{0,1} & \cdots & x_{0,N_b-1} \\ x_{1,0} & x_{1,1} & \cdots & x_{1,N_b-1} \\ x_{2,0} & x_{2,1} & \cdots & x_{2,N_b-1} \\ x_{3,0} & x_{3,1} & \cdots & x_{3,N_b-1} \end{pmatrix} \quad (3.7)$$

where every  $\omega_{i,j}$  an integer in  $Z_{256}$ .

Rindol is the installation of transformations on rindol positions, and these transformations we will call iterations:

$$RIJ(\underline{x}) = \underline{y} = (T_{N_r} \circ T_{N_r-1} \circ \cdots \circ T_{N_1} \circ T_{N_0}) \quad (3.8)$$

Each  $T_i: \omega \rightarrow \omega$  the domain and range are the rindol positions, the number of turns is  $(N_t)$  related to the length of the key  $(N_k)$  and the length of the text  $(N_b)$ . Table 3.1 shows rindol cycles  $(N_T)$  [13].

**Table 3.1** Rindol cycles [14]

| $N_b = 8$ | $N_b = 6$ | $N_b = 4$ |           |
|-----------|-----------|-----------|-----------|
| 14        | 12        | 10        | $N_k = 4$ |
| 14        | 12        | 12        | $N_k = 6$ |
| 14        | 14        | 14        | $N_k = 8$ |

The first cycle  $T_0$  is the XOR between the text (first position) and the encryption key:

$$T_0(x) = \begin{pmatrix} k_{0,0} & k_{0,1} & \cdots & k_{0,N_k-1} \\ k_{1,0} & k_{1,1} & \cdots & k_{1,N_k-1} \\ k_{2,0} & k_{2,1} & \cdots & k_{2,N_k-1} \\ k_{3,0} & k_{3,1} & \cdots & k_{3,N_k-1} \end{pmatrix} \oplus \begin{pmatrix} x_{0,0} & x_{0,1} & \cdots & x_{0,N_b-1} \\ x_{1,0} & x_{1,1} & \cdots & x_{1,N_b-1} \\ x_{2,0} & x_{2,1} & \cdots & x_{2,N_b-1} \\ x_{3,0} & x_{3,1} & \cdots & x_{3,N_b-1} \end{pmatrix} \quad (3.9)$$

The cycles that come after this will be concerned with transforming the current position and to complete this algorithm, it does this in stages:

3.19.3.1 The linear mixing operation - transformations are shift row and – mix column.

3.19.3.2 The nonlinear operation is the byte sub transformation.

3.19.3.3 Add round key Extension Process add round key.

In order to show the ciphering, it is enough to overturn the transformations:

### Replacement process

$$RIJ^{-1}(\underline{y}) = \underline{x} = (T_{N_0}^{-1} \circ T_{N_1}^{-1} \circ \dots \circ T_{N_{r-1}}^{-1} \circ T_{N_r}^{-1}) \quad (3.10)$$

The byte substitution operation is always an array S (that is, when we want to encode, the substitution operation is always done through this box) and the substitution is done according to the following array [14]:

word8 S [256] = {

99, 124, 119, 123, 242, 107, 111, 197, 48, 1, 103, 43, 254, 215, 171, 118,  
 202, 130, 201, 125, 250, 89, 71, 240, 173, 212, 162, 175, 156, 164, 114, 192,  
 183, 253, 147, 38, 54, 63, 247, 204, 52, 165, 229, 241, 113, 216, 49, 21,  
 4, 199, 35, 195, 24, 150, 5, 154, 7, 18, 128, 226, 235, 39, 178, 117,  
 9, 131, 44, 26, 27, 110, 90, 160, 82, 59, 214, 179, 41, 227, 47, 132,  
 83, 209, 0, 237, 32, 252, 177, 91, 106, 203, 190, 57, 74, 76, 88, 207,  
 208, 239, 170, 251, 67, 77, 51, 133, 69, 249, 2, 127, 80, 60, 159, 168,  
 81, 163, 64, 143, 146, 157, 56, 245, 188, 182, 218, 33, 16, 255, 243, 210,  
 205, 12, 19, 236, 95, 151, 68, 23, 196, 167, 126, 61, 100, 93, 25, 115,  
 96, 129, 79, 220, 34, 42, 144, 136, 70, 238, 184, 20, 222, 94, 11, 219,  
 224, 50, 58, 10, 73, 6, 36, 92, 194, 211, 172, 98, 145, 149, 228, 121,  
 231, 200, 55, 109, 141, 213, 78, 169, 108, 86, 244, 234, 101, 122, 174, 8,  
 186, 120, 37, 46, 28, 166, 180, 198, 232, 221, 116, 31, 75, 189, 139, 138,  
 112, 62, 181, 102, 72, 3, 246, 14, 97, 53, 87, 185, 134, 193, 29, 158,  
 225, 248, 152, 17, 105, 217, 142, 148, 155, 30, 135, 233, 206, 85, 40, 223,  
 140, 161, 137, 13, 191, 230, 66, 104, 65, 153, 45, 15, 176, 84, 187, 22  
 };

Example: If the number we want to replace is 0x19 (according to the hexadecimal system), then it is replaced as follows: We go to the first line, the ninth column, and the result is 0x4d or 212 (according to rule 10) as shown in the Figure 3.22.

```
word8 S[256] = {
  99, 124, 119, 123, 242, 107, 111, 197, 48, 1, 103, 43, 254, 215, 171, 118,
  202, 130, 201, 125, 250, 89, 71, 240, 173, 212, 162, 175, 156, 164, 114, 192,
  183, 253, 147, 38, 54, 63, 247, 204, 52, 165, 229, 241, 113, 216, 49, 21,
  4, 199, 35, 195, 24, 150, 5, 154, 7, 18, 128, 226, 235, 39, 178, 117,
  9, 131, 44, 26, 27, 110, 90, 160, 82, 59, 214, 179, 41, 227, 47, 132,
  83, 209, 0, 237, 32, 252, 177, 91, 106, 203, 190, 57, 74, 76, 88, 207,
  208, 239, 170, 251, 67, 77, 51, 133, 69, 249, 2, 127, 80, 60, 159, 168,
  81, 163, 64, 143, 146, 157, 56, 245, 188, 182, 218, 33, 16, 255, 243, 210,
  205, 12, 19, 236, 95, 151, 68, 23, 196, 167, 126, 61, 100, 93, 25, 115,
  96, 129, 79, 220, 34, 42, 144, 136, 70, 238, 184, 20, 222, 94, 11, 219,
  224, 50, 58, 10, 73, 6, 36, 92, 194, 211, 172, 98, 145, 149, 228, 121,
  231, 200, 55, 109, 141, 213, 78, 169, 108, 86, 244, 234, 101, 122, 174, 8,
  186, 120, 37, 46, 28, 166, 180, 198, 232, 221, 116, 31, 75, 189, 139, 138,
  112, 62, 181, 102, 72, 3, 246, 14, 97, 53, 87, 185, 134, 193, 29, 158,
  225, 248, 152, 17, 105, 217, 142, 148, 155, 30, 135, 233, 206, 85, 40, 223,
  140, 161, 137, 13, 191, 230, 66, 104, 65, 153, 45, 15, 176, 84, 187, 22
};
```

Figure 3.22 Replace example [14]

### Line offset operation

It is a process that shifts the position lines with a circular shift, and it shifts the  $i$  line:  $i$  shifts to the left [14]:

$$SR : \omega = \begin{pmatrix} \omega_{0,0} & \omega_{0,1} & \omega_{0,2} & \omega_{0,3} \\ \omega_{1,0} & \omega_{1,1} & \omega_{1,2} & \omega_{1,3} \\ \omega_{2,0} & \omega_{2,1} & \omega_{2,2} & \omega_{2,3} \\ \omega_{3,0} & \omega_{3,1} & \omega_{3,2} & \omega_{3,3} \end{pmatrix} \rightarrow \begin{pmatrix} \omega_{0,0} & \omega_{0,1} & \omega_{0,2} & \omega_{0,3} \\ \omega_{1,1} & \omega_{1,2} & \omega_{1,3} & \omega_{1,0} \\ \omega_{2,2} & \omega_{2,3} & \omega_{2,0} & \omega_{2,1} \\ \omega_{3,3} & \omega_{3,0} & \omega_{3,1} & \omega_{3,2} \end{pmatrix} \quad (3.11)$$

### Mix columns

It is a linear mixing process for columns, meaning that it is done by a matrix, and this process is defined by operations in  $GF 2^8$ , meaning that for each column [14]:

$$\begin{bmatrix} s'_0 \\ s'_1 \\ s'_2 \\ s'_3 \end{bmatrix} = \begin{bmatrix} 2 & 3 & 1 & 1 \\ 1 & 2 & 3 & 1 \\ 1 & 1 & 2 & 3 \\ 3 & 1 & 1 & 2 \end{bmatrix} \begin{bmatrix} s_0 \\ s_1 \\ s_2 \\ s_3 \end{bmatrix} \quad (3.12)$$

The field  $GF 2^8$  is based on the polynomial  $x^8 + x^4 + x^3 + x + 1$ .

### Add session key

Simply this operation does the following: it takes the current position and XOR works with the session key (the session key has the same length as the current position the text) The session key is calculated by the key generation algorithm. If the current situation is [14]:

$$\begin{pmatrix} k_{0,0} & k_{0,1} & k_{0,2} & k_{0,3} \\ k_{1,0} & k_{1,1} & k_{1,2} & k_{1,3} \\ k_{2,0} & k_{2,1} & k_{2,2} & k_{2,3} \\ k_{3,0} & k_{3,1} & k_{3,2} & k_{3,3} \end{pmatrix} \oplus \begin{pmatrix} \omega_{0,0} & \omega_{0,1} & \omega_{0,2} & \omega_{0,3} \\ \omega_{1,0} & \omega_{1,1} & \omega_{1,2} & \omega_{1,3} \\ \omega_{2,0} & \omega_{2,1} & \omega_{2,2} & \omega_{2,3} \\ \omega_{3,0} & \omega_{3,1} & \omega_{3,2} & \omega_{3,3} \end{pmatrix} \quad (3.13)$$

### Encryption and decoding

The encryption is as follows:

First, we add the first period key ( $K_0$ )

Second, ( $N_T$ )cycles per cycle:

3.19.4.1 Replacement process.

3.19.4.2 Line offset.

3.19.4.3 Shuffling columns (except for the last cycle).

3.19.4.4 Add the period key (that is, in period  $i$  we add the key  $K_i$ ).

In order to decrypt, as we mentioned at the beginning, the order of the encryption operations must be reversed in order [14].

### Key production algorithm

It is necessary to produce a new key from the one we used before (so we won't use the same key twice) and the algorithm input is a large array  $N_K$  words (each word is 32 bits) and the algorithm calculates the period key  $N_T + 1$  (next cycle), let  $W$  be an array of words and is as big as  $W: W \ 4 \times (N_T + 1)$ . Then the first 4 words become the key of the first cycle and the next 4 words are the key of the second cycle, and so on ... Figure 3.23 shows key production algorithm as follows [14]:

```

W[0..Nk-1] = key[*];
for i := Nk to 4*(Nr+1)-1 do {
temp = W[i-1]
if((i%Nk)==0)
temp = bytesubstitution(temp<<<8) ^ RCON[i/Nk];
if((Nk==8) & ((i%Nk)==4))
temp = bytesubstitution(temp);
W[i] = W[i-Nk] ^ temp;
}

```

**Figure 3.23** Key production algorithm [14]

Byte substitution is an implementation of the matrix S, whereas the RCON is the following array:

```

word32 RCON [] = {
01x, 02x, 04x, 08x, 10x, 20x, 40x, 80x,
1bx, 36x, 6cx, d8x, abx, 4dx, 9ax, 2fx
}

```

Note that these numbers are powers of 2 in the field in GF 2<sup>8</sup>.

### Safety features

There is no complimentary adjective as in DES. That is, it is

$$A E S_k(x) \neq A E S_{k^-}(x^-) \quad (3.14)$$

The security of the algorithm is all related to the selection of the matrix S, which is the only part in the algorithm that is not linear or

$$S[i] + S[j] \neq [i + j] \quad (3.15)$$

harmonious, as it is: for example, if S was a symmetric matrix, then the whole process would be symbiotic and therefore not safe and easily broken [13].

The best attacks on this algorithm are on 7 cycles of the algorithm take time 2<sup>110</sup> when the key length is 128 bits However, if the key length is 256 bits, the best attack for 8 turns is 2<sup>204</sup> there are no attacks with a shorter time than this. Also, there is no effective attack on all cycles. the time required to crack the whole algorithm is 2 when the key length is 128 bits [13].

Although there is no proof that rindol is safe, the algorithm is safe for all known types of attacks. The effectiveness of these attacks on the algorithm has been examined, and all of them failed, as it could not reduce the time needed to break the algorithm, meaning that the best time to attack the algorithm is  $2^{128}$  by these means [14].

### **Is AES a one-way function?**

General form there is no proof that AES is a one-way function, nor is it even unbreakable! But in general, it is believed that it is unbreakable, which makes it a candidate to be a one-way function, but so far it can be considered as such because the percentage of data that we can get its reciprocal is very small [14];

### **Uses**

Since AES is an encryption algorithm, so it has many uses that include user protection over the Internet to protect and ensure data in banks and laboratories, and AES has been used in military fields. What ensured that AES is useful in all these applications is that there is no way effective to break it, and some of the most famous programs and protocols rely on AES resistance to electronic attacks, including [14]:

13.19.5.1 AES has been used in WinZIP programs if the user requests encryption of data after it has been compressed.

13.19.5.2 It is used in TLS, a protocol for establishing a secure connection.

13.19.5.3 It also has use in the IPsec protocol, which is a protocol to ensure security in IP-based communications over the Internet.

The two algorithms are used as needed in experiments and implementation [5].

The following Table 3.2 shows the methods used for coding in the thesis stages.

**Table 3.2** The ciphering and encryption process in the five experiments

| Scientific Purpose                                     | Location of Work                                                   | Encryption Algorithm | Experiment Number |
|--------------------------------------------------------|--------------------------------------------------------------------|----------------------|-------------------|
| Encryption and protection of the communication channel | The communication channel between the transmitter and the receiver | XOR cipher           | 1-3               |

|                                                        |                                                               |                                    |     |
|--------------------------------------------------------|---------------------------------------------------------------|------------------------------------|-----|
| Encryption and protection of the communication channel | The communication channel between the sender and the receiver | Advanced Encryption Standard (AES) | 4-5 |
| Encryption and protection of the database              | Database                                                      | Advanced Encryption Standard (AES) | 5   |



## CHAPTER IV

### EXPERIMENTS AND RESULTS

In order to evaluate the performance of the designed system, a series of experiments were carried out using a station to send information and a station to receive information through five stages gradually developed to obtain the best results, the advantages and disadvantages of each case were presented and discussed.

#### 4.1 First Experiment

The components and stages required for the Transmission System are given in Table 4.1 and Receiving System in Table 4.2.

**Table 4.1** First experiment transmitting system

| Scientific purpose                                                                            | Device                                                                                                                       |
|-----------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Generating an audio signal capable of carrying an information signal<br>(Geographic location) | Manual walkie talkie device of the type Baofeng BF777S capacity of 5 watts (Figure 4.1)                                      |
| Geolocation                                                                                   | GPS (GPS module with compass powered by ublox 7N (Figure 4.2)                                                                |
| The connection between the transmitting circuit, the GPS module, and the Walkie-Talkie        | Copper wire scheduled double insulated, AWG measuring the radius of 5 mm (Figure 4.3)                                        |
| Passing the modified signal (voice radio) into space in the direction of the receiving system | The antenna used in the Walkie-Talkie-uhf /vhf antenna (Figure 4.4)                                                          |
| Converting from the analog system to the digital system and the modulation process            | two ATmega328P single-chip microcontroller, two 3.3V LDO (IC 317EMP) and a bunch of basic electronic components (Figure 4.5) |
| Circuit encapsulation                                                                         | A plastic box measuring 10 x 10 x 5 cm (Figure 4.6)                                                                          |

**Table 4.2** First experiment receiving system

| Scientific purpose                                                                 | Device                                                                                                               |
|------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| Receive the modified signal (voice radio) from the antenna                         | Manual walkie talkie device of the type Baofeng BF777S capacity of 5 watts (Figure 4.1)                              |
| The connection between the receiving circuit and the Walkie-Talkie                 | Copper wire scheduled double insulated, AWG measuring the radius of 5 mm (Figure 4.2)                                |
| To capture the modified signal (voice radio) and pass it to the receiving system   | The antenna used in the Walkie-Talkie- uhf /vhf antenna (Figure 4.3)                                                 |
| Converting from the digital system to the analog system and the modulation process | ATmega328P single-chip microcontroller, 3.3V LDO (IC 317EMP) and a bunch of basic electronic components (Figure 4.7) |
| Circuit encapsulation                                                              | A plastic box measuring 10 x 10 x 5 cm (Figure 4.6)                                                                  |



**Figure 4.1** Manual walkie talkie device of the type baofeng BF777S



**Figure 4.2** GPS module with compass powered by ublox 7N



**Figure 4.3** Copper wire scheduled double insulated, AWG



**Figure 4.4** The antenna used in the walkie-talkie



**Figure 4.5** Implementation of the transmission circuit



**Figure 4.6** A plastic box with the size 10 x 10 x 5 cm

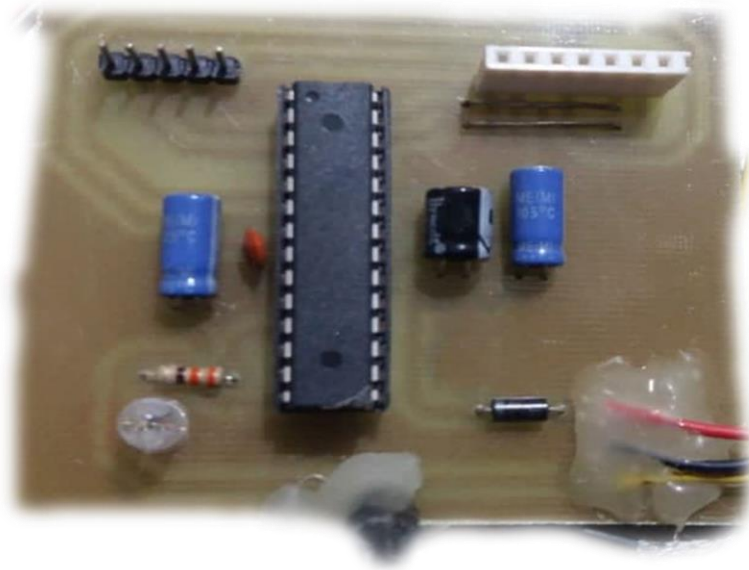


**Figure 4.7** Implementation of the receiving circuit

## 4.2 Experimental Results and Analysis for the First Experiment

Positives:

The signal is formed and the connection between the equipment is achieved and the modification method is successful.

Negatives:

- 4.2.1 The problem of large size and excess weight.
- 4.2.2 The problem of wasting energy, as there is no power regulator.
- 4.2.3 Little electric power.
- 4.2.4 Covering a small geographical area 3-5 km.
- 4.2.5 It should be no concrete barriers or buildings in the place of the experiment.
- 4.2.6 Equipment sensitivity is weak (-dB).

## 4.3 Second Experiment

The components and stages required for the Transmission System are given in Table 4.3 and Receiving System in Table 4.4.

**Table 4.3** Second experiment transmitting system

| Scientific purpose                                                                            | Device                                                                                                                       |
|-----------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Generating an audio signal capable of carrying an information signal (Geographic location)    | Manual walkie talkie device of the type Baofeng BF777S capacity of 5 watts (Figure 4.1)                                      |
| Geolocation                                                                                   | GPS (GPS module with compass powered by ublox 7N (Figure 4.2)                                                                |
| The connection between the transmitting circuit, the GPS module, and the Walkie-Talkie        | Copper wire scheduled double insulated, AWG measuring the radius of 5 mm (Figure 4.3)                                        |
| Passing the modified signal (voice radio) into space in the direction of the receiving system | The antenna used in the Walkie-Talkie-uhf /vhf antenna (Figure 4.4)                                                          |
| Converting from the analog system to the digital system and the modulation process            | two ATmega328P single-chip microcontroller, two 3.3V LDO (IC 317EMP) and a bunch of basic electronic components (Figure 4.5) |
| Circuit encapsulation                                                                         | A plastic box measuring 10 x 10 x 5 cm (Figure 4.6)                                                                          |

**Table 4.4** Second experiment receiving system

| Scientific purpose                                                                 | Device                                                                                                               |
|------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| Receive the modified signal (voice radio) from the antenna                         | Walkie talkie device is intended for vehicles and cars of the type Vertex Standard capacity of 25 watts (Figure 4.8) |
| The connection between the receiving circuit and the Walkie-Talkie                 | Copper wire scheduled double insulated, AWG measuring the radius of 5 mm (Figure 4.3)                                |
| Converting from the digital system to the analog system and the modulation process | ATmega328P single-chip microcontroller, 3.3V LDO (IC 317EMP) and a bunch of basic electronic components (Figure 4.7) |
| Circuit encapsulation                                                              | A plastic box measuring 10 x 10 x 5 cm (Figure 4.6)                                                                  |



**Figure 4.8** Walkie talkie device for vehicles of the type vertex

#### 4.4 Experimental Results and Analysis for the Second Experiment:

Positives:

- 4.4.1.1 Capable of solving the problem of energy waste in the first experiment.
- 4.4.1.2 The possibility of covering areas with concrete blocks to a good extent.

Negatives:

- 4.4.2.1 The problem of large size and excess weight.
- 4.4.2.2 Equipment sensitivity is weak (-dB).
- 4.4.2.3 Expensive equipment prices are not suitable for increasing the number of beneficiaries.

#### 4.5 Third Experiment

The components and stages required for the Transmission System are given in Table 4.5 and Receiving System in Table 4.6.

**Table 4.5** Third experiment transmitting system

| Scientific purpose                                                                            | Device                                                                                  |
|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| Generating an audio signal capable of carrying an information signal (Geographic location)    | Manual walkie talkie device of the type Baofeng BF777S capacity of 5 watts (Figure 4.1) |
| Geolocation                                                                                   | GPS (GPS module with compass powered by ublox 7N (Figure 4.2)                           |
| The connection between the transmitting circuit, the GPS module, and the Walkie-Talkie        | Copper wire scheduled double insulated, AWG measuring the radius of 5 mm (Figure 4.3)   |
| Passing the modified signal (voice radio) into space in the direction of the receiving system | Opek car -uhf /vhf antenna (Figure 4.9)                                                 |

**Table 4.5** continue

|                                                                                    |                                                                                                                              |
|------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Connection between the antenna and the transmitting circuit                        | Coaxial cable with impedance 50 ohm (Figure 4.10)                                                                            |
| Converting from the analog system to the digital system and the modulation process | two ATmega328P single-chip microcontroller, two 3.3V LDO (IC 317EMP) and a bunch of basic electronic components (Figure 4.5) |
| Circuit encapsulation                                                              | A plastic box measuring 10 x 10 x 5 cm (Figure 4.6)                                                                          |

**Table 4.6** Third experiment receiving system

|                                                                                               |                                                                                                                       |
|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| Scientific purpose                                                                            | Partitions                                                                                                            |
| Generating an audio signal capable of carrying an information signal (Geographic location)    | Walkie talkie device is intended for vehicles and cars of the type HYTERA standard capacity of 25 watts (Figure 4.11) |
| Geolocation                                                                                   | GPS (GPS module with compass powered by ublox 7N (Figure 4.2)                                                         |
| The connection between the transmitting circuit, the GPS module, and the Walkie-Talkie        | Copper wire scheduled double insulated, AWG measuring the radius of 5 mm (Figure 4.3)                                 |
| Passing the modified signal (voice radio) into space in the direction of the receiving system | Opek car -uhf /vhf antenna (Figure 4.9)                                                                               |
| Connection between the antenna and the transmitting circuit                                   | Coaxial cable with impedance 50 ohm (Figure 4.10)                                                                     |
| Converting from the analog system to the digital system and the modulation process            | ATmega328P single-chip microcontroller, 3.3V LDO (IC 317EMP) and a bunch of basic electronic components (Figure 4.7)  |
| Circuit encapsulation                                                                         | A plastic box measuring 10 x 10 x 5 cm (Figure 4.6)                                                                   |



**Figure 4.9** Opek car -uhf /vhf antenna



**Figure 4.10** Coaxial cable with impedance 50 ohm



**Figure 4.11** Walkie talkie device for vehicles of the type hytera

## 4.6 Experimental Results and Analysis for the Third Experiment

Positives:

4.6.1.1 Capable of solving the problem of energy waste in the first experiment.

4.6.1.2 The possibility of covering areas with concrete blocks to a good extent.

Negatives:

4.6.2.1 The problem of large size and excess weight.

4.6.2.2 Expensive equipment prices are not suitable for increasing the number of beneficiaries.

NOTE: The station from Vertex has good transmission, but its receiving is weak, unlike the station from HYTERA, so the station from Vertex was used in the transmission and the station from HITRA was used in receiving.

## 4.7 Fourth Experiment

The components and stages required for the Transmission System are given in Table 4.7 and Receiving System in Table 4.8.

**Table 4.7** Fourth experiment transmitting system

| Scientific purpose                                                                            | Device                                                                                                                           |
|-----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Generating an audio signal capable of carrying an information signal (Geographic location)    | The Walkie-Talkie devices were replaced with a modular type DRA818V - Dorji Installed with the transmitter circuit (Figure 4.12) |
| Geolocation                                                                                   | GPS (GPS module with compass powered by ublox 7N (Figure 4.2)                                                                    |
| The connection between the transmitting circuit, the GPS module, and the Walkie-Talkie        | Copper wire scheduled double insulated, AWG measuring the radius of 5 mm (Figure 4.3)                                            |
| Passing the modified signal (voice radio) into space in the direction of the receiving system | Letter-shaped antenna V Of my design length of 12 cm (Figure 4.13)                                                               |
| Connection between the antenna and the transmitting circuit                                   | Coaxial cable with impedance 50 ohm (Figure 4.10)                                                                                |

**Table 4.7** continue

|                                                                                    |                                                                                                                              |
|------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Converting from the analog system to the digital system and the modulation process | two ATmega328P single-chip microcontroller, two 3.3V LDO (IC 317EMP) and a bunch of basic electronic components (Figure 4.5) |
| Circuit encapsulation                                                              | A plastic box measuring 10 x 10 x 5 cm (Figure 4.6)                                                                          |

**Table 4.8** Fourth experiment receiving system

| Scientific purpose                                                                            | Device                                                                                                                           |
|-----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Generating an audio signal capable of carrying an information signal (Geographic location)    | The Walkie-Talkie devices were replaced with a modular type DRA818V - Dorji Installed with the transmitter circuit (Figure 4.12) |
| Geolocation                                                                                   | GPS (GPS module with compass powered by ublox 7N (Figure 4.2)                                                                    |
| The connection between the transmitting circuit, the GPS module, and the Walkie-Talkie        | Copper wire scheduled double insulated, AWG measuring the radius of 5 mm (Figure 4.3)                                            |
| Passing the modified signal (voice radio) into space in the direction of the receiving system | Letter-shaped antenna V Of my design length of 12 cm (Figure 4.13)                                                               |
| Connection between the antenna and the transmitting circuit                                   | Coaxial cable with impedance 50 ohm (Figure 4.10)                                                                                |
| Converting from the analog system to the digital system and the modulation process            | ATmega328P single-chip microcontroller, 3.3V LDO (IC 317EMP) and a bunch of basic electronic components (Figure 4.7)             |
| Circuit encapsulation                                                                         | A plastic box measuring 10 x 10 x 5 cm (Figure 4.6)                                                                              |

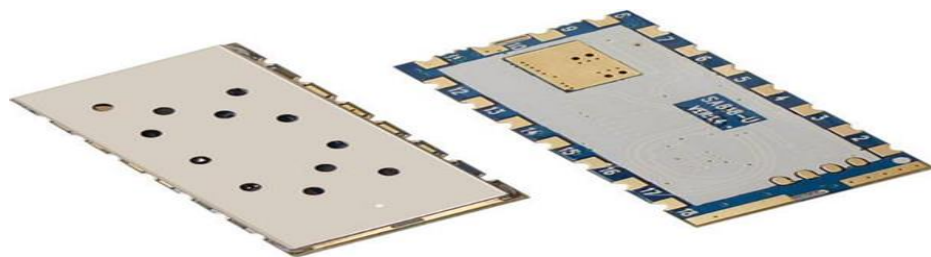
**Figure 4.12** Module DRA818V – Dorji



**Figure 4.13** Letter-shaped antenna V length of 12 cm

#### 4.8 Experimental results and analysis for the fourth experiment

Positives:

- 4.8.1.1 Capable of solving the problem of large size and excess weight
- 4.8.1.2 Capable of solving the problem of expensive equipment prices

Negatives:

The fourth model was able to solve all hardware problems, but software and geographic problems remained. The solutions are discussed in the software section

- 4.8.2.1 There is still a problem of poor encryption as the (XOR) algorithm is used.
- 4.8.2.2 The problem of disconnection appeared when passing in blind spots or valleys.
- 4.8.2.3 The problem of internet disconnection arose due to the absence of a central service operator and the destruction of a central infrastructure.

#### 4.9 Fifth Experiment

**Table 4.9** Fifth experiment transmitting system

| Scientific purpose                                                                         | Device                                                                                                                           |
|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Generating an audio signal capable of carrying an information signal (Geographic location) | The Walkie-Talkie devices were replaced with a modular type DRA818V - Dorji Installed with the transmitter circuit (Figure 4.12) |
| Geolocation                                                                                | GPS (GPS module with compass powered by ublox 7N (Figure 4.2)                                                                    |
| The connection between the transmitting circuit, the GPS module, and the Walkie-Talkie     | Copper wire scheduled double insulated, AWG measuring the radius of 5 mm (Figure 4.3)                                            |

**Table 4.9** continue

|                                                                                               |                                                                                                                              |
|-----------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Passing the modified signal (voice radio) into space in the direction of the receiving system | Letter-shaped antenna V Of my design length of 12 cm (Figure 4.13)                                                           |
| Connection between the antenna and the transmitting circuit                                   | Coaxial cable with impedance 50 ohm (Figure 4.10)                                                                            |
| Converting from the analog system to the digital system and the modulation process            | two ATmega328P single-chip microcontroller, two 3.3V LDO (IC 317EMP) and a bunch of basic electronic components (Figure 4.5) |
| Circuit encapsulation                                                                         | A plastic box measuring 10 x 10 x 5 cm (Figure 4.6)                                                                          |

**Table 4.10** Fifth experiment receiving system

| Scientific purpose                                                                            | Device                                                                                                                           |
|-----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Generating an audio signal capable of carrying an information signal (Geographic location)    | The Walkie-Talkie devices were replaced with a modular type DRA818V - Dorji Installed with the transmitter circuit (Figure 4.12) |
| Geolocation                                                                                   | GPS (GPS module with compass powered by ublox 7N (Figure 4.2)                                                                    |
| The connection between the transmitting circuit, the GPS module, and the Walkie-Talkie        | Copper wire scheduled double insulated, AWG measuring the radius of 5 mm (Figure 4.3)                                            |
| Passing the modified signal (voice radio) into space in the direction of the receiving system | Monopole antenna from my design, length 50 Cm (Figure 4.14)                                                                      |
| Connection between the antenna and the transmitting circuit                                   | Coaxial cable with impedance 50 ohm (Figure 4.10)                                                                                |
| Converting from the analog system to the digital system and the modulation process            | ATmega328P single-chip microcontroller, 3.3V LDO (IC 317EMP) and a bunch of basic electronic components (Figure 4.7)             |
| Database                                                                                      | bord computer from raspberry pi3 (Figure 4.15)                                                                                   |
| Circuit encapsulation                                                                         | A plastic box measuring 10 x 10 x 5 cm (Figure 4.6)                                                                              |

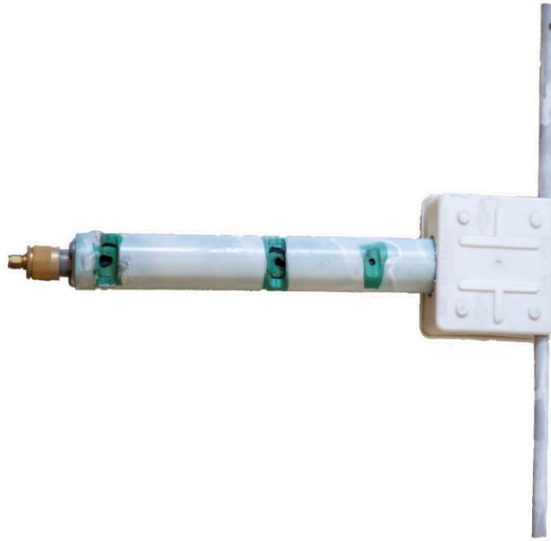


**Figure 4.14** Monopole antenna receiving system

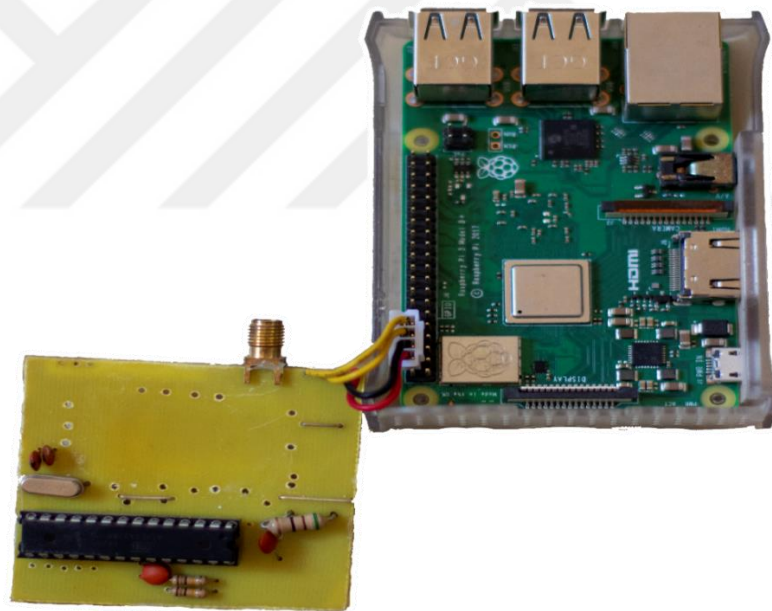


**Figure 4.15** Bord computer from raspberry pi3

#### **4.10 Additional Actions on the Fifth Experiment**

4.10.1.1 Expanding the coverage area by erecting three towers.

4.10.1.2 The height of the tower is six meters.

4.10.1.3 On the top of the iron tower, the antenna is placed the letter T in Figure 4.16.

4.10.1.4 The four highest mountains in the experiment area were selected to ensure the greatest coverage of cities and their neighboring areas.

4.10.1.5 The four mountains are from the east the mountain of Andan, which is in the western countryside of the Aleppo governorate, and from the west the al-Wastani mountain which is in the north of Hama governorate, and from the north the heights of the city of Sarmada close to the Bab al-Hawa border crossing with Turkey, and finally from the south, Jabal al-Arbacien, which is in the north of Idlib governorate.

#### **4.11 Experimental Results and Analysis for the Fifth Experiment**

Positives:

4.11.1 Among the achievements of the fifth model is that the coverage expanded to cover approximately 215 square kilometers, bypassing the problems of blind spots and depressions, and solving the problem of disconnection in the previous models.

4.11.2 The problem of internet interruption was solved by modifying connection protocols.



**Figure 4.16** Antenna tower

## 4.12 Data Transfer Tests

### 4.12.1 Laboratory and computational method

To perform data tests, one of the modems is inserted between the radio and telephone line analyzer in the old fixed communication applications, or the bit error rate analyzer device is inserted between the transmitting station and the receiving station, specifically on the access port of the receiving station, as is the case in this thesis [15].

This method requires a special device which is not available in the laboratory. There are modern methods that depend on computer programs and high-level programming languages such as Excel and MATLAB, and it gives ease of implementation, accuracy in the given results, and greater tolerance for analyzing the results with the statistical rates available on these programs, which means more samples are examined. Unlike the traditional method that requires much more effort to reach a data level in a short time, the second method is the one that was adopted in this thesis, through which we were able to calculate the two main variables, namely, BER and SNR [15].

From the previous two variables, we were able to statistical procedures related to them from the study of "productivity analysis", "data rate analysis" and "delay analysis" on the last fifth model in the thesis, which was more beneficial than others in terms of equipment, prices, and geographical coverage, as was clarified by experiments.

### 4.12.2 Operational steps

To start a test transmission, the transmitting systems were selected, the transmitting station was selected, and a computer was placed on the receiving port. Based on an audio request for data from the transmitting circuit, the baseband data is 600 pseudorandom bits, and the following theoretical equation is adopted for the calculations and the relationship between them [15]:

$$BER \leq \frac{1}{2} \operatorname{erfc} \left( \frac{E_b}{2N_0} \right) \quad (4.1)$$

where:  $E_b$  is the one-bit power, and  $N_0$  is the noise.

The signal-to-noise ratio is defined as the ratio of a signal's power (a meaningful input value) to the background noise power (a stale or unwanted input):

$$SNR = \frac{P_{signal}}{P_{nose}} \quad (4.2)$$

where  $P$  is the average power. Both signal and noise power must be measured at the same or equivalent points in the system, and within the same bandwidth of the system.

The following program was adopted on the MATLAB program to obtain the required data transmission tests:

```
N = 10^6 % number of bits or symbols
rand('state',100); % initializing the rand() function
randn('state',200); % initializing the randn() function
% Transmitter
ip = rand(1,N)>0.5; % generating 0,1 with equal probability
s = 2*ip-1; % BPSK modulation 0 -> -1; 1 -> 1
n = 1/sqrt(2)*[randn(1,N) + j*randn(1,N)]; % white gaussian noise, 0dB variance
Eb_N0_dB = [-3:10]; % multiple Eb/N0 values
for ii = 1:length(Eb_N0_dB)
    % Noise addition
    y = s + 10^(-Eb_N0_dB(ii)/20)*n; % additive white gaussian noise
    % receiver - hard decision decoding
    ipHat = real(y)>0;
    % counting the errors
    nErr(ii) = size(find([ip- ipHat]),2);
end
simBer = nErr/N; % simulated ber
theoryBer = 0.5*erfc(sqrt(10.^(Eb_N0_dB/10))); % theoretical ber
% plot
close all
figure
semilogy(Eb_N0_dB,theoryBer,'b.-');
hold on
semilogy(Eb_N0_dB,simBer,'mx-');
axis([-3 10 10^-5 0.5])
grid on
legend('theory', 'simulation');
```

```
xlabel('Eb/No, dB');
```

```
ylabel('Bit Error Rate');
```

```
title('Bit error probability curve for BPSK modulation');
```

The binary FSK modulation technology was selected, which is a simple type of digital FSK modulation that encodes only two symbols. BFSK stands for Binary Frequency Shift Keying. The data rate used can be categorized as 600, 1200, and 1800 bits per second. For transfer rate analysis, the transfer rate is fixed, so it is 1200 bps. The length of the selected bit block is adopted for each transmission of 3000 bits.[15]

#### **4.12.3 Geographical locations of the study**

4.12.3.1 Five main cities were identified to conduct the experiments, which are Jarablus, Al-Bab, Afrin, Sarmada, and Idlib.

4.12.3.2 These cities are densely populated cities with poor traffic roads, surrounded by military bases that transmit jamming packages, and within them, there are many Wi-Fi networks to transmit the Internet, and the UHF spectrum is crowded with them. First, the car was moved at a speed of 50 kilometers per hour. On the looped road surrounding the city, then the main road that divides the city into a northern section and a southern section was entered, then the main road that divides the city into eastern and western sections was entered, then all the city roundabouts were walked on the roads. In the most crowded and close to the buildings, the speed of movement inside the city decreased to 20 km and sometimes 10 km in the most crowded areas. This experiment was repeated at three different times a day, including early morning 6-8 in the morning and peak time 12-2 in the afternoon and at night 8-10.

4.12.3.3 The external roads linking these cities were cut off, and the speed of movement ranged between 60-80 km, three times a day, 6-8 in the morning, 2-12 in the afternoon, and 6-8 at night.

4.12.3.4 Previous experiments were repeated three times to obtain greater accuracy of the samples.

4.12.3.5 The following abbreviations have been adopted: Outer Ocean Road OOR, The fair road from north to south FNS, The fair road from east to west FEW, inner alleys IA.

4.12.3.6 These speeds, along with test location, date and time, data rate, modulation system, transmitter frequency, and errors measured are given in the tables of Appendix.

4.12.3.7 A special table has been developed for the tests of each city at each time separately. The table contains the name of the city, the time at which the geographical locations samples were taken while moving the vehicle, and the geographical area of the city in addition to the net distance traveled by the vehicle during movement.

4.12.3.8 The total number of geographical samples was taken and placed in the table for each city or highway, for the purpose of making full calculations for each city or for each highway, as the total number of samples is considered a basic parameter in signal-to-noise ratio and Bit error rate.

4.12.3.9 The detailed data taken in the tables contributes to the formation of statistical data to test the quality of the network by analyzing the throughput and analyzing the data rate by simulating it with the Matlab program.

**Table 4.11** Comparison of theoretical and measured results

| N  | Location                             | Calculated SNR | Actual BER           | Calculated BER       | Actual SNR |
|----|--------------------------------------|----------------|----------------------|----------------------|------------|
| 1  | Jarablus City                        | 37 dB          | $2.0 \times 10^{-4}$ | $1.1 \times 10^{-3}$ | 27 dB      |
| 2  | Bab City                             | 31 dB          | $8.0 \times 10^{-4}$ | $3.3 \times 10^{-3}$ | 33 dB      |
| 3  | Afrin city                           | 30 dB          | $6.0 \times 10^{-4}$ | $4.2 \times 10^{-3}$ | 35 dB      |
| 4  | Sarmada City                         | 15 dB          | $2.0 \times 10^{-4}$ | $1.4 \times 10^{-3}$ | 30 dB      |
| 5  | Idlib city                           | 12 dB          | $1.0 \times 10^{-4}$ | $1.3 \times 10^{-3}$ | 27 dB      |
| 6  | The road between al-Bab and Afrin    | 12 dB          | $1.0 \times 10^{-4}$ | $1.2 \times 10^{-3}$ | 27 dB      |
| 7  | The road between Jarablus and Al-Bab | 12 dB          | $1.0 \times 10^{-4}$ | $1.2 \times 10^{-3}$ | 82 dB      |
| 8  | The road between Jarablus and Afrin  | 12 dB          | $2.0 \times 10^{-4}$ | $1.2 \times 10^{-3}$ | 27 dB      |
| 9  | The road between Afrin and Sarmada   | 13 dB          | $2.0 \times 10^{-4}$ | $1.2 \times 10^{-3}$ | 27 dB      |
| 10 | The road between Sarmada and Idlib   | 12 dB          | $1.0 \times 10^{-4}$ | $1.1 \times 10^{-3}$ | 27 dB      |

#### **4.12.4 Data transfer tests conclusions**

Here is a summary of the results identified by evaluating the test data:

- 4.12.4.1 Vehicle speed has been adjusted even when overclocking is possible to reduce additional parameters that could lead to miscalculation.
- 4.12.4.2 The number zero in the speed field indicates that the car has stopped as a result of a traffic light or a security barrier at city entrances.
- 4.12.4.3 In all data rates tested, most bit errors were due to power-limited effects rather than bandwidth limitations.
- 4.12.4.4 Overcrowded principles led to the interruption of the Internet, but TNC was continuing to record sites and then upload them after the return of the Internet.
- 4.12.4.5 In UHF, the number of errors detected increased with the increase of the signaling rate. This is primarily because longer signaling times associated with lower data rates allow longer integration times through fading and noise bursts.
- 4.12.4.6 In general, the number of errors recorded at a particular test point decreased as the vehicle speed increased in the test range from 40 to 60 km.
- 4.12.4.7 Error bursts were generally less than 8 bits long and never more than 10 bits long.
- 4.12.4.8 Reception of high-quality data was generally simultaneous with reception of high-quality audio.
- 4.12.4.9 Although higher data rates allowed for more overall information throughput, the number of errors did not increase to the extent that error detection and retransmission, or error correction, would be required to take advantage of the increased throughput at higher rates.
- 4.12.4.10 The differences in the error rate measured with changes in the data rate and modulation technique were not considered large enough to ensure that high data usage was avoided. FM radio data connection rates.
- 4.12.4.11 98 percent of messages were received without error

## **CHAPTER V**

### **CONCLUSION**

After much experimentation, five basic models have been selected. The experiments took a full year and included all seasons of the year and all climatic fluctuations (sun, rain, snow, wind ... etc.) and the efficiency of the project was proven to withstand different weather conditions.

Because the project is directly related to the citizen, the aspect of size and dimensions was of great importance, so Table 5.1 was drawn up, which shows the comparison of the five models in terms of size and dimensions, and the latter is the most appropriate model for implementation and spread because it summarizes five devices in two devices and this is shown in Figure 5.1.

Table 5.2 shows a comparison of five models in terms of weight, which is very important for implementation in production, and it is shown in Figure 5.2 and it turned out that the fifth model is the lightest in terms of the transmitter and reception system.

Since the main objective of this thesis is to implement this project using the cheapest methods, it was important to make a financial comparison of the implemented models and to prove that the project achieved its most important objectives in Table 5.3 and Figure 5.3.

The project also achieved a significant expansion in geographical coverage, which made the project effectively on the ground and contribute to raising the service and security infrastructure for the affected areas, and this is the main motive for this thesis and the project that emerges from it, and it can be seen in Table 5.4 and Figure 5.4

The fifth model, after a series of experiments, achieved all the objectives of the project in terms of equipment, lightweight, cheap cost, availability of parts, and achieved wide implementation. As in Figures [5.5-5.10], six maps of different trajectories were tested in different geographical areas for long and short periods.

Figures 5.11 and 5.12 show the interfaces of the map viewer, as well as Figure 5.13 which shows the location of the data in the database. Finally, in Figure. 5.14 a map is drawn showing the final and diffusion of the system.

The project achieved its purpose by building a network to track vehicles with ready-made components capable of covering an area of 217 km in diameter in a politically and security volatile region and is considered an important point for raising the infrastructure and moving towards stability in Figure 5.14.

**Table 5.1** Comparison of the physical sizes of the five experimental devices

| Number                         | First                                                                                                                                                                                    | Second                                                                                                                                                                                    | Third                                                                                                                                                                                      | Fourth                                                                                                                                                                     | Fifth                                                                                                                                     |
|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Size in millimeters is approx. | 415*60*33 transmitter station +<br>100*100*50 transmitting circuit box<br>+<br>415*60*33 receiving station<br>+<br>100*100*50 receiving circuit box<br>+<br>380*280*25 Personal computer | 415*60*33 transmitter station +<br>100*100*50 transmitting circuit box<br>+<br>130*120*50 receiving station<br>+<br>100*100*50 receiving circuit box<br>+<br>380*280*25 Personal computer | 130*120*50 transmitter station +<br>50*100*100 transmitting circuit box<br>+<br>130*120*50 receiving station<br>+<br>100*100*50 receiving circuit box<br>+<br>380*280*25 Personal computer | 100*100*50 transmitting circuit box +<br>150 transmitting antenna<br>+<br>100*100*50 receiving circuit box<br>+<br>150 receiving antenna +<br>380*280*25 Personal computer | 100*100*50 transmitting circuit box +<br>150 transmitting antennae<br>+<br>100*100*50 receiving circuit box<br>+<br>500 receiving antenna |

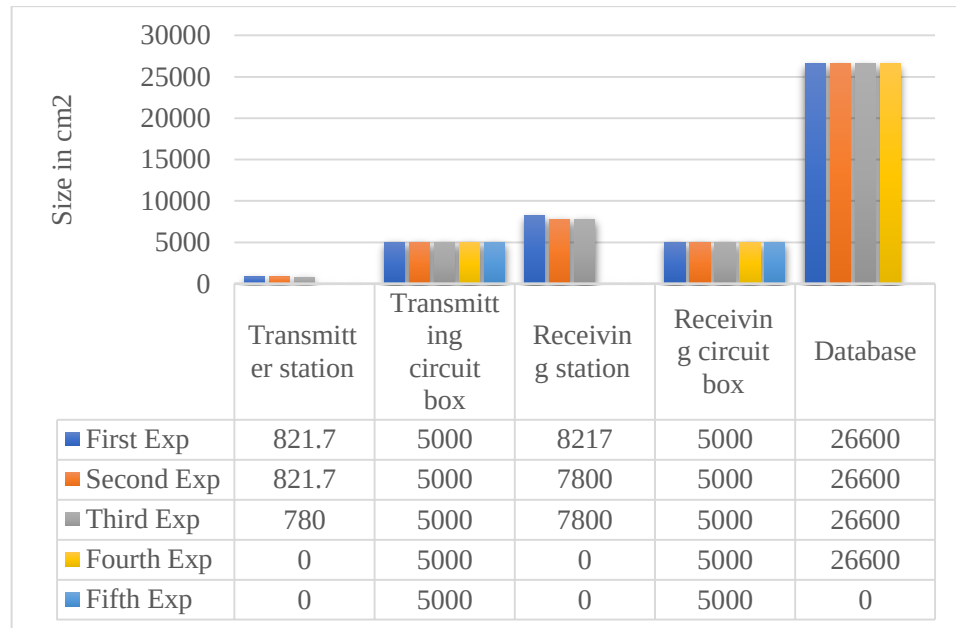


**Figure 5.1** Comparison of the sizes of the five experimental devices

**Table 5.2** Comparison between the weight of the devices in the transmitting and receiving systems

| Number             | First                                                             | Second                                                            | Third                                                              | Fourth                                                           | Fifth                                                            |
|--------------------|-------------------------------------------------------------------|-------------------------------------------------------------------|--------------------------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|
| the weight Approx. | 250 grams transmitting equipment + 1750 grams receiving equipment | 250 grams transmitting equipment + 3000 grams receiving equipment | 1400 grams transmitting equipment + 3000 grams receiving equipment | 60 grams transmitting equipment + 1640 grams receiving equipment | 60 grams transmitting equipment + 1000 grams receiving equipment |

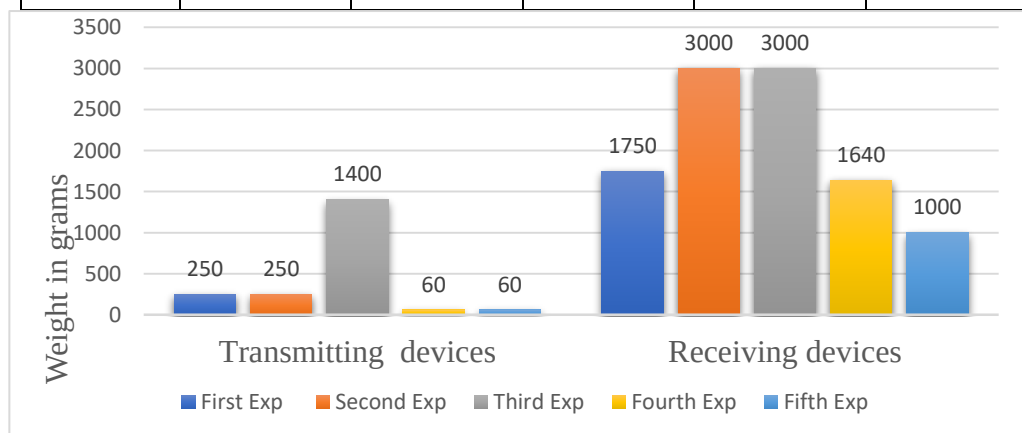


**Figure 5.2** Comparison between the weight of the devices in the transmitting and receiving systems

**Table 5.3** Comparison of the models about cost

| Number                    | First                                                                                                                                                                                                                                                                              | Second                                                                                                                                                                                                                                                                                        | Third                                                                                                                                                                                                                                                                                                                                                                                                   | Fourth                                                                                                                                                                                                                                                                                                            | Fifth                                                                                                                                                                                                                                                                                                     |
|---------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Costs<br>Approx<br>.      | 23\$<br>transmitting<br>station<br>+<br>8\$<br>transmitting<br>circuit box<br>+<br>40\$ GPS<br>+<br>1.4\$ wires<br>+<br>23\$<br>receiving<br>station<br>+<br>8\$ box for<br>the<br>receiving<br>circuit<br>+<br>1.4\$ wires<br>+<br>500\$ laptop<br>receiving<br>signal<br>display | 23\$<br>transmitting<br>station<br>+<br>8\$<br>transmitting<br>circuit box<br>+<br>40\$ GPS<br>+<br>1.4\$ .wires<br>+<br>200 \$ at the<br>receiving<br>station<br>+<br>8 \$ box for<br>the<br>receiving<br>circuit<br>+<br>1.4\$ wires<br>+<br>500\$ laptop<br>receiving<br>signal<br>display | 200 \$<br>transmitting<br>station<br>+<br>8\$<br>transmitting<br>circuit box<br>+<br>40\$ GPS<br>+<br>1.4\$ wires+<br>3.5\$ coaxial<br>cable<br>+<br>10\$<br>transmitter<br>antenna<br>+<br>200 \$ at the<br>receiving<br>station<br>+<br>8 \$ a box<br>for the<br>receiving<br>circuit<br>+<br>1.4\$ wires<br>+<br>10\$<br>receiving<br>antenna<br>+<br>500\$ laptop<br>receiving<br>signal<br>display | 18 \$<br>transmitting<br>circuit box<br>+<br>40\$ GPS<br>+<br>1.4\$ wires<br>+<br>3.5\$ coaxial<br>cable<br>+<br>0.25\$<br>transmitter<br>antenna<br>+<br>18 \$<br>receiving<br>circuit box<br>+<br>1.4\$ <b>wires</b><br>+<br>0.25\$<br>receiving<br>antenna<br>+<br>500\$ laptop<br>receiving<br>signal display | 18 \$<br>transmitting<br>circuit box<br>+<br>40\$ GPS<br>+<br>1.4\$ wires<br>+<br>3.5\$ coaxial<br>cable<br>+<br>0.25\$<br>transmitter<br>antenna<br>+<br>18\$<br>receiving<br>circuit box<br>+<br>1.4 \$ wires<br>+<br>4*43=172\$<br>raspberry Pi<br>+ 50\$<br>database<br>+<br>1\$ receiving<br>antenna |
| Total<br>costs<br>approx. | 604.8\$                                                                                                                                                                                                                                                                            | 804.8\$                                                                                                                                                                                                                                                                                       | 1028.3\$                                                                                                                                                                                                                                                                                                                                                                                                | 628.80\$                                                                                                                                                                                                                                                                                                          | 351.8\$                                                                                                                                                                                                                                                                                                   |

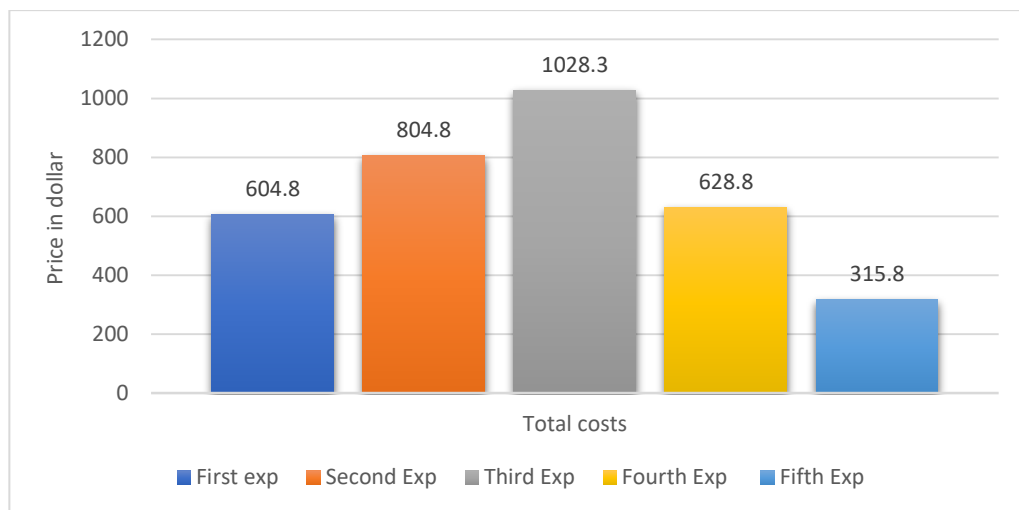


**Figure 5.3** Comparison of the models about total cost

**Table 5.4** Comparison of the models about covered geographic area

| Number                  | First                                 | Second                                | Third                                                        | Fourth                             | Fifth                                |
|-------------------------|---------------------------------------|---------------------------------------|--------------------------------------------------------------|------------------------------------|--------------------------------------|
| Covered geographic area | 3 square km without concrete barriers | 3 square km without concrete barriers | 5 km square meters with the presence of barriers to concrete | 5 km square with concrete barriers | 215 km square with concrete barriers |

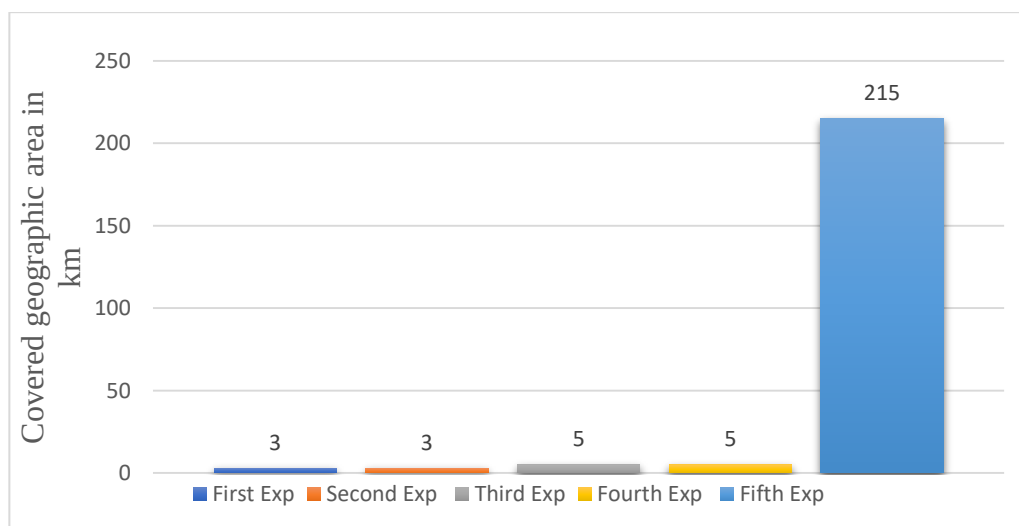


**Figure 5.4** Comparison of the models about covered geographic area



**Figure 5.5** Cars locating test maps in the idlib city

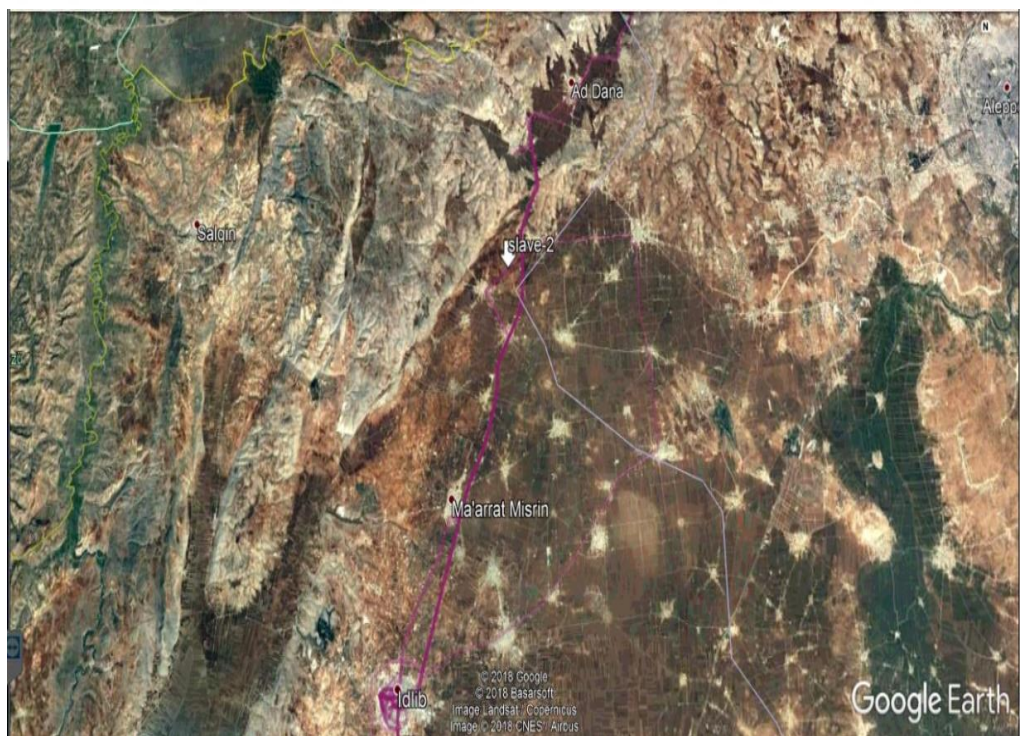


**Figure 5.6** Cars locating test maps in the idlib area idlib - maarrat misrin - dana 45 km

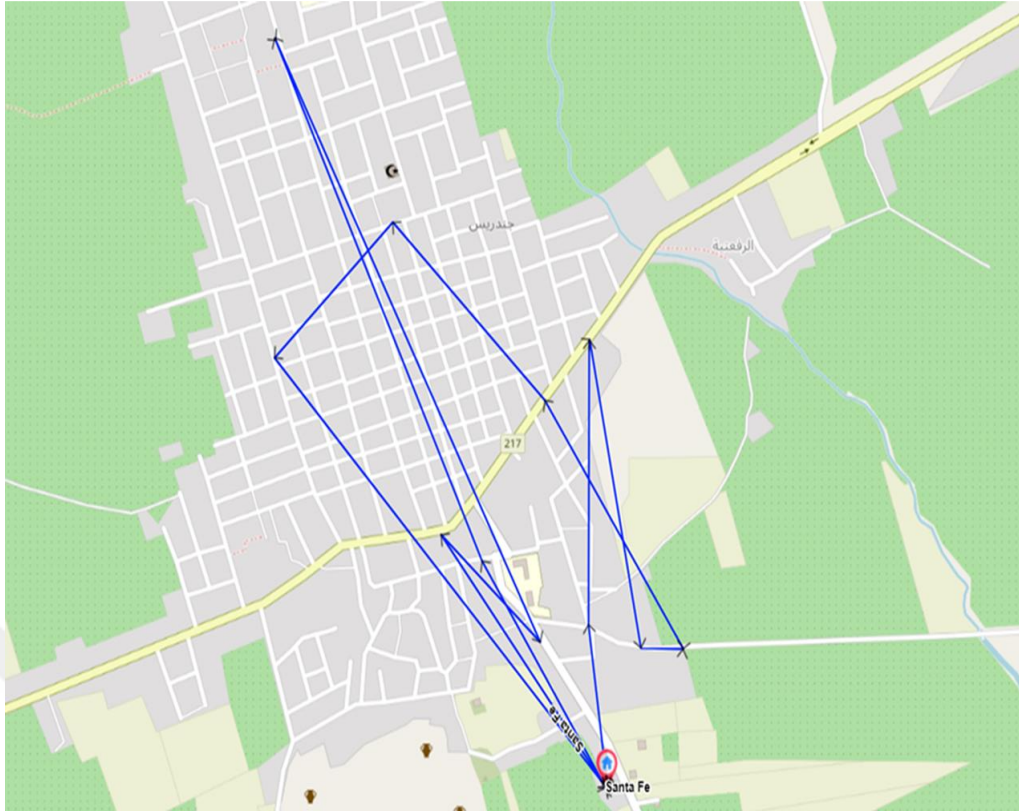


**Figure 5.7** Maps to locate test vehicles in jindires city

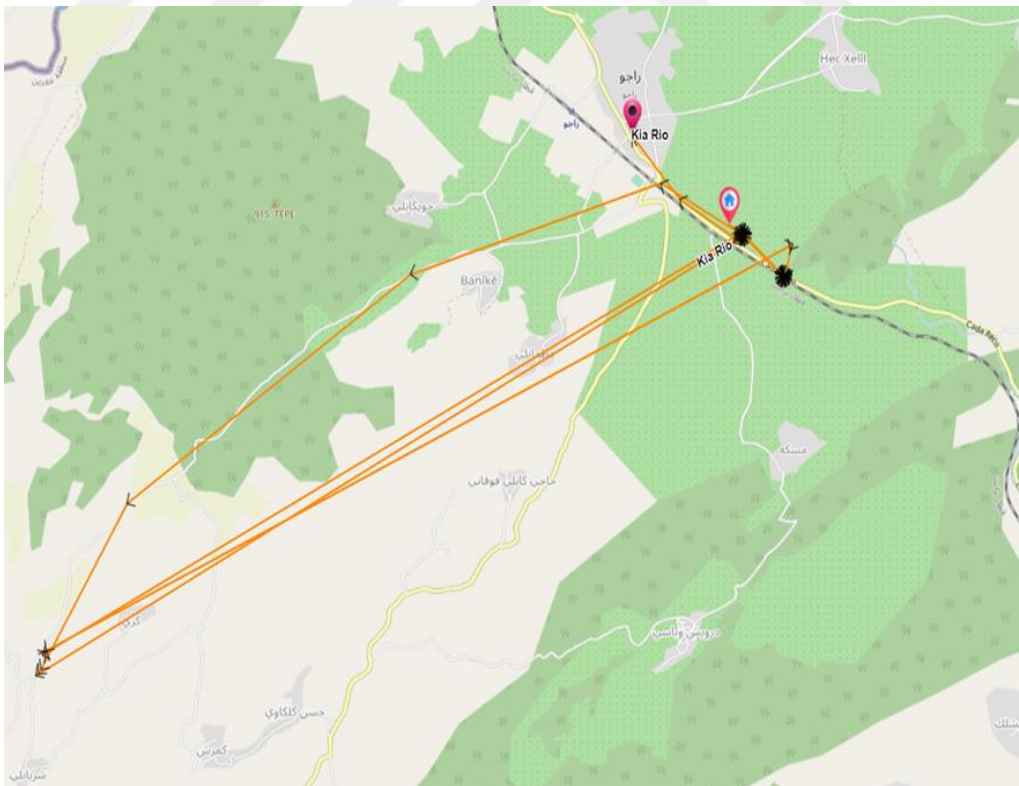


**Figure 5.8** Maps to locate test vehicles in the aleppo area jindires - raju 60 km

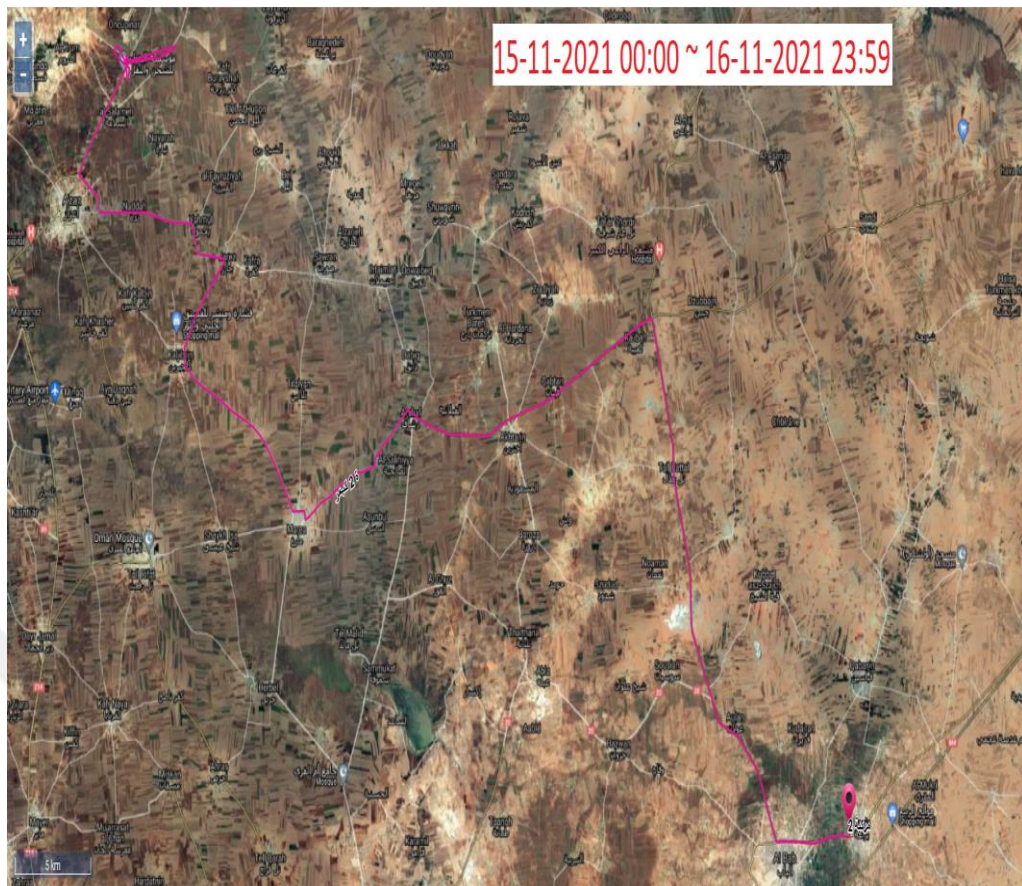


**Figure 5.9** A test track for a vehicle for two days in the northern countryside of aleppo

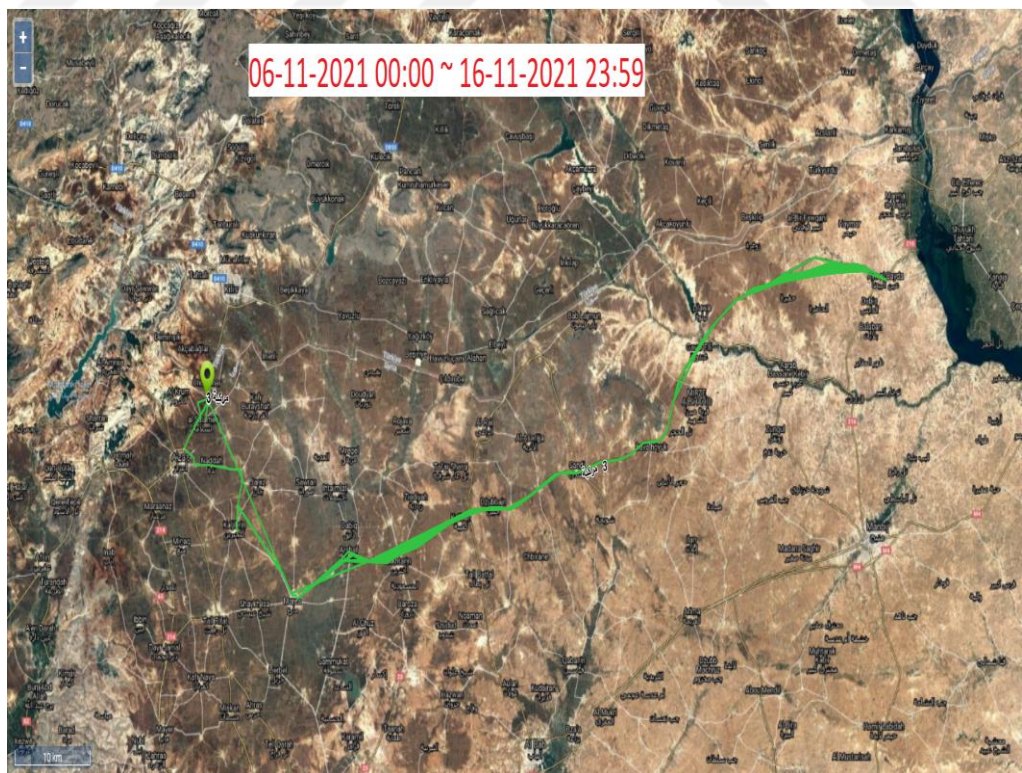


**Figure 5.10** A test track for a vehicle for ten days in the northern countryside of aleppo

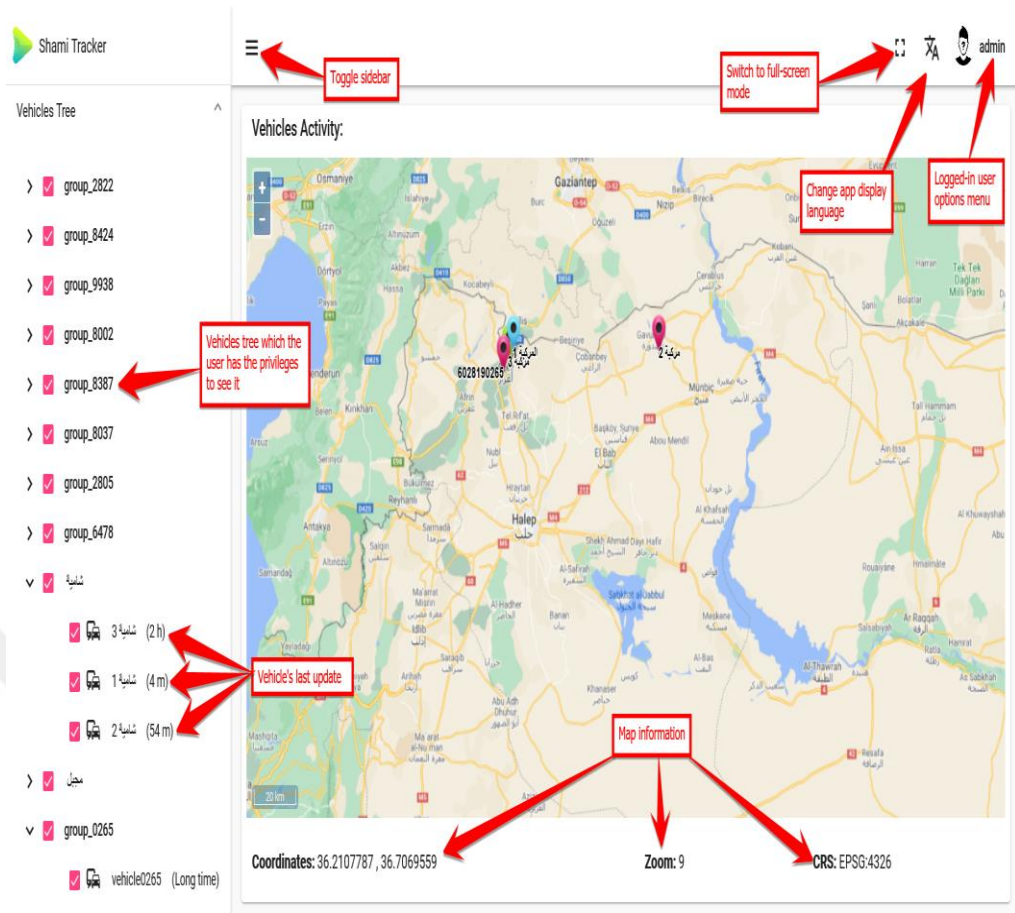


Figure 5.11 Observer options in user's own account

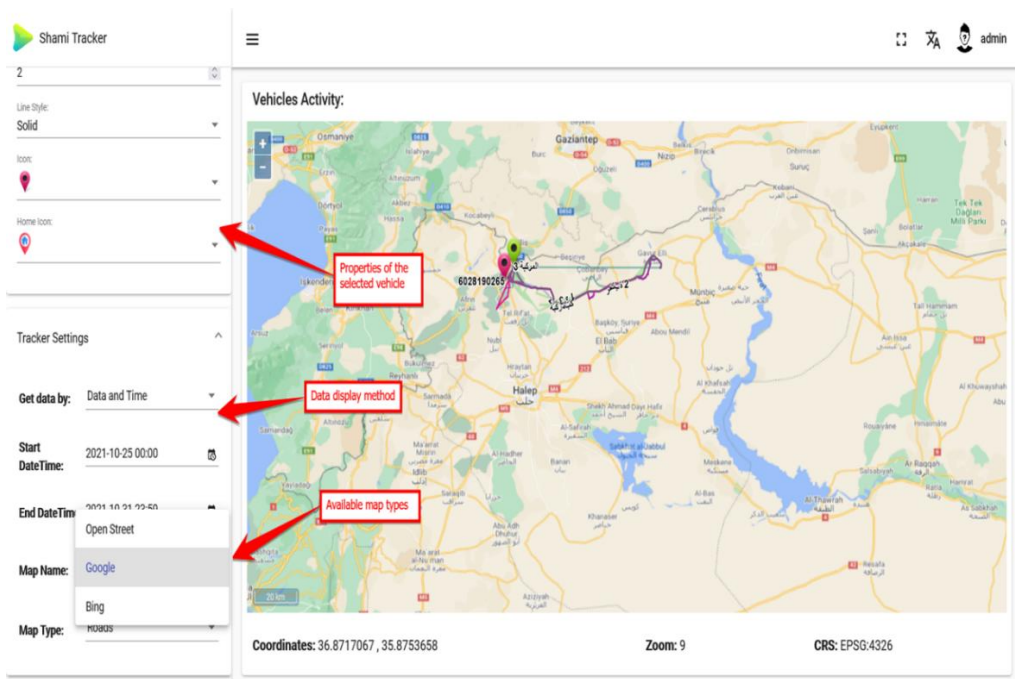


Figure 5.12 Advanced options for the observer in user's own account

| <input type="checkbox"/> ID      | Vehicle Name | Date & Time              | Position                               | Coverage Point |
|----------------------------------|--------------|--------------------------|----------------------------------------|----------------|
| <input type="checkbox"/> 2541203 | 2 شامية      | Nov 19, 2021, 7:45:12 PM | 37.976481666666665, 36.722521666666665 |                |
| <input type="checkbox"/> 2541204 | 2 شامية      | Nov 19, 2021, 7:45:12 PM | 37.977, 36.72267333333333              |                |
| <input type="checkbox"/> 2541205 | 2 شامية      | Nov 19, 2021, 7:45:12 PM | 37.977498333333334, 36.72282833333333  |                |
| <input type="checkbox"/> 2541206 | 2 شامية      | Nov 19, 2021, 7:45:20 PM | 37.97918833333333, 36.723685           |                |
| <input type="checkbox"/> 2541207 | 2 شامية      | Nov 19, 2021, 7:45:32 PM | 37.979171666666666, 36.723778333333335 |                |
| <input type="checkbox"/> 2541208 | 2 شامية      | Nov 19, 2021, 7:45:44 PM | 37.979211666666664, 36.723885          |                |
| <input type="checkbox"/> 2541209 | 1 شامية      | Nov 19, 2021, 7:47:00 PM | 37.08425833333333, 36.633891666666666  |                |
| <input type="checkbox"/> 2541210 | 1 شامية      | Nov 19, 2021, 7:47:36 PM | 37.08425833333333, 36.633891666666666  |                |
| <input type="checkbox"/> 2541211 | 1 شامية      | Nov 19, 2021, 7:51:56 PM | 37.08425833333333, 36.633891666666666  |                |
| <input type="checkbox"/> 2541212 | 1 شامية      | Nov 19, 2021, 8:06:58 PM | 37.08425833333333, 36.633891666666666  |                |

Records per page 10 420281 - 420290 of 420314 < > >>

**Figure 5.14** The location of the data in the database

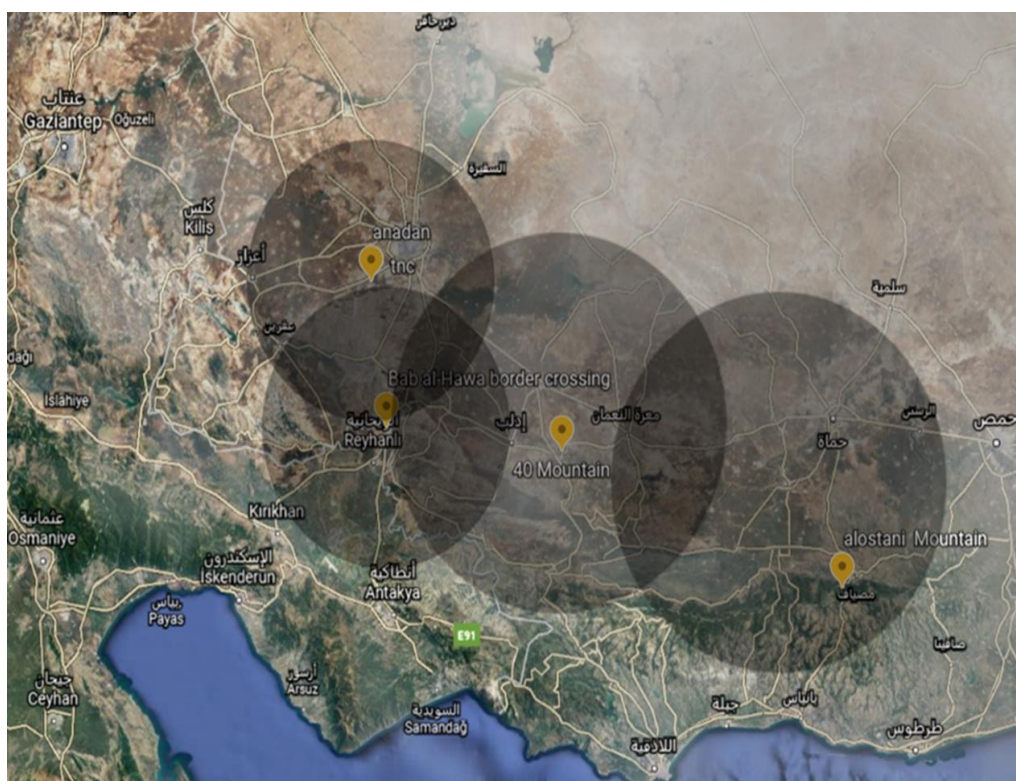


**Figure 5.14** Coverage zones of the final product

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## APPENDIX

### Data Transfer Tests

**Table A1.1** Intra-city data transfer tests

|                              |            |        |           |            |                              |        |            |        |
|------------------------------|------------|--------|-----------|------------|------------------------------|--------|------------|--------|
| Time: 6:00 to 8:00 a.m.      |            |        | City: Bab |            | Area: 26.4 Km <sup>2</sup>   |        |            |        |
| Total number of samples: 100 |            |        |           |            | Actual trip duration: 50 min |        |            |        |
| Point                        | Speed (Km) | Errors | Point     | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 OOR                        | 0          | 0      | 1 FNS     | 0          | 0                            | 1 FEW  | 0          | 0      |
| 2 OOR                        | 20         | 0      | 2 FNS     | 20         | 0                            | 2 FEW  | 20         | 0      |
| 3 OOR                        | 50         | 0      | 3 FNS     | 40         | 0                            | 3 FEW  | 40         | 0      |
| 4 OOR                        | 50         | 0      | 4 FNS     | 40         | 0                            | 4 FEW  | 40         | 0      |
| 5 OOR                        | 50         | 0      | 5 FNS     | 40         | 0                            | 5 FEW  | 40         | 0      |
| 6 OOR                        | 50         | 0      | 6 FNS     | 40         | 0                            | 6 FEW  | 40         | 0      |
| 7 OOR                        | 50         | 0      | 7 FNS     | 40         | 0                            | 7 FEW  | 40         | 0      |
| 8 OOR                        | 50         | 0      | 8 FNS     | 40         | 0                            | 8 FEW  | 40         | 0      |
| 9 OOR                        | 50         | 0      | 9 FNS     | 40         | 0                            | 9 FEW  | 40         | 0      |
| 10 OOR                       | 50         | 0      | 10 FNS    | 40         | 0                            | 10 FEW | 40         | 0      |
| 11 OOR                       | 50         | 0      | 11 FNS    | 40         | 0                            | 11 FEW | 40         | 0      |
| 12 OOR                       | 50         | 0      | 12 FNS    | 40         | 0                            | 12 FEW | 40         | 0      |
| 13 OOR                       | 50         | 0      | 13 FNS    | 40         | 0                            | 13 FEW | 40         | 0      |
| 14 OOR                       | 50         | 0      | 14 FNS    | 40         | 0                            | 14 FEW | 40         | 0      |
| 15 OOR                       | 50         | 0      | 15 FNS    | 40         | 0                            | 15 FEW | 40         | 0      |
| 16 OOR                       | 50         | 0      | 16 FNS    | 40         | 0                            | 16 FEW | 40         | 0      |
| 17 OOR                       | 50         | 0      | 17 FNS    | 40         | 0                            | 17 FEW | 40         | 0      |
| 18 OOR                       | 50         | 0      | 18 FNS    | 40         | 0                            | 18 FEW | 40         | 0      |
| 19 OOR                       | 50         | 0      | 19 FNS    | 40         | 0                            | 19 FEW | 40         | 0      |
| 20 OOR                       | 50         | 0      | 20 FNS    | 40         | 0                            | 20 FEW | 40         | 0      |

| Point                        | Speed (Km) | Errors | Point     | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
|------------------------------|------------|--------|-----------|------------|------------------------------|--------|------------|--------|
| 1 IA                         | 0          | 0      | 1 IA      | 20         | 0                            | 1 IA   | 0          | 0      |
| 2 IA                         | 10         | 0      | 2 IA      | 20         | 0                            | 2 IA   | 10         | 0      |
| 3 IA                         | 10         | 0      | 3 IA      | 20         | 0                            | 3 IA   | 10         | 0      |
| 4 IA                         | 10         | 0      | 4 IA      | 10         | 0                            | 4 IA   | 10         | 0      |
| 5 IA                         | 10         | 0      | 5 IA      | 10         | 0                            | 5 IA   | 10         | 0      |
| 6 IA                         | 10         | 0      | 6 IA      | 10         | 0                            | 6 IA   | 10         | 0      |
| 7 IA                         | 10         | 0      | 7 IA      | 10         | 0                            | 7 IA   | 10         | 0      |
| 8 IA                         | 20         | 0      | 8 IA      | 10         | 0                            | 8 IA   | 10         | 0      |
| 9 IA                         | 20         | 0      | 9 IA      | 10         | 0                            | 9 IA   | 10         | 0      |
| 10 IA                        | 20         | 0      | 10 IA     | 20         | 0                            | 10 IA  | 20         | 0      |
| 11 IA                        | 20         | 0      | 11 IA     | 20         | 0                            | 11 IA  | 20         | 0      |
| 12 IA                        | 10         | 0      | 12 IA     | 0          | 0                            | 12 IA  | 20         | 0      |
| 13 IA                        | 0          | 0      | 13 IA     | 20         | 0                            | 13 IA  | 40         | 0      |
| 14 IA                        | 0          | 0      |           |            |                              |        |            |        |
| Time: 12:00 to 2:00 p.m.     |            |        | City: Bab |            | Area: 26.4 Km <sup>2</sup>   |        |            |        |
| Total number of samples: 120 |            |        |           |            | Actual trip duration: 60 min |        |            |        |
| Point                        | Speed (Km) | Errors | Point     | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 OOR                        | 0          | 0      | 1 FNS     | 0          | 0                            | 1 FEW  | 0          | 0      |
| 2 OOR                        | 20         | 0      | 2 FNS     | 20         | 0                            | 2 FEW  | 20         | 0      |
| 3 OOR                        | 50         | 0      | 3 FNS     | 40         | 0                            | 3 FEW  | 40         | 0      |
| 4 OOR                        | 50         | 0      | 4 FNS     | 40         | 0                            | 4 FEW  | 40         | 0      |
| 5 OOR                        | 50         | 0      | 5 FNS     | 40         | 0                            | 5 FEW  | 40         | 0      |
| 6 OOR                        | 50         | 0      | 6 FNS     | 40         | 0                            | 6 FEW  | 40         | 0      |
| 7 OOR                        | 50         | 0      | 7 FNS     | 40         | 0                            | 7 FEW  | 40         | 0      |
| 8 OOR                        | 50         | 0      | 8 FNS     | 40         | 0                            | 8 FEW  | 40         | 0      |
| 9 OOR                        | 50         | 0      | 9 FNS     | 40         | 0                            | 9 FEW  | 40         | 0      |
| 10 OOR                       | 50         | 0      | 10 FNS    | 40         | 0                            | 10 FEW | 40         | 1      |
| 11 OOR                       | 50         | 0      | 11 FNS    | 40         | 0                            | 11 FEW | 40         | 0      |

|        |               |        |        |               |        |        |               |        |
|--------|---------------|--------|--------|---------------|--------|--------|---------------|--------|
| 12 OOR | 50            | 0      | 12 FNS | 40            | 0      | 12 FEW | 40            | 1      |
| 13 OOR | 50            | 0      | 13 FNS | 40            | 0      | 13 FEW | 40            | 0      |
| 14 OOR | 50            | 0      | 14 FNS | 40            | 0      | 14 FEW | 40            | 0      |
| 15 OOR | 50            | 0      | 15 FNS | 40            | 0      | 15 FEW | 40            | 0      |
| 16 OOR | 50            | 0      | 16 FNS | 40            | 0      | 16 FEW | 40            | 0      |
| 17 OOR | 50            | 0      | 17 FNS | 40            | 0      | 17 FEW | 40            | 0      |
| 18 OOR | 50            | 0      | 18 FNS | 40            | 0      | 18 FEW | 40            | 0      |
| 19 OOR | 50            | 0      | 19 FNS | 40            | 0      | 19 FEW | 40            | 0      |
| 20 OOR | 50            | 0      | 20 FNS | 40            | 0      | 20 FEW | 40            | 0      |
| Point  | Speed<br>(Km) | Errors | Point  | Speed<br>(Km) | Errors | Point  | Speed<br>(Km) | Errors |
| 1 IA   | 0             | 0      | 1 IA   | 20            | 0      | 1 IA   | 0             | 0      |
| 2 IA   | 10            | 0      | 2 IA   | 20            | 0      | 2 IA   | 10            | 0      |
| 3 IA   | 10            | 0      | 3 IA   | 20            | 0      | 3 IA   | 10            | 0      |
| 4 IA   | 10            | 0      | 4 IA   | 10            | 1      | 4 IA   | 10            | 0      |
| 5 IA   | 10            | 0      | 5 IA   | 10            | 1      | 5 IA   | 10            | 0      |
| 6 IA   | 10            | 0      | 6 IA   | 10            | 1      | 6 IA   | 10            | 0      |
| 7 IA   | 10            | 0      | 7 IA   | 10            | 0      | 7 IA   | 10            | 0      |
| 8 IA   | 20            | 0      | 8 IA   | 10            | 0      | 8 IA   | 10            | 0      |
| 9 IA   | 20            | 0      | 9 IA   | 10            | 0      | 9 IA   | 10            | 0      |
| 10 IA  | 20            | 0      | 10 IA  | 20            | 0      | 10 IA  | 20            | 0      |
| 11 IA  | 20            | 0      | 11 IA  | 20            | 0      | 11 IA  | 20            | 0      |
| 12 IA  | 10            | 0      | 12 IA  | 0             | 0      | 12 IA  | 20            | 0      |
| 13 IA  | 0             | 1      | 13 IA  | 20            | 0      | 13 IA  | 40            | 1      |
| 14 IA  | 0             | 1      | 14 IA  | 20            | 0      | 14 IA  | 30            | 0      |
| 15 IA  | 20            | 0      | 15 IA  | 20            | 0      | 15 IA  | 20            | 0      |
| 16 IA  | 20            | 0      | 16 IA  | 10            | 0      | 16 IA  | 20            | 0      |
| 17 IA  | 20            | 0      | 17 IA  | 10            | 0      | 17 IA  | 0             | 0      |
| 18 IA  | 10            | 0      | 18 IA  | 10            | 0      | 18 IA  | 20            | 0      |
| 19 IA  | 20            | 0      | 19 IA  | 0             | 0      | 19 IA  | 20            | 0      |
| 20 IA  | 20            | 0      | 20 IA  | 10            | 0      | 20 IA  | 10            | 0      |

**Table A1.2** Intra-city data transfer tests

|                              |            |        |           |            |                              |        |            |        |
|------------------------------|------------|--------|-----------|------------|------------------------------|--------|------------|--------|
| Time: 6:00 to 8:00 p.m.      |            |        | City: Bab |            | Area: 26.4 Km²               |        |            |        |
| Total number of samples: 100 |            |        |           |            | Actual trip duration: 50 min |        |            |        |
| Point                        | Speed (Km) | Errors | Point     | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 OOR                        | 0          | 0      | 1 FNS     | 0          | 0                            | 1 FEW  | 0          | 0      |
| 2 OOR                        | 20         | 0      | 2 FNS     | 20         | 0                            | 2 FEW  | 20         | 0      |
| 3 OOR                        | 50         | 0      | 3 FNS     | 40         | 0                            | 3 FEW  | 40         | 0      |
| 4 OOR                        | 50         | 0      | 4 FNS     | 40         | 0                            | 4 FEW  | 40         | 0      |
| 5 OOR                        | 50         | 0      | 5 FNS     | 40         | 0                            | 5 FEW  | 40         | 0      |
| 6 OOR                        | 50         | 0      | 6 FNS     | 40         | 0                            | 6 FEW  | 40         | 0      |
| 7 OOR                        | 50         | 0      | 7 FNS     | 40         | 0                            | 7 FEW  | 40         | 0      |
| 8 OOR                        | 50         | 0      | 8 FNS     | 40         | 0                            | 8 FEW  | 40         | 0      |
| 9 OOR                        | 50         | 0      | 9 FNS     | 40         | 0                            | 9 FEW  | 40         | 0      |
| 10 OOR                       | 50         | 0      | 10 FNS    | 40         | 0                            | 10 FEW | 40         | 0      |
| 11 OOR                       | 50         | 0      | 11 FNS    | 40         | 0                            | 11 FEW | 40         | 0      |
| 12 OOR                       | 50         | 0      | 12 FNS    | 40         | 0                            | 12 FEW | 40         | 0      |
| 13 OOR                       | 50         | 0      | 13 FNS    | 40         | 0                            | 13 FEW | 40         | 0      |
| 14 OOR                       | 50         | 0      | 14 FNS    | 40         | 0                            | 14 FEW | 40         | 0      |
| 15 OOR                       | 50         | 0      | 15 FNS    | 40         | 0                            | 15 FEW | 40         | 0      |
| 16 OOR                       | 50         | 0      | 16 FNS    | 40         | 0                            | 16 FEW | 40         | 0      |
| 17 OOR                       | 50         | 0      | 17 FNS    | 40         | 0                            | 17 FEW | 40         | 0      |
| 18 OOR                       | 50         | 0      | 18 FNS    | 40         | 0                            | 18 FEW | 40         | 0      |
| 19 OOR                       | 50         | 0      | 19 FNS    | 40         | 0                            | 19 FEW | 40         | 0      |
| 20 OOR                       | 50         | 0      | 20 FNS    | 40         | 0                            | 20 FEW | 40         | 0      |
| Point                        | Speed (Km) | Errors | Point     | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 IA                         | 0          | 0      | 1 IA      | 20         | 0                            | 1 IA   | 0          | 0      |
| 2 IA                         | 10         | 0      | 2 IA      | 20         | 0                            | 2 IA   | 10         | 0      |
| 3 IA                         | 10         | 0      | 3 IA      | 20         | 0                            | 3 IA   | 10         | 0      |
| 4 IA                         | 10         | 0      | 4 IA      | 10         | 0                            | 4 IA   | 10         | 0      |
| 5 IA                         | 10         | 0      | 5 IA      | 10         | 0                            | 5 IA   | 10         | 0      |

|       |    |   |       |    |   |       |    |   |
|-------|----|---|-------|----|---|-------|----|---|
| 6 IA  | 10 | 1 | 6 IA  | 10 | 0 | 6 IA  | 10 | 0 |
| 7 IA  | 10 | 0 | 7 IA  | 10 | 0 | 7 IA  | 10 | 0 |
| 8 IA  | 20 | 0 | 8 IA  | 10 | 0 | 8 IA  | 10 | 0 |
| 9 IA  | 20 | 0 | 9 IA  | 10 | 0 | 9 IA  | 10 | 0 |
| 10 IA | 20 | 0 | 10 IA | 20 | 0 | 10 IA | 20 | 0 |
| 11 IA | 20 | 0 | 11 IA | 20 | 0 | 11 IA | 20 | 0 |
| 12 IA | 10 | 0 | 12 IA | 0  | 0 | 12 IA | 20 | 0 |
| 13 IA | 0  | 0 | 13 IA | 20 | 0 | 13 IA | 40 | 0 |
| 14 IA | 0  | 0 |       |    |   |       |    |   |

**Table A1.3** Intra-city data transfer tests

|                             |            |        |             |            |                              |        |            |        |
|-----------------------------|------------|--------|-------------|------------|------------------------------|--------|------------|--------|
| Time: 6:00 to 8:00 a.m.     |            |        | City: Idlib |            | Area: 23 Km <sup>2</sup>     |        |            |        |
| Total number of samples: 80 |            |        |             |            | Actual trip duration: 40 min |        |            |        |
| Point                       | Speed (Km) | Errors | Point       | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 OOR                       | 0          | 0      | 1 FNS       | 0          | 0                            | 1 FEW  | 0          | 0      |
| 2 OOR                       | 20         | 0      | 2 FNS       | 20         | 0                            | 2 FEW  | 20         | 0      |
| 3 OOR                       | 50         | 0      | 3 FNS       | 40         | 0                            | 3 FEW  | 40         | 0      |
| 4 OOR                       | 50         | 0      | 4 FNS       | 40         | 0                            | 4 FEW  | 40         | 0      |
| 5 OOR                       | 50         | 0      | 5 FNS       | 40         | 0                            | 5 FEW  | 40         | 0      |
| 6 OOR                       | 50         | 0      | 6 FNS       | 40         | 0                            | 6 FEW  | 40         | 0      |
| 7 OOR                       | 50         | 0      | 7 FNS       | 40         | 0                            | 7 FEW  | 40         | 0      |
| 8 OOR                       | 50         | 0      | 8 FNS       | 40         | 0                            | 8 FEW  | 40         | 0      |
| 9 OOR                       | 50         | 0      | 9 FNS       | 40         | 0                            | 9 FEW  | 40         | 0      |
| 10 OOR                      | 50         | 0      | 10 FNS      | 40         | 0                            | 10 FEW | 40         | 0      |
| 11 OOR                      | 50         | 0      | 11 FNS      | 40         | 0                            | 11 FEW | 40         | 0      |
| 12 OOR                      | 50         | 0      | 12 FNS      | 40         | 0                            | 12 FEW | 40         | 0      |
| 13 OOR                      | 50         | 0      | 13 FNS      | 40         | 0                            | 13 FEW | 40         | 0      |
| 14 OOR                      | 50         | 0      | 14 FNS      | 40         | 0                            | 14 FEW | 40         | 0      |
| 15 OOR                      | 50         | 0      | 15 FNS      | 40         | 0                            | 15 FEW | 40         | 0      |

| Point | Speed (Km) | Errors | Point | Speed (Km) | Errors | Point | Speed (Km) | Errors |
|-------|------------|--------|-------|------------|--------|-------|------------|--------|
| 1 IA  | 0          | 0      | 1 IA  | 20         | 0      | 1 IA  | 0          | 0      |
| 2 IA  | 10         | 0      | 2 IA  | 20         | 0      | 2 IA  | 10         | 0      |
| 3 IA  | 10         | 0      | 3 IA  | 20         | 0      | 3 IA  | 10         | 0      |
| 4 IA  | 10         | 0      | 4 IA  | 10         | 0      | 4 IA  | 10         | 0      |
| 5 IA  | 10         | 0      | 5 IA  | 10         | 0      | 5 IA  | 10         | 0      |
| 6 IA  | 10         | 0      | 6 IA  | 10         | 0      | 6 IA  | 10         | 0      |
| 7 IA  | 10         | 0      | 7 IA  | 10         | 0      | 7 IA  | 10         | 0      |
| 8 IA  | 20         | 0      | 8 IA  | 10         | 0      | 8 IA  | 10         | 0      |
| 9 IA  | 20         | 0      | 9 IA  | 10         | 0      | 9 IA  | 10         | 0      |
| 10 IA | 20         | 0      | 10 IA | 20         | 0      | 10 IA | 20         | 0      |
| 11 IA | 20         | 0      | 11 IA | 20         | 1      | 11 IA | 20         | 0      |
| 12 IA | 10         | 0      | 12 IA | 0          | 0      |       |            |        |

**Table A1.4** Intra-city data transfer tests

|                              |            |        |             |            |                              |        |            |        |
|------------------------------|------------|--------|-------------|------------|------------------------------|--------|------------|--------|
| Time: 12:00 to 2:00 P.m.     |            |        | City: Idlib |            | Area: 25 Km <sup>2</sup>     |        |            |        |
| Total number of samples: 120 |            |        |             |            | Actual trip duration: 60 min |        |            |        |
| Point                        | Speed (Km) | Errors | Point       | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 OOR                        | 0          | 0      | 1 FNS       | 0          | 0                            | 1 FEW  | 0          | 0      |
| 2 OOR                        | 20         | 0      | 2 FNS       | 20         | 0                            | 2 FEW  | 20         | 0      |
| 3 OOR                        | 50         | 0      | 3 FNS       | 40         | 0                            | 3 FEW  | 40         | 0      |
| 4 OOR                        | 50         | 0      | 4 FNS       | 40         | 0                            | 4 FEW  | 40         | 0      |
| 5 OOR                        | 50         | 0      | 5 FNS       | 40         | 0                            | 5 FEW  | 20         | 0      |
| 6 OOR                        | 50         | 0      | 6 FNS       | 10         | 0                            | 6 FEW  | 40         | 0      |
| 7 OOR                        | 50         | 0      | 7 FNS       | 40         | 0                            | 7 FEW  | 40         | 0      |
| 8 OOR                        | 50         | 0      | 8 FNS       | 40         | 0                            | 8 FEW  | 40         | 0      |
| 9 OOR                        | 50         | 0      | 9 FNS       | 40         | 0                            | 9 FEW  | 40         | 0      |
| 10 OOR                       | 50         | 0      | 10 FNS      | 40         | 0                            | 10 FEW | 40         | 0      |
| 11 OOR                       | 50         | 0      | 11 FNS      | 40         | 0                            | 11 FEW | 40         | 0      |
| 12 OOR                       | 50         | 0      | 12 FNS      | 40         | 0                            | 12 FEW | 40         | 0      |

|        |               |        |        |               |        |        |               |        |
|--------|---------------|--------|--------|---------------|--------|--------|---------------|--------|
| 13 OOR | 50            | 0      | 13 FNS | 40            | 0      | 13 FEW | 40            | 0      |
| 14 OOR | 50            | 0      | 14 FNS | 40            | 0      | 14 FEW | 10            | 0      |
| 15 OOR | 50            | 0      | 15 FNS | 40            | 0      | 15 FEW | 40            | 0      |
| 16 OOR | 50            | 0      | 16 FNS | 10            | 0      | 16 FEW | 40            | 0      |
| 17 OOR | 50            | 0      | 17 FNS | 40            | 0      | 17 FEW | 40            | 0      |
| 18 OOR | 50            | 0      | 18 FNS | 40            | 0      | 18 FEW | 40            | 0      |
| 19 OOR | 50            | 0      | 19 FNS | 40            | 0      | 19 FEW | 40            | 0      |
| 20 OOR | 50            | 0      | 20 FNS | 40            | 0      | 20 FEW | 40            | 0      |
| Point  | Speed<br>(Km) | Errors | Point  | Speed<br>(Km) | Errors | Point  | Speed<br>(Km) | Errors |
| 1 IA   | 0             | 0      | 1 IA   | 20            | 0      | 1 IA   | 20            | 0      |
| 2 IA   | 20            | 0      | 2 IA   | 20            | 0      | 2 IA   | 10            | 0      |
| 3 IA   | 20            | 0      | 3 IA   | 20            | 0      | 3 IA   | 10            | 0      |
| 4 IA   | 20            | 0      | 4 IA   | 10            | 0      | 4 IA   | 20            | 0      |
| 5 IA   | 20            | 0      | 5 IA   | 10            | 0      | 5 IA   | 20            | 0      |
| 6 IA   | 20            | 0      | 6 IA   | 10            | 0      | 6 IA   | 20            | 0      |
| 7 IA   | 10            | 0      | 7 IA   | 10            | 0      | 7 IA   | 20            | 0      |
| 8 IA   | 20            | 0      | 8 IA   | 10            | 0      | 8 IA   | 20            | 0      |
| 9 IA   | 20            | 0      | 9 IA   | 10            | 0      | 9 IA   | 20            | 0      |
| 10 IA  | 20            | 0      | 10 IA  | 20            | 0      | 10 IA  | 20            | 0      |
| 11 IA  | 20            | 0      | 11 IA  | 20            | 0      | 11 IA  | 20            | 0      |
| 12 IA  | 10            | 0      | 12 IA  | 20            | 0      | 12 IA  | 20            | 0      |
| 13 IA  | 20            | 0      | 13 IA  | 20            | 0      | 13 IA  | 40            | 0      |
| 14 IA  | 20            | 0      | 14 IA  | 20            | 0      | 14 IA  | 30            | 0      |
| 15 IA  | 20            | 0      | 15 IA  | 20            | 0      | 15 IA  | 20            | 0      |
| 16 IA  | 20            | 0      | 16 IA  | 10            | 0      | 16 IA  | 20            | 0      |
| 17 IA  | 20            | 0      | 17 IA  | 10            | 1      | 17 IA  | 10            | 0      |
| 18 IA  | 10            | 0      | 18 IA  | 10            | 1      | 18 IA  | 20            | 0      |
| 19 IA  | 20            | 0      | 19 IA  | 30            | 0      | 19 IA  | 20            | 0      |
| 20 IA  | 20            | 0      | 20 IA  | 10            | 0      | 20 IA  | 0             | 0      |

**Table A1.5** Intra-city data transfer tests

|                             |            |        |             |            |                                |        |            |        |
|-----------------------------|------------|--------|-------------|------------|--------------------------------|--------|------------|--------|
| Time: 6:00 to 8:00 P.m.     |            |        | City: Idlib |            | Area: 23 Km <sup>2</sup>       |        |            |        |
| Total number of samples: 81 |            |        |             |            | Actual trip duration: 40.5 min |        |            |        |
| Point                       | Speed (Km) | Errors | Point       | Speed (Km) | Errors                         | Point  | Speed (Km) | Errors |
| 1 OOR                       | 0          | 0      | 1 FNS       | 0          | 0                              | 1 FEW  | 0          | 0      |
| 2 OOR                       | 20         | 0      | 2 FNS       | 20         | 0                              | 2 FEW  | 20         | 0      |
| 3 OOR                       | 50         | 0      | 3 FNS       | 40         | 0                              | 3 FEW  | 40         | 0      |
| 4 OOR                       | 50         | 0      | 4 FNS       | 40         | 0                              | 4 FEW  | 40         | 0      |
| 5 OOR                       | 50         | 0      | 5 FNS       | 40         | 0                              | 5 FEW  | 40         | 0      |
| 6 OOR                       | 50         | 0      | 6 FNS       | 40         | 0                              | 6 FEW  | 40         | 0      |
| 7 OOR                       | 50         | 0      | 7 FNS       | 40         | 0                              | 7 FEW  | 40         | 0      |
| 8 OOR                       | 50         | 0      | 8 FNS       | 40         | 0                              | 8 FEW  | 40         | 0      |
| 9 OOR                       | 50         | 0      | 9 FNS       | 40         | 0                              | 9 FEW  | 40         | 0      |
| 10 OOR                      | 50         | 0      | 10 FNS      | 40         | 0                              | 10 FEW | 40         | 0      |
| 11 OOR                      | 50         | 0      | 11 FNS      | 40         | 0                              | 11 FEW | 40         | 0      |
| 12 OOR                      | 50         | 0      | 12 FNS      | 40         | 0                              | 12 FEW | 40         | 0      |
| 13 OOR                      | 50         | 0      | 13 FNS      | 40         | 0                              | 13 FEW | 40         | 0      |
| 14 OOR                      | 50         | 0      | 14 FNS      | 40         | 0                              |        |            |        |
| Point                       | Speed (Km) | Errors | Point       | Speed (Km) | Errors                         | Point  | Speed (Km) | Errors |
| 1 IA                        | 0          | 0      | 1 IA        | 20         | 0                              | 1 IA   | 0          | 0      |
| 2 IA                        | 10         | 0      | 2 IA        | 20         | 0                              | 2 IA   | 10         | 0      |
| 3 IA                        | 10         | 0      | 3 IA        | 20         | 0                              | 3 IA   | 10         | 0      |
| 4 IA                        | 10         | 0      | 4 IA        | 10         | 0                              | 4 IA   | 10         | 0      |
| 5 IA                        | 10         | 0      | 5 IA        | 10         | 0                              | 5 IA   | 10         | 0      |
| 6 IA                        | 10         | 0      | 6 IA        | 10         | 0                              | 6 IA   | 10         | 0      |
| 7 IA                        | 10         | 0      | 7 IA        | 10         | 0                              | 7 IA   | 10         | 0      |
| 8 IA                        | 20         | 0      | 8 IA        | 10         | 0                              | 8 IA   | 10         | 0      |
| 9 IA                        | 20         | 0      | 9 IA        | 10         | 0                              | 9 IA   | 10         | 0      |
| 10 IA                       | 20         | 0      | 10 IA       | 20         | 0                              | 10 IA  | 20         | 0      |
| 11 IA                       | 20         | 0      | 11 IA       | 20         | 0                              | 11 IA  | 20         | 0      |

|       |    |   |       |    |   |       |    |   |
|-------|----|---|-------|----|---|-------|----|---|
| 12 IA | 10 | 0 | 12 IA | 0  | 0 | 12 IA | 20 | 0 |
| 13 IA | 0  | 0 | 13 IA | 20 | 0 | 13 IA | 40 | 0 |
| 14 IA | 0  | 0 | 14 IA | 20 | 0 | 14 IA | 30 | 0 |
| 15 IA | 20 | 0 | 15 IA | 20 | 0 | 15 IA | 20 | 0 |

**Table A1.6** Intra-city data transfer tests

|                             |            |        |             |            |                              |        |            |        |
|-----------------------------|------------|--------|-------------|------------|------------------------------|--------|------------|--------|
| Time: 6:00 to 8:00 a.m.     |            |        | City: Afrin |            | Area: 19.2 Km <sup>2</sup>   |        |            |        |
| Total number of samples: 90 |            |        |             |            | Actual trip duration: 45 min |        |            |        |
| Point                       | Speed (Km) | Errors | Point       | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 OOR                       | 0          | 0      | 1 FNS       | 0          | 0                            | 1 FEW  | 0          | 0      |
| 2 OOR                       | 20         | 0      | 2 FNS       | 20         | 0                            | 2 FEW  | 20         | 0      |
| 3 OOR                       | 50         | 0      | 3 FNS       | 40         | 0                            | 3 FEW  | 40         | 0      |
| 4 OOR                       | 50         | 0      | 4 FNS       | 40         | 0                            | 4 FEW  | 40         | 0      |
| 5 OOR                       | 50         | 0      | 5 FNS       | 40         | 0                            | 5 FEW  | 40         | 0      |
| 6 OOR                       | 50         | 0      | 6 FNS       | 40         | 0                            | 6 FEW  | 40         | 0      |
| 7 OOR                       | 50         | 0      | 7 FNS       | 40         | 0                            | 7 FEW  | 40         | 0      |
| 8 OOR                       | 50         | 0      | 8 FNS       | 40         | 0                            | 8 FEW  | 40         | 0      |
| 9 OOR                       | 50         | 0      | 9 FNS       | 40         | 0                            | 9 FEW  | 40         | 0      |
| 10 OOR                      | 50         | 0      | 10 FNS      | 40         | 0                            | 10 FEW | 40         | 0      |
| Point                       | Speed (Km) | Errors | Point       | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 IA                        | 0          | 0      | 1 IA        | 20         | 0                            | 1 IA   | 0          | 0      |
| 2 IA                        | 10         | 0      | 2 IA        | 20         | 0                            | 2 IA   | 10         | 0      |
| 3 IA                        | 10         | 0      | 3 IA        | 20         | 0                            | 3 IA   | 10         | 0      |
| 4 IA                        | 10         | 0      | 4 IA        | 10         | 0                            | 4 IA   | 10         | 0      |
| 5 IA                        | 10         | 0      | 5 IA        | 10         | 0                            | 5 IA   | 10         | 0      |
| 6 IA                        | 10         | 0      | 6 IA        | 10         | 0                            | 6 IA   | 10         | 0      |
| 7 IA                        | 10         | 0      | 7 IA        | 10         | 0                            | 7 IA   | 10         | 0      |
| 8 IA                        | 10         | 0      | 8 IA        | 10         | 0                            | 8 IA   | 10         | 0      |
| 9 IA                        | 10         | 0      | 9 IA        | 10         | 0                            | 9 IA   | 10         | 0      |

|       |    |   |       |    |   |       |    |   |
|-------|----|---|-------|----|---|-------|----|---|
| 10 IA | 10 | 0 | 10 IA | 20 | 0 | 10 IA | 10 | 0 |
| 11 IA | 10 | 0 | 11 IA | 20 | 0 | 11 IA | 20 | 0 |
| 12 IA | 10 | 0 | 12 IA | 0  | 0 | 12 IA | 20 | 0 |
| 13 IA | 0  | 0 | 13 IA | 20 | 0 | 13 IA | 10 | 0 |
| 14 IA | 0  | 0 | 14 IA | 20 | 0 | 14 IA | 10 | 0 |
| 15 IA | 20 | 0 | 15 IA | 20 | 0 | 15 IA | 10 | 0 |
| 16 IA | 20 | 0 | 16 IA | 20 | 0 | 16 IA | 20 | 0 |
| 17 IA | 20 | 0 | 17 IA | 20 | 0 | 17 IA | 20 | 0 |
| 18 IA | 20 | 0 | 18 IA | 20 | 0 | 18 IA | 20 | 0 |
| 19 IA | 20 | 0 | 19 IA | 20 | 0 | 19 IA | 20 | 0 |
| 20 IA | 20 | 0 | 20 IA | 20 | 0 | 20 IA | 20 | 0 |

**Table A1.7** Intra-city data transfer tests

|                              |            |        |             |            |                              |        |            |        |
|------------------------------|------------|--------|-------------|------------|------------------------------|--------|------------|--------|
| Time: 12:00 to 2:00 p.m.     |            |        | City: Afrin |            | Area: 19.2 Km <sup>2</sup>   |        |            |        |
| Total number of samples: 140 |            |        |             |            | Actual trip duration: 70 min |        |            |        |
| Point                        | Speed (Km) | Errors | Point       | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 OOR                        | 0          | 0      | 1 FNS       | 0          | 0                            | 1 FEW  | 0          | 0      |
| 2 OOR                        | 20         | 0      | 2 FNS       | 20         | 0                            | 2 FEW  | 20         | 0      |
| 3 OOR                        | 40         | 0      | 3 FNS       | 40         | 0                            | 3 FEW  | 40         | 0      |
| 4 OOR                        | 40         | 0      | 4 FNS       | 40         | 0                            | 4 FEW  | 40         | 0      |
| 5 OOR                        | 40         | 0      | 5 FNS       | 40         | 0                            | 5 FEW  | 40         | 0      |
| 6 OOR                        | 40         | 0      | 6 FNS       | 40         | 0                            | 6 FEW  | 40         | 0      |
| 7 OOR                        | 40         | 0      | 7 FNS       | 40         | 0                            | 7 FEW  | 40         | 0      |
| 8 OOR                        | 40         | 0      | 8 FNS       | 40         | 0                            | 8 FEW  | 40         | 0      |
| 9 OOR                        | 40         | 0      | 9 FNS       | 40         | 0                            | 9 FEW  | 40         | 0      |
| 10 OOR                       | 40         | 0      | 10 FNS      | 40         | 0                            | 10 FEW | 40         | 1      |
| 11 OOR                       | 40         | 0      | 11 FNS      | 40         | 0                            | 11 FEW | 40         | 0      |
| 12 OOR                       | 40         | 0      | 12 FNS      | 40         | 0                            | 12 FEW | 40         | 1      |
| 13 OOR                       | 40         | 0      | 13 FNS      | 40         | 0                            | 13 FEW | 40         | 0      |
| 14 OOR                       | 40         | 0      | 14 FNS      | 40         | 0                            | 14 FEW | 40         | 0      |

|        |               |        |        |               |        |        |               |        |
|--------|---------------|--------|--------|---------------|--------|--------|---------------|--------|
| 15 OOR | 40            | 0      | 15 FNS | 40            | 0      | 15 FEW | 40            | 0      |
| 16 OOR | 40            | 0      | 16 FNS | 40            | 0      | 16 FEW | 40            | 0      |
| 17 OOR | 40            | 0      | 17 FNS | 40            | 0      | 17 FEW | 40            | 0      |
| 18 OOR | 40            | 0      | 18 FNS | 40            | 0      | 18 FEW | 40            | 0      |
| 19 OOR | 40            | 0      | 19 FNS | 40            | 0      | 19 FEW | 40            | 0      |
| 20 OOR | 40            | 0      | 20 FNS | 40            | 0      | 20 FEW | 40            | 0      |
| Point  | Speed<br>(Km) | Errors | Point  | Speed<br>(Km) | Errors | Point  | Speed<br>(Km) | Errors |
| 1 IA   | 0             | 0      | 1 IA   | 10            | 0      | 1 IA   | 10            | 0      |
| 2 IA   | 10            | 0      | 2 IA   | 10            | 0      | 2 IA   | 10            | 2      |
| 3 IA   | 10            | 0      | 3 IA   | 10            | 0      | 3 IA   | 10            | 0      |
| 4 IA   | 10            | 0      | 4 IA   | 10            | 0      | 4 IA   | 10            | 0      |
| 5 IA   | 10            | 0      | 5 IA   | 10            | 0      | 5 IA   | 0             | 0      |
| 6 IA   | 10            | 0      | 6 IA   | 10            | 0      | 6 IA   | 0             | 0      |
| 7 IA   | 10            | 0      | 7 IA   | 10            | 0      | 7 IA   | 10            | 0      |
| 8 IA   | 10            | 0      | 8 IA   | 10            | 0      | 8 IA   | 10            | 0      |
| 9 IA   | 10            | 0      | 9 IA   | 10            | 0      | 9 IA   | 10            | 0      |
| 10 IA  | 10            | 0      | 10 IA  | 10            | 0      | 10 IA  | 10            | 0      |
| 11 IA  | 10            | 0      | 11 IA  | 10            | 0      | 11 IA  | 10            | 0      |
| 12 IA  | 10            | 0      | 12 IA  | 10            | 0      | 12 IA  | 10            | 0      |
| 13 IA  | 10            | 0      | 13 IA  | 10            | 0      | 13 IA  | 10            | 0      |
| 14 IA  | 10            | 0      | 14 IA  | 10            | 0      | 14 IA  | 0             | 0      |
| 15 IA  | 10            | 0      | 15 IA  | 10            | 0      | 15 IA  | 0             | 0      |
| 16 IA  | 10            | 0      | 16 IA  | 10            | 1      | 16 IA  | 10            | 0      |
| 17 IA  | 10            | 0      | 17 IA  | 10            | 1      | 17 IA  | 10            | 0      |
| 18 IA  | 0             | 0      | 18 IA  | 10            | 0      | 18 IA  | 10            | 0      |
| 19 IA  | 10            | 0      | 19 IA  | 10            | 0      | 19 IA  | 10            | 0      |
| 20 IA  | 10            | 0      | 20 IA  | 10            | 2      | 20 IA  | 10            | 0      |
| 21 IA  | 10            | 1      | 21 IA  | 10            | 0      | 21 IA  | 10            | 0      |
| 22 IA  | 10            | 0      | 22 IA  | 10            | 0      | 22 IA  | 10            | 0      |
| 23 IA  | 10            | 0      | 23 IA  | 10            | 0      | 23 IA  | 10            | 0      |

|       |    |   |  |
|-------|----|---|--|
| 24 IA | 10 | 0 |  |
|-------|----|---|--|

**Table A1.8** Intra-city data transfer tests

|                             |            |        |             |            |                              |        |            |        |
|-----------------------------|------------|--------|-------------|------------|------------------------------|--------|------------|--------|
| Time: 6:00 to 8:00 p.m.     |            |        | City: Afrin |            | Area: 19.2 Km <sup>2</sup>   |        |            |        |
| Total number of samples: 80 |            |        |             |            | Actual trip duration: 40 min |        |            |        |
| Point                       | Speed (Km) | Errors | Point       | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 OOR                       | 0          | 0      | 1 FNS       | 0          | 0                            | 1 FEW  | 0          | 0      |
| 2 OOR                       | 20         | 0      | 2 FNS       | 20         | 0                            | 2 FEW  | 20         | 0      |
| 3 OOR                       | 50         | 0      | 3 FNS       | 40         | 0                            | 3 FEW  | 40         | 0      |
| 4 OOR                       | 50         | 0      | 4 FNS       | 40         | 0                            | 4 FEW  | 40         | 0      |
| 5 OOR                       | 50         | 0      | 5 FNS       | 40         | 0                            | 5 FEW  | 40         | 0      |
| 6 OOR                       | 50         | 0      | 6 FNS       | 40         | 0                            | 6 FEW  | 40         | 0      |
| 7 OOR                       | 50         | 0      | 7 FNS       | 40         | 0                            | 7 FEW  | 40         | 0      |
| 8 OOR                       | 50         | 0      | 8 FNS       | 40         | 0                            | 8 FEW  | 40         | 0      |
| 9 OOR                       | 50         | 0      | 9 FNS       | 40         | 0                            | 9 FEW  | 40         | 0      |
| 10 OOR                      | 50         | 0      | 10 FNS      | 40         | 0                            | 10 FEW | 40         | 0      |
| 11 OOR                      | 50         | 0      | 11 FNS      | 40         | 0                            | 11 FEW | 40         | 0      |
| 12 OOR                      | 50         | 0      | 12 FNS      | 40         | 0                            | 12 FEW | 40         | 0      |
| 13 OOR                      | 50         | 0      | 13 FNS      | 40         | 0                            | 13 FEW | 40         | 0      |
| 14 OOR                      | 50         | 0      |             |            |                              |        |            |        |
| Point                       | Speed (Km) | Errors | Point       | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 IA                        | 0          | 0      | 1 IA        | 20         | 0                            | 1 IA   | 20         | 0      |
| 2 IA                        | 10         | 0      | 2 IA        | 20         | 0                            | 2 IA   | 20         | 0      |
| 3 IA                        | 20         | 0      | 3 IA        | 20         | 0                            | 3 IA   | 20         | 0      |
| 4 IA                        | 20         | 0      | 4 IA        | 20         | 0                            | 4 IA   | 20         | 0      |
| 5 IA                        | 20         | 0      | 5 IA        | 20         | 0                            | 5 IA   | 20         | 0      |
| 6 IA                        | 20         | 0      | 6 IA        | 20         | 0                            | 6 IA   | 20         | 0      |
| 7 IA                        | 20         | 0      | 7 IA        | 20         | 0                            | 7 IA   | 20         | 0      |
| 8 IA                        | 20         | 0      | 8 IA        | 20         | 0                            | 8 IA   | 20         | 0      |
| 9 IA                        | 20         | 0      | 9 IA        | 20         | 0                            | 9 IA   | 20         | 0      |

|       |    |   |       |    |   |       |    |   |
|-------|----|---|-------|----|---|-------|----|---|
| 10 IA | 20 | 0 | 10 IA | 20 | 0 | 10 IA | 20 | 0 |
| 11 IA | 20 | 0 | 11 IA | 20 | 0 | 11 IA | 20 | 0 |
| 12 IA | 20 | 0 | 12 IA | 20 | 0 | 12 IA | 20 | 0 |
| 13 IA | 20 | 0 | 13 IA | 20 | 1 | 13 IA | 20 | 0 |
| 14 IA | 20 | 0 | 14 IA | 20 | 0 | 14 IA | 20 | 0 |
| 15 IA | 20 | 0 | 15 IA | 20 | 1 | 15 IA | 20 | 0 |

**Table A1.9** Intra-city data transfer tests

|                             |            |        |               |            |                              |       |            |        |
|-----------------------------|------------|--------|---------------|------------|------------------------------|-------|------------|--------|
| Time: 6:00 to 8:00 a.m.     |            |        | City: Sarmada |            | Area: 9 Km <sup>2</sup>      |       |            |        |
| Total number of samples: 60 |            |        |               |            | Actual trip duration: 30 min |       |            |        |
| Point                       | Speed (Km) | Errors | Point         | Speed (Km) | Errors                       | Point | Speed (Km) | Errors |
| 1 OOR                       | 0          | 0      | 1 FNS         | 0          | 0                            | 1 FEW | 0          | 0      |
| 2 OOR                       | 20         | 0      | 2 FNS         | 20         | 0                            | 2 FEW | 20         | 0      |
| 3 OOR                       | 50         | 0      | 3 FNS         | 40         | 0                            | 3 FEW | 40         | 0      |
| 4 OOR                       | 50         | 0      | 4 FNS         | 40         | 0                            | 4 FEW | 40         | 0      |
| 5 OOR                       | 50         | 0      | 5 FNS         | 40         | 0                            | 5 FEW | 40         | 0      |
| 6 OOR                       | 50         | 0      | 6 FNS         | 40         | 0                            | 6 FEW | 40         | 0      |
| 7 OOR                       | 50         | 0      | 7 FNS         | 40         | 0                            | 7 FEW | 40         | 0      |
| 8 OOR                       | 50         | 0      | 8 FNS         | 40         | 0                            | 8 FEW | 40         | 0      |
| 9 OOR                       | 50         | 0      | 9 FNS         | 40         | 0                            | 9 FEW | 40         | 0      |
| Point                       | Speed (Km) | Errors | Point         | Speed (Km) | Errors                       | Point | Speed (Km) | Errors |
| 1 IA                        | 0          | 0      | 1 IA          | 20         | 0                            | 1 IA  | 20         | 0      |
| 2 IA                        | 10         | 0      | 2 IA          | 20         | 0                            | 2 IA  | 20         | 0      |
| 3 IA                        | 20         | 0      | 3 IA          | 20         | 0                            | 3 IA  | 20         | 0      |
| 4 IA                        | 20         | 0      | 4 IA          | 20         | 0                            | 4 IA  | 20         | 0      |
| 5 IA                        | 20         | 0      | 5 IA          | 20         | 0                            | 5 IA  | 20         | 0      |
| 6 IA                        | 20         | 0      | 6 IA          | 20         | 0                            | 6 IA  | 20         | 0      |
| 7 IA                        | 20         | 0      | 7 IA          | 20         | 0                            | 7 IA  | 20         | 0      |
| 8 IA                        | 20         | 0      | 8 IA          | 20         | 0                            | 8 IA  | 20         | 0      |
| 9 IA                        | 20         | 0      | 9 IA          | 20         | 0                            | 9 IA  | 20         | 0      |

|                              |            |        |               |            |                              |        |            |        |
|------------------------------|------------|--------|---------------|------------|------------------------------|--------|------------|--------|
| Time: 12:00 to 2:00 p.m.     |            |        | City: Sarmada |            | Area: 9 Km <sup>2</sup>      |        |            |        |
| Total number of samples: 120 |            |        |               |            | Actual trip duration: 60 min |        |            |        |
| Point                        | Speed (Km) | Errors | Point         | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 OOR                        | 0          | 0      | 1 FNS         | 0          | 0                            | 1 FEW  | 0          | 0      |
| 2 OOR                        | 20         | 0      | 2 FNS         | 20         | 0                            | 2 FEW  | 20         | 0      |
| 3 OOR                        | 50         | 0      | 3 FNS         | 40         | 0                            | 3 FEW  | 40         | 0      |
| 4 OOR                        | 50         | 0      | 4 FNS         | 40         | 0                            | 4 FEW  | 40         | 0      |
| 5 OOR                        | 50         | 1      | 5 FNS         | 40         | 0                            | 5 FEW  | 40         | 0      |
| 6 OOR                        | 50         | 0      | 6 FNS         | 40         | 0                            | 6 FEW  | 40         | 0      |
| 7 OOR                        | 50         | 0      | 7 FNS         | 40         | 0                            | 7 FEW  | 40         | 0      |
| 8 OOR                        | 50         | 0      | 8 FNS         | 40         | 0                            | 8 FEW  | 40         | 0      |
| 9 OOR                        | 50         | 1      | 9 FNS         | 40         | 0                            | 9 FEW  | 40         | 0      |
| 10 OOR                       | 50         | 0      | 10 FNS        | 40         | 0                            | 10 FEW | 40         | 0      |
| 11 OOR                       | 50         | 0      | 11 FNS        | 40         | 0                            | 11 FEW | 40         | 0      |
| 12 OOR                       | 50         | 0      | 12 FNS        | 40         | 0                            | 12 FEW | 40         | 0      |
| 13 OOR                       | 50         | 1      | 13 FNS        | 40         | 0                            | 13 FEW | 40         | 0      |
| 14 OOR                       | 50         | 0      | 14 FNS        | 40         | 0                            | 14 FEW | 40         | 0      |
| 15 OOR                       | 50         | 0      | 15 FNS        | 40         | 0                            | 15 FEW | 40         | 0      |
| 16 OOR                       | 50         | 0      | 16 FNS        | 40         | 0                            | 16 FEW | 40         | 0      |
| 17 OOR                       | 50         | 0      | 17 FNS        | 40         | 0                            | 17 FEW | 40         | 0      |
| 18 OOR                       | 50         | 0      | 18 FNS        | 40         | 2                            | 18 FEW | 40         | 0      |
| 19 OOR                       | 50         | 0      | 19 FNS        | 40         | 0                            | 19 FEW | 40         | 0      |
| 20 OOR                       | 50         | 0      | 20 FNS        | 40         | 0                            | 20 FEW | 40         | 0      |
| Point                        | Speed (Km) | Errors | Point         | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 IA                         | 20         | 0      | 1 IA          | 20         | 0                            | 1 IA   | 40         | 0      |
| 2 IA                         | 20         | 0      | 2 IA          | 20         | 0                            | 2 IA   | 20         | 0      |
| 3 IA                         | 20         | 0      | 3 IA          | 20         | 0                            | 3 IA   | 20         | 0      |
| 4 IA                         | 20         | 0      | 4 IA          | 20         | 0                            | 4 IA   | 20         | 0      |
| 5 IA                         | 20         | 0      | 5 IA          | 20         | 0                            | 5 IA   | 20         | 0      |
| 6 IA                         | 40         | 0      | 6 IA          | 20         | 0                            | 6 IA   | 20         | 0      |

|       |    |   |       |    |   |       |    |   |
|-------|----|---|-------|----|---|-------|----|---|
| 7 IA  | 40 | 0 | 7 IA  | 20 | 0 | 7 IA  | 20 | 1 |
| 8 IA  | 40 | 0 | 8 IA  | 20 | 0 | 8 IA  | 20 | 0 |
| 9 IA  | 40 | 0 | 9 IA  | 20 | 0 | 9 IA  | 20 | 0 |
| 10 IA | 40 | 0 | 10 IA | 20 | 0 | 10 IA | 20 | 0 |
| 11 IA | 40 | 0 | 11 IA | 20 | 0 | 11 IA | 20 | 0 |
| 12 IA | 40 | 0 | 12 IA | 20 | 0 | 12 IA | 20 | 0 |
| 13 IA | 40 | 0 | 13 IA | 20 | 0 | 13 IA | 20 | 0 |
| 14 IA | 40 | 0 | 14 IA | 20 | 0 | 14 IA | 40 | 1 |
| 15 IA | 20 | 0 | 15 IA | 20 | 0 | 15 IA | 40 | 0 |
| 16 IA | 20 | 0 | 16 IA | 20 | 0 | 16 IA | 40 | 0 |
| 17 IA | 20 | 0 | 17 IA | 20 | 0 | 17 IA | 40 | 0 |
| 18 IA | 20 | 0 | 18 IA | 20 | 0 | 18 IA | 40 | 0 |
| 19 IA | 20 | 0 | 19 IA | 20 | 0 | 19 IA | 40 | 0 |
| 20 IA | 20 | 0 | 20 IA | 20 | 0 | 20 IA | 40 | 0 |

**Table A1.10** Intra-city data transfer tests

|                             |            |        |               |            |                              |        |            |        |
|-----------------------------|------------|--------|---------------|------------|------------------------------|--------|------------|--------|
| Time: 6:00 to 8:00 p.m.     |            |        | City: Sarmada |            | Area: 9 Km <sup>2</sup>      |        |            |        |
| Total number of samples: 60 |            |        |               |            | Actual trip duration: 30 min |        |            |        |
| Point                       | Speed (Km) | Errors | Point         | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 OOR                       | 0          | 0      | 1 FNS         | 0          | 0                            | 1 FEW  | 0          | 0      |
| 2 OOR                       | 20         | 0      | 2 FNS         | 20         | 0                            | 2 FEW  | 40         | 0      |
| 3 OOR                       | 50         | 0      | 3 FNS         | 40         | 0                            | 3 FEW  | 40         | 0      |
| 4 OOR                       | 50         | 0      | 4 FNS         | 40         | 0                            | 4 FEW  | 40         | 0      |
| 5 OOR                       | 50         | 0      | 5 FNS         | 40         | 0                            | 5 FEW  | 40         | 0      |
| 6 OOR                       | 50         | 0      | 6 FNS         | 40         | 0                            | 6 FEW  | 40         | 0      |
| 7 OOR                       | 50         | 0      | 7 FNS         | 40         | 0                            | 7 FEW  | 40         | 0      |
| 8 OOR                       | 50         | 0      | 8 FNS         | 40         | 0                            | 8 FEW  | 40         | 0      |
| 9 OOR                       | 50         | 0      | 9 FNS         | 40         | 0                            | 9 FEW  | 40         | 0      |
| 10 OOR                      | 50         | 0      | 10 FNS        | 40         | 0                            | 10 FEW | 40         | 0      |

| Point | Speed (Km) | Errors | Point | Speed (Km) | Errors | Point | Speed (Km) | Errors |
|-------|------------|--------|-------|------------|--------|-------|------------|--------|
| 1 IA  | 0          | 0      | 1 IA  | 20         | 0      | 1 IA  | 20         | 0      |
| 2 IA  | 10         | 0      | 2 IA  | 20         | 0      | 2 IA  | 20         | 0      |
| 3 IA  | 20         | 0      | 3 IA  | 20         | 0      | 3 IA  | 20         | 0      |
| 4 IA  | 20         | 0      | 4 IA  | 20         | 0      | 4 IA  | 20         | 0      |
| 5 IA  | 20         | 0      | 5 IA  | 20         | 0      | 5 IA  | 20         | 0      |
| 6 IA  | 20         | 0      | 6 IA  | 20         | 0      | 6 IA  | 20         | 0      |
| 7 IA  | 20         | 0      | 7 IA  | 20         | 0      | 7 IA  | 20         | 0      |
| 8 IA  | 20         | 0      | 8 IA  | 20         | 0      | 8 IA  | 20         | 0      |
| 9 IA  | 20         | 0      | 9 IA  | 20         | 0      | 9 IA  | 20         | 0      |
| 10 IA | 20         | 0      | 10 IA | 20         | 0      | 10 IA | 20         | 0      |

**Table A1.11** Intra-city data transfer tests

|                             |            |        |                |            |                              |       |            |        |
|-----------------------------|------------|--------|----------------|------------|------------------------------|-------|------------|--------|
| Time: 6:00 to 8:00 a.m.     |            |        | City: Jarablus |            | Area: 8 Km <sup>2</sup>      |       |            |        |
| Total number of samples: 60 |            |        |                |            | Actual trip duration: 30 min |       |            |        |
| Point                       | Speed (Km) | Errors | Point          | Speed (Km) | Errors                       | Point | Speed (Km) | Errors |
| 1 OOR                       | 0          | 0      | 1 FNS          | 0          | 0                            | 1 FEW | 0          | 0      |
| 2 OOR                       | 20         | 0      | 2 FNS          | 20         | 0                            | 2 FEW | 20         | 0      |
| 3 OOR                       | 50         | 0      | 3 FNS          | 40         | 0                            | 3 FEW | 40         | 0      |
| 4 OOR                       | 50         | 0      | 4 FNS          | 40         | 0                            | 4 FEW | 40         | 0      |
| 5 OOR                       | 50         | 0      | 5 FNS          | 40         | 0                            | 5 FEW | 40         | 0      |
| 6 OOR                       | 50         | 0      | 6 FNS          | 40         | 0                            | 6 FEW | 40         | 0      |
| 7 OOR                       | 50         | 0      | 7 FNS          | 40         | 0                            | 7 FEW | 40         | 0      |
| 8 OOR                       | 50         | 0      | 8 FNS          | 40         | 0                            | 8 FEW | 40         | 0      |
| 9 OOR                       | 50         | 0      | 9 FNS          | 40         | 0                            | 9 FEW | 40         | 0      |
| Point                       | Speed (Km) | Errors | Point          | Speed (Km) | Errors                       | Point | Speed (Km) | Errors |
| 1 IA                        | 0          | 0      | 1 IA           | 20         | 0                            | 1 IA  | 20         | 0      |
| 2 IA                        | 10         | 0      | 2 IA           | 20         | 0                            | 2 IA  | 20         | 0      |
| 3 IA                        | 20         | 0      | 3 IA           | 20         | 0                            | 3 IA  | 20         | 0      |

|                             |            |        |                |            |                              |        |            |        |
|-----------------------------|------------|--------|----------------|------------|------------------------------|--------|------------|--------|
| 4 IA                        | 20         | 0      | 4 IA           | 20         | 0                            | 4 IA   | 20         | 0      |
| 5 IA                        | 20         | 0      | 5 IA           | 20         | 0                            | 5 IA   | 20         | 0      |
| 6 IA                        | 20         | 0      | 6 IA           | 20         | 1                            | 6 IA   | 20         | 0      |
| 7 IA                        | 20         | 0      | 7 IA           | 20         | 0                            | 7 IA   | 20         | 0      |
| 8 IA                        | 20         | 0      | 8 IA           | 20         | 0                            | 8 IA   | 20         | 0      |
| 9 IA                        | 20         | 0      | 9 IA           | 20         | 0                            | 9 IA   | 20         | 0      |
| Time: 12:00 to 2:00 P.m.    |            |        | City: Jarablus |            | Area: 8 Km <sup>2</sup>      |        |            |        |
| Total number of samples: 40 |            |        |                |            | Actual trip duration: 20 min |        |            |        |
| Point                       | Speed (Km) | Errors | Point          | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 OOR                       | 0          | 0      | 1 FNS          | 0          | 0                            | 1 FEW  | 0          | 0      |
| 2 OOR                       | 20         | 0      | 2 FNS          | 20         | 0                            | 2 FEW  | 20         | 0      |
| 3 OOR                       | 50         | 0      | 3 FNS          | 40         | 0                            | 3 FEW  | 40         | 0      |
| 4 OOR                       | 50         | 0      | 4 FNS          | 40         | 0                            | 4 FEW  | 40         | 0      |
| 5 OOR                       | 50         | 0      | 5 FNS          | 40         | 0                            | 5 FEW  | 40         | 0      |
| 6 OOR                       | 50         | 0      | 6 FNS          | 40         | 0                            | 6 FEW  | 40         | 0      |
| 7 OOR                       | 50         | 0      | 7 FNS          | 40         | 0                            | 7 FEW  | 40         | 0      |
| 8 OOR                       | 50         | 0      | 8 FNS          | 40         | 0                            | 8 FEW  | 40         | 0      |
| 9 OOR                       | 50         | 0      | 9 FNS          | 40         | 0                            | 9 FEW  | 40         | 0      |
| 10 OOR                      | 50         | 0      | 10 FNS         | 40         | 0                            | 10 FEW | 40         | 0      |
| Point                       | Speed (Km) | Errors | Point          | Speed (Km) | Errors                       | Point  | Speed (Km) | Errors |
| 1 IA                        | 0          | 0      | 1 IA           | 20         | 0                            | 1 IA   | 20         | 0      |
| 2 IA                        | 10         | 0      | 2 IA           | 20         | 0                            | 2 IA   | 20         | 0      |
| 3 IA                        | 20         | 0      | 3 IA           | 20         | 0                            | 3 IA   | 20         | 0      |
| 4 IA                        | 20         | 0      | 4 IA           | 20         | 0                            | 4 IA   | 20         | 0      |
| 5 IA                        | 20         | 0      | 5 IA           | 20         | 0                            | 5 IA   | 20         | 0      |

**Table A1.12** Intra-city data transfer tests

|                             |            |        |                |            |                              |       |            |        |
|-----------------------------|------------|--------|----------------|------------|------------------------------|-------|------------|--------|
| Time: 6:00 to 8:00 P.m.     |            |        | City: Jarablus |            | Area: 9 Km <sup>2</sup>      |       |            |        |
| Total number of samples: 42 |            |        |                |            | Actual trip duration: 21 min |       |            |        |
| Point                       | Speed (Km) | Errors | Point          | Speed (Km) | Errors                       | Point | Speed (Km) | Errors |
| 1 OOR                       | 0          | 0      | 1 FNS          | 0          | 0                            | 1 FEW | 0          | 0      |
| 2 OOR                       | 20         | 0      | 2 FNS          | 20         | 0                            | 2 FEW | 20         | 0      |
| 3 OOR                       | 50         | 0      | 3 FNS          | 40         | 0                            | 3 FEW | 40         | 0      |
| 4 OOR                       | 50         | 0      | 4 FNS          | 40         | 0                            | 4 FEW | 40         | 0      |
| 5 OOR                       | 50         | 0      | 5 FNS          | 40         | 0                            | 5 FEW | 40         | 0      |
| Point                       | Speed (Km) | Errors | Point          | Speed (Km) | Errors                       | Point | Speed (Km) | Errors |
| 1 IA                        | 0          | 0      | 1 IA           | 20         | 0                            | 1 IA  | 20         | 0      |
| 2 IA                        | 10         | 0      | 2 IA           | 20         | 0                            | 2 IA  | 20         | 0      |
| 3 IA                        | 20         | 0      | 3 IA           | 20         | 0                            | 3 IA  | 20         | 0      |
| 4 IA                        | 20         | 0      | 4 IA           | 20         | 0                            | 4 IA  | 20         | 0      |
| 5 IA                        | 20         | 0      | 5 IA           | 20         | 0                            | 5 IA  | 20         | 0      |
| 6 IA                        | 20         | 0      | 6 IA           | 20         | 0                            | 6 IA  | 20         | 0      |
| 7 IA                        | 20         | 0      | 7 IA           | 20         | 1                            | 7 IA  | 20         | 0      |
| 8 IA                        | 20         | 0      | 8 IA           | 20         | 0                            | 8 IA  | 20         | 0      |
| 9 IA                        | 20         | 0      | 9 IA           | 20         | 0                            | 9 IA  | 20         | 0      |

**Table B1.1** Off road data transmission tests

| Time: 6:00 to 8:00 a.m. |            |        | Distance: 81.6 km                            |            |        | Theoretical trip time: 1.59 h |            |        |
|-------------------------|------------|--------|----------------------------------------------|------------|--------|-------------------------------|------------|--------|
| Actual trip time: 2 h   |            |        | Itinerary: The road between al-Bab and Afrin |            |        | Total number of samples: 120  |            |        |
| Point                   | Speed (Km) | Errors | Point                                        | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                       | 0          | 0      | 40                                           | 60         | 0      | 86                            | 60         | 0      |
| 2                       | 40         | 0      | 41                                           | 60         | 0      | 87                            | 60         | 0      |
| 3                       | 60         | 0      | 43                                           | 60         | 1      | 88                            | 60         | 0      |
| 4                       | 60         | 0      | 44                                           | 60         | 0      | 89                            | 60         | 0      |

|    |    |   |    |    |   |     |    |   |
|----|----|---|----|----|---|-----|----|---|
| 5  | 60 | 0 | 45 | 60 | 0 | 90  | 60 | 0 |
| 6  | 60 | 0 | 46 | 60 | 0 | 91  | 60 | 0 |
| 7  | 60 | 0 | 47 | 60 | 0 | 92  | 60 | 0 |
| 8  | 60 | 0 | 48 | 60 | 0 | 93  | 60 | 0 |
| 9  | 60 | 0 | 49 | 60 | 0 | 94  | 60 | 0 |
| 10 | 60 | 0 | 50 | 60 | 0 | 95  | 60 | 0 |
| 11 | 60 | 0 | 51 | 60 | 0 | 96  | 60 | 0 |
| 12 | 60 | 0 | 52 | 60 | 0 | 97  | 60 | 0 |
| 13 | 60 | 0 | 53 | 60 | 0 | 98  | 60 | 0 |
| 14 | 60 | 0 | 54 | 60 | 0 | 99  | 60 | 0 |
| 15 | 60 | 0 | 55 | 60 | 0 | 100 | 60 | 0 |
| 16 | 60 | 0 | 56 | 60 | 0 | 101 | 60 | 0 |
| 17 | 60 | 0 | 57 | 60 | 0 | 102 | 60 | 0 |
| 18 | 60 | 0 | 58 | 60 | 0 | 103 | 60 | 0 |
| 19 | 60 | 0 | 59 | 60 | 0 | 104 | 60 | 0 |
| 20 | 60 | 0 | 60 | 60 | 1 | 105 | 60 | 0 |
| 21 | 60 | 0 | 61 | 60 | 0 | 106 | 60 | 0 |
| 22 | 60 | 0 | 62 | 60 | 0 | 107 | 60 | 0 |
| 23 | 60 | 0 | 63 | 60 | 0 | 108 | 60 | 0 |
| 24 | 60 | 0 | 64 | 60 | 0 | 109 | 60 | 0 |
| 25 | 60 | 0 | 65 | 60 | 0 | 110 | 60 | 0 |
| 26 | 60 | 0 | 66 | 60 | 0 | 111 | 60 | 0 |
| 27 | 60 | 0 | 67 | 60 | 0 | 112 | 60 | 0 |
| 28 | 60 | 0 | 68 | 60 | 0 | 112 | 60 | 0 |
| 29 | 60 | 0 | 69 | 60 | 0 | 113 | 60 | 0 |
| 30 | 60 | 1 | 70 | 60 | 0 | 114 | 60 | 1 |
| 31 | 60 | 0 | 71 | 60 | 0 | 115 | 60 | 0 |
| 32 | 60 | 0 | 72 | 60 | 0 | 116 | 60 | 0 |
| 33 | 60 | 0 | 79 | 60 | 0 | 117 | 60 | 0 |
| 34 | 60 | 0 | 80 | 60 | 0 | 118 | 60 | 0 |
| 35 | 60 | 0 | 81 | 60 | 0 | 119 | 60 | 0 |

|    |    |   |    |    |   |     |    |   |
|----|----|---|----|----|---|-----|----|---|
| 36 | 60 | 0 | 82 | 60 | 0 | 120 | 60 | 0 |
| 37 | 60 | 0 | 83 | 60 | 0 |     |    |   |
| 38 | 60 | 0 | 84 | 60 | 0 |     |    |   |
| 39 | 60 | 0 | 85 | 60 | 0 |     |    |   |

**Table B1.2** Off road data transmission tests

| Time: 12:00 to 2:00 p.m. |            |        | Distance: 81.6 km                            |            |        | Theoretical trip time: 1.59 h |            |        |
|--------------------------|------------|--------|----------------------------------------------|------------|--------|-------------------------------|------------|--------|
| Actual trip time: 2 h    |            |        | Itinerary: The road between al-Bab and Afrin |            |        | Total number of samples: 120  |            |        |
| Point                    | Speed (Km) | Errors | Point                                        | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                        | 0          | 0      | 40                                           | 60         | 0      | 86                            | 60         | 0      |
| 2                        | 40         | 0      | 41                                           | 60         | 0      | 87                            | 60         | 0      |
| 3                        | 60         | 0      | 43                                           | 60         | 0      | 88                            | 60         | 0      |
| 4                        | 60         | 0      | 44                                           | 60         | 0      | 89                            | 60         | 0      |
| 5                        | 60         | 0      | 45                                           | 60         | 0      | 90                            | 60         | 0      |
| 6                        | 60         | 0      | 46                                           | 60         | 0      | 91                            | 60         | 0      |
| 7                        | 60         | 0      | 47                                           | 60         | 0      | 92                            | 60         | 0      |
| 8                        | 60         | 0      | 48                                           | 60         | 0      | 93                            | 60         | 0      |
| 9                        | 60         | 0      | 49                                           | 60         | 0      | 94                            | 60         | 0      |
| 10                       | 60         | 0      | 50                                           | 60         | 0      | 95                            | 60         | 0      |
| 11                       | 60         | 0      | 51                                           | 60         | 0      | 96                            | 60         | 0      |
| 12                       | 60         | 0      | 52                                           | 60         | 0      | 97                            | 60         | 0      |
| 13                       | 60         | 0      | 53                                           | 60         | 0      | 98                            | 60         | 0      |
| 14                       | 60         | 0      | 54                                           | 60         | 0      | 99                            | 60         | 0      |
| 15                       | 60         | 0      | 55                                           | 60         | 0      | 100                           | 60         | 0      |
| 16                       | 60         | 0      | 56                                           | 60         | 0      | 101                           | 60         | 0      |
| 17                       | 60         | 0      | 57                                           | 60         | 0      | 102                           | 60         | 0      |
| 18                       | 60         | 0      | 58                                           | 60         | 0      | 103                           | 60         | 0      |
| 19                       | 60         | 0      | 59                                           | 60         | 0      | 104                           | 60         | 0      |
| 20                       | 60         | 0      | 60                                           | 60         | 0      | 105                           | 60         | 0      |

|    |    |   |    |    |   |     |    |   |
|----|----|---|----|----|---|-----|----|---|
| 21 | 60 | 0 | 61 | 60 | 0 | 106 | 60 | 0 |
| 22 | 60 | 0 | 62 | 60 | 0 | 107 | 60 | 0 |
| 23 | 60 | 0 | 63 | 60 | 0 | 108 | 60 | 0 |
| 24 | 60 | 0 | 64 | 60 | 0 | 109 | 60 | 0 |
| 25 | 60 | 0 | 65 | 60 | 0 | 110 | 60 | 0 |
| 26 | 60 | 0 | 66 | 60 | 0 | 111 | 60 | 0 |
| 27 | 60 | 0 | 67 | 60 | 0 | 112 | 60 | 0 |
| 28 | 60 | 0 | 68 | 60 | 0 | 112 | 60 | 0 |
| 29 | 60 | 0 | 69 | 60 | 0 | 113 | 60 | 0 |
| 30 | 60 | 0 | 70 | 60 | 0 | 114 | 60 | 0 |
| 31 | 60 | 0 | 71 | 60 | 0 | 115 | 60 | 0 |
| 32 | 60 | 0 | 72 | 60 | 0 | 116 | 60 | 0 |
| 33 | 60 | 0 | 79 | 60 | 0 | 117 | 60 | 0 |
| 34 | 60 | 0 | 80 | 60 | 0 | 118 | 60 | 0 |
| 35 | 60 | 0 | 81 | 60 | 0 | 119 | 60 | 0 |
| 36 | 60 | 0 | 82 | 60 | 0 | 120 | 60 | 0 |
| 37 | 60 | 0 | 83 | 60 | 0 |     |    |   |
| 38 | 60 | 0 | 84 | 60 | 0 |     |    |   |
| 39 | 60 | 1 | 85 | 60 | 0 |     |    |   |

**Table B1.3** Off road data transmission tests

| Time: 6:00 to 8:00 p.m. |            |        | Distance: 81.6 km                            |            |        | Theoretical trip time: 1.59 h |            |        |
|-------------------------|------------|--------|----------------------------------------------|------------|--------|-------------------------------|------------|--------|
| Actual trip time: 2 h   |            |        | Itinerary: The road between al-Bab and Afrin |            |        | Total number of samples: 120  |            |        |
| Point                   | Speed (Km) | Errors | Point                                        | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                       | 0          | 0      | 40                                           | 60         | 0      | 86                            | 60         | 0      |
| 2                       | 40         | 0      | 41                                           | 60         | 0      | 87                            | 60         | 0      |
| 3                       | 60         | 0      | 43                                           | 60         | 1      | 88                            | 60         | 0      |
| 4                       | 60         | 0      | 44                                           | 60         | 0      | 89                            | 60         | 0      |
| 5                       | 60         | 0      | 45                                           | 60         | 0      | 90                            | 60         | 0      |

|    |    |   |    |    |   |     |    |   |
|----|----|---|----|----|---|-----|----|---|
| 6  | 60 | 0 | 46 | 60 | 0 | 91  | 60 | 0 |
| 7  | 60 | 0 | 47 | 60 | 0 | 92  | 60 | 0 |
| 8  | 60 | 0 | 48 | 60 | 0 | 93  | 60 | 0 |
| 9  | 60 | 0 | 49 | 60 | 0 | 94  | 60 | 0 |
| 10 | 60 | 0 | 50 | 60 | 0 | 95  | 60 | 0 |
| 11 | 60 | 0 | 51 | 60 | 0 | 96  | 60 | 0 |
| 12 | 60 | 0 | 52 | 60 | 0 | 97  | 60 | 0 |
| 13 | 60 | 0 | 53 | 60 | 0 | 98  | 60 | 0 |
| 14 | 60 | 0 | 54 | 60 | 0 | 99  | 60 | 0 |
| 15 | 60 | 0 | 55 | 60 | 0 | 100 | 60 | 0 |
| 16 | 60 | 0 | 56 | 60 | 0 | 101 | 60 | 0 |
| 17 | 60 | 0 | 57 | 60 | 0 | 102 | 60 | 0 |
| 18 | 60 | 0 | 58 | 60 | 0 | 103 | 60 | 0 |
| 19 | 60 | 0 | 59 | 60 | 0 | 104 | 60 | 0 |
| 20 | 60 | 0 | 60 | 60 | 1 | 105 | 60 | 0 |
| 21 | 60 | 0 | 61 | 60 | 0 | 106 | 60 | 0 |
| 22 | 60 | 0 | 62 | 60 | 0 | 107 | 60 | 0 |
| 23 | 60 | 0 | 63 | 60 | 0 | 108 | 60 | 0 |
| 24 | 60 | 0 | 64 | 60 | 0 | 109 | 60 | 0 |
| 25 | 60 | 0 | 65 | 60 | 0 | 110 | 60 | 0 |
| 26 | 60 | 0 | 66 | 60 | 0 | 111 | 60 | 0 |
| 27 | 60 | 0 | 67 | 60 | 0 | 112 | 60 | 0 |
| 28 | 60 | 0 | 68 | 60 | 0 | 112 | 60 | 0 |
| 29 | 60 | 0 | 69 | 60 | 0 | 113 | 60 | 0 |
| 30 | 60 | 0 | 70 | 60 | 0 | 114 | 60 | 1 |
| 31 | 60 | 1 | 71 | 60 | 0 | 115 | 60 | 0 |
| 32 | 60 | 0 | 72 | 60 | 0 | 116 | 60 | 0 |
| 33 | 60 | 0 | 79 | 60 | 0 | 117 | 60 | 0 |
| 34 | 60 | 0 | 80 | 60 | 0 | 118 | 60 | 0 |
| 35 | 60 | 0 | 81 | 60 | 0 | 119 | 60 | 0 |
| 36 | 60 | 0 | 82 | 60 | 0 | 120 | 60 | 0 |

|    |    |   |    |    |   |  |
|----|----|---|----|----|---|--|
| 37 | 60 | 0 | 83 | 60 | 0 |  |
| 38 | 60 | 0 | 84 | 60 | 0 |  |
| 39 | 60 | 0 | 85 | 60 | 0 |  |

**Table B1.4** Off road data transmission tests

| Time: 6:00 to 8:00 a.m. |            |        | Distance: 49 km                               |            |        | Theoretical trip time: 1.24 h |            |        |
|-------------------------|------------|--------|-----------------------------------------------|------------|--------|-------------------------------|------------|--------|
| Actual trip time: 2 h   |            |        | Itinerary: The road between Sarmada and Idlib |            |        | Total number of samples: 120  |            |        |
| Point                   | Speed (Km) | Errors | Point                                         | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                       | 0          | 0      | 40                                            | 60         | 0      | 86                            | 60         | 0      |
| 2                       | 40         | 0      | 41                                            | 60         | 0      | 87                            | 60         | 2      |
| 3                       | 60         | 0      | 43                                            | 60         | 0      | 88                            | 60         | 0      |
| 4                       | 60         | 0      | 44                                            | 60         | 0      | 89                            | 60         | 0      |
| 5                       | 60         | 0      | 45                                            | 60         | 0      | 90                            | 60         | 0      |
| 6                       | 60         | 0      | 46                                            | 60         | 0      | 91                            | 60         | 0      |
| 7                       | 60         | 0      | 47                                            | 60         | 0      | 92                            | 60         | 0      |
| 8                       | 60         | 0      | 48                                            | 60         | 0      | 93                            | 60         | 0      |
| 9                       | 60         | 0      | 49                                            | 60         | 0      | 94                            | 60         | 0      |
| 10                      | 60         | 0      | 50                                            | 60         | 0      | 95                            | 60         | 0      |
| 11                      | 60         | 0      | 51                                            | 60         | 0      | 96                            | 60         | 0      |
| 12                      | 60         | 0      | 52                                            | 60         | 0      | 97                            | 60         | 0      |
| 13                      | 60         | 0      | 53                                            | 60         | 0      | 98                            | 60         | 0      |
| 14                      | 60         | 0      | 54                                            | 60         | 0      | 99                            | 60         | 1      |
| 15                      | 60         | 1      | 55                                            | 60         | 0      | 100                           | 60         | 0      |
| 16                      | 60         | 0      | 56                                            | 60         | 0      | 101                           | 60         | 0      |
| 17                      | 60         | 0      | 57                                            | 60         | 0      | 102                           | 60         | 0      |
| 18                      | 60         | 0      | 58                                            | 60         | 0      | 103                           | 60         | 0      |
| 19                      | 60         | 0      | 59                                            | 60         | 0      | 104                           | 60         | 0      |
| 20                      | 60         | 0      | 60                                            | 60         | 0      | 105                           | 60         | 0      |
| 21                      | 60         | 0      | 61                                            | 60         | 0      | 106                           | 60         | 0      |

| 22                       | 60         | 0      | 62                                            | 60         | 0      | 107                           | 60         | 0      |
|--------------------------|------------|--------|-----------------------------------------------|------------|--------|-------------------------------|------------|--------|
| 23                       | 60         | 0      | 63                                            | 60         | 0      | 108                           | 60         | 0      |
| 24                       | 60         | 0      | 64                                            | 60         | 0      | 109                           | 60         | 0      |
| 25                       | 60         | 0      | 65                                            | 60         | 0      | 110                           | 60         | 0      |
| 26                       | 60         | 0      | 66                                            | 60         | 0      | 111                           | 60         | 0      |
| 27                       | 60         | 0      | 67                                            | 60         | 0      | 112                           | 60         | 0      |
| 28                       | 60         | 0      | 68                                            | 60         | 0      | 112                           | 60         | 0      |
| 29                       | 60         | 0      | 69                                            | 60         | 0      | 113                           | 60         | 0      |
| 30                       | 60         | 0      | 70                                            | 60         | 0      | 114                           | 60         | 0      |
| 31                       | 60         | 0      | 71                                            | 60         | 0      | 115                           | 60         | 0      |
| 32                       | 60         | 0      | 72                                            | 60         | 0      | 116                           | 60         | 0      |
| 33                       | 60         | 0      | 79                                            | 60         | 0      | 117                           | 60         | 0      |
| 34                       | 60         | 0      | 80                                            | 60         | 0      | 118                           | 60         | 0      |
| 35                       | 60         | 0      | 81                                            | 60         | 0      | 119                           | 60         | 0      |
| 36                       | 60         | 0      | 82                                            | 60         | 0      | 120                           | 60         | 0      |
| 37                       | 60         | 0      | 83                                            | 60         | 0      |                               |            |        |
| 38                       | 60         | 0      | 84                                            | 60         | 0      |                               |            |        |
| 39                       | 60         | 1      | 85                                            | 60         | 0      |                               |            |        |
| Time: 12:00 to 2:00 p.m. |            |        | Distance: 49 km                               |            |        | Theoretical trip time: 1.24 h |            |        |
| Actual trip time: 2 h    |            |        | Itinerary: The road between Sarmada and Idlib |            |        | Total number of samples: 120  |            |        |
| Point                    | Speed (Km) | Errors | Point                                         | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                        | 0          | 0      | 40                                            | 60         | 0      | 86                            | 60         | 0      |
| 2                        | 40         | 0      | 41                                            | 60         | 0      | 87                            | 60         | 0      |
| 3                        | 60         | 0      | 43                                            | 60         | 0      | 88                            | 60         | 0      |
| 4                        | 60         | 0      | 44                                            | 60         | 0      | 89                            | 60         | 0      |
| 5                        | 60         | 0      | 45                                            | 60         | 0      | 90                            | 60         | 0      |
| 6                        | 60         | 0      | 46                                            | 60         | 0      | 91                            | 60         | 0      |
| 7                        | 60         | 0      | 47                                            | 60         | 0      | 92                            | 60         | 0      |
| 8                        | 60         | 0      | 48                                            | 60         | 0      | 93                            | 60         | 0      |

|    |    |   |    |    |   |     |    |   |
|----|----|---|----|----|---|-----|----|---|
| 9  | 60 | 0 | 49 | 60 | 0 | 94  | 60 | 0 |
| 10 | 60 | 0 | 50 | 60 | 0 | 95  | 60 | 0 |
| 11 | 60 | 0 | 51 | 60 | 0 | 96  | 60 | 0 |
| 12 | 60 | 0 | 52 | 60 | 0 | 97  | 60 | 0 |
| 13 | 60 | 0 | 53 | 60 | 0 | 98  | 60 | 0 |
| 14 | 60 | 0 | 54 | 60 | 0 | 99  | 60 | 0 |
| 15 | 60 | 0 | 55 | 60 | 0 | 100 | 60 | 0 |
| 16 | 60 | 0 | 56 | 60 | 1 | 101 | 60 | 0 |
| 17 | 60 | 0 | 57 | 60 | 0 | 102 | 60 | 0 |
| 18 | 60 | 0 | 58 | 60 | 0 | 103 | 60 | 0 |
| 19 | 60 | 0 | 59 | 60 | 0 | 104 | 60 | 0 |
| 20 | 60 | 0 | 60 | 60 | 0 | 105 | 60 | 0 |
| 21 | 60 | 0 | 61 | 60 | 0 | 106 | 60 | 0 |
| 22 | 60 | 0 | 62 | 60 | 0 | 107 | 60 | 0 |
| 23 | 60 | 0 | 63 | 60 | 0 | 108 | 60 | 0 |
| 24 | 60 | 0 | 64 | 60 | 0 | 109 | 60 | 0 |
| 25 | 60 | 1 | 65 | 60 | 0 | 110 | 60 | 0 |
| 26 | 60 | 0 | 66 | 60 | 0 | 111 | 60 | 0 |
| 27 | 60 | 0 | 67 | 60 | 0 | 112 | 60 | 0 |
| 28 | 60 | 0 | 68 | 60 | 0 | 112 | 60 | 0 |
| 29 | 60 | 0 | 69 | 60 | 0 | 113 | 60 | 0 |
| 30 | 60 | 0 | 70 | 60 | 0 | 114 | 60 | 0 |
| 31 | 60 | 0 | 71 | 60 | 0 | 115 | 60 | 0 |
| 32 | 60 | 0 | 72 | 60 | 0 | 116 | 60 | 0 |
| 33 | 60 | 0 | 79 | 60 | 0 | 117 | 60 | 0 |
| 34 | 60 | 0 | 80 | 60 | 0 | 118 | 60 | 0 |
| 35 | 60 | 0 | 81 | 60 | 0 | 119 | 60 | 0 |
| 36 | 60 | 0 | 82 | 60 | 0 | 120 | 60 | 0 |
| 37 | 60 | 0 | 83 | 60 | 0 |     |    |   |
| 38 | 60 | 0 | 84 | 60 | 0 |     |    |   |
| 39 | 60 | 1 | 85 | 60 | 0 |     |    |   |

**Table B1.5** Off road data transmission tests

| Time: 6:00 to 8:00 p.m. |            |        | Distance: 49 km                               |            |        | Theoretical trip time: 1.24 h |            |        |
|-------------------------|------------|--------|-----------------------------------------------|------------|--------|-------------------------------|------------|--------|
| Actual trip time: 2 h   |            |        | Itinerary: The road between Sarmada and Idlib |            |        | Total number of samples: 120  |            |        |
| Point                   | Speed (Km) | Errors | Point                                         | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                       | 0          | 0      | 40                                            | 60         | 0      | 86                            | 60         | 0      |
| 2                       | 40         | 0      | 41                                            | 60         | 0      | 87                            | 60         | 0      |
| 3                       | 60         | 0      | 43                                            | 60         | 0      | 88                            | 60         | 0      |
| 4                       | 60         | 0      | 44                                            | 60         | 0      | 89                            | 60         | 0      |
| 5                       | 60         | 0      | 45                                            | 60         | 0      | 90                            | 60         | 0      |
| 6                       | 60         | 0      | 46                                            | 60         | 0      | 91                            | 60         | 0      |
| 7                       | 60         | 0      | 47                                            | 60         | 0      | 92                            | 60         | 0      |
| 8                       | 60         | 1      | 48                                            | 60         | 0      | 93                            | 60         | 0      |
| 9                       | 60         | 0      | 49                                            | 60         | 0      | 94                            | 60         | 0      |
| 10                      | 60         | 0      | 50                                            | 60         | 0      | 95                            | 60         | 0      |
| 11                      | 60         | 0      | 51                                            | 60         | 0      | 96                            | 60         | 0      |
| 12                      | 60         | 0      | 52                                            | 60         | 0      | 97                            | 60         | 0      |
| 13                      | 60         | 0      | 53                                            | 60         | 0      | 98                            | 60         | 0      |
| 14                      | 60         | 0      | 54                                            | 60         | 0      | 99                            | 60         | 0      |
| 15                      | 60         | 0      | 55                                            | 60         | 0      | 100                           | 60         | 0      |
| 16                      | 60         | 0      | 56                                            | 60         | 0      | 101                           | 60         | 0      |
| 17                      | 60         | 0      | 57                                            | 60         | 0      | 102                           | 60         | 0      |
| 18                      | 60         | 0      | 58                                            | 60         | 0      | 103                           | 60         | 0      |
| 19                      | 60         | 0      | 59                                            | 60         | 0      | 104                           | 60         | 0      |
| 20                      | 60         | 0      | 60                                            | 60         | 0      | 105                           | 60         | 0      |
| 21                      | 60         | 0      | 61                                            | 60         | 0      | 106                           | 60         | 0      |
| 22                      | 60         | 0      | 62                                            | 60         | 0      | 107                           | 60         | 0      |
| 23                      | 60         | 0      | 63                                            | 60         | 0      | 108                           | 60         | 0      |
| 24                      | 60         | 0      | 64                                            | 60         | 0      | 109                           | 60         | 0      |
| 25                      | 60         | 0      | 65                                            | 60         | 0      | 110                           | 60         | 0      |

|    |    |   |    |    |   |     |    |   |
|----|----|---|----|----|---|-----|----|---|
| 26 | 60 | 0 | 66 | 60 | 0 | 111 | 60 | 0 |
| 27 | 60 | 0 | 67 | 60 | 0 | 112 | 60 | 0 |
| 28 | 60 | 0 | 68 | 60 | 0 | 112 | 60 | 0 |
| 29 | 60 | 0 | 69 | 60 | 0 | 113 | 60 | 0 |
| 30 | 60 | 0 | 70 | 60 | 0 | 114 | 60 | 0 |
| 31 | 60 | 0 | 71 | 60 | 0 | 115 | 60 | 0 |
| 32 | 60 | 0 | 72 | 60 | 0 | 116 | 60 | 0 |
| 33 | 60 | 0 | 79 | 60 | 0 | 117 | 60 | 0 |
| 34 | 60 | 0 | 80 | 60 | 0 | 118 | 60 | 0 |
| 35 | 60 | 0 | 81 | 60 | 0 | 119 | 60 | 2 |
| 36 | 60 | 0 | 82 | 60 | 0 | 120 | 60 | 0 |
| 37 | 60 | 0 | 83 | 60 | 0 |     |    |   |
| 38 | 60 | 0 | 84 | 60 | 0 |     |    |   |
| 39 | 60 | 1 | 85 | 60 | 0 |     |    |   |

**Table B1.6** Off road data transmission tests

| Time: 6:00 to 9:00 a.m. |            |        | Distance: 82.1 km                               |            |        | Theoretical trip time: 1.48 h |            |        |
|-------------------------|------------|--------|-------------------------------------------------|------------|--------|-------------------------------|------------|--------|
| Actual trip time: 3 h   |            |        | Itinerary: The road between Jarablus and Al-Bab |            |        | Total number of samples: 180  |            |        |
| Point                   | Speed (Km) | Errors | Point                                           | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                       | 0          | 0      | 61                                              | 60         | 0      | 121                           | 60         | 0      |
| 2                       | 40         | 0      | 62                                              | 60         | 0      | 122                           | 60         | 0      |
| 3                       | 60         | 0      | 63                                              | 60         | 0      | 123                           | 60         | 0      |
| 4                       | 60         | 0      | 64                                              | 60         | 0      | 124                           | 60         | 0      |
| 5                       | 60         | 0      | 65                                              | 60         | 0      | 125                           | 60         | 0      |
| 6                       | 60         | 0      | 66                                              | 60         | 0      | 126                           | 40         | 0      |
| 7                       | 60         | 0      | 67                                              | 60         | 0      | 127                           | 0          | 0      |
| 8                       | 60         | 0      | 68                                              | 60         | 0      | 128                           | 60         | 0      |
| 9                       | 60         | 0      | 69                                              | 60         | 0      | 129                           | 60         | 0      |
| 10                      | 60         | 0      | 70                                              | 60         | 0      | 130                           | 60         | 0      |
| 11                      | 60         | 0      | 71                                              | 60         | 0      | 131                           | 60         | 0      |

|    |    |   |     |    |   |     |    |   |
|----|----|---|-----|----|---|-----|----|---|
| 12 | 60 | 0 | 72  | 60 | 0 | 132 | 60 | 0 |
| 13 | 60 | 0 | 73  | 60 | 0 | 133 | 60 | 0 |
| 14 | 60 | 0 | 74  | 60 | 0 | 134 | 60 | 0 |
| 15 | 60 | 0 | 75  | 60 | 0 | 135 | 60 | 0 |
| 16 | 60 | 0 | 76  | 60 | 0 | 136 | 60 | 0 |
| 17 | 60 | 0 | 77  | 60 | 0 | 137 | 60 | 0 |
| 18 | 60 | 0 | 78  | 60 | 0 | 138 | 60 | 0 |
| 19 | 60 | 0 | 79  | 60 | 0 | 139 | 60 | 0 |
| 20 | 60 | 0 | 80  | 60 | 0 | 140 | 60 | 0 |
| 21 | 60 | 0 | 81  | 60 | 0 | 141 | 60 | 0 |
| 22 | 60 | 0 | 82  | 60 | 0 | 142 | 60 | 0 |
| 23 | 60 | 0 | 83  | 60 | 0 | 143 | 60 | 0 |
| 24 | 60 | 0 | 84  | 60 | 0 | 144 | 60 | 0 |
| 25 | 60 | 0 | 85  | 60 | 0 | 145 | 60 | 0 |
| 26 | 60 | 0 | 86  | 60 | 0 | 146 | 60 | 0 |
| 27 | 60 | 0 | 87  | 60 | 0 | 147 | 60 | 0 |
| 28 | 60 | 0 | 88  | 60 | 0 | 148 | 60 | 0 |
| 29 | 60 | 0 | 89  | 60 | 0 | 149 | 60 | 0 |
| 30 | 60 | 0 | 90  | 60 | 0 | 150 | 60 | 0 |
| 31 | 60 | 0 | 91  | 60 | 0 | 151 | 60 | 0 |
| 32 | 60 | 0 | 92  | 60 | 0 | 152 | 60 | 0 |
| 33 | 60 | 0 | 93  | 60 | 0 | 153 | 60 | 0 |
| 34 | 60 | 0 | 94  | 60 | 0 | 154 | 60 | 0 |
| 35 | 60 | 0 | 95  | 60 | 0 | 155 | 60 | 0 |
| 36 | 60 | 0 | 96  | 60 | 0 | 156 | 60 | 0 |
| 37 | 60 | 0 | 97  | 60 | 0 | 157 | 60 | 0 |
| 38 | 60 | 0 | 98  | 60 | 0 | 158 | 60 | 0 |
| 39 | 60 | 0 | 99  | 0  | 0 | 159 | 60 | 0 |
| 40 | 60 | 0 | 100 | 60 | 0 | 160 | 60 | 0 |
| 41 | 60 | 0 | 101 | 60 | 0 | 161 | 60 | 0 |
| 42 | 60 | 0 | 102 | 60 | 0 | 162 | 60 | 0 |

| 43                       | 60         | 0      | 103                                             | 60         | 0      | 163                           | 60         | 0      |
|--------------------------|------------|--------|-------------------------------------------------|------------|--------|-------------------------------|------------|--------|
| 44                       | 60         | 0      | 104                                             | 60         | 0      | 164                           | 60         | 0      |
| 45                       | 60         | 0      | 105                                             | 60         | 0      | 165                           | 60         | 0      |
| 46                       | 60         | 0      | 106                                             | 60         | 1      | 166                           | 60         | 0      |
| 47                       | 60         | 0      | 107                                             | 60         | 0      | 167                           | 60         | 0      |
| 48                       | 60         | 0      | 108                                             | 60         | 0      | 168                           | 60         | 0      |
| 49                       | 60         | 0      | 109                                             | 60         | 0      | 169                           | 60         | 0      |
| 50                       | 60         | 0      | 110                                             | 60         | 0      | 170                           | 60         | 0      |
| 51                       | 60         | 0      | 111                                             | 60         | 0      | 171                           | 60         | 0      |
| 52                       | 60         | 2      | 112                                             | 60         | 0      | 172                           | 60         | 0      |
| 53                       | 60         | 1      | 113                                             | 60         | 0      | 173                           | 60         | 0      |
| 54                       | 60         | 0      | 114                                             | 60         | 0      | 174                           | 60         | 0      |
| 55                       | 60         | 0      | 115                                             | 60         | 0      | 175                           | 60         | 0      |
| 56                       | 60         | 0      | 116                                             | 60         | 0      | 176                           | 60         | 0      |
| 57                       | 60         | 0      | 117                                             | 60         | 0      | 177                           | 60         | 0      |
| 58                       | 60         | 0      | 118                                             | 60         | 0      | 178                           | 60         | 0      |
| 59                       | 60         | 0      | 119                                             | 60         | 0      | 179                           | 60         | 0      |
| 60                       | 60         | 0      | 120                                             | 60         | 0      | 180                           | 60         | 0      |
| Time: 12:00 to 3:00 p.m. |            |        | Distance: 82.1 km                               |            |        | Theoretical trip time: 1.48 h |            |        |
| Actual trip time: 3 h    |            |        | Itinerary: The road between Jarablus and Al-Bab |            |        | Total number of samples:180   |            |        |
| Point                    | Speed (Km) | Errors | Point                                           | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                        | 0          | 0      | 61                                              | 60         | 0      | 121                           | 60         | 0      |
| 2                        | 40         | 0      | 62                                              | 60         | 0      | 122                           | 60         | 0      |
| 3                        | 60         | 0      | 63                                              | 60         | 0      | 123                           | 60         | 0      |
| 4                        | 60         | 0      | 64                                              | 60         | 0      | 124                           | 60         | 0      |
| 5                        | 60         | 0      | 65                                              | 60         | 0      | 125                           | 60         | 0      |
| 6                        | 60         | 0      | 66                                              | 60         | 0      | 126                           | 60         | 0      |
| 7                        | 60         | 0      | 67                                              | 60         | 0      | 127                           | 60         | 0      |
| 8                        | 60         | 0      | 68                                              | 60         | 0      | 128                           | 60         | 0      |

|    |    |   |    |    |   |     |    |   |
|----|----|---|----|----|---|-----|----|---|
| 9  | 60 | 0 | 69 | 60 | 0 | 129 | 60 | 0 |
| 10 | 60 | 0 | 70 | 60 | 0 | 130 | 60 | 0 |
| 11 | 60 | 0 | 71 | 60 | 0 | 131 | 60 | 0 |
| 12 | 60 | 0 | 72 | 60 | 0 | 132 | 60 | 0 |
| 13 | 60 | 0 | 73 | 60 | 0 | 133 | 60 | 0 |
| 14 | 60 | 0 | 74 | 60 | 0 | 134 | 60 | 0 |
| 15 | 60 | 0 | 75 | 60 | 0 | 135 | 60 | 0 |
| 16 | 60 | 0 | 76 | 60 | 0 | 136 | 60 | 0 |
| 17 | 60 | 0 | 77 | 60 | 0 | 137 | 60 | 0 |
| 18 | 60 | 0 | 78 | 60 | 1 | 138 | 60 | 0 |
| 19 | 60 | 0 | 79 | 60 | 0 | 139 | 60 | 0 |
| 20 | 60 | 0 | 80 | 60 | 0 | 140 | 60 | 0 |
| 21 | 60 | 0 | 81 | 60 | 0 | 141 | 60 | 0 |
| 22 | 60 | 0 | 82 | 60 | 0 | 142 | 60 | 0 |
| 23 | 60 | 0 | 83 | 60 | 0 | 143 | 60 | 0 |
| 24 | 60 | 0 | 84 | 60 | 0 | 144 | 60 | 0 |
| 25 | 60 | 0 | 85 | 60 | 0 | 145 | 60 | 0 |
| 26 | 60 | 0 | 86 | 60 | 0 | 146 | 60 | 0 |
| 27 | 60 | 0 | 87 | 60 | 0 | 147 | 60 | 0 |
| 28 | 60 | 0 | 88 | 60 | 0 | 148 | 60 | 0 |
| 29 | 60 | 0 | 89 | 60 | 0 | 149 | 60 | 0 |
| 30 | 60 | 0 | 90 | 60 | 0 | 150 | 60 | 0 |
| 31 | 60 | 0 | 91 | 60 | 0 | 151 | 60 | 0 |
| 32 | 60 | 0 | 92 | 60 | 0 | 152 | 60 | 0 |
| 33 | 60 | 0 | 93 | 60 | 0 | 153 | 60 | 0 |
| 34 | 60 | 0 | 94 | 60 | 0 | 154 | 60 | 0 |
| 35 | 60 | 0 | 95 | 60 | 0 | 155 | 60 | 0 |
| 36 | 60 | 0 | 96 | 60 | 0 | 156 | 60 | 0 |
| 37 | 60 | 0 | 97 | 60 | 0 | 157 | 60 | 0 |
| 38 | 60 | 0 | 98 | 60 | 0 | 158 | 60 | 0 |
| 39 | 60 | 0 | 99 | 60 | 0 | 159 | 60 | 0 |

|                         |            |        |                                                 |            |        |                               |            |        |
|-------------------------|------------|--------|-------------------------------------------------|------------|--------|-------------------------------|------------|--------|
| 40                      | 60         | 0      | 100                                             | 60         | 0      | 160                           | 60         | 0      |
| 41                      | 60         | 0      | 101                                             | 60         | 0      | 161                           | 60         | 0      |
| 42                      | 60         | 0      | 102                                             | 60         | 0      | 162                           | 60         | 0      |
| 43                      | 60         | 0      | 103                                             | 60         | 0      | 163                           | 60         | 0      |
| 44                      | 60         | 0      | 104                                             | 60         | 0      | 164                           | 60         | 0      |
| 45                      | 60         | 0      | 105                                             | 60         | 0      | 165                           | 60         | 0      |
| 46                      | 60         | 0      | 106                                             | 60         | 1      | 166                           | 60         | 0      |
| 47                      | 60         | 0      | 107                                             | 60         | 0      | 167                           | 60         | 0      |
| 48                      | 60         | 0      | 108                                             | 60         | 0      | 168                           | 60         | 0      |
| 49                      | 60         | 0      | 109                                             | 60         | 0      | 169                           | 60         | 0      |
| 50                      | 60         | 0      | 110                                             | 40         | 0      | 170                           | 60         | 0      |
| 51                      | 60         | 0      | 111                                             | 60         | 0      | 171                           | 60         | 0      |
| 52                      | 60         | 0      | 112                                             | 60         | 0      | 172                           | 60         | 0      |
| 53                      | 60         | 0      | 113                                             | 60         | 0      | 173                           | 60         | 0      |
| 54                      | 60         | 0      | 114                                             | 60         | 0      | 174                           | 60         | 0      |
| 55                      | 60         | 0      | 115                                             | 60         | 0      | 175                           | 60         | 0      |
| 56                      | 60         | 0      | 116                                             | 60         | 0      | 176                           | 60         | 0      |
| 57                      | 60         | 0      | 117                                             | 60         | 0      | 177                           | 60         | 0      |
| 58                      | 60         | 0      | 118                                             | 60         | 0      | 178                           | 60         | 1      |
| 59                      | 60         | 0      | 119                                             | 60         | 0      | 179                           | 60         | 1      |
| 60                      | 60         | 0      | 120                                             | 60         | 0      | 180                           | 60         | 0      |
| Time: 6:00 to 9:00 p.m. |            |        | Distance: 82.1 km                               |            |        | Theoretical trip time: 1.48 h |            |        |
| Actual trip time: 3 h   |            |        | Itinerary: The road between Jarablus and Al-Bab |            |        | Total number of samples: 180  |            |        |
| Point                   | Speed (Km) | Errors | Point                                           | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                       | 0          | 0      | 61                                              | 60         | 0      | 121                           | 60         | 0      |
| 2                       | 40         | 0      | 62                                              | 60         | 0      | 122                           | 60         | 0      |
| 3                       | 60         | 0      | 63                                              | 60         | 0      | 123                           | 60         | 0      |
| 4                       | 60         | 0      | 64                                              | 60         | 0      | 124                           | 60         | 0      |
| 5                       | 60         | 0      | 65                                              | 60         | 0      | 125                           | 60         | 0      |
| 6                       | 60         | 0      | 66                                              | 60         | 0      | 126                           | 60         | 0      |

|    |    |   |    |    |   |     |    |   |
|----|----|---|----|----|---|-----|----|---|
| 7  | 60 | 0 | 67 | 60 | 0 | 127 | 60 | 0 |
| 8  | 60 | 0 | 68 | 60 | 0 | 128 | 60 | 0 |
| 9  | 60 | 0 | 69 | 60 | 0 | 129 | 60 | 0 |
| 10 | 60 | 0 | 70 | 60 | 0 | 130 | 60 | 0 |
| 11 | 60 | 0 | 71 | 60 | 0 | 131 | 60 | 0 |
| 12 | 60 | 0 | 72 | 60 | 0 | 132 | 60 | 0 |
| 13 | 60 | 0 | 73 | 60 | 0 | 133 | 60 | 0 |
| 14 | 60 | 0 | 74 | 60 | 0 | 134 | 60 | 0 |
| 15 | 60 | 0 | 75 | 60 | 0 | 135 | 60 | 0 |
| 16 | 60 | 0 | 76 | 60 | 0 | 136 | 60 | 0 |
| 17 | 60 | 0 | 77 | 60 | 0 | 137 | 60 | 0 |
| 18 | 60 | 0 | 78 | 60 | 0 | 138 | 60 | 0 |
| 19 | 60 | 0 | 79 | 60 | 0 | 139 | 60 | 0 |
| 20 | 60 | 0 | 80 | 60 | 0 | 140 | 60 | 0 |
| 21 | 60 | 0 | 81 | 60 | 0 | 141 | 0  | 0 |
| 22 | 60 | 0 | 82 | 60 | 0 | 142 | 0  | 0 |
| 23 | 60 | 0 | 83 | 60 | 0 | 143 | 0  | 0 |
| 24 | 60 | 0 | 84 | 60 | 0 | 144 | 0  | 0 |
| 25 | 60 | 0 | 85 | 60 | 0 | 145 | 60 | 0 |
| 26 | 60 | 0 | 86 | 60 | 0 | 146 | 60 | 0 |
| 27 | 60 | 0 | 87 | 60 | 0 | 147 | 60 | 0 |
| 28 | 60 | 0 | 88 | 60 | 0 | 148 | 60 | 0 |
| 29 | 60 | 0 | 89 | 60 | 0 | 149 | 60 | 0 |
| 30 | 60 | 0 | 90 | 60 | 0 | 150 | 60 | 0 |
| 31 | 60 | 0 | 91 | 60 | 0 | 151 | 60 | 0 |
| 32 | 60 | 0 | 92 | 60 | 0 | 152 | 60 | 0 |
| 33 | 60 | 0 | 93 | 60 | 0 | 153 | 60 | 0 |
| 34 | 60 | 0 | 94 | 60 | 0 | 154 | 60 | 0 |
| 35 | 60 | 0 | 95 | 60 | 0 | 155 | 60 | 0 |
| 36 | 60 | 0 | 96 | 60 | 0 | 156 | 60 | 0 |
| 37 | 60 | 0 | 97 | 60 | 0 | 157 | 60 | 0 |

|    |    |   |     |    |   |     |    |   |
|----|----|---|-----|----|---|-----|----|---|
| 38 | 60 | 0 | 98  | 60 | 0 | 158 | 60 | 0 |
| 39 | 60 | 0 | 99  | 60 | 0 | 159 | 60 | 0 |
| 40 | 60 | 0 | 100 | 60 | 0 | 160 | 60 | 0 |
| 41 | 60 | 0 | 101 | 60 | 0 | 161 | 60 | 0 |
| 42 | 60 | 0 | 102 | 60 | 0 | 162 | 60 | 0 |
| 43 | 60 | 0 | 103 | 60 | 0 | 163 | 60 | 0 |
| 44 | 60 | 0 | 104 | 60 | 0 | 164 | 60 | 0 |
| 45 | 0  | 0 | 105 | 60 | 0 | 165 | 60 | 0 |
| 46 | 0  | 0 | 106 | 60 | 0 | 166 | 60 | 0 |
| 47 | 40 | 0 | 107 | 60 | 0 | 167 | 60 | 0 |
| 48 | 60 | 0 | 108 | 60 | 0 | 168 | 60 | 0 |
| 49 | 60 | 0 | 109 | 60 | 0 | 169 | 60 | 0 |
| 50 | 60 | 0 | 110 | 60 | 0 | 170 | 60 | 0 |
| 51 | 60 | 0 | 111 | 60 | 0 | 171 | 60 | 0 |
| 52 | 60 | 0 | 112 | 60 | 0 | 172 | 60 | 0 |
| 53 | 60 | 0 | 113 | 60 | 0 | 173 | 60 | 0 |
| 54 | 60 | 0 | 114 | 60 | 0 | 174 | 60 | 0 |
| 55 | 60 | 0 | 115 | 60 | 0 | 175 | 60 | 0 |
| 56 | 60 | 0 | 116 | 60 | 0 | 176 | 60 | 0 |
| 57 | 60 | 0 | 117 | 60 | 0 | 177 | 60 | 0 |
| 58 | 60 | 0 | 118 | 60 | 0 | 178 | 60 | 0 |
| 59 | 60 | 0 | 119 | 60 | 0 | 179 | 60 | 0 |
| 60 | 60 | 0 | 120 | 60 | 0 | 180 | 60 | 0 |

**Table B1.7** Off road data transmission tests

|                         |            |        |                                               |            |        |                              |            |        |
|-------------------------|------------|--------|-----------------------------------------------|------------|--------|------------------------------|------------|--------|
| Time: 6:00 to 9:00 a.m. |            |        | Distance: 130.9 km                            |            |        | Theoretical trip time: 3.2 h |            |        |
| Actual trip time: 3 h   |            |        | Itinerary The road between Jarablus and Afrin |            |        | Total number of samples: 180 |            |        |
| Point                   | Speed (Km) | Errors | Point                                         | Speed (Km) | Errors | Point                        | Speed (Km) | Errors |
| 1                       | 0          | 0      | 61                                            | 80         | 0      | 121                          | 60         | 0      |
| 2                       | 40         | 0      | 62                                            | 80         | 0      | 122                          | 60         | 0      |

|    |    |   |    |    |   |     |    |   |
|----|----|---|----|----|---|-----|----|---|
| 3  | 60 | 0 | 63 | 80 | 0 | 123 | 60 | 0 |
| 4  | 60 | 0 | 64 | 80 | 0 | 124 | 60 | 0 |
| 5  | 60 | 0 | 65 | 80 | 0 | 125 | 60 | 0 |
| 6  | 60 | 0 | 66 | 80 | 0 | 126 | 60 | 0 |
| 7  | 80 | 0 | 67 | 80 | 0 | 127 | 60 | 0 |
| 8  | 80 | 0 | 68 | 80 | 0 | 128 | 60 | 0 |
| 9  | 80 | 0 | 69 | 80 | 0 | 129 | 60 | 0 |
| 10 | 80 | 0 | 70 | 80 | 0 | 130 | 60 | 0 |
| 11 | 80 | 0 | 71 | 80 | 0 | 131 | 60 | 0 |
| 12 | 80 | 0 | 72 | 80 | 0 | 132 | 60 | 0 |
| 13 | 80 | 0 | 73 | 80 | 0 | 133 | 60 | 0 |
| 14 | 80 | 0 | 74 | 80 | 0 | 134 | 60 | 0 |
| 15 | 80 | 0 | 75 | 80 | 0 | 135 | 60 | 0 |
| 16 | 80 | 0 | 76 | 80 | 0 | 136 | 60 | 0 |
| 17 | 80 | 0 | 77 | 80 | 0 | 137 | 60 | 0 |
| 18 | 80 | 0 | 78 | 80 | 0 | 138 | 60 | 0 |
| 19 | 80 | 0 | 79 | 80 | 0 | 139 | 60 | 0 |
| 20 | 80 | 0 | 80 | 80 | 0 | 140 | 60 | 0 |
| 21 | 80 | 0 | 81 | 80 | 0 | 141 | 60 | 0 |
| 22 | 80 | 0 | 82 | 80 | 0 | 142 | 60 | 0 |
| 23 | 80 | 0 | 83 | 80 | 0 | 143 | 60 | 0 |
| 24 | 80 | 0 | 84 | 80 | 0 | 144 | 60 | 0 |
| 25 | 80 | 0 | 85 | 80 | 0 | 145 | 60 | 0 |
| 26 | 80 | 0 | 86 | 80 | 0 | 146 | 60 | 0 |
| 27 | 80 | 0 | 87 | 80 | 0 | 147 | 60 | 0 |
| 28 | 80 | 0 | 88 | 80 | 0 | 148 | 60 | 0 |
| 29 | 80 | 0 | 89 | 80 | 0 | 149 | 60 | 0 |
| 30 | 80 | 0 | 90 | 80 | 0 | 150 | 60 | 0 |
| 31 | 80 | 0 | 91 | 80 | 0 | 151 | 60 | 0 |
| 32 | 80 | 0 | 92 | 80 | 0 | 152 | 60 | 0 |
| 33 | 80 | 0 | 93 | 80 | 0 | 153 | 60 | 0 |

|    |    |   |     |    |   |     |    |   |
|----|----|---|-----|----|---|-----|----|---|
| 34 | 80 | 0 | 94  | 80 | 0 | 154 | 60 | 0 |
| 35 | 80 | 0 | 95  | 80 | 0 | 155 | 60 | 0 |
| 36 | 80 | 0 | 96  | 80 | 0 | 156 | 60 | 0 |
| 37 | 80 | 0 | 97  | 80 | 0 | 157 | 60 | 0 |
| 38 | 80 | 0 | 98  | 80 | 0 | 158 | 60 | 0 |
| 39 | 80 | 0 | 99  | 80 | 0 | 159 | 60 | 0 |
| 40 | 80 | 0 | 100 | 80 | 0 | 160 | 60 | 0 |
| 41 | 80 | 0 | 101 | 80 | 0 | 161 | 60 | 0 |
| 42 | 80 | 0 | 102 | 80 | 0 | 162 | 60 | 0 |
| 43 | 80 | 0 | 103 | 80 | 0 | 163 | 60 | 0 |
| 44 | 80 | 0 | 104 | 80 | 0 | 164 | 60 | 0 |
| 45 | 80 | 0 | 105 | 80 | 0 | 165 | 60 | 0 |
| 46 | 80 | 0 | 106 | 80 | 1 | 166 | 60 | 0 |
| 47 | 80 | 0 | 107 | 80 | 0 | 167 | 60 | 0 |
| 48 | 80 | 0 | 108 | 80 | 0 | 168 | 60 | 0 |
| 49 | 80 | 0 | 109 | 60 | 0 | 169 | 60 | 0 |
| 50 | 80 | 0 | 110 | 60 | 0 | 170 | 60 | 0 |
| 51 | 80 | 0 | 111 | 60 | 0 | 171 | 60 | 0 |
| 52 | 80 | 0 | 112 | 60 | 0 | 172 | 60 | 0 |
| 53 | 80 | 0 | 113 | 60 | 0 | 173 | 60 | 0 |
| 54 | 80 | 0 | 114 | 60 | 0 | 174 | 60 | 0 |
| 55 | 80 | 0 | 115 | 60 | 0 | 175 | 60 | 0 |
| 56 | 80 | 0 | 116 | 60 | 1 | 176 | 60 | 0 |
| 57 | 80 | 0 | 117 | 60 | 0 | 177 | 60 | 0 |
| 58 | 80 | 0 | 118 | 60 | 0 | 178 | 60 | 0 |
| 59 | 80 | 0 | 119 | 60 | 0 | 179 | 60 | 0 |
| 60 | 80 | 0 | 120 | 60 | 0 | 180 | 60 | 0 |

**Table B1.8** Off road data transmission tests

| Time: 12:00 to 3:00 a.m. |            |        | Distance: 130.9 km                            |            |        | Theoretical trip time: 3.2 h |            |        |
|--------------------------|------------|--------|-----------------------------------------------|------------|--------|------------------------------|------------|--------|
| Actual trip time: 3 h    |            |        | Itinerary The road between Jarablus and Afrin |            |        | Total number of samples:180  |            |        |
| Point                    | Speed (Km) | Errors | Point                                         | Speed (Km) | Errors | Point                        | Speed (Km) | Errors |
| 1                        | 0          | 0      | 61                                            | 60         | 0      | 121                          | 60         | 0      |
| 2                        | 40         | 0      | 62                                            | 60         | 0      | 122                          | 60         | 0      |
| 3                        | 60         | 0      | 63                                            | 60         | 0      | 123                          | 60         | 0      |
| 4                        | 60         | 0      | 64                                            | 60         | 0      | 124                          | 60         | 0      |
| 5                        | 60         | 0      | 65                                            | 60         | 0      | 125                          | 60         | 0      |
| 6                        | 60         | 0      | 66                                            | 60         | 0      | 126                          | 60         | 0      |
| 7                        | 60         | 0      | 67                                            | 60         | 0      | 127                          | 60         | 0      |
| 8                        | 60         | 0      | 68                                            | 60         | 0      | 128                          | 60         | 0      |
| 9                        | 60         | 0      | 69                                            | 60         | 0      | 129                          | 60         | 0      |
| 10                       | 60         | 0      | 70                                            | 60         | 0      | 130                          | 60         | 0      |
| 11                       | 60         | 0      | 71                                            | 60         | 0      | 131                          | 60         | 0      |
| 12                       | 60         | 0      | 72                                            | 60         | 0      | 132                          | 60         | 0      |
| 13                       | 60         | 0      | 73                                            | 60         | 0      | 133                          | 60         | 0      |
| 14                       | 60         | 0      | 74                                            | 60         | 0      | 134                          | 60         | 0      |
| 15                       | 60         | 0      | 75                                            | 60         | 0      | 135                          | 60         | 0      |
| 16                       | 80         | 0      | 76                                            | 60         | 0      | 136                          | 80         | 0      |
| 17                       | 80         | 0      | 77                                            | 60         | 0      | 137                          | 80         | 0      |
| 18                       | 80         | 0      | 78                                            | 60         | 0      | 138                          | 80         | 0      |
| 19                       | 80         | 0      | 79                                            | 60         | 0      | 139                          | 80         | 0      |
| 20                       | 80         | 0      | 80                                            | 60         | 0      | 140                          | 80         | 0      |
| 21                       | 80         | 0      | 81                                            | 60         | 0      | 141                          | 80         | 0      |
| 22                       | 80         | 0      | 82                                            | 60         | 0      | 142                          | 80         | 0      |
| 23                       | 80         | 0      | 83                                            | 60         | 0      | 143                          | 80         | 0      |
| 24                       | 80         | 0      | 84                                            | 60         | 0      | 144                          | 80         | 0      |
| 25                       | 80         | 0      | 85                                            | 60         | 0      | 145                          | 80         | 0      |
| 26                       | 80         | 0      | 86                                            | 60         | 0      | 146                          | 80         | 0      |

|    |    |   |     |    |   |     |    |   |
|----|----|---|-----|----|---|-----|----|---|
| 27 | 80 | 0 | 87  | 60 | 0 | 147 | 80 | 0 |
| 28 | 80 | 0 | 88  | 60 | 0 | 148 | 80 | 0 |
| 29 | 80 | 0 | 89  | 60 | 0 | 149 | 80 | 0 |
| 30 | 80 | 0 | 90  | 60 | 0 | 150 | 80 | 0 |
| 31 | 80 | 0 | 91  | 60 | 0 | 151 | 80 | 0 |
| 32 | 80 | 0 | 92  | 60 | 0 | 152 | 80 | 0 |
| 33 | 80 | 0 | 93  | 60 | 0 | 153 | 80 | 0 |
| 34 | 80 | 0 | 94  | 60 | 0 | 154 | 80 | 0 |
| 35 | 80 | 0 | 95  | 60 | 0 | 155 | 80 | 0 |
| 36 | 80 | 0 | 96  | 60 | 0 | 156 | 80 | 0 |
| 37 | 80 | 0 | 97  | 60 | 0 | 157 | 80 | 0 |
| 38 | 80 | 0 | 98  | 60 | 0 | 158 | 80 | 0 |
| 39 | 80 | 0 | 99  | 60 | 0 | 159 | 80 | 0 |
| 40 | 80 | 0 | 100 | 60 | 0 | 160 | 80 | 0 |
| 41 | 80 | 0 | 101 | 60 | 0 | 161 | 80 | 0 |
| 42 | 80 | 0 | 102 | 60 | 0 | 162 | 80 | 0 |
| 43 | 80 | 0 | 103 | 60 | 0 | 163 | 80 | 0 |
| 44 | 80 | 0 | 104 | 60 | 0 | 164 | 80 | 0 |
| 45 | 80 | 0 | 105 | 60 | 0 | 165 | 80 | 0 |
| 46 | 80 | 0 | 106 | 60 | 0 | 166 | 80 | 0 |
| 47 | 80 | 0 | 107 | 60 | 0 | 167 | 80 | 0 |
| 48 | 80 | 0 | 108 | 60 | 0 | 168 | 80 | 0 |
| 49 | 80 | 0 | 109 | 60 | 0 | 169 | 60 | 0 |
| 50 | 80 | 0 | 110 | 60 | 0 | 170 | 60 | 0 |
| 51 | 80 | 0 | 111 | 60 | 0 | 171 | 60 | 0 |
| 52 | 80 | 0 | 112 | 60 | 0 | 172 | 60 | 0 |
| 53 | 80 | 0 | 113 | 60 | 0 | 173 | 60 | 0 |
| 54 | 60 | 0 | 114 | 60 | 0 | 174 | 60 | 0 |
| 55 | 60 | 0 | 115 | 60 | 0 | 175 | 60 | 0 |
| 56 | 60 | 0 | 116 | 60 | 0 | 176 | 60 | 0 |
| 57 | 60 | 0 | 117 | 60 | 0 | 177 | 60 | 0 |

| 58                      | 60         | 0      | 118                                           | 60         | 0      | 178                          | 60         | 0      |
|-------------------------|------------|--------|-----------------------------------------------|------------|--------|------------------------------|------------|--------|
| 59                      | 60         | 0      | 119                                           | 60         | 0      | 179                          | 60         | 0      |
| 60                      | 60         | 0      | 120                                           | 60         | 0      | 180                          | 60         | 0      |
| Time: 6:00 to 9:00 a.m. |            |        | Distance: 130.9 km                            |            |        | Theoretical trip time: 3.2 h |            |        |
| Actual trip time: 3 h   |            |        | Itinerary The road between Jarablus and Afrin |            |        | Total number of samples: 180 |            |        |
| Point                   | Speed (Km) | Errors | Point                                         | Speed (Km) | Errors | Point                        | Speed (Km) | Errors |
| 1                       | 0          | 0      | 61                                            | 60         | 0      | 121                          | 60         | 0      |
| 2                       | 40         | 0      | 62                                            | 60         | 0      | 122                          | 60         | 0      |
| 3                       | 60         | 0      | 63                                            | 60         | 0      | 123                          | 60         | 0      |
| 4                       | 60         | 0      | 64                                            | 60         | 0      | 124                          | 60         | 0      |
| 5                       | 60         | 0      | 65                                            | 60         | 0      | 125                          | 60         | 0      |
| 6                       | 60         | 0      | 66                                            | 60         | 0      | 126                          | 60         | 0      |
| 7                       | 60         | 0      | 67                                            | 60         | 0      | 127                          | 60         | 0      |
| 8                       | 60         | 0      | 68                                            | 60         | 0      | 128                          | 60         | 0      |
| 9                       | 60         | 0      | 69                                            | 60         | 0      | 129                          | 60         | 0      |
| 10                      | 60         | 0      | 70                                            | 60         | 0      | 130                          | 60         | 0      |
| 11                      | 60         | 0      | 71                                            | 60         | 0      | 131                          | 60         | 0      |
| 12                      | 60         | 0      | 72                                            | 60         | 0      | 132                          | 60         | 0      |
| 13                      | 60         | 0      | 73                                            | 60         | 0      | 133                          | 60         | 0      |
| 14                      | 60         | 0      | 74                                            | 60         | 0      | 134                          | 60         | 0      |
| 15                      | 60         | 0      | 75                                            | 60         | 0      | 135                          | 60         | 0      |
| 16                      | 60         | 0      | 76                                            | 60         | 0      | 136                          | 60         | 0      |
| 17                      | 60         | 0      | 77                                            | 60         | 0      | 137                          | 60         | 0      |
| 18                      | 60         | 0      | 78                                            | 60         | 0      | 138                          | 60         | 0      |
| 19                      | 60         | 0      | 79                                            | 60         | 0      | 139                          | 60         | 0      |
| 20                      | 60         | 0      | 80                                            | 60         | 0      | 140                          | 60         | 0      |
| 21                      | 60         | 0      | 81                                            | 60         | 0      | 141                          | 60         | 0      |
| 22                      | 60         | 0      | 82                                            | 60         | 0      | 142                          | 60         | 0      |
| 23                      | 60         | 0      | 83                                            | 60         | 0      | 143                          | 60         | 0      |
| 24                      | 60         | 0      | 84                                            | 60         | 0      | 144                          | 60         | 0      |

|    |    |   |     |    |   |     |    |   |
|----|----|---|-----|----|---|-----|----|---|
| 25 | 60 | 0 | 85  | 60 | 0 | 145 | 60 | 0 |
| 26 | 60 | 0 | 86  | 60 | 0 | 146 | 60 | 0 |
| 27 | 60 | 0 | 87  | 60 | 0 | 147 | 60 | 0 |
| 28 | 60 | 0 | 88  | 60 | 0 | 148 | 60 | 0 |
| 29 | 60 | 0 | 89  | 60 | 0 | 149 | 60 | 0 |
| 30 | 60 | 0 | 90  | 60 | 0 | 150 | 60 | 0 |
| 31 | 60 | 0 | 91  | 60 | 0 | 151 | 60 | 0 |
| 32 | 60 | 0 | 92  | 60 | 0 | 152 | 60 | 0 |
| 33 | 60 | 0 | 93  | 60 | 0 | 153 | 60 | 0 |
| 34 | 60 | 0 | 94  | 60 | 0 | 154 | 60 | 0 |
| 35 | 60 | 0 | 95  | 60 | 0 | 155 | 60 | 0 |
| 36 | 60 | 0 | 96  | 60 | 0 | 156 | 60 | 0 |
| 37 | 60 | 0 | 97  | 60 | 0 | 157 | 60 | 0 |
| 38 | 60 | 0 | 98  | 60 | 0 | 158 | 60 | 0 |
| 39 | 60 | 0 | 99  | 80 | 0 | 159 | 60 | 0 |
| 40 | 60 | 0 | 100 | 80 | 0 | 160 | 60 | 0 |
| 41 | 60 | 0 | 101 | 80 | 0 | 161 | 60 | 0 |
| 42 | 80 | 0 | 102 | 80 | 0 | 162 | 80 | 0 |
| 43 | 80 | 0 | 103 | 80 | 0 | 163 | 80 | 0 |
| 44 | 80 | 0 | 104 | 80 | 0 | 164 | 80 | 0 |
| 45 | 80 | 0 | 105 | 80 | 0 | 165 | 80 | 0 |
| 46 | 80 | 0 | 106 | 80 | 0 | 166 | 80 | 0 |
| 47 | 80 | 0 | 107 | 80 | 0 | 167 | 80 | 0 |
| 48 | 80 | 0 | 108 | 80 | 0 | 168 | 80 | 0 |
| 49 | 80 | 0 | 109 | 80 | 0 | 169 | 80 | 0 |
| 50 | 80 | 0 | 110 | 80 | 0 | 170 | 80 | 0 |
| 51 | 80 | 0 | 111 | 80 | 0 | 171 | 80 | 0 |
| 52 | 80 | 0 | 112 | 80 | 0 | 172 | 80 | 0 |
| 53 | 80 | 0 | 113 | 80 | 0 | 173 | 80 | 0 |
| 54 | 80 | 0 | 114 | 80 | 2 | 174 | 80 | 0 |
| 55 | 80 | 0 | 115 | 80 | 0 | 175 | 80 | 0 |

|    |    |   |     |    |   |     |    |   |
|----|----|---|-----|----|---|-----|----|---|
| 56 | 80 | 0 | 116 | 80 | 0 | 176 | 80 | 0 |
| 57 | 80 | 0 | 117 | 80 | 0 | 177 | 80 | 0 |
| 58 | 80 | 0 | 118 | 80 | 0 | 178 | 80 | 0 |
| 59 | 60 | 0 | 119 | 80 | 0 | 179 | 80 | 0 |
| 60 | 60 | 1 | 120 | 80 | 0 | 180 | 80 | 0 |

**Table B1.9** Off road data transmission tests

|                          |            |        |                                              |            |        |                               |            |        |
|--------------------------|------------|--------|----------------------------------------------|------------|--------|-------------------------------|------------|--------|
| Time: 6:00 to 7:00 a.m.  |            |        | Distance: 43.8 km                            |            |        | Theoretical trip time: 0.54 h |            |        |
| Actual trip time: 1 h    |            |        | Itinerary The road between Sarmada and Idlib |            |        | Total number of samples: 30   |            |        |
| Point                    | Speed (Km) | Errors | Point                                        | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                        | 0          | 0      | 11                                           | 80         | 0      | 21                            | 80         | 0      |
| 2                        | 40         | 0      | 12                                           | 80         | 0      | 22                            | 80         | 0      |
| 3                        | 60         | 0      | 13                                           | 80         | 0      | 23                            | 80         | 0      |
| 4                        | 80         | 0      | 14                                           | 80         | 0      | 24                            | 80         | 0      |
| 5                        | 80         | 0      | 15                                           | 80         | 0      | 25                            | 80         | 0      |
| 6                        | 80         | 0      | 16                                           | 80         | 0      | 26                            | 80         | 0      |
| 7                        | 80         | 0      | 17                                           | 80         | 0      | 27                            | 80         | 0      |
| 8                        | 80         | 0      | 18                                           | 80         | 0      | 28                            | 80         | 0      |
| 9                        | 80         | 0      | 19                                           | 80         | 0      | 29                            | 80         | 0      |
| 10                       | 80         | 0      | 20                                           | 80         | 0      | 30                            | 80         | 0      |
| Time: 12:00 to 1:00 a.m. |            |        | Distance: 43.8 km                            |            |        | Theoretical trip time: 0.54 h |            |        |
| Actual trip time: 1 h    |            |        | Itinerary The road between Sarmada and Idlib |            |        | Total number of samples: 30   |            |        |
| Point                    | Speed (Km) | Errors | Point                                        | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                        | 0          | 0      | 11                                           | 80         | 0      | 21                            | 80         | 0      |
| 2                        | 40         | 0      | 12                                           | 80         | 0      | 22                            | 80         | 0      |
| 3                        | 60         | 0      | 13                                           | 80         | 0      | 23                            | 80         | 0      |
| 4                        | 80         | 0      | 14                                           | 80         | 0      | 24                            | 80         | 0      |

|    |    |   |    |    |   |    |    |   |
|----|----|---|----|----|---|----|----|---|
| 5  | 80 | 0 | 15 | 80 | 0 | 25 | 80 | 0 |
| 6  | 80 | 0 | 16 | 80 | 0 | 26 | 80 | 0 |
| 7  | 80 | 0 | 17 | 80 | 0 | 27 | 80 | 0 |
| 8  | 80 | 0 | 18 | 80 | 0 | 28 | 80 | 0 |
| 9  | 80 | 0 | 19 | 80 | 0 | 29 | 80 | 0 |
| 10 | 80 | 0 | 20 | 80 | 0 | 30 | 80 | 0 |

**Table B1.10** Off road data transmission tests

| Time: 6:00 to 7:00 a.m. |            |        | Distance: 43.8 km                            |            |        | Theoretical trip time: 0.54 h |            |        |
|-------------------------|------------|--------|----------------------------------------------|------------|--------|-------------------------------|------------|--------|
| Actual trip time: 1 h   |            |        | Itinerary The road between Sarmada and Idlib |            |        | Total number of samples: 30   |            |        |
| Point                   | Speed (Km) | Errors | Point                                        | Speed (Km) | Errors | Point                         | Speed (Km) | Errors |
| 1                       | 0          | 0      | 11                                           | 80         | 0      | 21                            | 80         | 0      |
| 2                       | 40         | 0      | 12                                           | 80         | 0      | 22                            | 80         | 0      |
| 3                       | 60         | 0      | 13                                           | 80         | 0      | 23                            | 80         | 0      |
| 4                       | 80         | 0      | 14                                           | 80         | 0      | 24                            | 80         | 0      |
| 5                       | 80         | 0      | 15                                           | 80         | 0      | 25                            | 80         | 0      |
| 6                       | 80         | 0      | 16                                           | 80         | 0      | 26                            | 80         | 0      |
| 7                       | 80         | 0      | 17                                           | 80         | 0      | 27                            | 80         | 0      |
| 8                       | 80         | 0      | 18                                           | 80         | 0      | 28                            | 80         | 0      |
| 9                       | 80         | 0      | 19                                           | 80         | 0      | 29                            | 80         | 0      |
| 10                      | 80         | 0      | 20                                           | 80         | 0      | 30                            | 80         | 0      |

## **CIRRICULUM VITAE (CV)**

### **Work Experience:**

Communication engineer in CONVEVO (Security solutions) I was responsible to provide technical expertise, solutions revolving around various modes of communication and information transfer, including:

Wireless telephony services - Radio and satellite communications Internet and broadband technologies. - security cameras and Walkie-talkie (Hetra) (2014 – 2015).

Communication engineer in Sabaa (Construction and Related Trades) I was responsible for the design, development and of communications equipment / systems. (2013 – 2014)

### **Academic qualification & Education:**

Bachelor's degree, Communication, Faculty of Engineering graduation project, (Multiple methods accessible from the second generation to fourth generation)

Sabaa, University Sana'a, Yemen (2008 – 2012)

Cisco Systems (CCNA)

General Telecom Institute, Sana'a, Yemen (2011 – 2012)

Cisco Systems (CCNB voice) (VOIP)

General Telecom Institute, Sana'a, Yemen (2012 – 2013)

TOEFL

Exceed Language Center (2014)

High school (2007-2008)

School of vigilance Sana'a University – Yemen.

**Training Courses:**

- 1- Cisco Systems (CCNA) General Telecom Institute Yemen 1250 hours
- 2- Cisco Systems (CCNB voice) General Telecom Institute Yemen 1250 hours.
- 3- GSM (Global System for Mobile Communications) MTN Group Yemen 120 hours.
- 4- GSM frequency bands, Sabafon Yemen 120 hours.
- 5- (CDMA) Code division multiple access. yemen mobile Yemen 140 hours.
- 6- IP-sentral. General Telecom Institute Yemen 240 hours.
- 7- 3CX Telephone System General Telecom Institute Yemen 240 hours.
- 8- Telephone switchboard System General Telecom Institute Yemen 240 hours.
- 9- ICDL, General Telecom Institute Yemen 480 hours

**Academic Experiences. Skills & Proficiencies:**

- Programming language include extensive use of, MAT Lab, VISUAL BASIC, C++.
- linux system.

- Computer skills include extensive use of MS Word, WORKBNSH, Cisco, Packet Tracer.

- 1-Data center General Telecom Institute Yemen 50 hours.
- 2-Wireless network General Telecom Institute Yemen 50 hours.
- 3- real practice (WAN) General Telecom Institute Yemen 50 hours.
- 4-GSM, General Telecom Institute Yemen 40 hours.
- 5-GPRS General Telecom Institute Yemen 40 hours.
- 6-CDMA General Telecom Institute Yemen 240 hours.
- 7- UMTS General Telecom Institute Yemen 40 hours.
- 8- LTE General Telecom Institute Yemen 40 hours.

9- Wi-max and Wi-fi General Telecom Institute Yemen 100 hours.

**More Information:**

- Very Familiar with Microsoft Windows Systems.
- Good capacity to work under pressure
- Can Use Office Equipment Effectively
- Excellent capacity to work in team.
- Excellent written and oral communication skills.
- Knowledgeable in OSHA regulations, fire safety, CPR training. Provide forklift training and instruction on related safety issues.
- Looking forward to learn more and more.