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ANALYSIS AND PLANNING MICROWAVE LINK TO ESTABLISHED EFFICIENT WIRELESS COMMUNICATIONS

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ABSTRACT

Wireless communication is observing a fast development in today's communication era. In mobile communication the Base Transceiver Station (BTS) to Base Station Controller (BSC) or Mobile Switching Centre (MSC) link is based on microwave link. Therefore, analysis and planning of a microwave link is very much important. The microwave equipment can be installed after a careful planning and detailed analysis a microwave radio system. A poorly designed path can result in periodic system outages, resulting in increased system latency, decreased throughput, or worst case, a complete failure of the system.

Planning a good, stable and reliable microwave network can be quite challenging. At the same time, it poses several interesting optimization problems. The theme of thesis work an iterative technique has been presented to explain the sequential communication of signal transmission for long and short distance radio communication through microwave link with better efficiency.

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Chapter 1

Introduction to Microwaves

Today wireless technology is used in many applications well integrated into our everyday life. Planning a good, stable and reliable microwave network can be quite challenging. Careful planning and detailed analysis is required for a microwave radio system before the equipment can be installed. A poorly designed path can result in periodic system outages, resulting in increased system latency, decreased throughput, or worst case, a complete failure of the system.

1.1 Microwave/Radio Frequency Wave

The term *microwave* refers to alternate current signals with frequencies between 300 MHz and 300 GHz with a corresponding electrical wavelength between $\lambda = c/f = 1$ m and $\lambda = 1$ mm respectively. Signals with wavelengths on the order of millimeters are called *millimeters waves*. The relation between the frequency f and wavelength λ being $f\lambda = c$, where c is velocity of propagation of the radio wave, which is equal to that of light waves in free space 3×10^8 m/sec.

Any frequency within the electromagnetic spectrum associated with radio wave propagation is referred as Radio Frequency (RF). When an RF current is supplied to an antenna, an electromagnetic field is created that then is able to propagate through space. Many wireless technologies are based on RF field propagation.

1.2 Wireless Communication

The basic motto of communication system is to ensure the exchange of information in between the people. When this communications without wired then it's referred to wireless communications. Now a day this wireless communications gets more attention from the Communication industry and provide better quality information transfer between portable devices. Autonomous sensor networks, Multimedia, Videoconferencing, Distance learning and Internet enabled cell phone are the Valuable Applications of this technology.

1.3 Historical Background

“In 1888 historically microwave signal was first introduced by Henrich Hertz at 66 cm wavelength (454.5 MHz) while millimeter wave signal was first generated by Sir J. C. Bose in 1895 at 5 mm wavelength (60 GHz). Subsequently in 1890s Sir J.C. Bose also generated microwave signal at wavelengths up to 2.5 cm (12 GHz) wavelength. Besides Sir J. C. Bose also developed the world’s first solid state point contact detector working at millimeter wave, infrared and optical wavelengths use Galena crystal as the detector material. Bose also developed world’s first horn antenna and waveguide radiator for microwave and millimeter wave bands.

In 1899 Sir J. C. Bose developed a highly sensitive iron-mercury detector in which a U-tube, made of glass, filled up with mercury, was used for a fine control of mercury contact pressure to optimize the sensitivity of the detector. Subsequently in 1901 Marconi employed Sir J. C. Bose’s technique of the highly sensitive iron-mercury detector.

Sir J. C. Bose also worked for the first time on the response of living and nonliving materials to microwave and millimeter wave bands, a subject which has now grown to a high level for the studies of microwave hazards to living beings animals and vegetation and also for microwaves diathermy therapy of tumor and cancer. From the above history of Science about Sir J. C. Bose who worked pioneering on a wide range of fields in Radio Science it seems that Sir J. C. Bose may be called the father of Radio Science.

Investigations of the millimeter waves were continued and stimulated by scientific and military developments. In 1930 the observation by L. A. Hyland of the Naval Research Laboratory (NRL) about the reflection of radio signals from over flying aircrafts, stimulated the investigation of radar techniques for detecting flying aircrafts in NRL.

During World War 2 J. H. Van Vleck predicated theoretically the Oxygen absorption band at 60 GHz. In 1950 Hughes Aircraft Company successfully extended the frequency range of coupled cavity traveling wave tubes to millimeters waves.

In 1960 intensive work in millimeter wave technology was done at BTL on the development of solid state components required in the development of underground repeaters using low loss over modes waveguides which was also first developed by Sir J. C. Bose.

In 1970s, Hughes began manufacturer a solid state sweep generator which apparently triggered a chain of development in Hughes in the Millimeter wave Technology area of a full range of device" [1].

1.4 Radio Frequency / Microwave Applications

The main part of radio frequency microwave signals can be classified in following terms.

1.4.1 Communication

The communication part concludes satellite and space systems, extensive distances, wired telephone, naval, mobiles telephone, airbus, roads vehicle, personal, and WLAN other than that there are also two significant subcategories of communications should be considered which are optical communication and television and radio broadcasting.

1.4.2 Television and Radio Broadcasting

In this category of communication radio frequency or microwaves are utilized as the carriers for audio and video signals. Direct Broadcast System (DBS) is an example which is deliberately designed to connect or link satellites systems directly to home users.

1.4.3 Optical Communications

In optical communication microwave modulator is used in the broadcasting part of a low pass optical fiber and microwave demodulator on the other side. The microwave signal operates as a transforming signal with the carrier optical signal. In case of larger frequency channels, optical communication is useful.

1.4.4 Radar and Navigation

This part comprises of air defense, airbus, ships direction, elegant weapons, police and weather and collision avoidance. The navigation system is used for the direction and supervision of airbus, ship and road vehicles. The typical applications are:

1. Microwaves Landing System - MLS used to direct airbus to land securely at airports.

2. Global Positioning System - GPS used to find exact positioning or spot on the globe.

1.4.5 Remote Sensing

In remote sensing many satellite systems monitor globe consistently for weather situations meteorology, ozone layer, soil, agriculture, crop protection from frost, forests, thickness of snow, sea icebergs and other parts such as examining and discovery of resources.

1.4.6 Domestic and Industrial Application

This area deals with microwave ovens, clothes dryers (microwaves), liquefied heating systems, humidity sensors, tank gauges, automatic doors opener, automatic toll tax detection, control and monitoring of motorway traffic, chip fault recognition, power transmission, food protection, bug control etc.

1.4.7 Medical applications and Surveillance

This deals with breeding of cats, heart functional reaction, bleeding control, sterilization. On the other hand surveillance concludes security alarm systems, burglar detection and Electronics Warfare (EW) receivers for monitoring of traffic signals.

1.4.8 Astronomy and Space Exploration

The astronomy and space deals with enormous dish antennas which are used for monitoring, collecting and record incoming microwave signals from external space, giving critical information about other planets, stars, other objects and galaxies.

1.5 Wireless Application and Mobile Cellular Networks

The smaller distance communication in and between buildings in a local area network (LAN) can be accomplished using RF and microwaves. Connecting buildings via cables creates serious problems in congested metropolitan areas because the cable has to be run underground from the upper floors [2]. Cellular companies frequently use to get hard schedules to make sure of services for clients to produce abrupt profits. In order to revolve up their networks, companies require

replacing the data of cell sites to their mobile switching stations. They must have taken microwave due to its consistency, speed of employment and cost payback over fiber or leased wired line. Microwave radio is deeply deployed in the rising 2.5G and 3G mobile infrastructures to maintain data handling. The larger numbers of cell sites required to support a new generation mobiles.

1.5.1 Last Mile Access

A considerable section of business grounds require broadband connectivity. Wireless networks give the ideal means for connecting new clients to defeat the last mile bottleneck. If an operator prefers to use non-licensed or multi-point wireless tools to fix customers, even then high ability microwave offers the perfect way out for backhaul of client traffic from contact hubs to the nearby fiber point.

1.5.2 Private Networks and Developing Nations

These days' companies may have high speed LAN and WAN network necessities. They need to unite elements of their industry on same ground, city or country. However, microwave radio communication is capable to offer fast, high capacity links which are compatible with quick and gigabit Ethernet connections, enabling LANs to be comprehensive without dependence on fiber.

There are various countries which resist with distantly telephone communications and require upgrading their systems to the most recent digital technology. The microwave radio has habitually permitted developing nations the way of setting up telecommunications rapidly over usual immature and unusable land such as desert, forest and frozen land where spreading cable would be all but impracticable. The modern digital microwave radio systems shape the foundation for several worldwide public networks.

1.5.3 Disaster Recovery

In case of natural disasters, it usually shatter pre established network. Thus, microwave is often used to reinstate connections when communication means i.e. equipment has been broken by earthquakes, water floods, hurricanes or human conflicts such as assault by terrorist or wars etc. These days microwave communication is used widely for speedily restore infrastructure in countries like

Kuwait, Iraq, Serbia, Afghanistan and Kosovo, where existing communications has been mostly destroyed or damaged.

1.5.4 Control and Monitoring

Railroads and public transport organizations are the most important users of microwave and play an important role for these companies to control and monitoring information and switching stations.

1.6 Microwave Advantages over cable/fiber based Transmission

Microwave radio offers a number of compelling advantages over cable/fiber based transmission. The various advantages pertaining to the wide use of microwaves are described as bellow:

1. Rapid Deployment – Microwave link can installed less than a day.
2. Reliability - In Radio communication MF/HF band, varies widely with time, weather condition and giving rise to fading effect. But a microwave frequencies, there is less fading since the propagation of microwaves from transmitter to receiver takes place by line of sight propagation.
3. No Right-of-Way Issues – Microwave radio can over come barrier such as railways, road and ponds as well and avoiding taking any permission to establish the communications and introduce time delay or cost.
4. Flexibility – At minimal or even no cost microwave link capacity can easily increased. If network needs any changes we can redeploy radios as a result of customer demand.
5. Easily Crosses City Terrain – In many cities there enormously restricted street digging to in install any cable/fiber in this situation Microwave radio is the best solution.
6. Operator Owned Infrastructure - no dependence on competitors.
7. Required negligible operational costs.
8. Radio infrastructure is already acquired by many networks in existing radio transmission towers, rooftops, and cellular masts.
9. Microwave radio can be repaired in minutes instead of hours or days where as the cable systems takes long time to fault diagnosis and fix it.
10. In natural disasters microwave link can give better flexibility

1.7 Microwave Disadvantages

Microwave radio offers various disadvantages as well over different circumstances. Following are the disadvantages:

1. Microwave engages huge capital investment in start if there is no vendor to finance it.
2. Microwave networks required maintenance because if a healthy planned, correctly implement network with quality equipment are not installed by good reputed vendor then maintenance required for longer run [3].
3. Microwave faces trouble like signals loss.
4. Microwave subject to Radio Interference from different environmental factors such as:
 - Thermal Inversion – a setback of the normal reduction of air temperature above sea level [4].
 - Passing Airplanes, birds and rain
 - Stellar Flare and Sunspots – stellar flare or solar flare is known as big explosion in atmosphere of Sun which affects layers. They generate electromagnetic radiations from radio waves to gamma rays to the entire wavelengths. Whereas sunspot is dark spots on sun occurred by severe magnetic action which earth temperature [5].
5. Microwave required a line-of-sight because signals travel in straight lines.
6. Microwave towers, repeaters and other equipment are very much expensive as compare to fiber optic [6].

1.8 Objective of This Thesis work

In this thesis work an iterative technique has been presented to explain the sequential communication of signal transmission for long and short distance radio communication through microwave link with better efficiency. The objective of our work is to analysis different path loss model and modulation technique that can help to build efficient microwave link to established wireless communication.

Chapter 2

Wireless Communication

Before going into the details of the Microwave link in Wireless communications one need to understand what is meant by communication. The communication is when information such as voice, data, image and video is transferred to one place and received at another place with some distance. The basic aim of a communication system is to ensure the sharing of data information among people over some distance.

2.1 Communication System's Basic Structure

Basically every communication system consists of a transmitter, a transmission medium and a receiver. Fig. 2.1 shows the basic part of a communication system.

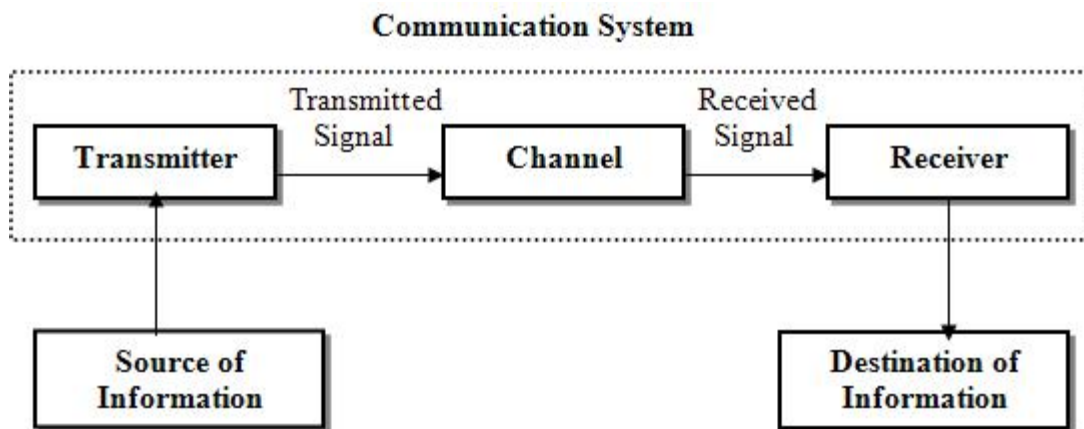


Figure 2.1 Basic Structure of Communication System

The Transmitter converts the source message into an electrical signal. The Transmitter is basically responsible for encoding the message and then this encoded message is multiplied by carrier frequency i.e. modulate the signal and then transmitted over the channel. At the receive end, the receiver demodulate the received signal and decode it and generate the original message. Minimal distortion at the receiver end is referred as a good communication property.

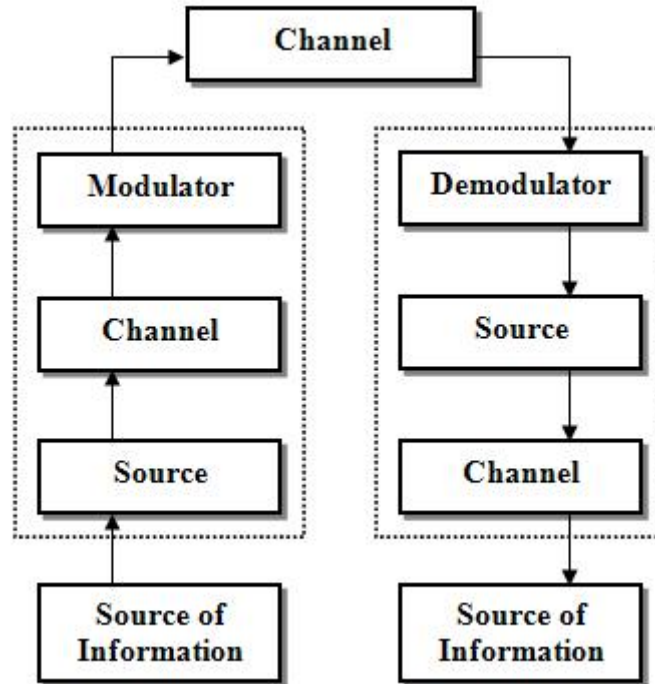


Figure 2.2 Communication System

The transmission standard from transmitter to the receiver can be categorized as direct medium and indirect medium. The direct medium is usually wired communications while the indirect medium is normally relied on wireless communication. The Public telephone, optical fiber and LAN based networks are examples of wired transmission whereas GSM, GPRS, 3G W-CDMA/UMTS, WiMAX, 3.9G LTE, WLAN and TV broadcasting are examples of wireless communication.

Communication systems could also be categorized as analog and digital communication. The existence of transmission impairments makes the difficulty in order to reproduce the analog signals at the receiver. All analog and digital systems transmit analog signals. These signals are poorly exaggerated by the noise or distortion. On the other hand digital systems offer fine performance and improved efficiency which is exempted from obligation to noise. Because of these favorable circumstances digital systems are more appropriate and popular. The communication system such as digital or analog may depends on modulation scheme. This scheme is described as the distinction of the carrier waves in provisions to the frequency, amplitude and phase in a radio signal or electromagnetic wave which tidy to make it appropriate for communication [7].

2.2 Some Important Terms Used In Communication Systems

Communication systems are based on different channels communication through which data is transferred. There are some important terms used in communication which are:

2.2.1 Multiplexing

It is used to transmit multiple signals through a single medium. While, demultiplexing is obtained at the receiver side to detached the multiplex radio signals. It is an integral part of transmitter.

2.2.2 Multiple Accesses

This term of communication system allows various users to connect who want to contribute for the similar channel. Following are the most common of multiple access technologies:

- **Frequency Division Multiple Access - FDMA**

In FDMA scheme, the frequency band is allocated to each single user by separating the frequency band into further smaller bands. This allocation of frequency band is done after guaranteeing lowest interference among frequency bands.

- **Time Division Multiple Access - TDMA**

The TDMA scheme is basically used for shared resources for wireless networks. It uses the same frequency band for all users in different time intervals. For utilization of complete frequency band during the period, a separate time slot is allocated to each user. In 2nd Generation (2G) Cellular networks TDMA channel access scheme is used and GSM used the combination of FDMA and TDMA schemes.

- **Code Division Multiple Access - CDMA**

One of the basic ideas of data communication is to allow transmitters for sending data information over single communication, simultaneously. In this way various users can share bandwidth of different frequencies. This idea is called multiplexing. CDMA channel scheme makes a data transmission to multiple users through assigned code for each transmitter to permit multiple users to be multiplexed over the same channel. Frequency Division Multiple Access separates

access by frequency whereas Time Division Multiple Access separates access through time, while CDMA deals with both frequency and time.

- **Orthogonal Frequency Division Multiple Access - OFDMA**

In OFDMA, the carrier signal is separated into different smaller subsets. For a single user this separated carrier signal subset is used to send data. To get quality of service OFDMA may be used beside OFDM.

2.3 Forms of Communication

In today's communication era wireless communication has taken on an entirely depth understanding. However, it can generally be categorized into following forms:

2.3.1 Point to Point Communication

The point to point communication describes that transmission take place among two points which are too much away from themselves. The common understanding of point to point communication is voice call among two communicators.

2.3.2 Point to Multipoint Communication

The point to multipoint communication describes that only one transmitter is present at the transmitter side and various receivers are present at the receiver side. For example video conferencing

2.3.3 Broadcasting

The Broadcasting communication describes that all users receive the conveyed signal. In this situation, the transmitter is generally at the middle position and it throws information to each receiver. Examples of broadcasting are TV and radio.

2.3.4 Simplex

When information is sent only in one direction then it's called a simplex mode of communication.

2.3.5 Half Duplex

In half duplex the data is transferred in both directions but at different time break such as from sender side to receiver side at once then from receiver part to sender part at other time then it's known as half duplex communications. Examples are walkie talkie sets.

2.3.6 Full Duplex

When the information is send to both directions simultaneously such as in half duplex then the transmitter and receiver can correspond concurrently. Mobile Global System for Mobiles - GSM, Hands Free for Voice over IP, 3G video networks etc are examples of full duplex communication.

2.4 Transmission Impairments

Electrical signals contains data or information with different voltage level which represents the data information steams. If the transmission medium is perfect then the receiver will get the exact signal which was send by transmitter during transmission, but generally communication means are not up to the mark so, the received signal will not be same as it transmitted. This impairment of signals leads to errors in signal information [8, 9]. Communication lines suffer from different problems.

1. Fading
2. Noise
3. Delay Distortion
4. Attenuation
5. Doppler shift

2.4.1 Fading

Fading is define as the noise or distortion gained by a carrier-modulated signal during transmission over certain propagation media such as multipath fading [10, 11]. It can be characterized as follows:

- Rayleigh Fading
- Ricean Fading

- Frequency selective Fading
- Slow Fading
- Fast Fading
- Flat Fading

2.4.1.1 Rayleigh Fading: In Rayleigh fading when there is no Line Of Sight (LOS) path exists between transmitter and receiver which have only indirect path than in result the received signal contains sum of all scattered and reflected waves [9].

2.4.1.2 Ricean Fading: This type of fading present in a condition when there exist a LOS and non LOS path between receiver and transmitter i.e. received signal consist of scattered and direct multipath waves [9].

2.4.1.3 Frequency Selective Fading: Take place when signal bandwidth and delay spread is larger than bandwidth of a channel and symbol period respectively [9].

2.4.1.4 Slow Fading: exist in a condition when Doppler Spread Spectrum is lower and coherence time is more than symbol period in channel [9].

2.4.1.5 Fast Fading: It takes place in condition when Doppler Spread Spectrum is higher and coherence time is smaller than symbol period in channel [9].

Coherence Time: duration of time when channel impulse response is invariant.

Symbol Time: time required to complete one symbol.

2.4.1.6 Flat Fading: Is a type of fading in which ratio of rising and falling of all parts of the received radio signal is same [9].

2.4.2 Noise

The data which is not used to transfer or transmit signal other than source is known as noise. It can be classified into following sub categories:

- AWGN
- Inter Symbol Interference
- Impulse Noise
- Intermodulation

- Cross Talk
- Thermal Noise

2.4.2.1 AWGN Noise: AWGN contains uniform continuous spectrum frequency over specified frequency band which affect the signal transmitted signal.

2.4.2.2 Inter Symbol Interference (ISI): Is a form of noise or distortion of signal interference for one symbol with frequent symbols. ISI is generally caused by channel's multipath propagation and the essential response of non-linear frequency. ISI communication is less reliable.

2.4.2.3 Impulse Noise: Occurs due to frequent disturbance caused by lightning and voltage spikes in equipment and result generate errors in transmission.

2.4.2.4 Intermodulation: Is a noise occurs due to non-linear characteristics of medium, when two signals sent through the medium with interferences and different frequencies. When these signals interfere with each other new frequencies occurs and they create redundant signals. These signals need to be filter out.

2.4.2.5 Cross Talk: Is a redundant noise occurred due to paths mixture of two signals which are near to each other.

2.4.2.6 Thermal Noise: Thermal noise occurs due to the "*thermal interruption of electrons in a conductor also know as White Noise*" [12]. It can be calculated for given bandwidth using the following equation:

$$N = kTB$$

where: N = Noise power in watts
 k = Boltzmann's constant. 1.3803×10^{-23} J/K
 T = Temperature in Kelvin
 B = Bandwidth in Hz

2.4.3 Delay Distortion

When different components of frequency arrive at different times, which deform the signal's amplitude and delay the signals at receiver end then delay distortion occurs. Following are the circumstances or factors involve in channel's delay distortion:

- Scattering
- Reflection
- Diffraction

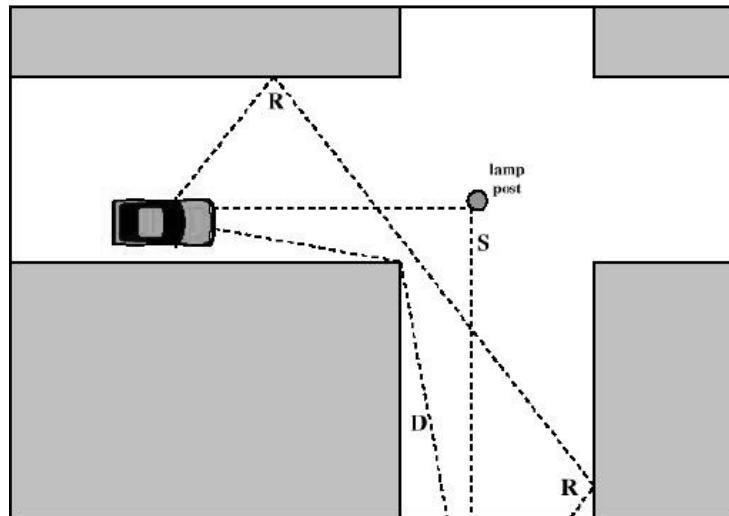


Figure 2.4 Sketch of three important Propagation Mechanisms Reflection (R), Scattering (S), Diffraction (D) [9].

2.4.3.1 Scattering - In scattering a signal can be scatter in different direction when it hits outsized abrasive surface with same or less length of the signal wavelength.

2.4.3.2 Reflection - when radio waves ram with flat surface which have the larger wavelength length of radios then the waves return backside by having the same angle at which they rammed to the surface.

2.4.3.3 Diffraction - occurs when a signal is prevented by the rim or edge of a dense body in which length of dense body is more as compare to wavelength of signal.

2.4.4 Attenuation

Attenuation is defined as power loss of the propagated signal with respect to time and distance. These Signals required to be strong sufficiently in a way that receiver can distinguish and detect the required signals. There is possibility that receiver may not be able to detect the signal at all if the attenuation level is high. Therefore, for unswerving communication, delay and attenuation must be stable [11]. Attenuation can be derived as signal power P_s at transmitter and signal power P_d at receiver, then $P_s > P_d$. Power attenuation A_p in dBs is:

$$A_p = 10 \text{Log}_{10} (P_s/P_d)$$

2.4.5 Doppler Shift

Various copies of same signals can be received at receiver end because of transmission of multipath radio's. The Doppler shift is known as when object is moving with little speed (velocity) then there will be a shift of frequencies in each received signals. It can be derived as:

$$f_d = (v f_c / \lambda) \cos \alpha$$

where,

f_d = Doppler shift frequency

v = velocity of moving object,

λ = wavelength of signal

α = angle w.r.t reference point.

Chapter 3

Microwave Communication and Considerable Parameters

Microwaves describes the contemporary current signals between 300 MHz to 300 GHz frequency ranges, microwaves have a resultant wavelength among $\lambda = c/f = 1\text{m}$ and $\lambda = 1\text{mm}$ respectively. These are ideal for transmission of data from one place to other because microwave power can infiltrate smog, rainfall, snow and clouds.

3.1 Microwave Communication

Microwave communication broadcast signals through radio using a progression of microwave towers. Microwave is a form of *line of sight* communication, because it requires the obstruction less transmission between the receiving and transmitting towers for signals to be communicated properly at both ends. After the successful effort of transmitting microwave message in 1940 from New York to Philadelphia, microwave communication is the most commonly used transmission technique for telecommunication services era.

With the continuous growth in cellular and satellite technologies, now microwave is less broadly used in telecom era. Communication is dominating towards the fiber optic data transmission. However, at various remote sites where economically it is not possible to install fiber optic cabling, microwave equipment is still in. Data communication through microwave occurs in both analog and digital formats. Whereas, digital format is the most advance type of microwave data communication.

3.2 Advantages of Microwave Communication over Fiber Optic

There are many convincing advantages of microwave radio over fiber optic cabling based transmission.

- Microwave link is possible to deploy in a day.

- Microwave link is flexible in the capacity that can be increase effortlessly at negligible or even no cost. Moreover, microwave radio link can be reinstalled depending on the customer requirement or if network demands changes. Therefore, losing clients does not make a sense that assets are lost as in case of fiber optic.
- Microwave is easily crossable in terrain areas. Whereas, in various metropolitan cities and authorities, road digging is totally banned to deploy fiber optic or prohibited or even expensive.
- Microwave radio infrastructure is owned by operator therefore, no dependence on competitors.
- Microwave radio infrastructure is already available for various networks in the shape of rooftops, cellular poles and residing towers of microwave radio transmission.
- Microwave radio systems are not inclined to common disastrous breakdown of fiber cable systems occurred by cable cuts, it may be fixed in no time rather than waiting for hours or days.
- It is controllable in the time of natural disasters for example flood, earthquakes.
- Operational cost is minimal recurring.

3.3 Considerable Parameters of Microwave

This section describes the most considerable parameters of microwaves antennas.

3.3.1 Microwave Antenna

Any conductor that can intercept an RF field can be an antenna. The Basic Principle of Microwave antennas are similar to those of antenna used at lower frequencies. Basically an antenna converts RF power into Electromagnetic radiation. More briefly an antenna is transducer which is specially designed to transmit and receive electromagnetic wave. A good transmitting antenna is often a good receiving antenna. For designing wireless systems, engineers must select an antenna that fulfils the system's requirements to firmly close the link between the remote points of the communications system.

3.3.2 The Isotropic Antenna

Isotropic Antenna means is an antenna that transmits equally in all directions. It is hard to achieve isotropic antenna in real life. Actually isotropic antennas do from a very important functions are used as a standards by which can determine how directional some other real life antennas are and what their antenna gain might be. All antennas are therefore compared to the theoretical workings of an isotropic antenna [13].

3.3.3 Parameters of Antenna

There are various considerable vital parameters that influence an antenna's performance and it can be synchronization during the designing procedure [14]. Following are the main considerable parameters for antenna:

1. Input Impedance
2. Radiation Pattern
3. Directivity
4. Polarization
5. Gain
6. Efficiency

3.3.3.1 Input Impedance - Input Impedance is the most important parameter that's related to the antenna and its transmission line. It is used to determine the transferring power from the antenna to transmission line and vice versa. Between antenna and transmission line the Impedance match is expressed by the term Standing wave ration (SWR) or reflection coefficient and is expressed in decibels. [14]

3.3.3.2 Radiation Pattern - The radiation pattern is the geometric pattern of the comparative field strengths of the field discharged by the antenna. It would be sphere in case of perfect isotropic antenna and a dipole antenna would be a toroid. Antenna radiation pattern is usually shown by a graph of three dimensions, or for vertical and horizontal cross sections may be

represented by polar plots. The graph must illustrate back and side lobes, where the gain of the antenna is at maximum or minimum. [14]

3.3.3.3 Directivity - Antenna Directivity means that maximum antenna gain compared with its gain that is averaged in all direction. Directivity go antenna always independent of its radiation efficiency. [14]

3.3.3.4 Polarization - The antenna polarization describes the electromagnetic wave polarization emitted by the antenna beside a vector initiating at the antenna and pointed along the principal direction of transmission. The polarization position of the wave is defined by the shape and direction of an ellipse produced by tracing the boundary of the electromagnetic field vector against time. However each antenna is elliptically polarized, mainly antennas are specified by the best polarization circumstances of spherical or linear polarization. [14]

3.3.3.5 Gain - The hypothetical isotropic antenna radiates power equally in all direction and measures any real type antenna gain with compare to the isotropic antenna. Actually the antenna gain means the amount of energy radiate in the direction compared to the isotropic antenna radiate the amount of energy in same direction. The maximum gain is that the direction antenna radiates most power.

The antenna gain may be calculated as:

$$G_{dBi} = 10 \log_{10} \left(\eta \frac{4\pi}{\lambda^2} A \right) \quad (3.1)$$

where, η is the efficiency of an antenna.

3.3.3.6 Efficiency - The efficiency of an antenna is generally determined on its capability to emit energy into the air. Antenna can be efficient when during the radiation procedure it dissipate very less energy. On the other hand antenna efficiency is generally referred to the power gain as measured with a regular reference antenna. Whereas, power gain of an antenna is a proportion to the radiated power of reference antenna which is basically dipole antenna.

When the energy is radiated both antenna should supply radio frequency energy in same behavior and position. [14]

3.4 Path Loss

Generally radio transmission systems consist of transmitter, antennas and receiver. In radio transmission the most important questions are: how far apart can the transmitter and receiver be in distance while maintaining acceptable performance, and what can be changed to increase this separation distance?

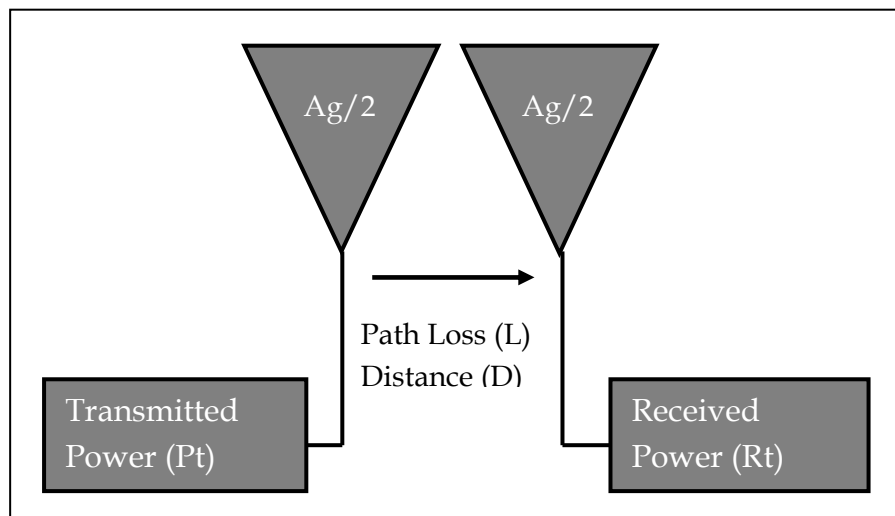


Figure 3.1 Typical RF Transmission System

The simple answer is: Use the Free Space Path Loss model in determining transmitter and receiver separation, and change the transmitter power to increase separation distance.

The following definitions are referring to the equations (3.2) and (3.3):

- P_t = Transmitter power in dBm
- G_{tot} = $(A_g - C_l)$ Total gain in dB
- L = Transmission path loss in dB
- R = Receiver sensitivity in dBm
- d = Distance between transmitter and receiver in meters

Figure 3.2 shows the typical RF Transmission system. The received signal strength R is equal to:

$$R = P_t + G_{tot} - L \quad (3.2)$$

For a known receiver sensitivity value, the maximum path loss can be derived as:

$$L = Pt + G_{tot} - R \quad (3.3)$$

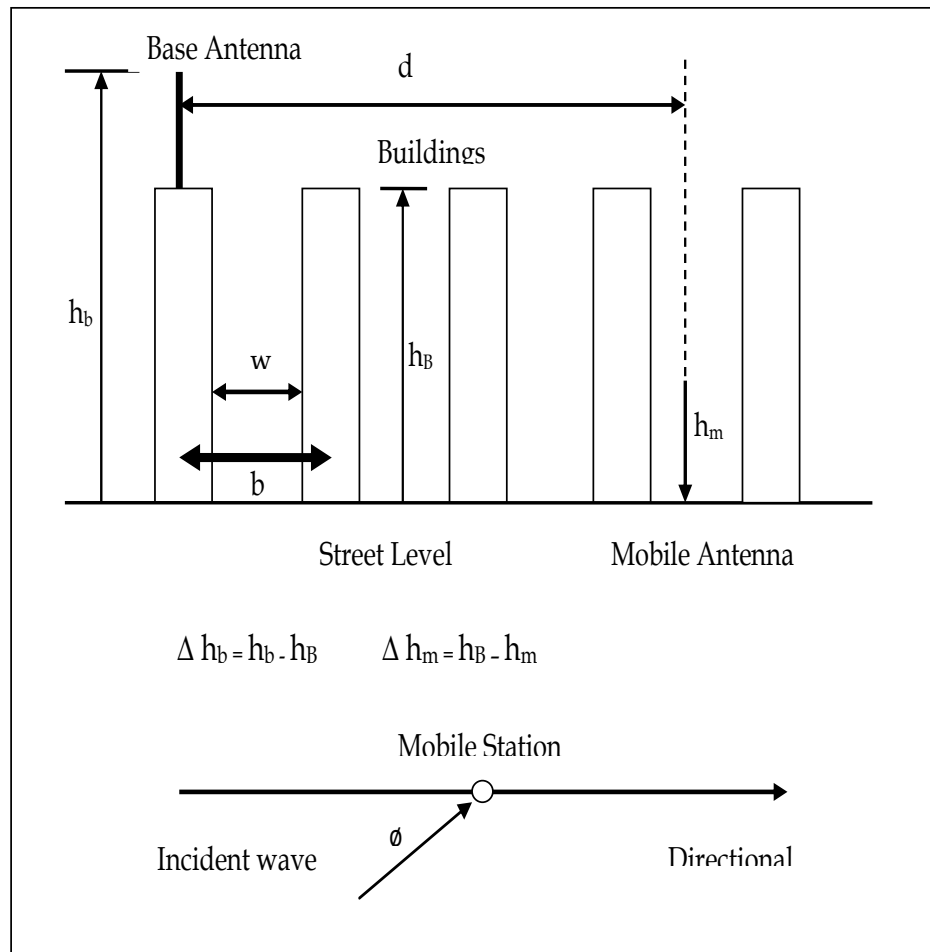


Figure 3.2 Physical Environment Path Loss Variables [15]

Figure 3.2 shows the path loss variables, where the following definitions are being used.

d = Distance in meters

h_b = Base antenna height over street level in meters

h_m = Mobile station antenna height in meters

h_B = Nominal height of building roofs in meters

$\Delta h_b = h_b - h_B$ = Height of base antenna above rooftops in meters

$\Delta h_m = h_B - h_m =$ Height of mobile antenna below rooftops in meters
 $b =$ Building separation in meters (20 to 50m if no data given)
 $w =$ Width of street ($b/2$ if no data given)
 $\emptyset =$ Angle of incident wave with respect to street (use 90° if no data)

3.4.1 Path Loss and Distance Calculation

Path Loss depends on many factors such as frequency, antenna height, receive terminal location relative to obstacles and reflectors, and link distance. It is the largest and most variable quantity in the link budget. Usually a statistical path loss model or prediction program is used to estimate the median propagation loss in dB. There are many different path loss models available now based on different condition such as line of sight (LOS) or non-LOS. Figure 3.2 shows the numerous physical environment variables used to some degree by each of the above models in calculating path loss [15].

The National Institute of Standards and Technology (NIST) have done an excellent job in documenting and comparing several realistic empirical propagation loss models. Based on the NIST study, the remainder of this document examines the following loss models [15]:

- Free Space Model
- CCIR Model
- Hata Models

3.4.1.1 Free Space Pathloss Model (FSPL)

FSPL is a fundamental factor for numerous radio frequency calculations and it is used in various locations for predicting power of radio signals which probably anticipated in a radio frequency system. FSPL is basically the sort of failure in signal strengths which happens when an electromagnetic wave communicate over a line of sight path in free space. In this condition there is no obstacle that may ground the signal to be refracted or reflected, or that may source of extra attenuation. The signal in FSPL decreases in a manner which is inversely proportional to square of distance among the signal source [15].

$$Signal = 1/distance^2 \quad (3.4)$$

FSPL Formula - The equation for free space path loss is pretty easy to employ. In this case path loss is proportional to the square of distance among the receiver and transmitter whereas, the signal level is proportional too for the square of frequency in use. It is describe more briefly below [15]:

$$FSPL = (4\pi d/\lambda)^2 = (4\pi df/c)^2 \quad (3.5)$$

where:

d is the distance in meters for the receiver from the transmitter

f is the frequency in Hertz

λ is the wavelength in meters

c is the speed of light in meters per second

Decibel Version of FSPL Equation - The majority radio frequency evaluations and dimensions are achieved in decibels (dB). It provides a simple and steady method to balance the signal levels formed at different positions [15].

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) + 32.44 \quad (3.6)$$

where:

d is the distance in km from receiver to the transmitter

f is the signal frequency in MHz

3.4.1.2 CCIR Path Loss Model (Lccir)

The pragmatic formula for the mutual effects of terrain induced and FSPL was developed by the CCIR - Comite' Consultative International Radio Communication, now ITU-R [15].

$$L_{ccir} = 69.55 + 26.16\log_{10}(f_{MHz}) - 13.82\log_{10}(h_b) - a(h_m) + [44.9 - 6.55\log_{10}(h_b)]\log_{10}(d_{Km}) \quad (3.7)$$

where:

$$a(h_m) = [1.1\log_{10}(f_{MHz}) - 0.7]h_m - [1.56\log_{10}(f_{MHz}) - 0.8]$$

$$B = 30 - 25\log_{10}(\% \text{ of area covered by buildings})$$

Substituting (3.7) into (3.2) and solving for distance yields the following CCIR maximum distance equation:

$$d_{ccir} = \log_{10} 10 \{ [Pt + G_{tot} - R - 69.55 - 26.16 \log_{10}(f_{MHz}) + 13.82 \log_{10}(h_b) + a(h_m) + B] / [44.9 - 6.55 \log_{10}(h_b)] \} \quad (3.8)$$

3.4.1.3 Hata Path Loss Models (Lhata)

Hata Model is the most popular model for path loss calculation. Okumura published many empirical curves useful for radio system planning and were subsequently reduced to a convenient set of formulas known as the Hata models that are widely used in the industry. The CCIR and Hata models differ on area coverage. There are four Hata models: Open, Suburban, Small City, and Large City [15].

The basic formula for Hata path loss is:

$$L_{hata} = 69.55 + 26.16 \log_{10}(f_{MHz}) - 13.82 \log_{10}(h_b) - a(h_m) + [44.9 - 6.55 \log_{10}(h_b)] \log_{10}(d_{km}) - K \quad (3.9)$$

Substituting (3.9) into (3.2) and solving for distance yields the following Hata maximum distance equation:

$$d_{hata} = \log_{10} 10 \left\{ \frac{[Pt + G_{tot} - R - 69.55 - 26.16 \log_{10}(f_{MHz}) + 13.82 \log_{10}(h_b) + a(h_m) + K]}{[44.9 - 6.55 \log_{10}(h_b)]} \right\} \quad (3.10)$$

Table 3.1 describes the working of equation (3.9) for different areas.

TABLE 3.1
DESCRIPTION OF EQUATION (3.9)

| Type of Area | A(h _m) | K |
|--------------|--|---|
| Open | [1.1 log ₁₀ (f _{MHz}) - 0.7] h _m - | 4.78 [log ₁₀ (f _{MHz})] ² - 18.33 log ₁₀ (f _{MHz}) + 40.94 |
| Suburban | [1.56 log ₁₀ (f _{MHz}) - 0.8] | 2 [log ₁₀ (f _{MHz} /28)] ² + 5.4 |
| Small City | | 0 |
| Large City | 3.2 [log ₁₀ 911.75 h _m] ² - 4.97 | 0 |

3.4.2 Use of Path Loss Model

This section describes the best path loss model to use. The Following Table 3.2 shows the calculated distance value of different path loss model and from this table our conclusion is that Hata model is best for different situations [15].

TABLE 3.2
CALCULATED DISTANCE VALUE FOR COMMON EXAMPLE [10]

| Path Loss Model | Calculated Distance Value in Meters |
|-----------------------|-------------------------------------|
| Free Space | 121,000 |
| WIM Los | 16,200 |
| Hata Open | 5,300 |
| Hata Suburban | 1,600 |
| WIM LOS | 820 |
| Hata Small/Large City | 740 |
| CCIR | 550 |

Figure 3.3 shows the calculated path loss in different models based on our matlab simulation result. Hata Model is widely used in Path loss prediction in wireless systems and Hata present in urban area propagation losses. So, it is good to use this model instead of other to predicts the total path loss along a link of terrestrial microwave or other type of cellular communications.

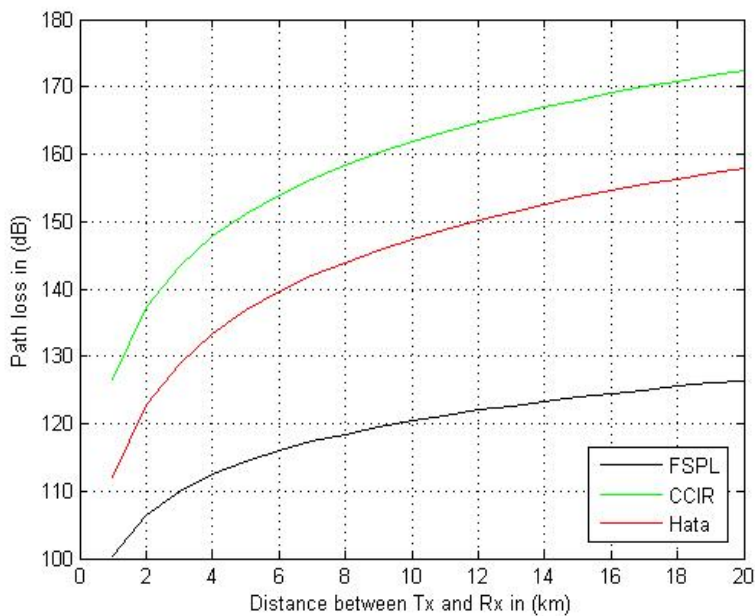


Figure 3.3 Calculated Path Loss in different Models

3.5 Link Budget

Shaping and calculating all the power gain and loss in a transmission system is known as link budget. It identifies the total of power from transmitter that is required to broadcast a signal with a definite Signal to Noise Ratio - SNR and satisfactory Bit Error Rate - BER. Path loss, distortion, failure by rain, connectors' losses, cable losses and antenna gain are the aspects which are obligatory to be taken into the consideration though estimation of link budget. Figure 3.5 illustrates the link budgeting procedure [16].

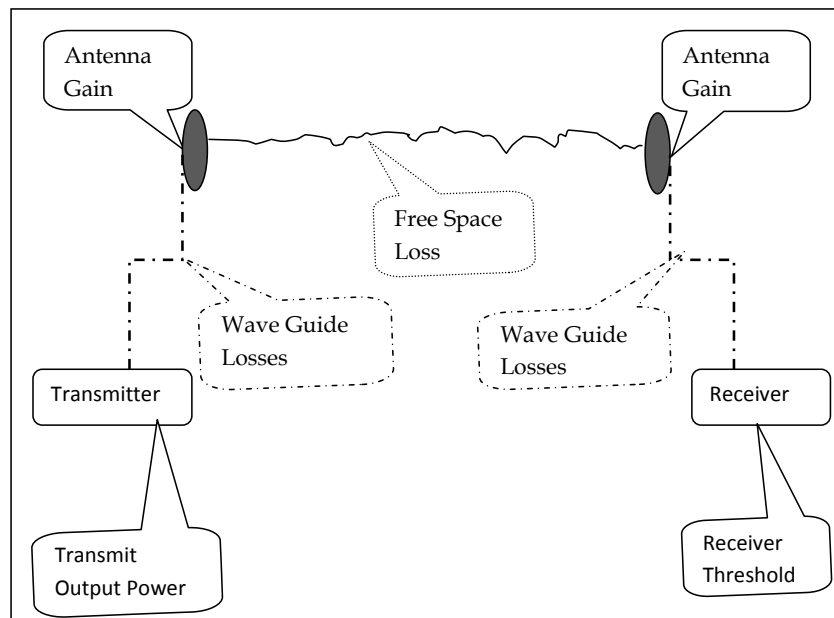


Figure 3.4 Link Budget

3.5.1 Calculation of Link Budget

In Figure 3.5 once the heights of the transmitting and receiving towers have been established the designer is in a position to select the appropriate antenna, or waveguide, transmitter power and receiver sensitivity to operate the proposed system. The next step is then to calculate the link budget to verify that the design will operate satisfactorily. There is a need to check, on both of the link transmitting frequencies, that sufficient signal arrives at the chosen receiver. This is done by consulting the appropriate data sheets for the chosen items of equipment to determine their appropriate gains and losses.

The starting point of any Link Budget is the equipment parameters of the intended microwave equipment to be used and these are; RF output power usually expressed in dBm or Watts. Receiver sensitivity usually expressed as a Bit Error Rate (BER) against a given RF signal level, for example BER 10^{-3} and -86 dBm. It is usually stated as antenna gain which is for example 45 dBm. It should be noted that this gain is Isotropic and not indicating any RF amplification.

The system Link Budget is then calculated using the following methodology [17]:

- The free space loss along the radio path is calculated (LFS)
- The effective power produced by the transmitter is calculated (EIRP)
- The effective gain of the receiving antenna is obtained (GRX)
- The losses of all components in the receiving chain is calculated (LRX)
- The signal arriving at the receiver is the algebraic sum of all the above gains and losses can be calculated as follows:

$$\text{Received Signal} = \text{EIRP} - \text{LFS} + \text{GRX} - \text{LRX dBW} \quad (3.11)$$

- This can be compared with its receiver sensitivity limit (RSL)

Providing the received signal exceeds the RSL with sufficient fade margin then the system is deemed satisfactory.

3.5.1.1 Free Space Loss

The other major factor in calculating the Link Budget is the operating frequency and the "Free Space Loss". Free space loss can be expressed with the simple calculation below:

$$L_{dB} = 92.44 + 20 \log d + 20 \log f \quad (3.12)$$

L_{dB} is the loss in dB

d is the distance or path length) Km.

f is the transmit frequency in GHZ.

Chapter 4

Adaptive Modulation, Modeling and Simulation

Adaptive modulation is a way to provide balance between Bit Error Rate (BER) and spectral efficiency. It is possible to make effective use of adaptive modulation in a slowly varying fading channel with noise based on SNR estimation. Phase of high gain of power or lower fading, will improve the SNR, which allow the higher modulation schemes to be worked with less probability of error. On the other hand, phase of higher fading, will deteriorate the SNR and force us to work with lower modulation schemes in order to make transmission more effective.

4.1 Adaptive Modulation and Coding Scheme (AMC)

In wireless communication AMC or Link Adaption indicates the identification of the coding, modulation and signals and protocol parameters depending on the circumstances of radio link. For more understandings consider the examples of pathloss, the intrusion due to transmitted signals from different transmitters, receiver sensitivity, and power outskirts of existing transmitter. Let's consider the example of Enhanced Data rates for GSM Evolution (EDGE) which uses the adaption algorithm of Modulation and Coding Schemes (MCS). It depends on the excellence of radio channel, bit rate and more importantly on data transmission robustness. The link adaption procedure is dynamic but protocol parameters and signal depends on the radio link circumstances. If circumstances change signals and protocol parameters change. As an example, High-Speed Downlink Packet Access (HSDPA) in Universal Mobile Telecommunications System (UMTS) occurs after every 2ms.

The channel information is frequently required by the adaptive modulation system at the transmitter. It can be assumed in time division duplex systems that the channel from the transmitter to receiver and receiver to transmitter are more or less be same. On the other hand the channel information may also be calculated deliberately at the receiver and gradually pass back to the transmitter. At the transmitter, the adaptive modulation improves the Bit Error Rate (BER) or rate of

transmission boldly by exploiting the channel information, especially over fading channels which represents the wireless broadcasting environments. In a result adaptive modulation reveal enormous performance as compared to system which does not exploit channel information at transmitter.

4.2 Adaptive Modulation in Microwave Link

In microwave radio systems adaptive modulation is introduced for point to point digital communication to give more capacity to user over air throughout the period of good transmission conditions, where the path conditions will adapt dynamically the modulation level of radio link. [18]

Automatic Transmit Power Control – ATPC is an adaptive technique which has been used in microwave radio system to lowers the output power when circumstances are good to lessen power utilization and network interface. If channel is suffering from fading then the power will be automatically increase in order to maintain the required level of performance link. ATPC is taken further by adaptive modulation by scheming of output power and modulation level dynamically, to regulate the link ability to fit with transmission conditions.

4.3 Key Benefits

Adaptive Modulation (AM) enables the service providers to easily grow the existing capability of links without increasing the size of antenna, no need of hardware changes and license conditions. Licensed radio links usually designed to carry system availability due to transmission give rise to outages of purely 99.9%, which means that the radio link will not be available for approximately 50 minutes in a year. For rest of the time the fading margin is essentially unexploited. Therefore, it is kept in reserve. The unexploited margin comes at elevated price, requiring radio links to be smaller duration, larger antennas or link capability to be inadequate than required. Whereas, adaptive modulation permit excessive use of fade margins to significantly increase the radio link capability for a smaller or no extra cost [18].

4.4 Adaptive Modulation

It is important to discuss about how to change the modulation scheme. In which our system will make a way to decide best suitable modulation scheme for present, future – delayed feedback conditions depending on different SNR level. Dunlop and Pons [18] asserted that BER at receiver level can be good enough to decide switching scheme. In this thesis the rejected metric of Pons and Dunlop is being used in order to estimate the Link SNR. The adaption rate would be restricted because BER estimation is complicated over short periods. Now, the question arises: How and what ranges of SNR can be best to use for which modulation scheme? The answer would be finding in performance of AWGN for each modulation scheme.

The received signal equation,

$$r(t) = c(t) \times s(t) + n(t) \quad (4.1)$$

where, $r(t)$ is a received signal, $c(t)$ is a fading channel which is multiply with transmitted signal $s(t)$ with addition of noise $n(t)$. Generally is the signal to noise ratio decided by the noise since the signal power usually is restricted. To consider this the transmitted power of the signal is multiplied by fading channel. In result, the direct received signal power can be compare instantaneously with noise, which allows us to put BER in fading or AWGN channel. Now, let's take the BER performance for three modulation schemes which are QPSK, 16 QAM and 64 QAM. Modulation scheme 128 QAM is an ideal state which is not used practically [19].

In [22] the formula can find for the probability of error when using 4-QAM system, this formula is extended for 16-QAM, 64-QAM and 128-QAM. By using, those calculations for different schemes following graph is plotted.

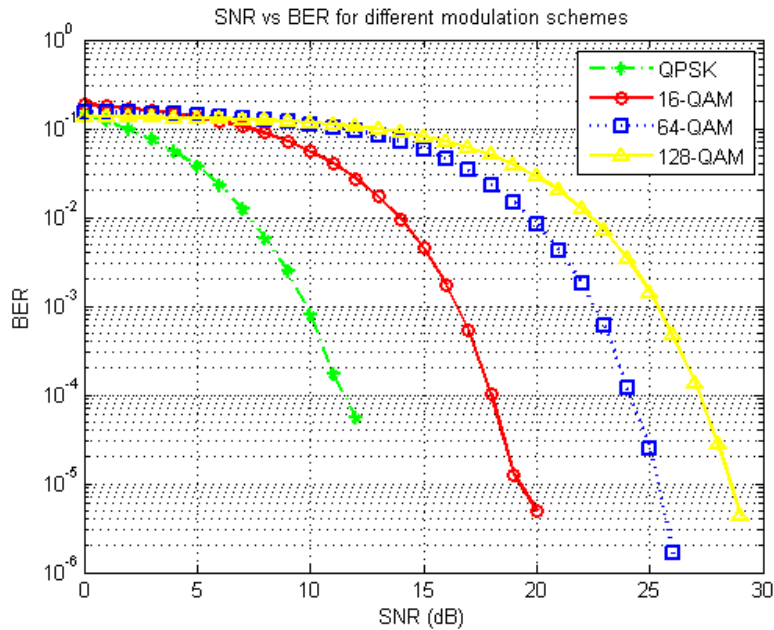


Figure 4.1 Modulation Schemes for different SNR levels

Figure 4.1 illustrates the probability of error for different modulation schemes for different SNR values. Now, consider that the minimum BER level is to be 10^{-3} , and dropped the 128-QAM as it is not practically used in normal situations. Now, the system will try to maintain a BER less than 10^{-3} with the best possible spectrally efficient scheme. In this way need to set the spectral efficiency as number of bits on a fixed transmission symbols.

TABLE 4.1
MODULATION SCHEMES DECISION LEVELS AND BITS/SYMBOL

| Modulation Techniques | SNR | Bits/Symbol |
|-----------------------|-----------------------|-------------|
| QPSK | $SNR < 17$ | 2 |
| 16-QAM | $17 \leq SNR \leq 23$ | 4 |
| 64-QAM | $SNR > 23$ | 6 |

Table 4.1 gives us two things, the level for which the modulation should be switched, and the number of bits per symbol which will be used to calculate the spectral efficiency for the adaptive modulation. While operating at BER of 10^{-3} no modulation scheme will provide preferred SNR level below 10dB. So, it will be good

to select the more robust QPSK which gives us SNR performance between 10dB and 17dB. The 16QAM system can get the better spectral efficiency which includes among 17dB and 23dB. For SNR greater than 23dB, 64QAM will provide maximum spectral efficiency for required BER performance.

4.5 Theoretical Performance of Adaptive Modulation

This section will illustrate the theoretical performance of adaptive modulation, under the light of spectrally efficient and BER. The ways to switch the modulation schemes is already discussed in section 4.4. Hanzo and Torrance gave the detailed study reference of adaptive modulation [19].

It is needed to address the received Power Density Function of instantaneous, Rayleigh amplitude s . The Rayleigh function is given by [20]:

$$F(s, S) = \frac{2\sqrt{s}}{S} e^{-\frac{s}{S}} \quad (4.2)$$

In equation 4.2 ' S ', is average signal power. Now, second step is to establish the BER for selected modulation schemes. It can be logically describe by [20]:

$$P_{\gamma}(S/N) = \int_0^{\infty} P_G(s/N) \cdot F(s, S) ds \quad (4.3)$$

In equation 4.3 P_{γ} is the channel BER, and P_G is the BER in an AWGN channel. The adaptive modulation for BER considerations [20]:

$$P_A(S|N) = B^{-1} \cdot \begin{cases} 2 \int_{l_1}^{l_2} P_{QPSK}(s/N) \cdot F(s, S) ds \\ +4 \int_{l_2}^{l_3} P_{16QAM}(s/N) \cdot F(s, S) ds \\ +6 \int_{l_3}^{l_4} P_{64QAM}(s/N) \cdot F(s, S) ds \end{cases} \quad (4.4)$$

In equation 4.4 ' B ', is average spectral efficiency. Here l_1 , l_2 , l_3 & l_4 are thresholds of Signal to Noise Ration among modulation schemes. The values for l_1 , l_2 , l_3 & l_4 can obtain from Table 4.1. B is calculated as:

$$B = 2 \cdot \int_{l_1}^{l_2} F(s, S) ds + 4 \int_{l_2}^{l_3} F(s, S) ds + 6 \int_{l_3}^{l_4} F(s, S) ds \quad (4.5)$$

Following are the graphical representation of adaptive modulation after obtaining the mathematical grounds. Figure 4.2, shows the spectral efficiency of adaptive modulation against SNR in dB [20]. The proposed system classified the spectral efficiency as per number of bits should be send for each modulation scheme. There is no condition for the bits sending criteria either correct ones or not. This is because the BER is implied to a point where system will adapt to maintain the required level of performance.

When foremost QPSK is used, system gets 2 bits/symbol where SNR level is low. Though, SNR level increases, gradually throughput improves, which shows that we are ready to take spectrally efficient schemes.

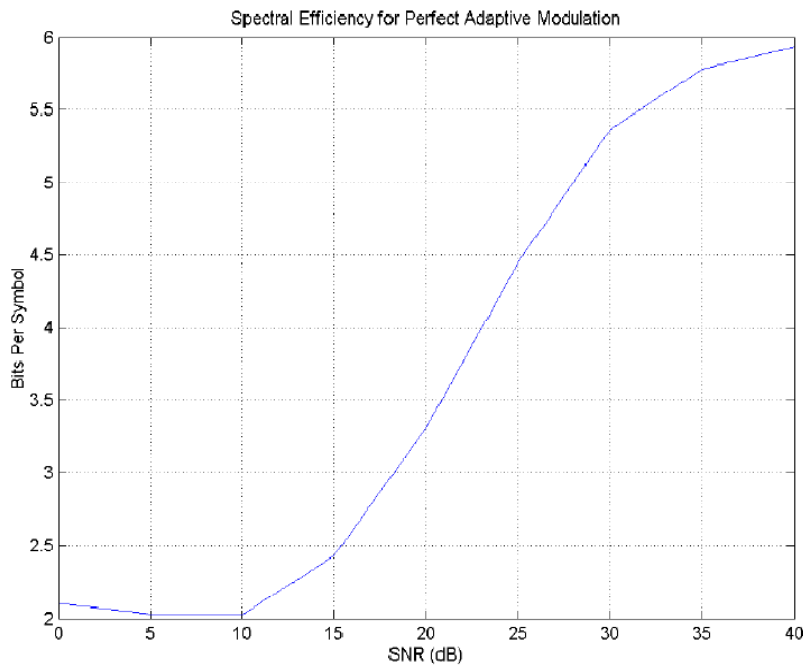


Figure 4.2 SNR versus Spectral Efficiency [21]

When required SNR achieve, the system will be able to select the more capable modulation schemes. When 64 QAM is used the curve reached up to the SNR level of 30dB, where QPSK is not often used.

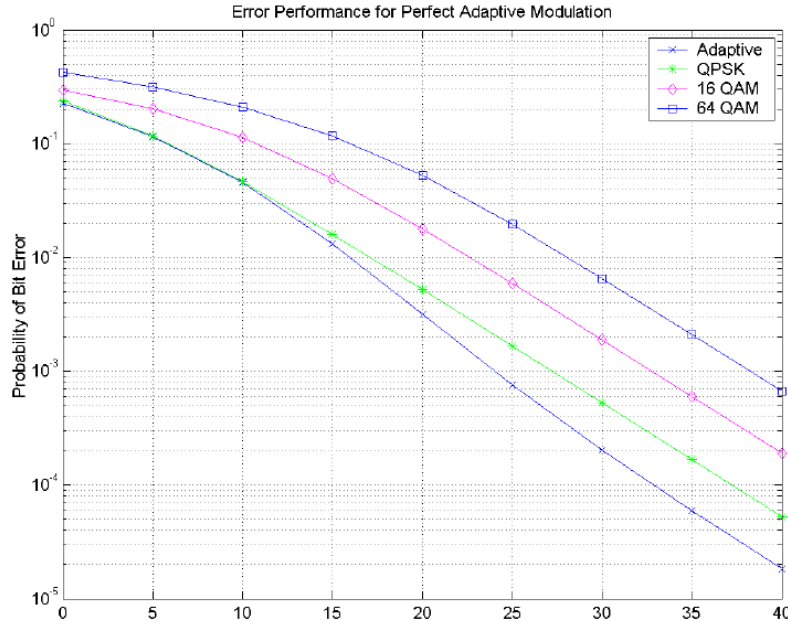


Figure 4.3 BER Performances versus SNR for a Fading Channel [21]

Figure 4.3 shows that QPSK curve is overlapped by adaptive modulation. It is comparable to the spectrally efficient curve in Figure 4.2, where QPSK is the prime scheme used for lower SNR. So, this improves the working of adaptive modulation as compared to QPSK provided results.

Let's consider a transmission which is facing intensive fading and also consider three modulation schemes QPSK, 16 and 64 QAM which are different in robustness and spectral efficiency. If we are taking the fade effect extremely intensive there may be a possibility that half of the bits would be in error. It can be advantage to send the fewer bits because number of errors would be decreased, where capacity BER is more than total number of bits sent. When the channel is fadeless it is possible to send many bits, in this way BER level can be low by sending more bits because there is less probability of errors. This is the amalgamation of two principles that consider the adaptive modulation system performance for BER which is more useful than static ones, which concurrently provide spectral efficiency for majority SNR ranges.

4.6 Proposed Adaptive Modulation Model

Every wireless communication system has the problem of a fading channel. In order to reduce this problem different modulation techniques are implemented which have different transmitted signal power, bandwidth efficiency and error probability. The objective of our work is to study and evaluate BER along with the spectral efficiency by using adaptive modulation technique.

Already defined wireless environment suffers from fading due to many reasons, multipath fading, free space loss and others. However, in this thesis work the proposed model shows the effect of the Additive White Gaussian Noise (AWGN) channel and this thesis will study a dynamically changed modulation scheme based on the channel status, mainly the SNR is to preserve the maximum throughput with minimum error rate. The adaptive modulation technique uses M-level of Phase Shift Keying (PSK) as well as M-level of Quadrature Amplitude Modulation (QAM) where $M = \{2, 4, 8, \dots\}$.

SNR, BER and Bandwidth Efficiency are the main factors which are taken into consideration. In wireless networks, the channel distorted due to the fading effect and AWGN.

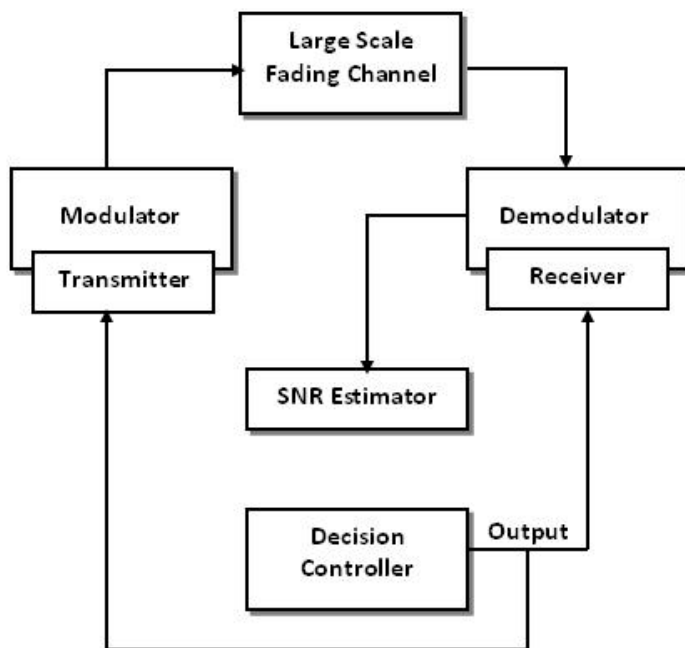


Figure 4.4 Block Diagram of Simulation Model

The modulation is build to be varying with the time depending on the channel condition, thus a feed back is needed. New model figure 4.4 is proposed using adaptive modulation and simulation is done based on the model.

Figure 4.4 illustrates the block diagram for the analysis, the main two important components are the decision controller which will decide which modulation scheme 4-QAM, 16-QAM, 64-QAM to be used and the modulator which will change the modulation based on the information received from the controller. This model will provide results for the slowly varying fading channel with addition of AWGN noise.

4.6.1 Performance of Adaptive Modulation

Different modulation techniques have been employed that reduces the fading and noise factors. In adaptive modulation technique, the system adopted different modulation schemes with respect to the distance of the subscriber from the base stations [23] and [25].

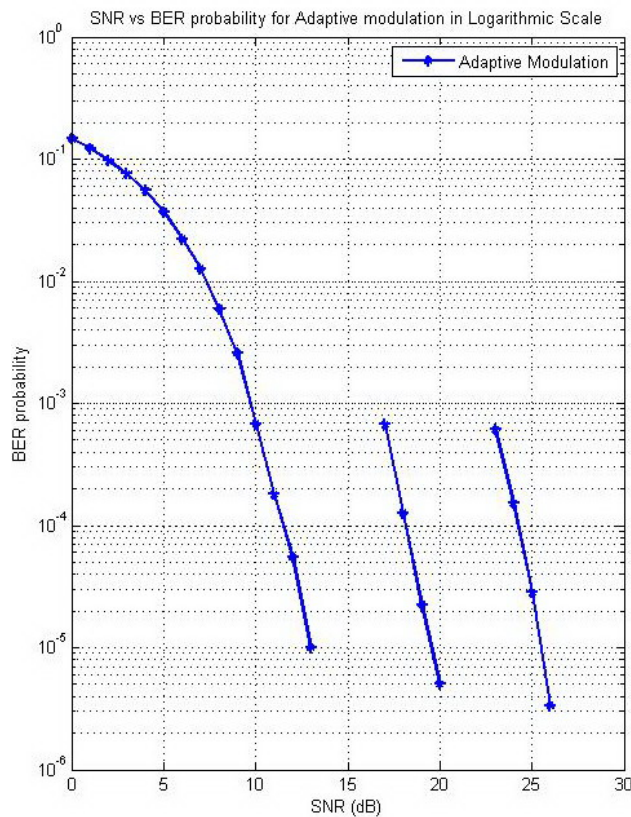


Figure 4.5 SNR vs BER Probability for AWGN Channel

Security and available bandwidth but high data rate is the main issue now for any wireless communications system. Improving the spectral efficiency over wireless fading channel adaptive modulation or link adaptation is powerful technique. With adaptive modulation a high spectral efficiency is attainable at a given bit error rate in favorable channel conditions [24] and [26].

From Figure 4.5 and figure 4.6 it is easy to conclude that by using AWGN channel system can keep the threshold level when SNR level is 10dB. When system wants to keep the same threshold level while fading channel is introduced then system needs to increase the SNR level.

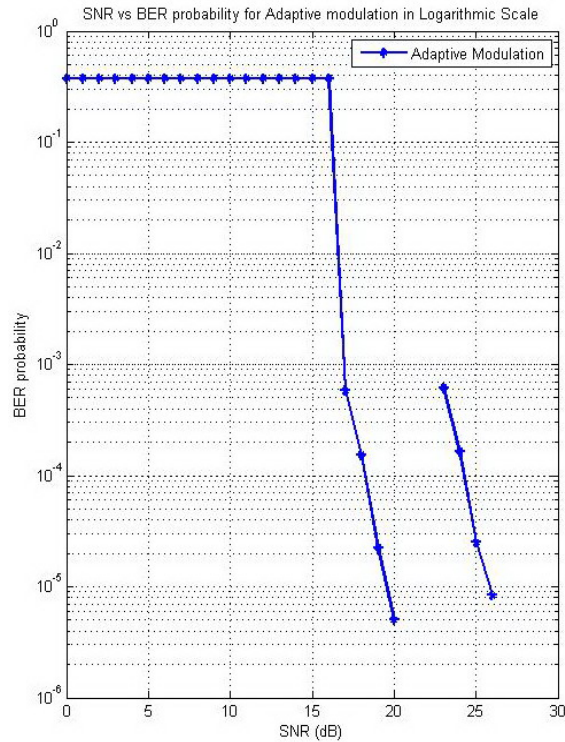


Figure 4.6 SNR vs. BER probability for Fading Channel

However, Figure 4.7 shows the joint advantage of this technique and reflects the main advantage achieved when adaptive modulation is used, it can be noticed that as the SNR is increased, the throughput is increased as compared to QPSK which maintains a constant level although the SNR is increased. Shanon Capacity is the theoretical capacity for error free system condition which cannot achieved in reality.

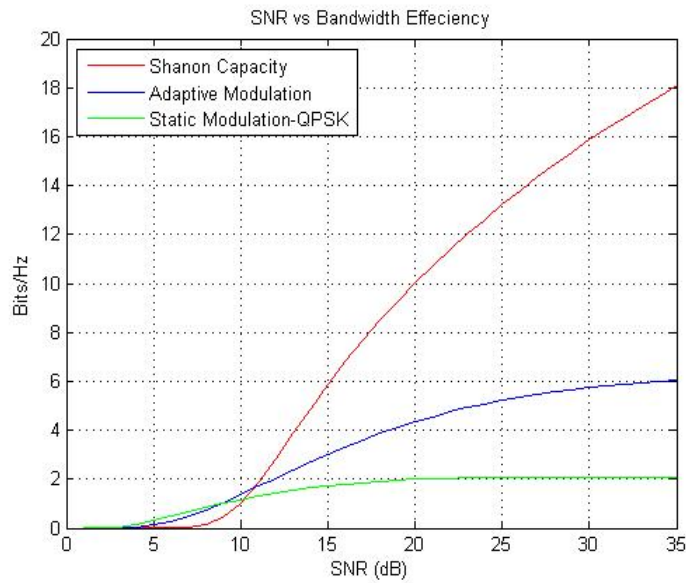


Figure 4.7 SNR vs. Bandwidth Efficiency for Adaptive Modulation

Chapter 5

Conclusion

Microwave communication is playing the role of a key factor in the current time of wireless communication. The performance and quality of service of all the Mobile Communication Service Providers broadly depends on the quality and availability of their Microwave Link. It requires a series of works to establish a microwave link between two long distance and short distance points. All the steps are performed by engineer as to establish a Microwave link. For establishing a microwave link analyzing factors, first factor is **Terrestrial factors** that are Site Survey, Condition of Terrain (Flat / Hilly / desert), and Presence of water body like big river/lake/sea, presence of forest or big trees. Second factor is select the modulation technique, environmental conditions and Link budget considering required Fade margin using appropriate antennas, cables, wave-guides and connectors.

5.1 There Are Several Advantages of Microwave Radio

Today's the various advantages pertaining to the wide use of microwaves. Most important are:

1. Less affected by natural calamities
2. Less prone to accidental damage
3. Links across mountains and rivers are more economically feasible
4. Single point installation and maintenance
5. Single point security
6. They are quickly deployed

5.2 Basic Recommendations

Some basic recommendations which are important for planning efficient wireless network through microwave links:

1. To use higher frequency bands for shorter hops and lower frequency bands for longer hops.
2. Avoid lower frequency bands in urban areas.

3. In areas with heavy precipitation, if possible, use frequency bands below 10 GHz.
4. The activities of microwave path planning and frequency planning preferably should be performed in parallel with line of sight activities and other network design activities for best efficiency.
5. To use updated maps that is not more than a year old. The terrain itself can change drastically in a very short time period.

APPENDICES

APPENDIX A

Abbreviations and Acronyms

| | |
|--------------|---|
| RF | Radio Frequency |
| GHz | Gigahertz |
| MHz | Megahertz |
| KHz | Kilohertz |
| WLAN | Wireless Local Area Network |
| DBS | Direct Broadcast System |
| MLS | Microwaves Landing System |
| GPS | Global Positioning System |
| EW | Electronics Warfare |
| MF | Medium Frequency |
| HF | High Frequency |
| PSTN | Public Switched Telephone Network |
| GSM | Global System for Mobile Communication |
| FDMA | Frequency Division Multiple Access |
| TDMA | Time Division Multiple Access |
| CDMA | Code Division Multiple Access |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| LOS | Line Of Sight |
| AWGN | Additive White Gaussian Noise |
| ISI | Inter Symbol Interference |

| | |
|--------------|--|
| SWR | Standing wave ration |
| NIST | National Institute of Standards and Technology |
| FSPL | Free Space Pathloss Model |
| SNR | Signal to Noise Ratio |
| BER | Bit Error Rate |
| EIRP | Equivalent Isotropic Radiated Power |
| RSL | Receiver Sensitivity Limit |
| QAM | Quadrature Adaptive Modulation |
| QPSK | Quadrature Phase Shift Keying |
| AM | Adaptive Modulation |
| AMC | Adaptive Modulation and Coding Scheme |
| EDGE | Enhanced Data rates for GSM Evolution |
| MCS | Modulation and Coding Schemes |
| UMTS | Universal Mobile Telecommunications System |
| HSDPA | High-Speed Downlink Packet Access |
| PSK | Phase Shift Keying |
| ATPC | Automatic Transmit Power Control |

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