Fiber to the Antenna

A Closer Look at Benefits and Issues in Integrated Optical and Wireless Networks

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Declaration

We hereby declare that, this thesis paper is based on the results found by our research and other researchers mentioned by reference. This thesis has not been previously submitted for any degree.

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ABSTRACT

With the fast-growing technology in the communication industry, demand for speed and mobility of the data exchange throughout the world is accelerating in an incredible rate. To meet such demand a need for the integration for the wireless network enhancing mobility and fiber network enhancing speed has become a necessity.

Hence, in our thesis work we have done an extensive research evaluating all the drawbacks and advantages of each of the two networks separately and also went through the latest developments of their integration. After studying we have found Fiber to the Antenna Solution (FTTA), which has proved to be a very promising solution to our problems.

Fiber to the Antenna (FTTA) solution in integrated optical and wireless networks brings significant benefits offering speed and mobility in communications. However, there are some unavoidable issues that field engineers constantly experience while implementing physical components of FTTA systems at cell sites. In this thesis paper, we study FTTA architecture, physical components, benefits and implementation issues very closely. The benefits of FTTA using Radio over Fiber technology are highlighted. Also, the implementation issues with power, environmental protection, surge protection etc. are analyzed thoroughly with currently available solutions in the market.

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Chapter 1

Introduction

1.1 Introduction

In 2011, the International Telecommunications Union reported that mobile broadband subscriptions reached 1.2 billion, and millions of new customers sign up each week [18]. Only video applications in 2011, occupied 52 percent of internet data traffic and this figure will rapidly grow up to 90 percent and more in the upcoming years. It is not surprising that mobile broadband traffic has nearly doubled last year. This change in demands is mainly driven by breakthroughs in modern devices i.e. smartphones, laptops, tabs along with new technologies which push the mobile data traffic of the consumers from one platform to another. The growth rates vary depending by region. Most growth was in Asia-Pacific countries (95 percent) and least in Europe [2].

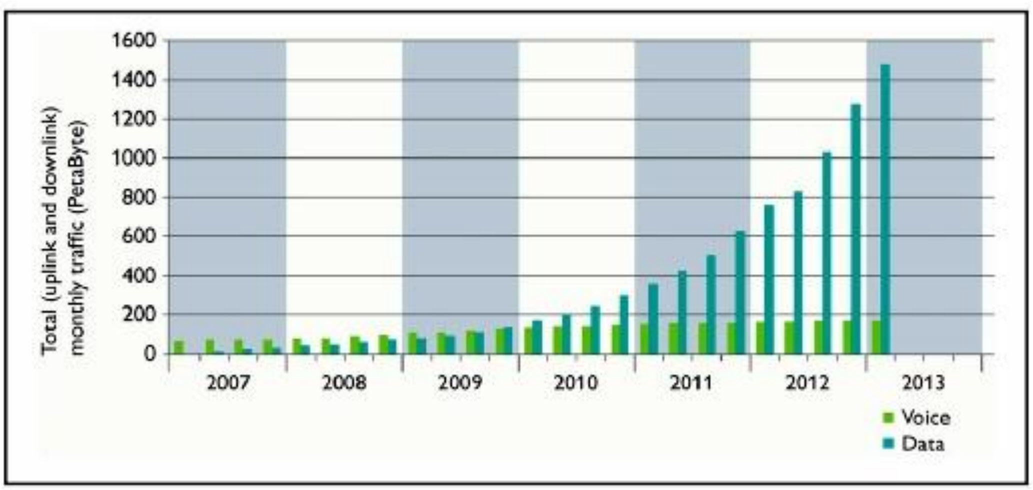


Figure 1.1: Global Mobile Traffic Development (Source: Ericsson 2013) [2]

Meanwhile, device manufacturers and wireless service providers have begun introducing LTE/4G-capable products. As a result, network capacity is increasingly strained and the biggest challenge in future for mobile operators will be the demand for spectrum. That is why mobile operators are currently working hard to upgrade the infrastructure and provide the bandwidth according to the customers demand.

In this scenario, an integrated solution of wireless and optical domain is needed to fulfill these demands. Thus data throughput demands of telecommunication systems have acted as a stimulus for a paradigm shift of the cell tower structure and introduced the implementation of the **Fiber to the Antenna (FTTA)** architecture **–** an integrated optical and wireless solution.

Our thesis work is based on fiber to the antenna. It is not just a concept. It came into existence from real world necessity and has been implemented and upgraded in many places. To accomplish our research for thesis work, we have studied wireless communication, optical communication and fiber to the antenna which are discussed in upcoming sections.

1.2 Wireless Communication

Today's communication system is mainly based on wireless communication system. Nowadays everybody has a cellphone which is the gift of modern technology. Every day we are talking with people who are at a distance of thousands of miles from us and we are not even thinking of it. Using Skype in our phones we are doing video conference sitting at different parts of the world. We are enjoying high speed internet in our smart phones whenever and wherever we want. These services are provided using wireless network.

Wireless communication is the transfer of information between two or more points which are not connected by any kinds of wire. In this system, first message signal is modulated by a high frequency signal to increase the energy of the signal. Then it is transmitted through antenna. In the reception end, transmitted signal is received by another antenna and then demodulated to get the main signal. This is the basis of wireless communication system.

The reason that facilitates the evolution of wireless system is mobility. Mobility means whether we can use any device while moving from one place to another or not without any connection attached to the device. Using telephone or desktop we can communicate in different places; however, these are the examples of wire line connection, which cannot be used while travelling. That is why mobile phones came into existence through which we can talk or use internet while moving and it is possible only because of wireless system.

1.3 Optical Communication

In the information society, fibers have become a significant technology. After the production of the first low-loss fibers in 1970, optical fiber communications improved very rapidly. New applications and installations appear regularly as well as commercial fiber systems are available now for use. Functions in communication previously carried out by copper-based systems are now replaced and extended by fibers.

Optical system is based on optical signals that can be transferred from one place to another through an optical fiber in the speed of light(3×108 m/s^2). In this process, before passing through the optical fiber, data signal is modulated into optical signal by the help of converter. After that, the signal is again converted into electrical signal before radiating the data by an antenna.

The major reasons behind using optical fiber are to achieve more speed and interlink cities, which cannot be obtained via wireless communication. Furthermore, they can work together with the remaining copper applications and the growing wireless infrastructure to meet consumer's high communication demand.

1.4 Integrated Wireless and Optical Network

Since people want both speed and mobilty option at the same time, modern day communication cannot just rely on wireless or optical network; hence, there is always a need for an integrated architecture of both. For providing speed and achieve more bandwidth, carrying out signal in optical domain is the best option available. If it was possible we would have used optical domain in every devices accessible, which will bring much more increment in speed. However, it has not become feasible yet as most of the devices we use are in electrical domain; that is why for mobility optical domain is not an option. As a solution to that, wireless network can come into use. It will make it plausible to get network service while being mobile. Considering both of these concepts, network enigineers came up with the idea of Fiber to the Antenna (FTTA) - an integration of both optical and wireless domain, which can provide both speed and mobility together with the help of RRH that makes it possible to interchange between optical and electrical domain.

In Bangladesh, recently the network operators have upgraded their system to 3G (3rd Generation). In some places operators (GrameenPhone and Robi) have installed RRH; however, the process of implementation and activation throughout the country of this system is still in initial stage and in progress.

1.5 Fiber to the Antenna

Fiber to the antenna (FTTA) is the new integrated optical and wireless solution to achieve more speed, bandwidth and mobility at the same time. In this process, optical fiber is used to carry out the message signal up to the antenna from the radio base station (RBS) with the help of **Remote Radio Head (RRH)**.

FTTA system allows us to get the benefits of distributed base station architecture via RRH, where some of the equipment previously used in conventional base station (RF filter and power amplifier, high-freuency modulator etc.) are now located rather than at the tower bottom that used to be in old-style base stations. Moreover, before sending the signal to the antenna, RRH converts the optical signal into electrical domain or from electrical signal to optical signal in case of receiving.

In addition to that, FTTA uses the concept of **Radio Over Fiber (RoF).** RoF is the signal processing and controlling side of FTTA. To take the advantage of relatively low loss of optical fibers and to simplify wireless access, RoF method is used, where light is modulated by a radio signal and transported over an optical fiber link to a Radio Base Station (RBS). In recent days, the system is designed to carry the microwave signals along with providing mobilty function as well as functionalities like data modulation, signal processing and frequency up-down conversion.

We have overcome some of the limitations of traditional coaxial cable and network system as well as achieved some new advantages by implementing FTTA. Although there are yet some challenging issues needed to be improved, FTTA is one of the most efficient way available for improving network service.

1.6 Thesis Organization

We have started with an introduction in which we have tried to provide an overview of our whole thesis. We have laid the ground work for other chapters that are going to be explained. Next we will see chapters titled as Overview of Wireless Communication, Overview of Optical Communication, Introduction to Fiber to the Antenna- an Integrated Optical and Wireless Solution, Benefits of FTTA, Implementation Challenges with FTTA and Possible Solutions and the last but not the least is the Conclusion.

In the second chapter, **Overview of Wireless Communication** , we have discussed wireless system in detail. Evolution of wireless system, different types of wireless systems, cellular concept and techniques used in this system are mentioned in this chapter.

The third chapter is titled **Overview of Optical Communication**. Historical persepective, how optical system works; its applications along with merits and demerits of optical communications are discussed in this chapter.

Fourth chapter is called **Introduction to Fiber to the Antenna - An Integrated Optical and Wireless Solution**. In this chapter we have discussed the architecture of FTTA system as well as the concept of radio over fiber (RoF) that is used by FTTA.

The fifth chapter is named **Benefits of FTTA**. Here, we have mentioned the benefits of FTTA and shown why FTTA system is better than the conventional network system through comparisons.

The chapter after this is called **Implementation Challenges with FTTA and Possible Solutions**. In this chapter we have discussed about the issues regarding implementation of FTTA and suggested some available solutions.

Finally, the seventh and the last chapter is **Conclusion**, which is the end of our thesis work. Here, we have explained our contribution and findings. We have also explained how our research work is going to help anyone for further research in the future and what could be done to enhance it.

Chapter Two

Wireless Communication

Wireless communications is the fastest growing segment of the communications industry. As such, it has captured the attention of the media and the imagination of the public. Cellular phones have experienced exponential growth over the last decade, and this growth continues worldwide, with more than a billion worldwide cell phone users projected in the near future. Indeed, cellular phones have become a critical business tool and part of everyday life in most developed countries. Many new applications, including wireless sensor networks, automated highways and factories, smart homes and appliances, and remote telemedicine, are emerging from research ideas to concrete systems. The explosive growth of wireless systems coupled with the proliferation of laptop and computers indicate a bright future for wireless networks, both as stand-alone systems and as part of the larger networking infrastructure. However, many technical challenges remain in designing robust wireless networks that deliver the performance necessary to support emerging applications. In this chapter we will discuss the examples of wireless communications, cellular concept in detail. We will also explain the techniques used in wireless systems to have an overview of wireless communications.

2.1 Evolution of Wireless Communication

The cellular wireless generation (G) generally refers to a change in the fundamental nature of the service, on-backwards compatible transmission technology, and new frequency bands. New generations have appeared in every ten years, since the first move from 1981-An analog (1G) to analog (2G) network. After that there was (3G) multimedia support, spread spectrum transmission and 2011 all –IP Switched networks (4G) comes. The last few years have witnessed a phenomenal growth in the wireless industry, both in terms of mobile technology and its subscribers. There has been a clear shift from fixed to mobile cellular telephony, especially since the turnoff the century. By the end of 2010, there were over four times more mobile cellular subscriptions than fixed telephone lines. Both the mobile network operators and vendors have felt the importance of efficient networks with equally efficient design [35].

2.1.1 First Generation (Analog)

First-generation mobile systems used analog transmission for speech services. In 1979, the first cellular system in the world became operational by Nippon Telephone and Telegraph (NTT) in Tokyo, Japan. Two years later, the cellular epoch reached Europe. In the United States, the Advanced Mobile Phone System (AMPS) was launched in 1982. The two most popular analogue systems were Nordic Mobile Telephones (NMT) and Total Access Communication Systems (TACS). The system was allocated a 40-MHz bandwidth within the 800 to 900MHz frequency range by the Federal Communications Commission (FCC) for AMPS. In fact, the smallest reuse factor that would fulfill the 18db signal-to-interference ratio (SIR) using 120-degree directional antennas was found to be 7. Hence, a 7-cell reuse pattern was adopted for AMPS. Transmissions from the base stations to mobiles occur over the forward channel using frequencies between 869-894MHz.The reverse channel is used for transmissions from mobiles to base station, using frequencies between 824-849 MHz AMPS and TACS use the frequency modulation (FM) technique for radio transmission. Traffic is multiplexed onto an FDMA (Frequency Division Multiple Access) system [35, 36].

2.1.2 Second Generation (Digital)

Second-generation (2G) mobile systems were introduced in the end of 1980s. Compared to first-generation systems, second-generation (2G) systems use digital multiple access technology, such as TDMA (Time Division Multiple Access) and CDMA (Code Division Multiple Access). Consequently, compared with first-generation systems, higher spectrum efficiency, better data services, and more advanced roaming were offered by 2G systems. In the United States, there were three lines of development in second-generation digital cellular systems. The first digital system, introduced in 1991, was the IS-54 (North America TDMA Digital Cellular), of which a new version supporting additional services (IS-136) was introduced in 1996.Meanwhile, IS-95 (CDMA One) was deployed in 1993 [33]. 2G communication is generally associated with global system for mobile (GSM) services; 2.5G is usually identified as being fueled by general packet radio service (GPRS) along with GSM [36].

2.1.3 Third Generation (WCDMA in UMTS, CDMA2000 & TD-SCDMA)

Evolution of 3G network occurred to meet the growing demand in network capacity after an intermediate stage of 2.5G where the 2nd generation communication system faced some significant improvements in regards of using packet data and GPRS introduction,. 3G network uses digital broadband packet data. The data are sent though packet switching while voice calls are interpreted though circuits switching. It has a peak speed of 3.1Mbps but the usual range is 500-700kbps. Users have a much larger variation in use. Examples include voice telephone, video calling, global roaming, high speed, TV streaming net and so on. CDMA2000, W-CDMA, EDGE are some of the technology that fall under the 3G systems. The system thus has proved itself to be quite efficient with all its high data rates, reliability and security with more bandwidths, rich multimedia services etc. Its main drawbacks include expense of 3G phones which are also quite large, numerous differences in licensing terms and so on [37].

2.1.4 Fourth Generation

Next there comes the fourth generation communication system with the ideology of “Mobile Broadband Anywhere”. This uses only digital broadband packet data and all IP unlike the previous generations. With 100Mbps it is faster and more reliable. The bandwidth is higher so ranges of application are larger including mobile ultra-broadband Internet access. Video streaming, TV broadcast, video conferencing, 3D television, gaming, cloud computing are just some of the many examples. Since it has higher bandwidth it also has higher security. It supports multimedia services at low transmission loss. WIMAX, LTE, HSPA+ are some of the technologies that use this method of communication. The main disadvantage here is the equipment required to implement this technology is quite high. Careful planning is required to keep the expenses realistic [36, 37].

2.1.5 Fifth Generation (WiMax, WWWW, RAT)

The 5G (Fifth Generation Mobile and Wireless Networks) can be a complete wireless communication without limitation, which bring us perfect real world wireless – World Wide Wireless Web (WWWW). 5G denotes the next major phase of mobile telecommunications standards beyond the 4G/IMT-Advanced standards. At present, 5G is not a term officially used for any particular specification or in any official document yet made public by telecommunication companies or standardization bodies such as 3GPP, WiMax Forum, or ITU-R. Each new release will further enhance system performance and add new capabilities with new application areas. Some of the additional applications, benefiting from mobile connectivity are home automation, smart transportation, security, and e-books [36]. 5G mobile technology has changed the means to use cell phones within very high bandwidth. User never experienced ever before such a high value technology. The 5G technologies include all type of advanced features which make 5G mobile technology most powerful and in huge demand in near future. For children rocking fun Bluetooth technology and Pico nets has become available in market. Users can also hook their 5G technology cell phones with their Laptop to get broadband internet access. 5G technology includes camera, MP3 recording, video player, large phone memory, dialing speed, audio player and much more one can never imagine [37]. In fifth generation, Network Architecture consists of a user terminal (which has a crucial role in the new architecture) and a number of independent, autonomous radio access technologies (RAT) [36]. 5G mobile system is all-IP based model for wireless and mobile networks interoperability. Within each of the terminals, each of the radio access technologies is seen as the IP link to the outside Internet world [35].

2.1.6 Bangladesh Scenario

Bangladesh scenario in respect of mobile communications is not an exception to that of other developing or underdeveloped countries. In September 2013, Bangladesh entered a new era in communications with the launch of third generation (3G) mobile network service, which is expected to offer faster internet access for millions of users. Information and communication technology experts and economists are anticipating that new service, to be offered by five cell phone providers, will open up new business and job opportunities for country’s youth. Faster internet browsing will facilitate all kinds of online businesses. The mobile app development sector will grow phenomenally, as more subscribers will be downloading and using the apps on their phones. During a September 8th auction of the 3G spectrum, four major private operators- GrameenPhone, Banglalink, Robi and Airtel – paid $525 m to the Bangladesh Telecommunication Regulatory Commission (BTRC) to secure licenses. GrameenPhone bought 10 MHz, while Banglalink, Robi and Airtel each bought 5MHz. State-owned operator Teletalk is already providing 3G services on an experimental basis. GrameenPhone , which covers 44% of the mobile market, launched Bangladesh’s first 3G network on September 29th, with services to Chittagong and Dhaka and said it was aiming for national coverage by April. The country is getting ready for the internet other services offering by 3G network. The service provider and the device manufacturers are offering and introducing its latest tech. products and service to ensure service towards the people. Now, the people are looking for the devices to enable the service [39].

2.2 Examples of Wireless Communication Systems

Some examples of the wireless communication systems are briefly described below.

2.2.1 Pager

Paging systems are communication systems which send brief massages to a subscriber (user pays subscription fees).The message can be different depending on the type of service. It can either be a numeric, voice or an alphanumeric. This system is usually used to remind a subscriber of the need to call a particular telephone number or travel to a known location to receive further instructions. As the technology is now advanced, news headlines, stock quotations, and faxes may be sent. A message is sent to a paging subscriber via the paging system access number (a toll-free mobile number) with a telephone or modem. The issued message is called a page. The paging system then transmits the page throughout the service area using base stations which broadcast the page on a radio carrier. There are different kinds of paging system based on their complexity and coverage area. Simple paging systems generally have the capacity to cover 2 to 5 km or may be confined to within individual buildings [31]. On the other hand, wide area paging system can provide worldwide coverage. This system consists of a network of telephone lines, many base station transmitters, and large radio towers that simultaneously broadcast a page from each base station. This is called simulcasting. Simulcast transmitters may be located within the same service area or in different cities or countries. Paging systems are designed to provide reliable communication to subscribers wherever they are. [31].

2.2.2 Cordless Telephone System

Cordless telephone systems are full duplex communication systems that use radio to connect a portable handset to a dedicated base station which is then connected to a dedicated telephone line with a specific telephone number on the public switched telephone network (PSTN). In first generation cordless telephone systems (manufactured in the 1980s), the portable unit communicates only to the dedicated base unit and only over distances of a few tens of meters. Early cordless telephones operate solely as extension telephones to a transceiver connected to a subscriber line on the PSTN and are primarily for in-home use. Second generation cordless telephones have recently been introduced which allow subscribers to use their handsets at many outdoor locations within urban centers such as London or Hong Kong. Modern cordless telephones are sometimes combined with paging receivers so that a subscriber may first be paged and then respond to the page using the cordless telephone. Cordless telephone systems provide the user with limited range and mobility, as it is usually not possible to maintain a call if the user travels outside the range of the base station. Typical second generation base stations provide coverage ranges up to a few hundred meters [31].

2.2.3 Cellular Telephone Systems

The cellular concept is the base of modern mobile communication system. By this we can have high capacity in terms of coverage area and also can accommodate a large number of users within a limited frequency spectrum. It is actually done by dividing the whole service area into lots of small geographic area which called cell. Cell is the smallest part of our human body and these millions of cell comes together to form our human body. In a similar fashion cellular system consists of cells which are the unit and it has one base station. As we know that we have a limited frequency spectrum, we have to make the best possible use of it and that is why this concept is introduced so that the same frequencies we can use for another base station which is near to one cell. This is called frequency reuse. Moreover, by adding some of the cells a MSC is formed which serves as a coordinator between these RBS. In this way there are lot of MSC exists in a cellular system and these are controlled by one center base station. So, every subscriber comes under one cell or another. But the question is what happens if one user crosses one cell to another during a call. In this particular situation a smooth handoff is done by MSC and call is transferred to one base station to another base station.

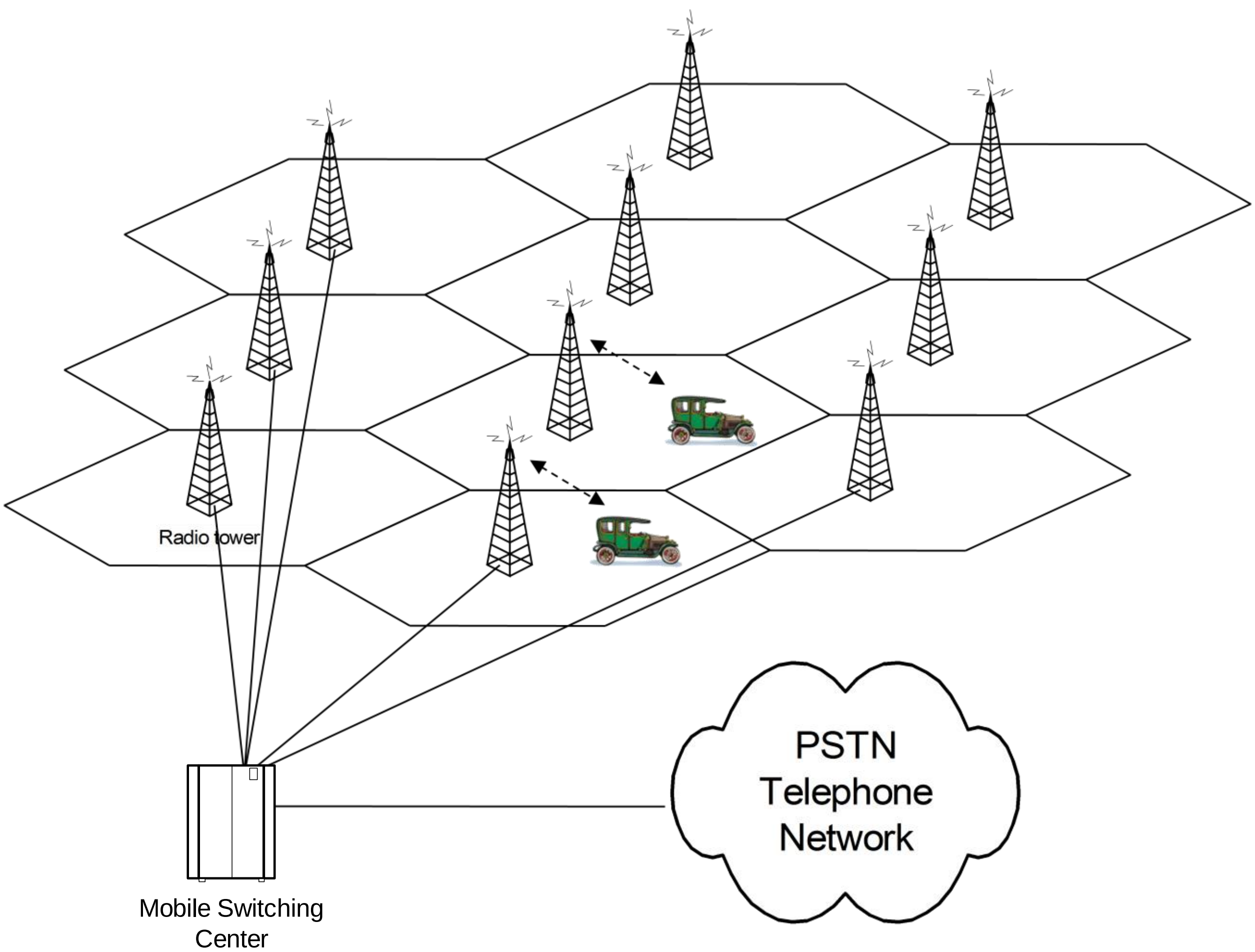


Figure 2.1: Wireless Network of Cellular Telephone System

We can see from the figure that a basic cellular system consists of mobile stations, base stations and a mobile switching center (MSC). The MSC is sometimes also called a mobile telephone switching office as it is responsible for connecting all mobiles to the PSTN in a cellular system. Every mobile communicates via radio with one of the base stations and throughout the duration of call may be handed-off to any number of base stations. The mobile station contains a transceiver, an antenna and control circuitry. On the other hand, a base station consists of several transmitters and receivers which simultaneously handle full duplex communications and generally have towers which support several transmitting and receiving antennas. The base station is the connector between the user and MSC which connects the calls through telephone lines or microwave links. A typical MSC handles 10000 cellular subscribers and 5000 simultaneous conversations at a time and accommodates all billing and system maintenance functions as well [31].

The communications between the base stations and mobiles happens through four different channels. The channels used for voice transmission from the base station to mobiles are called forward voice channels (FVC), and the channels used the voice transmission from mobiles to the base station are called reverse voice channels (RVC). The two channels responsible for initiating mobile calls are the forward control channels (FCC) and reverse control channels (RCC). Control channels are often called setup channels because they are only involved in setting up a call and moving it to an unused voice channel. These control channels transmit and receive data messages that carry call initiation and service requests, and are monitored by mobiles when they do not have a call in progress [31]. For better understanding we have briefly discussed about frequency reuse, channel capacity, channel assignment strategies, handoff procedures etc.

2.2.3.1 Frequency Reuse

Every cell of cellular system has a base station. Each base station is allocated with some channels which are completely different from the neighbouring cell. The base station antennas cover only the particular cell. It means that the transmission does not affect other BS. By limiting the coverage of each cell, we can use same number of channels to cover another cell which is far away. So, there will be a distance between the cells which will use the same group of channels to eliminate the interference. This concept is called frequency reuse. In this concept, a group of cell makes a cluster and the total number of channels replicated in the next cluster [33].

- Cells with same letter use the same set of frequencies.
- Cluster outlined in bold, replicated over coverage area.
- Example: cluster size N=7, Frequency reuse factor = 1/7, as each cell contains 1/7 of total available channels.

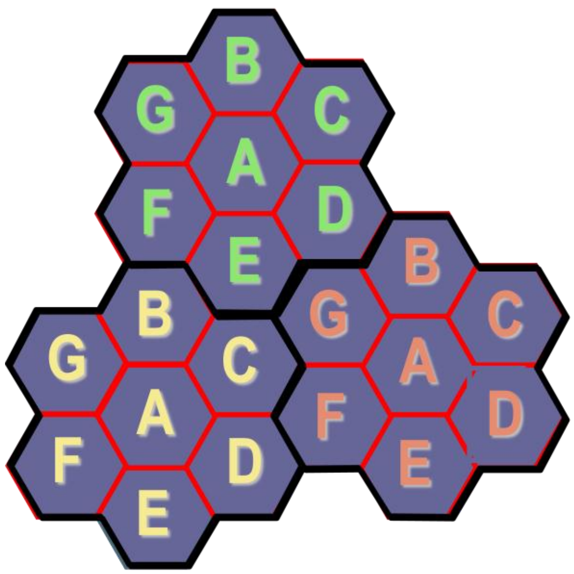


Figure 2.2: Frequency Reuse and Clusters

2.2.3.2 Channel Capacity

- Let a cellular system have total of S duplex channels
- The S channels are divided into the N cells in a cluster.

  ⇒ Number of channels available to each cell is:

$k = S/N$

- Let the cluster be replicated M times within the system

⇒ Total number of channels, or the system capacity, is:

$$C = MS = MkN$$

- Each cell is assigned fraction $1/N$ of the total number of channels available to the system (S)

⇒ $1/N$ i s the frequency reuse factor

2.2.3.3 Channel Assignment Strategies

We have limited number of channels and excessive amount of user which is the real problem. That is why how the channels are assigned to a particular cell is very important because it affects the overall performance of the system. Basically there are two types of strategies called fixed or dynamic.

In fixed channel assignment strategy, each cell is given a fixed number of channels. If all the channels are occupied, extra calls are blocked and subscriber does not receive service. This is a disadvantage of this strategy. But there is a process called borrowing strategy by which each cell can borrow channels from neighboring cell. MSC controls the borrowing process [33].

In dynamic channel assignment strategy, there are no fixed numbers of channels for each cell. Every time a call is made, the concern base station requests MSC to assign a channel and MSC does it by following a algorithm which takes into account of the likelihood of future blocking within the cell, the frequency of use of the candidate channel, the reuse distance of the channel, and other cost functions [33].

2.2.3.4 Handoff

When a user goes from one cell to another while in conversation, MSC automatically transfers the call to a new channel belonging to the new base station. This is called handoff and it is an important task in any radio cellular system. The user should not get affected by this process. If the process fails, some call can get lost. Fig (2.2a) represents an improper handoff scenario where a handoff is not made and the signal drops below the minimum acceptable level to keep the channel active. This dropped call event can happen when there is an excessive delay by the

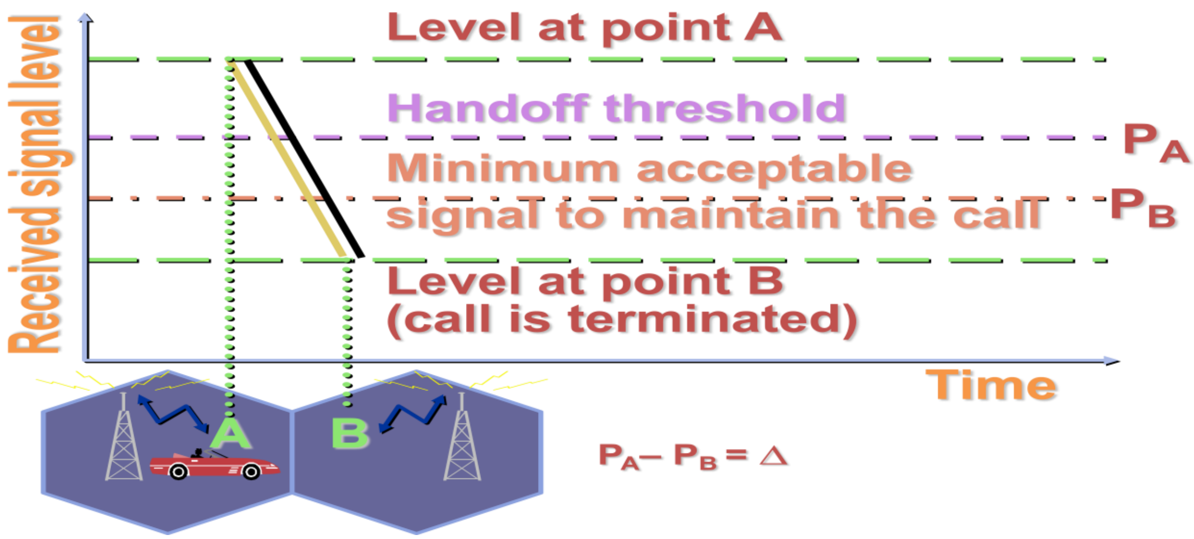


Figure 2.3(a): Improper Handoff Scenario [33].

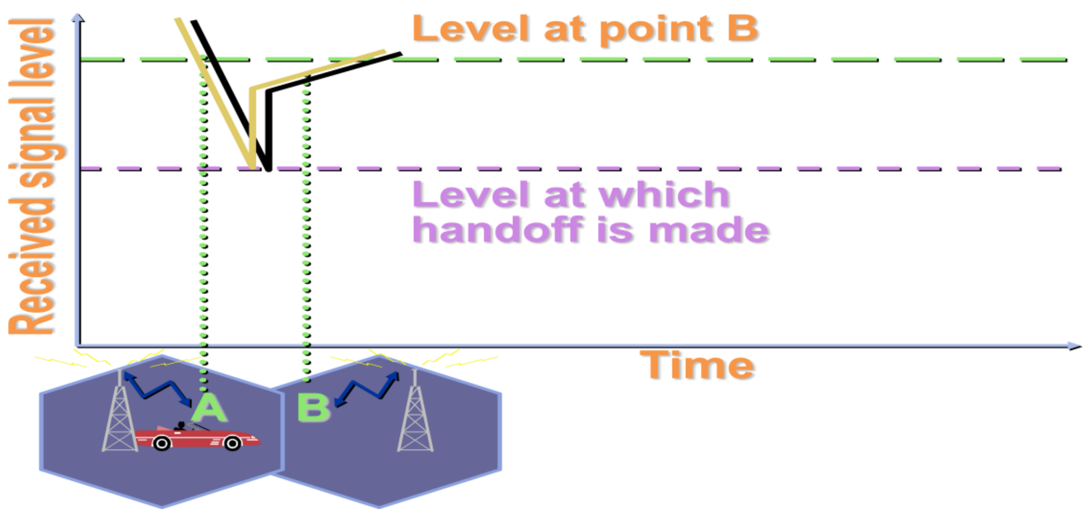


Figure 2.3(b): Proper Handoff Scenario [33].

MSC in assigning a handoff or when the threshold delta is too small for the handoff time in the system. Fig (2.2b) is a proper ideal handoff scenario where handoff is made before the signal drops below the minimum acceptable level.

$P_A - P_B = \Delta$

Δ should not be too large or too small

Δ too large: too many handoffs

Δ too small: chance of call being lost

Different Types of Handoff

There are various types of handoffs popular in the system and some of them are described below:

Hard Handoff

- MSC breaks mobile's connection to base station in old cell
- makes new connection using new channel in new cell
- seamless transfer that goes unnoticed by user

Soft Handoff

- Mobile always retains same channel across the system
- MSC compares signals from neighbouring base stations to determine the strongest
- MSC selects between instantaneous signals received from a number of base stations
- This method is used in CDMA Spread Spectrum systems

Mobile-Assisted Handoff (MAHO)

- Every mobile measures the received power from surrounding base stations, and continuously reports value to serving base station
- Faster hand-off rate than with the MSC-controlled type

- Particularly suited for micro-cell environments

Inter-system Handoff

- One cellular system to a different cellular system

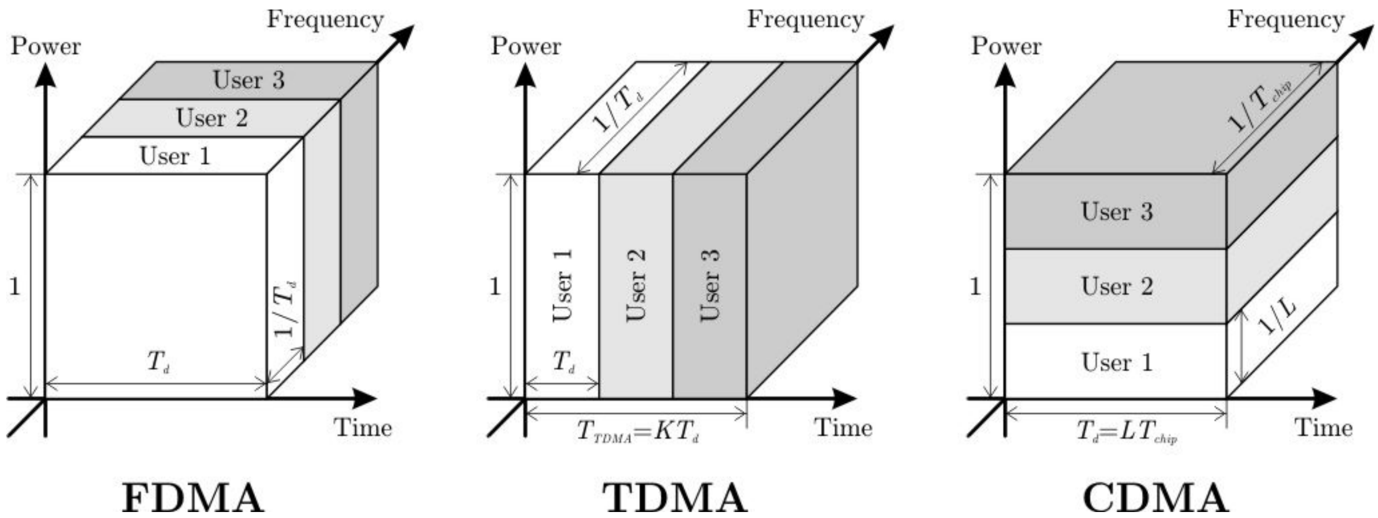
2.3 Modern Wireless Communication Systems

Since the mid-1990s, the cellular communications industry has witnessed explosive growth. Wireless communications networks have become much more pervasive than anyone could have imagined when cellular concept was first developed in 1960s and 1970s. The worldwide success of cellular has led to the development of newer wireless systems and standards for many other types of telecommunication traffic besides mobile voice telephone calls. To understand modern wireless communication system, we need to discuss about the techniques and standards used for high capacity in this system [32].

2.3.1 Techniques Used in Different Wireless Systems

CELLULAR SYSTEMS	MULTIPLE ACCESS TECHNIQUE
DECT	FDMA/FDD
IS-95 or CDMA	CDMA/FDD
AMPS	FDMA/FDD
US DC	TDMA/FDD
JDC	TDMA/FDD
GSM	TDMA,FDMA/FDD

Table 2.1: Techniques Used in Different Wireless Systems



2.3.1.1 FDMA (Frequency Division Multiple Access)

- Different subscribers are allocated a different Frequency slots and access to the network.
- Since the user has his portion of the bandwidth all the time, FDMA does not require synchronization or timing control which is algorithmically simple.
- Guard bands are there which actually lead to less adjacent channel interference.
- When continuous transmission is not required, bandwidth goes wasted since it is not being utilized for a portion of the time.
- During the period of the call no other user can share the same frequency band.
- FDMA achieves simultaneous transmission and reception by using Frequency Division Duplexing (FDD) that requires duplexers. As a result, this process proves it to be expensive.

- FDMA mobile systems are less complex as compare to TDMA mobile systems.

- The bandwidth of the FDMA systems is narrow as it supports only one call per carrier signal.

- ISI (inter symbol interference) low as the symbol time large compared to average delay spread [34].

CAPACITY OF FDMA SYSTEMS

$$N = \frac{B_t - 2B_{guard}}{B_c}$$

Here,

B_t: Total spectrum allocation
B_{guard}: Guard band allocated at the edges of the spectrum band
B_c: Bandwidth of a channel

2.3.1.2 TDMA (Time Division Multiple Access)

- Users are allotted time slots during which they have the entire channel bandwidth at their disposal.
- Continuous transmission is not required because users do not use the allotted bandwidth all the time
- Global Systems for Mobile communications (GSM) uses the TDMA technique.
- In TDMA, the entire bandwidth is available to the user but only for a finite period of time. available bandwidth is divided into fewer channels compared to FDMA
- TDMA requires careful time synchronization since users share the bandwidth in the frequency domain.

- Since the number of channels are less, inter channel interference is almost negligible, hence the guard time between the channels is considerably smaller.
- In cellular communications, when a user moves from one cell to another there is a chance that user could experience a call loss if there are no free time slots available.
- TDMA uses different time slots for transmission and reception. This type of duplexing is referred to as Time division duplexing (TDD). TDD does not require duplexers [34].

TDMA Frames

- Multiple fixed number of slots make a frame
- A frame repeats
- In TDMA/TDD half of the slots in the frame used for forward channels, half for reverse channels
- In TDMA/FDD different carrier frequencies are used for reverse and forward channels within time slot.

General Frame and Time Slot Structure in TDMA Systems [34]

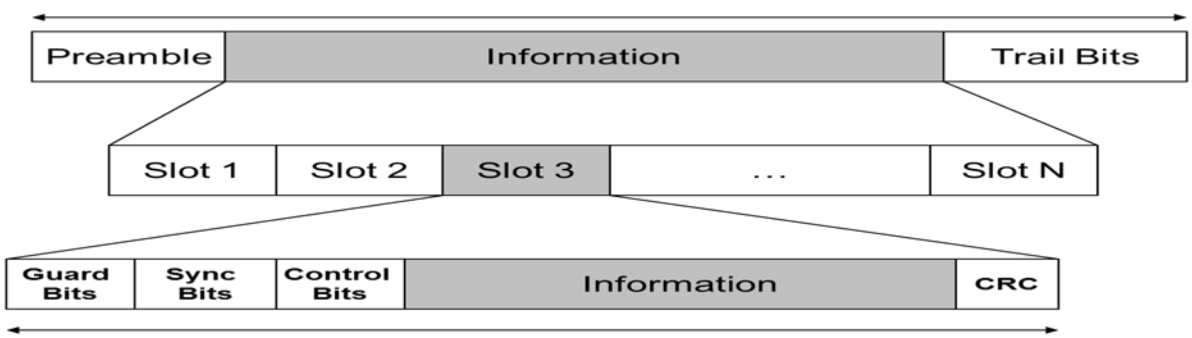


Figure 2.4: General Frame and Time Slot Structure in TDMA System

Description of a Single TDMA Frame

1. Preamble contains address and synchronization info to identify base stations and mobiles to each other
2. Guard times are used to synchronize the receivers between different slots and frames.

(Different mobiles may have different propagation delays to base stations because of different distances)

2.3.1.3 CDMA (Code Division Multiple Access)

- All the users occupy the same bandwidth; however, they are all assigned separate codes, which differentiate them from each other.
- Utilize a spread spectrum technique in which a spreading signal, which is uncorrelated to the signal and has a large bandwidth.
- Many users share the same frequency.
- In CDMA unlike FDMA and TDMA the number of users is not limited.
- Channel data rates are very high.
- Direct Sequence Spread Spectrum (DS-SS) is most commonly used for CDMA. In DS-SS, the message signal is multiplied by a Pseudo Random Noise Code (PN code), which has noise-like properties.
- Unlike TDMA, CDMA does not require time synchronization between the users.
- CDMA system experiences a problem called self-jamming which arises when the spreading codes used for different users are not exactly orthogonal [34].

Processing gain of CDMA

$$G_p = \frac{B_{spread}}{R} = \frac{B_{chip}}{R}$$

G_p: processing gain
B_{spread}: PN code rate
B_{chip}: Chip rate
R: Data rate

Advantages of CDMA

1. Low power Spectral Density: Signal is spread over a larger frequency band.
2. Limited Interference Operation: Full frequency spectrum is used.
3. Privacy: Codeword is known only to the sender and receiver. No eavesdrops possible.
4. Reduction of multipath affects by using a larger spectrum.
5. Random access possible: User can start transmission at any given time.
6. Cell capacity not concretely fixed like TDMA/FDMA. (Soft capacity)
7. Higher capacity than TDMA/FDMA.
8. No frequency management.
9. No guard time needed.
10. Soft handoff possible.
11. Energy Efficient: CDMA automatically adjusts the power level to one that is powerful enough to provide a clear call but not so powerful that it creates excessive interference. Because it is not always transmitting at peak power the call uses less energy from the phone’s battery [34].

Disadvantages of CDMA

1. Self-jamming is a problem in CDMA as the PN sequence is not exactly orthogonal.
2. The near far problem occurs at a CDMA receiver if an undesired user has high detected

2.3.2 GSM

GSM (Global System for Mobile communications) is an open, digital cellular technology used for transmitting mobile voice and data services. GSM supports voice calls and data transfer speeds of up to 9.6 kbps, together with the transmission of SMS (Short Message Service). GSM operates in the 900MHz and 1.8GHz bands in Europe and the 1.9GHz and 850MHz bands in the US. GSM services are also transmitted via 850MHz spectrum in Australia, Canada and many Latin American countries. The use of harmonized spectrum across most of the globe, combined with GSM’s international roaming capability, allows travelers to access the same mobile services at home and abroad. GSM enables individuals to be reached via the same mobile number in up to 219 countries [35].

GSM Architecture and Interfaces [35]

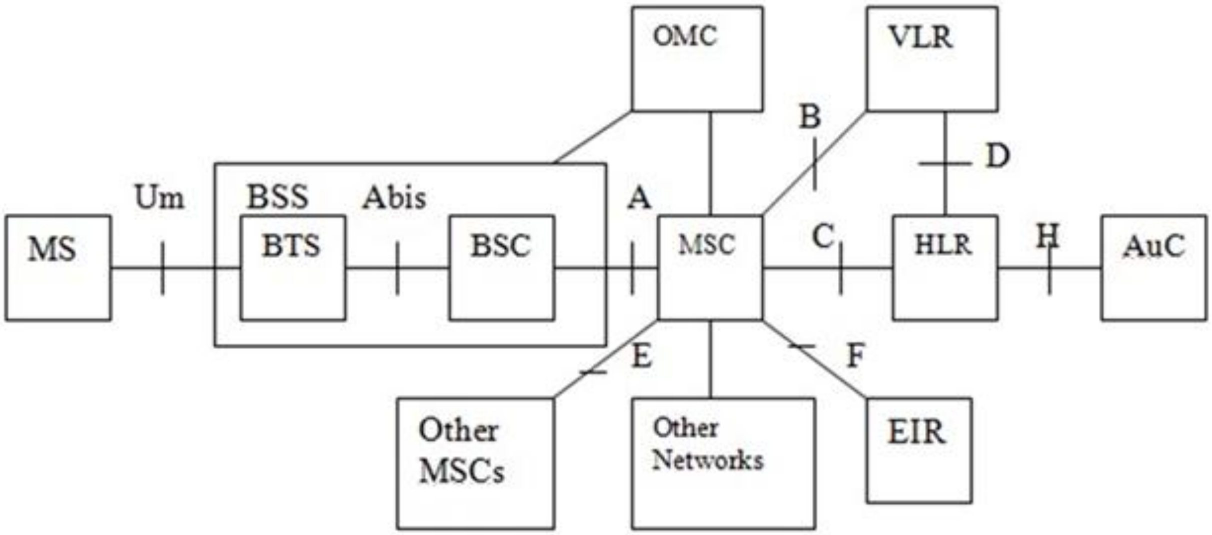


Figure 2.5: GSM Architecture

- **U_m Interface**: Mobile station and base station subsystem communicate through this this.
- **A_{bis} interface:** Base transceiver station and Base station controller communicate across it.
- **A interface:** Base station subsystem communicates with mobile switching centre across it.

•MS = Mobile Equipment

•BTS = Base Transceiver Station

•BSC = Base Station Controller

•MSC = Mobile Switching Center

•VLR = Visitor Location Register

•OMC = Operation and Maintenance Center

•AuC= Authentication Center

•HLR = Home Location Register

•EIR = Equipment Identity Register

2.3.2.1 Mobile Station (MS)

Mobile Station consists of two components.

1. **Mobile Equipment (ME):** A unit used by the subscribers to get access to the network; commonly known as mobile handset or cellphone. Different range of frequencies can be used to communicate depending on the handset.

2. **Subscriber Identity Module (SIM**): One of the key features of GSM is the Subscriber Identity Module, commonly known as a SIM card. The SIM is a detachable smart card containing the user's subscription information and phone book. This allows the user to retain his or her information after switching handsets. Alternatively, the user can also change operators while retaining the handset simply by changing the SIM. Some operators will block this by allowing the phone to use only a single SIM, or only a SIM issued by them; this practice is known as SIM locking [35].

2.3.2.2 MSC (Mobile Switching Centre)

- Connected to BSS through A interface
- Interface between radio system and fixed networks
- Each MSC covers several BSS
- Performs signaling between MSC and other functional entities: Registration,

Authentication, Location Updating, Handovers, Call routing to a roaming subscriber

2.3.2.3 HLR (Home Location Register)

- It is the central Database for all subscribers. The data that it stores are:
  - ❑ Identity of the subscriber
  - ❑ Services accessible to the subscriber
  - ❑ Current location of the subscriber
- Each subscriber appears only once in the Database
- HLR may be physically distributed in several sites.

The following identification numbers are also available in HLR

- International Mobile Subscriber Identity (IMSI), a permanent ID assigned to each GSM network subscriber.
- International Mobile Subscriber ISDN Number (MSISDN), the ISDN number (phone number) permanently assigned to each GSM subscriber.
- Mobile Station Roaming Number (MSRN), a temporary ISDN number of a subscriber. This number is assigned by the local VLR each time, the subscriber enters its MSC/VLR area. The MSRN is then sent to the HLR and to the GMSC.
- The address of current VLR and MSC (if available), an address of the area the subscriber is currently in.
- Local Mobile Subscriber Identity (if available), a short ID temporarily assigned to an active subscriber by a VLR and sent to the HLR.

2.3.2.4 VLR (Visitor Location Register)

VLR contains information about all MSs which are currently within range of the associated MSC. This information is needed for routing a call to a particular MS (mobile telephone) via the proper BSS and radio cell. The VLR also maintains a list of MSs belonging to subscribers of other GSM networks. Such subscribers have logged or roamed into the network of the associated MSC [34].

- Database with information on MS within area served by MSC:
    - MS Roaming number
    - Location area in which was last registered
    - Supplementary services
- Used by an MSC to retrieve information for various purposes:
    - Handling of calls to or from a roaming mobile station currently located in its area
- Typically part of MSC

The following identification numbers are stored temporarily at the VLR associated with the MSC which is currently controlling an active MS:

- IMSI
- MSISDN
- MSRN
- Location Area Identity (LAI), the ID of the Location Area (LA), in which subscriber is or has been connected to a GSM network.
- Temporary Mobile Subscriber Identity (TMSI) temporarily assigned to an active MS in order to prevent the IMSI from being transmitted too often over the radio interface. The TMSI is periodically changed during a call.

2.3.2.5 AuC (Authentication Center)

AuC is the security component on the network side. AuC generates and manages all cryptographic keys and algorithms needed for network operation, especially for authentication of the MSs (i.e., the SIMs) [34].

- Entity associated with HLR for authentication
- Allows International Mobile Subscriber Identity (IMSI) to be authenticated
- Allows ciphering of communication over radio path between mobile station and network
- Transmits data needed for authentication and ciphering from HLR to VLR and MSC

2.3.2.6 EIR (Equipment Identity Register)

Equipment Identity Register (EIR) is a database for mobile equipment information of all subscribers. In this database, three lists (white, black and gray) store identification numbers, which are unique to all mobile terminals. The white list contains allowed terminals, the black list contains unauthorized terminals (e.g. stolen or lost), and the gray contains terminals with known bugs. It ensures that the MEs being used are valid and authorized to function [34].

The existing wireless systems can hardly provide transmission capacity of the order of few Mbps. To deliver multimedia/broadband signals at remotely distributed cells, wireless transmission channels are no more able to fulfill the demands of higher bandwidth. On the other hand, optical fiber is well known as a transmission media with an enormous transmission capacity of about 4 Tbps [31]. Hence the requirements of broadband wireless system can be achieved through the integration of optical fiber and wireless systems. We suggest modified wireless system with optical fiber as feeder network as an up gradation of existing wireless network in terms of transmission capability. An integration of optical and wireless network suggests an excellent cost effective means for transmitting various wideband applications. For enhancing the capacity of the existing network we have to investigate various aspects of integrated fiber radio network so that data carrying capacity can be increased at an acceptable level [31].

Throughout this chapter we have discussed about how wireless communication has evolved and how the technology used in wireless communication has developed different wireless systems (i.e. pager, cordless telephone, cellular telephone etc.) and various multiple access techniques (i.e. FDMA, TDMA, CDMA etc.) that have been used in modern wireless communication system. We have also discussed why we need the integration between wireless and optical system. We have mainly focused on how cellular network works and how this recent advancements have increased speed and mobility which is the rising demand of current world.

In the following chapter, we have discussed about optical communication system, the advantages and limitations of using it, and the application of optical fiber.

Chapter 3

Overview of Optical Communications

In today's world, signal transmission through optical fiber has found a vast array of applications. Since we are moving towards a more sophisticated and modern future, the uses of fiber optics are going to grow in all computer systems as well as telecommunication networks. In addition to that, as fiber optic is a progressive medium in communication system, different devices that work in optical domain are already introduced in the market and are upgraded by the manufacturers on a regular basis to meet the demands in networking world. There are a number of essential points about fiber optics that we have learnt through our thesis. The major parts are the historical side of optical fiber, basic communication system, advantages and limitations of using fiber optics and applications of fiber optics. In the following few sections, we are going to describe these things in more details.

3.1 Historical Perspective

One of the oldest techniques of communication is light. People used hand signals which comprised of the necessity of light as the message carrier. In 800 BC Greeks used smoke and fire signals to transfer different messages such as victory in war [45]. In 2nd century BC, signaling lamps were used to send encrypted messages. The speed of the optical communication link was limited due to the requirement of line of sight transmission paths, the human eye as the receiver and unreliable nature of transmission paths affected by atmospheric effects such as fog and rain [20]. In 1790's the first "optical telegraph" was invented by the French brothers [46]. It was a system involving a series of lights mounted on towers where operators would relay a message from one tower to the next. Over the course of the next century great strides were made in optical science. In the 1840s, physicists Daniel Collodon and Jacques Babinet showed that light could be directed along jets of water for fountain displays [46]. In 1854, John Tyndall, a British physicist, demonstrated that light could travel through a curved stream of water; thereby proving that a light signal could be bent. He proved this by setting up a tank of water with a pipe that ran out of one side. As water flowed from the pipe, he shone a light into the tank into the stream of water. As the water fell, an arc of light followed the water down William Wheeling, in 1880, patented a method of light transfer called “piping light” [46]. Wheeling believed that by using mirrored pipes branching off from a single source of illumination, i.e. a bright electric arc; he could send the light to many different rooms in the same way that water, through plumbing, is carried throughout buildings today. Due to the ineffectiveness of Wheeling’s idea and to the concurrent introduction of Edison’s highly successful incandescent light bulb, the concept of piping light never took off. That same year, Alexander Graham Bell developed an optical voice transmission system he called the photo-phone [20] [46]. The photo-phone used free-space light to carry the human voice 200 meters. Specially placed mirrors reflected sunlight onto a diaphragm attached within the mouthpiece of the photo-phone. At the other end, mounted within a parabolic reflector, was a light-sensitive selenium resistor. This resistor was connected to a battery that was, in turn, wired to a telephone receiver. As one spoke into the photo-phone, the illuminated diaphragm vibrated, casting various intensities of light onto the selenium resistor. The changing intensity of light altered the current that passed through the telephone receiver which then converted the light back into speech. Bell believed this invention was superior to the telephone because it did not need wires to connect the transmitter and receiver though at that time telephone was proved to be more realistic [47].

Fiber optic technology experienced a phenomenal rate of progress in the second half of the twentieth century. Early success came during the 1950’s with the development of the fiberscope [47]. This image-transmitting device, which used the first practical all-glass fiber, was concurrently devised by Brian O’Brien at the American Optical Company and Narinder Kapany (who first coined the term “fiber optics” in 1956) and colleagues at the Imperial College of Science and Technology in London. The development of laser technology was the next important step in the establishment of the industry of fiber optics. Only the laser diode (LD) or its lower-power cousin, the light-emitting diode (LED), had the potential to generate large amounts of light in a spot tiny enough to be useful for fiber optics. In 1957, Gordon Gould popularized the idea of using lasers when, as a graduate student at Columbia University, he described the laser as an intense light source. Shortly after, Charles Townes and Arthur Schawlow at Bell Laboratories supported the laser in scientific circles. Lasers went through several generations including the development of the ruby laser and the helium-neon laser in 1960. Semiconductor lasers were first realized in 1962; these lasers are the type most widely used in fiber optics today [47]. The first working fiber-optical data transmission system was demonstrated by German physicist Manfred Börner at Telefunken Research Labs in Ulm in 1965, which was followed by the first patent application for this technology in 1966 [48].Charles K. Kao and George A. Hockham of the British company Standard Telephones and Cables (STC) were the first to promote the idea that the attenuation in optical fibers could be reduced below 20 decibels per kilometer (dB/km), making fibers a practical communication medium [49]. They proposed that the attenuation in fibers available at the time was caused by impurities that could be removed, rather than by fundamental physical effects such as scattering. They correctly and systematically theorized the light-loss properties for optical fiber, and pointed out the right material to use for such fibers — silica glass with high purity. This discovery earned Kao the Nobel Prize in Physics in 2009 [49].

3.2 Basic Communication System

The basic communication system is made up of mainly the transmitter, information channel and receiver as shown in figure 3.1.

Figure 3.1: The Basic Communication System

The information travels from transmitter to receiver through the channel which is of two types- guided channel and unguided channel. Unguided channel like the atmosphere around is a medium through which waves can propagate. Radio broadcast, satellite television are examples of some systems that use unguided channel for transmission. Guided channels use a number of conducting transmission structures such as coaxial cables. Fiber optics also uses the guided channel. A more detailed block diagram of the system is illustrated below:

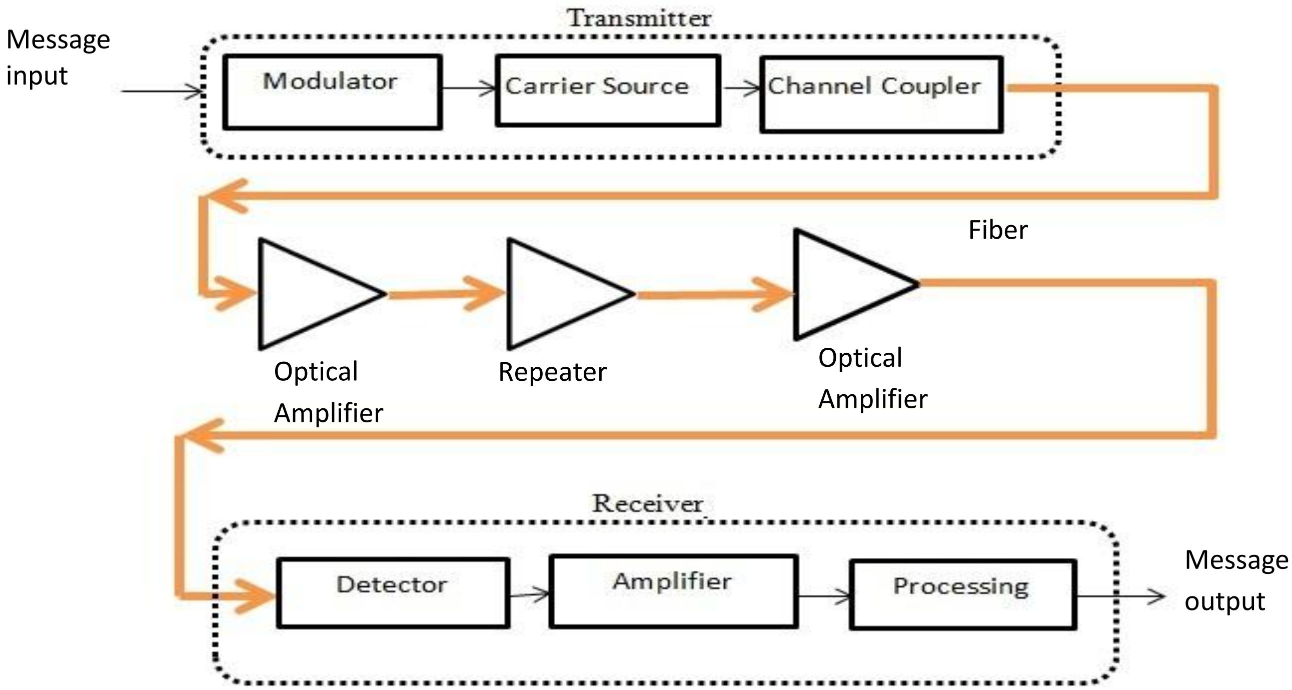


Figure 3.2: The General Fiber optical Communication System

Message origin can take various forms. However, a transmitter can only have electrical signals. Hence, a transducer is often used to convert non-electrical signals into electrical ones.

The signal then goes into the transmitter through the modulator. The modulator first converts the electrical signal into proper optical format and then feeds it into the carrier (optical) source. The optical carrier can be both internally and externally modulated through electro-optic modulator or acoustic optic modulator. Laser diodes (LD) or light emitting diodes (LED), which are also known as optics oscillators, are used as carrier. Usually these devices emit a range of frequencies radiating only a few milliwatts of average power in practical life. Since the receivers are very sensitive this power is enough for detection but the continuous decrease of power during the transmission limits the length of the communication link. The absence of a single frequency also worsens the system limiting the amount of information to be sent. Hence, such LDs and LEDs have been made that emit at frequencies where glass fibers have low attenuation so that transmission is possible. Next the signal goes into the channel coupler which impresses the power into the information channel. The coupler must efficiently transmit modulated light beam from source to fiber optic since otherwise there will be huge power loss. Hence complex but efficient couplers have been constructed. Basically, the encoded electrical input signal modulates the intensity of light from LEDs or LDs and converts them into optical pulses to be passed into the information channel.

The information channel is consisted of a glass (or plastic) fiber. Optical amplifiers are used to amplify the weak signals. Weak, distorted signals are also converted to electrical ones then regenerated for further transmission by regenerators. All these are done during the transmission through channel.

At the receiver end the optic wave is converted into electrical current by a photo-detector such as avalanche photo diode (APD) or positive-intrinsic-negative (PIN) diodes. The signal is amplified and further processed (filtered) to give a message output in the form of visual or sound [20].

3.3 Advantages and Limitations

Despite of some limitations the fiber optic has, the use of fiber in this progressive world is increasing due to its more useful sides. Both the advantages and limitations are described below:

3.3.1 Advantages

Availabilty of Fundamental Element

Silicon dioxide and transparent plastic are the basic element of glass fibers and some the optical fibers respectively. These both materials are readily available in the environment [20].

Less Expensive

For long paths, transporting signal through fiber cables is cheaper and easier rather than transporting it through equivalent lengths of metal cables.

Thinner and Lightweight

Optical fibers can be drawn to smaller diameters and are surprisingly lightweight and flexible. In a cable design, a 12m micro-meter fiber in diameter enclosed by a plastic sheath of 2.5 mm in outer diameter has a weight of 6 kg/km. On the other hand, the RG-19/U coaxial cable having an outer diameter of 28.4 weighs mm 1110 kg/km [20].

Flexibility

Optical fiber cables are strong and flexible. They can be laid both within the buildings (Indoor Fiber Cables) and outside the buildings (Shielded Fiber Cables). In most of the cases, they are buried under the ground (with a depth of minimum 3 feet) using a Trench and protective materials [21]. Some fibers are so slender that when wrapped around curves of few centimeters radius, they do not break [20].

Ease of Installation

The small size, lightweight and flexibility of fiber optic cables make them easier to be used for installation.

Higher Carrying Capacity

Because optical fibers are thinner than copper wires, more fibers can be bundled into a given-diameter cable than copper wires. This allows more channels to go over the same cable. A dramatic comparison between a standard wire telephone cable and a fiber cable would be that the metal cable contains 900 twisted-wire pairs, and its diameter is 70 mm. 24 voice channels are carried by each pair, and so the cable capacity is 21,600 calls. Whereas, one of the fiber cables developed for telephone applications of 12.7 mm diameter contains 144 fibers, operating at the T3 rate. This cable has a total capacity of 96,768 calls. The fiber has nearly 4.5 times as much capacity as the wire cable and with a 30 times less cross-sectional area [20].

Higher Bandwidth over Long Distances

Fiber optical cable has a large capacity to carry high speed signals over longer distances without repeaters than other types of cables. Generally, coaxial cables have a bandwidth parameter of a few MHz/km, where as the fiber optic cable has a bandwidth of 400MHz/km [22]. In addition, fiber optic cable can carry more information with greater fidelity than copper wire. That is why telephone and CATV companies are converting to fiber [23].

Less Signal Degradationand Greater Distance

Techniques have been developed for the production of fibers with very low transmission losses. Now-a-days, to operate at a wavelength around 1.3 micrometer and 1.55 micrometer, fibers are available with losses of only a few tenths of a dB/km [20].

Furthermore, as the fiber optic signal is made of light, very little signal loss occurs during transmission, and data can move at higher speeds and to greater distances. Fiber does not have the 100 meter (9328 ft.) distance limitation like unshielded twisted pair copper (without a booster). Fiber distances can range from 300 meters (984.2 ft.) to 40 kilometers (24.8 mi.), depending on the style of cable, wavelength, and network. Because fiber signals need less boosting than copper ones do, the cable performs better [23].

Low Power Consumption

Because signals in optical fibers degrade less, lower-power transmitters and amplifiers at large intervals can be used. As a result power consumption by the system is reduced.

Data Security

There are no radiated magnetic fields around optical fibers; the electromagnetic fields are confined within the fiber. That makes it impossible to tap the signal being transmitted through a fiber without cutting into the fiber, which takes great skill to go undetected.

Protected from Interference

As the fibers (optic fibers, glass or plastic) are insulators, no electric currents flow (induced from transmitted signal or external radiation) through them. Additionally, light cannot couple into the fiber from its side. These are the reasons fibers are well protected from radio-frequency interference (RFI) and electromagnetic interference (EMI) as well as coupling from other communications channels.

Less Susceptible to Damage

Glass fibers can withstand extreme temperatures (more than 800 degree Celsius) and are less affected to corrosion caused by water and chemicals [20].

Electrical Isolation

The insulating nature of fiber aids it not to create troublesome earth loop and interface problems. Furthermore, this property makes optical fiber transmission ideally suited for communication in electrically hazardous environments as the fibers create no arcing or spark hazard at abrasions or short circuits.

Duplex Communication

Optical Fiber Cables support duplex communications (simultaneous upstream and downstream), but they use two cores for doing so. One core is used for transmission (Tx) and the other core is used for reception (Rx).

3.3.2 Limitations

System Reconfiguration

Converting existing hardware and software for the use of optical fibers does take a lot of time and money. This changeover requires modification in both hardware and software.

Ease of Maintenance and Repair

More Technicians have learnt to take care of copper-wire systems than fiber ones and it is easier to repair copper lines than fiber. Again, fiber splicing is a complicated procedure and requires skilled manpower to do so. If it is not done properly, there will be performance degradation.

Limitations in LANs

The hardware and software implementation to make LAN run efficiently in optical domain increases the package price.

Costly Components

Fiber optic cables are much cheaper, but the main difference comes when all the other components of fiber optics, such as transmitters, receivers, couplers and connectors etc., add up. At initial stage of system installation, the network companies may have to spend some extra money on these components.

Power Supplier

Copper UTP cables can carry data as well as power. Some POE enabled IP devices like IP Phones, Wireless Access Points etc. are powered directly using the UTP Cables/ POE switches. This is not supported by the optical fiber cables as they carry only data.

Termination

Fiber cables cannot be directly terminated on to the network/optical switches. They need a whole array of active/ passive components like SFP Modules, Fiber Patch Cords, appropriate connectors, Fiber Patch Panel (LIU), Pigtails and Couplers.

Wildlife Damage to Fiber Optic Cables

Many birds, for example, find the Kevlar reinforcing material of fiber cable jackets particularly appealing as nesting material, so they peck at the fiber cable jackets to utilize bits of that material.

3.4 Applications

The use and demand for optical fiber has grown tremendously and optical-fiber applications are numerous. With the modernization people are finding new sectors for using fiber optic. It has brought new dimension to various applications. Some of these are mentioned below:

Telecommunication Applications

Telecommunication applications are widespread, ranging from global networks to desktop computers. These involve the transmission of voice, data, or video over distances of less than a meter to hundreds of kilometers, using one of a few standard fiber designs.

Fiber Optics for Sensing

Fiber optics for sensing applications are used to communicate with a sensor device, or use a fiber as the sensor itself, to conduct continuous monitoring of physical, chemical, and biological changes in the subject or object of study. Optical fiber sensing is a key component to improving industrial processes, quality control systems, medical diagnostics, and preventing and controlling general process abnormalities. Fiber optical cable used for these applications provide very acute sensitivity and data collection versatility, while allowing for a wide range of specialized application uses.

Military Applications

Optical fiber is used for communications command and control links on ships and aircraft, data links for satellite earth stations, and transmission lines for tactical command-post communications. On aircraft and ships, the reduced shock, fire and spark hazards are obtained because of using fiber optic. The high resistance to corrosion justifies the use of fibers at sea either abroad ship or in the ocean.

Carrier Network

Carriers use optical fiber to carry plain old telephone service (POTS) across their nationwide networks. Local exchange carriers (LECs) use fiber to carry this same service between central office switches at local levels, and sometimes as far as the neighborhood or individual home (fiber to the home [FTTH]).

Transmission of Data

Optical fiber is also used extensively for transmission of data. Multinational firms need secure and reliable systems to transfer data and financial information between buildings to the desktop terminals or computers and to transfer data around the world. Cable television companies also use fiber for delivery of digital video and data services. The high bandwidth provided by fiber makes it the perfect choice for transmitting broadband signals, such as high-definition television (HDTV) telecasts.

Intelligent Transportation Systems

Smart highways with intelligent traffic lights, automated tollbooths, and changeable message signs also use optical fiber based telemetry systems.

FTTx (Fiber to the X)

Most commonly covers FTTh (Fiber to the Home), FTTc (Fiber to the curb), FTTp (Fiber to the Premises), and FTTd (Fiber to the Desk) FTTA (Fiber to the Antenna) applications running from the central office or head-end to business, residential, or multi-unit dwellings [24].

Biomedical Industry

Another important application for optical fiber is the biomedical industry. Fiber optic systems are used in most modern telemedicine devices for transmission of digital diagnostic images. Other applications for optical fiber include space, military, sensing application, automotive, and the industrial sector.

Fiber Optics for Electronics

Typically used in professional audio/video, alarm/security, and OEM component connections, fiber optics provide high bandwidth, EMI and RFI immunity, and compact packaging, enabling product designers and manufacturers to offer a small, lighter, and higher performance finished product.

Fiber Optic Illumination

It is the conveyance or transmission of light from a source (output) to one or several fibers, allowing light to escape through the end of the fiber and illumination apparatus. Widely used in medical, dental, automotive, and research applications, fiber optic illumination provides a clean, cold light to be routed, targeted, focused, and/or directed to very specific hard to reach locations or areas [24].

Fiber Optic Imaging

It is used for a myriad of applications across several different industries. The concept of fiber optic imaging uses the optical transmission properties of fiber to transmit an image from end to end. To accomplish this, most imaging applications use an image guide or coherent bundle to collect an image of the target or subject area, then relays that information to the view end for interpretation [24].

Fiber Optic for Harsh Environment

Harsh environment applications include conditions in which these products are exposed to extreme high/low temperatures, shock, vibration, radiation, corrosive conditions, high electromagnetic interference (EMI), high radio-frequency interference (RFI), and/or pressure extremes.

In above, some of the applications of optical fiber are stated. There are other areas as well where optical fiber is used.

3.5 Optical Wireless Integration

With the huge increase of traffic in the mobile network these days integration of wireless and optical has become almost a mandatory action for efficiency. The advantage of fiber over wireless communication in the light of speed and other factors shows how it can be of preference in theory. Large distance information transmission can be possible through fiber optics communication in the highest of efficiency in regards of speed and power loss. However, in the practical world its sole use as communication medium is not yet possible. Wireless network despite the disadvantages is still in preference to many extent due to it mobility, something fiber optics still have to work on. Hence, to maximize the efficacy with power loss, speed as well as mobility in mind integrated wireless-optical communication technology has come up. Our next chapters will discuss about one such integration, Fiber to the Antenna (FTTA) technology to evaluate a new possibility in answer to our increasing demand for a fast efficient information system.

Chapter 4

Introduction to Fiber to the Antenna – An Integrated Optical and Wireless Solution

To achieve more speed, bandwidth and mobility together, Fiber to the Antenna (FTTA) is the new integrated optical and wireless solution. The main concept is to carry out the message signal through optical fiber up to the antenna from the radio base station (RBS) with the help of mounted Remote Radio Head (RRH) at near to the top of the tower.

Legacy cellular base stations have baseband unit and radio-frequency (RF) units mounted inside an air-conditioned enclosure at the base of cellular tower with coaxial cables connected, transmitting signals to antennas that are placed at the top of the tower. Telecommunications industry is now moving into FTTA based distributed network and Remote Radio Head (RRH) architectures where the baseband units are digitally connected to a group of RF components mounted on top of antenna towers [1].

RF units in traditional architecture are located at a distance from the antennas; however, in the new architecture RF units are in RRH that is mounted close to the antenna. RRH based system supports 3G, 4G/LTE and LTE-Advanced networks. In this chapter, the changes in cell tower architecture being implemented to meet fourth generation network operating performance criteria as well as the concept of radio over fiber, tremendous benefits offered by FTTA, and using RRH to operate are analyzed.

4.1 System Architecture

In legacy wireless communication system, radio base station (RBS) uses coaxial cable to transmit the high-frequency signal from the base station to the remote antenna [2]. The RBS includes several modules such as base band unit (BBU), RF filter, signal power amplifier, radio signal modulator as well as transmitter and receiver. The entire base station control and base band signal processing are maintained here. Before transmitting the signal to the antenna, the RBS modulates the data signals into allocated high-frequency band and consequently amplify the power of the modulated signals. Afterwards, the output signals are transmitted via coaxial cables to the tower mounted amplifier (TMA) from where the re-amplified signals are sent to antenna through coaxial jumper cables. The signals are then radiated into the radio cell.

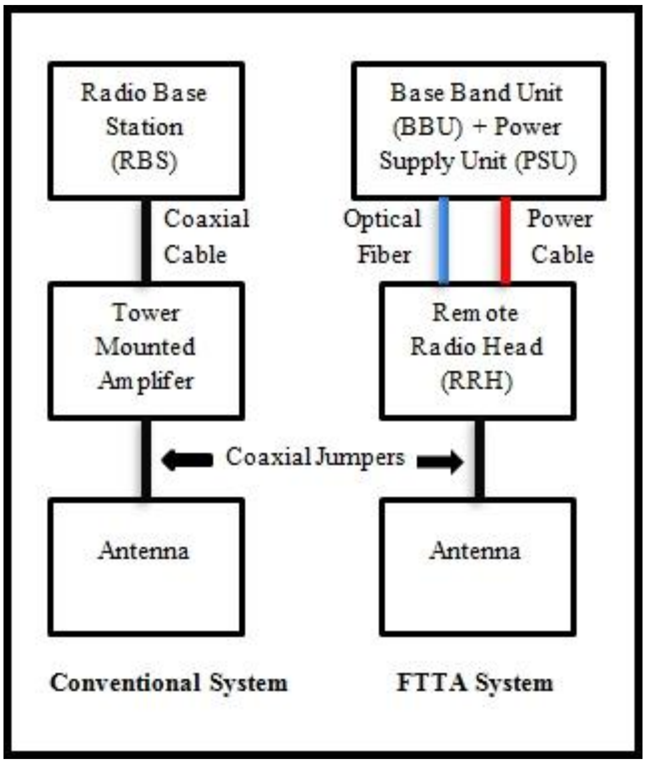


Figure 4.1: Block Diagram of Both Conventional and FTTA System

With FTTA system, it is now possible to get the benifits of distributed base station architecture which allows installing remote radio head (RRH), where the RF filter and power amplifier of a base station are now located rather than at the tower bottom that used to be in old-style base stations, near to the antenna on a tower as depicted in Figure 4.2. To increase performance and lower costs, many operators are looking to remote radio unit (RRU) deployments. They are an important part of many network modernization processes. RRH includes number of digital interfacing and processing functions as well as efficient and frequency-agile analog functions, all bundled into a low-weight (9.7 Kg) device [3]. Moreover, RRH supports advanced network technologies like MIMO and RET.

- **Multiple-Input and Multiple-Output (MIMO)** technology is a wireless technology that uses multiple transmitters and receivers to transfer more data at the same time to improve communication performance. It offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. MIMO technology takes advantage of a natural radio-wave phenomenon called multipath. With multipath, transmitted information bounces off walls, ceilings, and other objects, reaching the receiving antenna multiple times via different angles and at slightly different times. MIMO makes antennas work smarter by enabling them to combine data streams arriving from different paths and at different times to effectively increase receiver signal-capturing power. Smart antennas use spatial diversity technology, which puts surplus antennas to good use. When there are more antennas than spatial streams, the antennas can add receiver diversity and increase range.

- The **Remote Electrical Tilt (RET)** Unit allows for accurate control of antenna tilt eliminating site-access requirement, allowing the tilt to be adjusted remotely from the base station control center and only in a matter of minutes. This allows for timely and accurate response to changing capacity requirements of the network. The solution comprises of a Motor driven Antenna, with communication to the RBS via RS-485 and a microprocessor that controls the communication and performs supervisory functions. Most of the RET systems use the AISG protocol (Antenna Interface Standard Group) which is an open specifications for the control interface for these systems.

Optical fiber connections are used to link the RRH to the base band unit. The base band signal processing still continues to take place in the base unit, where the last operation i.e. converting electro-optical signal is done by means of an SFP (Small Form-factor Pluggable) tranceiver [4]. Later on, the optical signal is transmitted over the optical fiber to the RRH that converts the optical signal back into an electrical signal with the help of another SFP module, prior to high-frequency modulation and final power amplification. In addition, no special measures are necessary for the protection of these fiber optical lines against electromagnetic interference within the meaning of lightning and surge protection.

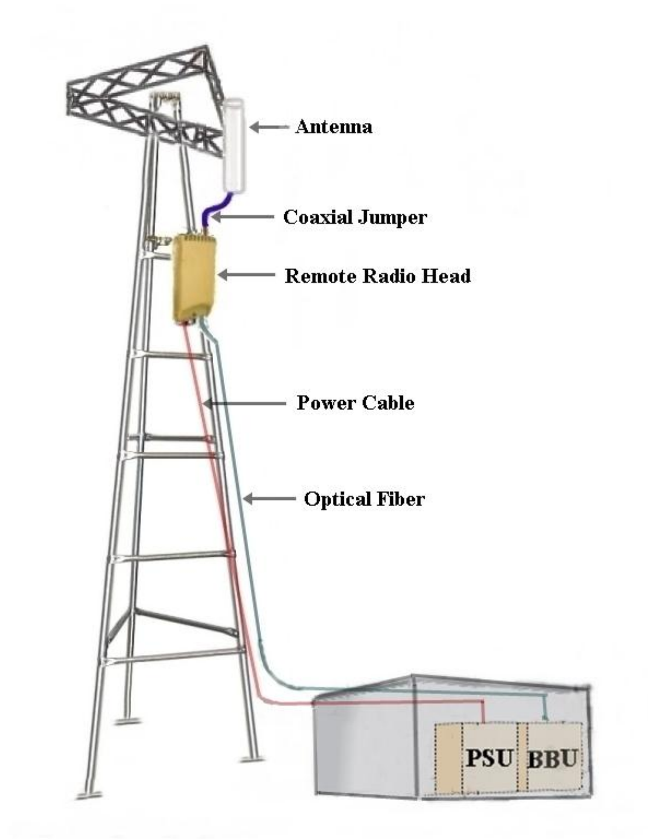


Figure 4.2 : FTTA Site Architecture

At last, using short coaxial cables, RF signal is transmitted to the antenna for broadcasting. Additionally, RRH is supplied with -24V or -48V DC through heavily shielded cables from the power supply unit (PSU) at the bottom of the tower as shown in Figure 4.2. The existing coaxial feeders in the traditional system can be used for this purpose. Solar panel system also can be used to supply the power to RRH.

The main reason behind using FTTA over conventional architecture is to increase speed and bandwidth limit as well as other features by using optical fiber over coax cable from the ground to the antenna. In this case, a question may appear why not we are taking the optical cable up to the antenna itself rather than connecting it to RRH. To answer the question it should be mentioned that we are using passive antennas, which means these can only radiate electrical signal which is transferred to them. These antennas cannot yet spread out optical signal or convert signal from optical domain to electrical domain. Moreover, our electrical devices use electrical signal not optical signal. That is why we are using RRH to do that for the antenna and then the antenna can radiate the signal. Of course, it would be better if the antenna can itself convert the signal or work in optical domain. Then the little loss in the jumper cables can be avoided and more speed can be achieved by carrying the optical cable up to the antenna. With this view, now research is going on and some progress is also made. In future, active antennas with active components will be used where the antenna can carry out the task of conversion and other processing functions like amplification and filtering. The progress of technology will implement the FTTA concept in a better way through the obsolescence of RRH. However, for the time being, RRH is the best option we have and there are some new updates are being made to RRH as well.

4.2 Radio over Fiber

Implementation of FTTA is based on Radio over Fiber (RoF) technology. Radio over fiber focuses more on the signal processing and controlling side of FTTA rather than its hardware related aspect. It is a technique to modulate light by a radio signal and transport it over an optical fiber link to RBS to take the advantage of relatively low loss of optical fibers and to simplify wireless access. Previously RoF was only used to carry the microwave signals along with providing mobilty function. However, in recent days, the system is designed with more functionalities like data modulation, signal processing and frequency up-down conversion [5].

In RoF system architecture, an optical fiber network creates the connection between a Central Base Station (CBS) and a RBS. Wireless signals are transported over this optical link from CBS to RBS before radiated or received signals are sent back to CBS by RBS. A CBS usually control several RBSs. It can remotely monitor radio signal distribution and also can detect the congestion that occurs in the RBSs which are connected to it and then takes steps like controlling bandwidth to eradicate the problem. The benefit of using this system is that equipment for WiFi, 3G and other protocols can be centralized in CBS, where the signal is processed, with remote antennas connected through fiber optical serving all protocols; this is opposite to the conventional system where each protocol type requires separate equipment at the location of the antenna.

4.2.1 Approaches Based on Frequency Bands

Different approaches can be followed to transport radio signal over optical fiber in RoF system. The approaches are categorized on the basis of the frequency bands (RF (Radio Frequency) bands, IF (Intermediate Frequency) bands, Baseband signal) that is used to transport signal over optical fiber [5].

4.2.1.1 RF over Fiber

The key optical and RF devices required at the CBS and the RBS for downstream signal transmission in a RoF system based on RF over fiber is shown in Figure 4.4.This configuration enables centralized control and remote monitoring of the radio signal distribution via the fiber backbone network and reduces the complexity of the RBS implementation, but is susceptible to fiber chromatic dispersion that seriously limits the transmission distance. The wireless data obtained from the trunk network are modulated onto a number of lower intermediate frequencies (IF) carriers, which are then combined to form a subcarrier multiplexed (SCM) signal [5].

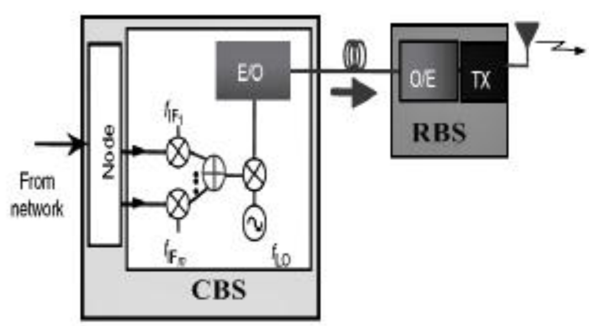


Figure 4.3: Downstream Signal Transmission via RF over Fiber

This SCM signal is up converted to the radio transmission frequency using a local oscillator (LO) source located at the CBS and then modulated onto an optical carrier. At the RBS, the analog optical signal is detected, amplified, filtered, and directed to an antenna for free space transmission. Upstream radio transmission to the RBS and subsequently back to the CBS will require a mechanism for modulating an optical source located at the RBS at the radio carrier frequency, and photo detection of this signal back at the CBS [5].

4.2.1.2 IF over Fiber

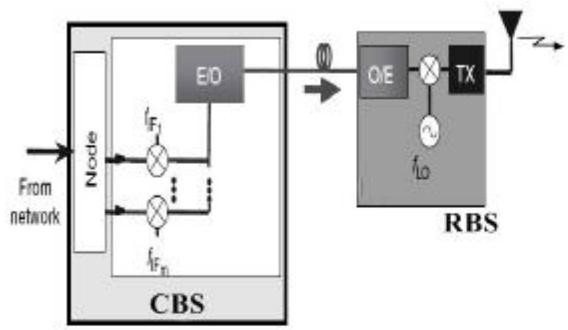


Figure 4.4: Downstream Signal Transmission via IF over Fiber

In Figure 4.5, a scheme of the basic hardware required is shown for downstream signal transmission in an RoF system based on the distribution of the radio signal at a lower IF, the so called ‘‘IF over fiber’’. IF signal transport schemes offer the advantage that the readily available mature microwave hardware can be utilized at the RBS, although the requirement for frequency conversion at the RBS increases the complexity of the RBS architecture particularly as the frequency of the wireless application moves into the millimeter wave frequency region. The RBS hardware now requires LOs and mixers for the frequency conversion processes, which may limit the ability to upgrade or reconfigure the radio network with the provision of additional radio channels or the implementation of required changes in RF frequency [5].

4.2.1.3 Baseband over Fiber

Baseband over fiber approach as shown in Figure 4.6 can be used to transport data carrying radio signals between the CBS and the RBS in RoF systems. The radio information for the radio carriers is transported to the RBS as a time division multiplexed (TDM) digital data stream. The individual data channels are then demultiplexed, up converted to IFs, before undergoing an additional frequency up conversion to the required radio frequency band via an LO located at the

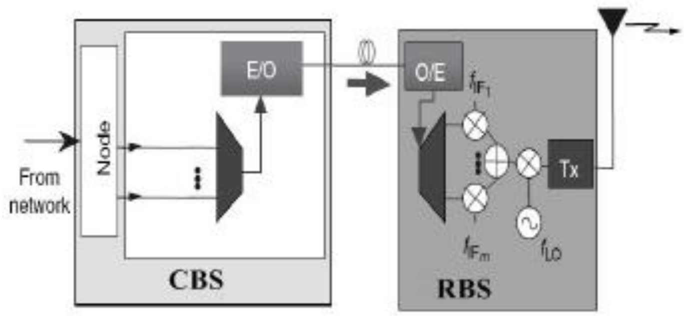


Figure 4.5: Downstream Signal Transmission via BB over Fiber

RBS. Upstream signal transport via baseband over fiber can also be accomplished by down converting the received wireless carriers at the RBS to the baseband before transmission back to the CBS. As with IF over fiber, RoF systems based on baseband over fiber transport schemes can readily exploit the use of mature and reliable RF and digital hardware for signal processing at the CBS and RBS as well as low cost optoelectronic interfaces. The need for frequency conversion at the RBS complicates the RBS architecture design as the air interface frequency increases. The additional LO source and extensive signal processing hardware (frequency conversion and multiplexing and demultiplexing of signals from many users) in the antenna RBS may also limit the upgradeability of the overall fiber radio system [5].

4.2.2 SCM-WDM Technology

To transport the signal over the fiber optical link SCM-WDM technique can be used. The process that is followed to do so is explained in this sector.

- The term wavelength-division multiplexing(WDM) is commonly applied to an optical carrier. Usually a single fiber can carry information in one direction only (simplex) which means that we usually require two fibers for bidirectional (duplex) communication. However, recent progress in wavelength division multiplexing makes it possible to use the same fiber for duplex communication using different wavelengths. WDM can be used to combine several wavelengths together to send them through a fiber optic network, greatly increasing the use of the available fiber bandwidth and maximizing total data throughput that in order to meet future wireless bandwidth requirements.

- **Subcarrier Multiplexing (SCM)** is a method for combining many different communications signals so that they can be transmitted along a single optical fiber.

In this process, as depicted in Fig. 3, n numbers of signals from the network trunk are modulated by N number of microwave carrier. After that with the help of a combiner these signals are combined and modulated onto an optical carrier using any of the two modulation process - direct intensity modulation or external intensity modulation can be used to modulate light source in the transmitter to form a subcarrier multiplexed signal occupying a specific wavelength [6]. Then WDM configuration is used to multiplex M numbers of such wavelengths together to transport through a single fiber link [7].

At the receiver, the remote site, the wavelengths are separated for individual detectors using optical demultiplexer and then optical receiver converts the optical signal to RF again.

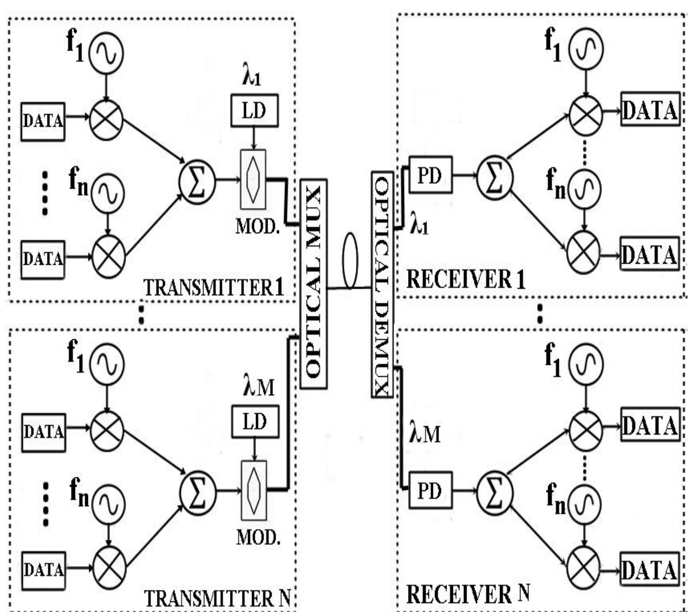


Figure 4.6: SCM-WDM Technique

Afterward, to separate the signal channels, RF coherent detection is used at the SCM level. Then the signal is amplified and filtered prior to directing to an antenna for free space radiation. On the other hand, for upstream radio transmission to the remote station and consequently transmitting back to the CBS a similar type of mechanism will be needed for modulating optical source, located at RS, with the RF signal and a photo detection system at the CBS [5, 7].

Finally, If we consider a SCM/WDM signal that is the sum of N fields, thenthe electric field of this signal can be written as:

$$E(r,t) = \sum_{i=1}^{N} [S_i]^{1/2} \cos(w_i t + \phi_i(t) - \beta_i Z) \quad (4.1)$$

where the intensity modulation by an RF subcarrier is represented by:

$$S_i(t) = S_0 \{1 + m \, .x_i(t)\} \quad (4.2)$$

Where $x_i(t)$ can have any form of digital or analog modulation, and m represents the intensity modulation index. B_i is the propagation constant for the WDM channels, with the corresponding angular frequencies w_i.

The additional phase $\varphi_i(t)$ of the electric field in equation (4.1) can have a chirp component $\varphi_{mi}(t)$ in the case of direct laser modulation, a phase noise component $\varphi_{ni}(t)$ modeled by a Wiener-Levy process, and possibly a random component $\varphi_{pi}(t)$ due to polarization fluctuation. Hence, the total phase can be written as:

$$\varphi_i(t) = \varphi_{pi}(t) + \varphi_{ni}(t) + \varphi_{mi}(t) \quad (4.3)$$

Because of its minor effect, phase noise $\varphi_{ni}(t)$ will be neglected. $\varphi_{mi}(t)$ is also neglected because we assume external modulation of the lasers. As a worst case assumption, the two fields will be assumed to have the same polarization phase; hence $\varphi_{pi}(t)$ will be set to zero [19].

In this chapter, we have discussed the architecture of Fiber to the Antenna in comparison with the conventional network architecture. We have seen how Remote Radio Head (RRH) is making it possible to carry signal in optical domain and how some of the equipment and features are now placed in RRH. Moreover, we have talked about Radio over Fiber (RoF), the concept used by FTTA; and then about the approaches taken to send optical signal i.e. RF bands, IF bands, Baseband signal. In addition, SCM-WDM technology used to transport the signal over the fiber optical link is described here.

In the next chapter, we are going to explain the benefits of FTTA for which we are inclined to use FTTA system over conventional system.

Chapter 5

Benefits of FTTA

To fulfill the thirst of the consumers for high data speed and bandwidth network operators are now changing their architecture of network system and taking advantages that is offered by FTTA over traditional system. To give a clear idea about the benefits that we can get from implementing FTTA are discussed in details:

5.1 Replacing Coaxial Cables

Using FTTA enables the replacement of coaxial cable. In traditional method, coaxial cables are the medium, used for transmitting high-frequency radio signals, connecting the base station on the ground to an antenna on the tower. However, it has the main disadvantage of signal loss. Along the length of the coaxial cable, part of the transmitted signal will be lost or attenuated. A small percent may escape the cable's shielding, and more will be converted to heat. The higher the frequency, the greater the losses are. For long-distance transmissions, repeater stations are necessary for amplifying and retransmitting weakened signals. Generally, almost 35% of the signal power is lost in coaxial cables (7/8") having a length of 30m and around 50% of the signal can be degraded before the signal is even transmitted by the antenna [4]. As a result of these losses, deterioration of the transmission power occurs, which results to reduction of the reception signal quality due to increased signal noise. On the other hand, fiber optics in FTTA is immune to electrical interference and has much lower rates of signal loss. Deployment of the FTTA concept has provided new configuration techniques for the placement of antennas and RRHs, which made it possible to minimize the signal loss by generating the signal near the antenna. Moreover, since the fiber optic cable weighs much less than the coaxial cable, FTTA reduces the total cable structural load on the tower [8].

5.2 Speed

Coaxial cables in conventional system offer electrical speed for data transmission which works in micro or nano second domain. Transmission speed of coax is 10 Mbps [9]. On the other hand, optical speed, which is in femto second domain, can be gained by using optical fiber all the way to near the antenna in FTTA. Various researches are on process exploring the upper limit of this signal data speed. Telecom giants Alcatel-Lucent and BT have successfully experimented data speeds of up to 1.4Tbps over an existing commercial grade fiber optic cable and data transmission speed of 31Tbps over a single long-haul 7200 km optical fiber [10]. To meet the increasing demand for high data rate signal a comparison of bit rate speed through different media is given in Figure 5.1.

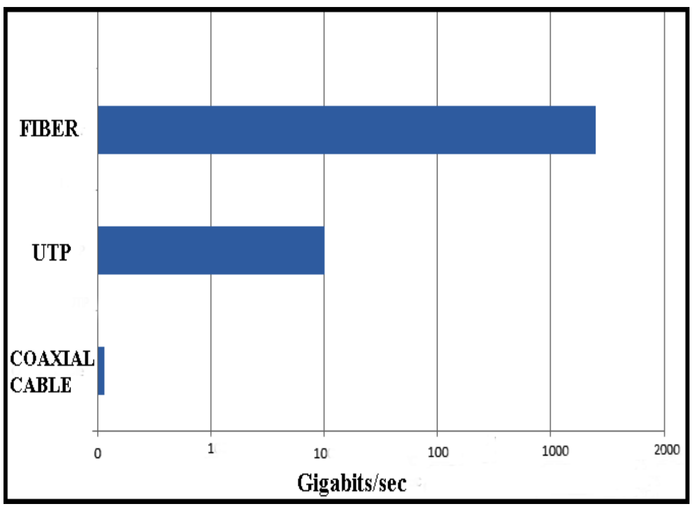


Figure 5.1: Working Speed of Different Media

5.3 Offers Wide-Range Coverage and Capacity

Since the coaxial cables are greatly prone to losses, the transmission distance via coax in legacy system is limited to less than 50 meters [4]. In case of larger distances, to eliminate the problem and extend the radio cell coverage low-loss but expensive coaxial cables which are also time-consuming to install due to their large external diameter are used. On the contrary, single mode glass fibers give the opportunity to extend the transmission distance limit up to 15 to 20 km [4]. In addition to that, now-a-days, most of the time, advanced antenna techniques like

MIMO (Multiple In Multiple Out) and RET (Remote Electrical Tilt) are supported by RRHs that offer significant increase in data throughput and link range without additional bandwidth or increased transmitting power [11].

5.4 Installation Time

Installation is faster by fiber fed solution compared to coax solution [12]. A four crew technician group would complete a coax tower work in four days whereas for FTTA it gets reduced to only three technician and two days. Companies are still upgrading the processes and there are now companies such as Corning who develops such technology that installation is possible within one day using three labour hands [12].

5.5 Power Reduced

When frequency of the radio signal increases the power-loss in the coaxial feeder also increases. In worst case scenario, double the original signal frequency has to be fed into the cable to get the required output in the antenna [11]. Besides, the electical losses in the coax results in higher power consupmtion. Installation of FTTA eliminates these complications. Use of power amplifiers in the RRH allows the use of -48V DC instead of 110V AC. This reduces the transmission power loss due to 110V AC [8]. As we are able to avoid high voltage AC power cable, we can use cable with less weight. By using DC power cable we eradicate the skin effect and also the frequency issues which further decrease the transmission power loss due to 110V AC. Finally, substituting the coax cable with the optical cable lessens the attenuation loss to a much greater level that results in high effectiveness of the power amplifiers.

5.6 Reduced Cooling System

The traditional RF amplifiers used in the base stations are very inefficient. Most of the energy used to drive the amplifier is lost as heat. The energy cost is thus increased since continuously active cooling systems are required in such situations. However with RF amplifier in the RRH tower, the cooling is done naturally by the air which in turn reduces the need of cooling system. Almost 25 percent of a tower's energy used for cooling system can be saved by using RRH, according to the 2010 "ATIS (Alliance for Telecommunications Industry Solutions) Report on Wireless Network Energy Efficiency" [11].

5.7 Hybrid Cables

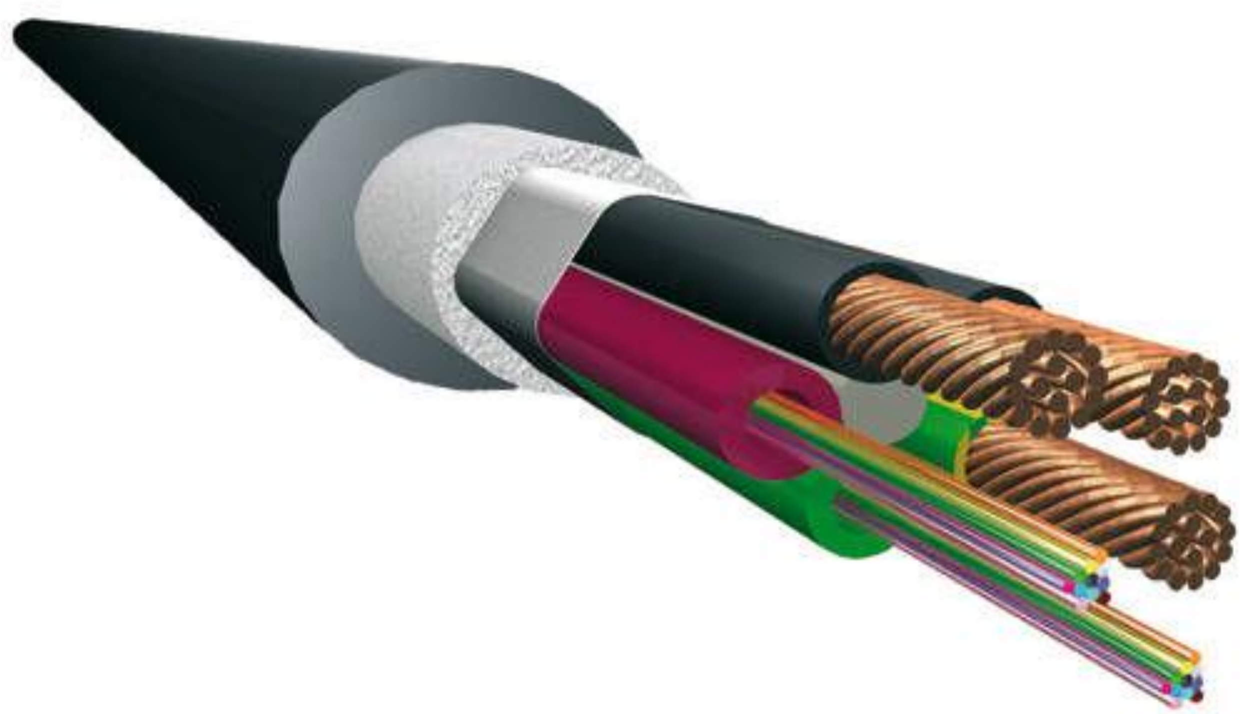


Figure 5.2: Hybrid Cables

Advancement of technology permits us to use hybrid cables where we are able to combine power and optical fiber elements in a single cable cross section. There may also exists separate optical and power cables; reusable feeders that reuse coaxial cables that already exist to carry the power while a new fiber optic data cable is fed through the existing central duct. Cases where involves upgrading the existing site reusable feeder cable solution is the most effective. The low friction design of the optical fiber means that the site engineer simply has to feed it in from the top connection of the antenna or RRH, usually at a height of 50 to 100 meters above ground. After a short length has been inserted, the cable will then continue to fall under its own weight.

The installation cost here is less because of fewer cable sheaths (70% less than using coax cables) [17].

5.8 Smaller Footprint

Improved FTTA systems use fiber cables those are thinner and carry more signal than the tradition coax cables. Thus it consumes less space and lessens or does not add to coaxial congestion and tower loading issues, saving tower real estate, reducing physical complexity and minimizing visual impact. There is also no need for the inefficient amplifiers and the cooling systems in this system. So the requirement of the storage units or shelter for these inefficient equipment decreases, consequently reducing the footprint. Furthermore, now we can control sevaral RBS from one CBS (as mentioned earlirer in section 4.2), which makes it possible to get rid of the necessity for setting up remote RBS with various equipment for each protocol. Hence, the need of extra space is reduced.

5.9 Distributive Antenna System

The concept of driving multiple antenna systems from one base station is commonly known as Distributive antenna system (DAS). The idea is to split the transmitted power among several antenna elements, separated in space so as to provide coverage over the same area as a single antenna but with reduced total power and improved reliability. Here less power is wasted in overcoming penetration and shadowing losses as a line-of-sight channel is present. This concept reduces the physical footprint and power requirements of the base station when compared to traditional base station designs as now we can control remote antenna from one central place. Here the need of setting equipment at each remote sites is overcome.

5.10 Lower Acquisition Cost

Due to lower rental costs of telecoms facilities and antenna sites, operating costs are reduced. For instance, pre-installed fiber optics infrastructure in city networks or in buildings can be used to establish the connection between the base station and the remote radio head. Again, network operators have to spend huge amount of money to rental and licensing issues for base stations and antenna sites. As a solution, FTTA can be used, which permits base stations to be installed at greater distances from the RRHs. Fiber-fed RRH can save around 50-60% on total material and installation costs compared to coax cable deployments, with 6 to 12 [12]. This makes things easier for the operators to acquire new sites to optimize network coverage.

5.11 Simpler Installation

The continuous research and advancement are makingFTTA system more and more easy to install and reliable. New and upgraded cables, connectors and tools are becoming available in the market which are lighter, safer, and easier to handle for a technician who climbs a tower some 300 to 500 feet in the air. Further, the radio heads are designed in such a way that they can be simply and easily installed due to their low weight and size.

5.12 Flexibility in Multi-mode Operations and Software

Equipment needs have been reduced due to combined and concurrent multi-standard operations. Further, Remote upgrades and frequency-agile operations have enabled easier capacity upgrades [3].

As it can be seen from above discussion, the FTTA architecture supports and provides some significant benificial features that can be used to replace our convention network system for a better and upgraded system, which can help to meet the demands of increasing number of consumers.

In the following page, The advantages of FTTA over conventional cell site architecture has been summerized in Table 1.

	Conventional Cell Site Architecture	**FTTA Architecture**
Co-axial Cable Replacement	Almost 35% of the signal power is lost in coaxial cables around 50% of the signal can be degraded before it is even transmitted by the antenna.	By using fiber, the concerns related to signal loss can be disregarded. The total structural load on the tower is also reduced.
Installation time	Time consuming.	Half the time required.
Transmission Distance	Limited to less than 50 meters (since via coax).	Limit is up to 15 to 20 km (since via glass fibers).
Footprint	Has larger footprint.Use of inefficient amplifiers.	Has much smaller footprint. No use of inefficient amplifiers.
Flexibility of upgrades	Upgrade is tough.	More easily upgradable.
Hybrid Cables	No use of hybrid cables	Use of hybrid cables which lowers installation cost by 70%
Transmission Power	Huge transmission power loss due to AC source.	Reduced transmission power loss due to DC source.
Cooling system	Cooling system required.	No cooling system required thus saving 25% of tower's energy usage.
Distributed Antenna System (DAS)	Does not support DAS.	Supports DAS.
Installation, maintenance and acquisition cost	High cost for installation and maintenance.	Simpler installation with reduced saving about 50%-60% of acquisition cost

Table 1: Summary of Advantages of FTTA over Coaxial Cellsite Architecture

Thus from discussion of this chapter, we have a clear picture about what are the advantages we can obtain by implementing FTTA system.

In the following chapter, we have mentioned and described the issues we face while implementing FTTA architecture as well as the solutions available to overcome these challenges.

Chapter 6

Implementation Challenges with FTTA and Possible Solutions

As much as benefits are there of FTTA, there are also a number of issues that is faced while practical implementation. Problems regarding surge, water and moisture, fiber connectors and not to mention labor skills and safety create great issues in practical life. However, many companies have come up with various tools and regulators as solutions. These, they have developed after numerous trial and error method which is evidently very costly. In this chapter we have tried to have a detailed discussion on the challenges and how they can be dealt with by some of the available solutions. We have also tried to give an optimum solution idea in some cases so as to reduce the cost problems. Regardless, further research work for each case is required.

6.1 Surge

Being exposed to the environment, surge and lightning have been an unavoidable issue for the sustainability of the whole FTTA structure. There are power cables coming from low voltage power supply (-48V DC) and coaxial jumpers (copper wires) which should be taken into consideration [Figure 4.2]. When the lightning is struck on the RRH primarily there is a high rise on the voltage of the elements around the exposed zone [2] and also some excessive current flow in the conductive elements around. As a result the unexposed elements which are not directly hit by lightning face some electromagnetic field effects. The RRH may be subdivided into different zones depending upon the fact how they are exposed to the surge or lightning

In case of solution, different Surge Protection Devices (SPDs) can be used to protect the system. Firstly, the lightning or surge may couple on the power supply lines and create trouble for the power supply. Thus a protective device (SPD) must be included on the output side of the power supply to protect the sensitive components of the power supply. To ensure better protection SPD should be provided at the power supply input of the RRH also. Now, depending on the arrangement of the components of the base station, the length of the supply lines may be 30 meters or more [2]. When a lightning event occurs such length may prove fatal causing high voltage difference adversely affecting the protection level of the SPD at the output of the power supply. It may also exceed the dielectric strength of the RRH components. From various experiments it is learned that for better performance it is customary to add a protective at the front of the power supply input of the RRH to reduce the induced voltages of conductor loop whenever the length of the power cable is more than 10m [2].

6.1.1 Different Sorts of Surge Protection Devices

	Component	**Discharge Capacity**	**Protection Level**	**Response Behavior**
Protection state 1 **(Lightning Current)**	Spark Gap GDT Varistor	High	Medium/High High Medium	Slow/Medium Medium Fast
Protection state 2 **(Surge Voltage)**	Varistor GDT	Medium	Medium High	Fast Medium
Protection state 3 **(Device Protection)**	Suppressor Diode Varistor GDT	Low	Very low Low High	Very Fast Fast Medium

Table 6.1: Comparison of Different Usages of SPDs

Whichever protection device we may use it is really important to make sure that the device is suitable for DC applications and can delete a possible occurring arc of DC. Most SPDs built for low voltage power supplies are designed and tested for AC systems. But we have to keep in mind that a SPD's characteristics for AC systems are completely different from DC systems. So before applying the SPD in our design we have to make sure it works perfectly with DC.

In addition to this and due to the new system-architecture with remote radio heads, new requirements to the concept of lightning and surge protection are given. For this issue it is recommended to revise the concept or to add the important items. In this concept, the system is divided into several lightning protection zones (LPZ). In this case, outer and inner zones are defined, according to their flash exposure parameters. At the boundary to the next protection zone, the conducted disturbances are reduced by means of lightning and surge protection devices.

Following outer zones are defined:

- **LPZ 0A** - zone where the threat is due to the direct lightning flash and the full lightning electromagnetic field. The internal systems may be subjected to full or partial lightning surge current.

- **LPZ 0B** - zone protected against direct lightning flashes but where the threat is the full lightning electromagnetic field. The internal systems may be subjected to partial lightning surge currents.

The inner zones include:

- **LPZ 1** - zone where the surge current is limited by current sharing and by isolating interfaces and/or SPDs at the boundary. Spatial shielding may attenuate the lightning electromagnetic field.

- **LPZ 2** - zone where the surge current may be further limited by current sharing and by isolating interfaces and/or additional SPDs at the boundary. Additional spatial shielding may be used to further attenuate the lightning electromagnetic field.

6.1.1.1 Spark Gaps

A spark gap consists of an arrangement of two conducting electrodes separated by a gap usually filled with a gas such as air, designed to allow an electric spark to pass between the conductors. When the voltage difference between the conductors exceeds the gap's breakdown voltage a spark forms, ionizing the gas and drastically reducing its electrical resistance. An electric current then flows until the path of ionized gas is broken or the current reduces below a minimum value called the "holding current". This usually happens when the voltage drops, but in some cases the heated gas rises, stretches out and then breaks the filament of ionized gas. Usually, the action of ionizing the gas is violent and disruptive, often leading to sound (ranging from a *snap* for a spark plug to thunder for a lightning discharge), light and heat.

They are known as so called “coarse protection”. They have a response time in the medium nanosecond range (‘hard’ response characteristics). Mainly there are two types of spark gaps commonly used: encapsulated and triggered spark gaps. The maximum discharge capacity it has for impulse current is between 25KA and 100KA [2].

The encapsulated spark gaps are used for diverting high voltages. In order to guarantee that the gas atmosphere of the structure of an encapsulated spark gap is reliably protected from the effect

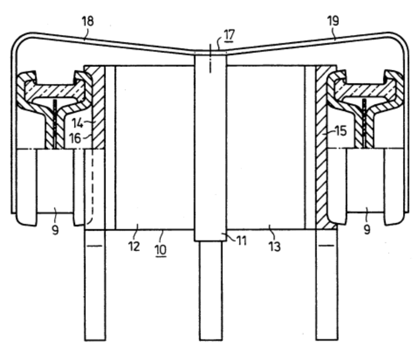


Figure 6.1: Encapsulated Spark Gaps

of moisture, two flat discharge surfaces of two dish-type electrodes, each designed with a collar-shaped rim, abut on both sides of a thin insulating layer having punched holes. A tubular glass insulator is sealed on the front side into the collar-shaped rims of the two electrodes [25].

Triggered spark gap can switch megawatts of power in a few microseconds, with jitters of less than a nanosecond. These devices make use of the very low impedance of an arc once the arc is established. Two electrodes are separated by sufficient distance that the gap doesn't spontaneously break down. The breakdown is initiated by a variety of means: UV irradiation from another spark or a laser, an overvoltage pulse, or reducing the gas pressure in the gap [26].

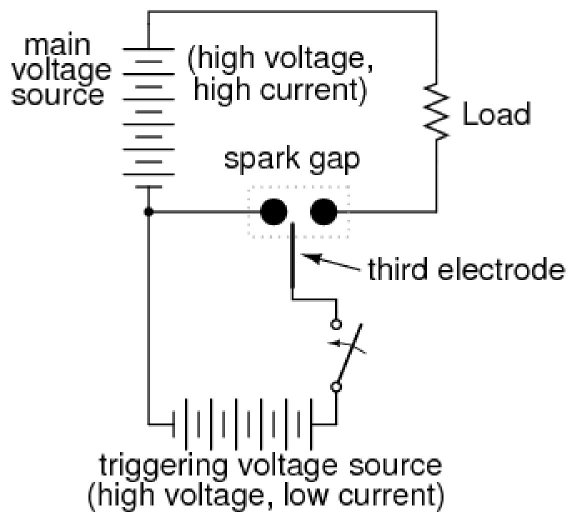


Figure 6.2: Triggered Spark Gaps

6.1.1.2 Gas Discharge Tubes

Gas discharge tubes dissipate voltage transients through a contained plasma gas. They have high insulation resistance plus low capacitance and leakage to ensure minimal effect on normal operation of equipment.

When a voltage disturbance reaches the GDT spark over value, the GDT will switch into a virtual short, known as the arc mode. In the arc mode, the GDT practically shorts the line, diverting the surge current through the GDT to ground and removes the voltage surge from the plant and equipment. At normal operating voltages below the GDT rated DC spark over voltage (measured at a rate of rise between 100 to 2000 V/s), the GDT remains in a high impedance off-state condition. All of our GDTs are rated at a minimum insulation resistance of 10^9 Ω at 200 V, 100 V bias or 50 V bias for the different breakdown values. With an increase in voltage across its conductors, the GDT will enter into its glow voltage region. The glow region is where the gas in the tube starts to ionize due to the charge developed across it. During the glow region the increase of current flow will create an avalanche effect in gas ionization that will transmit the GDT into a virtually short circuit mode and current (dependent on the impedance of the voltage source) will pass between the two conductors. The voltage developed across the GDT with a short circuit condition is called the “Arc Voltage” V ARC .The transition time between the glow and arc region is dependent on the available current of the impulse, the distance and shape of the electrodes, the gas composition, gas pressure and the proprietary emission coatings [27].

They are used as protection elements for so called “coarse protection”. Usually they have the capacity to arrest transient current up to 20KA. But powerful GDT have the capacity of arresting up to 100KA transient current [2].

Figure 6.3: GDT

6.1.1.3 Varistors

A varistor is an electronic component with a "diode-like" nonlinear current–voltage characteristic. Simply, at low voltage it is high resistance, and at high voltage it changes and becomes low resistance. Varistors are often used to protect circuits against excessive transient voltages by incorporating them into the circuit in such a way that, when triggered, they will shunt the current created by the high voltage away from sensitive components. A varistor is also known as voltage-dependent resistor (VDR). A varistor's function is to conduct significantly increased current when voltage is excessive. [28]

They are used as protection elements for so called "medium protection". Their response time is in the lower nanosecond range ('soft' response characteristics). Usual Varistors have the capability of discharging surge current up to several 10KA at maximum but very powerful Varistors have the capability of discharging high energy lightning currents [2].

Figure 6.4: Metal Oxide Varistor

6.1.1.4 A Comparison between the Functions of MOV and GDT

MOV and GDT technologies have been around for many years. Both of these technologies work by going from normally high impedance to low impedance when a high fault voltage is detected. The idea is that when they are at a high impedance state, they have no effect on circuit operation. But when there is a high voltage present, high enough to damage circuit components, they activate by becoming low resistance and shunting the energy to ground. The mechanical analogy would be a relief valve on a high-pressure pipe or tank that opens and vents gas or liquid if the pressure gets too high.

Overvoltage devices can be divided into two categories: clamping and crowbar devices. Crowbar devices go to a short circuit when they trip. (The name “crowbar” comes from the concept of dropping a crowbar across a pair of power lines and shorting them out.) Clamping devices don’t go to a short circuit when they trip; however they do go to a low enough resistance to limit the voltage to a rated clamping voltage. In a perfect world, this voltage would be constant no matter what level of current is present. But, in reality, clamping devices (like MOVs) have a higher clamping voltage when the current is higher.

GDTs are crowbar devices and MOVs are clamping devices. Because GDTs are crowbar devices, they have a very low voltage drop while in the tripped condition. This means that they can conduct a lot of current without dissipating a lot of power ($P = V \times I$, a low voltage multiplied by a high current results in lower power than a high voltage multiplied by a high current). As a result, GDTs are rated for very high current surges. Since MOVs are clamping devices, they dissipate more power in the tripped condition than GDTs, so they typically have lower surge current ratings.

So, why would anyone use an MOV or other clamping device if they have lower surge current ratings than crowbar devices? The answer is that there are many times when you don’t want to have a short circuit; for example, on an AC power line. Having a short circuit on a 120 volt AC branch circuit can cause very high currents to flow. The circuit breaker should trip to protect the branch wiring, but the components in the equipment plugged into that outlet may be damaged. This is why MOVs are commonly used in AC power applications. GDTs, on the other hand, are more commonly used in communications circuits where a short circuit will not cause high currents to flow because the source is impedance limited.

Another factor to consider is capacitance. MOVs have relatively high capacitance and GDTs have relatively low capacitance. On a 50-60 Hz AC power line, capacitance is not an issue, which is another reason to use MOVs. On communications circuits, capacitance may or may not be an issue, depending on the frequency. For voice telephone line applications, the capacitance of an MOV is usually not an issue. At higher frequencies, like in DSL or RF applications, the capacitance in the MOV can produce low impedance across the communications lines and attenuate the signal. Many telecom designers of VDSL systems use GDTs because of their low capacitance.

One final factor to consider is reaction time. MOVs are very fast, reacting in the nanosecond range. GDTs are slower, so more energy will get past them before they trip. Most GDT manufactures will specify different tripping voltages based on the rise time of the voltage surge.

So to summarize, GDTs become a short circuit when they trip. They can withstand higher currents and have low capacitance, but they are relatively slow. MOVs clamp to a low impedance but not a short circuit when they trip. They are very fast, but they have high capacitance. (Note: this is a basic overview of MOVs and GDTs. There are exceptions to the generalizations made here, and there are some cases where it is appropriate to use MOVs combined with GDTs.)

6.1.1.5 Suppressor Diodes

They are used as protection elements for so called “fine protection”. They have the capacity of discharging surge current up to approximately 1.5KA.

This has been tested that these components perform better when they are used in a combination of two or more rather than using a single component as SPD. These components are used accordingly to the requirements of the application and a comparison of the different usages of these components is described in Table 6.1.

6.1.2 Different Combinations of SPD Components

For better performance different combinations of these SPDs are used. Some popular examples and their functions are briefly described below.

6.1.2.1 GDT in Combination with MOV

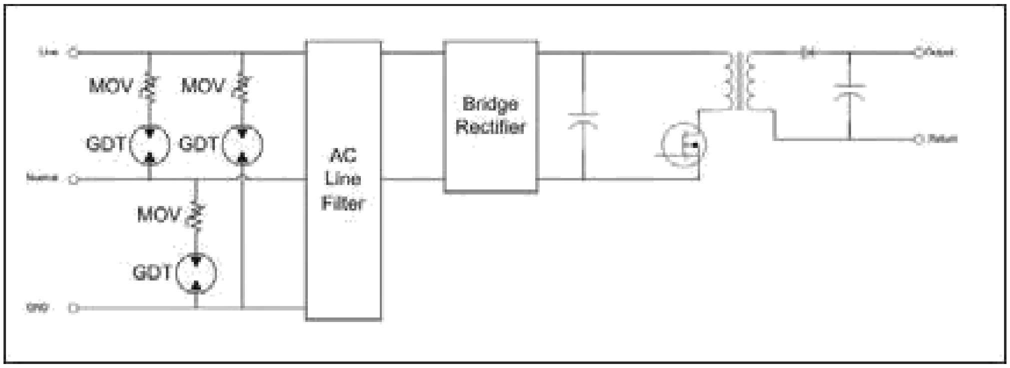


Figure 6.5: GDT in Combination with MOV

This combination may be used for 50KA lightning current and has a voltage protection level of 800V [8]. As the GDT is environmentally sealed it has a tightly controlled trigger voltage level, lower discharge surge current rating and faster response time.

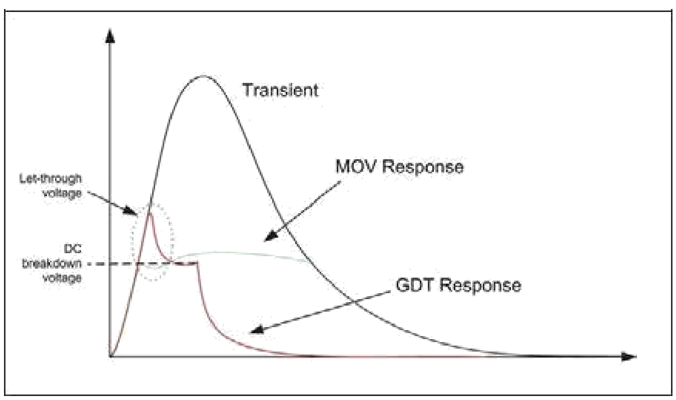


Figure 6.6: Response Behaviour of MOV and GDT

MOVs offer excellent overall protection, with good energy and current handling capabilities. They have low let-through voltage (from figure 6.6) so very little of the leading edge of the transient above the DC breakdown voltage is let through before the device starts to conduct. This means there is little EFT (Electrical Fast Transient) coming through. They also stop conducting when the voltage across them drops below the breakdown voltage, meaning no follow-on current problems. For suppressing high-energy transients GDTs perform better than MOVs. However, GDTs have poor let-through voltage and follow-on current characteristics. Therefore a good approach for is to combine a GDT in series with a MOV.

Using this combination allows the designer to choose a lower-voltage MOV than would be needed if the MOV alone were placed across the line. Lower-voltage MOVs offer the benefit of handling more current for a given energy rating. The MOV acts as a limiter for follow-on current to the GDT.

We have to know the failure point of the device to be protected. Your surge protection should limit the energy below that level, but not too far below. For example, if your device can take a low-energy 2-kV spike, you should clamp to 1.5 V kV rather than 1 kV. Over-de-signing the protection adds unnecessary costs [29].

6.1.2.2 Spark Gaps with Metal Oxide Varistors (MOV)

This combination can be used for 100KA lightning current and Consist a high voltage protection level 1000V (approximately) [8]. But due to the deviations in altitude, humidity and temperature the open air spark gap faces wide deviations of triggering voltage. To extenuate this variation triggered spark gap design is used.

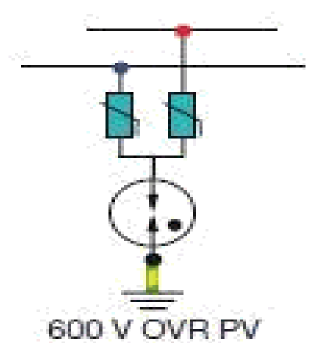


Figure 6.7: Combination of Spark Gap and MOV

When used in series with Varistors, the PTC (spark gap) can be used as a Voltage Dependent Switch which allows conduction of current through itself and the Varistor only if a surge energizes it. In the process the Clamping Voltage Level of the PTC itself is less than 30V which is negligible in the context of this application. As a corollary, in the INACTIVE (open) state, when the Insulation Resistance of the PTC is very high only very miniscule current is allowed through (in Pico Amperes) thus preventing flow of current through the Varistor and prolonging its protection life. In other words, when used in series with the PTC the Varistor Voltage can be reduced to improve the Protection Level without compromising the Protection Life.

Features of the Varistor + Spark Gap Series Combination

· Lower Clamping Voltage

· No Thermal Runaway

· No Leakage Current at steady state operating conditions

· Longer Life

· Extremely Low Capacitance

· High Insulation Resistance

· Stability against Repeated Surges

· Low Cost Solution

6.1.2.3 Parallel MOVs

This combination may be used for lightning current in the range of 25KA to 40KA and has the lowest voltage protection level which is approximately 400V [8]. It has the fastest response time when compared with previous two combinations and lowest lightning current peak values.

Many SPD manufacturers design products using multiple identical MOVs connected in parallel. That’s because using multiple MOVs together increases the level of protection, while sharing the load of diverting a power surge. For instance, a single 20mm diameter MOV will withstand a 6kV, 3kA surge between 2 and 10 times before its failure becomes a real possibility. Two of the same MOVs connected in parallel will withstand that 3kA surge approximately50times. Three MOVs will take that surge about 100 times. Four MOVs will do it about 500 times. Nine MOVs will handle up to 5000 6kV, 3kA surges.

Under normal conditions, MOVs are like open switches.

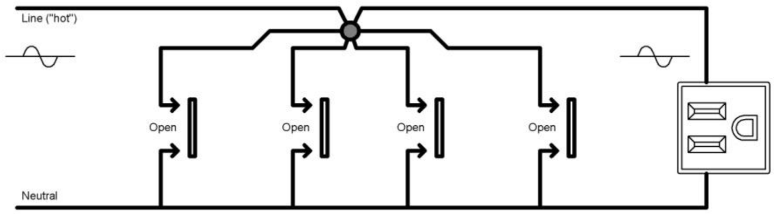


Figure 6.8(a): Operations of Parallel MOV- Step 1

When a surge happens, they all close or “turn on” at the same time and each does their share in getting rid of the surge.

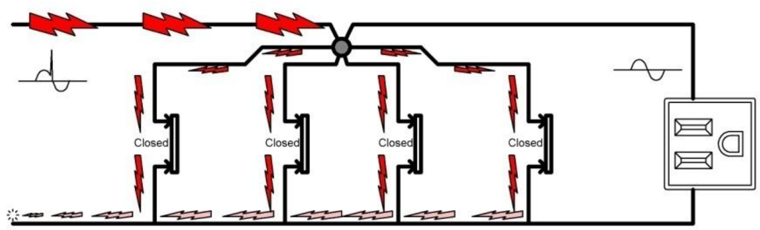


Figure 6.8(b): Operations of Parallel MOV- Step 2

Sometimes electronic components fail. MOVs are no exception. On the rare occasion when they fail they usually become a short circuit, that is, they don’t go open or “turn off” after the surge has subsided. They stay closed or “on” until the current flowing through them causes them to heat up to the point that they literally break apart, thereby becoming an open circuit again, permanently this time. Because of that failure mode, MOVs (or groups of MOVs) should always have some provision for disconnecting them from the power line before they self -destruct to the point of harming anything else. This is usually accomplished with fuses, thermal cut-offs (TCOs) or a combination of both.

That is why having parallel MOVs in the design is a good idea. Should one fail then the others are there to continue providing protection, like this:

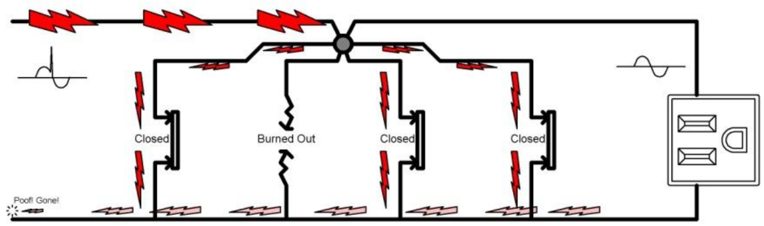


Figure 6.8(c): Operations of Parallel MOV- Step 3

In a redundant design with multiple MOVs, surge protection is maintained at the same level despite the failure of one (or even more than one) MOV. However, should one or more MOV fail, that will put an extra load on the remaining MOVs which can decrease their life span. Because of this possibility, well designed surge protective devices provide some sort of failure notification, usually in the form of an LED indicator. The LED indicator is typically 'on' when the protection circuitry is working properly [30].

6.1.2.4 1+1 Circuit

Here it has a SPD component between the grounded positive pole (RTN) and the -48V DC pole and another SPD component between the RTN and the general ground potential [2]. This avoids corrosion currents through soil and parasitic noise current through the grounded line. This may be designed by various combinations of SPDs.

A 1+1 solution with two varistors in serial can be used to optimize the protection level. Compared with that, solutions with a varistor and a GDT in serial have a bit worse protection level but they separate possible occurring grounding conditions. Interferences can be avoided and the longevity and lasting availability of the system is improved by the variant.

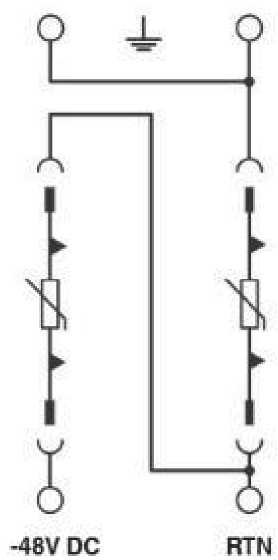


Figure 6.9(a): 1+1 Solution with Two Varistors

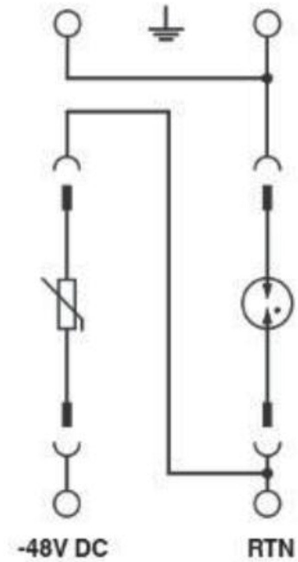


Figure 6.9(b): 1+1 Solution with One Varistor and One GDT

6.1.2.5 1+0 Circuit

There is also a 1+0 combination which can be made through a single pole version and can be used in the protection of the power supply. This may be designed using a triggered spark gap and a varistor in parallel.

Here we have introduced some new combinations that are being used as per required in different tower sites to combat the surge issues. Next we discuss about another important issue which is water and moisture and how we can improve them.

6.2 Water and Moisture

Rain water, ice and moisture are the major environmental problem in the FTTA system. The coaxial jumper cable (refer to Figure 4.2) can be greatly affected by the rain since coax is destroyed by water. When rain water penetrates the cable through connectors the signal frequencies are hampered. Even a small drop of rain can diminish the high frequency signal causing unwanted network problems [13].

Moisture that may form inside the cable can also deteriorate the signal. The di-electric of the co-axial cable is made up of open cell foam which behaves like sponge and hence, absorbs the moisture [13]. This increases the chances of corrosion around the connectors which in turn ultimately causes the signals to combine randomly to form passive inter-modulation (PIM) distortion. PIM occurs when non-linear passive components or other general elements such as connectors or rusty bolts in antenna cause two or more signals to mix and multiply. The created signals follow the same principles as those of wanted signal as various harmonics of the input frequencies mix to form products that can remain within the operation band. PIM causes interference at times which not only may hide the original signal but also lead to problems with other operators for security breach.

To confront these problems regarding weather various companies are introducing new solutions, which are explained below.

6.2.1 Tapes and Mastics

We see how connecters play an important part for good signal performance. Traditionally, tapes and mastics were used to wrap around the connectors. At first a vinyl tape is used as a first layer to wrap so as to act as protection from the viscous mastic type which is used as the second layer of wrapping. Mastic tapes act as seal against water. A third layer is again given around the connectors with vinyl tape to protect the mastic tape from UV radiation. This method of protection is really effective and long-lasting if applied properly. However, the problem with this method is the clarity of proper wrapping which is also very time-consuming. Also, any repair work means cutting of the tapes and mastics which may damage the connector body and the wires. Only for permanent connections this method is really effective.

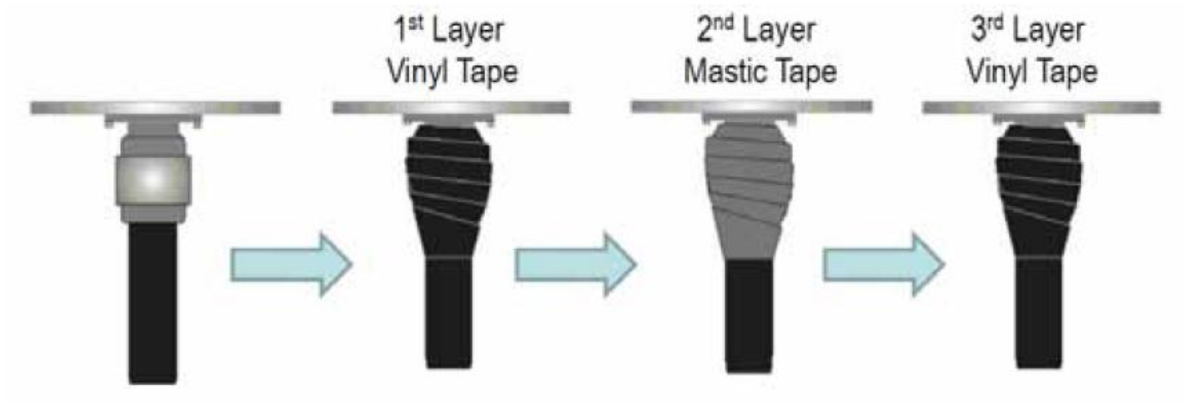


Figure 6.10: Process of Tapes and Mastics [11]

6.2.2 Tubing

Another method of connection developed is pre-stretched tubing which is again of two types:

1) Heat Shrink Tubing- Usually made of nylon or polyolefin, this type of tubing is expanded mechanically and placed over the connection to be heated. The diameter of the tube contracts and fit into the connection. This method however is fire hazardous as heat needs to be applied from a fire source.

Figure 6.11: Illustrating Heat Shrink Tubing

2) Cold Shrink Tubing – This consists of a factory expanded, open ended rubber sleeve with a removable plastic core with holes in a spiral pattern. The core is removed by hand after the tube is placed over the connection and the sleeve then forms a waterproof clasp around the connection. This method eliminates the fire hazards related to heat shrink tubing. However, both of these methods are applicable for permanent connections. Any repair-work would cause the hazard of contamination of disconnection and reconnection.

Figure 6.12: Illustrating Cold Shrink Tubing

6.2.3 Closures

Next come first generation closures. These closures consist of a hard, hollow body that snaps around the connection and latches shut [13]. A sealing gel around the edges forms an effective moisture barrier surrounding the connection. The closures are easy to install without tools. Typically, a person can install one in a minute or less. In figure 6.13, a first generation closure is depicted.

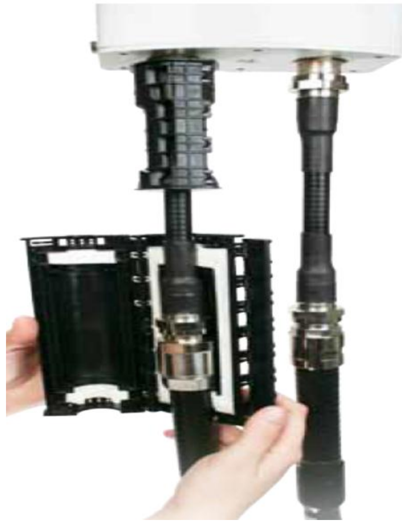


Figure 6.13: First Generation Closure [11]

At present the second generation closure are developed to meet the requirements of MIMO or multiband antenna configurations. With all the features of earlier closures-easy and faster to install with no tools requirement and reusable-it is more suitable for congested connections.

New connection developments are still on progress by various companies. For example, 3M™ Slim Lock Closure contains a highly compliant sealing gel inside that conforms to the entire connection rather than a perimeter seal, displacing air so that in the absence of air, condensation cannot occur, and the connection is further protected from corrosive moisture [13].

Figure 6.14: Second Generation 3M Slim Lock Closure [11]

6.2.4 PIM Testing

The PIM distortion is a rather insidious problem which can never be fully eliminated. The solution therefore is to minimize it by quality constructions and maintenance. Inspection and cleaning is required. Proper torque is important because the seals and interface areas are designed for this pressure.

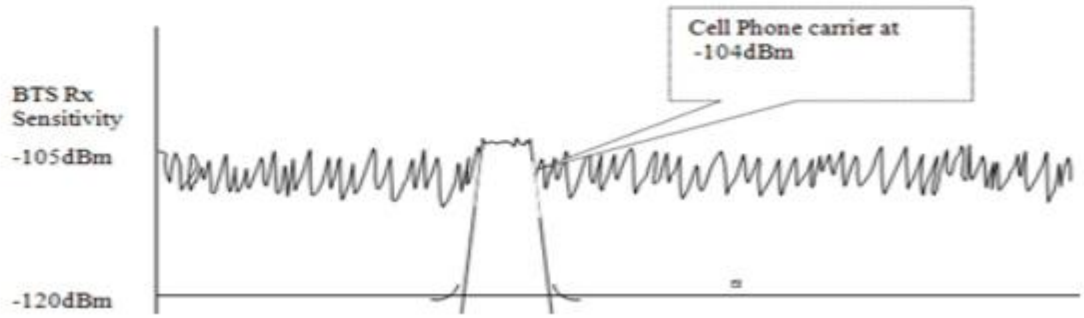


Figure 6.15: An Example of an Operator Needing to Keep PIM Signals below -106 dBm Since the Base Station (BTS) Rx Sensitivity is at - 105 dBm [42]

PIM testers or analyzers are sophisticated forms of test equipment. While a PIM test system can be assembled from signal generators and a spectrum analyzer together with a few other components, specialized PIM testers are often needed because testing is undertaken in situations such as cellular base station sites, etc.

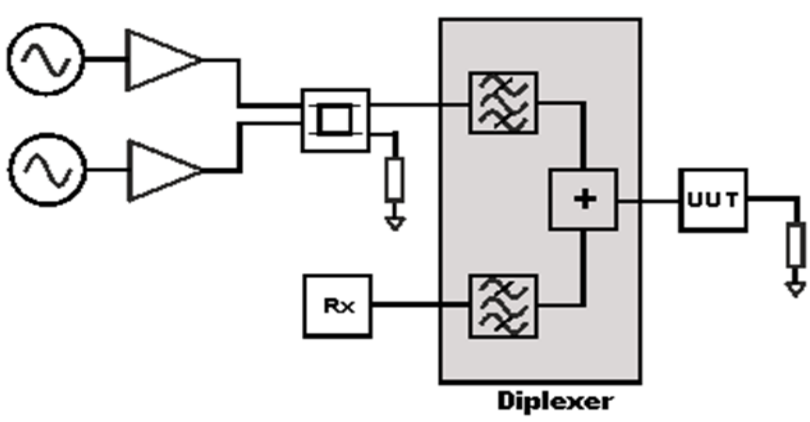


Figure 6.16: Basic Block Diagram of PIM Testers [41]

The block diagram shows a typical passive intermodulation test system. In the PIM tester two signals at the relevant frequencies are generated and then amplified to ensure that they are of a sufficiently high level for the test.

The signals are combined - in many testers an RF isolator may be used to prevent reverse RF power from the combiner entering the signal generator and causing spurious intermodulation products in the signal generator output that would alter the readings.

The two signals from the signal generators simulating the transmitted signals are then applied to a diplexer within the PIM tester. This only allows signals through from the transmitter in the transmit band to the unit or component under test, e.g. a feeder, feeder assembly, etc. The item under test is terminated in a matched load - typically 50 Ω to ensure a lifelike simulation [41].

Any PIM spurious signals generated within the receive band will be able to return through the diplexer and be routed through to the receiver / detector where they can be detected and their levels and frequencies noted. The frequencies of the PIM signals will be known because they are related to the two original frequencies of the signal generator frequencies, f1 and f2 as $n \cdot f1 \pm m \cdot f2$ [41].

Different companies such as Communication Components Inc. (CCI) and Antrisu are providing PIM testers [42]. PIM testing is run by the companies to identify whether it is in desirable range. Acceptable range is decided by the owners. Typical PIM guidelines for antenna systems are between -150 dBc and -170 dBc using a 2 x 20 watt PIM tester. This essentially equates to a maximum PIM level of -107 dBm [14].

6.3 Fiber Optic Connector

Poor connectivity or dirty connectors are one of the leading reasons for troubleshooting in optical networks and fiber performance degradation. Enough signal loss and back reflection can be created by microscopic particles of dirt. Improperly mated or contaminated fiber optic connectors prevent signal delivery and impact the quality of service (QoS).

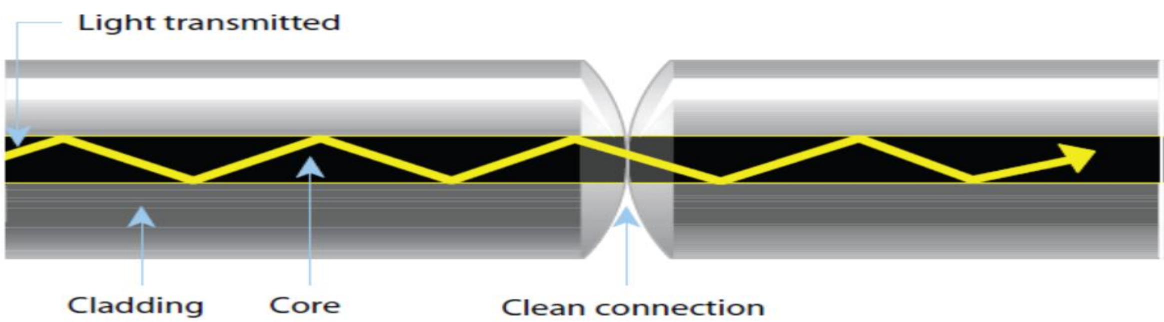


Figure 6.17: A Clean Connection [44]

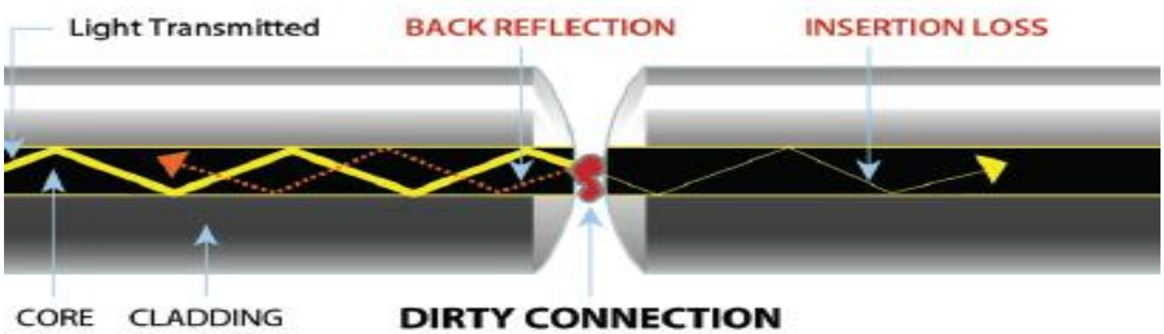


Figure 6.18: A Dirty Connection [44]

6.3.1 Development of Various Connectors

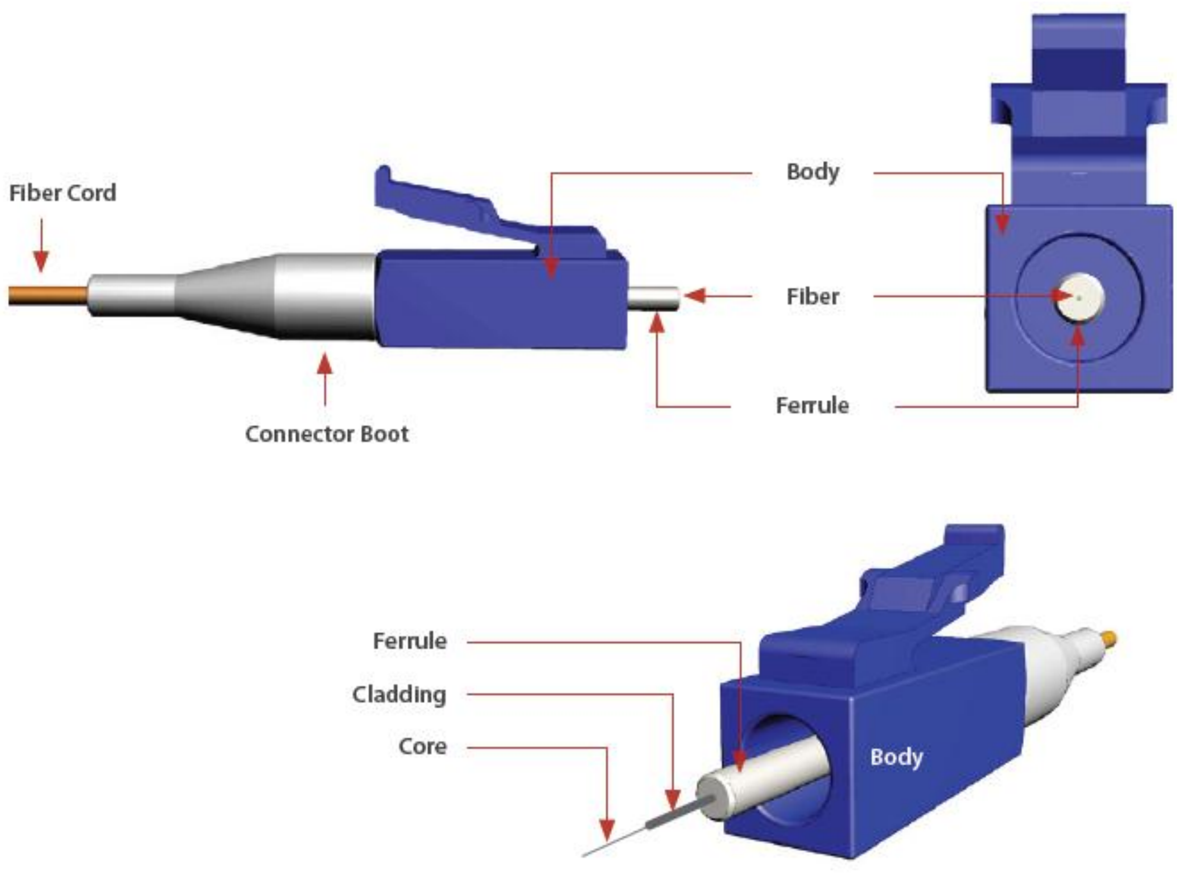
Three basic principles that that are very important for efficient connections are:

1. Perfect core alignment
2. Physical contact
3. Pristine connector interface

Most of the problems regarding core and physical contact have been overcome by technological advancement. What is still a problem is to have a pristine connection. Depending on various uses fiber connectors have been developed. The following show the general components of the fiber connectors [15].

Body- This keeps the ferrule in proper position and uses a "latch and key" mechanism that aligns the fiber and prevents rotation of ferrules of two mated connectors.

Ferrule- This is a thin cylinder where fiber is mounted and acts as the fiber alignment mechanism; the end of the fiber is located at the end of the ferrule which is referred to as the end face. The overall diameter of the ferrule depends on the connector type. There are usually two ferrule connector types used: 2.5 mm and 1.25 mm diameter.



.**Figure 6.19:** General Components of Fiber Connectors [15]

Cladding- This is a glass layer surrounding the fiber core that prevents the signal from escaping (125 micrometer for single connectors).

Core- This is the critical center layer of the fiber; the conduit that light passes through (8-10micrometer diameter for single mode diameters).

A good connector design has:

- Low insertion loss
- High return loss (low amounts of reflection at the interface)
- Ease of installation
- Low cost
- Reliability
- Low environmental sensitivity
- Ease of use

Some of the more popular types of connectors available in the market today are listed below [16]:

- ST connector-a type using slotted bayonet.
  2.5mm ferrule and mostly used in multimode.
- SC connector-a push/pull or snap in type.
  2.5mm ferrule and used in datacom and telecom.
- FC connector-a slotted screw on type.
  2.5mm ferrule and used in datacom, telecom, measurement and single mode lasers.
- LC connector- a type with small positive latching with duplex configuration.
  1.25mm ferrule and used in high density connections.
- MT-RJ connectors-duplex connector and using pin alignment and has both male and female versions.2.45x4.44 ferrule and used in duplex mode connections.
- Opti Jack-neat rugged duplex connector type that uses two ST-type ferrules in package the size of RJ-45.
- VF45- duplex connector type with no ferrules and aligns fibers in a V-groove like a splice. Used in datacom.
- MU-looks like miniature SC; 1.25mm ferrule and used in Japan.

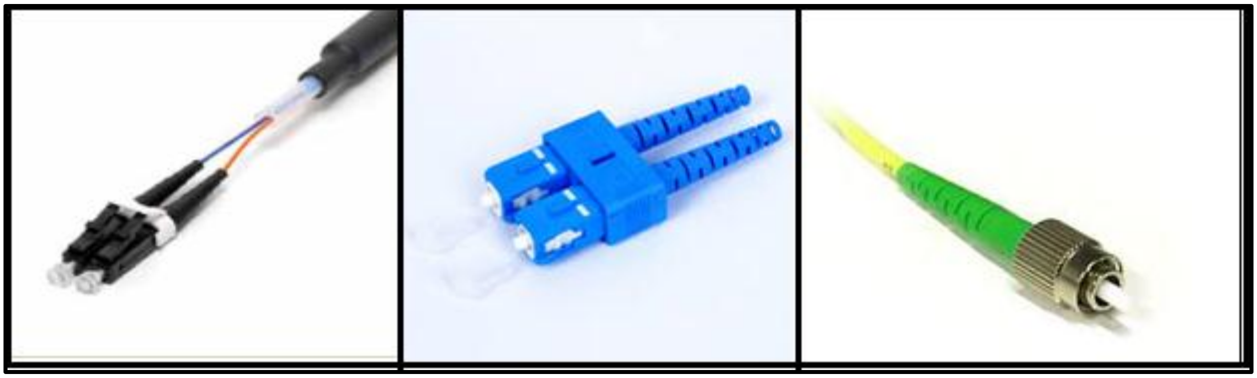


Figure 6.20: Connectors: Duplex LC Connector (left), Duplex SC Connector (middle), and FC Connector (right)

Fiber optic connectors can be both pre-terminated in the factory and field terminated during installation. Pre-terminated ones however have the disadvantages of high expense, delay and so on when required cable length is not there, rejected cable when connectors are damaged and storage cost when the installers have various cable lengths. Hence, field terminated connectors are more preferable nowadays since they have higher efficiency in terms of easiness in installation with less tools and training.

6.3.2 Connector Cleanings

Testing before connections is a common practice now. Companies have developed various tools for efficient installation. The diagram below shows the basic cycle that an installer undergoes before making connections.

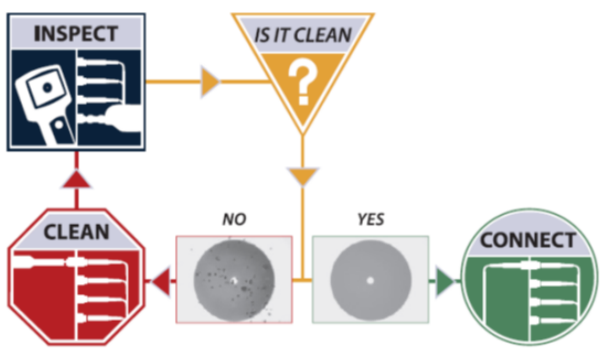


Figure 6.21: Basic Cycle before Ideal Connection Making [43]

Nowadays, the fiber optic connectors have dust caps as protection. It is required to keep the dust caps in place until the connection is actually made. Also some companies like JDSU have test solutions, as shown in following figure, using which whether or not connectors are contaminated can be tested as well as cleaned before installation [15].

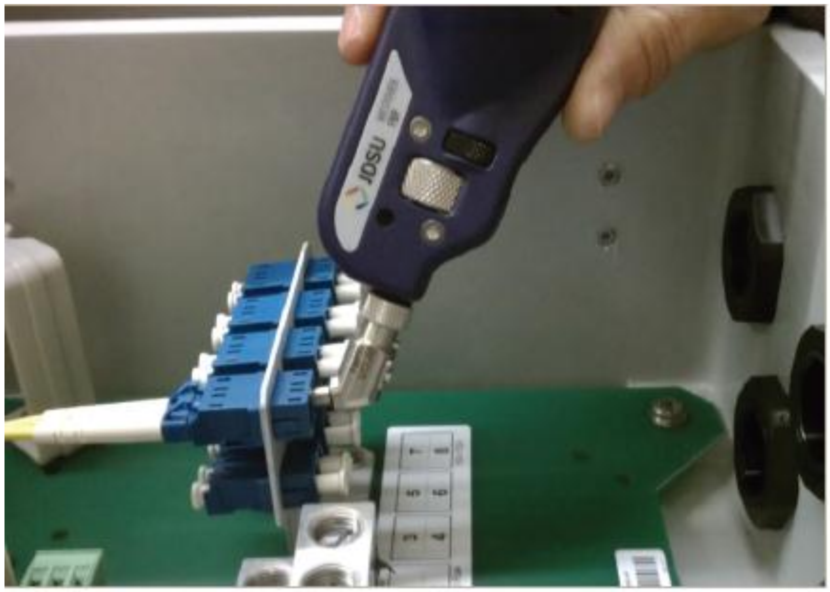


Figure 6.22: Connectors Inspected Before Installation [44]

From above it can be clearly understood how important role the connectors can play in this whole FTTA communication. Next we talked about human labour skill - another issue related to FTTA.

6.4 Lack of Human Labour Skill and Safety

The main problem with RF installers is their skill. Current labor-hands are familiar with handling thick, heavy robust cables. They not experienced in handling sensitive fiber cables and installing reliable, robust services. While pulling or hauling the cable trunks or feeders, fiber is more susceptible to damage from crimping, bending or straining; this can significantly reduce the fiber performance (See figure below). Poor fiber performance can be the result of macrobending, for example, which is the physical bends in the fiber that exceeds the fiber bend radius limitations of more than 2mm. Hence, skill is very important.

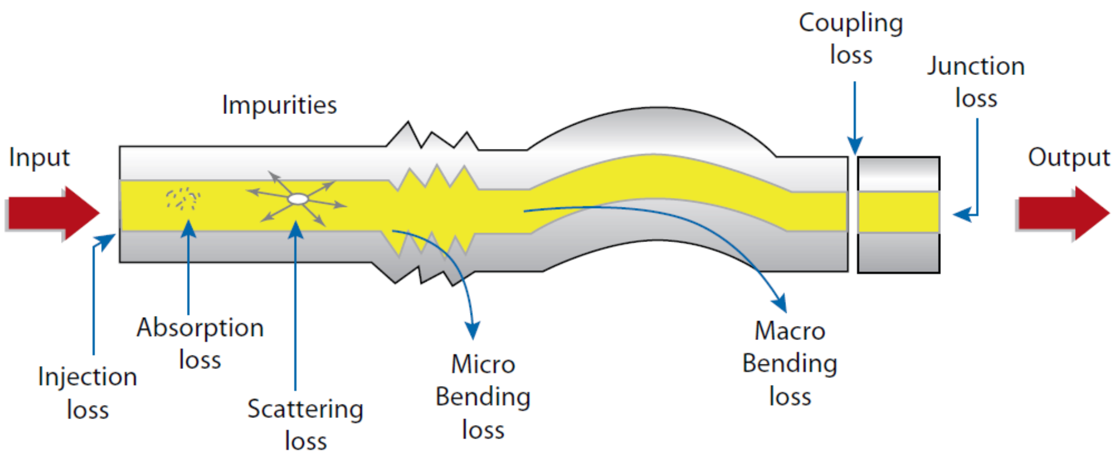


Figure 6.23: Showing Various Attetuaniton Effects Including Macrobending Caused by Poor Installation [15]

Again, many of the installers are not proficient yet to work with the RRH or other components from such a height above the ground. In traditional cell sites the base station is at the ground level where the repair work is easier to perform. However, in FTTA technology RRH is the major component which is at a great height above the ground in the cell tower. This does not only create problem for installation but also require more frequent maintenance and skill by the labour due to adverse weather conditions and safety features.

6.4.1 Labour Training and Safety Measures

It is evident that technicians who are well-informed and skilled in fiber cable installation, testing and repairing are needed by mobile operators. Since this is a comparative new technology, the advancement and improvement tools still required for installation need much more extensive research. As solution, proper training to the worker, safety equipment and improved tools for repair and installation process should be provided. Already we have seen from previous discussions that companies such as JDSU, 3M and so on have come up with various tools for more efficient installations. Further research is required along with improved training of the labor. Enhanced safety equipment is also necessary. Adequate treatment facilities in case of emergency should be available at the site for any undesirable situation.

Thus, different analyses of the challenges have been shown. We have tried to come up with the optimum solutions from the existing ones and also gave some suggestions. However, scope for further research for each section especially the tools and labour skill is many and need further improvements in some cases. Elimination or reduction of these implementation issues will further enhance the FTTA benefits in real life.

Chapter 7

Conclusion

To deal with the rapid increase of number of subscribers with the limited bandwidth of wireless technology, network engineers have had to come up with some idea that will provide the required bandwidth as well as prevail to the mobility factor. Optical fiber provides us with the benefit of enormous bandwidth; however, it has some constraints regarding the mobility factors. Hence, such integration has to occur where the mobility benefit from wireless and the enormous bandwidth of optical domain can be used to combat this particular issue. Fiber to the antenna (FTTA) is an innovative method of such integration.

During our discussion in this paper, we have proposed an architecture of FTTA that will provide better performance as per required. RRH has been introduced in this structure, which is one of the most important key components in this architecture. RRH basically works as a two way converter (electrical to optical and optical to electrical) along with as a power amplifier of the signal and high frequency modulator. For effective use, we take the fiber optic up to RRH from the Radio Base Station from where it converts to electrical signal and transmitted afterwards through antenna. Same procedure is followed during signal reception but only backwards. Now the research is going on to introduce active antenna in this whole system and get rid of RRH, so that we can take optical fiber directly up to the antenna and increase the efficiency of the system.

FTTA advancement has not only contributed to the speed, mobility and bandwidth issues; it also has provided us with distinctive advantages (compared to the conventional structure) in the whole communication system. Advancement of FTTA offers us with the opportunity of wide range coverage and increased capacity with the help of advanced antenna techniques like MIMO and RET while the installation time gets reduced. The quality of the attenuated signal has upgraded because of using the fiber optic cable (replacing the coax cable) whereas the use of hybrid cables has become handy which incorporates powercables and optical fiber elements in a single cable cross-section. Then again the reduction of RF amplifiers eliminates the costly cooling procedures used earlier and also rental costs of telecom facilities and antenna sites reduce proving this architecture as a very cost effective one. Furthermore, FTTA architecture approves the use of DAS and new upgrades could be done easily proving it to be much better than the conventional system.

While in implementation phase in 3G and 4G communications, the field engineers have faced various issues which they primarily intended to take care with the trial and error method. But this process actually proved a bit costly as equipment had to be tested and replaced a lot of times. New equipment was also being developed but one type of equipment could not be the best fit for all situations. In this thesis we have tried to serve up with the best feasible solutions for different situations. Here we have hashed out the most alarming issues regarding the implementation of FTTA i.e. Surge, Water and Moisture, Connecters, Human skills. As it is a high overhead structure, weather has an immense effect on the implementation. The high transient voltage and current create a massive problem and we have discussed about several SPDs (MOV, GDT, and Varistors) for defending this issue. We have also presented some combinations of the SPDs those best fit the versatile situations. Then again there are issues regarding water and moisture, human skills for which we suggested some significant tools and training facilities. Moreover there is the issue of connectors as the optic fiber is pretty sensitive and we have provided suggestions like Second generation slim lock closure concerning this issue.

In Bangladesh, we could not find many implementation of this architecture. It would have been better if we could have some real life experience of all these. Then maybe we could have suggested more new ideas and solutions for the problems. Nevertheless, recently in 2013 the telecommunication sytem has been upgraded to 3G. As our suggested FTTA architecture is applicable for 3G, 4G and next generation communication systems, we have come to know about the fact that at some tower sites of GrameenPhone and Robi, RRHs are being installed; however, these are not implemented and activated throughout the whole country Real soon these RRH will come to task for experimental use. However, our thesis can be considered as information storage regarding FTTA system for anyone. We have tried to sum up all the scattered information required to implement this new architecture. Our analysis in this paper can be useful in planning a better implementation process of FTTA without having major issues in the near future and help to develop further research in this promising sector.

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Glossary of Abbreviation

1G - First Generation

2G - Second Generation

3G - Third Generation

4G - Fourth Generation

AISG - Antenna Interface Standard Group

AMPS - Advanced Mobile Phone System

APD - Avalanche Photo Diode

AuC - Authentication Center

BBU - Base Band Unit

BRS - Base Receiving Station

BSC - Base Station Controller

BSS - Base Station Subsystem

BTS - Base Transceiver Station

CBS - Central Base Station

CDMA - Code Division Multiple Access

DAS - Distributive Antenna System

EFT - Electrical Fast Transient

EIR - Equipment Identity Register

EMI - Electromagnetic Interference

FCC - Forward Control Channels

FDD - Frequency Division Duplexing

FDMA - Frequency Division Multiple Access

FTTA - Fiber to the Antenna

FTTD - Fiber to the Desk

FTTH - Fiber to the Home

FTTP - Fiber to the Premises

FVC - Forward Voice Channels

GDT - Gas Discharge Tubes

GPRS - General Packet Radio Service

GSM - Global Systems for Mobile communications

HLR - Home Location Register

IF - Intermediate Frequency

IMSI - International Mobile Subscriber Identity

LAI - Location Area Identity

LAN - Local Access Network

LD - Laser Diode

LEC - Local Exchange Carriers

LED - Light-Emitting Diode

LO - Local Oscillator

LPZ - Lightning Protection Zones

LTE - Long Term Evolution

MAHO - Mobile-Assisted Handoff

MIMO - Multiple-Input and Multiple-Output

MOV - Metal Oxide Varistor

MS - Mobile Equipment

MSC - Mobile Switching Center

MSISDN - International Mobile Subscriber ISDN Number

MSRN - Mobile Station Roaming Number

OMC - Operation and Maintenance Center

PIM - Passive Inter-modulation

PIN - Positive-Intrinsic-Negative

POE – Power over Ethernet

POTS - Plain Old Telephone Service

PSTN - Public Switched Telephone Network

QoS - Quality of Service

RAT - Radio Access Technologies

RBS - Radio Base Station

RCC - Reverse Control Channels

RET - Remote Electrical Tilt

RFI - Radio-Frequency Interference

RF - Radio-Frequency

RoF - Radio over Fiber

RRH - Remote Radio Head

RRU - Remote Radio Unit

RVC - Reverse Voice Channels

SCM - Subcarrier Multiplexing

SFP - Small Form-factor Pluggable

SIM - Subscriber Identity Module

SMS - Short Message Service

SPD - Surge Protection Devices

STC - Standard Telephones and Cables

TCO - Thermal Cut-offs

TDD - Time Division Duplexing

TDMA - Time Division Multiple Access

TMA - Tower Mounted Amplifier

TMSI - Temporary Mobile Subscriber Identity

VDR - Voltage-Dependent Resistor

VLR - Visitor Location Register

WDM - Wavelength-Division Multiplexing

WWWW – World Wide Wireless Web

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