CHAPTER 1

INTRODUCTION TO WIRELESS NETWORKS

1.1 Introduction

The interconnection of more than one device is known as ‘Network’. In a network, connections between devices are made using electrical wires. To establish a network in an office, wires should run the entire length of it. Wires are subjected to physical damage also. People have to stick on with their devices to transfer data in ‘wired network’.

With movement of devices became a necessity, the devices could not be followed through ‘wired networks’. The wired connections are replaced by wireless connections. The fundamental principle of operation in wireless communication is the transfer of data from ‘sender’ to ‘receiver’ with the help of Electromagnetic [EM] wave propagation. When a device communicates with another device at a distance without any connected wires in between, it is known as ‘Wireless Communication’. Devices which can communicate wirelessly among themselves are forming a ‘Wireless Network’.

The EM waves are characterized by ‘Frequency’. Various wireless transmissions differ by operating at different frequency bands. Receivers are tuned to receive only the specified frequency from a transmitter, operating in that frequency. Another term which is related is ‘Wavelength’. The product of frequency and wavelength gives velocity of the EM wave. In free space, EM waves travel with the velocity of light. In materials other than free space, the velocity of the EM waves depends on the properties of that material.

Though Electromagnetic spectrum is very long, the frequencies used for wireless communication are generally in ‘Giga Hertz [GHz]’ range. The range of frequencies from 1 GHz to 40 GHz is known as ‘Microwaves’. In Asia, mobile phones operate around 0.9 GHz.
Wireless networks connect wired networks through antennas. Through wireless networks, it is possible to access wired networks.

In the initial stages, wireless networks are generally voice-oriented networks. Later on with the requirement of data to be sent, it is developed into data-oriented networks.

Wireless networks causes less cabling and less initial cost. The placement of cables across rivers, mountains and old buildings are really difficult. In this situation, the implementation of wireless networks is cost effective and also less time consuming.

1.2 Evolution of Wireless Networks

The modern wireless communication started with the introduction of radio transmission in 1895 by Marconi. In this year, he demonstrated successful radio transmission for a distance of 1.5 Kilometers. He tried to increase the transmission distance by employing various devices. In 1897, he demonstrated first ever over the sea wireless transmission for a distance of six Kilometers. Four years later, he successfully transmitted the radio signal across the Atlantic Ocean from Cornwall to Newfoundland. In 1902, the first bidirectional radio transmission was demonstrated by him. In 1915, the first radio based conversation was established between ships [76].

In 1946, the first mobile telephone system [MTS] was introduced at United States. Due to technological limitation, the system was large in size, so it was termed as Car based mobile telephony. MTS was an analog, half duplex system. MTS used a base station [BS] with a single high power transmitter that covers the entire operating area of the system. To cover neighboring area, another BS was to be installed. As these BS were operating with the same frequency, these base stations should be spaced further apart so that they should not interfere with each other. Major limitations of the MTS were the manual switching of calls and limited number of available channels. Generally, a maximum of three voice calls can be processed at the same time and at the same area. In 1957, a
Russian engineer, Leonid Kupriyanovich developed a portable mobile phone. It was named as LK-1 after its inventor. LK-1 was three Kilograms of weight and its battery lasted for 20 hours. It worked with a distance of 20 to 30 Kilometers. In 1958, Kupriyanovich developed a smaller version of LK-1 which was 500 grams weight [77]. An enhancement of MTS, known as Improved MTS [IMTS] was introduced at 1964. It is considered as a ‘0G’ radio system which is connected with public switched telephone system [PSTN]. It operated with additional channels and automatic handling of calls [78].

1.2.1 Analog Cellular Telephony

IMTS operated with inefficient spectrum usage and reduced capacity. Also the interference caused by the adjacent BS created drawbacks. To overcome this, D.H.Ring and W.R.Young of bell labs, proposed a method at 1947. Their ‘Cellular’ concept replaces high coverage BS with a number of low coverage stations which were called as ‘Cell’. The operating area of the system was divided into a set of adjacent, non-overlapping cells of hexagonal shape. Each base station was connected to a Mobile Switching Center [MSC]. MSC’s were interconnected via wires or through second level MSC’s.

Neighboring cells used different frequencies so that they cannot interfere. But cells of sufficient distance can have the same frequency which was known as ‘Frequency Reuse’. This concept was introduced in 1970’s.

Early mobile services did not work when user moved from one coverage region to another one. The concept of ‘Handoff” helped the user change their coverage region. This was introduced by Armos E. Joel Jr. of Bell labs in 1970.

In 1973, Martin cooper, of Motorola made the first analog mobile phone call using a prototype model to Joel S. Engel of Bell labs [77].
1.2.2 Digital Cellular Telephony

The next generation systems were based on digital transmission techniques. Digital Systems have some advantages compared with the analog one.

1. Digitized traffic can be easily encrypted to provide privacy and security.
2. In Analog transmission, systems are highly susceptible to Interference.

1.2.3 Cordless Phones

Cordless phones first appeared in 1970. They were originally provided to offer mobility within small coverage regions such as home, office. Cordless phones comprise of a handset, which communicates with a BS, connected to a Public switched telephone network [PSTN].

1.2.4 Wireless Data Systems

The first wireless data transmission was developed at University of Hawaii in 1971 under the research project ALOHAnet. This project helped users to share information among four computers spread in four islands with central computer placed at the island of Oahu without using phone lines. ALOHA utilized star topology with the central computer acting as the central hub. The initial protocol is known as ‘Pure ALOHA’. Later on it is modified into ‘Slotted ALOHA’ [79].

1.2.5 Wide area data systems

There are three types of wide area data systems are available. They are given as

1. Paging Systems
   These are one way cell based systems that offer very low data rate transmission.
2. Mobitex
   This is a packet switched system developed by Ericsson for telemetry applications.

3. Adris
   This is a circuit switched system developed by Motorola and IBM.

### 1.3 Wireless data Communication

Based on the works of J.C. Bose, Marconi and Papov, Wireless technology has been categorized as an integral part of human life. From 1950’s to 1970’s people enjoyed the songs and news from radios. Big sized vacuum tube radios to the packet transistors, the radios made huge impact on the life of common people. Later on, with the advent of Television, people can see the picture along with sound. The cable television appeared in 1990’s and now we have Direct Home television [DTH]. All these developments happened in the wireless sector as people are living with it.

Wireless networks are coming into the picture with the success of wireless communication. With the advent of Telephones, People have been interested in exchanging information quite fast and more than that they can hear the voice of their beloved ones. But there is a requirement of wires to run the entire length of the world and also there was the problem of small bandwidth which responded with lot of ‘Busy Tones’. The advent of ‘Walkie – Talkie’ informed the world the possibility of speech communication without wires even though for a small distance.

The Cellular Mobile Technology gives the world a cutting edge in many applications. It shows any person anywhere in the world can get connected and share information within few seconds. This is considered as the most important invention of this century as it helps many people run their business even without their physical presence.
As the mobile phones reach common man there are similar communication techniques invented for office and educational purposes. Local Area Networks [LAN] connect various computers within an office. The difficulty with the implementation and maintenance of wired connections brings a new technology known as Wireless Local Area Networks [WLAN].

WLAN is used to provide high speed data within a relatively small region. As Industrial scientific and medical [ISM] bands are made license free, WLAN started functioning in this band. But this band is having lot of interference.

The first 802.11 standard for WLAN offered data rate of 2 Mbps using spread spectrum in ISM bands. The next standard 802.11 b extends the data rate up to 11 Mbps at 2.4 GHz physical layer. There is another standard, 802.11 a provided higher data rates up to 54 Mbps but at 5 GHz of operating frequency of physical layer. All these standards used the same Medium Access Control [MAC] layer, known as distributed foundation wireless MAC [DFWMAC]. Carrier sense multiple access protocol is also found suitable for wireless environment. IEEE 802.11 is known as wireless Ethernet and it can operate either in ad-hoc mode or in centralized mode. WLAN in ad-hoc mode is a peer to peer network that is working as a temporary node. An infrastructure WLAN makes use of higher speed wired or wireless backbone.

Another WLAN standard, High Performance European Radio LAN [HIPERLAN] was developed. It covers physical and MAC layers covering 2 to 25 Mbps of data rate. It operates at 5.2 GHz band.

Bluetooth is the most widely used Wireless Personal Area Network [WPAN] technology. A WPAN is a small scale wireless network that connects a few computing or communication devices in the range of several meters. A WPAN may comprise a wide range of fixed or mobile devices that have been equipped with radio interfaces such as computers, cell phones, Personal Digital Assistants [PDA] and so on.
Bluetooth works in short range, between 10 to 100m. Its cost is very low, hardly $5 and the power of the transmission is also low – 10 to 100 mW. It can transmit data with low data rate of 1 to 2 Mbps.

Bluetooth and WLAN operate at the same frequency – 2.4 GHz. Bluetooth is used in low power mobile devices for data transfer within short distance. But WLAN operates with more power, more distance and also with more bandwidth.

WiMAX [Worldwide Interoperability for Microwave Access] provides fixed and mobile Internet access. It is considered as a ‘Last mile’ wireless access to users replacing cables. It is specified as IEEE 802.16 standard. IEEE 802.16m is the current standard which can provide data rate of 40 Mbit/s. WiMAX forum focus on fixed wireless access for home and business users, portable wireless access without mobility support and mobile access with seamless mobility support.

Wireless Sensor Networks [WSN] represent networks that are embedded into our physical environments. A sensor is a tiny electronic device that can respond to a physical stimulus and convert it into numeric data. A WSN is composed of many low-power, low-cost, autonomous sensor nodes interconnected with wireless communication devices.

WSN is being used in object tracking, Global Positioning System [GPS], measuring environmental properties such as temperature, humidity and air pressure. Sensor nodes in WSN can self-organize into a network topology which improves robustness and reduce maintenance costs.

Wireless Sensor Networks [WSN] help the people in getting data from a distant location wirelessly. The possibility of adding and deleting any node in a network without any central server is known as ‘Ad-hoc Networks’. All these types of networks have one thing in common – they are operating wirelessly.
Radio Frequency Identification [RFID] is a wireless radio-frequency technology that allows objects, persons and places to be remotely identified using low cost electromagnetic tags. RFID is a part of WSN. An RFID tag is attached to an object which can store data. By identifying this tag, the object can be identified with the help of a RFID reader. RFID tags operate at the frequency bands of Low frequency [LF-120 to 140 KHz], High frequency [HF-13.56 MHz], Ultra High frequency [UHF-868 to 956 MHz] and microwave [2.4 GHz]. In the last decade, RFID technology improved a lot with longer signal range, faster data transfer rate and shorter tag reading intervals. The retail chain company Wal-Mart used this technology and many more companies followed.

RFID tags are of two types: Active and Passive. In active tag, a small battery is used. It can transmit signal of its own with the help of available power source. Passive tag is not having its own power source. It receives the signal from RFID reader and it reflects part of the power back. Passive tags are cheaper than active tags.

The Digital Enhanced Cordless Telecommunication [DECT] standard in Europe defines 1880 – 1990 MHz for digital cordless phone communication. In United States, 900 MHz, 2.4 GHz and 5.5 MHz are frequency bands at which cordless phones are used.

GPS satellite use the frequency band 1575.42 MHz [Referred as L1] and 1227.6 MHz [Referred as L2] to transmit signals.

The Ultra High Frequency [UHF] – ‘L’ band – from 1530 MHz to 1650 MHz is used by metrological satellites and global environment monitoring satellites to transmit data.

Radio frequency remote keyless entry systems and garage door openers operate at short range wireless transmission. They are used in automobile industry. The range of frequencies used in United States is 27, 128, 418, 433 and 868 MHz.
1.4 Radio Wave Propagation Mechanisms

Radio signals with the frequencies above 800 MHz are used in Wireless networks [1]. The Electromagnetic [EM] signal travels in a straight line path in free space unless the path of propagation is blocked by any object. In practice, the Electromagnetic signal is subjected to lot of such blocks. To characterize, the path of such signal, there are few models being used. The Ray tracing model has been followed to characterize those signals often. There are three basic mechanisms are used to characterize the ray path in this model:

1.4.1 Reflection and Transmission

When EM signal is falling on objects which are larger than the operating wavelength, the EM wave is subjected to reflection and refraction. The ground, the walls of the buildings, the ceiling and the floor are few objects which satisfy the condition mentioned above. The ray attenuates after reflection based on the frequency of operation, angle of incidence, and the type of the medium. This mechanism is more dominant in Indoor environment. So, for WLAN applications, this is a very important one. But for outdoor applications, this is not having much significance as multiple transmissions occur.

1.4.2. Diffraction

Rays which are falling on the edges of the buildings and walls excite the edges to act as the secondary wave sources. They travel away from the diffracting edge as cylindrical waves. The diffracted field can reach a receiver which is in the shadow region to the transmitter. The secondary source has more loss compared to reflection. Diffraction is more dominant in out-door applications and is less consequential in indoor applications as the diffracted signal strength is very weak compared to the reflected signal.
1.4.3 Scattering

EM signal scatter in all directions of irregular Objects such as walls with rough surfaces, furniture and vehicles. Scattering occurs when dimension of objects are in the order of a wavelength or less compared to that of EM wave. As scattering spreads EM signal in all directions, the power level of those signals are reduced a lot. So, this mechanism is not very significant in most of the cases.

1.5 Signal Coverage and Path loss model

When a WLAN is to be installed, the first design criterion to be considered is the region which it can cover. But fixing the region of coverage for any Access Point is not very easy as it involves so many parameters. The signal coverage can be covered by the path loss models and there are different path loss models available. These models can be employed depending on the environment. First, Free space propagation is discussed and then few other path loss models are discussed [1].

1.5.1 Free Space Propagation

When an Access Point radiates in free space, the measurement of radio signal is scaled under the free space propagation model. The radio signal falls as some power ‘α’ of the distance. It is known as ‘Power- distance gradient’ or ‘path – loss gradient’. If the transmitted power is ‘P_t’, after a distance ‘d’ in meters, the signal strength will be proportional to $P_t d^{-\alpha}$. In simple case, the signal strength falls as the square of the distance in free space [$\alpha =2$].

With an Access point radiated energy in all directions, the signal strength density is the total signal strength radiated divided by the area of the sphere, $4\pi d^2$. Based on the operating frequency, there may be some losses occur in the transmitted EM signal. The relation between the transmitted power and the received power is given as follows:
\[
\frac{P_r}{P_t} = G_t G_r \left[ \frac{\lambda}{4\pi d^2} \right]
\]  --- (1.1)

Here, ‘\(G_t\)’ is the gain of transmitter antenna
‘\(G_r\)’ is the gain of receiver antenna
‘\(\lambda\)’ is the wavelength
’d’ is the distance between transmitter and the receiver.

Equation [1.1] is known as Friis transmission equation.

If ‘\(P_o\)’ is the received signal strength at the first meter [d =1 meter], equation [1.1] is written as,
\[
P_r = \frac{P_o}{d^2}
\]  --- (1.2)

In decibels, equation [1.2] is written as,
\[
10 \log (P_r) = 10 \log (P_o) – 20 \log (d)
\]  ---(1.3)

1.5.2 Two ray model

In free space, the signal from the transmitter to the receiver travels in a straight line. But in practical cases, the signal reaches the receiver in multiple paths. The signal from the transmitter may reach the receiver in a straight line as discussed in the free space model. But there are various paths with reflection, refraction from the walls. Furniture can cause multiple paths for the receiver. All these signals may be received with various directions. But these signals are differing in its phase causing attenuation. Calculation of the proper model for this practical case is important. There are various such models available.

The two ray model deals with two rays which exist between transmitter and the receiver. One ray is as shown in free space model, existing as Line of Sight ray between the
transmitter and the receiver. The other is the ray which gets reflected on the flat earth surface and then reaches the receiver. The received power is given by

\[ P_r = P_r G_t G_r \left( \frac{h_t^2 h_r^2}{d^4} \right) \]  

---(1.4)

Here, \( h_t \) is the height of transmitter antenna
\n\( h_r \) is the height of receiver antenna

### 1.5.3 Path loss models for Macro Cellular Areas

Areas ranging few kilometers to few tens of kilometers are known to be Macro Cellular areas. Okumura – Hata Model gives the path loss model for this category. This model is given by

\[ L_p = 69.55 + 26.16 \log f_c - 13.82 \log h_t - a(h_r) + [44.9 - 6.55 \log h_t] \log (d) \]  

---(1.5)

In (1.5), \( f_c \) is known as the center frequency of operation.

### 1.5.4 Path loss model for Pico Cellular Indoor Areas

Pico Cells are radio cells which cover a building or parts of buildings. The range of these cells is between 30 m and 100 m. WLAN, Wireless PBX systems are coming under this category.

When more than one floor is available in the building, the effect of multifloor attenuation model is to be employed for the EM Signal. The signal attenuation by the various floors of the building can be considered as a constant independent of the distance. The path loss model for the multifloor model is given by

\[ L_p = L_0 + nF + 10 \log (d) \]  

--- (1.6)
Here, ‘F’ represents the signal attenuation provided by each floor, 
‘L_0’ is the path loss at the first meter 
‘d’ is the distance between transmitter and the receiver; 
‘n’ is the number of floors.

The value for ‘F’ is selected in such a way that it provides the minimum mean square error between the line and data. For 900 MHz, the value of ‘F’ is selected as 10 dB.

The existence of furniture and other equipments causes shadow fading for the EM signal which is traveling within the indoor region. The variation of the signal from its mean value is considered as Log normal distribution.

Equation [1.6] tells us that the path loss and the number of floors are linear. But practical measurements suggest that the above said relation is actually nonlinear. The corresponding path loss model is given as

\[ L_p = A + L_f (n) + B \log (d) + X \] ---(1.7)

In equation [1.7], ‘L_f (n)’ indicates the power loss as a function of number of floors ‘n’. Here ‘X’ is log normally distributed random variable representing the shadow fading.

1.5.5 Path Loss Model using Building Material

The path loss model based on the building material is given by

\[ L_p = L_0 + 20 \log (d) + \sum m_{type} w_{type} \] ---(1.8)

Here, ‘m_{type}’ refers to the number of partitions of a given type 
‘w_{type}’ is the loss in dB corresponding to such partition.
For example, if the partition is made up of a window in brick wall, it offers ‘2 dB’ attenuation. Similarly, the office wall provides ‘6 dB’ attenuation and cinder wall provides ‘4 dB’ attenuation.

1.6 SIMO and MIMO Channel Models

The receiver of a wireless system is exposed to radio waves in its surrounding environment. So, it receives indirect signals from different paths such as reflected signals, shadow signals and refracted signals. It can also receive signals generated from other sources.

The receiver can have signals with different levels of attenuation and distortion which can cause the actual signal not to be received properly. The most severe effect of multi-path propagation is inter-symbol interference [ISI] which is caused by overlapping of delayed multi-path pulses. The degree of attenuation of these signals varies from time to time due to path changes or environmental disturbances which makes it more difficult to recover the transmitted bits. To prevent ISI from occurring, the first pulse and second pulse have to be separated by a sufficient time difference. So, the symbol rate of the signal and bandwidth of the radio channel are limited by multi-path propagation.

The concept of multi-path components is found wide importance for Indoor environment. The signal transmitted takes multiple paths and gets reflected at various angles to reach the receiver. As the paths taken by those signals are differing, the phase of the signals which arrive at the receiver is also differing. So, there is a possibility of the signal to get fade out. To avoid this situation, the concept of Single Input Multiple Output [SIMO] or multiple input multiple output [MIMO] are to be used. SIMO model is generally applied at mobile environments.

Multiple Input and Multiple Output [MIMO] systems enable increased spectral efficiency for a given transmitted power. Increased capacity is achieved by introducing additional spatial channels which use space time coding. The term ‘multi-channel’ indicates both
transmitter and receiver are equipped with multiple antennas. The channel impulse response is an $M \times N$ matrix that is having transmission coefficient between each pair of antennas for each multi-path component.

MIMO can reduce the effects of fading which occurs due to multi-path propagation in an environment.

Two important formats of MIMO are given as

i) Spatial Diversity:
   Transmit and receive with a narrower radiation beam.

ii) Spatial Multiplexing:
    Increase data handling capacity.

1.7 Spread Spectrum Techniques

Wireless networks employ spread spectrum techniques to maintain security. Spread spectrum converts the narrow band signals to signals of a much wider band. The power density is reduced based on the signal spreading scheme. Because of the low power density, the signal appears as background noise to people who are unaware of the spreading scheme. Only the designated receiver can reconstruct the original signal.

Spread spectrum technique increases the channel capacity and offers high resistance to narrow band interference. The disadvantage of spread spectrum is complexity of spreading mechanisms which results in complex radio hardware design and higher cost.

There are three types of spread spectrum techniques are being used: Direct Sequence Spread Spectrum [DSSS], Frequency Hopping Spread Spectrum [FHSS] and Orthogonal Frequency Division Multiplexing [OFDM].
1.8 Conclusion

Though the field of wireless communication has been around for more than a century, it found wide applications over the last 20 years. In the modern world, the field of wireless communication is rapidly developing. Wireless communication systems such as Cellular phones, Wireless LAN [WLAN] and Wireless Sensor Networks [WSN] are having widespread use and found themselves in the day to day life of common people. The number of wireless communication devices and service providers have exceeded over the fixed line devices and operators in these days. The wireless systems have become very popular among the people due to the advantages it enjoys over the wire line systems. The most important of these advantages are mobility and cost saving.

In this chapter, evolution of wireless network is explained. Introduction on various wireless data communication systems such as WLAN, WSN, ‘Walkie- Talkie’ and Mobile phones is also discussed. The signal coverage methods in EM wave propagation and various path loss models with which the wireless networks are to be planned are also provided. The concept of multi-path propagation and the methods to overcome the drawbacks of EM propagation using MIMO are also discussed. The spread spectrum technique which is used to provide security of wireless networks is also briefed.

Collectively chapter 1 provides insight into the world of wireless networks. The proposed work is based on WLAN which is a part of wireless networks. The next chapter deals with the introduction of WLAN.