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COMPARATIVE ANALYSIS OF COMMUNICATION AND INTERNET TRANSMISSION MEDIA

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ABSTRACT

This work takes a view on three different communication and internet transmission media commonly used in telecommunication. The structure and working principle is reviewed alongside the recent developments in cabling standards and applications. Comparison is made based on the properties of the individual medium, signal impairments and other factors that affect transmission media in a network. It also demonstrates how problems due to signal impairments can be mitigated and how various media can be optimized in a network. A broad overview of the media properties and application is given, in order to enable network designers and potential investors choose a suitable medium for their network and environment.

KEYWORDS: Fibre, Transmission, Media, Internet, Copper, Wireless

INTRODUCTION

Telecommunications systems deliver messages using a number of different transmission media, including copper wires, fiber-optic cables, communication satellites, and microwave radio. One way to categorize telecommunications media is to consider whether the media uses wire or air. In voice and data communication we require a channel to convey information in form of signals, this channel is referred to as the transmission medium. [1]

Transmission medium serves as a physical pathway that connects devices and people on a network. Each transmission medium requires specialized network hardware that has to be compatible with that medium.[2] [3] The transmission medium is located below the physical layer of the OSI model. The different media types used in both voice and data communication can be classified into two forms guided (wired) and unguided media (wireless).

The Guided media (Wired) provides a direct connection from one device to another, it includes twisted-pair cable, coaxial cable and fiber optic cable while the Unguided media (Wireless) transports electromagnetic waves without using a physical conductor, this includes radio waves, microwaves, infrared and satellites. The medium here is usually air, vacuum or water. [4]

The characteristics and quality of a data transmission are determined both by the characteristics of the medium and the characteristics of the signal. In the case of guided media, the medium itself is more important in determining the limitations of transmission but for unguided media, the bandwidth of the signal produced by the transmitting antenna is more important than the medium in determining transmission characteristics. One key property of signals transmitted by antenna is directionality. [5] [6] In general, signals at lower frequencies are omnidirectional; that is, the signal propagates in all directions from the antenna. At higher frequencies, it is possible to focus the signal into a directional beam. In considering the design of data transmission systems, key concerns are data rate and distance: the greater the data rate and distance the better.

The focus here is on three media types, the twisted pair and the fiber optics cable for guided media and microwaves for unguided media. Transmission media are generally not perfect, in other words the signals traveling through these media are subjected to several kinds of impairments. This means that the received signal at the other end of the medium is not exactly the same with that which was been transmitted. [7] [8] [9] Comparison of the various media type as mentioned above is based on the following media and signal characteristics; Interference, Bandwidth requirement, Attenuation, Speed of operation, Security, Cost and Distance

Twisted Pair Cable

A twisted pair consists of two insulated copper wires, typically 1 mm thick. The wires are twisted together in a helical. The purpose of twisting the wires is to reduce electrical interference from similar pairs close by. Twisted pair wires are commonly used in local telephone communication, and for digital data transmission over short distances up to 1 km.[5] [10] [11]

Characteristics of Twisted-Pair

The total usable frequency spectrum of telephony twisted-pair copper cable is about 1MHz (i.e., 1 million cycles per second). Newer standards for broadband DSL, also based on twisted-pair, use up to 2.2MHz of spectrum. Loosely translated into bits per second (bps)—a measurement of the amount of data being transported, or capacity of the channel—twisted-pair cable offers about 2Mbps to 3Mbps over 1MHz of spectrum. But there's an inverse relationship between distance and the data rate that can be realized. The longer the distance, the greater the impact of errors and impairments, which diminish the data rate In order to achieve higher data rates, two techniques are commonly used: The distance of the loop can be shortened, and advanced modulation schemes can be applied, which means we can encode more bits per cycle. A good example of this is Short Reach VDSL2, which is based on twisted copper pair but can support up to 100Mbps, but over a maximum loop length of only 330 feet (100 m). New developments continue to allow more efficient use of twisted-pair and enable the higher data rates that are needed for Internet access and Web surfing, but each of these new solutions specifies a shorter distance, over which the twisted-pair is used, and more sophisticated modulation and error control techniques are used as well. [12] [13] [14]

Another characteristic of twisted-pair is that it requires short distances between repeaters. Again, this means that more components need to be maintained and there are more points where trouble can arise, which lead to higher costs in terms of long-term operation. Twisted-pair is also highly susceptible to interference and distortion, including electromagnetic interference (EMI), radio frequency interference (RFI), and the effects of moisture and corrosion. Therefore, the age and health of twisted-pair cable are important factors. There are two types of twisted-pair: UTP and STP. In STP, a metallic shield around the wire pairs minimizes the impact of outside interference. Most implementations today use UTP. Twisted-pair is divided into categories that specify the maximum data rate possible. The predominant cable categories in use today are Cat 3 (due to widespread deployment in support of 10Mbps Ethernet—although it is no longer being deployed) and Cat 5e. [15] [16]

Optical Fiber Cable

An optical fiber is a thin (2 to 125 µm), flexible medium capable of guiding an optical ray. Various glasses and plastics can be used to make optical fibers. An optical fiber cable has a cylindrical shape and consists of three concentric sections: the core, the cladding, and the jacket. The core is the innermost section and consists of one or more very thin strands, or fibers, made of glass or plastic; the core has a diameter in the range of 8 to 50 µm. Each fiber is surrounded by its own cladding, a glass or plastic coating that has optical properties different from those of the core and a diameter of 125 µm. The interface between the core and cladding acts as a reflector to confine light that would otherwise escape the core. The outermost layer, surrounding one or a bundle of cladded fibers, is the jacket. The jacket is composed of plastic and other material layered to protect against moisture, abrasion, crushing, and other environmental dangers. [17] [18] [19]

Optical fiber already enjoys considerable use in long-distance telecommunications, and its use in military applications is growing. The continuing improvements in performance and decline in prices, together with the inherent advantages of optical fiber, have made it increasingly attractive for local area networking. Five basic categories of application have become important for optical fiber: Long-haul trunks, Metropolitan trunks, rural exchange trunks, Subscriber loops & Local area networks. [20] [21]

Characteristics of Optical Fiber

Optical fiber transmits a signal-encoded beam of light by means of total internal reflection. Total internal reflection can occur in any transparent medium that has a higher index of refraction than the surrounding medium. In effect, the optical fiber acts as a waveguide for frequencies in the range of about 1014 to 1015 Hertz; this covers portions of the infrared and visible spectra. Two different types of light source are used in fiber optic systems: the light-emitting diode (LED) and the injection laser diode (ILD). Both are semiconductor devices that emit a beam of light when a voltage is applied. The LED is less costly, operates over a greater temperature range, and has a longer operational life. The ILD, which operates on the laser principle, is more efficient and can sustain greater data rates. There is a relationship among the wavelength employed, the type of transmission, and the achievable data rate. Both single mode and multimode can support several different wavelengths of light and can employ laser or LED light sources. Light from a source enters the cylindrical glass or plastic core. Rays at shallow angles are reflected and propagated along the fiber; other rays are absorbed by the surrounding material. This form of propagation is called step-index multimode, referring to the variety of angles that will reflect. With multimode transmission, multiple propagation paths exist, each with a different path length and hence time to traverse the fiber. This causes signal elements (light pulses) to spread out in time, which limits the rate at which data can be accurately received. This type of fiber is best suited for transmission over very short distances. When the fiber core radius is reduced, fewer angles will reflect. By reducing the radius of the core to the order of a wavelength, only a single angle or mode can pass: the axial ray. This single-mode propagation provides superior performance for the following reason. Because there is a single transmission path with single-mode transmission, the distortion found in multimode cannot occur. Single-mode is typically used for long-distance applications, including telephone and cable television. [22] [23]

Finally, by varying the index of refraction of the core, a third type of transmission, known as graded-index multimode, is possible. The higher refractive index at the center makes the light rays moving down the axis advance more slowly than those near the cladding. Rather than zig-zagging off the cladding, light in the core curves helically because of the graded index, reducing its travel distance. The shortened path and higher speed allows light at the periphery to arrive at a receiver at about the same time as the straight rays in the core axis. Graded-index fibers are often used in local area networks.

Microwave Radio

- Digital microwave radio systems are used to transmit and receive information between two points that can be separated by up to 60 kilometers (and sometimes farther) in a telecommunications network. The information can be voice, data, or video as long as it is in a digital format.
- A typical microwave radio consists of three basic components: a digital modem for interfacing with digital terminal equipment, a radio frequency (RF) unit for converting a carrier signal from the modem to a microwave signal, and an antenna to transmit and receive the signal. The combination of these three components is referred to as a radio terminal. Two terminals are required to establish a microwave communications link, commonly referred to as a microwave hop.
- There are two basic configurations for microwave terminals: non-protected and protected or monitored-hot-standby (MHSB). The non-protected configuration is a single standalone terminal. The protected or MHSB configuration has a redundant set of electronics that serves as a back up to the in-service electronics in case of a failure. [24] [25]

Characteristics of Microwave Radio

- One very important characteristic of digital microwave radio transmission is its immunity to noise. Noise refers to unwanted electromagnetic waveforms that corrupt a message signal. Noise is inevitable in electrical communications systems. In order to transmit an electrical signal over a long distance it is necessary to boost the signal level at intervals along the transmission path; this is the job of a device called a repeater. [26] [27]
- Microwave radio offers several advantages over cable-based transmission. Microwave radio is simpler, faster, more feasible and more flexible to implement than cable systems. Because there is no buried cable involved, microwave systems do not require right-of-way, and they are not susceptible to cable cuts.
- Today’s microwave radios can be installed quickly and relocated easily. The major time delays are usually in getting through the regulatory process in a governmentally controlled environment. [9]

Attenuation

Due to the signal spreading and the resistance of the medium, the signal strength reduces as it travels on a cable or in the air. Such reduction in signal strength is referred to as attenuation. For each medium, the attenuation can usually be predicted from the knowledge of medium characteristics. In general, there is less attenuation in cables than free space. Atmosphere is worse than free space and usually causes significant amounts of attenuation. [11]

Fiber attenuation, which necessitates the use of amplification systems, is caused by a combination of material absorption, Rayleigh scattering, Mie scattering, and connection losses. Although material absorption for pure silica is only around 0.03 dB/km (modern fiber has attenuation around 0.3 dB/km), impurities in the original optical fibers caused attenuation of about 1000 dB/km.

Today's optical fiber attenuation ranges from 0.5dB/km to 1000dB/km depending on the optical fiber used. Attenuation limits are based on intended application. Other forms of attenuation are caused by physical stresses to the fiber, microscopic fluctuations in density, and imperfect splicing techniques. [12]

The peak in loss in the 1400-nm region is due to hydroxyl ion (OH−) impurities in the fiber. However, in Lucent's All Wave fiber this peak is reduced significantly. In today's optical communications systems three wavelength bands are used: 0.85, 1.3, and 1.55µm, where the latter band provides the smallest attenuation of 0.25 dB/km. [3] [13]

Light power on an optic fiber is lost during transmission either by leakage or due to lack of clarity of the material and the loss is expressed in decibels per kilometer and is written as dBkm–1. [21]

The attenuation for twisted pair is a very strong function of frequency. An attenuation test was carried out on twisted pair cable (by Minicom Advanced Systems) alongside other tests such as wiremap, near end coss talk (NEXT) and length tests. The result of the test showed that the more attenuation there is, the less signal there will be present at the receiver. It also showed that attenuation increases with distance and frequency. In addition for every 6dB of loss, the original signal will be half the original amplitude.[3] [14]

Attenuation is an inherent characteristic of RF (radio frequency) signal and also is very important in the design aspect. So it should be taken into consideration while designing and calculating the RSL (Receive Signal Level) of the RF signal between two stations. Attenuation is directly proportional to the frequency, that means the RF signal gets significantly attenuated at higher frequencies and there is less effect of attenuation at lower frequencies. There are also some losses (signal attenuation) in transmitter as well as in receiver block; however the major attenuation occurs in the transmission medium between Tx and Rx antennas of two stations.

The signal gets attenuated as it propagates through the medium and the longer the distance it travels the more it gets attenuated and finally after propagating through a long distance, the signal get vanished completely, so as the signal travels, it gets attenuated exponentially. In general, the maximum transmission distance between two stations is 50 km but when the signal propagates through the reflected surfaces such as rivers, oceans, lakes, sea etc., then the maximum distance it can propagate is only about 35 km.

Another important source of microwave signal attenuation is rain. When the rain rate intensity is high, then the microwave signal gets significantly attenuated. For example, it is observed that at high rain intensity (150 mm/hr), the fading of RF signal at 2.4 GHz reached the value 0.02 dB/km. So even if the transmission distance is near and the transmitted power is large enough, the signal will be attenuated in a very significant amount due to heavy rain that the link between the two stations may break down. The attenuation becomes significant at higher frequencies and more precisely saying at frequencies greater than 10 GHz. At higher frequencies, the signal can get attenuated up to 1 dBm/km due to heavy rain fall.

Another factor that engenders the signal attenuation is the tree. The signal often has to propagate via dense forest. The absorption of signal is significant while propagating through the dense forest. Isolated trees are not the problem for microwave signal as their individual effect of attenuation is very small. In one experiment, it is observed that the trees having wet leaves can cause huge attenuation as compared to the trees bearing the dry leaves. It is observed that the signal can get attenuated up to 0.4 dB/m at 3 GHz.So there is a huge path loss if the signal passes through several hundred meters through the jungle.

INTERFERENCE

Interference from competing signals in overlapping frequency bands can distort or wipe out a signal. Interference is of particular concern for unguided media, but is also a problem with guided media. For guided media, interference can be caused by emanations from nearby cables. For example, twisted pairs are often bundled together and conduits often carry multiple cables. Interference can also be experienced from unguided transmissions. Proper shielding of a guided medium can minimize this problem. Optical fiber systems are not affected by external electromagnetic fields. Thus the system is not vulnerable to interference. By the same token, fibers do not radiate energy, so there is little interference with other equipment and there is a high degree of security from eavesdropping. In addition, fiber is inherently difficult to tap.

Twisted pair cable is quite susceptible to interference and noise because of its easy coupling with electromagnetic fields. Several measures are taken to reduce impairments. Shielding the wire with metallic braid or sheathing reduces interference. The twisting of the wire reduces low-frequency interference, and the use of different twist lengths in adjacent pairs reduces crosstalk.

The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radio communication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy. Permissible Interference is an observed or predicted interference which complies with quantitative interference and sharing criteria contained in the Regulations or in ITU-R recommendations or in special agreements as provided for in these Regulations. Accepted Interference is an Interference at a higher level than that defined as permissible interference and which has been agreed upon between two or more administrations without prejudice to other administrations. Harmful Interference is an Interference which endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radio communication service operating in accordance with these Regulations.[18] There are two sources of Interference in microwave, the first is the Intra-System Interference which could be as a result of Multipath, Cross Polarization Component, Adjacent Channel Interference or Co-channel Interference while the second is Inter-System Interference which comprises of Satellite Systems, Other Systems, or Out-of-Band Interference.

Speed

There are two different forms of speed, the first is the Propagation speed which refers to the time it takes to send the first bit across the medium, this speed depends upon the medium. Airwaves and fiber are speed of light while Copper wire is two thirds the speed of light. The second is the Data transfer speed – the time to transmit the rest of the bits in the message. This speed is measured in bits per second and is commonly referred to as data rate. The data rate of a medium is limited by the range of frequencies it operates in

Security

Security is another important characteristic. There is no such thing as complete security, and no transmission medium in and of itself can provide security. But using encryption and authentication helps ensure security. Also, different media types have different characteristics that enable rapid intrusion as well as characteristics that enable better detection of intrusion. [6] One of the first thoughts or considerations should be the security issues that could arise when choosing a medium for transferring data across the network. As the areas that need encryption technology have grown and changed, the technology itself has improved in time. One of the more advanced technologies that will provide protection for all types of media is IPSec or Internet Protocol Security. [19]

Fiber Optic connections are considered very secure because the data is transmitted as beams of light; therefore no electromagnetic waves are generated. Insulation surrounds the fiber optic strands making it impossible to detect the light pulses without tapping into the actual strands. The fiber strands are extremely thin and virtually impossible to tap into without breaking the strand, which would immediately shutdown the connection. The dielectric nature of optical fiber can eliminate the dangers found in areas of high lightning-strike incidence. Since optical fiber has no metallic components, it can be installed in areas with electromagnetic interference (EMI), including radio frequency interference (RFI).

The nature of optical fiber makes it virtually impossible to detect the signal being transmitted inside the cable. The only way to do so is by actually tapping into the optical fiber itself. This normally can be detected by surveillance systems and is usually accomplished during a sabotaged power outage or under other circumstances where detection would not be likely. These characteristics make fiber cabling attractive to organizations with major security concerns.

The equipment used for tapping into is expensive and the number of fibers in the cables made it difficult to narrow down captured transmissions to a particular connection. In addition, physical interruption of the fibers could be detected using time domain reflectometry, this of course makes taps hard to conceal. It was also common knowledge that separating the fiber strands and bending them in a tight curve would allow the escape of a small portion of the signal without revealing the data interception.

Twisted pair has the obvious problem that it can be tapped into at any point along which it is run. This is a nightmare for administrators since the media can run behind walls and under floors where someone could tap into the cabling undetected. Twisted pair cabling also emits electromagnetic energy that can be picked up with sensitive equipment even without physically tapping into the media; this is known as cross-talk and for many years was just considered a nuisance. Now it is considered a security threat.

There is another side of transmission media considerations which is not secure or safe that many organizations use today. This type of network is wireless local area networks (WLAN) or WiFi. People generally assume that the biggest security hole in wireless communication is that the data is transmitted through air, thus allowing an intruder to catch the data with a receiver from a distance. While this is true that an intruder can catch the data, the data received is usually either encrypted or sent in spread spectrum.

Distance

Distance here is based on repeater spacing i.e maximum distance coverable by the transmission medium before the use of repeaters. It also covers anticipated distance for future applications.

Fiber optics can space repeaters about 500 miles (800 km) apart, but new developments continue to increase the distance or spacing. Trials have been successfully completed at distances of 2,500 miles (4,000 km) and 4,000 miles (6,400 km) [6]

Structured cable systems for the data world have a length limit of 100 meters (328 feet) total. (Note: this restriction does not directly apply to the transmission of analog signals.)

Typical microwave distances before repeaters are necessary is shown in the table below [17]

Table 1

Frequency	Approximate Distance
2-6 GHz	30 miles
10-12 GHz	20 miles
18 GHz	7 miles
23 GHz	5 miles

DISCUSSIONS OF ANALYSIS

Bandwidth Comparison

Twisted pair cable offers a maximum bandwidth of 600MHz which could increase to 1200MHz in the near future with the development of cat 8 cables. Fiber optics offers the largest bandwidth between 600MHz and 2GHz using single mode fiber. The 1THz bandwidth of fiber has been proven through laboratory tests using dense wave division multiplexing (DWDM) but this has not yet been put into practice. In the future it is expected that devices that can carry such technology will be made available and bandwidths 0f 1THz would be utilized.

Speed Comparison

Speed in a medium increases as bandwidth increases, this means the greater the bandwidth of a medium the greater the speed (i.e data rate). Although twisted pair shows a maximum data rate of 600Mbps, it only covers 10Mbps for distance of 100m.

Distance Comparison

The maximum distance covered by twisted pair cable is 2-10km for telephone lines using cat 1 and cat 2 cables and 100m for LAN connections using cat3- cat 7 cables. This is one of the factors that limit the use of twisted pair to indoor application for LAN purposes. With the 100m distance coverage, 10m is set out for patch cords while 90m goes for horizontal cabling from data center to the end user.

Microwave radio would go a maximum distance of 50km before the use of repeaters while single mode fiber covers distances of upto 300km, but with satellites we have unlimited distance eliminating the use of repeaters. This is one of the reasons satellites have found application in long distance communication, linking different continents together and also used in GPS and tracking devices to monitor movements even in remote areas, where other media are not available. It also gives room for expansion of individual networks, that is why it has been employed by banks and CATV providers, it allows multiple stations distance away to communicate with the base station without using repeaters or attracting extra cost.

Attenuation Comparison

The highest amount of attenuation is found in twisted pair as compared to fiber optics, this limits the distance of the cable, hence making it unfit for long distance communication.

Security

Fiber is more secured than every other media, this is because with microwave and satellite, the signal travels through air which makes it open to eavesdroppers although fiber can be tapped into, it requires special devices and time to do so

Microwaves are not considered secure media since the signal is transmitted over unsecure distances, often over metropolitan areas.

CONCLUSIONS

Transmission media have their individual strengths and weaknesses, most networks are made up of a combination of transmission media capitalizing on the respective strengths of wireless, electrical and optical networks.

While twisted pair cables have become relatively cheap and easy to work with, Wireless and optical networks can be thought of as quite complementary. Optical fiber does not go everywhere, but where it does go, it provides a huge amount of available bandwidth. Wireless networks, on the other hand, potentially go almost everywhere and are thus able to support mobility and reachability, while microwave radio can cover both indoor and outdoor communication, VSATs are able to reach even remote areas.

As opposed to the wireless channel, optical fiber exhibits a number of advantageous transmission properties such as low attenuation, large bandwidth, and immunity from electromagnetic interference but they provide a highly band width-constrained transmission channel, susceptible to a variety of impairments

Fiber optic backbone with copper to the desktop is commonly used where people want direct connections especially in corporate environment. Each situation in an international market presents a uniquely different environment and each environment must be looked at individually to determine the appropriate media for installation. By understanding the advantages and disadvantages of each media and it so perating characteristics within the environmental constraints described, an intelligent decision can be made.

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