ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
MASTER'S THESIS

STUDY OF RADIO-BASED NETWORKING APPLICATION TO AAWSA WATER METER READING

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ABBREVIATIONS

µP -	Microprocessor
AAWSA -	Addis Ababa Water and Sewerage Authority
AC -	Alternate Current
AEC -	Advanced Encryption Scheme
AM -	Amplitude Modulation
AWGN-	Additive White Gaussian Noise
BBR-	‘Bole Bulbula’ Reservoir
BER -	Bite Error Rate
CCIR-	Consultative committee for International Radio communication
CRC-	Cyclic Redundancy Code
CT-	Collection Tank
dB -	Decibel
dBi-	Decibels Relative to an isotropic Radiation
dBm-	Decibels Relative to 1 Milli-watt
dBw-	Decibels Relative to 1 watt
D/A-	Digital to Analog
DC -	Direct Current
DES -	Data Encryption Standard
ETA -	Ethiopian Telecommunication Agency
FCC -	Federal Communications Commission
FM -	Frequency Modulation
GHz-	Giga Hertz
GW-	Ground Water
GMSK-	Gaussian Filtered Minimum Shift Keying
ISI-	Inter Symbol Interference
ISM –	Industrial, Scientific, and Medical
LAN –	Local Area Network
LCD -	Liquid Cristile Dyspay
LOS -	Line of Sight
MAN –	Metropolitan Area Network

MKBH-	‘Mekanissa’ Borehole
MKR-	‘Mekanissa’ Reservoir
NBS -	National Bureau of Standards
NF -	Noise Figure
NIC -	Network Interface Card
NIST -	National Institute of Standards and Technology
Non LOS -	Non Line Of Sight
O & M -	Operation and Maintenance
OFDM-	Orthogonal Frequency Division Multiplex
PD -	Positive Displacement
PLC-	Programmable Logic Controller
RF -	Radio Frequency
RTU -	Remote Terminal Unit
SCADA-	Supervisory Control and Data Acquisition
SNR-	Signal to Noise Ratio
SSB -	Single Side Band Modulation
ST-	Surge Tank
Tx/Rx-	Transmit/Receive
UFW –	Unaccounted For Water
UHF -	Ultra high Frequency
US -	United State
VHF -	Very High Frequency
WAN –	Wide Area Network
WLAN -	Wireless Local Area Network
WTP-	Water Treatment Plant

ABSTRACT

The study has been conducted in Addis Ababa Water and Sewerage Authority in the title of 'Study of Radio Based Networking Application to AAWSA Water Meter Reading'.

Radio based networking is currently the most common method for providing connectivity within a metropolitan area, like Addis Ababa. Radio based networking utilizes radio waves as a transport for the transmission of information, in the case of this thesis water meter readings will be the information to be transmitted.

Water meter reading using radio link could be defined as the sensing and measuring of information, water consumption in cubic meter, at some remote location and then transmitting that information to a central or host location through radio wave. At a central or host location water meter reading can be processed and used for various purposes.

The study will show how radio based networking system could be implemented on water meter reading. Besides, the study will include identification of basic components and tools of radio based water metering, and specific requirements for implementing in AAWSA.

The major contribution of this research is the development of a systematic implementation model of radio based networking system as applied to water meter reading at main potable water sources of AAWSA.

Finally, findings and recommendations believed to be useful are forwarded.

CHAPTER - I

GENERAL INTRODUCTION

1.1 Rational of the Thesis

The thesis addresses the implementation of radio - based networking concepts to the water supply sector with the focus on Addis Ababa Water and Sewerage Authority (AAWSA) water meter reading.

Over the last thirty years, researchers and companies have been busy developing protocols and systems that provide wireless connectivity for Local Area Networks (LANs), Metropolitan Area Networks (MANs), and Wide Area Networks (WANs). Experiments showed that lower frequencies, such as radio waves and infrared lights, could be sent through the air with moderate amounts of transmit power and easy-to-manufacture antennas. As a result, companies begin building radio transmitters and receivers, making public and private radio communications, television, and wireless networking possible. The basic ideas behind radio-based networking are having benefits of ease of installation in difficult-to-wire areas, reduced installation time, increased reliability and long term cost saving.

The primary objective of radio-based networking is to provide connectivity within a Metropolitan area, where

- There is problem of getting right -of- way for cable installation
- The cities are developing, like Addis Ababa, cables could be damaged and cause un-reliable communication.

AAWSA has supervisory, control and data acquisition (SCADA) system at 'Akaki ' well field. This SCADA system is designed to enable the pump operators to monitor and control the status of the entire pumping system from the control room at collection tank (CT).

The communication network for the ‘Akaki’ well field is a data network, which utilizes a master radio modem station located at CT and a slave radio modem station located at each borehole. The communication features are [17]:

- Scanning Master/Slave protocol
- Message include 16 Bit CRC checks on each form of data
- Update of 29 boreholes achieved every 15 seconds or better
- Utilizes frequency shift keying (FSK) modulation of a carrier frequency 25 KHz.
- Communication speed is 1200 Baud

The well field master radio modem station at CT comprises of a controller board and UHF 1 watt Tx/Rx CMS radio set for a frequency of 464.600 MHz. A UHF end fed dipole aerial is used. At slave station, at each borehole, the same radio modem is used at the same frequency as master station. A further radio link is there between CT and boosting stations at GW1, GW2, GW3 and GW4, each having different frequencies. By doing so AAWSA was able to monitor Akaki well field system, which includes boreholes at Akaki well field and boosting stations at CT , GW1, GW2 and GW3 (near ‘Gotera’ confusion square) from one location, CT pumping house at Akaki. This system is working since 2003 with out any problem.

Having such experience in using radio network for pump monitoring and control in the authority under consideration besides radio based networking advantages for metropolitan area seen above, there is no good reason not to use radio network to read remote water meters mounted at water sources, distribution main and bulk consumers’ compound from one central location. This is the rational to think of this thesis.

1.2 Problem Statement

Traditionally, customer utility meters are read and transfer to the billing system by sending meter readers to each customer house every month and manually prepare meter reading sheet. Due to so many reasons meters may not read on similar day and time every months, and some times reading may be done by approximation instead of actual reading just due to non-responsible meter readers, which primarily causes customer dissatisfaction and utility organizations to suffer with uncollected supply charge and customer compliant.

The water metering system of the authority in focus (AAWSA) has been suffering from a lot of challenges. In general the problems are:

- High errors and reworks
- High operation cost
- High inventory costs
- High uncollected bills
- High Customer dissatisfaction, are few due mentioned.

To over come these problems automatic water meter reading using radio wave will be studied under this thesis.

1.3 Outline of the Thesis

A water meter is used to measure water usage. Water meters are normally used at water sources, every residence and commercial building to determine potable water produced and distributed. Water meters typically measure and display total water flow in cubic meters or other equivalent units on a mechanical or electronic register fitted on them.

In AAWSA water meter readings are taken and transferred to billing system by sending meter readers to water source sites every day and to each customer house every month and manually prepare meter reading sheets. This method has a lot of problems to get correct reading on time; some of the challenges are mentioned under section 1.2.

Water meter reading using radio wave offers several advantages over other water meter reading systems. Some of them are :

- Fast response time
- Flexible water reading gathering system
- Operate for many years with very little maintenance

While it seems that implementing radio-based networking for meter reading is costly and impractical to adapt for all AAWSA's customer, it is possible to implement it at first at water sources, distribution system, on bulk consumers water meters like universities, industries, hotels, apartments, etc..., and implement on other non-domestic consumers gradually. Therefore, the researcher believes that radio - based networking implementation in AAWSA water meter reading would lead the authority to satisfy its customers and become profitable.

1.4 Objectives

The objective of this thesis is to justify the implementation of radio-based networking system on water meter reading for Addis Ababa Water and Sewerage Authority (AAWSA). Other things will include analysis of radio-based networking system from its conception to its success today, basic components and tools of radio based wireless networking system, and specific requirements for implementing radio based wireless networking on water meter reading in authority in focus.

General Objective is to:-

- Justify the implementation of radio based wireless networking system for water meter reading in Addis Ababa Water and Sewerage Authority.

Specific Objectives are to:-

- Systematically demonstrate how radio based networking system philosophy is used for reading customer water meters.
- Study the benefits gained through the implementation of radio based networking system on water meter reading.
- Know the implementation requirements of radio-based networking.
- Develop the implementation model of radio based networking as applied to water metering for the Authority in focus.

1.5 Methods

The methodologies to be used to achieve the above listed objectives are :

- **Literature Survey on the Subject Matter** : Books, Journals, and Websites will be sources on the subject matter.
- **Consultations**: Consultations will be held with representatives of AAWSA (General Manager, technical deputy general manager, Branch Managers, Meter readers, Data in coders) and other stakeholders.
- **Data Collection**: data will be collected from AAWSA through different methods like reviewing various reports, structured questionnaire, and observations. Electronic retrieval of the relevant sources will be used from the AAWSA.
- **System Analysis**: the data collected will be systematically and logically analyzed to reach a better end result and draw conclusions and recommendations.
- **Model Development**: The implementation model of Radio based wireless network water metering will be developed.

1.6 Intended Application

The major contribution of this research is the development of implementation model of radio based networking system as applied to water meter reading at potable water sources (Legedadi WTP, Gefersa WTP and Akaki well field) of AAWSA. Previously there was no effort to implement this system.

From the result of this thesis primarily AAWSA as organization and then AAWSA's customers will be beneficiaries.

Benefits of AAWSA :

- Improvement of revenue collection
- Reduces unaccounted for water and reduces unbilled legal consumption.
- Reduces meter reading errors and reworks
- Reduces customer complaints which implies customer dissatisfaction, and
- Reduces operation and maintenance cost

Benefits of AAWSA's Customers:

- Not being asked for incorrect water bills : since non responsible water meter readers could transfer reading sheet to the billing system with out going each customer houses every month.
- Being satisfied with uniform billing : since water meter readers may not visit each customer house at the same day and time every month, customers can’t budget their monthly fee based on last month bill.

CHAPTER - II

BACKGROUND AND LITERATURE REVIEW

2.1 Introduction to Wireless Networking

Traditionally, companies utilize physical media - such as buried wire or optical fiber, or leased telephone line - to provide necessary connections. These forms of media, however, might require a great deal of installation time and can result in expensive monthly service fees. A cable installation between sites several thousand meters apart can cost thousands of dollars or more, and leasing fees can easily be hundreds of dollars per month. In some cases, leased communication lines might not even be available.

Radio based networking, as one of the wireless networking, avoids digging trenches and routing cabling around rivers and installation of wiring along the roadway. A wireless networking can provide communications links avoiding the costly installation of cabling or leased fees and the down time associated with system failures.

Radio based networking utilizes radio waves as a transport for the transmission of data. Here after radio based network and wireless network are used interchangeably.

A radio-based networking is currently the most common method for providing connectivity within a Metropolitan area. These products have highly directional antenna to focus the signal power in a narrow beam, maximizing the transmission distance. As a result, spread spectrum products operating under one watt of power can reach single transmission distance of 30 miles [16]. The actual transmission distance of a particular product, though, is dependent on environmental conditions. Rain, for example, causes resistance to the propagation of radio signals, decreasing the effective range. Fig. 2.1 shows the local verses remote bridge, where remote bridge to access remote server is through radio link.

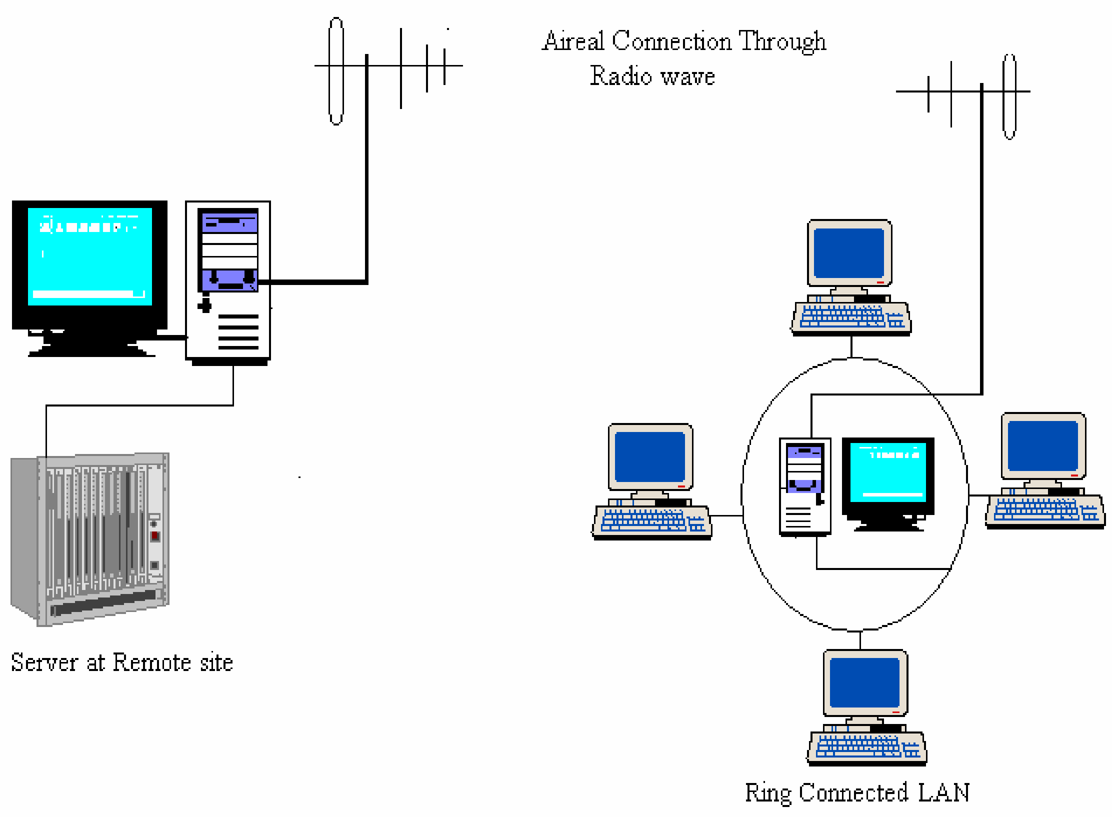


Fig. 2.1 Local verses remote bridge using radio link

2.1.1 Benefits of Wireless Networks [14]

The following benefits can be achieved by implementing wireless networks:

i. Ease of installation in difficult - to - wire area
ii. Reduced installation time
iii. Increased reliability
iv. Mobility

i. Ease of Installation in Difficult to Wire Area

The implementation of wireless networks offers many tangible cost savings when performing installations in difficult -to-wire areas. If rivers, freeways, or other obstacles separate buildings we want to connect, a wireless network solution may be much more economical than installing physical cable or leasing communications circuits. Some municipalities, for example, may restrict right-of-way within the cities may also block the digging of trenches in the ground to lay optical fibre for the interconnection of networked sites.

ii. Reduced Installation Time

We might need weeks or possibly months to receive right-of-way approvals and dig through ground and asphalt to install cables or optical fibres. The deployment of wireless network greatly reduced the need for cable installation, making the network available for use much sooner. Thus, many countries lacking a network infrastructure have turned to wireless networking as a method of providing connectivity among computers without the expense and time associated with installing physical media.

iii. Increased Reliability

A problem inherent to wired networks is the downtime due to cable faults. Moisture erodes metallic conductors. These imperfect cable splices can cause signal reflections that result in unexplainable errors. The accidental cutting of cables can also bring a network down quickly. Water intrusion can also damage communications lines during storms. These problems interfere with the user’s ability to utilize network resources, causing havoc for network managers. The advantage of wireless networking, then, is experiencing fewer problems because less cable is used.

iV. Mobility

User mobility indicates constant physical movement of the person and their network appliance. Wireless networking offers mobility to its users much like the wireless phone, providing a constant connection to information on the network. This connection can be extremely useful if you are at a customer's site discussing a new product, delivering emergency care to a crash victim, or in a hotel room sending and receiving e-mail.

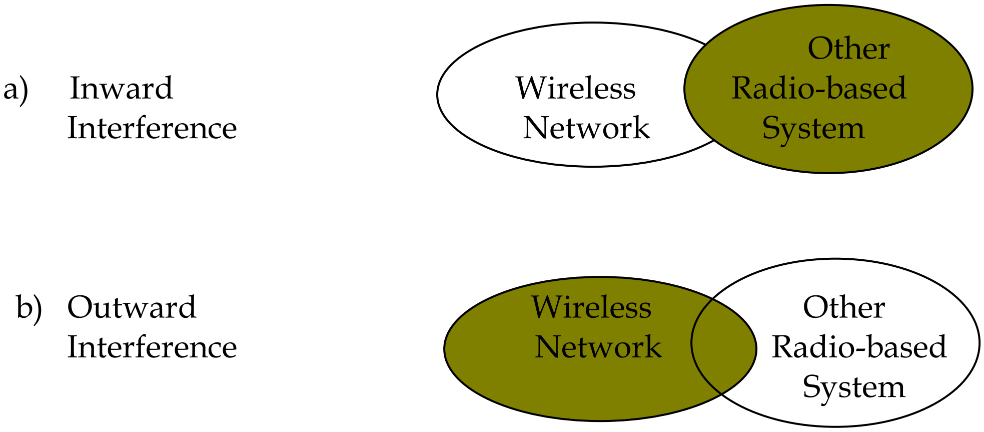
2.1.2 Wireless Network Concerns [14]

The benefits of a wireless network are certainly welcomed by companies and organizations. Network managers and engineers should be aware, however, of the following concerns that surround the implementation and use of wireless networking:

i. Radio signal interference
ii. Network security
iii. Installation issues

i. Radio Signal interference

The purpose of radio-based networks is to transmit and receive signals efficiently over airwaves. This process, though, makes these systems exposed to atmospheric noise and transmissions from other systems. In addition, these wireless networks could interfere with other radio wave equipment. As shown in figure 2.2 [14] interference may be inward or outward.


a) Inward Interference

b) Outward Interference

Fig. 2.2 a) Inward Interference and b) Out Interference

a) Inward Interference

Most of us have experienced radio signal interference while talking on a wireless telephone, watching television, or listening to a radio. Someone close by might be communicating with another person via a short-wave radio system, causing harmonic frequencies that you can hear while listening to your favourite radio station. These types of interference might also disturb radio-based wireless networks in the form of inward interference.

The products using the ISM bands incorporate spread spectrum modulation that limits the amount of damage an interfering signal causes. The spread spectrum signal covers a wide amount of bandwidth, and typical narrow bandwidth interference only affects a small part of the information signal, resulting in few or no errors. Thus, spread spectrum-type products are highly resistant to interference. Narrowband interference with signal-to-interference ratios of less than 10 dB does not usually affect a spread spectrum transmission. Wideband interference, however, can have damaging effects on any type of radio transmission.

b) Outward Interference

Inward interference is only half of the problem. The other half of the issue, outward interference, occurs when a wireless network's signal disrupts other systems, such as adjacent wireless LANs, navigation equipment on aircraft, and so on. This disruption results in the loss of some or all of the system's functionality. Interference is uncommon with ISM band products because they operate on such little power.

The transmitting components must be very close to each other and operating in the same bandwidth to experience inward or outward interference.

c) Techniques for Reducing Interference

When dealing with interference, we have to coordinate the operation of radio based wireless network products with frequency management organisation, such as

Ethiopian Telecommunication Agency (ETA). This will avoid potential interference problems. In fact, the coordination with frequency management officials is mandatory before operating radio based wireless devices of any kind.

Another way, especially if no frequency management organization exists, is to run some test to determine the propagation patterns within and around our building. These test let we know if existing systems may interfere with, and thus block and cause delay to our network.

ii. Network Security

Network security refers to the protection of information and resources from loss, corruption, and improper use. Are wireless network secure? Among business considering the implementation of a wireless system, this is a common and very important question. To answer this question, you must consider the functionality of a wireless network performs. A wireless network provides a bit pipe, consisting of a medium, synchronization, and error control that supports the flow of data bits from one point to another. This setup corresponds to the lowest levels of the network architecture and does not include other functions such as end-to-end connection establishment or login service. Therefore, the only security issue relevant to wireless networks is those dealing with these lower architecture layers, such as data privacy.

Security Threats

The main security issue with wireless networks, especially radio networks, is that they propagate data over an area that may exceed the limits of the area the organization physically controls. For instance, radio waves easily penetrate building walls and are receivable from the facility’s parking lot and possibly a few blocks away. Someone can passively retrieve your company’s sensitive information by using the same wireless NIC from this distance without being noticed by network security personnel. This problem also exists with wired Ethernet networks, but to a lesser degree. Current flow through the wires emits electromagnetic waves that someone could receive by using sensitive listening equipment. They must be very close to the cable, however, meaning they must first break through physical security.

Another security problem is the potential for electronic sabotage, in which someone maliciously jams the radio-based network and keeps you from using the network. Remember, wireless networks utilize a carrier sense protocol to share the use of the common medium. If one station is transmitting, all others must wait. Someone can easily jam our network by using a wireless product of the same manufacture that we have within our network and setting up a station to continually resend packets. These transmissions block all stations in that area from transmitting, which is most serious if our company stands to experience a great loss if the network becomes inoperable.

Security safeguards

Wireless network vendors solve most security problems by restricting access to the data. Most products require you to establish a network access code and set the code within each workstation. A wireless station will not process the data unless its code is set to the same number as the network. Proxim's RangeLAN, for example, can utilize over two billion possible network IDs. If the code is kept secret, it becomes much more difficult for someone to receive and process our data. Some vendors also offer encryption as an option. Lucent's Wave LAN, for example, has two options for encryption. One version encrypts according to the Data Encryption Standard (DES) as defined by the U.S. Department of Commerce, National Institute of Standards and Technology (NIST), formerly called the National Bureau of Standards (NBS). The other version implements a proprietary method called Advanced Encryption Scheme (AES).

The DES and AES algorithms use a 16-digit hexadecimal key for encryption, as shown in figure 2.3 [14]. The key is loaded into the security chip when the adapter is configured at installation. When a message is received or sent, the security chip uses the key to encrypt or decrypt the message. Only those workstations in the network with the same security chip and key will be able to understand the messages.

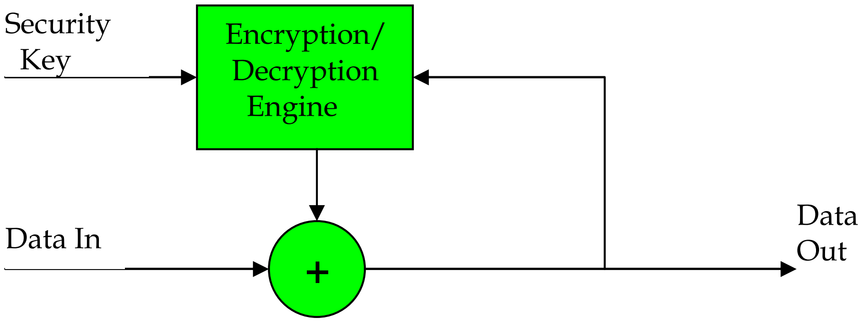


Fig. 2.3 The data encryption process

Other users of Wave LAN who do not have the key will be unable to decrypt any messages. Both DES and AES perform the encryption in one continuous stream of bits that pass through the system's modulator without affecting performance.

iii. Installation Issues

With wired networks, planning the installation of cabling is fairly straightforward. You can survey the site and look for routes where installers can run the cable. You can measure the distances and quickly determine whether cable runs are possible. If some users are too far away from the network, you can design a remote net working solution or extend the length of the cable by using repeaters. Once the design is complete, installers can run the cables, and the cable plant will most likely support the transmission of data as planned.

A radio-based wireless network installation is not as predictable. It is difficult to design the wireless system by merely inspecting the facility. Predicting the way in which the contour of the building will affect the propagation of radio waves is difficult. To avoid installation problems, an organization should perform propagation model study and propagation tests to assess the coverage of the network.

2.2 Basics of Water Meter Automatic Reading Using Radio Based Network

A water meter is used to measure water usage. Water meters are normally used at every residence and commercial building in a water supply system. Water meters can also be used at the water source or throughout a water system to determine flow through that portion of the system. Water meters typically measure and display total usage in US gallons, cubic feet, or cubic meters on a mechanical or electronic register.

There are several types of water meters in common use. Selection is based on different flow measurement methods, the type of end user, the required flow rates, and accuracy requirements.

There are three common methods of flow measurement in use [5]:

i. Displacement
ii. Velocity, and
iii. Electromagnetic

i. Displacement Water Meters

This type of water meter is most often used in residential and small commercial applications. Displacement meters are commonly referred to as Positive Displacement, or "PD" meters. Two common methods of positive displacement measuring are Oscillating Piston meters and Nutating Disk meters. Either method relies on the water to physically displace the moving measuring element in direct relation to the amount of water that passes through the meter. The piston or disk moves a magnet that drives the register.

PD meters are generally very accurate at low to moderate flow rates typical of residential and small commercial users, and are common in sizes from 5/8" to 2". Because displacement meters rely on all flowing through the meter to "push" the measuring element, they generally are not practical in large commercial applications requiring high flow rates or low pressure loss. PD meters normally have a built in strainer to protect the measuring element from rocks or other debris that could stop or break the measuring element. PD meters normally have bronze, brass or plastic bodies with internal measuring chambers made from molded plastics and stainless steel.

ii. Velocity Water Meters

A velocity type meter measures the velocity of flow through a meter of a known internal capacity. The speed of the flow can then be converted into volume of flow for usage. There are a number of types of meters that measure water flow velocity to determine totalized usage. They include jet meters (sinlge-jet and mulit-jet), turbine meters, propeller meters, and mag meters. Most velocity based meters have an adjustment vane for calibration of the meter to required accuracy standards.

iii. Electromagnetic Meters

Magnetic flow meters, commonly referred to as "mag meters" are technically a velocity type water meter, except that they use electromagnetic properties to determine the water flow velocity rather than mechanical means which jet and turbine meters use. Mag meters use the physics principal of Faradays laws for measurement, and require AC or DC electricity to operate the electromagnets. Since mag meters have no mechanical measuring element, they normally have the advantage of being able to measure flow in either direction. Mag meters can also be useful for measuring untreated water, raw (untreated/unfiltered) water, and wastewater, since there is no mechanical measuring element to get clogged or damaged by debris flowing through the meter. Strainers are not required with mag meters, since there is no measuring element in the stream of flow that could be damaged. Stray electrical energy flowing through the flow tube can cause inaccurate readings, therefore most mag meters are installed with either grounding rings or grounding electrodes to insure this bypasses the electrodes inside the flow tube which are used to measure the flow.

2.2.1 Water Meter Registers

There are several types of registers on water meters. A standard register normally has a dial similar to a clock with gradations around the perimeter to indicate water usage measured by the meter, as well as a set of odometer wheels similar to that in a car. Modern registers are normally driven by a magnetic coupling between a magent in the measuring chamber attached to the measuring element, and another attached to the bottom of the register. Gears in the register convert the motion of the measuring element to the proper usage increment for display on the sweep hand and the odometer. Many registers also have a leak detector. This is a small visible disk or hand that is geared closer to the rotation speed of the drive magnet so that very small flows that would be visually undetectable on the regular sweep hand can be seen.

With automatic meter reading, manufacturers have developed pulse or encoder registers to produce electronic output for radio transmitters, reading storage devices, and data logging devices. Pulse meters send a digital or analog electronic pulse to a recording device. Encoder registers have an electronic means for an external device to interrogate the register for either the position of the odometer wheels or a stored electronic reading.

There are also some specialized types of registers such as LCD display instead of mechanical odometers, and registers to output data or pulses to a variety of recording and controller devices refer figure 2.4 [24]. For industrial applications, output is often 4 - 20mA analog, for the recording or control of different flow rates in addition to totalization.

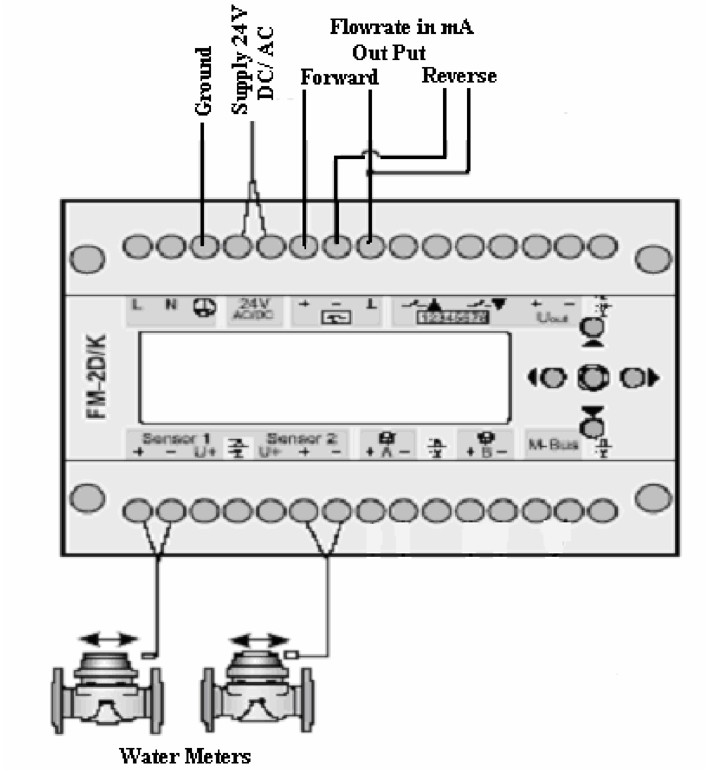


Fig. 2.4 FM-2D/K (*from SeNSUS Metering Systems*) µP- controlled flow converter.

2.2.2 Water Meter Reading Using Radio Link

Water meter reading using radio link could be defined as the sensing and measuring of information, water consumption in M^3, at some remote location and then transmitting that information to a central or host location through radio wave. There, it can be processed and used to prepare customer bills at the central or host location. Various mediums or methods of transmitting data from one site to another have been used. Water meter reading using radio waves or wireless offers several distinct advantages over other water meter reading transmission methods, like using telephone line. Some of these advantages are [23] :

- No transmission lines to be cut or broken.
- Faster response time
- Lower cost compared to leased lines
- Ease of use in remote areas where it is not practical or possible to use wire or coaxial cables

- Easy relocation
- Functional over a wide range of operating conditions

Properly designed radio links can provide low cost, effective and flexible data gathering systems that operate for many years with very little maintenance.

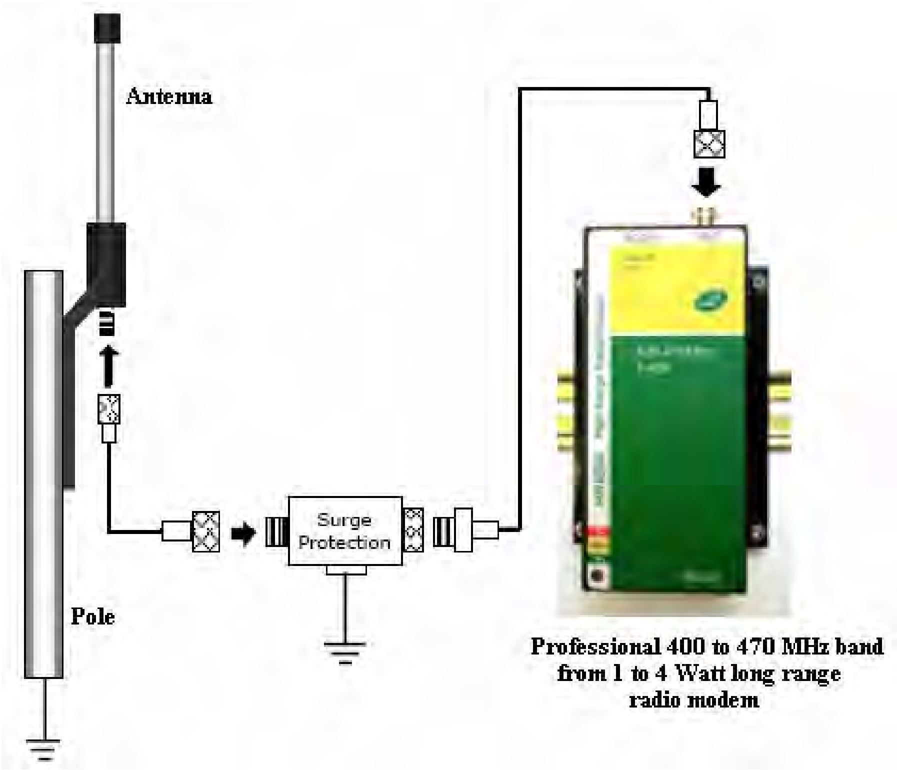


Fig. 2.5 [22] Long range HR1200 radio modem (*from ATIM SARL radio communication*)

In radio based water meter reading process water meters at the remote site are the data source. The output of the water meter(s), 4 – 20 mA analogue signals, is converted to digital data and processed by RTU (Remote Terminal Unit). The RTU is interfaced to radio modem device that converts the digital data into a form suitable for radio transmission over the air. The radio transmitter then transmits the signal to the host site radio receiver. Now, at the receiver, the process is reversed. The modem takes the analog signal received and converts it back to a digital form that can be processed by the data recovery equipment.

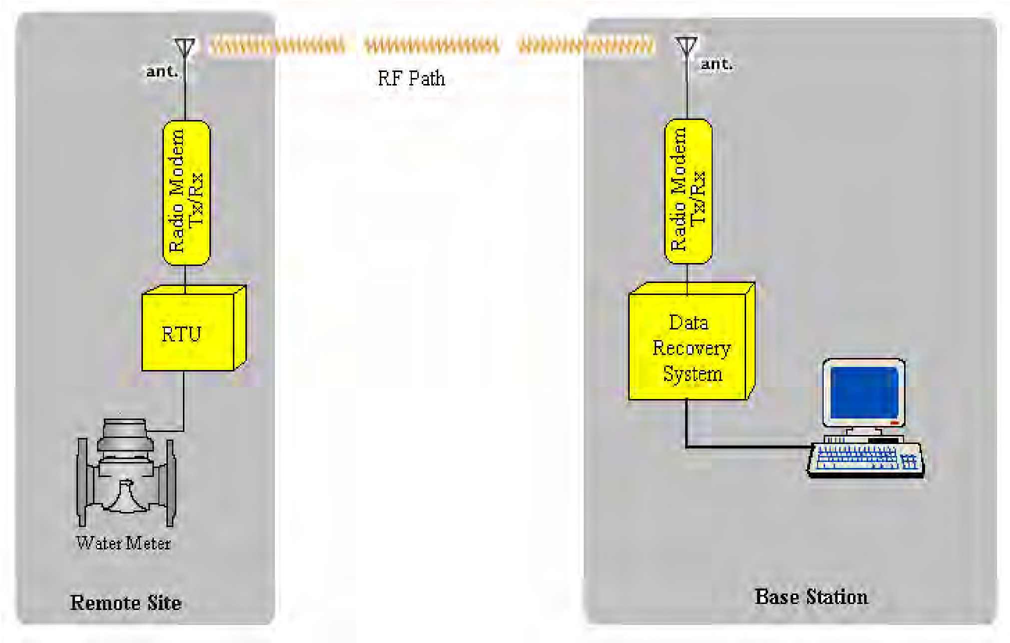


Fig. 2.6 Basic components of Radio Based Water Meter Reading

In a typical application, the base or host site requests data from the remote site(s). The base transmits a request to the remote unit telling it to send its data. The base reverts to a receive mode and awaits the transmission from the remote site. After the remote sends its data, it goes back to a receive mode waiting for further instructions to come from the base. Once the base receives the remote site information, it may send additional instructions to that site or continue on to request data from the next remote site. This polling process continues until all the remotes in the system have sent their data.

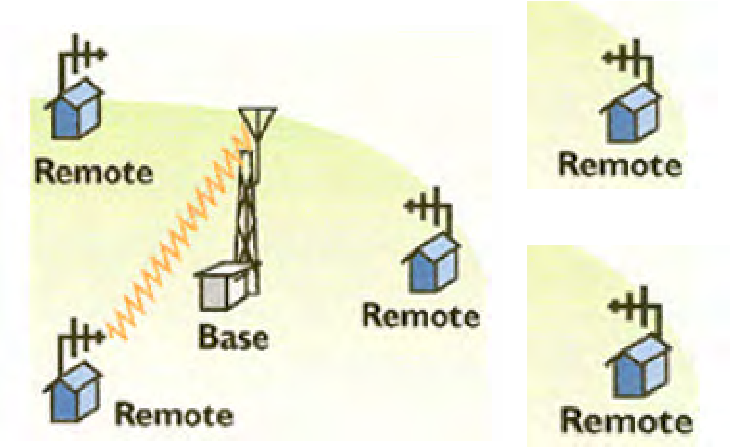


Fig. 2.7 [22] Base station polling process scheme

2.3 Recommended Frequency Bands

Radio-based networking systems are normally configured as a fixed base station that obtains information from another fixed station at a remote site. The frequency control agency, like ETA has allocated certain frequencies that can be used for fixed operation. There are certain frequencies available in the VHF band, UHF band and 900 MHz band for this type of operation.

VHF Band (150-174 MHZ)

Man-made noise such as that from automobiles and power lines, and skip interference caused by radio waves reflecting off the ionosphere back to earth, are much less of a problem at the VHF frequencies. Under certain atmospheric conditions, long-range transmissions can occur and cause interference. Normally, the dielectric constant of the atmosphere decreases with an increase in altitude. However, with some weather conditions, the opposite occurs. This causes the radio wave to be trapped between the earth and the maximum height of the radio wave path as shown in figure 2.8 [22]. This is called guided propagation, or ducting, and causes the wave to travel much further than line-of-sight. This ducting occurs infrequently and may cause interference with direct wave signals.

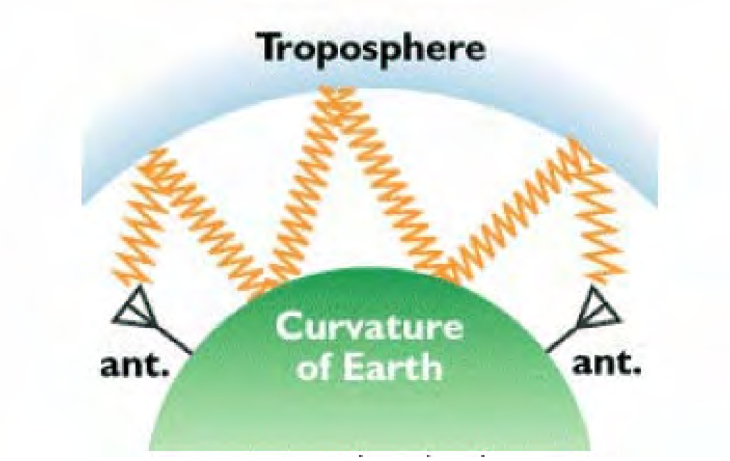


Fig. 2.8 Propagation ducting

UHF Band (450-470 MHZ)

This band is the one most often used in recent years because of the number of channels available. Range is not quite as good as at VHF, but this band is free of most man-made noise, skip interference and ducting effects. Absorption by trees and foliage causes a greater path loss, but penetration into buildings is better because the short wavelength signal has the ability to reflect off conducting objects.

Multi path reception can occur and cause fading, but it is more of a problem at the higher frequencies because of the ability to reflect off objects increases with frequency. This problem is most common with communication between two moving vehicles or one moving vehicle and a fixed station. However, it can also occur when two fixed stations are communicating, if there are moving vehicles or other types of moving reflective objects in the communications path.

900 MHZ Band (928-960)

Skip Interference and ducting are insignificant in this band. However, foliage absorption of the short wavelength is greater which reduces range. In addition, moving objects in the communications path can cause fading due to multi path reception. Multi path reception occurs when the direct wave and a reflected wave arrive at the antenna at different phase angles. (See figure 2.9) This phase difference occurs because the reflected wave has to travel further than the direct wave [22]. This causes canceling, which weakens the received signal.

The preceding description highlighted some of the problems encountered in the various bands when radio waves are used to establish a telemetry link. Most of these propagation problems are not common occurrences, and there are usually engineering solutions to overcome them when they do occur.

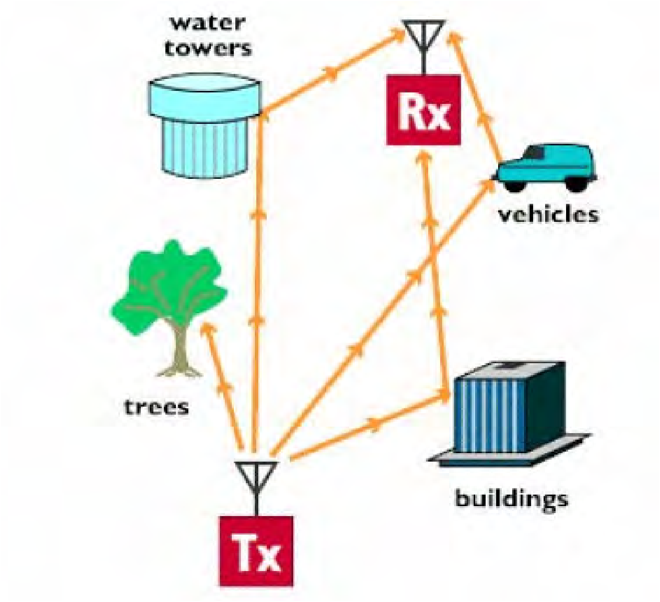


Fig. 2.9 [22] Multi path reception

For example, one thing that minimizes interference when FM (Frequency Modulation) receivers are used is a characteristic of these receivers call "capture effect". Unlike AM or SSB receivers, if the desired signal is only a few dB greater in strength than the interfering signal, the desired signal completely captures the receiver. Therefore, it is important that losses between the transmitter and receiver be minimized to take advantage of this effect.

2.4 Radio Propagation

There are several kinds of radio wave, such as ground, space, sky, and satellite waves. As the name indicates, the ground wave propagates along the surface of the earth, and the sky wave propagates in the space but can return to earth by reflection either in the troposphere or in the ionosphere. Different wavelengths are reflected to dissimilar extent in the troposphere and ionosphere.

Based on the attributes of these waves, we can partition the spectrum. Classification of the radio spectrum is based on propagation properties and the system aspects. Table 2.1 [3] shows the radio frequency bands.

Table 2.1 Radio frequency Bands

Classification Band	Initials	Frequency Range	Characteristics
Extremely low	ELF	< 300 Hz	
Infra low	ILF	300 Hz ~ 3 kHz	
Very low	VLF	3 kHz ~ 30 kHz	
Low	LF	30 kHz ~ 300 kHz	Surface/ground wave
Medium	MF	300 kHz ~ 3 MHz	
High	HF	3 MHz ~ 30 MHz	Sky wave
Very high	VHF	30 MHz ~ 300 MHz	Space wave
Ultra high	UHF	300 MHz ~ 3 GHz	
Super high	SHF	3 GHz ~ 30 GHz	
Extremely high	EHF	30 GHz ~ 300 GHz	Sky wave
Tremendously high	THF	300 GHz ~ 3000 GHz	

Propagation in free space and without any obstacle is the most ideal situation. When the radio waves reach close to an obstacle, propagation effects do occur to the waves.

Losses other than free space path loss are known as multi-path or selective fading. Due to multi-path fading, signals can reach a receiver with different amplitude, phase or time. Multi-path signals may even cancel each other out. Diffraction and scattering result in small scale fading effects, while reflection results in a large-scale fading.

2.4.1 Free Space Propagation

The benchmark by which we measure the loss in a transmission link is the loss that would be expected in free space - in other words, the loss that would occur in a region, which is free of all objects that might absorb or reflect radio energy. This represents the ideal case, which we hope to approach in our real world radio link (in fact, it is possible to have path loss which is less than the "free space" case, as we shall see later, but it is far more common to fall short of this goal).

Calculating free space transmission loss is quite simple. Consider a transmitter with power P_t coupled to an antenna, which radiates equally in all directions (everyone's favorite mythical antenna, the *isotropic* antenna). At an arbitrary, large distance d from the transmitter, the radiated power is distributed uniformly over an area of $4\pi d^2$ (i.e. the surface area of a sphere of radius d), so that the received signal power at distance d is given by [2]:

$$P_r = \frac{A_e G_t P_t}{4\pi d^2} \qquad (2.4.1)$$

Where : A_e is effective area and G_t is the transmitting antenna gain.

The relationship between an effective aperture and the receiving antenna gain G_r, derived in (2.4.1), can be given by

$$G_r = \frac{4\pi A_e}{\lambda^2} \qquad (2.4.2)$$

Where : λ is the wavelength of the electromagnetic wave. By substituting A_e of equation (2.4.2) into equation (2.4.1), we obtain

$$P_r = \frac{G_r G_t P_t}{(4\pi d/\lambda)^2}$$

Free space path loss L_f is defined as

$$L_f = \frac{P_t}{P_r}$$

$$L_f = \frac{1}{G_r G_t}(4\pi d/\lambda)^2 \qquad (2.4.3)$$

When $G_t = G_r = 1$, free space path loss is given by

$$L_f = \left[\frac{4\pi d}{\lambda}\right]^2$$

$$L_f = \left[\frac{4\pi f_c d}{c}\right]^2 \qquad (2.4.4)$$

Where : c is the speed of light ($= 2.998 \times 10^8$ m/sec) and $f_c = c/\lambda$ is carrier frequency.

This shows the classic square-law dependence of signal level versus distance. What troubles some people when they see this equation is that the path loss also increases as the square of the frequency. Does this mean that the transmission medium is inherently more lossy at higher frequencies? While it is true that absorption of RF by various materials (buildings, trees, water vapor, etc.) tends to increase with frequency, remember we are talking about "free space" here. The frequency dependence in this case is solely due to the decreasing effective aperture of the receiving antenna as the frequency increases. This is intuitively reasonable, since the physical size of a given antenna type is inversely proportional to frequency. If we double the frequency, the linear dimensions of the antenna decrease by a factor of one half, and the capture area by a factor of one-quarter. The antenna therefore captures only one-quarter of the power flux density at the higher frequency versus the lower one, and delivers 6 dB less signal to the receiver. However, in most cases we can easily get this 6 dB back by increasing the effective aperture, and hence the gain, of the receiving antenna.

For example, suppose we are using a parabolic dish antenna at the lower frequency. When we double the frequency, instead of allowing the dish to be scaled down in size so as to produce the same gain as before, we can maintain the same reflector size. This gives us the same effective aperture as before (assuming that the feed is properly redesigned for the new frequency, etc.), and 6 dB more gain (remembering that the gain is with respect to an isotropic or dipole reference antenna at the *same frequency*).

Thus the free space path loss is now the same at both frequencies; moreover, if we maintained the same physical aperture at *both* ends of the link, we would actually have 6 dB *less* path loss at the higher frequency. You can picture this in terms of being able to focus the energy more tightly at the frequency with the shorter wavelength.

The free space path loss equation is more usefully expressed logarithmically [3]:

$$\mathbf{L_f = 32.45 + 20\log_{10} f_c\,(MHz) + 20\log_{10} d(km)} \tag{2.4.5}$$

This shows more clearly the relationship between path loss and distance: path loss increases by 20 dB/decade or 6 dB/octave, so each time you double the distance, you lose another 6 dB of signal under free space conditions. Of course, in looking at a real system, we must consider the actual antenna gains and cable losses in calculating the signal power Pr, which is available at the receiver input:

$$P_r = P_t + G_r + G_t - (L_f + L_t + L_r) \tag{2.4.6}$$

Where : P_t = transmitter power output (dBm or dBW, same units as Pr)

L_f = free space path loss between isotropic antennas (dB)

G_t = transmit antenna gain (dBi)

G_r = receive antenna gain (dBi)

L_t = transmission line loss between transmitter and transmit antenna (dB)

L_r = transmission line loss between receive antenna and receiver input (dB)

$L = L_f + L_t + L_r$ = Propagation loss in the channel (dB)

The term dBW denotes dB greater or less than 1 watt (0 dBW). The units dBW and dBm (dB greater or less 1 mW) are widely used in communication engineering. Since 1 W is equal to 1000 mW, x dBW is equal to $x + 10\log_{10}1000$ (= $x + 30$) *dBm.*

A table of transmission line losses for various bands and popular antenna cable types is given below.

Table 2.2 Attenuation of Various Transmission Lines in Amateur and ISM Bands in dB/ 100 m.

Cable Type	144 MHz	220 MHz	450 MHz	915 MHz	1.2 GHz	2.4 GHz	5.8 GHz
RG-58	20.3	24.3	34.8	54.1	69.2	105.6	169.2
RG-8X	15.4	19.7	28.2	42.0	52.8	75.8	134.2
LMR-240	9.8	12.1	17.4	24.9	30.2	42.3	66.9
RG-213/214	9.2	11.5	17.1	26.2	33.1	49.9	93.8
9913	5.2	6.2	9.2	13.8	17.1	25.3	45.3
LMR-400	4.9	5.9	8.9	12.8	15.7	22.3	35.4
0.375" LDF	4.3	5.2	7.5	11.2	13.8	19.4	26.6
LMR - 600	3.1	3.9	5.6	8.2	10.2	14.4	23.9
0.5" LFD	2.8	3.6	4.9	7.2	8.9	12.8	21.6
0.875" LFD	1.5	2.1	2.7	3.9	4.9	7.5	12.5
1.25" LFD	1.1	1.4	2.0	3.0	3.6	5.6	9.2
1.625" LFD	0.92	1.1	1.7	2.5	3.1	4.6	8.2

Notes : Attenuation data based on figures from the "Communications Coax Selection Guide" from Times Microwave Systems and other sources. (http://www.timesmicrowave.com/products/commercial/selectguide/atten/)
The LMR series is manufactured by Times Microwave. 9913 is manufactured by Belden Corp. RG-series cables are manufactured by Belden and many others. The LDF series are foam dielectric, solid corrugated outer conductor cables, best known by the brand name HELIAX (Andrew Corp.).

2.4.2 Path Loss on Line of Sight Links

The term Line of Sight (LOS) as applied to radio links has a pretty obvious meaning that the antennas at the ends of the link can "see" each other, at least in a radio sense. In many cases, radio LOS equates to optical LOS that is you are at the location of the antenna at one end of the link, and with the unaided eye or binoculars, you can see the antenna (or its future site) at the other end of the link.

In other cases, we may still have an LOS path even though we can't see the other end visually. This is because the radio horizon extends beyond the optical horizon. Radio waves follow slightly curved paths in the atmosphere, but if there is a direct path between the antennas, which doesn't pass through any obstacles, then we still have radio LOS. Does having LOS mean that the path loss will be equal to the free space case, which we have just considered? In some cases, the answer is yes, but it is definitely not a sure thing. There are four mechanisms, which may cause the path loss to differ from the free space case [3]:

Reflection : When radio waves hit a reflective surface, such as a building, they bounce off or are reflected from the surface. When this happens, they collide with each other and get cancelled.

Refraction : Changes in atmospheric density can bend and change the path of radio waves. This is known as refraction.

Diffraction : When a radio wave bends sharply around an obstacle in its path, diffraction occurs. Radio path between a transmitter and a receiver is obstructed by a surface with sharp irregular edges (for example, waves bend around the obstacle, even when LOS does not exist).

Scattering : When objects are smaller than the wavelength of the propagating wave (for example, foliage, street signs, lamp posts), the incoming signal is scattered into several weaker outgoing signals.

A typical propagation effect of radio signals is shown in fig 2.10.

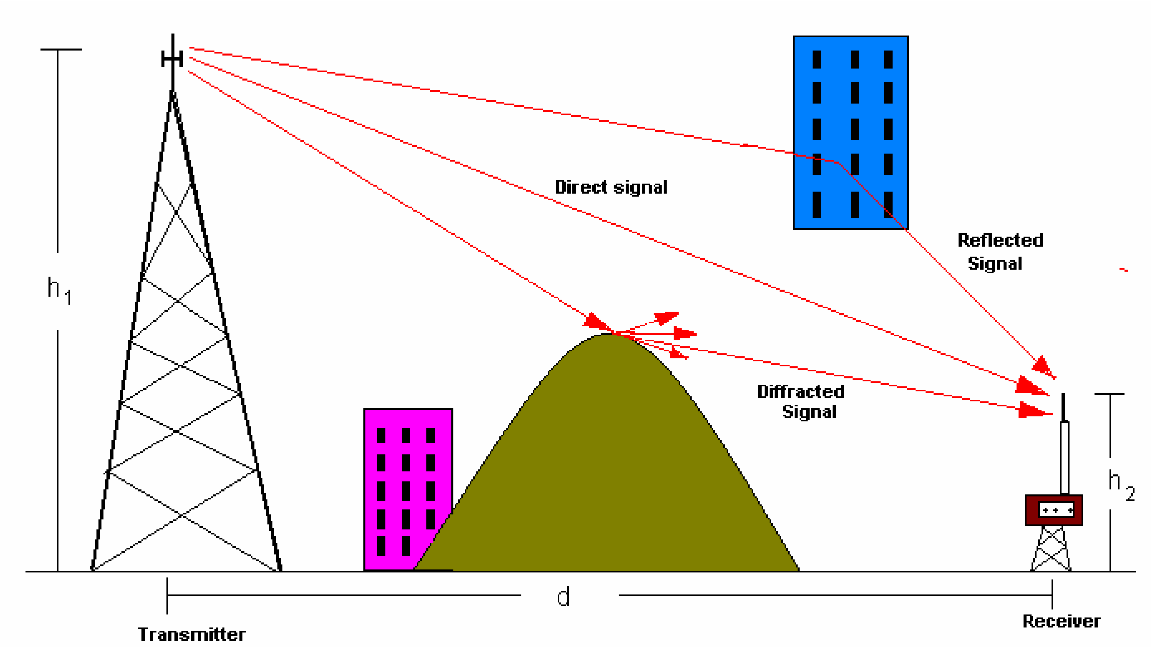


Fig. 2.10 Reflection and diffraction of radio signals

Atmospheric Refraction [6]

As mentioned previously, radio waves near the earth's surface do not usually propagate in precisely straight lines, but follow slightly curved paths. Under normal circumstances, the index of refraction decreases monotonically with increasing height, which causes the radio waves emanating from the transmitter to bend slightly downwards towards the earth's surface instead of following a straight line. The effect is more pronounced at radio frequencies than at the wavelength of visible light, and the result is that the radio waves can propagate beyond the optical horizon, with no additional loss other than the free space distance loss. There is a convenient artifice, which is used to account for this phenomenon: when the path profile is plotted, we reduce the curvature of the earth's surface. If we choose the curvature properly, the paths of the radio waves can be plotted as straight lines. Under normal conditions, the gradient in refractivity index is such that real world propagation is equivalent to straight-line propagation over an earth whose radius is greater than the real one by a factor of 4/3 - thus the often-heard term "4/3 earth radius" in discussions of terrestrial propagation. However, this is just an approximation that applies under typical conditions - as VHF/UHF experimenters well know, unusual weather conditions can change the refractivity profile dramatically. This can lead to several different conditions.

In *super refraction*, the rays bend more than normal and the radio horizon is extended; in extreme cases, it leads to the phenomenon known as *ducting*, where the signal can propagate over enormous distances beyond the normal horizon. This is little practical use for people who want to run data links. The main consequence for digital experimenters is that they may occasionally experience interference from unexpected sources.

A more serious concern is *sub refraction*, in which the bending of the rays is less than normal, thus shortening the radio horizon and reducing the clearance over obstacles along the path. This may lead to increased path loss, and possibly even an outage. It's also a good idea to build in some margin to allow for fading due to unusual propagation situations, and to allow as much clearance from obstacles along the path as possible. For short-range links, the effects of refraction can usually be ignored.

Diffraction and Fresnel Zones [6]

Refraction and reflection of radio waves are mechanisms, which are fairly easy to picture, but diffraction is much less intuitive. To understand diffraction, and radio propagation in general, it is very helpful to have some feeling for how radio waves behave in an environment that is not strictly “free space”. Consider Fig. 2.11, in which a wave front is traveling from left to right, and encountering an obstacle that absorbs or reflects all of the incident radio energy. Assume that the incident wave front is uniform; i.e., if we measure the field strength along the line A-A′, it is the same at all points. Now, what will be the field strength along a line B-B′ on the other side of the obstacle? To quantify this, we provide an axis in which zero coincides with the top of the obstacle, and negative and positive numbers denote positions above and below this, respectively.

Intuition may lead one to expect the field strength along B-B′ to look like the dashed line in Fig. 2.12, with complete shadowing and zero signal below the top of the obstacle, and no effect at all above it. The solid line shows the reality: not only does energy “leak” into the shadowed area, but the field strength above the top of the obstacle is also disturbed. At a position, which is level with the top of the obstacle, the signal power density is down by some 6 dB, despite the fact that this point is in “line of sight” of the source. This effect is less surprising when one considers other familiar instances of wave motion.

The explanation for the non-intuitive behavior of radio waves in the presence of obstacles, which appear in their path is found in something called *Huygens′ Principle*. Huygens showed that propagation occurs as follows: each point on a wave front acts as a source of a secondary wave front known as a *wavelet*, and a new wave front is then built up from the combination of the contributions from all of the wavelets on the preceding wave front.

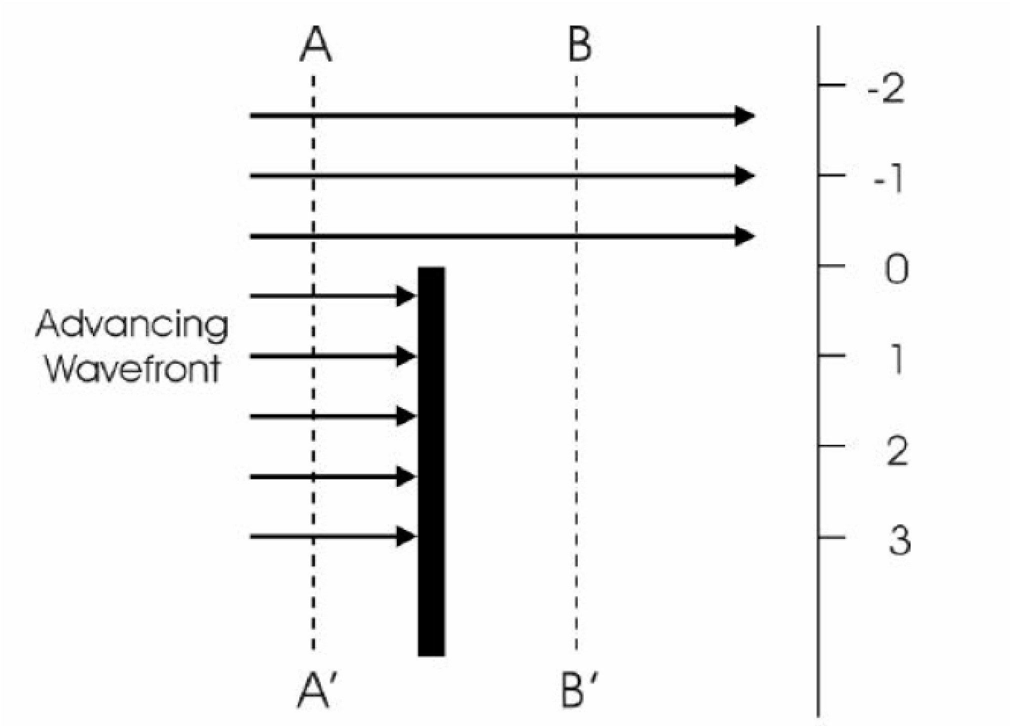


Fig. 2.11 Shadowing of radio waves by an object

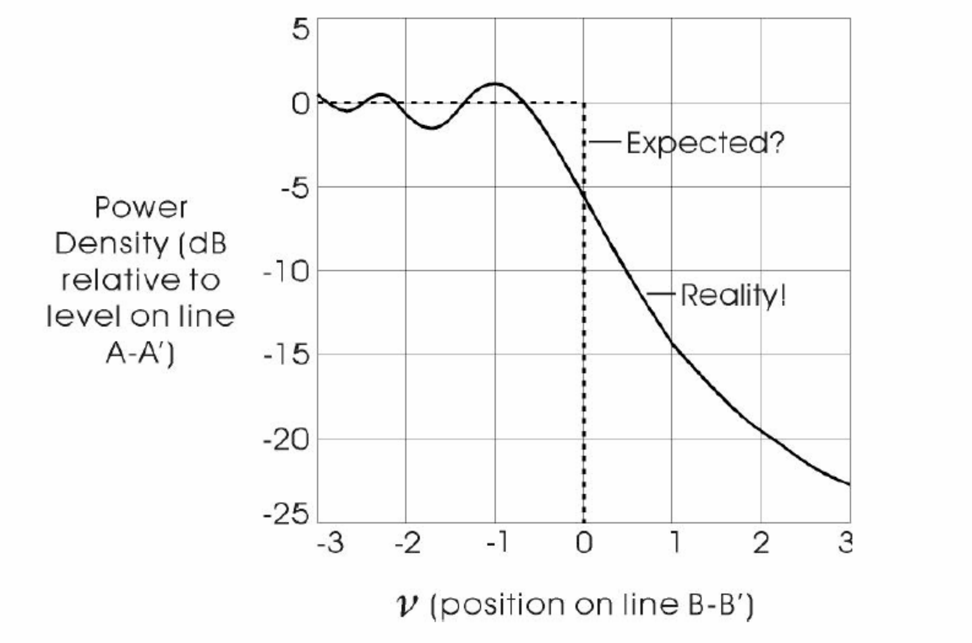


Fig. 2.12 Signal levels on the far side of the shadowing object

The secondary wavelets do not radiate equally in all directions - their amplitude in a given direction is proportional to (1 + cos θ), where θ is the angle between that direction and the direction of propagation of the wave front. The amplitude is therefore maximum in the direction of propagation (i.e., normal to the wave front), and zero in the reverse direction. The representation of a wave front as a collection of wavelets is shown in Fig. 2.13.

At a given point on the new wave front (point B), the signal vector (phasor) is determined by vector addition of the contributions from the wavelets on the preceding wave front, as shown in Fig. 2.14. The largest component is from the nearest wavelet, and we then get symmetrical contributions from the points above and below it. These latter vectors are shorter, due to the angular reduction of amplitude mentioned above, and also the greater distance traveled.

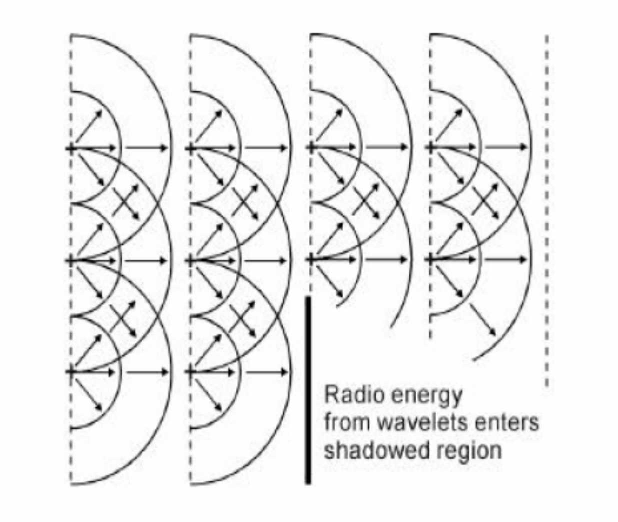


Fig. 2.13 Representation of radio waves as wavelets

The greater distance also introduces more time delay, and hence the rotation of the vectors as shown in the figure. As we include contributions from points farther and farther away, the corresponding vectors continue to rotate and diminish in length, and they trace out a double-sided spiral path, known as the *Cornu spiral*.

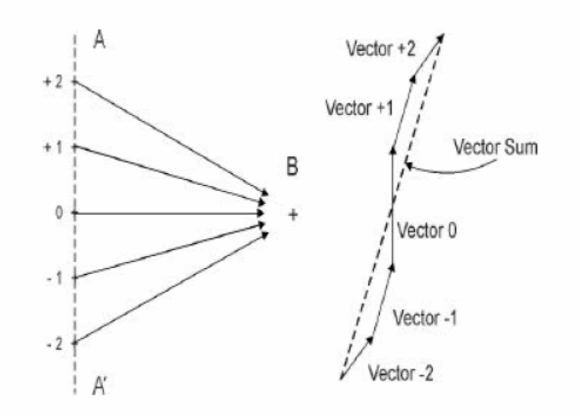


Fig. 2.14 Building of a new wave front by vector summation

The Cornu spiral, shown in Fig. 2.15, provides the tool we need to visualize what happens when radio waves encounter an obstacle.

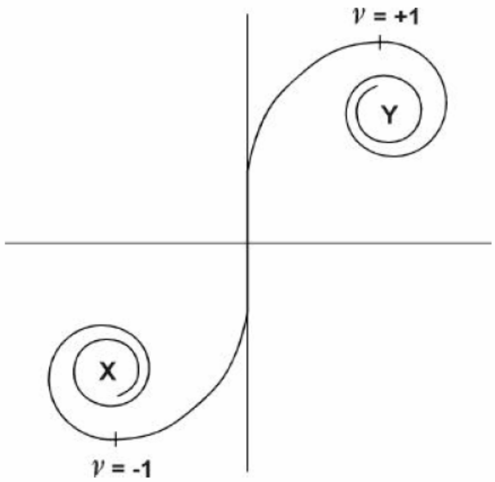


Fig. 2.15 The Cornu spiral

In free space, at every point on a new wave front, all contributions from the wavelets on the preceding wave front are present and un-attenuated, so the resultant vector corresponds to the complete spiral (i.e., the endpoints of the vector are X and Y). Now, consider again the situation shown in Fig. 2.11, and for each location on the wave front B-B′, visualize the makeup of the Cornu spiral (note that the top of the obstacle is assumed to be sufficiently narrow that no significant reflections can occur from it). At position 0, level with the top of the obstacle, we will have only contributions from the positive half of the preceding wave front at A-A′, since all of the others are blocked by the obstacle.

Therefore, the received components form only the upper half of the spiral, and the resultant vector is exactly half the length of the free space case, corresponding to a 6 dB reduction in amplitude. As we go lower on the line B-B′, we start to get blockage of components from the positive side of the A-A′ wave front, removing more and more of the vectors as we go, and leaving only the tight upper spiral. The resulting amplitude diminishes monotonically towards zero as we move down the new wave front, but there *is* still signal present at all points behind the obstacle, as shown in the graph in Fig. 2.12. How about the points along line B-B′ *above* the obstacle, where the graph shows those mysterious ripples? Again, look at the Cornu spiral: as we move up the line, we begin to add contributions from the negative side of the A-A′ wave front (vectors -1, -2, etc.). Note what happens to the resultant vector - as we make the first turn around the bottom of the spiral, it reaches its maximum length, corresponding to the highest peak in the graph of Fig. 2.12. As we continue to move up B-B′ and add more components, we swing around the spiral and reach the minimum length for the resultant vector (minimum distance from point Y). Further progression up B-B′ results in further motion around the spiral, and the amplitude of the resultant oscillates back and forth, with the amplitude of the oscillation steadily decreasing as the resultant converges on the free space value, given by the complete Cornu spiral (vector X-Y).

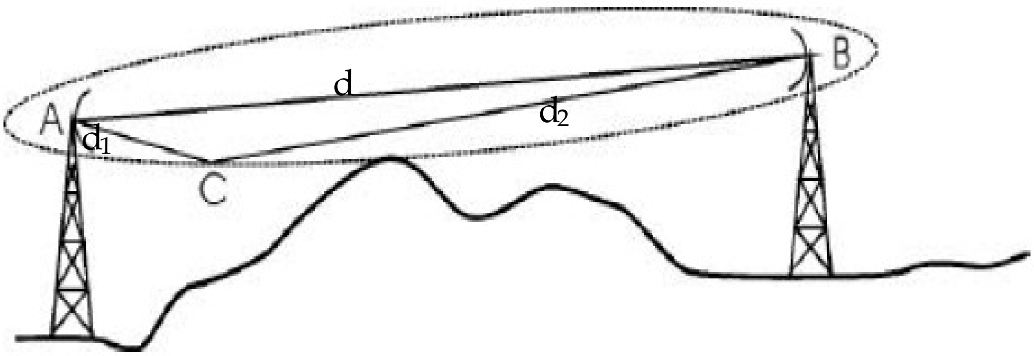


Fig. 2.16 Fresnel zone for a radio link

So, in a nutshell, to visualize what happens to radio waves when they encounter an obstacle, we have to develop a picture of the wave front after the obstacle as a function of the wave front just before it (as opposed to simply tracing rays from the distant source). Now we're in a position to talk about Fresnel zones. A Fresnel zone is a simpler concept once you have some understanding of diffraction: it is the volume of space enclosed by an ellipsoid, which has the two antennas at the ends of a radio link at its foci.

The two-dimensional representation of a Fresnel zone is shown in Fig. 2.16. The surface of the ellipsoid is defined by the path ACB, which exceeds the length of the direct path AB by some fixed amount. This amount is $n\lambda/2$, where n is a positive integer. For the first Fresnel zone, n = 1 and the path length differs by $\lambda/2$ (i.e., a 180^0phase reversal with respect to the direct path). For most practical purposes, only the first Fresnel zone need be considered. A radio path has *first Fresnel zone clearance* if, as shown in Fig. 2.16, no objects capable of causing significant diffraction penetrate the corresponding ellipsoid. What does this mean in terms of path loss? Recall how we constructed the wave front behind an object by vector addition of the wavelets comprising the wave front in front of the object, and apply this to the case where we have exactly first Fresnel zone clearance. We wish to find the strength of the direct path signal after it passes the object. Assuming there is only one such object near the Fresnel zone, we can look at the resultant wave front at the destination point B. In terms of the Cornu spiral, the upper half of the spiral is intact, but part of the lower half is absent, due to blockage by the object. Since we have exactly first Fresnel clearance, the final vector, which we add to the bottom of the spiral is 180^0 out of phase with the direct-path vector - i.e., it is pointing downwards. This means that we have passed the bottom of the spiral and are on the way back up, and the resultant vector is near the free space magnitude (a line between X and Y in Fig. 2.15). In fact, it is sufficient to have 60% of the first Fresnel clearance, since this will still give a resultant, which is very close to the free space value.

In order to quantify diffraction losses, they are usually expressed in terms of a dimensionless parameter ν, given by:

$$\nu = 2\sqrt{\Delta d/\lambda} \qquad (2.4.7)$$

Where : Δd is the difference in lengths of the straight-line path between the endpoints of the link and the path, which just touches the tip of the diffracting object (see fig. 2.17) $\Delta d = d_1 + d_2 - d$.

By convention, ν is positive when the direct path is blocked (i.e., the obstacle has positive height), and negative when the direct path has some clearance ("negative height"). When the direct path just grazes the object, ν = 0. This is the parameter shown in Figures 2.11 and 2.12. Since in this section we are considering LOS paths, this corresponds to specifying that ν = 0. For first Fresnel zone clearance, we have Δd = λ/2, so from equation (2.4.7), ν = -1.4. From Fig. 2.11, we can see that this is more clearance than necessary - in fact, we get slightly higher signal level (and path loss less than the free space value) if we reduce the clearance to ν = -1, which corresponds to Δd = λ/4. The ν = -1 point is also shown on the Cornu spiral in Fig. 2.15. Since Δd= λ/4, the last vector added to the summation is rotated 90^0 from the direct-path vector, which brings us to the lowest point on the spiral. The resultant vector then runs from this point to the upper end of the spiral at point Y. It's easy to see that this vector is a bit longer than the distance from X to Y, so we have a slight gain (about 1.2 dB) over the free space case. We can also see how we can back off to 60% of first Fresnel zone clearance (ν ≈ -0.85) without suffering significant loss.

But how do we calculate whether we have the required clearance? The geometry for Fresnel zone calculations is shown in Fig. 2.17. Keep in mind that this is only a two - dimensional representation, but Fresnel zones are three-dimensional. The same considerations apply when the objects limiting path clearance are to the side or even above the radio path.

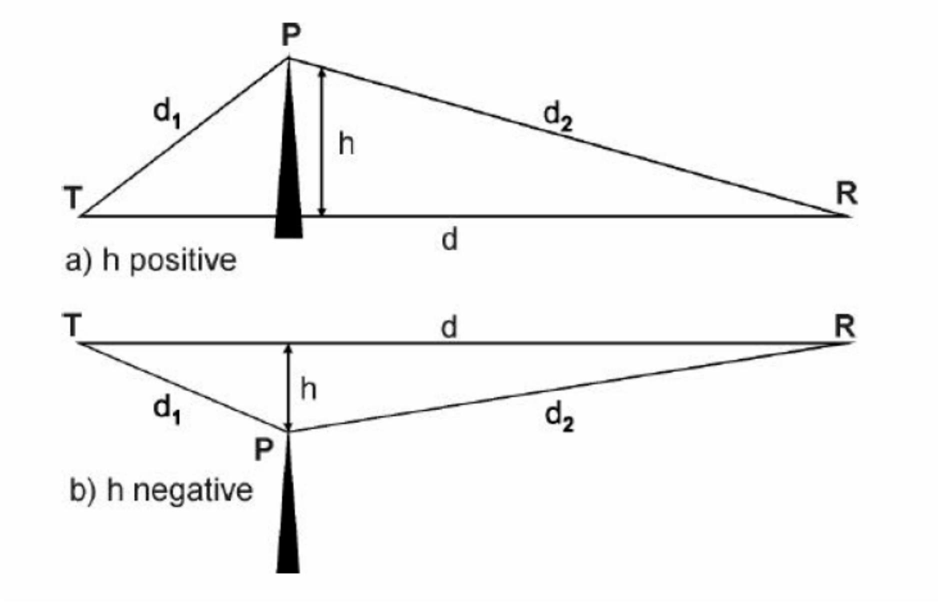


Fig. 2.17 Fresnel zone geometry

Since we are considering LOS paths in this section, we are dealing only with the "negative height" case, shown in the lower part of the figure. We will look at the case where h is positive later, when we consider non-LOS paths.

For first Fresnel zone clearance, the distance h from the nearest point of the obstacle to the direct path must be at least

$$h = 2\sqrt{\frac{d_1 d_2}{d_1 + d_2}} \tag{2.4.8}$$

Where d_1 and d_2 are the distances from the tip of the obstacle to the two ends of the radio circuit. This formula is an approximation, which is not valid very close to the endpoints of the circuit. For convenience, the clearance can be expressed in terms of frequency:

$$h = 17.3\sqrt{\frac{d_1 d_2}{f(d_1 + d_2)}} \tag{2.4.9}$$

Where f is the frequency in GHz, d_1 and d_2 are in km, and h is in meters. Or:

$$h = 72.1\sqrt{\frac{d_1 d_2}{f(d_1 + d_2)}} \qquad (2.4.10)$$

Where f is in GHz, d_1 and d_2 in miles, and h is in feet.

Now it's time to confess that the situation depicted in Figures 2.11 and 2.12 is a special case, known as "knife edge" diffraction. Basically, this means that the top of the obstacle is small in terms of wavelengths. This is *sometimes* a reasonable approximation of an object in the real world, but more often than not, the obstacle will be rounded (such as a hilltop) or have a large flat surface (like the top of a building), or otherwise depart from the knife - edge assumption. So, Fresnel zone clearance can be pretty important on real-world paths. And, again, keep in mind that the Fresnel zone is three-dimensional, so clearance must also be maintained from the sides of buildings, etc. if path loss is to be minimized.

Ground Reflections [6]

An LOS path may have adequate Fresnel zone clearance, and yet still have a path loss, which differs significantly from free space under normal refraction conditions. If this is the case, the cause is probably multi-path propagation resulting from reflections.

One common source of reflections is the ground. It tends to be more of a factor on paths in rural areas; in urban settings, the ground reflection path will often be blocked by the clutter of buildings, trees, etc. In paths over relatively smooth ground or bodies of water, however, ground reflections can be a major determinant of path loss. For any radio link, it is worthwhile to look at the path profile and see if the ground reflection has the potential to be significant. It should also be kept in mind that the reflection point is not at the midpoint of the path unless the antennas are at the same height and the ground is not sloped in the reflection region - just remember the old maxim from optics that the angle of incidence equals the angle of reflection.

Ground reflections can be good news or bad news, but are more often the latter. In a radio path consisting of a direct path plus a ground-reflected path, the path loss depends on the relative amplitude and phase relationship of the signals propagated by the two paths. In extreme cases, where the ground reflected path has Fresnel clearance and suffers little loss from the reflection itself (or attenuation from trees, etc.), then its amplitude may approach that of the direct path. Then, depending on the relative phase shift of the two paths, we may have an enhancement of up to 6 dB over the direct path alone, or cancellation resulting in additional path loss of 20 dB or more. The difference in path lengths can be estimated from the path profile, and then translated into wavelengths to give the phase relationship. Then we have to account for the reflection itself, and this is where things get interesting. The amplitude and phase of the reflected wave depend on a number of variables, including conductivity and permittivity of the reflecting surface, frequency, angle of incidence, and polarization.

It is difficult to summarize the effects of all of the variables, which affect ground reflections, but a typical case is shown in Fig. 2.18 . This particular figure is for typical ground conditions at 100 MHz, but the same behavior is seen over a wide range of ground constants and frequencies. Notice that there is a large difference in reflection amplitudes between horizontal and vertical polarization (denoted on the curves with “h” and “v”, respectively), and that vertical polarization in general gives rise to a much smaller reflected wave. However, the difference is large only for angles of incidence greater than a few degrees (note that, unlike in optics, in radio transmission the angle of incidence is normally measured with respect to a tangent to the reflecting surface rather than a normal to it); in practice, these angles will only occur on very short paths, or paths with extraordinarily high antennas.

For typical paths, the angle of incidence tends to be of the order of one degree or less - for example, for a 10 km path over smooth earth with 10 m antenna heights, the angle of incidence of the ground reflection would only be about 0.11 degrees. In such a case, both polarizations will give reflection amplitudes near unity (i.e., no reflection loss). Perhaps more surprisingly, there will also be a phase reversal in both cases. Horizontally-polarized waves always undergo a phase reversal upon reflection, but for vertically-polarized waves, the phase change is a function of the angle of incidence and the ground characteristics.

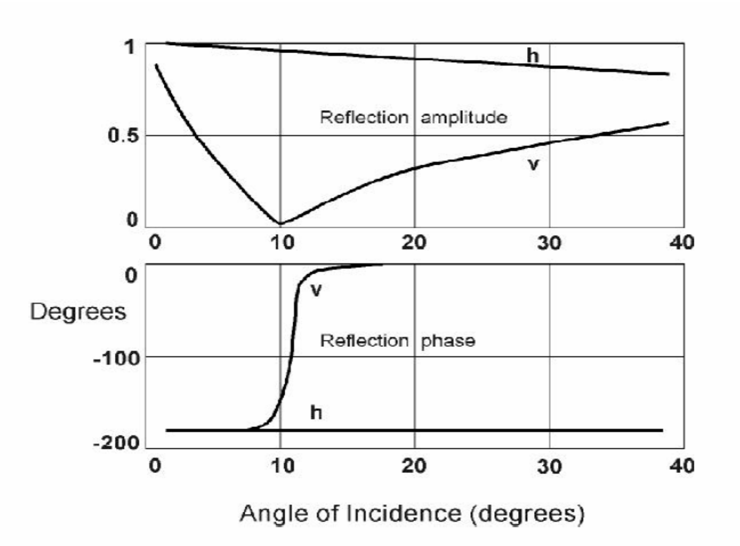


Fig. 2.18 Typical ground reflection parameters

The upshot of all this is that for most paths in which the ground reflection is significant (and no other reflections are present), there will be very little difference in performance between horizontal and vertical polarization. For very short paths, horizontal polarization will generally give rise to a stronger reflection. If it turns out that this causes cancellation rather than enhancement, switching to vertical polarization may provide a solution. In other words, for shorter paths, it is usually worthwhile to try both polarizations to see which works better (of course, other factors such as mounting constraints and rejection of other sources of multi path and interference also enter into the choice of polarization).

As stated above, for either polarization, as the path gets longer we approach the case where the ground reflection produces a phase reversal and very little attenuation. At the same time, the direct and reflected paths are becoming more nearly equal. The path loss ripples up and down as we increase the distance, until we reach the point where the path lengths differ by just one-half wavelength. Combined with the 180° phase shift caused by the ground reflection, this brings the direct and reflected signals into phase, resulting in an enhancement over the free space path loss (theoretically 6 dB, but this will seldom be realized in practice). Thereafter, it's all downhill as the distance is further increased, since phase difference between the two paths approaches in the limit the 180° phase shift of the ground reflection. It can be shown that, in this region, the received power follows an inverse fourth-power law as a function of distance instead of the usual square law (i.e., 12 dB more attenuation when you double the distance, instead of 6 dB). The distance at which the path loss starts to increase at the fourth-power rate is reached when the ellipsoid corresponding to the first Fresnel zone just touches the ground.

A reasonably good estimate of this distance can be calculated from the equation

$$d = \frac{4h_1h_2}{\lambda} \tag{2.4.11}$$

Where : h_1 and h_2 are the antenna heights above the ground reflection point. For example, for antenna heights of 10 m, at 915 MHz (λ = 33 cm) we will be into the fourth-law loss region for links longer than about 1.2 km.

So, for longer-range paths, ground reflections are always bad news. Serious problems with ground reflections are most commonly encountered with radio links across bodies of water. Spread spectrum techniques and diversity antenna arrangements usually can't overcome the problems - the solution lies in sitting the antennas (e.g., away from the shore of the body of water) such that the reflected path is cut off by natural obstacles, while the direct path is unimpaired. In other cases, it may be possible to adjust the antenna locations so as to move the reflection point to a rough area of land, which scatters the signal rather than creating a strong specular reflection.

Other Sources of Reflections [4]

Much of what has been said about ground reflections applies to reflections from other objects as well. The "ground reflection" on a particular path may be from a building rooftop rather than the ground itself, but the effect is much the same. On long links, reflections from objects near the line of the direct path will almost always cause increased path loss - in essence, you have a permanent "flat fade" over a very wide bandwidth. Reflections from objects, which are well off to the side of the direct path are a different story, however. This is a frequent occurrence in urban areas, where the sides of buildings can cause strong reflections. In such cases, the angle of incidence may be much larger than zero, unlike the ground reflection case. This means that horizontal and vertical polarization may behave quite differently - as we saw in Fig. 2.18, vertically polarized signals tend to produce lower-amplitude reflections than horizontally polarized signals when the angle of incidence exceeds a few degrees. When the reflecting surface is vertical, like the side of a building, a signal, which is transmitted with horizontal polarization effectively, has vertical polarization as far as the reflection is concerned. Therefore, horizontal polarization will generally result in weaker reflections and less multi-path than vertical polarization in these cases.

2.4.3 Path Loss on Non Line of Sight Paths

We have spent quite a bit of time looking at LOS paths, and described the mechanisms, which often cause them to have path loss, which differs from the "free space" assumption. We've seen that the path loss isn't always easy to predict. When we have a path that is not LOS, it becomes even more difficult to predict how well signals will propagate over it. Unfortunately, non-LOS situations are sometimes unavoidable, particularly in urban areas. The following sections deal with some of the major factors, which must be considered.

Diffraction Losses

In some special cases, such as diffraction over a single obstacle, which can be modeled as a knife-edge, the loss of a non-LOS path can be predicted fairly readily. In fact, this is the same situation that we saw in Figures 2.11 and 2.12, with the diffraction parameter $\nu > 0$. This parameter, from equation (2.4.7), is

$$\nu = 2\sqrt{\frac{\Delta d}{\lambda}} \qquad (2.4.12)$$

To get Δd, measure the straight-line distance between the endpoints of the link. Then measure the length of the actual path, which includes the two endpoints and the tip of the knife-edge, and take the difference between the two. The geometry is shown in Fig. 2.17(a), the "positive h" case. A good approximation to the knife-edge diffraction loss in dB can then be calculated from

$$L(v) = 6.9 + 20 \log [\sqrt{(v^2+1} + v)] \qquad (2.4.13)$$

Unfortunately, the losses which non line of sight path propagations are faced with are seldom this simple. They will frequently involve diffraction over multiple rooftops or other obstacles, many of which don't resemble knife-edges. The path losses will generally be substantially greater in these cases than predicted by the single knife-edge model. The paths will also often pass through objects such as trees and wood-frame buildings, which are semi-transparent at radio frequencies. Many models have been developed to try and predict path losses in these more complex cases. The most successful are those, which deal with restricted scenarios rather than trying to cover all of the possibilities. One common scenario is diffraction over a single obstacle, which is too rounded to be considered a knife-edge. There are different ways of treating this problem; the one described here is that the top of the object is modelled as a cylinder of radius r [7], as shown in Fig. 2.19. To calculate the loss, you need to plot the profile of the actual object, and then draw straight lines from the link endpoints such that they just graze the highest part of the object as seen from their individual perspectives. Then the parameters D_s, d_1, d_2 and α are estimated, and an estimate of the radius r can then be calculated from

$$r = \frac{2D_s d_1 d_2}{d_1^2 + d_2^2} \tag{2.4.14}$$

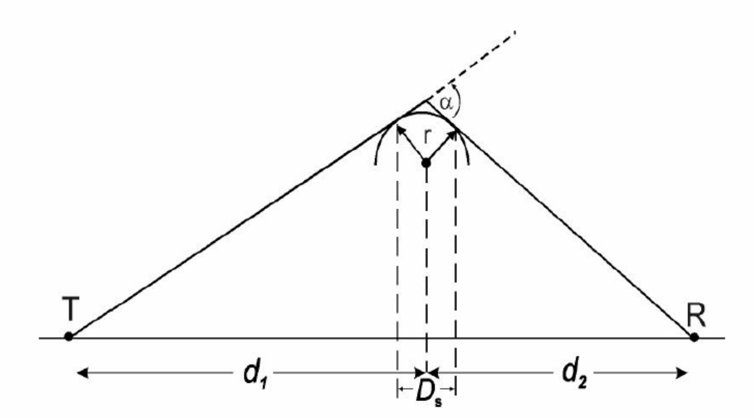


Fig. 2.19 [7] Diffraction by a rounded obstacle

Note that the angle α is measured in radians. The procedure then is to calculate the knife edge diffraction loss for this path as outlined above, and then add to it an excess loss factor L_{ex}, calculated from

$$L_{ex} = 11.7\alpha\sqrt{\frac{\pi r}{\lambda}} \tag{2.4.15}$$

There is also a correction factor for roughness: if the object is, for example, a hill which is tree-covered rather than smooth at the top, the excess diffraction loss is said to be about 65% of that predicted in (2.4.15). In general, smoother objects produce greater diffraction losses.

So, summed with the knife-edge loss calculated previously, we have an estimated total diffraction loss of 37.3 dB (assuming the ridge is "smooth" rather than "rough"). This is a lot, but you can easily imagine scenarios where the losses are much greater: just look at the direct dependence on the angle α in (2.4.15) and picture from Fig. 2.19

what happens when the obstacle is closer to one of the link endpoints. Amateurs doing weak signal work are accustomed to dealing with large path losses in non-LOS propagation, but such losses are usually intolerable in high-speed digital links.

2.5 Non-Line of sight Propagation Path Loss Models

There are many more general models and empirical techniques, like Okumura-Hara path loss Model and Lee's path loss Model [2], for predicting non-LOS path losses, most of them are aimed at prediction of the paths between elevated base stations and mobile stations near ground level, and they typically have restrictions on the frequency range and distances for which they are valid; thus they may be of limited usefulness in the planning of radio link design between fixed stations.

One useful, non - LOS path losses approximation given by [7]:

☞ The loss on many non-LOS paths in urban areas can be modeled quite well by a fourth-power distance law. In other words, Substitute d^4 for d^2 in equation (2.4.4), that is

$$L_f = \left[\frac{4\pi f_c}{c}\right]^2 \text{x}\, d^4 \qquad (2.5.1)$$

Or, substitute 40 log(d) for the 20 log(d) term in equation (2.4.5), that is

$$L_f = 32.45 + 20 \log_{10} f_c\,(\text{MHz}) + 40 \log_{10} d(\text{km}) \qquad (2.5.2)$$

This is probably an overly optimistic assumption for heavily built-up areas, but is at least a useful starting point.

Diffraction losses given by [6]:

☞ Knife edge diffraction loss in dB from equation 2.4.13 becomes

$$L(v) = 6.9 + 20 \log \left[\sqrt{(v^2 + 1} + v)\right] \qquad (2.5.3)$$

- Excess loss factor L_{ex} in dB from equation 2.4.15 becomes

$$L_{ex} = 11.7\alpha\sqrt{\frac{\pi r}{\lambda}} \qquad (2.5.4)$$

- Let 's define that P_T (dB) is the transmitter power averaged over the assigned burst duration for a single channel. Because there is a power loss due to the cable between the transmitter RF amplifier and the antenna, the transmitter power is reduced by a certain amount. Where L_t be transmitter side antenna cable loss, then effective radiated power (ERP) is given [1]

$$\mathbf{P_{ERP}(dB) = P_T\,(dB) + G_T\,(dB) - L_t\,(dB)} \qquad (2.5.5)$$

- Where L_r be receiver side antenna cable loss, then received signal power is given by [1]:

$$\mathbf{Pr\,(dB) = P_{ERP}(dB) + G_r\,(dB) - L_f\,(dB) - L_r\,(dB) - L\,(\nu)\,(dB) - L_{ex}\,(dB)} \qquad (2.5.6)$$

- Let P_{rs} in dB be receiver sensibility, Maximum acceptable path loss L_{fmax} (dB) is given by [1]:

$$\mathbf{L_{fmax}\,(dB) = [\,P_T\,(dB) - P_{rs}\,(dB)\,] + [\,G_r\,(dB) + G_T\,(dB)\,] - [\,L_t\,(dB) + L_r\,(dB) + L\,(\nu)\,(dB) + L_{ex}\,(dB)\,]} \qquad (2.5.7)$$

Using this result, we can estimate the coverage area of a system. In this process, the key factors are the relationship between the coverage area and the path loss as well as how to obtain diffraction losses.

The propagation losses on non-LOS paths can be very high, particularly in urban areas. Antenna height becomes a critical factor, and getting your antennas up above rooftop heights will often spell the difference between success and failure. Due to the great variability of propagation in cluttered urban environments, accurate path loss predictions can be difficult.

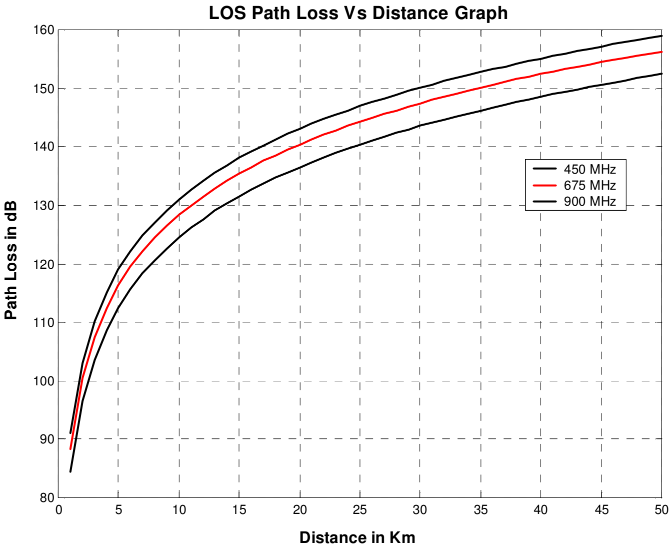


Fig. 2.20 Line of sight propagation path loss

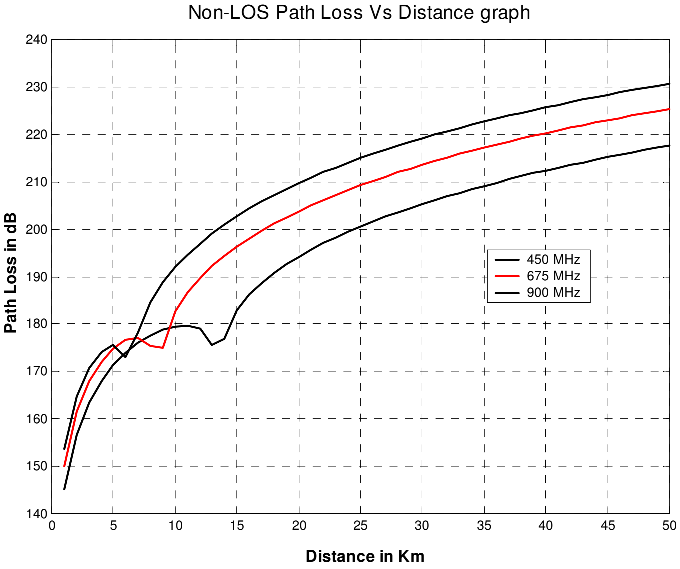


Fig. 2.21 Non line of sight propagation path loss

2.6 Multi-Path Propagation Environment [19]

The wireless propagation channel contains objects, which randomly scatter the energy of the transmitted signal. The scattered signals arrive at the destination receiver out of step. These objects are referred to as scatterers. Scatterers introduce a variety of channel impairments including fading, multipath delay spread, Doppler spread, attenuation, etc., and the inherent background noise. Background noise can be approximated as thermal noise and treated as additive white Gaussian noise (AWGN). Digital transmission over practical wireless channels is mainly limited by interference and distortion other than AWGN.

Scattering by randomly located scatterers gives rise to different paths with different path lengths, resulting in multipath delay spread. If the propagation channel does not exhibit multipath delay spread, the point source would appear at the front end of the receiver as another point source. A mutipath situation arises when a transmitted point source is received as a multipoint source, with each of the individually received points experiencing a different transmission delay. The effect of multipath propagation on digital transmission can be characterized by fading.

Fading [20]

When the delay differences among various distinct propagation paths are very small compared with the symbol interval in digital transmission, the multi-path components are almost indistinguishable at the receiver. These multi-path components can add constructively or destructively, depending on the carrier frequency and delay differences. The effect is that the receiver signal level fluctuates with time, a phenomenon called fading. For example, consider the transmission of sinusoidal signal with frequency f_c over a channel with two distinct paths, as shown in figure 2.23. For simplicity, the delay of the LOS or direct path is assumed to be zero, and the delay of the non-LOS or reflected path is τ. The received signal, in the absence of noise, can be represented as

$$\mathbf{r(t) = \alpha_1 Cos\ (2\pi f_c t\ ) + \alpha_2 Cos\ (2\pi f_c (t - \tau))}$$

Where α_1 and α_2 are amplitudes of the signal components from the two paths respectively. The received signal can be represented as

$$\mathbf{r(t) = \alpha\, Cos\ (2\pi f_c t + \phi\ )}$$

Where

$$r(t) = \sqrt{\alpha_1^{\,2} + \alpha_2^{\,2} + 2\alpha_1^{\,2}\,\alpha_2^{\,2}\,Cos\ (2\pi f_c t\ )}$$

and

$$\phi = -\tan^{-1}\left[\frac{\alpha_2\ Cos\ (2\pi f_c \tau)}{\alpha_1 + \alpha_2\ Cos\ (2\pi f_c \tau)}\right]$$

are the amplitude and phase of the received signal. Both α and ϕ are functions of α_1, α_2 and τ.

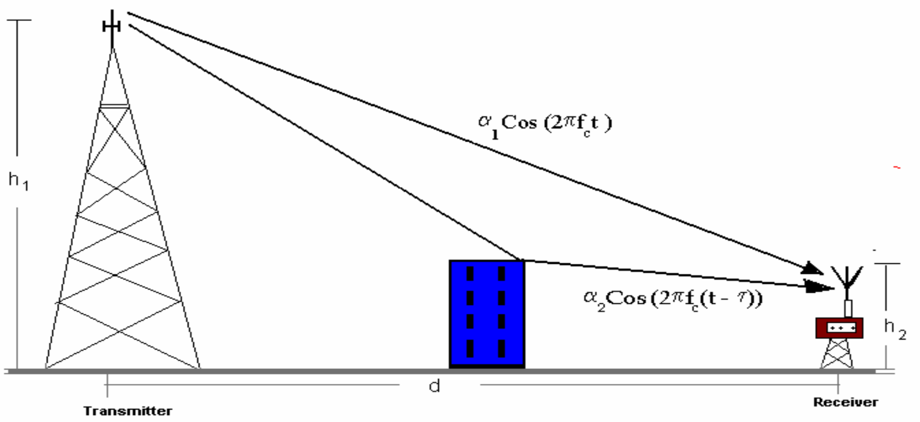


Fig. 2.23 Channel with two propagation paths

Fig. 2.24 plots the amplitude α as a function of $f_c\tau$, where $\alpha_1 = 2$ and $\alpha_2 = 1$. It can be observe that the two received signal components add constructively when $f_c\tau = 0,1,2,$ ... and destructively when $f_c\tau = 0.5, 1.5, 2.5,$ ....

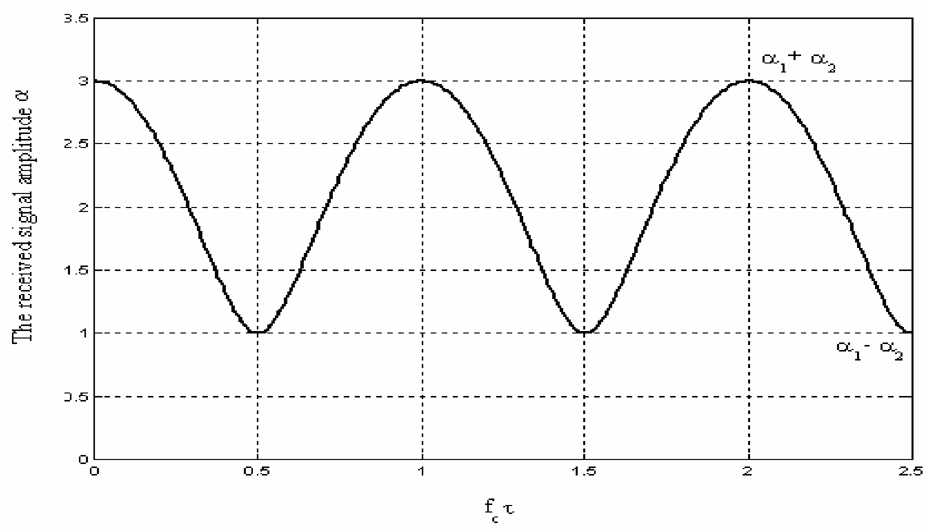


Fig. 2.24 The amplitude fluctuation of the two-path channel with α_1=2 and α_2=1.

When the signal components from the two paths add destructively, the transmitted signal experiences deep-fading with a small value of the amplitude α. During each deep fade, the instantaneously received signal power is very low, resulting in poor transmission quality (i.e. high transmission error rate).

CHAPTER - III

DATA COLLECTION METHODS AND PRESENTATION

3.1 Introduction

In Addis Ababa water both for household and industrial consumption is provided by Addis Ababa Water and Sewerage Authority (AAWSA). The city of Addis Ababa is rapidly expanding due to many factors chief among them being the rural-urban migration and the effects of urbanization. Another factor that is responsible for the rapid increase of population is the expansion of the administrative boundaries of the city. (1) Out of entire 54,000 hectare of the city's land, built-up area comprises 31.3% and green area (forests, riverside greens etc) accounts for 23.4%.

Addis Ababa obtains water from three major sources :

- Legedadi Dam and treatment plant with a current average total production of 168,000 m^3/day
- Gefersa dam and treatment plant with a current average total production of 23,000 m^3/day
- Akaki ground water field with a production of 42,000 m^3/ day

The total water production from formal sources is thus just about 233,000 m^3/ day.

Legedadi water treatment plant treats raw water from two sources: Legedadi Dam and Dire Dam. Treated water from Legedadi treatment plant transported to Addis Ababa through 1400 mm and 900 mm pipes. On 1400mm and 900mm pipes Faure Herman Insertion type flow meters are fitted in the treatment compound. These flow meters are not working and needs replacement.

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1. *Extracted from 'Addis Ababa city administration urban Development indicator, Bureau of finance & economic development, august 2006*

Gefersa treatment plant will be equipped with plant SCADA system, which comprises raw water inlet from Gefersa dam and treated water outlet to distribution network flow measurements. Now treated water from Gefersa water treatment plant is measured using bulk water meter, which can't be used for automatic water meter reading.

Akaki well field water source has it's own SCADA system for borehole pumps, boosting pumps and reservoirs control and monitoring. Electro-magnetic flow meters are measuring water collected from the boreholes and boosted to Addis Ababa city. They are suitable for automatic water meter reading.

The above on site data gathering helps AAWSA to monitor and manage the water supply sources and their respective raw water inlet and treated water outlets to the distribution network. Under this thesis a model will be developed to interconnect these on site data gathered through radio link and monitor the system from Head office central monitoring desk.

3.2 Radio Communication History in AAWSA

AAWSA uses vocal radio communication for operation and maintenance purpose with a repeater installed at 'Furi' mountain for one channel, namely channel one, and one repeater installed in old AAWSA head office compound, Belay Zeleke road, for channel two. Channel one, which is with 'Furi' repeater, covers Addis Ababa city area including water source, Legedadi water treatment plant, Dire Dam, Geferssa water treatment plants and Akaki boreholes, which are outside Addis Ababa city. Channel two with the second repeater covers Southern, Northern and Western parts of Addis Ababa. Remaining six channels from channel three to eight with out repeaters used only for emergency purpose among head office departments or individual branch offices. Table 3.2 below shows licensed frequency used.

Table 3.1 AAWSA licensed voice frequency bands

	Channel or Frequency group	UHF frequency for vocal communication	
		Tx (MHz)	Rx (MHz)
1	Channel one	450.600	455.600
2	Channel two	458.200	463.200
3	Channel three	464.200 (PTT)	464.200 (PTT)
4	Channel four	469.200	469.200
5	Channel five	458.725	458.725
6	Channel six	442.075	442.075
7	Channel seven	463.725	463.725
8	Channel eight	465.550	465.550

Besides vocal radio communication AAWSA has data radio communication systems, which are telemetry system between Legedadi treatment plant and Terminal Pumping station at 'Lamberet - Megenagna' around 18 Km air distance as depicted in figure 3.1, and SCADA (Supervisory Control And Data Acquisition) system of Akaki borehole water sources as depicted in figure 3.2.

The Legedadi telemetry system uses to transfer reservoir level at Terminal pumping station, over flow condition at ST-2 (Surge tank - 2) and ST - 3 (surge tank - 3) to the central control station at Legedadi treatment plant in order to monitor water production and transfer from Legedadi water treatment plant to Addis Ababa.

The SCADA system of Legedadi water treatment plant consists of :

- UHF Motorola Tx/Rx radio modems
- Sofrel RTU
- PcVue 32 SCADA programming software

Akaki well field SCADA system is designed to enable operators to monitor the status of 29 deep borehole pump sites, four booster pump stations and four water reservoirs level from CT (Collection Tank) pumping station, which is one of booster pumping stations. Figure 3.2 represent radio communication scheme.

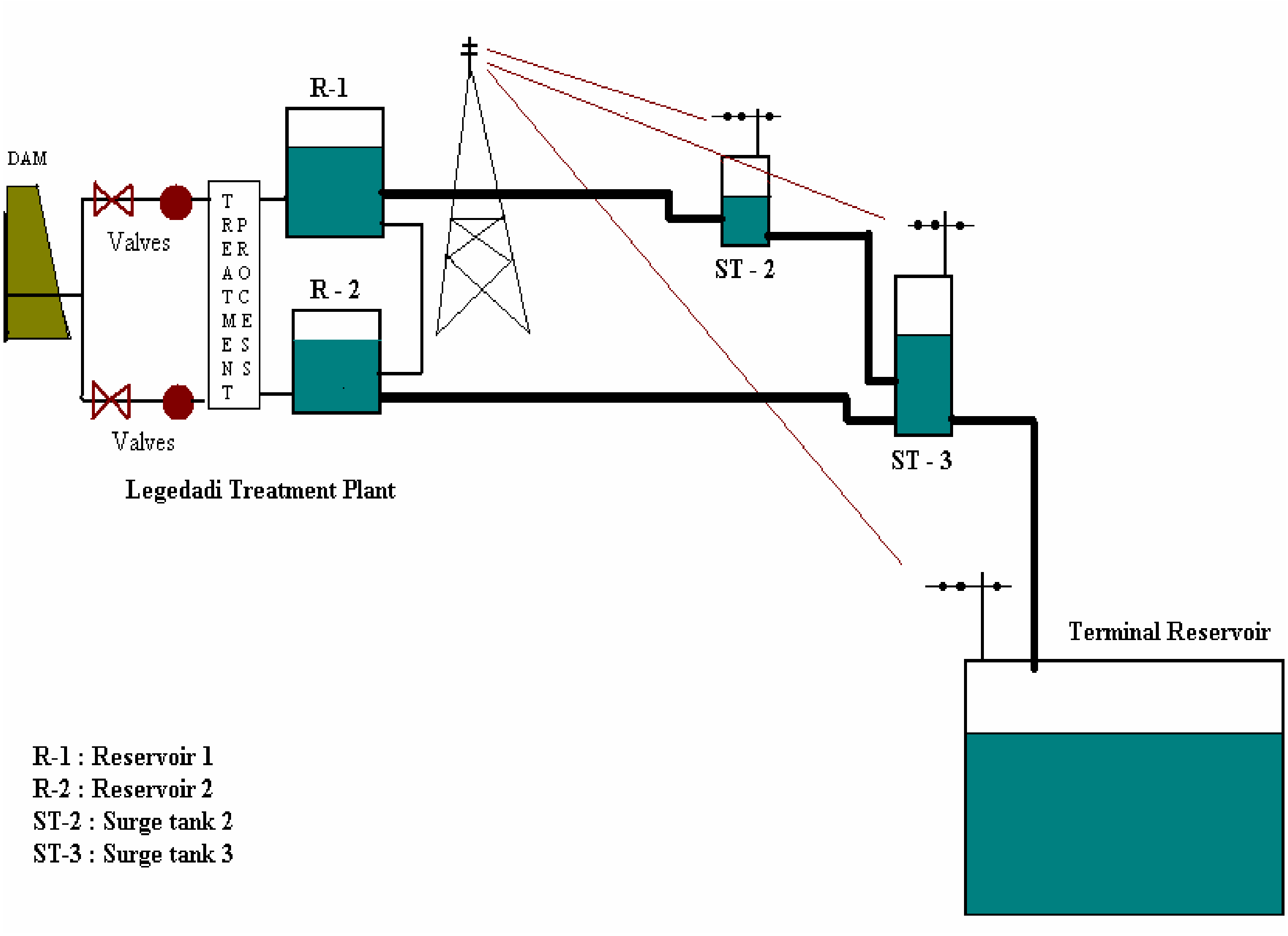

Fig. 3.1 Legedadi Telemetry scheme

Table 3.2 [17] AAWSA licensed Akaki SCADA radio frequency bands

	Frequency group	Tx/Rx frequencies (in MHz)
1	CT - Deep Boreholes	464.600
2	CT - GW1, CT - GW2, CT - GW3 and CT - GWA1	462.775
3	GW3 - GW4, GW3 - MKR1, GW3 - MKBh and GW3 - BBR1	462.875

The SCADA system consists of [17]:

- UHF 1 watt PACS PACSNET Tx/Rx radio modems
- Allen - Bradley PLCs (Programmable Logic Controllers)
- RSLogix 500 and RSView 32 programming software

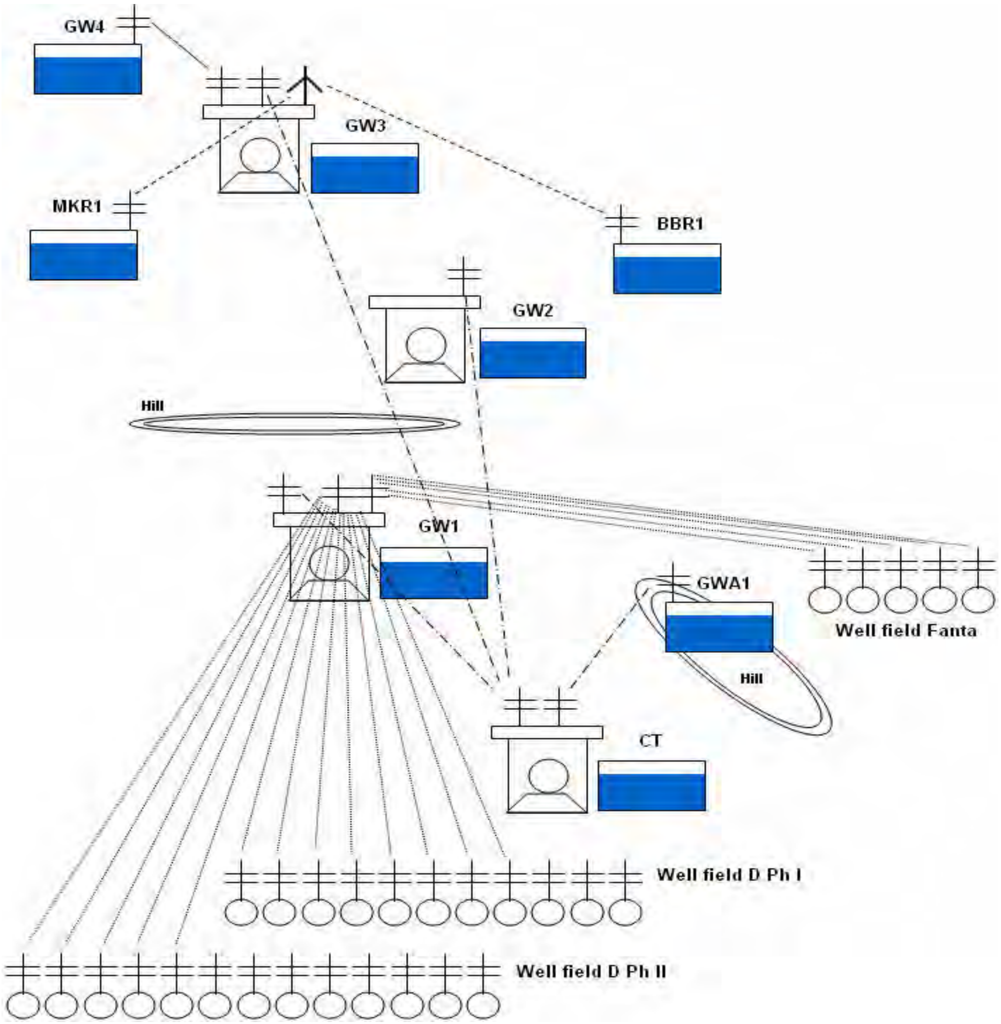

Fig. 3.2 Radio communication scheme of Akaki SCADA system

3.3 AAWSA Water Meter Reading Methods

Traditionally, water meter reading is performed by meter reading team. The meter reading team in each branch office of AAWSA manually collects meter reading information in the field and a meter-reading sheet is prepared, again manually. This is submitted to the information technology department, which enters the information in the computer system. The system then generates reports on key aspects as over billing, under-billing and any other anomalies that are detected by the system. This information resubmitted the branch offices again for verification before the final bill to the customer is printed. The customers' bills are then delivered by hand and customers are then allowed 4 - 5 days within which to settle the bill.

Two types of customers are recognized : bulk customers including large hotels and industries, and the domestic customers. For the bulk customers, an invoice is usually sent to the customers to settle. For the domestic customers, AAWSA has established 32 collection centers, which are run jointly with the Ethiopian Electricity Company. The payment slips for the bills are sent to the information technology department which generates various reports. The reports include volumes of water billed per branch, the amount of money collected, the percentage of bills collected and also the percentage not collected and gives a summary report per branch. The printed information is then handed to the finance department. From the summary report water consumption and consumer number in 'Tikemet', 1999 Ethiopian Calendar is summarized in the table 3.1.

Table 3.3 water consumption and number of customers ('Tikmete', 1999)

No	Branch office	Water Consumption between 0 - 7 m^3	No. of customers	Water cons. between 8 - 20 m^3	No. of customers	Water cons. above 20 m^3	No. of customers
1	Central	68,466	20,026	97,471	8,131	698,171	4,003
2	South	113,745	32,596	214,632	17,682	980,599	8,787
3	North	90,704	24,329	139,372	11,821	323,819	3,358
4	West	8,4909	24,949	160,079	13,236	511,143	4,868
5	East	29,423	91,365	245,653	19,725	976,489	9,994
6	Akaki	29,446	8,222	32,469	2,836	164,615	1,044
	Total	**416,693**	**201,487**	**889,676**	**73,431**	**3,654,836**	**32,054**
	Consumption	**8.4 %**		**17.9%**		**73.7%**	
	Customers		**65.5%**		**23.9%**		**10.4%**
	(2)**Cost (In Birr)**	**729,213**		**2,802,479**		**13,888,377**	

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2. *5 years tariff for water supply & sewerage disposal service, Regulation No. 31/2002, Addis Negarit Gazeta, 13th July, 2002.*

From the table we can see 74% of water supply is consumed by customers who use above 20 m^3 per month, they are 10% of the over all customers. The top 100 water consumers of the city are listed in the appendex 1.

These information justifies that the bulk customers are fewer than domestic customers, whose consumption is between 0 - 20 m^3 a day, while water bills collected from bulk consumers are far away from domestic customers, that is 80 % of the total water bill in a month. From this finding we can conclude that having good billing system of bulk customers enhances AAWSA billing efficiency, which in turn brings up the authority capacity to provide enough and durable water system for the city of Addis Ababa.

CHAPTER - IV

RADIO LINK MODEL

4.1 Introduction

The propagation model is designed on the bases that from each remote sites station at Legedadi water treatment plant, Gefersa water treatment plant and Akaki ground water supply system monthly production in meter cube will be transmitted to central (host) stations. In this model base station is considered to be at AAWSA head office. At the center station the data will be analyzed and could be used for billing purpose or others as required. The model overview is shown in fig. 4.1.

Table 4.1 Air Distance in Km between center station and remote station and highest point between center station and remote station

No.	From	To	Air Distance (Km)	Height difference (m)
1	Legedadi water treatment plant Elevation : 2431m.a.s.	AAWSA Head office Elevation : 2360 m.a.s.	18.40	71.00
2	Gefersa water treatment plant Elevation : 2570.06 m.a.s.	AAWSA Head office Elevation : 2360 m.a.s.	18.05	210.06
3	Collection tank (CT) Reservoir Elevation : 2095m.a.s.	AAWSA Head office Elevation : 2360 m.a.s.	18.60	(-) 265.00
4	Legedadi water treatment plant Elevation : 2431m.a.s.	Highest point b/n Legedadi W.T.P. and AAWSA Head office Elevation : 2415 m.a.s.	10.60	16.00
5	Gefersa water treatment plant Elevation : 2571.00 m.a.s.	Highest point b/n Gefersa W.T.P. and AAWSA Head office Elevation : 2565 m.a.s.	4.10	5.00
6	Collection tank (CT) Elevation : 2095m.a.s.	Highest point b/n CT Reservoir and AAWSA Head office Elevation : 2195 m.a.s.	0.70	(-) 100.00

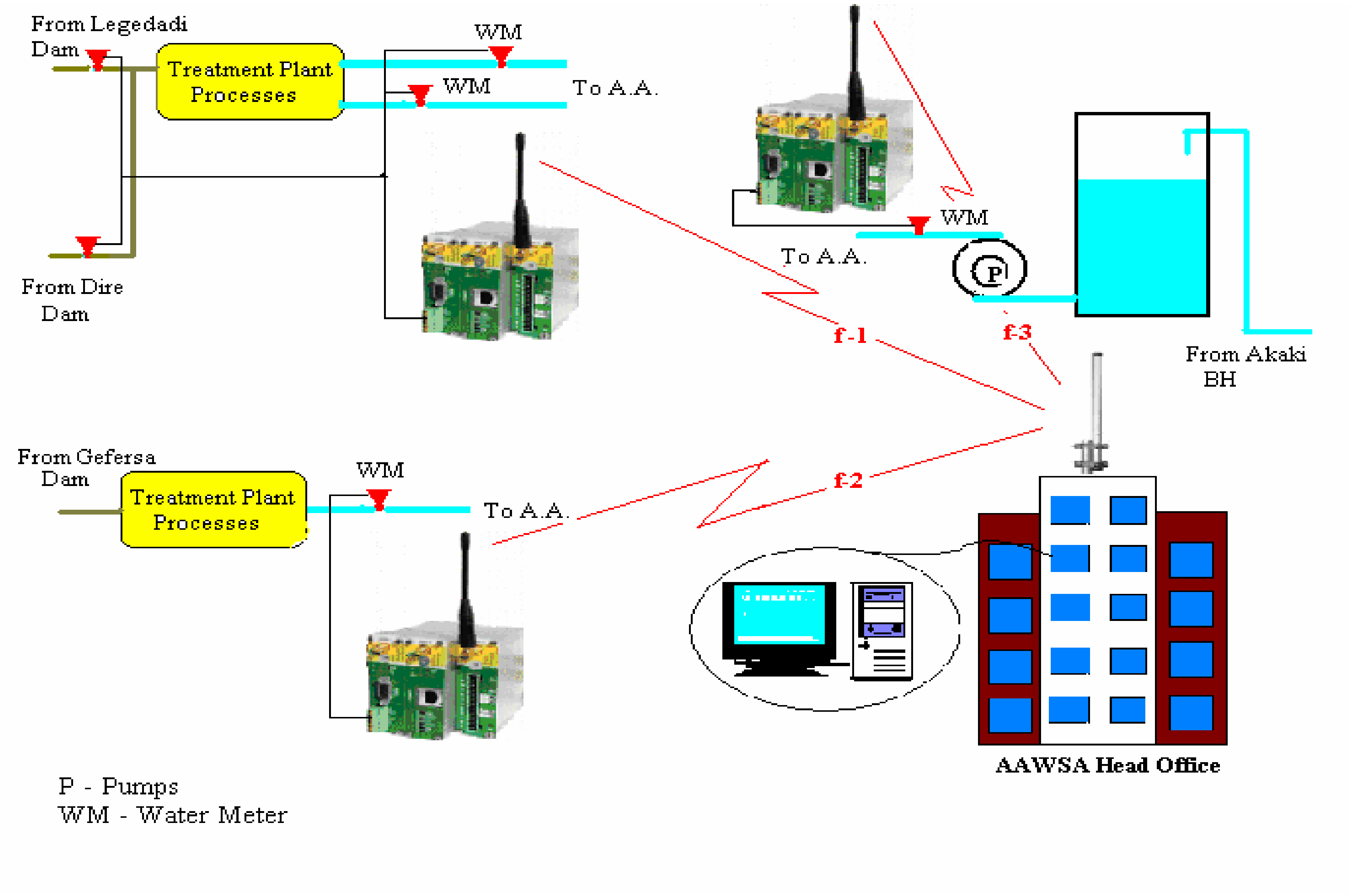

Fig. 4.1 Overview of model

For the model radio link design purpose CMS radio modem with the following specification from the manufacturer is used :

TECHNICAL SPECIFICATION

Frequency of operation :	450 to 470MHz (other frequency bands available)
Modulation Type :	GMSK with radio baud rate 4800
Channel spacing :	25kHz (12.5kHz available as an option)
Number of RF channels :	One, set by PIC micro controller
RF output power :	2W nominal at 12V DC
Receiver Sensitivity:	Selectable -110, -100 or -80dBm, or OFF (default)
Frequency stability :	±2.5ppm over temperature range
Supply voltage :	+12V DC nominal (+10 to +14 volts possible)
Size :	119 x 57 x 21mm (l x w x h) including connectors
Weight :	120 gms
Temperature (operating) :	-30 to +55 °C standard
Temperature (storage) :	-30 to +70 °C

Notes : The specification is extracted from CMS radio user manual, this radio is used for Akaki well field SACDA system telemetry.

4.2 Radio Link Coverage Model

Radio coverage is the service area supported by each center (host) station. The coverage depends on

- Service quality requirement, such as the required minimum received signal power level given the transmitted signal power, and
- The propagation environment.

For free space transmission with an omni directional antenna, the coverage area is a circle centered at the master station (transmitted) with a radius depending on the propagation loss. Given the transmitted signal power level, the minimum required received power level could be mapped to the maximum allowed path loss. Then from equation (2.5.2), the radius (d) can be determined. In practice, the path loss depends on the propagation environment, including the transmitter and receiver antenna height, and may differ from angle to angle as seen from the master station transmitter antenna. As a result, the coverage will generally have an irregular shape (not a circle). Thus, for proposed model, that is water major sources of AAWSA – Legedadi water treatment plant, Gefersa water treatment plant & Akaki well field, three frequencies in UHF band are proposed which are near by already used frequencies by AAWSA as deprecated in chapter 3. These arrangement could minimize the effects of irregular shape (not a circle) since one frequency could be used for 120^0 as seen from master station transmitter antennas.

To design the radio link coverage model non line of site propagation path loss models in section 2.5 are used. Using this model and proposed antenna mast length reception power (open field reception power and additional attenuation from land) and reception gain margin are determined. Tables 4.3, 4.4 and 4.5 show the detail evaluation of non-line of sight propagation path loss for radio link between AAWSA Head office and Legedadi water treatment plant, between AAWSA Head office and Gefersa water treatment plant and between AAWSA Head office and Akaki well field.

Besides initially proposed model site, water sources of AAWSA, as recommended by researcher adviser the nine higher water consumers radio link reception power and reception gain margin are determined. Tables 4.6 shows detailed evaluation of non line of sight propagation path loss for radio link between AAWSA head office and nine higher water consumers.

The propagation model for these higher customers is designed on the bases that from each remote sites station, nine consumers, monthly consumption in meter cube will be transmitted to central (host) stations, AAWSA head office. These nine consumers are assigned to either of three frequencies used for water source based on their direction as shown in the table 4.2. As it will be difficult to mount antenna mast at each customer compound proposed antenna height is 6 meters, assuming that the antenna could be installed in each customer's roof.

Table 4.2 Selected AAWSA customers distance from AAWSA head office

No.	Customer Name	Air Distance from Host station (Km)	Proposed Frequency (MHz)	Water Consumption (M^3)
1	Civil Aviation Authority (C.A)	3.39	466.000	42860.00
2	Filwoha Administation Corp. (F. Wuha)	4.58	465.750	29178.17
3	Tikur Anbessa Hospital (B.L.H)	5.48	465.750	23109.41
4	Special Housing Project (CMC)	5.36	465.500	22841.58
5	Sheraten Addis Hotel	4.40	465.750	16969.00
6	Matador Addis Tyre S.C (A. Tyre)	8.34	466.000	15771.25
7	Moha Soft Drinks I.S.C (Moha)	7.79	465.750	15017.08
8	Hilton Hotel (H. hotel)	3.81	465.750	14615.23
9	Addis Ababa University (6-kilo)	5.46	465.750	11900.67

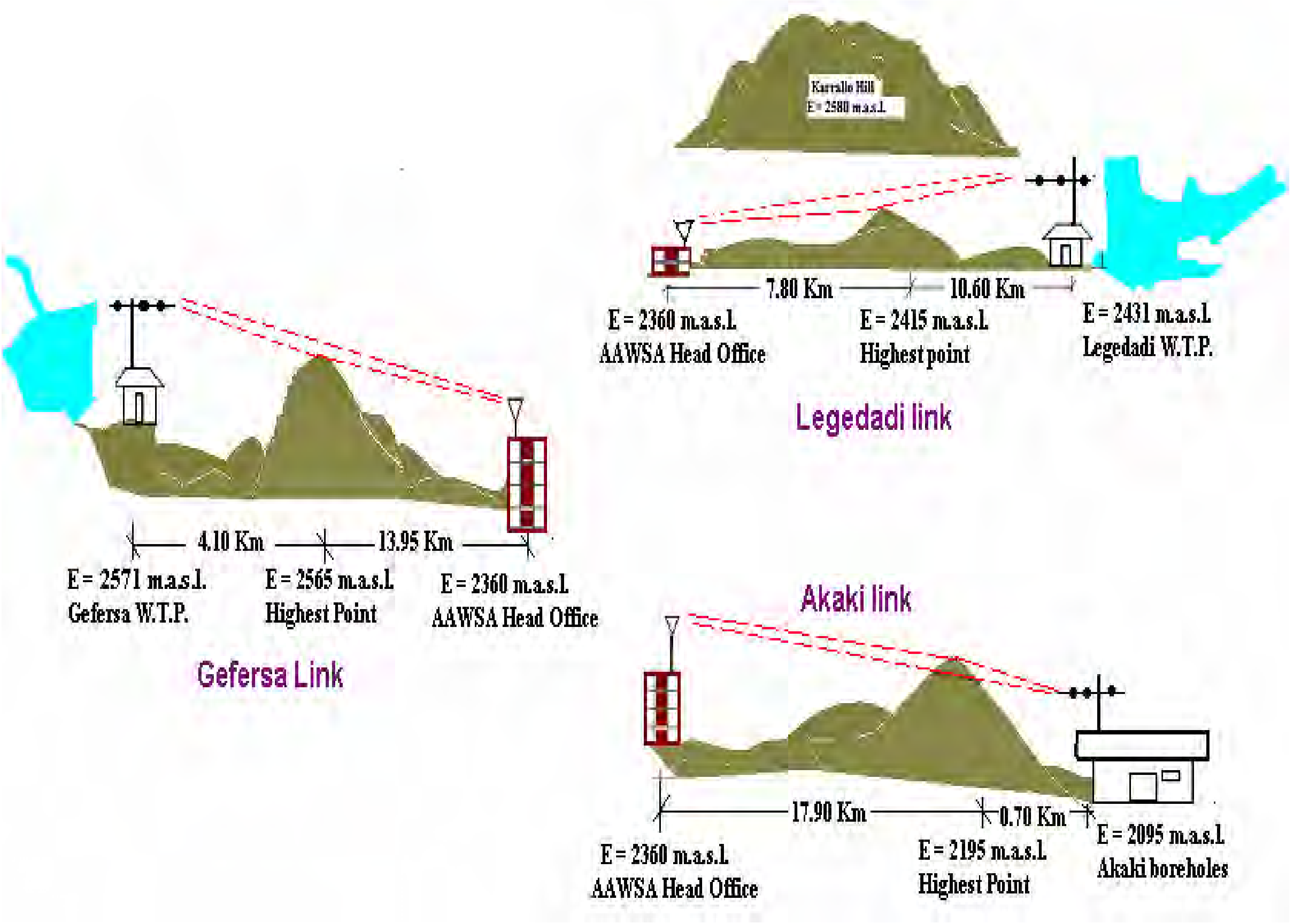

Fig. 4.2 Model radio link profile

Table 4.3 Non line of sight propagation path loss calculation for radio link between AAWSA Head office and Legedadi water treatment plant

Description	Value	Gain/Loss	Relation for Gain/Loss
Reception sensibility	-110.0 dBm		*From Selected radio model*
Transmission power	2.0 W	33.0 dBm	$P_t = 10\log(2x1000)$
Isotropic transmission constant	-	-32.4 dBm	*Constant*
Operating frequency	465.5 MHz	-53.4 dBm	$-20\log(465.500)$
Transmitter cable length (LMR -600)	20 m	-1.12 dBm	*From Appendix 1 table*
Transmitter antenna gain	20.0 dBm	20.0 dBm	*Assumption*
Receiver cable length (RG213U)	60 m	-1.12 dBm	*From Appendix 1 table*
Receiver antenna gain	20.0 dBm	20.0 dBm	*Assumption*
Distance between sites	18.4 km	-50.6 dBm	$-40\log(18.4)$
Open field reception power (P_{ro})		**-65.6 dBm**	
Proposed antenna mast	**12.0 m**		
Highest point height-1	43.0 m		
Highest point distance-1	7.8 km		
Highest point height-2	28.0 m		
Highest point distance-2	10.6 km		
incident angle alpha 1	0.00551 rd		
incident angle alpha 2	0.00264 rd		
Diffraction coefficient at highest point v	187.739	-58.4 dBm	$= -6.9 - 20\log(\sqrt{\nu^2+1}+\nu)$
Radius at the highest point r	20 m	-0.3 dBm	$= -11.7(\alpha_1 - \alpha_2)\sqrt{(\pi r/\lambda)}$
Additional attenuation from land (Att.)		**-58.7 dBm**	$= L(\nu) + L_{ex}$
Reception power		**-124.3 dBm**	$= pro + Att.$
Reception gain margin		-14.3 dBm	$= P_r - P_{rs}$

Table 4.4 Non line of sight propagation path Loss calculation for radio link between AAWSA Head office and Gefersa water treatment plant

Description	Value	Gain/Loss	Relation for Gain/Loss
Reception sensibility	-110.0 dBm		*From Selected radio model*
Transmission power	2.0 W	33.0 dBm	$P_t = 10\log(2x1000)$
Isotropic transmission constant	-	-32.4 dBm	*Constant*
Operating frequency	465.75 MHz	-53.4 dBm	$-20\log(465.7500)$
Transmitter cable length (LMR -600)	20 m	-1.12 dBm	*From Appendix 1 table*
Transmitter antenna gain	20.0 dBm	20.0 dBm	*Assumption*
Receiver cable length (RG213U)	60 m	-1.12 dBm	*From Appendix 1 table*
Receiver antenna gain	20.0 dBm	20.0 dBm	*Assumption*
Distance between sites	18.05 km	-50.3 dBm	$-40\log(18.05)$
Open field reception power (P_{ro})		**-65.3 dBm**	
Proposed antenna mast	**12.0 m**		
Highest point height-1	193.0 m		
Highest point distance-1	13.95km		
Highest point height-2	18.0 m		
Highest point distance-2	4.1 km		
incident angle alpha 1	0.01383 rd		
incident angle alpha 2	0.00439 rd		
Diffraction coefficient at highest point v	497.542	-66.9 dBm	$= -6.9 - 20\log(\sqrt{\nu^2+1}+\nu)$
Radius at the highest point r	20 m	1.1 dBm	$= -11.7(\alpha_1 - \alpha_2)\sqrt{(\pi r/\lambda)}$
Additional attenuation from land (Att.)		**-65.8 dBm**	$= L(\nu) + L_{ex}$
Reception power		**-131.0 dBm**	$= pro + Att.$
Reception gain margin		-21.0 dBm	$= P_r - P_{rs}$

Table 4.5 Non line of sight propagation path Loss calculation for radio link between AAWSA Head office and Akaki well field

Description	Value	Gain/Loss	Relation for Gain/Loss
Reception sensibility	-110.0 dBm		*From Selected radio model*
Transmission power	2.0 W	33.0 dBm	*P_t = 10log (2x1000)*
Isotropic transmission constant	-	-32.4 dBm	*Constant*
Operating frequency	466.000 MHz	-53.4 dBm	*- 20log(466)*
Transmitter cable length (LMR -600)	20 m	-1.12 dBm	*From Appendix 1 table*
Transmitter antenna gain	20.0 dBm	20.0 dBm	*Assumption*
Receiver cable length (RG213U)	20 m	-1.12 dBm	*From Appendix 1 table*
Receiver antenna gain	20.0 dBm	20.0 dBm	*Assumption*
Distance between sites	18.6 km	-50.8 dBm	*- 40log(18.6)*
Open field reception power		**-65.8 dBm**	
Proposed antenna mast	**12.0 m**		
Highest point height-1	165.0 m		
Highest point distance-1	17.9 km		
Highest point height-2	88.0 m		
Highest point distance-2	.7 km		
incident angle alpha 1	0.00922 rd		
incident angle alpha 2	0.12506 rd		
Diffraction coefficient at highest point v	62.246	-48.8 dBm	$= -6.9 - 20\log(\sqrt{\nu^2+1}+\nu)$
Radius at the highest point r	20 m	-13.4 dBm	$= -11.7(\alpha_1+\alpha_2)\sqrt{(\pi r/\lambda)}$
Additional attenuation from land (Att.)		**-62.2 dBm**	$= L(\nu) + L_{ex}$
Reception power		**-128.0 dBm**	*= pro + Att.*
Reception gain margin		-18.0 dBm	$= P_r - P_{rs}$

In the table 4.6 below reception power and reception power gain of nine selected consumers are evaluated using the path loss model in section 2.5 the same as path loss evaluation for water sources. The results are summarized in the table below.

Table 4.6 Path loss evaluation between AAWSA head office and the nine consumers

No.	Customer Name	Frequency Group	Reception Power	Reception Power Gain
1	Civil Aviation Authority (C.A)	Akaki	-43.1 dBm	66.9 dBm
2	Filwoha Administation Corp. (F. Wuha)	Gefersa	-48.3 dBm	61.7 dBm
3	Tikur Anbessa Hospital (B.L.H)	Gefersa	-51.4 dBm	58.6 dBm
4	Special Housing Project (CMC)	Legedadi	-51.1 dBm	58.9 dBm
5	Sheraten Addis Hotel	Gefersa	-47.6 dBm	62.4 dBm
6	Matador Addis Tyre S.C (A. Tyre)	Akaki	-58.7 dBm	51.3 dBm
7	Moha Soft Drinks I.S.C (Moha)	Gefersa	-57.6 dBm	52.4 dBm
8	Hilton Hotel (H. hotel)	Gefersa	-45.1 dBm	64.9 dBm
9	Addis Ababa University (6-kilo)	Gefersa	-51.4 dBm	58.6 dBm

4.3 Bit Error Rate (BER) Performance Model [1]

To design convenient radio communication model, it is very important to select modulation and demodulation techniques based on the following three requirements:

- **High spectral efficiency:** In radio communication systems, we have to maximize spectral efficiency in terms of bit rate per unit bandwidth per unit area (bit/s/Hz/m^2) for data transmission or in terms of the number of voice channels per unit bandwidth per unit area (ch/Hz/m^2) for voice transmission.
- **High power efficiency:** Terminals for radio communication systems should be small under strict limitation of battery size. To satisfy this requirement, power efficiency for the transmitter amplifier should be high.
- **High fading immunity:** Terminals for radio communication systems are located in multi path fading environments, Therefore, they should be operated under time-varying multi path (both flat Rayleigh and frequency selective fading) condition.

Based on these requirements constant envelope digital modulation schemes using C - class amplifier aiming to achieve high power efficient terminals with high robustness to signal level variation due to fading is commonly used for city radio link design. Among such modulation schemes Gaussian - filtered minimum shift keying (GMSK) is selected for the proposed model design.

4.3.1 GMSK Modulation Process [21]

GMSK is minimum shift keying (MSK) (frequency modulation with its modulation index of 0.5) with a pre-modulation Gaussian filter. Fig. 4.3 shows a configuration of the GMSK modulator and coherent detection. When the transmitted data sequence is $\{a_n\}$, a waveform of the transmitted bit sequence after passing through data to phase converter can be expressed as :

$$\mathbf{a}(t) = \sum_{k=-\infty}^{\infty} b_k \mathbf{u}(t - kT_b) \tag{4.3.1}$$

Where : $b_k = \begin{cases} 1; & a_k = 1 \\ -1; & a_k = 0 \end{cases}$ $\quad$ $u(t) = \begin{cases} 1; & 0 \leq t < T_b \\ 0; & \text{otherwise} \end{cases}$

When $a(t)$ is filtered by a Gaussian LPF with its 3-dB band width of B_b, its output is given by

$$b(t) = a(t) \otimes c_b(t) \tag{4.3.2}$$

Where : $c_b = \sqrt{\frac{2\pi}{\ln 2}} B_b \exp\left(-\frac{2\pi^2}{\ln 2} B_b^2 t^2\right)$

b(t) is then fed to the FM modulator as shown in fig. 4.5 with its modulation index of 0.5 to obtain the transmitted signal expressed as

(4.3.3)

$$s_T = A \cos (2\pi f_c t + \phi (t) + \theta_0)$$

$$\phi(t) = \frac{\pi}{2T_b} \int_{-\infty}^{t} b(\tau)\, d\tau \qquad (4.3.4)$$

Where the signal phase is shifted with an angle frequency of $0.5\ \pi\ /T_b$ when $a_n = 1$, and it is rotated with an angle frequency of $-0.5\ \pi/T_b$ when $a_n = 0$.

4.3.2 GMSK with Coherent Detection [1]

Figure 4.3 shows a receiver configuration of GMSK with coherent detection. The received signal is first filtered by a BPF to pick up the desired signal as well as to suppress adjacent channel interference and noise. When the output signal of the Voltage Controlled Oscillator (VCO) is expressed as

$$s_{VCO} = \cos (2\pi f_c t + \theta_1) \qquad (4.3.5)$$

the LPF outputs of the in phase and quadreture component given by :

$$v_I(t) = 0.5A \cos (\phi(t) + \Delta\theta) \qquad (4.3.6)$$

$$v_Q(t) = 0.5A \sin (\phi(t) + \Delta\theta) \qquad (4.3.7)$$

Where : $\Delta\theta = \theta_0 - \theta_1$

When we multiply $v_I(t)$ and $v_Q(t)$, we can obtain

$$v_p(t) = 0.125A^2 \sin (2\phi(t) + 2\Delta\theta) \qquad (4.3.8)$$

Using this signal, the symbol timing clock

$$v_{CLK}(t) = \cos \left(\frac{\pi}{T_s} t \right) \qquad (4.3.9)$$

is first regenerated by the symbol timing synchronization circuits. Suppose that the bandwidth of the pre-modulation Gaussian filter is infinite (that corresponds to MSK), and the initial phase is 0 radian for analysis convenience. In this case, $\phi(t)$ can be expressed as

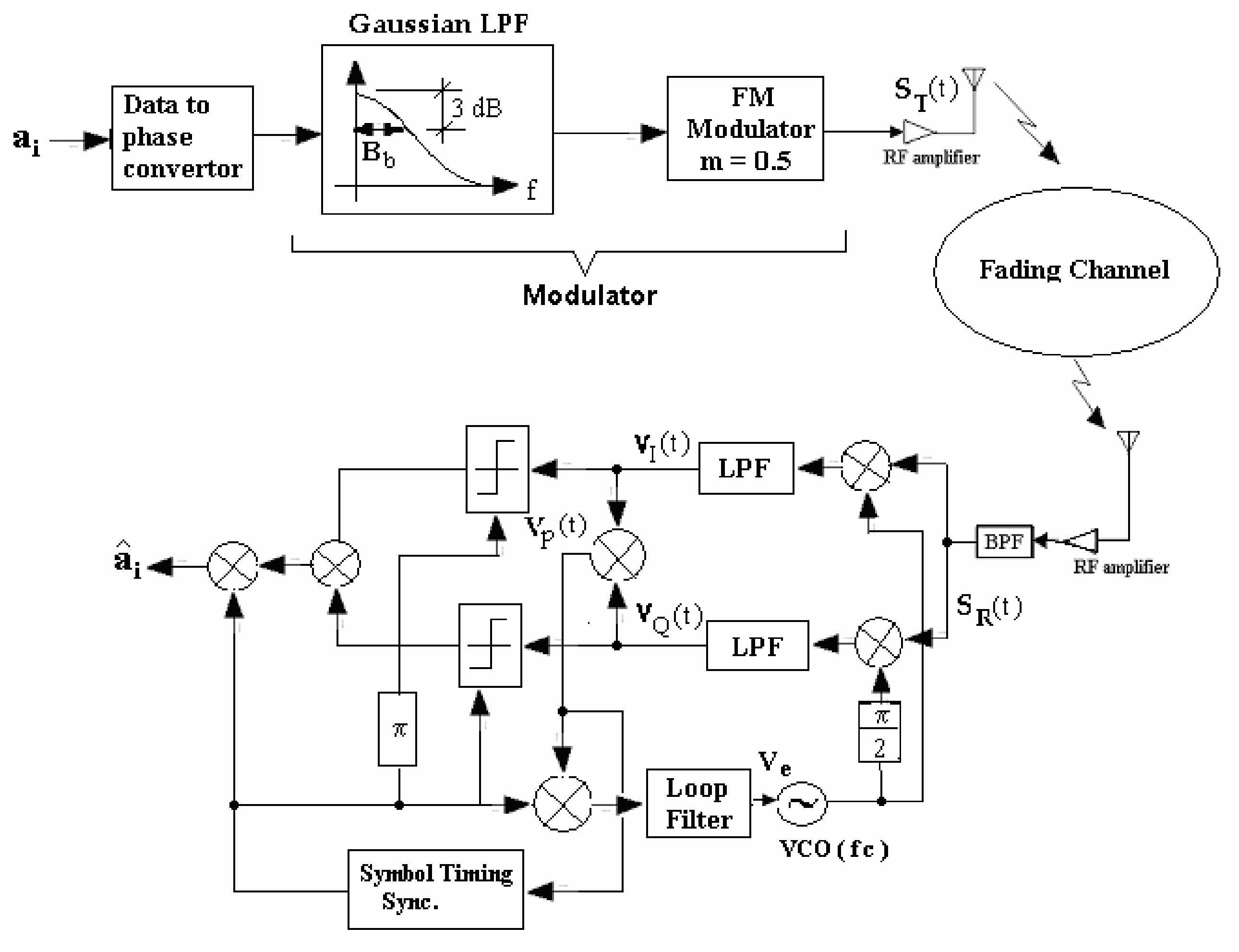

Fig. 4.3 Model transmitter and receiver configuration of GMSK

$$\phi(t)=\begin{cases} a_n\pi\dfrac{t-nT_b}{2T_b}+\begin{pmatrix}0\\ \pi\end{pmatrix}+\Delta\theta & n=\text{even}\\[2ex] a_n\pi\dfrac{t-nT_b}{2T_b}+\begin{pmatrix}\pi/2\\ -\pi/2\end{pmatrix}+\Delta\theta & n=\text{odd}\end{cases} \tag{4.3.10}$$

When we substitute equation (4.3.10) into equation (4.3.8), multiply $V_p(t)$ and $V_{CLK}(t)$, and remove the high-frequency component by a loop filter, we can obtain

$$V_e(t) = 0.0625A^2 \sin(2\Delta\theta) \tag{4.3.11}$$

When $v_e(t)$ is fed to the VCO, the VCO signal phase is controlled to keep the average $v_e(t)$ at 0. As a result, $v_I(t)$ and $v_Q(t)$ are obtained as

$$v_I(t) = \cos(\phi(t)) \tag{4.3.12}$$

$$v_Q(t) = \sin(\phi(t)) \tag{4.3.13}$$

When n is an odd number, if the transmitted data is logical 1, $\phi(t)$ stays in the first or third quadrants of the phase plane, and if the transmitted data is logical 0, it stays in the second or fourth quadrants. On the other hand, when n is an even number and the transmitted data is logical 1, $\phi(t)$ stays in the second or fourth quadrants, and it stays in the first or third quadrants when the transmitted data is logical 0. As a result, the transmitted data can be estimated as

$$\hat{a}(t) = \mathrm{sgn}(v_I(t)) \bullet \mathrm{sgn}(v_Q(t)) \bullet v_{CLK}(t) \tag{4.3.14}$$

The BER performance of GMSK under AWGN channel, when the base band signal before an FM modulator is band limited by Gaussian LPF, is approximated by

$$P_{GMSK}(\gamma) \cong \mathrm{erfc}(\mathrm{sqrt}(\beta\gamma)) \tag{4.3.15}$$

Where : β is a factor determined by the degradation due to the pre-modulation filter and γ is signal to noise ratio.

Table 4.7 [1] shows the relationship between B_bT_b and the 99.99% bandwidth of the GMSK modulated signal. As can be seen from the table, a narrow pre-modulation filter can reduce the bandwidth of the modulated signal by sacrificing the BER performance.

Table 4.7 Relationship between B_bT_b, 99.99% bandwidth of the transmitted signal, and β

B_bT_b	99.99% Bandwidth	β
0.20	1.22	0.76
0.25	1.37	0.84
0.30	1.41	0.89
0.40	1.80	0.94
0.50	2.08	0.97

4.4 Required Minimum Received Signal Level Evaluation [1] [11]

At the receiver, dominant noise is generated at the front-end RF amplifier. At this stage, the power spectrum of the thermal noise is given by

$$N_o = 10\log_{10}(kT) \ \ [\text{dBm/Hz}] \tag{4.4.1}$$

Where $k = 1.38 \times 10^{-20}$ (mW/Hz/K) is Boltmann's constant and T is temperature in degree Kelvin (K). Therefore, the noise power spectral density generated at the receiver RF amplifier is given by

$$N_o = 10\log_{10}(kT) \ \ [\text{dBm/Hz}] + NF \ (\text{dB}) \tag{4.4.2}$$

Where NF is the noise figure of the RF amplifier. Using equation (4.4.2), we can obtain the relationship between the minimum received signal level (P_{rsl}) and the required E_b/N_o as follows :

$$P_{rsl} \ [\text{dBm}] = (E_b/N_o)_{req} \ [\text{dB}] + 10\log_{10}R_b \ [\text{bit/s}] + N_o \ [\text{dBm/Hz}] \tag{4.4.3}$$

Where R_b is a bit rate of desired signal. Using this result, we can evaluate required receiver sensitivity for the model, considering temperature T = 299.15 K (26^0C), R_b = 4800 bit/sec. and BER assumed to be 10^{-2} where E_b/N_o will be ≈5.25 dB from fig. 5.4, evaluated as follows:

$N_o = 10\log_{10}(1.38\text{x}10^{-20}\text{ x }299.15) = -173.84$ [dBm/Hz], and

P_{rsl} [dBm] = $(E_b/N_o)_{req}$ [dB] + $10\log_{10}R_b$ [bit/s] + N_o [dBm/Hz]

P_{rsl} = 5.25[dB] + $10\log_{10}4800$ [bit/s] + (-173.84) [dBm/Hz]

P_{rsl} = 5.25 [dB] + 36.81 [bit/s] + (-173.84) [dBm/Hz] = **-131.77 dBm**

This shows that the model received signal strength -124.30 dBm, -131.00 dBm and -128.00 dBm for Legedadi water treatment plant, Gefersa water treatment plant and Akaki well field radio link, respectively, is higher than the required minimum signal strength, -131.77 dBm.

Similarly, for selected nine bulk consumers evaluated reception power is higher than the minimum required signal strength with specified BER and data rate in the technical specification of proposed radio modem.

CHAPTER - V

SIMULATIONS, FINDING AND DISCUSSION

5.1 Path Loss Model Simulations

Proposed model radio link design, propagation path loss due to distance depends on the system operation environments. Therefore, we have to create appropriate path loss model for each operational environment as discussed in chapter 2, and then we have to evaluate the coverage area of a system using the created model.

The result obtained from the model is simulated as shown in the figure 5.1, 5.2 and 5.3 using MATLAB program [13] and data from GPS site map attached in appendix 2, 3, 4 and appendix 6.

a. Non-line of sight propagation path loss simulation for radio link between AAWSA Head office and Legedadi water treatment plant
    - Highest point distance from Head Office 7.80 Km
    - Highest point distance from Legedadi water treatment plant 10.60 Km
    - Height difference between Head office antenna and highest point is 5 meters
    - Height difference between Legedadi water treatment plant and highest point is 76 meters
    - Antenna mast height is 12 m and cylindrical hill top diameter approximated Ds = 20 m

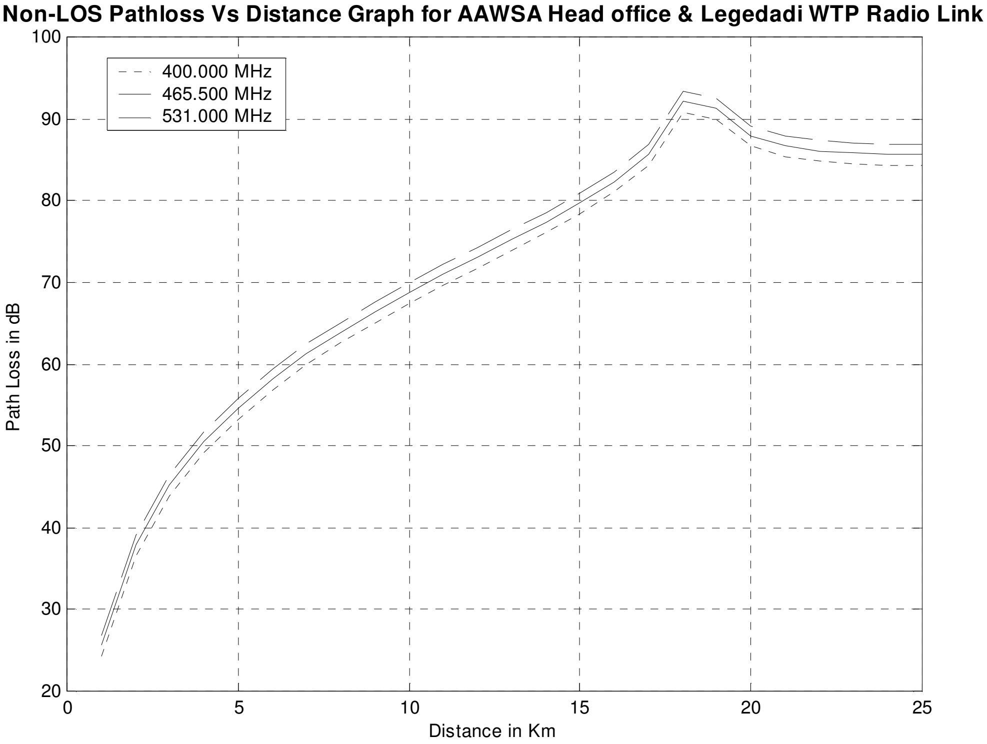

Fig. 5.1 Path loss Vs distance curve between Legedadi treatment and AAWSA head office *{ MATLAB code is attached in appendix 2 }*

b. Non line of sight propagation pathloss simulation for radio link between AAWSA head office and Gefersa water treatment plant

   - Highest point distance from Head Office 13.95 Km
   - Highest point distance from Gefersa water treatment plant 4.60 Km
   - Height difference between Head office antenna and highest point is 145 meters
   - Height difference between Gefersa water treatment plant and highest point is 66 meters
   - Antenna mast height is 12 m and Cylindrical hill top diameter approximated Ds = 20 m

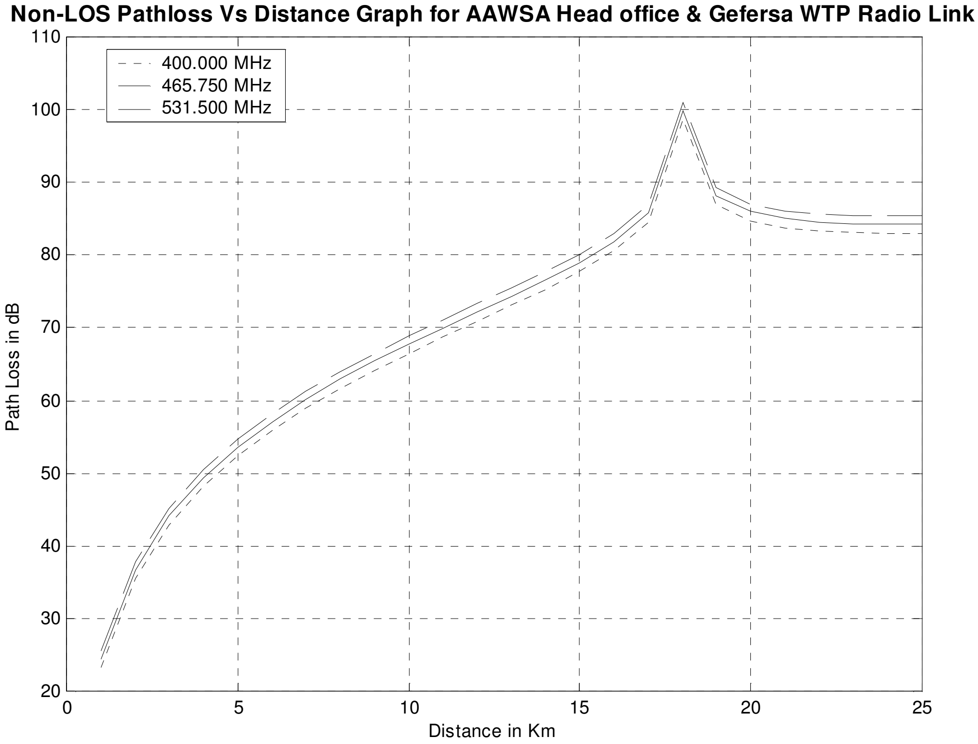

Fig. 5.2 Path loss Vs distance curve between Geferssa WTP and AAWSA Head office

{ MATLAB code is attached in appendix 3 }

c. Non line of sight propagation path loss simulation for radio link between AAWSA Head office and Akaki well field

- Highest point distance from AAWSA Head Office 17.90 Km
- Highest point distance from Akaki borehole 0.70 Km
- Height difference between Head office antenna and highest point is 39 meters
- Height difference between Akaki borehole water treatment plant and highest point is 79 meters
- Antenna mast height is 12 m and Cylindrical hill top diameter approximated Ds = 20 m

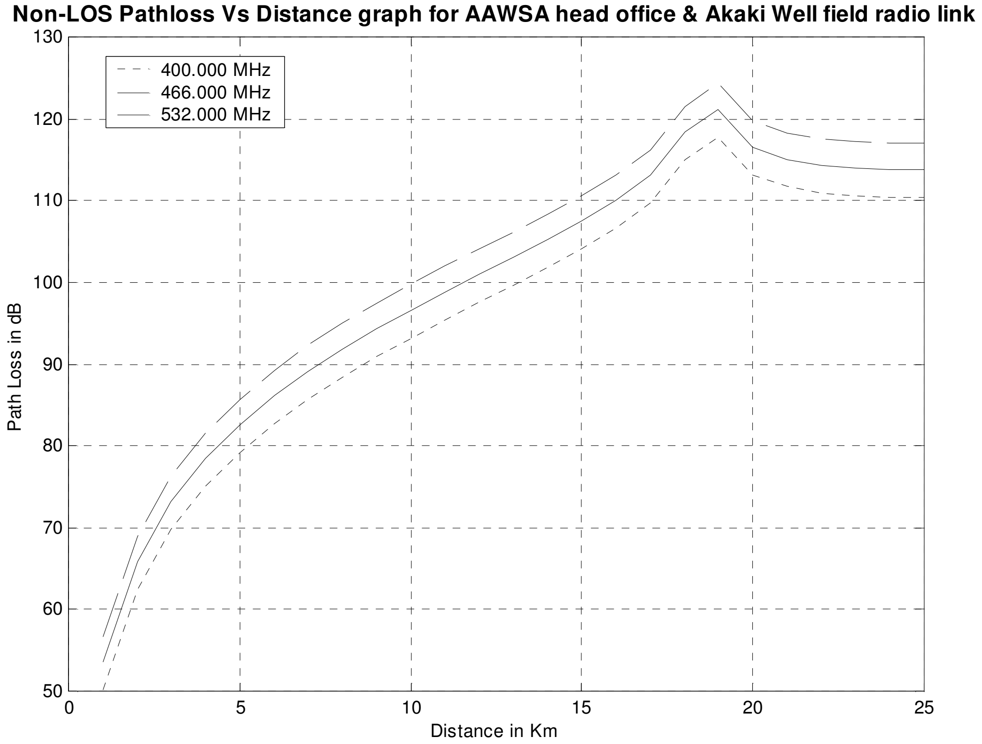

Fig. 5.3 Path loss Vs distance between Akaki borehole and AAWSA head office

{ MATLAB code is attached in appendix 4 }

d. Non line of sight propagation path loss simulation for radio link between AAWSA Head office and the nine selected bulk consumers

  - Air distances as indicated in the table 4.2
  - Frequencies are included in table 4.2
  - Antenna height proposed 6 meters
  - Highest point between AAWSA head office and nine customers 0 meter

Figures 5.4, 5.5 and 5.6 shows the path loss model simulation for radio link between AAWSA head office and the nine consumers water meter through their respective frequency group.

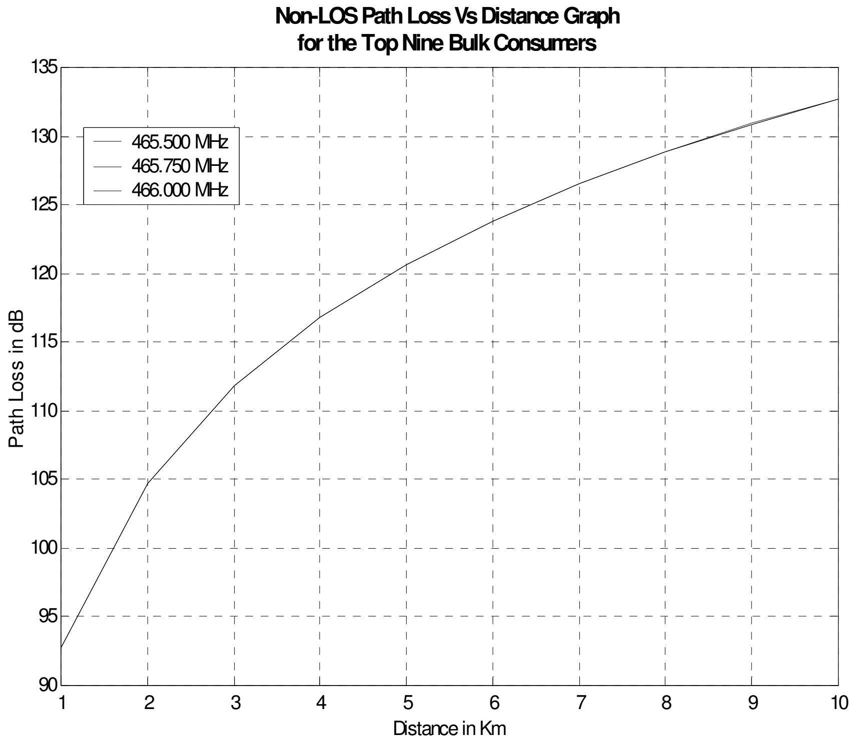

Fig. 5.4 Path loss Vs distance between Nine customers water meters and AAWSA head office *{ MATLAB code is attached in appendix 5}*

5.2 BER Performance Simulation [1] [12]

It is also important to know under which conditions the BER is evaluated, that is AWGN conditions or fading conditions. Actually it depends on the holding time of a radio channel. When the holding time is relatively long compared to the fading duration as in the case of voice transmission, we have to evaluate the BER under fading conditions. In this case the fading margin is obtained by the statistics of the large-scale signal variation, such as the log-normal fading. In the case under consideration, data transmission, the holding time is relatively short and even if there is fading retry could be performed, thus, we can evaluate the BER under AWGN conditions. Therefore, for the model BER performances of GMSK (B_bT_b = 0.25) with coherent detection under AWGN conditions as simulated using MATLAB code (in Appendix 6). is shown in fig. 5.7.

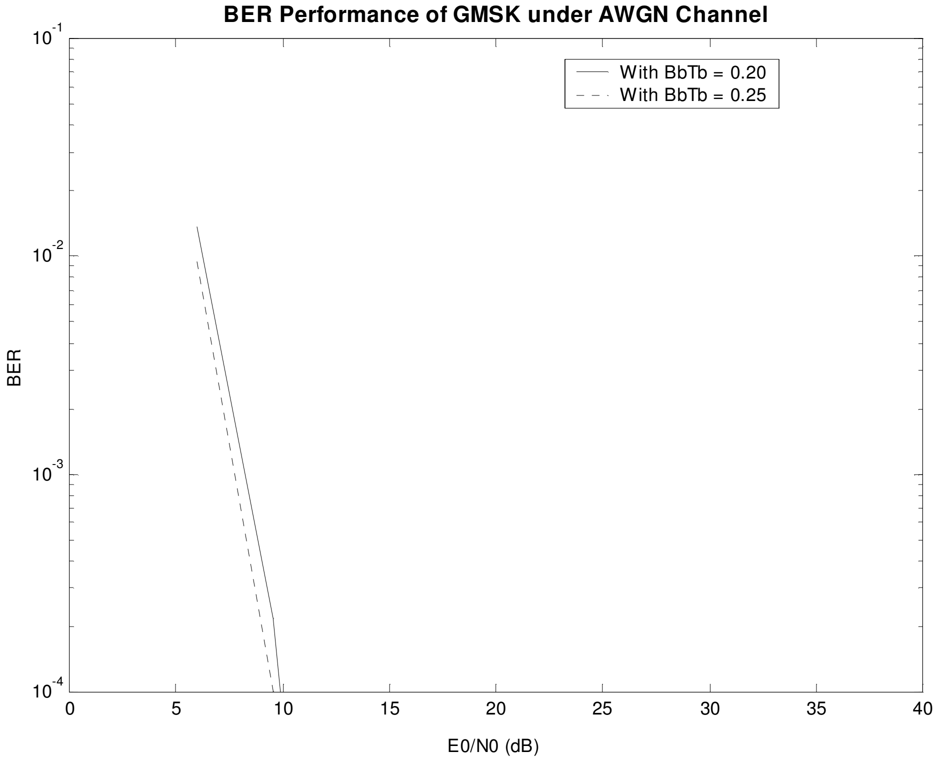

Fig. 5.5 BER performances of GMSK with coherent detection under AWGN

{ MATLAB code is attached in appendix 6}

5.3 Findings

Information collected from AAWSA, included in chapter 3, justifies that the bulk customers, only 10 %, are fewer than domestic customers, whose consumption is between 0 - 20 m^3 a day, while water bills collected from bulk consumers are far away from domestic customers, that is 80 % of the total water bill in a month. From this finding we can conclude that having good water meter reading system of bulk customers enhances AAWSA billing efficiency, which in turn brings up the authority capacity to provide enough and durable water system for the city of Addis Ababa. Mean while AAWSA can get money to enhance water metering efficiency on domestic customers by employing advanced technology like drive through water metering or prepaid water billing.

Treated water from Legedadi water treatment plant transported to Addis Ababa city through 1400 mm diameter and 900 mm diameter pipes. To measure outflow from the plant on both 1400 mm diameter and 900 mm diameter pipes Faure Herman insertion flow meters are fitted in the treatment plant compound. Similarly, Gefersa treatment plant has bulk water meter to measure outflow from the plant and Akaki well field has electromagnetic flow meters installed on 600 mm diameter pipe through which water is pumped to the city.

Monthly and yearly production report is generated by manually collect readings by respective plant operators and manually prepare production sheet and transfer to the head office. At the head office this production sheet is used to prepare report but the researcher observed that the way the information handled is not possible for data analysis and to take action accordingly. The water meter reading collected from the water sources and water meter reading from AAWSA customers are used to determine unaccounted for water. AAWSA has high UFW estimated about 37% , Thus, the researcher believes that if AAWSA has better water metering system both at the water sources and customer taps, it can over came one of its challenge as indicated in AAWSA business plan.

One of the specific objectives of this thesis is to know the implementation requirements of radio based water meter reading, thus the researcher identified that there are in the global market water meters or flow meters that could be connected to the radio modem through water meter registers. It is also identified that AAWSA has good experience in using radio modems for data transmission as far as around 15 km using Motorola Radio modem, CMS radio modem and Wood and Duglas radio modems for the last five years without considerable problems.

From the model analytical result & simulation it is shown that :

- The model radio link reception power for the link between AAWSA head office and Legedadi W.T.P. is higher than the required minimum signal strength by the receiver, which is -131.78 dBm. Therefore, the radio link is possible with good reception gain margin.

- The model radio link reception power for radio link between AAWSA head office and Gefersa W.T.P. is higher than the required minimum signal strength by the receiver, which is -131.78 dBm. Therefore, the radio link is possible with good reception gain margin.
- The model radio link reception power for the radio link between AAWSA head office and Akaki W.T.P. is higher than the required minimum signal strength by the receiver, which is -131.78 dBm. Therefore, the radio link is possible with good reception gain margin.

5.4 Discussions

In this thesis the components required for radio-based networking application are identified and demonstrated. Once the components are available in the global market, next the radio propagation characteristics of proposed model studied. Based on the theories outlined under chapter 2 appropriate path loss model for fixed radio link is used to develop mathematical relation for propagation path loss. Similarly, BER performance evaluated based on proposed type radio modem technical specification and the Modulation model developed.

There are many more general models and empirical techniques for predicting non line of sight path losses [12], but most of them are aimed at prediction of the paths between elevated base stations and mobile or portable stations near ground level, and they typically have restrictions on the frequency range and distances for which they are valid; thus they may be of limited usefulness in the planning of fixed radio digital links. The best loss approximation on many non line of sight paths in urban areas like Addis Ababa as dealt in this thesis model is a fourth power distance law for a distance more than 1 km [7].

The fundamental aim of a radio link is to deliver sufficient signal power to the receiver at the far end of the link to achieve the required performance, water meter remote reading in the thesis case, objective. For water meter reading data transmission, the required aim is to transmit data with a minimum bit error rate. In the receiver demodulator, the BER is a function of Signal to noise ratio (SNR). At the frequency under consideration, 400 – 470 MHz UHF band, the noise power is often dominated by the internal receiver noise. In addition, the noise may also include significant power from interfering signals, necessitating the delivery of higher signal power to the receiver than would be the case under more ideal circumstances.

Accordingly, the model prepared for this thesis considers this fact to determine whether the radio links under consideration is possible or not. Thus, the researcher believes that the findings of this research demonstrated potential gains in using radio link for automatic water meter reading.

It is worth mentioning that there could also be some limitations and potential barriers in implementing radio based networking application to AAWSA water meter reading. This includes issues like:-

- Initial cost of water meters and radio system.
- Radio signal interference.
- System interoperability.
- Skilled manpower to run the system
- Management commitment and support through out the implementation phase are some due mentioned.

But the intention of this work is not to implement radio based water meter reading for all type of AAWSA customers, implementation could be started from water sources and zonal bulk meters, which immensely help AAWSA to reduce its high water leakage problem in the city through implementing appropriate leakage reduction strategy.

CHAPTER - VI

CONCLUSTIONS, RECOMMENDATIONS, AND FUTURE DIRECTIONS

6.1 Introduction

In this chapter, the key aspects of this thesis are concluded and recommendations are suggested. The contributions of this research are addressed and future directions are offered for the work.

6.2 Conclusions

The main goal of this research was to develop a general model to implement radio based networking application to AAWSA water meter reading system. As gained from the survey results, the more driving force to implement this system in AAWSA are :

- Improvement of revenue collection,
- Reduction water meter reading errors and reworks,
- Improvement of leakage reduction efforts
- Reduces operation and maintenance cost, and
- Bring customer satisfaction.

AAWSA is facing series problem in collecting supply charges effectively, due to meters are not read on similar day and time every month and some times reading may be done by approximation instead of actual reading just due to non responsible meter readers, which also cause customer dissatisfactions. To be effective AAWSA must implement minimum error, cost effective, on time meter reading and billing system, and have to be innovative than ever before.

From the literature review, we can conclude that, one of the best ways to do this is to implement radio based automatic meter reading system principles into AAWSA water meter reading methods. As it has been seen so far, radio based water meter reading principles can be applied for :

- Flow meters at water sources to measure actual treated water production of each water sources and register water flow trends
- Zonal bulk meters for sub-system isolation
- Bulk consumers water meter that is for customers who consume more than 20 meter cube per day, and
- Domestic consumers like customers living in apartments and condominiums, gradually.

From the data collected, refer table 3.1, it can be seen that 74% of water supply is consumed by bulk customers who use above 20 m^3 per month. These customers are only 10% of the over all customers where as 80 % of the total bills are collected from these customers. This justifies the fact that if AAWSA implement effective means of water metering for these bulk consumers, billing efficiency will be enhanced, which in turn brings up the authority capacity to provide enough and durable water system for Addis Ababa city residence.

The other part of this work is to investigate the availability of technology, which allows AAWSA to implement radio based water metering system. The study result shows that there are a number of manufacturers who produce water meters and flow meters for automatic potable water metering. Similarly a number of UHF radio modem manufacturers are available in the global market, like Motorola radio, Tait radio, CMS radio, Wood and Dauglas Radio.

Other investigation shows that AAWSA has good experience of using radio link for voice and data transmission and reception. The system for vocal radio link was working since 2001 for operation and maintenance purpose, and the system at Akaki borehole and Legedadi water treatment plant for control and monitoring data radio link is working since 2002 and 2003, respectively. These confirm that reliable communication could be achieved in UHF band.

Finally a general implementation model was developed based on radio link between AAWSA Head office and Legedadi water treatment plant, Gefersa water treatment plant and Akaki well field.

In the model, in order to evaluate coverage area, appropriate path loss model for each radio link was used as a tool. The model can be uses to implement radio link design for zonal bulk meters for sub-system isolation and bulk consumers' water meter reading which have coverage area less than the model radio links.

From the model analytical result it is shown that the model radio link received signal strength, for the link between AAWSA head office and Legedadi W.T.P., Gefersa W.T.P. and Akaki W.T.P., is higher than the required minimum signal strength, which is -131.78 dBm.

6.3 Recommendations

The implementation model of radio based networking developed for the AAWSA is made with the consideration of where the authority is at the moment. The readiness of AAWSA is rated at good stage to implement the model as a beginning. Therefore, it is recommended to implement the model first, Zonal bulk meters and bulk consumers meter as phase two and three, respectively, using the same frequencies used for the model.

After implementing the first phase, the model radio based automatic water metering, and evaluating the result gained:

- Improved measurement.
- Reliability of connection, and
- Operation and maintenance cost reduction

The second and third phase could be continued, by doing so AAWSA gain the following advantages:

- Improved meter reading efficiency
- Introduce zone metering at area level
- Introduce best leakage control mechanism at area bases.
- Improve revenue collection
- Record consumption properly
- Reduce illegal connection

6.4 Research Contributions and Future Directions

The major contribution of this research is the development of a systematic implementation model of radio link between AAWSA Head office and Legedadi water treatment plant, Gefersa water treatment plant and Akaki well field for automatic water metering as good starting point. Previously there was no effort to implement this innovative system in AAWSA.

The primary idea of this research is to help AAWSA to take initiatives in using such technology in order to become more cost-effective, meet public need and provide sustainable and properly managed water supply system. The model developed for AAWSA can be readily extended to other town water supply Authorities.

The study in this work was conducted focusing on determining availability of technology to support automatic water meter reading through radio wave and study on radio propagation characteristics and determine whether the link is possible. So a natural extension of this work is once water meter reading become possible how effectively the frequencies could be utilized and to investigate, through the same system, whether it is possible system pressure at least on zonal bases could be monitored for various operation purpose and leakage control.

Other extension of this work can be to interconnect the radio based water metering system to the billing system so that reading and bill generation could be performed in one go.

APPENDIXES

Appendix 1 : Top 100 Customers Based on their Consumption

No	Customer Name	AAWSA Branch offices	Average Monthly Consumption (M^3)
1.	Yemidir Tore Mehandis Memiri	West Branch	17098.92
2.	Agip Benzinmadeya	West Branch	7865.42
3.	Yeshimebet Guma Woiz	West Branch	7066.29
4.	St Pouls Hospital	West Branch	6326.58
5.	Keneni Goshu	West Branch	6033.00
6.	Yemidir Tore Mehandis Memiri	West Branch	5588.50
7.	Matador Addis Tyre S.C	South branch	15771.25
8.	National Tobacco Enterprise	South Branch	10383.00
9.	Tele Communication	South Branch	9188.57
10.	Admini Of Rent Houses	South Branch	8646.58
11.	Awash Leather Indust	South Branch	7566.00
12.	Gebrena Minster	South Branch	7483.25
13.	Housing Adm.Corp	South Branch	7178.79
14.	National Alcohol And Liquor	South Branch	6524.42
15.	National Service	South Branch	6144.77
16.	Adel Abeba Yarn Factory	South Branch	4910.42
17.	Mun.A.A Abattoris Organizati	South Branch	4722.25
18.	A.A.R.H	South Branch	4540.83
19.	Ethio Ceiment Factory	South Branch	4520.58
20.	Pepsi Cola Fabrica	South Branch	4484.31
21.	Yencomad Inc.Put.Ltd.Co	South Branch	3839.00
22.	Shell Ethiopia Limitied	South Branch	3692.58
23.	Yetor Sefer Siradirgt	South Branch	3638.69
24.	Foot Ball Federation	South Branch	3181.00
25.	Ethio Pharmaceticals Manfact	South Branch	3125.25
26.	National Hotel	South Branch	2839.33
27.	Gibrna Minster	South Branch	2828.42
28.	Wohinibet Tsihfet Bete	South Branch	2763.67
29.	River Side Hotel	South Branch	2724.62
30.	Housing Adm.Corp	South Branch	2718.69
31.	H Michael Zewdie Ato	South Branch	2696.77
32.	Organization Of Africa Union	South Branch	2675.08
33.	Awash Winery Ac.Ma	South Branch	2619.17
34.	E C A F Co	South Branch	2586.67
35.	Addis Ababa University	North branck	11900-67
36.	A.A.Water and Sewer.Authority	North branck	11545.62
37.	Addis Ababa Univercity	North branck	9710.08
38.	A.A University Science Cent	North branck	8377.58
39.	Addis Ababa University	North branck	8321.33
40.	Addis Ababa University	North branck	7929.00

No	Customer Name	AAWSA Branch offices	Average Monthly Consumption (M^3)
41.	First Army Division	North branck	6484.00
42.	H Selassie Umiversityu	North branck	4641.33
43.	American Embassy	North branck	4457.08
44.	Nega And Melese	North branck	4191.08
45.	Addis Ababa University	North branck	3848.08
46.	Addis Ababa University	North branck	3841.08
47.	Minilik Hospital	North branck	3104.50
48.	Addis Ababa University	North branck	2734.92
49.	A.A.W.S.A Ankorcha	North Branch	3302.62
50.	Mekelakeya Mehandis Wanaa Memria	North Branch	2613.83
51.	Ethiopian Civil Service College	East Branch	24002.25
52.	Addis Ababa Gorif Masiwegejj	East Branch	5712.92
53.	Housing Administration	East Branch	3971.36
54.	Civil Aviation Authority	East Branch	42860.00
55.	Special Housing Project	East Branch	22841.58
56.	Yehager Mekelakeya	East Branch	21603.33
57.	Hilton Hotel	East Branch	14615.23
58.	Summit Partners P.L.C	East Branch	10300.17
59.	Economic Commission For Afr.	East Branch	10287.42
60.	Ministry Of Agriculture and R.D	East Branch	9577.50
61.	Ye Alktrik M.H Baleslt	East Branch	7029.08
62.	Girum Melaku Ato	East Branch	6237.19
63.	Midertore Mehandis Memiria	East Branch	5886.77
64.	ILRI	East Branch	5611.47
65.	Embassy Of Ussr	East Branch	5352.08
66.	Summit Partners Plc	East Branch	4877.33
67.	Ayat Private Limited Co.	East Branch	4492.17
68.	Telahun Tadesse Ato	East Branch	3321.67
69.	Asfaw Tefera Ato	East Branch	2784.67
70.	Friendship B Group	East Branch	2782.00
71.	C.C.E	East Branch	2614.83
72.	Filwoha Adm Corp	Central Branch	29178.17
73.	Tikur Anbessa Hospital	Central Branch	23109.41
74.	Tikur Anbesa Hospital	Central Branch	16983.92
75.	Sheraten Addis Hotel	Central Branch	16969.00
76.	Moha Soft Drinks I.S.C	Central Branch	15017.08
77.	Talaku Bete Mengist	Central Branch	10706.67
78.	Ghion Hote Enterprise	Central Branch	10135.67
79.	National Palace	Central Branch	8821.33
80.	Fila Wiwocha Asitedaoebi	Central Branch	8544.85
81.	A.A. Sanitation Beautification (Parks)	Central Branch	8112.25
82.	Palace Administration	Central Branch	7243.07
83.	Zewoditu Hospital	Central Branch	7193.92
84.	National Alchol Lico	Central Branch	5977.58

No	Customer Name	AAWSA Branch offices	Average Monthly Consumption (M^3)
85.	Police Hospital	Central Branch	5368.42
86.	E.Africa Bottling Pvt.Co	Central Branch	5110.50
87.	Dej Balicha Hospital	Central Branch	4518.17
88.	Ethio Transport Const.Author	Central Branch	4009.50
89.	A A City Council	Central Branch	3590.58
90.	Building College	Central Branch	3048.00
91.	Giyon Hotell	Central Branch	2969.25
92.	Ministry Of Post Office	Central Branch	2550.46
93.	Yemidir Tore Mehandis Memiri	Central Branch	2524.75
94.	Feresegna Police Tabia	Central Branch	2514.08
95.	Wabi Shebele Hotel	Central Branch	2510.54
96.	Yebahlina Sink Maderaja	Akaki Branch	7222.00
97.	Akaki Branch Office W.T. No 4	Akaki Branch	4850.75
98.	Akaki Spare Parts End Handto.S.C	Akaki Branch	4191.00
99.	Ministry Of Defence	Akaki Branch	3672.77
100.	Akaki Ketema Advantist Schoo	Akaki Branch	2542.83

Appendix 2 : MATLAB code for path loss model between AAWSA Head office and Legedadi water treatment plant

```
function modelpathloss1r(Pt,Hp,ht,hr,dh1,dh2,Ds)

%Non-LOS propagation path loss Vs distance graph where base station and Radio link between AAWSA
%Head office and Legedadi water treatment plant.

h1=Hp-ht;
h2=Hp-hr;
Pt=10*log10(Pt*1000);
Prs=-110.00;
Gt=10.00;
Gr=10.00;
Lt=-1.12;
Lr=-1.12;
for fc=400.000:65.500:531.000
  Lamda=2.998E8/(fc*1e8);
  for d=1:25;
    if d>=(4*h1*h2/Lamda)
      Lf=32.45+20*log10(fc)+40*log10(d);
    else d<(4*h1*h2/Lamda);
      Lf=32.45+20*log10(fc)+20*log10(d);
    end
    Alpha1=atan(h1/(dh1*1000));
    Alpha2=atan(h2/(dh2*1000));
    if h1<0
      H=h1;
    else h2<0;
      H=h2;
    end
    if H>0
      V=2*sqrt((abs(h1/sin(Alpha1))+abs(h2/sin(Alpha2))-(d*1000))/Lamda);
    else H<=0;
      V=-2*sqrt((abs(h1/sin(Alpha1))+abs(h2/sin(Alpha2))-(d*1000))/Lamda);
    end
    Lv=6.9+20*log10(sqrt(V^2+1)+V);
    r=(2*Ds*dh1*dh2)/(dh1^2+dh2^2);
    Lex =11.7*abs(Alpha1-Alpha2)*sqrt(pi*r/Lamda);
    Lp(d)=Lf+Lv+Lex;
  end
d=1:25;
plot(d,Lp(d),'g')
grid on
hold on
xlabel('Distance in Km');  ylabel('Path Loss in dB');
title('Non-LOS Pathloss Vs Distance Graph for AAWSA Head office and Legedadi WTP Radio Link');
end
```

Appendix 3 : MATLAB code for path loss model between AAWSA Head office and Gefersa water treatment plant

```
function modelpathloss2r(Pt,Hp,ht,hr,dh1,dh2,Ds)

% Non-LOS propagation path loss Vs distance graph for Radio link between AAWSA Head office
%and Gefersa water treatment plant,


h1=Hp-ht
h2=Hp-hr
Prs=-110.00;
Gt=10.00;
Gr=10.00;
Lt=-1.12;
Lr=-1.12;
Pt=10*log10(Pt*1000);
for fc=400.000:65.750:531.500
   Lamda=2.998E8/(fc*1e8);
   for d=1:25;
      if d>=(4*h1*h2/Lamda)
         Lf=32.45+20*log10(fc)+40*log10(d);
      else d<(4*h1*h2/Lamda);
         Lf=32.45+20*log10(fc)+20*log10(d);
      end
      Alpha1=atan(h1/(dh1*1000));
      Alpha2=atan(h2/(dh2*1000));
      if h1<0
         H=h1;
      else h2<0;
         H=h2;
      end
      if H>0
         V=2*sqrt((abs(h1/sin(Alpha1))+abs(h2/sin(Alpha2))-(d*1000))/Lamda);
      else
         V=-2*sqrt((abs(h1/sin(Alpha1))+abs(h2/sin(Alpha2))-(d*1000))/Lamda);
      end
      Lv=6.9+20*log10(sqrt(V^2+1)+V);
      r=(2*Ds*dh1*dh2)/(dh1^2+dh2^2);
      Lex =11.7*abs(Alpha1+Alpha2)*sqrt(pi*r/Lamda);
      Lp(d)=Lf+Lv+Lex;
   end
   d=1:25;
   plot(d,Lp(d),'g')
   grid on
   hold on
   xlabel('Distance in Km');  ylabel('Path Loss in dB');
   title('Non-LOS Pathloss Vs Distance Graph for AAWSA Head office and Gefersa
WTP  Radio Link');
end
```

Appendix 4 : MATLAB code for path loss model between AAWSA Head office and Akaki Bore hole CT (Collection Tank) reservoir

```
function modelpathloss3r(Pt,Hp,ht,hr,dh1,dh2,Ds)

% Non-LOS propagation path loss Vs distance graph for Radio link between AAWSA Head office
%and Akaki water treatment plant,
```

```
h1=Hp-ht;
h2=Hp-hr;
Pt=10*log10(Pt*1000);
Prs=-110.00;
Gt=10.00;
Gr=10.00;
Lt=-1.12;
Lr=-1.12;
for fc=400.000:66.000:532
   Lamda=2.998E8/(fc*1e8);
   for d=1:25;
      if d>=(4*h1*h2/Lamda)
         Lf=32.45+20*log10(fc)+40*log10(d);
      else d<(4*h1*h2/Lamda);
         Lf=32.45+20*log10(fc)+20*log10(d);
      end
      Alpha1=atan(h1/(dh1*1000));
      Alpha2=atan(h2/(dh2*1000));
      if h1<0
         H=h1;
      else h2<0;
         H=h2;
      end
      if H>0
         V=2*sqrt((abs(h1/sin(Alpha1))+abs(h2/sin(Alpha2))-(d*1000))/Lamda);
      else
         V=-2*sqrt((abs(h1/sin(Alpha1))+abs(h2/sin(Alpha2))-(d*1000))/Lamda);
      end
      Lv=6.9+20*log10(sqrt(V^2+1)+V);
      r=(2*Ds*dh1*dh2)/(dh1^2+dh2^2);
      Lex =11.7*abs(Alpha1+Alpha2)*sqrt(pi*r/Lamda);
      Lp(d)=Lf+Lv+Lex;
   end
   d=1:25;
   plot(d,Lp(d),'g')
   grid on
   hold on
   xlabel('Distance in Km');  ylabel('Path Loss in dB');
   title('Non-LOS Pathloss Vs Distance graph for AAWSA head office and Gefersa
WTP radio link');
end
```

Appendix 5 : MATLAB code for path loss model between AAWSA Head office and Nine higher bulk water users.

```
function modelpathloss

%Non-LOS propagation path loss Vs distance graph where base station and
%Radio link between AAWSA Head office & the nine bulk consumers using
%legedadi, Geferssa and Akaki radio link frequencies.

h1=0;
h2=0;
Pt=10*log10(2*1000);
Prs=-110.00;
Gt=20.00;
Gr=20.00;
Lt=-1.12;
```

```
Lr=-1.12;
r=0;
V=0;
for fc=465.500:0.250:466.000
   Lamda=2.998E8/(fc*1e8);
   for d=1:10;
      if d>=(4*h1*h2/Lamda)
         Lf=32.45+20*log10(fc)+40*log10(d);
      else d<(4*h1*h2/Lamda);
         Lf=32.45+20*log10(fc)+20*log10(d);
      end
      Alpha1=0;
      Alpha2=0;
      Lv=6.9+20*log10(sqrt(V^2+1)+V);
      Lex =11.7*abs(Alpha1-Alpha2)*sqrt(pi*r/Lamda);
      Lp(d)=Lf+Lv+Lex;
   end
d=1:10;
plot(d,Lp(d),'g')
grid on
hold on
xlabel('Distance in Km');  ylabel('Path Loss in dB');
title('Non-LOS Pathloss Vs Distance Graph for the nine bulk consumers ');
end
```

Appendix 6 : MATLAB code for BER performance of GMSK modulation

```
function GMSK

% BER performances of GMSK with BbTb = 0.20 & BbTb = 0.25
beta=[0.76 0.84]
for n=1:5
   gamma=4:5:10000;
   BER=erfc(sqrt(beta(n)*gamma));
   gamma=4:5:10000;
   SNR=10*log10(gamma);
   semilogy(SNR,BER,'r')
   hold on
   axis([0  40  1e-4  1e-1])
   xlabel('E0/N0 (dB)');  ylabel('BER');
   title('AWGN Channel BER Performance of GMSK');
end
```

Appendix 7 : Site plan (next two pages)


Faculty of Technology
DRAWING Title:-
PREPARED BY:-
Date:-
DIRE DAM
E=2522
LEGEDADI W.T.P
E=2431
d2=10.60km
D=18.70KM
KOTEBE S.T.P
E=2450
D=7.30KM
D=18.60KM
D=1.40KM
D=11.80KM
D=7.60KM
D=3.30KM
BELAY ZELEKE
E=2645
GEFERSA W.T.P
E=2570.76
d1=4.10km
GW1
E=2150
CT
E=2095
E=2195


FEKADU ZELEKE
CMC
ALTAD
TT COLLEGE
dist=5,360 m
TR
TERMINAL
SHOLLA
YEKEK
YR
AR
Megenagna
AAWSA
IMPERIAL
dist=3,390 m
C.A
Bole
Air port
UK EMBASSY
ADEWA
dist=4,402 m
dist=4,582 m
dist=5,450 m
4 KILO
GR
Palace
Sheraton
H.hotel
F.Wuha
MESKEL SQUARE
dist=8,300 m
B.L.H
MØR
Mexico
dist=7,792 m
Moha
AHR
A.H
G.F
GW3
GW2
dist=8,340 m
A. T

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