Wireless Communication

CSE-472

Wireless Communication

Wireless communications is a type of data communication that is performed and delivered wirelessly. This is a broad term that incorporates all procedures and forms of connecting and communicating between two or more devices using a wireless signal through wireless communication technologies and devices.

Wireless communication generally works through electromagnetic signals that are broadcast by an enabled device within the air, physical environment or atmosphere. The sending device can be a sender or an intermediate device with the ability to propagate wireless signals. The communication between two devices occurs when the destination or receiving intermediate device captures these signals, creating a wireless communication bridge between the sender and receiver device.

Common examples of wireless equipment in use today include:

- Cellular phones and pagers -- provide connectivity for portable and mobile applications, both personal and business
- Global Positioning System (GPS) -- allows drivers of cars and trucks, captains of boats and ships, and pilots of aircraft to ascertain their location anywhere on earth
- Cordless computer peripherals -- the cordless mouse is a common example; keyboards and printers can also be linked to a computer via wireless
- Cordless telephone sets -- these are limited-range devices, not to be confused with cell phones
- Home-entertainment-system control boxes -- the VCR control and the TV channel control are the most common examples; some hi-fi sound systems and FM broadcast receivers also use this technology
- Remote garage-door openers -- one of the oldest wireless devices in common use by consumers; usually operates at radio frequencies
- Two-way radios -- this includes Amateur and Citizens Radio Service, as well as business, marine, and military communications
- Satellite television -- allows viewers in almost any location to select from hundreds of channels
- Wireless LANs or local area networks -- provide flexibility and reliability for business computer users

Types of signals

Different types of signals are used in communication between the devices for wireless transmission of data. The following are the different electromagnetic signals are used depending on their wavelength and frequency.

- Radio Frequency Transmission
- Infrared Transmission
- Microwave Transmission
- Lightwave Transmission

Radio Frequency Transmission

Radio frequency is a form of electromagnetic transmission used in wireless communication. RF signals are easily generated, ranging 3kHz to 300GHz. These are used in wireless communication because of their property to penetrate through objects and travel long distances.

Radio communication depends on the wavelength, transmitter power, receiver quality, type, size and height of the antenna.

Drawbacks

- These are frequency dependent
- These have the relatively low bandwidth for data transmission.

Infrared Transmission

Infrared radiations are electromagnetic radiations with longer wavelengths than visible light. These are usually used for short-range communications. These signals do not pass through solid objects.

Examples: like Television remote control, mobile data sharing.

Microwave Transmission

Microwaves are the form of electromagnetic transmission used in wireless communication systems. The wavelength of microwave ranges from one meter to one millimeter. The frequency varies from 300MHz to 300GHz. These are widely used for long distance communications and are relatively less expensive.

Drawbacks

- The microwave does not pass through buildings.
- Bad weather affects the signal transmission.
- These are frequency dependent.

Light-wave Transmission

Light is an electromagnetic radiation with a wavelength ranging between infrared radiations and ultraviolet radiations. The wavelength ranges from 430 to 750THz. These are unguided optical signals such as laser and are unidirectional.

Drawbacks

- These signals cannot penetrate through rain and fog.
- The laser beam gets easily diverted by air.

Paging System?

A paging system allows for one-way communication to a large audience. Regardless of the broadcast source, a one-way paging system lets the speaker provide clear, amplified instructions throughout a facility. The paging employee speaks a message into a telephone and that message is then broadcast through a network of speakers. Messages can also be recorded and broadcast at a later time.

Advantages Of Paging Systems

- Emails are often ignored or captured by spam blockers.
- Mass texts depend on a strong, local phone network.

- A paging system is hard-wired into the building's infrastructure, allowing reliable mass communication.
- A network of speakers ensure that a message is communicated to every area of a building simultaneously. It's also possible to send pages to specific building "zones" if needed.
- Another key benefit of a paging system is that no dedicated broadcast mechanism is required. An employee can simply pick up the phone, select the paging system and broadcast to the entire building.

Propagation Loses

Antenna and Wave propagation plays a vital role in wireless communication networks. An antenna is an electrical conductor or a system of conductors that radiates/collects (transmits or receives) electromagnetic energy into/from space. An idealized isotropic antenna radiates equally in all directions.

Propagation Mechanisms

Wireless transmissions propagate in three modes. They are −

- Ground-wave propagation
- Sky-wave propagation
- Line-of-sight propagation

Ground wave propagation follows the contour of the earth, while **sky wave propagation** uses reflection by both earth and ionosphere.

Line of sight propagation requires the transmitting and receiving antennas to be within the line of sight of each other. Depending upon the frequency of the underlying signal, the particular mode of propagation is followed.

Examples of ground wave and sky wave communication are **AM radio** and **international broadcasts** such as BBC. Above 30 MHz, neither ground wave nor sky wave propagation operates and the communication is through line of sight.

Transmission Limitations

In this section, we will discuss the various limitations that affect electromagnetic wave transmissions. Let us start with attenuation.

Attenuation

The strength of signal falls with distance over transmission medium. The extent of attenuation is a function of distance, transmission medium, as well as the frequency of the underlying transmission.

Distortion

Since signals at different frequencies attenuate to different extents, a signal comprising of components over a range of frequencies gets distorted, i.e., the shape of the received signal changes.

A standard method of resolving this problem (and recovering the original shape) is to amplify higher frequencies and thus equalize attenuation over a band of frequencies.

Dispersion

Dispersion is the phenomenon of spreading of a burst of electromagnetic energy during propagation. Bursts of data sent in rapid succession tend to merge due to dispersion.

Noise

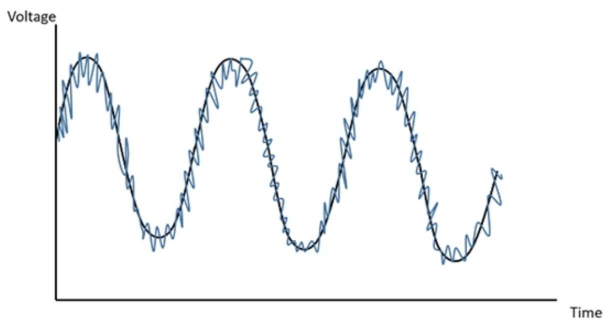
The most pervasive form of noise is thermal noise, which is often modeled using an additive Gaussian model. Thermal noise is due to thermal agitation of electrons and is uniformly distributed across the frequency spectrum.

Other forms of noise include −

- **Inter modulation noise** (caused by signals produced at frequencies that are sums or differences of carrier frequencies)
- **Crosstalk** (interference between two signals)
- **Impulse noise** (irregular pulses of high energy caused by external electromagnetic disturbances).

While an impulse noise may not have a significant impact on analog data, it has a noticeable effect on digital data, causing **burst errors**.

The below figure clearly illustrates how the noise signal overlaps the original signal and tries to change its characteristics.



Fading

Fading refers to the variation of the signal strength with respect to time/distance and is widely prevalent in wireless transmissions. The most common causes of fading in the wireless environment are multipath propagation and mobility (of objects as well as the communicating devices).

Multipath propagation

In wireless media, signals propagate using three principles, which are reflection, scattering, and diffraction.

- **Reflection** occurs when the signal encounters a large solid surface, whose size is much larger than the wavelength of the signal, e.g., a solid wall.
- **Diffraction** occurs when the signal encounters an edge or a corner, whose size is larger than the wavelength of the signal, e.g., an edge of a wall.
- **Scattering** occurs when the signal encounters small objects of size smaller than the wavelength of the signal.

One consequence of multipath propagation is that multiple copies of a signal propagation along multiple different paths, arrive at any point at different times. So the signal received at a point is not only affected by the **inherent noise, distortion, attenuation**, and **dispersion** in the channel but also the **interaction of signals** propagated along multiple paths.

Delay spread

Suppose we transmit a probing pulse from a location and measure the received signal at the recipient location as a function of time. The signal power of the received signal spreads over time due to multipath propagation.

The delay spread is determined by the density function of the resulting spread of the delay over time. **Average delay spread** and **root mean square delay spread** are the two parameters that can be calculated.

Doppler spread

This is a measure of **spectral broadening** caused by the rate of change of the mobile radio channel. It is caused by either relative motion between the mobile and base station or by the movement of objects in the channel.

When the velocity of the mobile is high, the Doppler spread is high, and the resulting channel variations are faster than that of the baseband signal, this is referred to as **fast fading**. When channel variations are slower than the base and signal variations, then the resulting fading is referred to as **slow fading**.

In some cases, there is a scope of performance deterioration, which affects the output. The major cause for this might be the mobile channel impairments. To resolve this, there are three popular techniques −

Equalizer

An equalizer within a receiver compensates for the average range of expected channel amplitude and delay characteristics. In other words, an equalizer is a filter at the mobile receiver whose impulse response is inverse of the channel impulse response. Such equalizers find their use in **frequency selective fading** channels.

Diversity

Diversity is another technique used to compensate **fast fading** and is usually implemented using two or more receiving antennas. It is usually employed to reduce the depths and duration of the fades experienced by a receiver in a flat fading channel.

Channel Coding

Channel coding improves mobile communication link performance by adding redundant data bits in the transmitted message. At the baseband portion of the transmitter, a channel coder maps a digital message sequence in to another specific code sequence containing greater number of bits than original contained in the message. Channel Coding is used to correct **deep fading** or **spectral null**.

Equalization

ISI (Inter Symbol Interference) has been identified as one of the major obstacles to high speed data transmission over mobile radio channels. If the modulation bandwidth exceeds the **coherence bandwidth** of the radio channel (i.e., frequency selective fading), modulation pulses are spread in time, causing ISI.

An equalizer at the front end of a receiver compensates for the average range of expected channel amplitude and delay characteristics. As the mobile fading channels are **random** and **time varying**, equalizers must track the time-varying characteristics of the mobile channel and therefore should be time varying or adaptive. An adaptive equalizer has two phases of operation: **training** and **tracking**.

Training Mode

Initially a known, fixed length training sequence is sent by the transmitter so that the receiver equalizer may average to a proper setting. **Training sequence** is typically a pseudo-random binary signal or a fixed, of prescribed bit pattern.

The training sequence is designed to permit an equalizer at the receiver to acquire the **proper filter coefficient** in the worst possible channel condition. An adaptive filter at the receiver thus uses a **recursive algorithm** to evaluate the channel and estimate filter coefficients to compensate for the channel.

Tracking Mode

When the training sequence is finished the filter coefficients are near optimal. Immediately following the training sequence, user data is sent.

When the data of the users are received, the **adaptive algorithms** of the equalizer tracks the changing channel. As a result, the adaptive equalizer continuously changes the filter characteristics over time.

Diversity

Diversity is a powerful communication receiver technique that provides wireless link improvement at a relatively low cost. **Diversity techniques** are used in wireless communications systems to primarily to improve performance over a fading radio channel.

In such a system, the receiver is provided with multiple copies of the same information signal which are transmitted over two or more real or virtual communication channels. Thus the basic idea of diversity is **repetition** or **redundancy of information**. In virtually all the applications, the diversity decisions are made by the receiver and are unknown to the transmitter.

Types of Diversity

Fading can be classified into small scale and large scale fading. Small-scale fades are characterized by deep and rapid amplitude fluctuations which occur as the mobile moves over distances of just a few wavelengths. For narrow-band signals, this typically results in a **Rayleigh faded envelope**. In order to prevent deep fades from occurring, microscopic diversity techniques can exploit the rapidly changing signal.

If the antenna elements of the receiver are separated by a fraction of the transmitted wavelength, then the various copies of the information signal or generically termed as branches, can be combined suitably or the strongest of them can be chosen as the received signal. Such a diversity technique is termed as Antenna or Space diversity.

Frequency Diversity

The same information signal is transmitted on different carriers, the frequency separation between them being at least the coherence bandwidth.

Time Diversity

The information signal is transmitted repeatedly in time at regularly intervals. The separation between the transmit times should be greater than the coherence time, T_c. The time interval depends on the fading rate, and increases with the decrease in the rate of fading.

Polarization diversity

Here, the electric and magnetic fields of the signal carrying the information are modified and many such signals are used to send the same information. Thus orthogonal type of polarization is obtained.

Angle Diversity

Here, directional antennas are used to create independent copies of the transmitted signal over multiple paths.

Space Diversity

In Space diversity, there are multiple receiving antennas placed at different spatial locations, resulting in different (possibly independent) received signals.

The difference between the diversity schemes lies in the fact that in the first two schemes, there is **wastage of bandwidth** due to **duplication of the information** signal to be sent. Thus problem is avoided in the remaining three schemes, but with the cost of increased **antenna complexity**.

The correlation between signals as a function of distance between the antenna elements is given by the relation −

$$\rho = J_0^2\left(\frac{2\Pi d}{\lambda}\right)$$

Where,

- **J_0** = Bessel function of zero order and first kind
- **d** = distance of separation in space of antenna elements
- **λ** = carrier wavelength.

Channel Characteristics

The wireless channel is susceptible to a variety of transmission impediments such as **path loss, interference** and **blockage**. These factors restrict the range, data rate, and the reliability of the wireless transmission.

Types of Paths

The extent to which these factors affect the transmission depends upon the environmental conditions and the mobility of the transmitter and receiver. The path followed by the signals to get to the receiver, are two types, such as −

Direct-path

The transmitted signal, when reaches the receiver directly, can be termed as a **directpath** and the components presents that are present in the signal are called as **directpath components**.

Multi-path

The transmitted signal when reaches the receiver, through different directions undergoing different phenomenon, such a path is termed as **multi-path** and the components of the transmitted signal are called as **multi-path components**.

They are reflected, diffracted and scattered by the environment, and arrive at the receiver shifted in amplitude, frequency and phase with respect to the direct path component.

Characteristics of Wireless Channel

The most important characteristics of wireless channel are −

- Path loss
- Fading
- Interference
- Doppler shift

In the following sections, we will discuss these channel characteristics one by one.

Path Loss

Path loss can be expressed as the ratio of the power of the transmitted signal to the power of the same signal received by the receiver, on a given path. It is a function of the propagation distance.

- Estimation of path loss is very important for designing and deploying wireless communication networks
- Path loss is dependent on a number of factors such as the radio frequency used and the nature of the terrain.
- The free space propagation model is the simplest path loss model in which there is a direct-path signal between the transmitter and the receiver, with no atmosphere attenuation or multipath components.

In this model, the relationship between the transmitted power P_t and the received power P_r is given by

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\Pi d}\right)^2$$

Where

- G_t is the transmitter antenna gain
- G_r is the receiver antenna gain
- **d** is the distance between the transmitter and receiver
- **λ** is the wavelength of the signal

Two-way model also called as two path models is widely used path loss model. The free space model described above assumes that there is only one single path from the transmitter to the receiver.

In reality, the signal reaches the receiver through multiple paths. The two path model tries to capture this phenomenon. The model assumes that the signal reaches the receiver through two paths, one a line-of-sight and the other the path through which the reflected wave is received.

According to the two-path model, the received power is given by

$$P_r = P_t G_t G_r \left(\frac{h_t h_r}{d^2}\right)^2$$

Where

- p_t is the transmitted power
- G_t represent the antenna gain at the transmitter

- $\mathbf{G_r}$ represent the antenna gain at the receiver
- **d** is the distance between the transmitter and receiver
- $\mathbf{h_t}$ is the height of the transmitter
- $\mathbf{h_r}$ are the height of the receiver

Fading

Fading refers to the fluctuations in signal strength when received at the receiver. Fading can be classified in to two types −

- Fast fading/small scale fading and
- Slow fading/large scale fading

Fast fading refers to the rapid fluctuations in the amplitude, phase or multipath delays of the received signal, due to the interference between multiple versions of the same transmitted signal arriving at the receiver at slightly different times.

The time between the reception of the first version of the signal and the last echoed signal is called **delay spread**. The multipath propagation of the transmitted signal, which causes fast fading, is because of the three propagation mechanisms, namely −

- Reflection
- Diffraction
- Scattering

The multiple signal paths may sometimes add constructively or sometimes destructively at the receiver causing a variation in the power level of the received signal. The received single envelope of a fast fading signal is said to follow a **Rayleigh distribution** to see if there is no line-of-sight path between the transmitter and the receiver.

Slow Fading

The name Slow Fading itself implies that the signal fades away slowly. The features of slow fading are as given below.

- Slow fading occurs when objects that partially absorb the transmission lie between the transmitter and receiver.
- Slow fading is so called because the duration of the fade may last for multiple seconds or minutes.
- Slow fading may occur when the receiver is inside a building and the radio wave must pass through the walls of a building, or when the receiver is temporarily shielded from the transmitter by a building. The obstructing objects cause a random variation in the received signal power.
- Slow fading may cause the received signal power to vary, though the distance between the transmitter and receiver remains the same.
- Slow fading is also referred to as **shadow fading** since the objects that cause the fade, which may be large buildings or other structures, block the direct transmission path from the transmitter to the receiver.

Interference

Interference occurs when unwanted signals disrupt wireless communication. It may prevent reception altogether, may cause only a temporary loss of a signal, or may affect the quality of the audio or video produced by our equipment.

Wireless transmissions have to counter interference from a wide variety of sources. Such as

- Physical objects Trees, masonry, buildings, and other physical structures are some of the most common sources of interference. The density of the materials used in a building's construction determines the number of walls the RF signal can pass through and still maintain adequate coverage. Concrete and steel walls are particularly difficult for a signal to pass through. These structures will weaken or, at times, completely prevent wireless signals.
- Radio frequency interference Wireless technologies such as 802.11b/g use RF range of 2.4GHz, and so do many other devices such as cordless phones, microwaves, and so on. Devices that share the channel can cause noise and weaken the signals.
- Electrical interference Electrical interference comes from devices such as computers, fridges, fans, lighting fixtures, or any other motorized devices. The impact that electrical interference has on the signal depends on the proximity of the electrical device to the wireless access point. Advances in wireless technologies and in electrical devices have reduced the impact these types of devices have on wireless transmissions.
- Environmental factors Weather conditions can have a huge impact on wireless signal integrity. Lighting, for instance, can cause electrical interference, and fog can weaken signals as they pass through.

Forms of Interference

Two main forms of interference are −

- Adjacent channel interference and
- Co-channel interference.

In Adjacent channel interference case, signals in nearby frequencies have components outside their allocated ranges, and these components may interfere with on-going transmission in the adjacent frequencies. It can be avoided by carefully introducing guard bands between the allocated frequency ranges.

Co-channel interference or **CCI** sometimes also referred to as narrow band interference, is cross-talk to two different radio transmitters using the same channel. It can be caused by many factors from weather conditions to administrative and design issues. Co-channel interference may be controlled by various radio resource management schemes.

Inter-symbol interference is another type of interference, where distortion in the received signal is caused by the temporal spreading and the consequent overlapping of individual pulses in the signal.

Adaptive equalization is a commonly used technique for combating inter symbol interference. It involves gathering the dispersed symbol energy into its original time interval. Complex digital processing algorithms are used in the equalization process.