CONGESTION CONTROL OF WIRELESS RADIO ACCESS NETWORK TRAFFIC USING RADIO OVER FIBER

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December 2013

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DECLARATION

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

Signature of Supervisor

Date: ……………………………

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Date: ……………………………

ACKNOWLEDGEMENTS

We are very much grateful to our thesis advisor Dr. Mohammed Zamshed Ali for guiding us in a right way throughout our thesis work. We were fortunate enough to be his student. He was very cooperative to us. He supported us every single moments during the thesis paper and gave us the knowledge superbly we needed for our research paper. We worked hard together to bring something new in the communication system and hopefully our work will be appreciated by our honorable advisor.

ABSTRACT

With the emergence of new communication methods and wireless generations we need new technique to battle the communication drawbacks. One of the most common communication drawbacks is Wireless Traffic Congestion. It happens due to excess population in a cell zone. This is a problem present in all specks of communication. To combat this drawback we went with RoF. RoF is Radio over Fiber. It uses Integrated Wireless and Optical Networks.

For this research paper we studied on the congestion issues, existing wireless network and optical networks. After studying we came up with a communication stricter which will be immune to noise and distortion to a new level so that there is less call drops and calls blockades. On the next stage we studied on different materials on researches done on wireless congestion by different individuals and organizations. On the next stage we tried to propose a communication system based on RoF technology and wrote a paper on it. In the final stage we wrote our findings in the form of a thesis paper.

In the thesis the first part consists of descriptions about Wireless Network, Optical Network, Integrated Wireless and Optical Network and finally Radio over Fiber. In the next chapter we showed our contribution in the thesis. In this chapter we also showed our contribution with the help of mathematical expressions. In the next chapter we showed our findings with the help of simulation in MATLAB. In the concluding chapter we showed how our research will help the communication sector and the new research sectors stemming from this research.

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GLOSSARY OF ABBREVIATION

1G -First Generation

2G -Second Generation

3G -Third Generation

4G-Fourth Generation

ARQ- Automatic Repeat Request

BSS-Base Station Subsystem

BTS-Base Transceiver Station

BSC-Base Station Controller

BCF- Base Station controller Function

BCCH- Broadcast Control Channel

BSSAP CBS-Central Base Station

CNR-Carrier to Noise Ratio

CN-Core Network

DWDM- Dense Wavelength Division Multiplexing

DR-Dynamic Range

EMI-Electro Magnetic Interference

EDFA- Erbium Doped Fiber Amplifier

E-UTRA- Evolved Universal Terrestrial Radio Access

FDMA-Frequency Division Multiple Access

FTP-File Transfer Protocol

FBG- Fiber Bragg Gratings

GBPS-Giga Bit per Second

GSM- Global Positioning System

GMSK- Gaussian Minimum-Shift Keying

GERAN-GSM EDGE Radio Access Network

GRAN-GSM Radio Access Network
HSPA-High Speed Packet Access
HSDPA-High Speed Digital Packet Access
HTTP- Hypertext Transfer Protocol
ITS- Intelligent Transport Systems
IVC-I intelligent Vehicle Communication
ITU- International Telecommunication Union
IMT-Advanced- International Mobile Telecommunications Advanced
IP-Internet Protocol
IM-DD- Intensity Modulation and Direct Detection
KBPS-Kilo Bit per Second
LTE- Long term evolution
MS-Mobile Station
MBPS-Mega Bit per Second
MSC-Mobile Switching Center
MMF-multi-mode fiber
MZI-Mech Zehnder Interferometer
NMS-Network Management System
NF-Noise Figure
OFDMA- Frequency-domain statistical multiplexing example
O&M-Operation and Maintenance
OSNR-Optical SNR
OTDM- Optical Time Division Multiplexing
OSS- Operation Support Subsystem
PSTN-Public Switched Telephone Network
PSK-Phase Shift Keying
P2P-Peer to Peer
PCU- Packet Control Unit
QoS-Quality of Service
RAN-Radio Access Network
RF-Radio Frequency

RPE-LTP- Regular Pulse Excited-Long Term Prediction

RNC-Radio Network Controller

RLP-Radio Ling Protocol

RNS- Radio Network Subsystem

RIN-Relative Intensity Noise

RBS-Radio Base Station

RoF-Radio over Fiber

SMS-Short Messaging Service

SNR- signal to noise

SGSN-Serving GPRS Support Node

SSH- Secure Shell

SMF-single-mode fiber

SCM-Sub-Carrier Multiplexing

TDM-Time Division Multiplexing

TRX-Transceiver

TDMA-Time Division Multiple Access

TRAU- Transcoder and Rate Adaptation Unit

UE-User Equipment

UTRAN- Universal Terrestrial Radio Access Network

UV-Ultra Violet

VPN-Virtual Public Network

Chapter One

INTRODUCTION

One of the most challenging fields in modern Electrical engineering is Communication sector. It is considered challenging for the fact that communication is needed on daily basis. Every day the users of the communication resources are increasing. Now these communication resources are merely some equipment's and frequency bandwidth. The equipment's used in communication sector range from Mobile set, Radio Base Station (RBS) antenna, high powered computers, filtering devices, signal converters etc. This equipment's are very expensive. These is a drawback in a way that these equipment's cannot be repaired be repaired or changed without experiencing communication irregularities and huge financial losses. Other resource is frequencies which are very constrained.

In communication sector a service provider is provided with a fixed allocation of frequency bandwidth and equipment's which are bought by the service provider. Now with these very limited and expensive resources a service provider has to serve their customer with performance and communication quality so that they can stay and profit in the business. These service providers deal with huge number of user/customers on a daily basis. These service providers are getting millions of new customers every day. Adding to this existing pressure is the emergence of new generations of mobile service which are called 3G, 3.5G, 4G and 5G etc. G here denotes generation. Each new generation is entitled to provide users with better call clarity, higher data speed and better service quality.

With the emergence of new generation of mobile services the service providers have to upgrade their systems for every new generation. This will mean that they have to change their equipment's every time. This will be economically inefficient for the service providers. It also may be possible that they may compensate service for profit. For these very reasons it is very important that there exists a mobile communication model which will remain universal for the upcoming 3G, 4G, 5G. That will make it easier for the service providers from one generation to another.

In our thesis we focused on this very problem. While studying we discovered that one of the major problems a service provider will face regardless of mobile generations is call traffic congestion. We hoped to find an answer to that. In this chapter we are going to talk about the modern telecommunication system and how they work. Integrated optical and wireless networking and how it may help us. Congestion issues and how it is hampering the communication sector. In the end our resolution to the problem and how we organized the thesis.

1.1 Modern Telecommunication

1.1.1 Evaluation up to 4G wireless networks

1G is the first generation cellular network that existed in 1980s. It transfer data (only voice) in analog wave, it has limitation because there are no encryption, the sound quality is poor and the speed of transfer is only at 9.6kbps.

2G is the second one, improved by introducing the concept of digital modulation, which means converting the voice (only) into digital code (in your phone) and then into analog signals (imagine that it flees in the air). Being digital, they overcame some of the limitations of 1G, such as it omits the radio power from handsets making life healthier, and it has enhanced privacy.

2.5G is a transition of 2G and 3G. In 2.5G, the most popular services like SMS (short messaging service), GPRS, EDGE, High Speed Circuit switched data, and more had been introduced.

3G is the current generation of mobile telecommunication standards. It allows simultaneous use of speech and data services and offers data rates of up to 2 Mbps, which provide services like video calls, mobile TV, mobile Internet and downloading.

There are a bunch of technologies that fall under 3G, like WCDMA, EV-DO, and HSPA and others.

Pre-4G technologies such as mobile Wi-Max and Long term evolution (LTE) have been on the market since 2006 and 2009 respectively, and are often branded as 4G. The current versions of these technologies did not fulfill the original ITU-R requirements of data rates approximately up to 1Gbit/s for 4G systems. Marketing materials use 4G as a description for LTE and Mobile-Wi-Max in their current forms.

In Telecommunications, 4G is the fourth generation of cellular wireless standards. It is a successor to the 3G and 2G families of standards. In 2008, the ITU-R organization specified the IMT-Advanced (International Mobile Telecommunications Advanced) requirements for 4G standards, setting peak speed requirements for 4G service at 100Mbit/s for high mobility communication (such as from trains and cars) and 1Gbit/s for low mobility communication (such as pedestrians and stationary users).

A 4G system is expected to provide a comprehensive and secure all-IP based mobile broadband solution to laptop computer, wireless modems, smart phones, and other mobile devices. Facilities such as ultra-broadband Internet access, IP telephony, gaming services, and streamed multimedia may be provided to users.[9][11]

1.1.2 The key difference between 3G and 4G

To understand the difference between 3G and 4G network we can consider some points to understand.

Key differentiating factors-

1. Speed
2. Network Structure
3. Switching Technology
4. Data rate

Speed

The first point of comparison between the 3G and the 4G network is the speed. The speed of 3G is dependent on the network implementation. The current 4G transmission speed is 4 times faster than the 3G network. The current 4G network can ideally be called advanced 3G. Actual 4G network will be about 10 times faster, than the current 3G network. If 3G in GSM can be enhanced, it will be equal to that of the 4G speed on a CDMA network.[10][11]

Network structure

The second point of comparison between the 3G and the 4G network is the network structure. With the help of 3G, the cell phone user was able to use speech and data services simultaneously, at higher data rates than 2G. The 4G data rates are expected to be higher than the current ones provided by 3G. 4G is also expected to give its users gaming, multimedia, and Internet access support.[10][11]

Switching technology

The third point of comparison is the switching technology used by 3Gand 4G.3G technology uses both packet switching and circuit switching network.4G uses the packet switching infrastructure. There is no difference in BW between the 3G and 4G network, both 3G and 4G have a bandwidth of 5 - 20 MHz All the calls in 4G are IP telephony calls, which is not the case with a 3G network.[10][11]

Data rate

Data rate is the fourth comparison. Data rate makes the big difference between the 3G and 4G.The data rate has been set at 100 Mbps in moving vehicles and 1 GB in stationary and walking users in 4G. The data rates specified by International

Telecommunication Union (ITU) for 3G are 2 Mbps for stationary or walking users, while it is set at 384 kbps in a moving vehicle. [10][11]

Advantages of 3G and 4G network

3G Network

1. Higher bit rate (than 2G, 2.5G, 2.75G)
2. Free of static and background noise
3. Mobile TV
4. 3G networks offer greater security than their 2G predecessors
5. Video Conferencing
6. Global Positioning System (GSM)

4G Network

1. Turbo error correcting codes to minimize the required SNR (signal to noise) at the receiver side
2. Channel dependent scheduling to use the time varying channel
3. Adaptive modulation
4. Mobile IP, utilized for mobility
5. IP based Femto-cells
6. Frequency-domain statistical multiplexing example (OFDMA) or (single-carrier FDMA)

1.2 Integrated Optical and Wireless Communications

The existing telecommunication system is completely based on Wireless communication system. Wireless communication is communicating through wireless signals. In this system the massage signal is first modulated by very high frequency. The modulated signal now has very high frequency. High frequency signals have very high penetrability. This modulated signal is then transferred and received through antennas. The transferring and receiving of massage signals between antenna and mobile is done in wireless domain. Although the call processing, modulation, demodulation, filtering etch are done in electrical domain.

On the other hand there is Optical communication. In this system based on the premise that optical signals can be transferred from one place to another through an optical fiber in the speed of light. In this system the massage signal is modulated as an optical signal by the help of a converter. After the conversion to optical signal, the signal is passed through optical fibers. In the optical fiber the optical signal will travel at the speed of light(3×$10^8 \mathrm{m/s}^2$).

The biggest advantage of optical communication is the fact that the data is immune from Electro-Magnetic Interference (EMI). Adding to this does the fact that the data is transferred faster than any other communications exist. Optical system is the speed the data is processed. In wireless communication the processing is done in electronic medium which has the speed of 10^{-9}s and in optical medium the data is optically which has the speed of 10^{-15}s. thus making the data processing much faster than the average then wireless communication. Although this system is really hard and expensive to install. On the contrary, wireless communication is preexisting and less complicated. It is prone to noise but this noise can be reduced to a certain level.

Modern communication engineers are now researching on combining the advantages of wireless communication and optical communication. This combination is called Integrated Wireless and Optical Communication. In this system all the call processing and filtering is done in optical medium and call transferring a receiving is done in wireless medium. The signals are transferred from optical to electrical and electrical to optical signals with the use of optical to electrical converter. This system is also called Radio over Fiber (RoF).The goal is to transfer radio waves through fiber optics.

1.3 Congestion Issues

In the modern era congestion issue is a major concern. To be more precise it is a concern which has been to the mind of communication engineers from the beginning of communication era.

Mobile communication is done by dividing the total service area of a network provider into several cell zones. All the cell zones are provided network using Radio Access Networking (RAN). RAN has the purpose of not only providing network to the users of the cell zone but also keep the network provider updated about the cell zone call traffic. RAN has Antenna and Radio Base Station (RBS). Antenna is used for transmitting and receiving radio wave signals. Radio base station handles call processing, filtering and updating the Mobile Base Station (MBS) about that cell zones user activates. Let us assume, in a cell zone might have thousands of active users in the area. Now if an active cell user is trying to call someone or requesting an internet service from the service provider. As the RBS is processing a service request, it is encountering some amount of noise.

As we assumed before, there might be thousands of active users in a cell zone. If two (2) active users are requesting any service then the noise gets increased by two folds. If there are ten (10) users requesting service then the noise is ten folds. Likewise the noise will increase 100 times with 100 user requests. If the number of requesting users increases in this way, there will come a time when the RBS will be dealing with so much noise that it will not be able to provide any new users with quality network. This situation will result in call drops and call blocking or delaying or canceling of the requesting internet service.

Above problems which are caused by cell zone being over populated by active users or RBS getting over crowded by user requests is call Congestion Issues. An RNS can provide efficiently a defined number of active users otherwise the network quality will drop.

Congestion problem is caused partly because the MBS does not have real time control over the RBS. It cannot know about the number of active users in a cell zone in real time. If MBS had this information then it might be able to do something to reduce the noise problem. Our concern is to device a solution so that congestion problem can be solved. In the next section we give a brief discussion about our proposal in the problem in hand.

1.4 Congestion Control using Radio over Fiber (RoF)

In the above section it is explained how congestion issues are creating performance problems for the service providers. Our thesis is dedicated to solving this very problem.

As stated before, congestion issues are caused due to MBS not having real time access to the RBS. In the modern telecommunication system an RBS is only responsible for the cell zone itself. It does call processing and filtering. RBS as to report to the MBS about the frequency allocation. As an RBS is reporting to the CBS is getting the congestion report of one RBS. The CBS is not getting the complete picture of a locality.

In our thesis we proposed the possibility of several RBSs overlapped in such a way that a user might get strong service signals from more than one neighboring cell zone RBS's. We proposed that 4 or 5 neighboring RBSs will be monitored by a Central Base Station (CBS). CBS will be reporting to the MBS.

As all the RBS under the CBS are overlapping each other, the congestion report sent by the RBS's will have a better picture of congestion to the CBS. Based on this reports CBS and MBS will have real time information's about the cell zone.

Let us assume a situation; there are several RBS's monitored by a CBS. In one of those RBS's there is an active user. This active user is getting strong service signals from neighboring RBSs. This thing is possible due to overlapping cell zones. Now let us assume that, the active user is in such a cell zone where the RBS is over crowded with service requests. As stated before when a RBS is crowded with service requests, there will be noise strong enough to make acceptance to new service requests very tough for the RBS. In conventional scenarios the service request will be dropped or blocked.

In our proposed model the user service request will be rerouted to a neighboring RBS with strong service signal and less congestion rate. If the congestion is less, there is less noise, less noise means less dropping and blocking. For this very reason we tried to introduce a threshold value below which the RBS will have to drop service request due to congestion.

In chapter 5 our contributions and analysis has been discussed broadly. We also submitted our findings in the form of a paper in IEEE ICC Conference, Sydney 2014.

1.5 Thesis Organization

As it started with the introduction of the thesis, in the introduction we explained our thesis briefly. We laid the ground work for other chapters to come to explain. The following chapters are Overview of Wireless Radio Access Networks, Overview of Optical Fiber Communications, Radio over Fiber Networks, Congestion Control of RAN traffic using Radio over Fiber Networks, Simulations and Results and Conclusion.

In the next chapter titled Overview of Wireless Radio Access Network the inner workings of wireless communication is explained detail. Also the existing wireless communication system and its problems are mentioned.

The following chapter is titled Overview of Optical Fiber Network. In this chapter we explained how optical network works and its benefit over wireless networking.

In the chapter named Radio over Fiber Networks we explained how RoF is the new technology in the horizon and how it works. We explained how integrated wireless and optical network works. We also explained what features of RoF we want to use.

In the chapter titled Congestion Control of RAN traffic using Radio over Fiber Networks is about our findings in the problem. Here we gave a mathematical explanation to the problem solution. Our thesis objective was to produce a fresh idea on communication and in this chapter we show our ideas and contribution in our thesis.

The next chapter is simulation and results which contains the simulations of our findings and the results we found. It also contains our assumptions and parameters set by us. We also simulated if our proposed model will perform with excellence or not. All the simulations are done on MATLAB.

Lastly there is conclusion. In this chapter we give an end to the thesis. We briefly explain our findings and contribution. We also give what further research could be done in the future and what could be done to enhance the research and make it more enlightening.

In the following chapter we will be talking about wireless communication. The inner working process of wireless communication and how it exists in the world right now. The benefits and drawbacks of wireless communication. Mostly the congestion issue will be explained here.

Chapter Two

OVERVIEW OF WIRELESS RADIO ACCESS NETWORK

Radio Access Network is the ground rooted infrastructure that is used to deliver wireless communication services, including high speed mobile communication. It is the RF (Radio Frequency) based portion of the network that is worked as core network for mobile terminal devices of PSTN (Public Switched Telephone Network).[1]

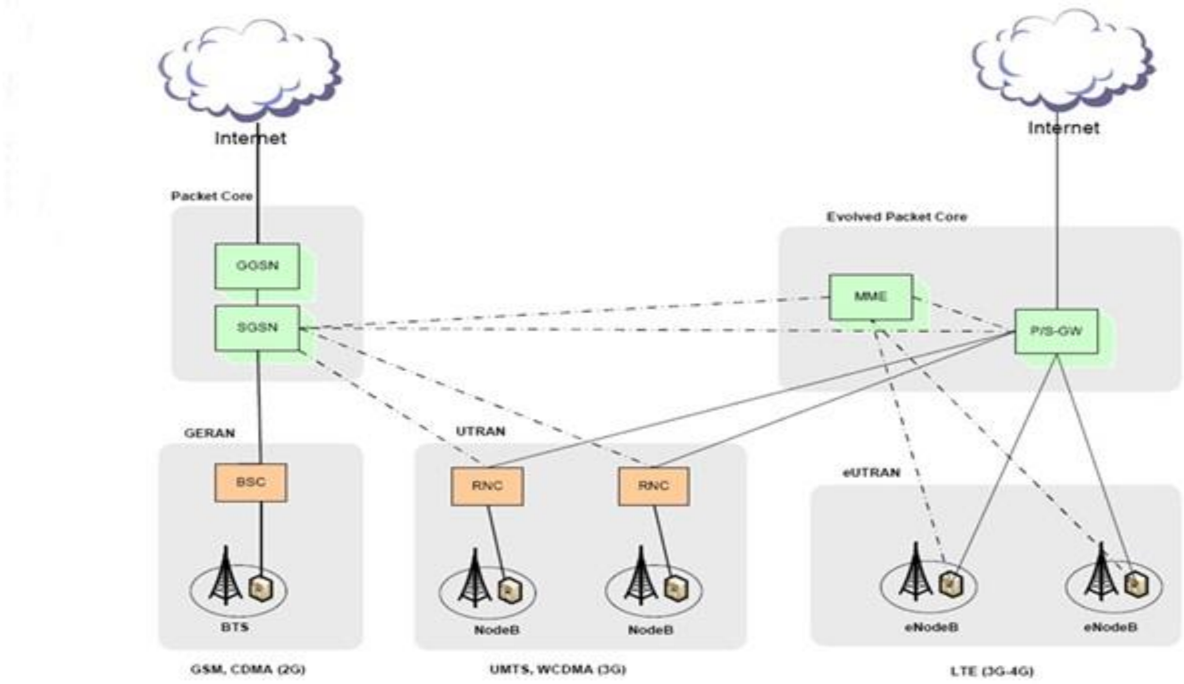

Figure 2.1: Wireless Network Overview.

2.1 Radio Access Network

Radio Access Network(RAN) referring to the wireless RF-based portion of a network providing access from a mobile terminal device (transmitter/receiver) to the core, or backbone network of the radio service provider and ultimately to the public switched telephone network (PSTN) or the Internet or other IP-based network. A RAN comprises a base station, a controller, and the radio links between them. A RAN may be in the form of a 2G TDM (Time Division Multiplexing)-based cellular service (e.g., D-AMPS or GSM), a 3G cellular service (e.g., EDGE, GPRS, and UMTS), or other licensed and unlicensed services (e.g., WiMAX) [1][6]. RAN implements a radio access technology. Conceptually, it resides between a devices such as a mobile phone, a computer, or any remotely controlled machine and provides connection with its core network (CN). Depending on the standard, mobile phones and other wireless connected devices are varyingly known as user equipment (UE), terminal equipment, mobile station (MS), etc. RAN functionality is typically provided by a silicon chip residing in both the core network as well as the user equipment [1][6].

2.2 Structures of RAN

2.2.1 Base station subsystem (BSS)

The base station subsystem (BSS) is the section of a traditional cellular telephone network which is responsible for handling traffic and signaling between a mobile phone and the network switching subsystem. The BSS carries out transcoding of speech channels, allocation of radio channels to mobile phones, paging, transmission and reception over the air interface and many other tasks related to the radio network [1][6].

2.2.1.1 Base transceiver station

The base transceiver station, or BTS, contains the equipment for transmitting and receiving radio signals (transceivers), antennas, and equipment for encrypting and decrypting communications with the base station controller (BSC). Typically a BTS for anything other than a Pico-cell will have several transceivers (TRXs) which allow it to serve several different frequencies and different sectors of the cell (in the case of sectorized base stations).

A BTS is controlled by a parent BSC via the "base station control function" (BCF). The BCF is implemented as a discrete unit or even incorporated in a TRX in compact base stations. The BCF provides an operations and maintenance (O&M) connection to the network management system (NMS), and manages operational states of each TRX, as well as software handling and alarm collection.

The functions of a BTS vary depending on the cellular technology used and the cellular telephone provider. There are vendors in which the BTS is a plain transceiver which receives information from the MS (mobile station) through the Um air interface and then converts it to a TDM (PCM) based interface, the ABIS interface, and sends it towards the BSC. There are vendors which build their BTSs so the information is preprocessed, target cell lists are generated and even intra cell handover (HO) can be fully handled. The advantage in this case is less loaded on the expensive ABIS interface.

The BTSs are equipped with radios that are able to modulate layer 1 of interface Um; for GSM 2G+ the modulation type is Gaussian minimum-shift keying (GMSK), while for EDGE-enabled networks it is GMSK and 8-PSK. This modulation is a kind of continuous-phase frequency shift keying. In GMSK, the signal to be modulated onto the carrier is first smoothed with a Gaussian low-pass filter prior to being fed to a frequency modulator, which greatly reduces the interference to neighboring channels (adjacent-channel interference).

Antenna combiners are implemented to use the same antenna for several TRXs (carriers), the more TRXs are combined the greater the combiner loss will be. Up to 8:1 combiners are found in micro and Pico cells only.

Frequency hopping is often used to increase overall BTS performance; this involves the rapid switching of voice traffic between TRXs in a sector. A hopping sequence is followed by the TRXs and handsets using the sector. Several hopping sequences are available, and the sequence in use for a particular cell is continually broadcast by that cell so that it is known to the handsets.

A TRX transmits and receives according to the GSM standards, which specify eight TDMA timeslots per radio frequency. A TRX may lose some of this capacity as some information is required to be broadcast to handsets in the area that the BTS serves. This information allows the handsets to identify the network and gain access to it. This signaling makes use of a channel known as the Broadcast Control Channel (BCCH) [1][6].

2.2.1.2 Sectorization

By using directional antennas on a base station, each pointing in different directions, it is possible to sectorise the base station so that several different cells are served from the same location. Typically these directional antennas have a beam width of 65 to 85 degrees. This increases the traffic capacity of the base station (each frequency can carry eight voice channels) whilst not greatly increasing the interference caused to neighboring cells (in any given direction, only a small number of frequencies are being broadcast). Typically two antennas are used per sector, at spacing of ten or more wavelengths apart. This allows the operator to overcome the effects of fading due to physical phenomena such as multipath reception. Some amplification of the received signal as it leaves the antenna is often used to preserve the balance between uplink and downlink signal [1][15].

2.2.2 Base station controller

The base station controller (BSC) provides, classically, the intelligence behind the BTSs. Typically a BSC has tens or even hundreds of BTSs under its control. The BSC handles allocation of radio channels, receives measurements from the mobile phones, and controls handovers from BTS to BTS (except in the case of an inter-BSC handover in which case control is in part the responsibility of the anchor MSC). A key function of the BSC is to act as a concentrator where many different low capacity connections to BTSs (with relatively low utilization) become reduced to a smaller number of connections towards the mobile switching center (MSC) (with a high level of utilization). Overall, this means that networks are often structured to have many BSCs distributed into regions near their BTSs which are then connected to large centralized MSC sites.

The BSC is undoubtedly the most robust element in the BSS as it is not only a BTS controller but, for some vendors, a full switching center, as well as an SS7 node with connections to the MSC and serving GPRS support node (SGSN) (when using GPRS). It also provides all the required data to the operation support subsystem (OSS) as well as to the performance measuring centers.

A BSC is often based on a distributed computing architecture, with redundancy applied to critical functional units to ensure availability in the event of fault conditions. Redundancy often extends beyond the BSC equipment itself and is commonly used in the power supplies and in the transmission equipment providing the A-ter interface to PCU.

The databases for all the sites, including information such as carrier frequencies, frequency hopping lists, power reduction levels, receiving levels for cell border calculation, are stored in the BSC. This data is obtained directly from radio planning engineering which involves modeling of the signal propagation as well as traffic projections [1][6][15].

2.2.3 Transcoder

The transcoder is responsible for transcoding the voice channel coding between the coding used in the mobile network, and the coding used by the world's terrestrial circuit-switched network, the Public Switched Telephone Network. Specifically, GSM uses a regular pulse excited-long term prediction (RPE-LTP) coder for voice data between the mobile device and the BSS, but pulse code modulation (A-law or μ-law standardized in ITU G.711) upstream of the BSS. RPE-LPC coding results in a data rate for voice of 13 Kbit/s where standard PCM coding results in 64 Kbit/s. Because of this change in data rate for the same voice call, the transcoder also has a buffering function so that PCM 8-bit words can be recoded to construct GSM 20 ms traffic blocks.

Although transcoding (compressing/decompressing) functionality is defined as a base station function by the relevant standards, there are several vendors which have implemented the solution outside of the BSC. Some vendors have implemented it in a stand-alone rack using a proprietary interface. In Siemens' and Nokia's architecture, the transcoder is an identifiable separate sub-system which will normally be co-located with the MSC. In some of Ericsson's systems it is integrated to the MSC rather than the BSC. The reason for these designs is that if the compression of voice channels is done at the site of the MSC, the number of fixed transmission links between the BSS and MSC can be reduced, decreasing network infrastructure costs.

This subsystem is also referred to as the transcoder and rate adaptation unit (TRAU). Some network use 32kbit/s ADPCM on the terrestrial side of the network instead 64kbit/s PCM and the TRAU converts accordingly. When the traffic is not voice but data such as fax or email, the TRAU enables its rate adaptation unit function to give compatibility between the BSS and MSC data rates. [1][15]

2.2.4 Packet control unit

The packet control unit (PCU) is a late addition to the GSM standard. It performs some of the processing tasks of the BSC, but for packet data. The allocation of channels between voice and data is controlled by the base station, but once a channel is allocated to the PCU, the PCU takes full control over that channel.

The PCU can be built into the base station, built into the BSC or even, in some proposed architectures, it can be at the SGSN site. In most of the cases, the PCU is a separate node communicating extensively with the BSC on the radio side and the SGSN on the Gb side [6][15].

2.2.5 BSS interface

2.2.5.1 Um

The Um is the air interface between the mobile station (MS) and the BTS. This interface uses LAPDm protocol for signaling, to conduct call control, measurement reporting, handover, power control, authentication, authorization, location update and so on. Traffic and signaling are sent in bursts of 0.577 ms at intervals of 4.615 ms, to form data blocks each 20ms [15].

2.2.5.2 Abis

The Abis is the interface between the BTS and BSC. Generally carried by a DS-1, ES-1, or E1 TDM circuit. Uses TDM sub channels for traffic (TCH), LAPD protocol for BTS supervision and telecom signaling, and carries synchronization from the BSC to the BTS and MS [15].

2.2.5.3 A

The A is the interface between the BSC and MSC. It is used for carrying traffic channels and the BSSAP user part of the SS7 stack. Although there are usually transcoding units between BSC and MSC, the signaling communication takes place between these two ending points and the transcoder unit doesn't touch the SS7 information, only the voice or CS data are transcoded or rate adapted [15].

2.2.5.4 Ater

The Ater is the interface between the BSC and transcoder. It is a proprietary interface whose name depends on the vendor (for example Ater by Nokia), it carries the A interface information from the BSC leaving it untouched [15].

2.2.5.5 Gb

Gb is the interface that connects the BSS to the SGSN in the GPRS core network [15].

2.2.6 Radio link protocol

Radio Link Protocol (RLP) is an automatic repeat request (ARQ) fragmentation protocol used over a wireless (typically cellular) air interface. Most wireless air interfaces are tuned to provide 1% packet loss, and most Vocoders are mutually tuned to sacrifice very little voice quality at 1% packet loss. However, 1% packet loss is intolerable to all variants of TCP, and so something must be done to improve reliability for voice networks carrying TCP/IP data.

A RLP detects packet losses and performs retransmissions to bring packet loss down to .01%, or even .0001%, which is suitable for TCP/IP applications. RLP also implements stream fragmentation and reassembly, and sometimes, in-order delivery. Newer forms of RLP also provide framing and compression, while older forms of RLP rely upon a higher-layer PPP protocols to provide these functions.

A RLP transport cannot ask the air interface to provide a certain payload size. Instead, the air interface scheduler determines the packet size, based upon constantly changing channel conditions, and up calls RLP with the chosen packet payload size, right before transmission. Most fragmentation protocols, such as those of 802.11b and IP, used payload sizes determined by the upper layers, and call upon the MAC to create a payload of a certain size. These other protocols are not as flexible as RLP, and can sometimes fail to transmit during a deep fade in a wireless environment.

Because a RLP payload size can be as little as 11 bytes, based upon a CDMA IS-95 network's smallest voice packet size, RLP headers must be very small, to minimize overhead. This is typically achieved by allowing both ends to negotiate a variable 'sequence number space', which is used to number each byte in the transmission stream. In some variants of RLP, this sequence counter can be as small as 6 bits.

A RLP protocol can be ACK-based or NAK-based. Most RLPs are NAK-based, meaning that forward-link sender assumes that each transmission got through, and the receiver only NAKs when an out-of-order segment is received. This greatly reduces reverse-link transmissions, which are spectrally inefficient and have a longer latency on most cellular networks. When the transmit pipeline goes idle, a NAK-based RLP must eventually retransmit the last segment a second time, in case the last fragment was lost, to reach a .01% packet loss rate. This duplicate transmission is typically controlled by a "flush timer" set to expire 200-500 milliseconds after the channel goes idle [1][6].

2.3 Different types of RANs

2.3.1 GERAN

GERAN is an abbreviation for GSM EDGE Radio Access Network. The standards for GERAN are maintained by the 3GPP (Third Generation Partnership Project). GERAN is a key part of GSM, and also of combined UMTS/GSM networks.

GERAN is the radio part of GSM/EDGE together with the network that joins the base stations (the Ater and ABIS interfaces) and the base station controllers (A interfaces, etc.) The network represents the core of a GSM network, through which phone calls and packet data are routed from and to the PSTN and Internet to and from subscriber handsets. A mobile phone operator's network comprises one or more GERANs, coupled with UTRANs in the case of a UMTS/GSM network. A GERAN without EDGE is a GRAN, but is otherwise identical in concept. A GERAN without GSM is an ERAN.[Fig.2.1][12][14]

2.3.2 GRAN

GRAN is an abbreviation of GSM radio access network. It consists of Base Transceiver Stations (BTS) and Base Station Controllers (BSC). Its purpose is to manage the radio link between mobile phones and a telecommunication core network. This access network provides access to both Circuits switched (CS) and Packet switched (PS) core networks [1].

2.3.3 UTRAN

UTRAN (short for "Universal Terrestrial Radio Access Network") is a collective term for the Node B's and Radio Network Controllers (RNCs) which make up the UMTS radio access network. This communications network, commonly referred to as 3G (for 3rd Generation Wireless Mobile Communication Technology), can carry many traffic types from real-time Circuit Switched to IP based Packet Switched. The UTRAN allows connectivity between the UE (user equipment) and the core network.

The UTRAN contains the base stations, which are called Node Bs, and Radio Network Controllers (RNC). The RNC provides control functionalities for one or more Node Bs. A Node B and an RNC can be the same device, although typical implementations have a separate RNC located in a central office serving multiple Node Bs. Despite the fact that they do not have to be physically separated, there is a logical interface between them known as the Iub. The RNC and its corresponding Node Bs are called the Radio Network Subsystem (RNS). There can be more than one RNS present in a UTRAN.

There are four interfaces connecting the UTRAN internally or externally to other functional entities: Iu, Uu, Iub and Iur. The Iu interface is an external interface that connects the RNC to the Core Network (CN). The Uu is also external; connecting the Node B with the User Equipment .The Iub is an internal interface connecting the RNC with the Node B. And at last there is the Iur interface which is an internal interface most of the time, but can, exceptionally be an external interface too for some network architectures. The Iur connects two RNCs with each other.[13]

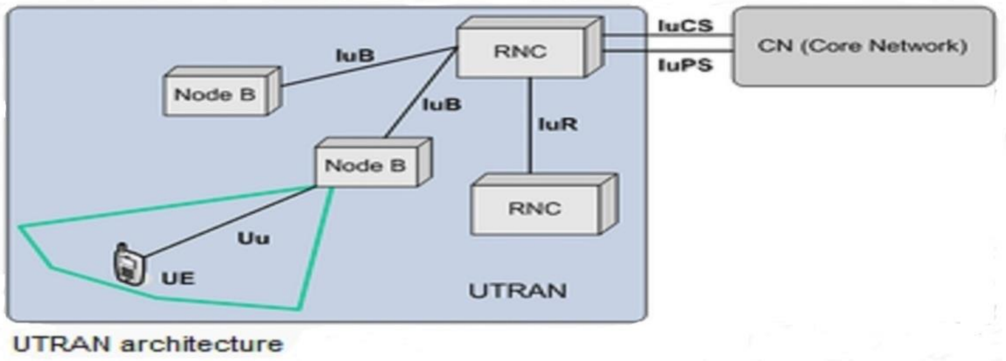

Figure2.2: Universal Terrestrial Radio Access Network Architecture.

2.3.4 E-UTRAN

E-UTRA is the air interface of 3GPP's Long Term Evolution upgrade path for mobile networks. It is the abbreviation for evolved UMTS Terrestrial Radio Access, also referred to as the 3GPP work item on the Long Term Evolution also known as the Evolved Universal Terrestrial Radio Access (E-UTRA) in early drafts of the 3GPP LTE specification’s-UTRAN is the initialize of Envolved UMTS Terrestrial Radio Access Network and is the combination of E-UTRA, UE's and EnodeB's.

It is a radio access network standard meant to be a replacement of the UMTS, HSDPA and HSUPA technologies specified in 3GPP releases 5 and beyond. Unlike HSPA, LTE's E-UTRA is an entirely new air interface system, unrelated to and incompatible with W-CDMA. It provides higher data rates, lower latency and is optimized for packet data. It uses OFDMA radio-access for the downlink and SC-FDMA on the uplink. Trials started in 2008. [2][5][Fig.2.1][4]

2.3.4.1 Features

EUTRAN has the following features:

Peaks download rates of 299.6Mbit/s for 4×4 antennas, and 150.8Mbit/s for 2×2 antennas with 20 MHz of spectrum. LTE Advanced supports 8×8 antenna configurations with peak download rates of 2998.6Mbit/s in an aggregated 100MHz channel. Peak uploads rates of 75.4Mbit/s for a 20MHz channel in the LTE standard, with up to1497.8Mbit/s in an LTE Advanced 100 MHz carrier. Low data transfer latencies (sub-5 ms latency for small IP packets in optimal conditions), lower latencies for handover and connection setup time. Support for terminals moving at up to 350km/h or 500km/h depending on the frequency band. Support for both FDD and TDD duplexes as well as

Half-duplex FDD with the same radio access technology Support for all frequency bands currently used by IMT systems by ITU-R. Flexible bandwidth: 1.4MHz, 3MHz, 5MHz, 15MHz and 20MHz are standardized. By comparison, W-CDMA uses fixed size 5MHz chunks of spectrum. Increased spectral efficiency at 2-5times more than in 3GPP (HSPA) release 6Support of cell sizes from tens of meters of radius (femto and picocells) up to over 100 km radius microcells Simplified architecture: The network side of EUTRAN is composed only by the enodeBs Support for inter-operation with other systems (e.g. GSM/EDGE, UMTS, CDMA2000, and Wi-Max).[3][4]

2.3.4.2 Architecture

EUTRAN consists only of enodeBs on the network side. The enodeB performs tasks similar to those performed by the nodeBs and RNC (radio network controller) together in UTRAN. The aim of this simplification is to reduce the latency of all radio interface operations. eNodeBs are connected to each other via the X2 interface, and they connect to the packet switched (PS) core network via the S1 interface.[4]

2.4 Performance Issue Due to Congestion

2.4.1 Congestion and its adverse effect on network

The word congestion means excessive crowding but in Telecommunication the term is used when a node or link or a channel carries excessive amount of data and thus degrades the QoS (Quality of the Service) of the network. Congestion is the most common and fast growing problem of today’s networking system. With the fast growth of Internet and increased demand to use Internet for voice and video applications congestion increases and as a result of congestion the QoS degrades. That means all the aspects of a connection, such as service response time, loss, signal-to-noise ratio, cross-talk, echo, interrupts, frequency response, loudness level and all other quality of service requirements degrades. It also results in incremental increases in offered load and that affects the network throughput [8].

2.4.2 Congestion in wireless radio access network

Cellular wireless networks have become an indispensable part of the communication infrastructure. RAN (Radio Access Network) is one of the key components of cellular wireless network. The main task of RAN is to provide connection between mobile station (Cellular phone, Computer or any Remotely controlled device) with core networks.RAN is designed to established certain number of calls with the core network and if it receives call establishment request beyond its capacity then it can’t serve the incoming request (Call establishment) of the subscribers and this problem is called congestion in RAN [8]. Congestion occurs when the offered traffic exceeds the engineered capacity.

2.4.3 Different types of congestions and their respective causes and impacts on network

There are different types of Congestions in wireless network.

2.4.3.1 Radio network controller congestion

RNC (Radio Network Controller) congestion occurred due to overload in RNCs because of applications such as push e-mail, VPNs, mobile port scanning, Hypertext Transfer Protocol (HTTP) over Secure Socket Layer (HTTPS), Secure Shell (SSH), location-based services, push-to-talk, wireless-specific signaling attacks and worms introduce anomalously high amounts of signaling in the network [7].

2.4.3.2 Backhaul congestion

Backhaul congestion is another type of congestion which is occurred because of applications such as video download, video upload, P2P, File Transfer Protocol (FTP), single-source flood attacks, and distributed source flood attacks, all of the application typically send large amounts of volume that contribute to the congestion of backhaul links between the base station, the RNC and network elements in the path [7].

2.4.3.3 Base station congestion

Base Station congestion that is caused due to capacity limitation (Base Station can process certain number of calls),for any new subscriber who is trying to connect to the network the connection probability depends on the availability of an open Slot in the total number of instantaneously supported subscribers at that particular base station [7].

Our study shows that Radio over Fiber (RoF) is a very potential solution to resolve this congestion issue and we study the RoF extensively in Chapter 5 and propose a resolution scheme in Chapter 6.

Chapter Three

OVERVIEW OF OPTICAL FIBER COMMUNICATION

3.1 Introduction

Optical fiber is a flexible, transparent fiber made of high quality extruded glass (silica) or plastic, slightly thicker than a human hair. It can function as a waveguide, or “light pipe”,[16] to transmit light between the two ends of the fiber.[17] The field of applied science and engineering concerned with the design and application of optical fibers is known as fiber optics. Optical fibers are widely used in fiber-optic communications, which permits transmission over longer distances and at higher bandwidths than other forms of communication. Fibers are used instead of metal wires because signals travel along them with less loss and are also immune to electromagnetic interference. Fibers are also used for illumination, and are covered in bundles so that they may be used to transmit images, thus allowing viewing in limited spaces. Specially designed fibers are used for a variety of other applications, including sensors and fiber lasers.

Optical fibers typically include a transparent core surrounded by a transparent cladding material with a lower index of refraction. Light is kept in the core by total internal reflection. This causes the fiber to act as a waveguide. Fibers that support many propagation paths or transverse modes are called multi-mode fibers (MMF), while those that only support a single mode are called single-mode fibers (SMF). Multi-mode fibers generally have a wider core diameter, and are used for short-distance communication links and for applications where high power must be transmitted. Single-mode fibers are used for most communication links longer than 1,000 meters (3,300 ft) [18].

3.1.1. Historical background

Using light transmitting information from one place to another place is one of the old techniques. In 800 BC,[19] the Greeks used fire and smoke signals for transferring information like victory in a war, alerting against enemy, call for help, etc.[19][20][21] During the second century B.C. optical signals were encoded using signaling lamps so that any message could be sent. There was no improvement in optical communication till the end of the 18th century. 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. In 1791, Chappe from France developed the semaphore for telecommunication on land. But that was also with limited information transfer. In 1835, Samuel Morse invented the telegraph and the era of electrical communications started throughout the world. The use of wire cables for the transmission of Morse coded signals was implemented in 1844. In 1872, Alexander Graham Bell proposed the “Photophone” with a diaphragm giving speech transmission over a distance of 200 m. Within four years, Graham Bell had changed the “Photophone” into “Telephone” using electrical current for transmission of speech signals. In 1878, the first telephone exchange was installed at New Haven. Meanwhile, Hertz discovered radio waves in 1887. Marconi demonstrated radio communication without using wires in 1895. Using modulation techniques, the signals were transmitted over a long distance using radio waves and microwaves as the carrier. During the middle of the twentieth century, it was realized that an increase of several orders of magnitude of bit rate distance product would be possible if optical waves were used as the carrier. Table 3.1 shows the different communication systems and their bit rate distance product. Here the repeater spacing is mentioned as distance. In the old optical communication system, the bit rate distance product is only about 1 (bit/s)-km due to enormous transmission loss (105 to 107 dB/km). The information carrying capacity of telegraphy is about hundred times lesser than telephony. Even though the high-speed coaxial systems were evaluated during 1975, they had smaller repeater spacing. Microwaves are used in modern communication systems with the increased bit rate distance product. However, a coherent optical carrier like laser will have more information carrying capacity. So the communication engineers were interested in optical communication using lasers in an effective manner from 1960 onwards. A new era in optical communication started after the invention of laser in 1960 by Maiman. The light waves from the laser, a coherent source of light waves having high intensity, high monochromaticity and high directionality with less divergence, are used as carrier waves capable of carrying large amount of information compared with radio waves and microwaves [19].

Jun-ichi Nishizawa, a Japanese scientist at Tohoku University, also proposed the use of optical fibers for communications in 1963, as stated in his book published in 2004 in India [22]. Nishizawa invented other technologies that contributed to the development of optical fiber communications, such as the graded-index optical fiber as a channel for transmitting light from semiconductor lasers [23][24]. 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 [25][26]. 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 [27]. 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 [28].

3.1.2 Unguided optical communication

The optical communication systems are different from microwave communication systems in many aspects. In the case of optical systems, the carrier frequency is about 100THz and the bit rate is about 1Tbit/s. Further the spreading of optical beams is always in the forward direction due to the short wavelengths. Even though it is not suitable for broadcasting applications, it may be suitable for free space communications above the earth’s atmosphere like inter-satellite communications. For the terrestrial applications, unguided optical communications are not suitable because of the scattering within the atmosphere, atmospheric turbulence, fog and rain. The unguided optical communication systems played an important role in the research between 1960 and 1970. For longer range unguided optical communication systems the neodymium laser (1.06 mm) and the carbon dioxide laser (10.6 mm) were the most favorable sources. Using narrow band gap compound semiconductors like indium Sulphide (for neodymium laser) and cadmium mercury telluride (for CO2 laser) one can have better detection using heterodyne detection techniques [19].

System	Bit rate distance product (bit/s)-km
Old optical communication	1
Telegraph	10
Telephone	10^3
Co-axial cable	10^5
Microwaves	10^6
Laser light in open air	10^7

Table 3.1: Bit rate distance product [19].

3.2. The Birth of Optical Fiber System

To guide light in a waveguide, initially metallic and non-metallic wave guides were fabricated. But they have enormous losses. Therefore, they were not suitable for telecommunication. Tyndall discovered that through optical fibers, light could be transmitted by the phenomenon of total internal reflection. During 1950s, the optical fibers with large diameters of about 1 or 2 millimeter were used in endoscopes to see the inner parts of the human body. Optical fibers can provide a much more reliable and versatile optical channel than the atmosphere, Kao and Hockham published a paper about the optical fiber communication system in 1966. But the fibers produced an enormous loss of 1000dB/km. But in the atmosphere, there is a loss of few dB/km. Immediately Kao and his fellow workers realized that these high losses were a result of impurities in the fiber material. Using a pure silica fiber these losses were reduced to 20dB/km in 1970 by Kapron, Maurer and. Keck At this attenuation loss, repeater spacing for optical fiber links become comparable to those of copper cable systems. Thus the optical fiber communication system became an engineering reality [19].

3.3. Basic Optical Fiber Communication System

Figure 3.3 shows the basic components in the optical fiber communication system. The input electrical signal modulates the intensity of light from the optical source. The optical carrier can be modulated internally or externally using an electro-optic modulator (or) acousto-optic modulator. Nowadays electro-optic modulators (KDP, $\mathrm{LiNbO_3}$ or beta barium borate) are widely used as external modulators which modulate the light by changing its refractive index through the given input electrical signal. In the digital optical fiber communication system, the input electrical signal is in the form of coded digital pulses from the encoder and these electric pulses modulate the intensity of the light from the laser diode or LED and convert them into optical pulses. In the receiver stage, the photo detector like avalanche photodiode (APD) or positive-intrinsic-negative (PIN) diode converts the optical pulses into electrical pulses. A decoder converts the electrical pulses into the original electric signal [19].

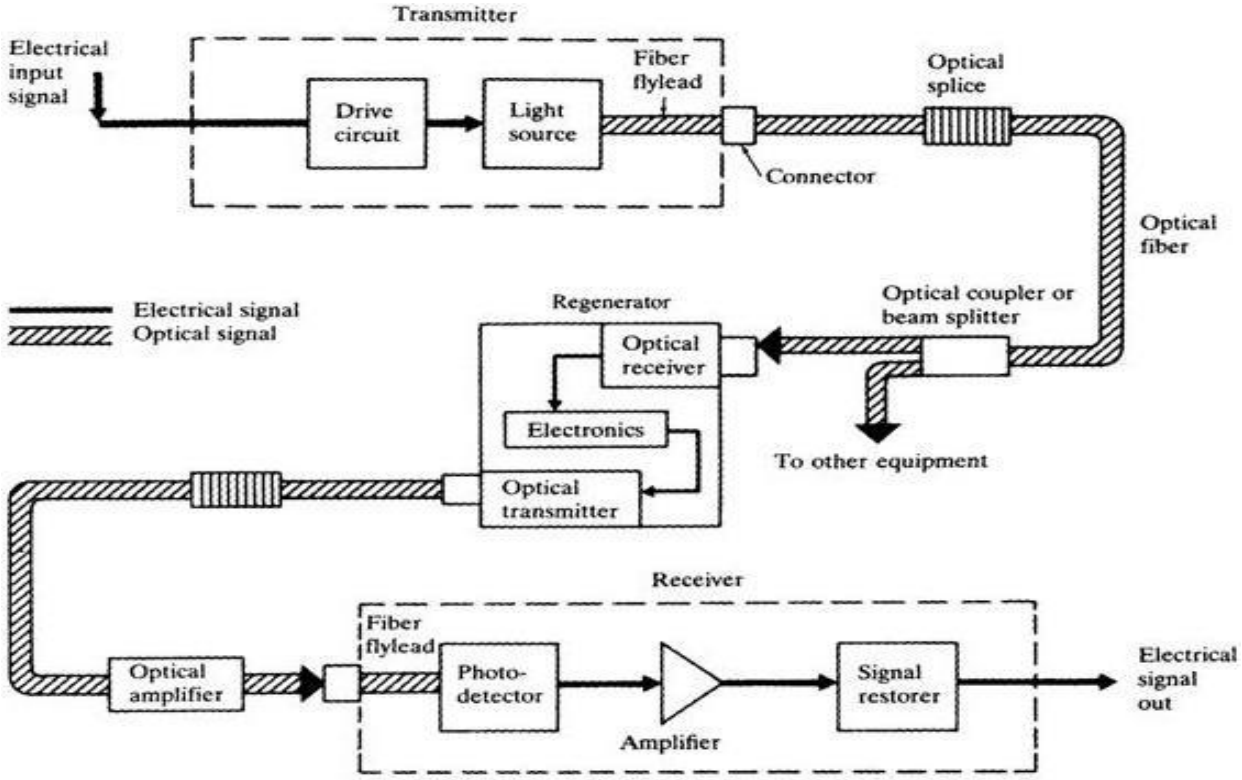

Figure 3.1: Basic Optical Fiber Communication System Block Diagram [65].

3.4. Principle of Operation

An optical fiber is a cylindrical dielectric waveguide (non-conducting waveguide) that transmits light along its axis, by the process of total internal reflection. The fiber consists of a core surrounded by a cladding layer, both of which are made of dielectric materials. To confine the optical signal in the core, the refractive index of the core must be greater than that of the cladding. The boundary between the core and cladding may either be abrupt, in step-index fiber, or gradual, in graded-index fiber [18].

3.4.1. Refractive index

The index of refraction is a way of measuring the speed of light in a material. Light travels fastest in a vacuum, such as outer space. The speed of light in a vacuum is about 300,000 kilometers (186,000 miles) per second. Index of refraction is calculated by dividing the speed of light in a vacuum by the speed of light in some other medium.

The index of refraction of a vacuum is therefore 1, by definition. The typical value for the water is 1.33 [29] and cladding of an optical fiber is 1.52. The core value is typically 1.62 [30]. The larger the index of refraction, the slower light travels in that medium. From this information, a good rule of thumb is that signal using optical fiber for communication will travel at around 200,000 kilometers per second. Or to put it another way, to travel 1000 kilometers in fiber, the signal will take 5 milliseconds to propagate. Thus a phone call carried by fiber between Sydney and New York, a 16,000-kilometer distance, means that there is an absolute minimum delay of 80 milliseconds (or around 1/12 of a second) between when one caller speaks to when the other hears. (Of course the fiber in this case will probably travel a longer route, and there will be additional delays due to communication equipment switching and the process of encoding and decoding the voice onto the fiber) [18].

3.4.2. Total internal reflection

When light traveling in an optically dense medium hits a boundary at a steep angle (larger than the critical angle for the boundary), the light is completely reflected. This is called total internal reflection. This effect is used in optical fibers to confine light in the core. Light travels through the fiber core, bouncing back and forth off the boundary between the core and cladding. Because the light must strike the boundary with an angle greater than the critical angle, only light that enters the fiber within a certain range of angles can travel down the fiber without leaking out. This range of angles is called the acceptance cone of the fiber. The size of this acceptance cone is a function of the refractive index difference between the fiber's core and cladding [18] [20].

In simpler terms, there is a maximum angle from the fiber axis at which light may enter the fiber so that it will propagate, or travel, in the core of the fiber. The sine of this maximum angle is the numerical aperture (NA) of the fiber. Fiber with a larger NA requires less precision to splice and work with than fiber with a smaller NA. Single-mode fiber has a small NA [18] [20].

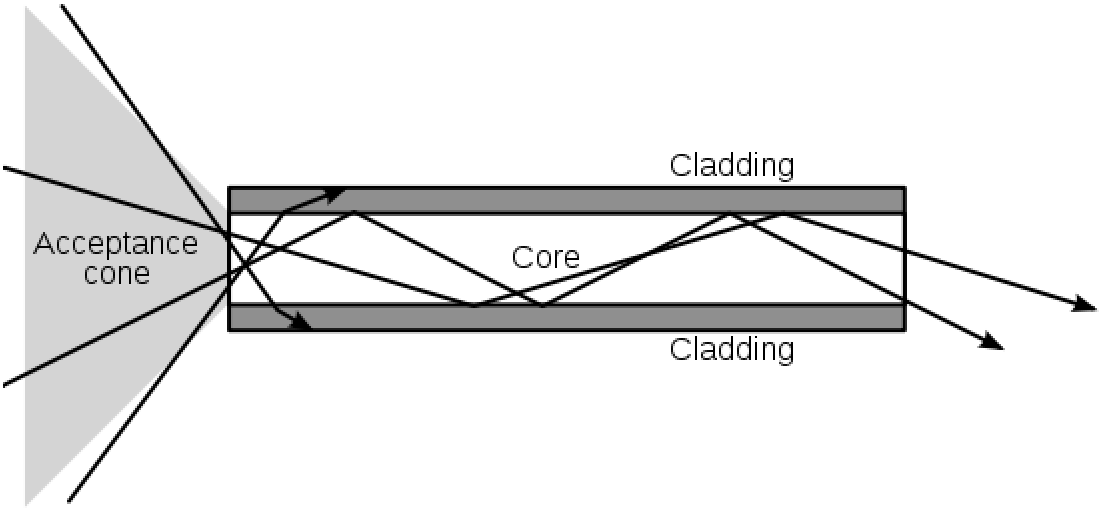

Figure 3.2: The propagation of light through a optical fiber [18].

3.5 Different Types of Fiber

3.5.1. Multimode optical fiber

Fiber with large core diameter (greater than 10 micrometers) may be analyzed by geometrical optics. Such fiber is called multi-mode fiber, from the electromagnetic analysis. In a step-index multi-mode fiber, rays of light are guided along the fiber core by total internal reflection. Rays that meet the core-cladding boundary at a high angle (measured relative to a line normal to the boundary), greater than the critical angle for this boundary, are completely reflected. The critical angle (minimum angle for total internal reflection) is determined by the difference in index of refraction between the core and cladding materials. Rays that meet the boundary at a low angle are refracted from the core into the cladding, and do not convey light and hence information along the fiber. The critical angle determines the acceptance angle of the fiber, often reported as a numerical aperture. A high numerical aperture allows light to propagate down the fiber in rays both close to the axis and at various angles, allowing efficient coupling of light into the fiber. However, this high numerical aperture increases the amount of dispersion as rays at different angles have different path lengths and therefore take different times to traverse the fiber [18].

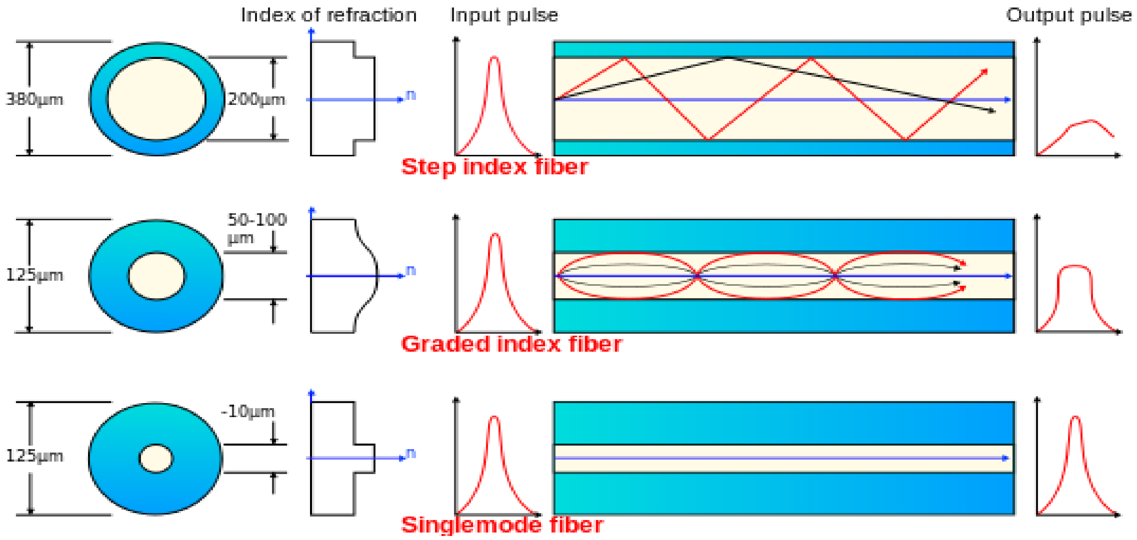

Figure 3.3: Different types of Optical Fiber mode [18]

In graded-index fiber, the index of refraction in the core decreases continuously between the axis and the cladding. This causes light rays to bend smoothly as they approach the cladding, rather than reflecting abruptly from the core-cladding boundary. The resulting curved paths reduce multi-path dispersion because high angle rays pass more through the lower-index periphery of the core, rather than the high-index center. The index profile is chosen to minimize the difference in axial propagation speeds of the various rays in the fiber. This ideal index profile is very close to a parabolic relationship between the index and the distance from the axis [18].

3.5.2 Single mode fiber

Fiber with a core diameter less than about ten times the wavelength of the propagating light cannot be modeled using geometric optics. Instead, it must be analyzed as an electromagnetic structure, by solution of Maxwell's equations as reduced to the electromagnetic wave equation. The electromagnetic analysis may also be required to understand behaviors such as speckle that occur when coherent light propagates in multi-mode fiber. As an optical waveguide, the fiber supports one or more confined transverse modes by which light can propagate along the fiber. Fiber supporting only one mode is called single-mode or mono-mode fiber. The behavior of larger-core multi-mode fiber can also be modeled using the wave equation, which shows that such fiber supports more than one mode of propagation. The results of such modeling of multi-mode fiber approximately agree with the predictions of geometric optics, if the fiber core is large enough to support more than a few modes.

The waveguide analysis shows that the light energy in the fiber is not completely confined in the core. Instead, especially in single-mode fibers, a significant fraction of the energy in the bound mode travels in the cladding as an evanescent wave.

The most common type of single-mode fiber has a core diameter of 8–10 micrometers and is designed for use in the near infrared. The mode structure depends on the wavelength of the light used, so that this fiber actually supports a small number of additional modes at visible wavelengths. Multi-mode fiber, by comparison, is manufactured with core diameters as small as 50 micrometers and as large as hundreds of micrometers. The normalized frequency V for this fiber should be less than the first zero of the Bessel function J_0 (approximately 2.405) [18].

3.5.3. Special purpose fiber

Some special-purpose optical fiber is constructed with a non-cylindrical core and/or cladding layer, usually with an elliptical or rectangular cross-section. These include polarization-maintaining fiber and fiber designed to suppress whispering gallery mode propagation. Polarization-maintaining fiber is a unique type of fiber that is commonly used in fiber optic sensors due to its ability to maintain the polarization of the light inserted into it.

Photonic-crystal fiber is made with a regular pattern of index variation (often in the form of cylindrical holes that run along the length of the fiber). Such fiber uses diffraction effects instead of or in addition to total internal reflection, to confine light to the fiber's core. The properties of the fiber can be tailored to a wide variety of applications [18].

3.6. Mechanism of Attenuation

Attenuation in fiber optics, also known as transmission loss, [20] is the reduction in intensity of the light beam (or signal) as it travels through the transmission medium. Attenuation coefficients in fiber optics usually use units of dB/km through the medium due to the relatively high quality of transparency of modern optical transmission media. The medium is usually a fiber of silica glass that confines the incident light beam to the inside. Attenuation is an important factor limiting the transmission of a digital signal across large distances. Thus, much research has gone into both limiting the attenuation and maximizing the amplification of the optical signal. Empirical research has shown that attenuation in optical fiber is caused primarily by both scattering and absorption.

3.6.1 Light scattering

The propagation of light through the core of an optical fiber is based on total internal reflection of the light wave. Rough and irregular surfaces, even at the molecular level, can cause light rays to be reflected in random directions. This is called diffuse reflection or scattering, and it is typically characterized by wide variety of reflection angles.

Light scattering depends on the wavelength of the light being scattered. Thus, limits to spatial scales of visibility arise, depending on the frequency of the incident light-wave and the physical dimension (or spatial scale) of the scattering center, which is typically in the form of some specific micro-structural feature. Since visible light has a wavelength of the order of one micrometer (one millionth of a meter) scattering centers will have dimensions on a similar spatial scale.

Thus, attenuation results from the incoherent scattering of light at internal surfaces and interfaces. In (poly) crystalline materials such as metals and ceramics, in addition to pores, most of the internal surfaces or interfaces are in the form of grain boundaries that separate tiny regions of crystalline order. It has recently been shown that when the size of the scattering center (or grain boundary) is reduced below the size of the wavelength of the light being scattered, the scattering no longer occurs to any significant extent. This phenomenon has given rise to the production of transparent ceramic materials.

Similarly, the scattering of light in optical quality glass fiber is caused by molecular level irregularities (compositional fluctuations) in the glass structure. Indeed, one emerging school of thought is that a glass is simply the limiting case of a polycrystalline solid. Within this framework, "domains" exhibiting various degrees of short-range order become the building blocks of both metals and alloys, as well as glasses and ceramics. Distributed both between and within these domains are micro-structural defects that provide the most ideal locations for light scattering. This same phenomenon is seen as one of the limiting factors in the transparency of IR missile domes [31].

At high optical powers, scattering can also be caused by nonlinear optical processes in the fiber [32][33].

3.6.2 UV-Vis-IR absorption

In addition to light scattering, attenuation or signal loss can also occur due to selective absorption of specific wavelengths, in a manner similar to that responsible for the appearance of color. Primary material considerations include both electrons and molecules as follows:

1) At the electronic level, it depends on whether the electron orbital are spaced (or "quantized") such that they can absorb a quantum of light (or photon) of a specific wavelength or frequency in the ultraviolet (UV) or visible ranges. This is what gives rise to color.

2) At the atomic or molecular level, it depends on the frequencies of atomic or molecular vibrations or chemical bonds, how close-packed its atoms or molecules are, and whether or not the atoms or molecules exhibit long-range order. These factors will determine the capacity of the material transmitting longer wavelengths in the infrared (IR), far IR, radio and microwave ranges.

The design of any optically transparent device requires the selection of materials based upon knowledge of its properties and limitations. The Lattice absorption characteristics observed at the lower frequency regions (mid IR to far-infrared wavelength range) define the long-wavelength transparency limit of the material. They are the result of the interactive coupling between the motions of thermally induced vibrations of the constituent atoms and molecules of the solid lattice and the incident light wave radiation. Hence, all materials are bounded by limiting regions of absorption caused by atomic and molecular vibrations (bond-stretching) in the far-infrared (>10 µm).

Thus, multi-phonon absorption occurs when two or more phonons simultaneously interact to produce electric dipole moments with which the incident radiation may couple. These dipoles can absorb energy from the incident radiation, reaching a maximum coupling with the radiation when the frequency is equal to the fundamental vibration mode of the molecular dipole (e.g. Si-O bond) in the far-infrared, or one of its harmonics.

The selective absorption of infrared (IR) light by a particular material occurs because the selected frequency of the light wave matches the frequency (or an integer multiple of the frequency) at which the particles of that material vibrate. Since different atoms and molecules have different natural frequencies of vibration, they will selectively absorb different frequencies (or portions of the spectrum) of infrared (IR) light.

Reflection and transmission of light waves occur because the frequencies of the light waves do not match the natural resonant frequencies of vibration of the objects. When IR light of these frequencies strikes an object, the energy is either reflected or transmitted [18].

3.7 Advantages of Optical Fiber Communication

i. Wider bandwidth

The information carrying capacity of a transmission system is directly proportional to the carrier frequency of the transmitted signals. The optical carrier frequency is in the range 10^{13} to 10^{15} Hz while the radio wave frequency is about 10^{6} Hz and Optical fiber communication the microwave frequency is about 10^{10} Hz. Thus the optical fiber yields greater transmission bandwidth than the conventional communication systems and the data rate or number of bits per second is increased to a greater extent in the optical fiber communication sys-tem. Further the wavelength division multiplexing operation by the data rate or information carrying capacity of optical fibers is enhanced to many orders of magnitude [19].

ii. Low transmission loss

Due to the usage of the ultra low loss fibers and the erbium doped silica fibers as optical amplifiers, one can achieve almost lossless transmission. In the modern optical fiber telecommunication systems, the fibers having a transmission loss of 0.002dB/km are used. Further, using erbium doped silica fibers over a short length in the transmission path at selective points; appropriate optical amplification can be achieved. Thus the repeater spacing is more than 100 km. Since the amplification is done in the optical domain itself, the distortion produced during the strengthening of the signal is almost negligible [19].

iii. Dielectric waveguide

Optical fibers are made from silica which is an electrical insulator. Therefore they do not pickup any electromagnetic wave or any high current lightning. It is also suitable in explosive environments. Further the optical fibers are not affected by any interference originating from power cables, railway power lines and radio waves. There is no cross talk between the fibers even though there are so many fibers in a cable because of the absence of optical interference between the fibers [19].

iv. Signal security

The transmitted signal through the fibers does not radiate. Further the signal cannot be tapped from a fiber in an easy manner. Therefore optical fiber communication provides hundred per cent signal security 19].

v. Small size and weight

Fiber optic cables are developed with small radii, and they are flexible, compact and lightweight. The fiber cables can be bent or twisted without damage. Further, the optical fiber cables are superior to the copper cables in terms of storage, handling, installation and transportation, maintaining comparable strength and durability [19].

vi. Immunity to interference and crosstalk

Optical fibers form a dielectric waveguide and are therefore free from electromagnetic interference (EMI), radio-frequency interference (RFI), or switching transients giving electromagnetic pulses (EMPs). Hence the operation of an optical fiber communication system is unaffected by transmission through an electrically noisy environment and the fiber cable requires no shielding from EMI. The fiber cable is also not susceptible to lightning strikes if used overhead rather than underground. Moreover, it is fairly easy to ensure that there is no optical interference between fibers and hence, unlike communication using electrical conductors, crosstalk is negligible, even when many fibers are cabled together [17].

vii. Electrical isolation

Optical fibers which are fabricated from glass, or sometimes a plastic polymer, are electrical insulators and therefore, unlike their metallic counterparts, they do not exhibit 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 [17].

3.8. Dispersion and losses in fibers

Dispersion in the fiber means the broadening of the signal pulse width due to dependence of the refractive index of the material of the fiber on the wavelength of the carrier. If we send digitized signal pulses in the form of square pulses, they are converted into broadened Gaussian pulses due to dispersion. The dispersion leads to the distortion (or) degradation of the signal quality at the output end due to overlapping of the pulses. There are two kinds of dispersion mechanisms in the fiber: (a) Intramodal dispersion and (b) Intermodal dispersion. The dispersion effects can be explained on the basis of behavior of group velocities of the guided modes in the optical fiber. Group velocity is the velocity at which the energy in a particular mode travels along the fiber [19].

The propagation constant, $\beta = n_1\frac{2\pi}{\lambda} = \frac{n_1\omega}{C}$

Therefore

Group velocity, $v_g = \frac{d\omega}{d\beta} = \frac{d\lambda}{d\beta}.\frac{d\omega}{d\lambda}$

Since, $= n_1\frac{2\pi}{\lambda}$,

$$\frac{d\beta}{d\lambda} = \frac{2\pi}{\lambda}.\frac{dn_1}{d\lambda} - n_1\frac{2\pi}{\lambda^2}$$

Using ω = $-\frac{2\pi C}{\lambda^2}$,

$$\frac{d\omega}{d\lambda} = -n_1\frac{2\pi C}{\lambda^2}$$

Therefore, $v_g = \frac{d\omega}{d\beta} = \frac{d\lambda}{d\beta}.\frac{d\omega}{d\lambda}$

$$v_g = -\frac{\frac{2\pi C}{\lambda^2}}{\frac{2\pi}{\lambda}.\frac{dn_1}{d\lambda} - n_1\frac{2\pi C}{\lambda^2}}$$

$$v_g = \frac{C}{(n_1 - \frac{dn_1}{d\lambda})} = \frac{C}{N_g}$$

Where, $N_g = n_1 - \frac{dn_1}{d\lambda}$ is called the group index of the fiber. Thus the group velocity and phase velocity ($v_p = \frac{C}{n_1}$) are different in the optical fiber. Otherwise an optical fiber is a dispersive medium. Intramodal dispersion arises due to the dependence of group velocity on the wavelength. Further it increases with the increase in spectral width of the optical source. This spectral width is the range of wavelengths emitted by the optical source. For example in the case of LED, it has a large spectral width about 40 nm since it emits wavelengths from 830– 870 nm with the peak emission wavelength at 850 nm. In the case of laser diode which has a very narrow spectral width, the spectral width is about 1 or 2 nm only. Thus the Intramodal dispersion can be reduced in an optical fiber using single mode laser diode as an optical source. Intramodal dispersion arises due to the dispersive properties of the optical fiber material (material dispersion) and the guidance effects of the optical fiber (waveguide dispersion) [19].

(a)Material Dispersion (or) Chromatic Dispersion

This dispersion arises due to the variation of the refractive index of the core material with the wavelength or frequency of light. It is directly proportional to the frequency bandwidth of the transmitted pulse. A material exhibits material dispersion when $d^2n_1/_{\lambda^2} \neq 0$. For pure silica, the material dispersion tends to zero at the wavelength of 1.3μm. Further by using an optical source with a narrow spectral width, the material dispersion can be reduced. For shorter wavelengths around 0.6μmto0.8μm, the material dispersion exponentially rises to a higher value [19].

(b)Waveguide Dispersion

This dispersion arises due to the finite frequency bandwidth and the dependence of the mode group velocity on the frequency of light. Higher the frequency bandwidth of the transmitted pulse, higher will be the waveguide dispersion. The amount of waveguide dispersion depends on the fiber design like core radius, since the propagation constant 'β' is a function of a=λ. In the case of single mode fibers, waveguide dispersion arises when $d^2\beta/_{d\lambda^2} \neq 0$. In the case of multimode fibers, most of the modes propagate far from the cutoff value. Therefore then all are almost free from waveguide dispersion [19].

(c)Intermodal Dispersion (or) Multimode Dispersion

Intermodal dispersion or multimode dispersion arises due to the variation of group velocity for each mode at a single frequency. Different modes arrive at the exit end of the fiber at different times. So there is multimode dispersion and hence there is broadening of the signal pulses.

Among the three dispersions,

Multimode dispersion > material dispersion > waveguide dispersion.

Based on the dispersion effects, one can get the following results:

(i) The multimode step index fibers exhibit a large value of dispersion due to the enormous amount of multimode dispersion which gives the greatest pulse broadening. At the same time the multimode graded index fiber exhibits an overall dispersion which is 100 times lesser than the multimode step index fiber's dispersion. This is due to the shaping of the refractive index profile in a parabolic manner.

(ii) In the case of single mode step index fibers, they have only intramodal dispersion. Further among the intramodal dispersions, the waveguide dispersion is the dominant one. The material dispersion in them is almost negligible due to axial ray propagation and small core radius. When we compare it with the dispersion in the multimode graded index fiber, the dispersion in the single mode fiber is negligible. That is why single mode fibers are highly useful in long distance communication systems [19].

3.9. Dispersion-shifted Single Mode Fibers

Generally in single mode fibers, zero dispersion is obtained at a wavelength of about 1.3µm. Since there is a finite loss in the silica fiber at 1.3µm, today the fibers are designed such that there is zero dispersion at 1.55µm with a minimum loss. At 1.55µm, the material dispersion in single mode fiber is positive and large, while the waveguide dispersion is negative and small. So to increase the waveguide dispersion equal to that of material dispersion, the relative refractive index difference 'Δ' may be slightly increased by adding more GeO_2 in the core (which increases the refractive index of the core) or adding more fluorine in the cladding (which decreases the refractive index of the cladding) or instead of parabolic refractive index profile, a triangular refractive index profile can be designed. Thus the dispersion-shifted fibers have minimum loss and zero dispersion at 1.55µm [19].

3.10. Dispersion Compensating Fibers

At present the installed fiber optic links are operating at the wavelength of 1.3µmusing conventional single mode fibers. Instead of 1.3µm wavelength if one wants to use 1.55 µm wavelengths to reduce the transmission loss, then the whole fiber optic link should be replaced with the new dispersion-shifted fibers. This will require an enormous expenditure. To avoid this huge expenditure and to use the old fiber optic links dispersion compensating fibers were evolved. These fibers have a large negative dispersion at 1.55µm, while the conventional single mode fibers operating at 1.3µm have positive dispersion at 1.55µm.

By suitably replacing 1 km length of conventional single mode fiber in the fiber optic link with the dispersion compensating fiber for every 100 km length of conventional single mode fiber optic link, one can achieve minimum loss and zero dispersion also [19].

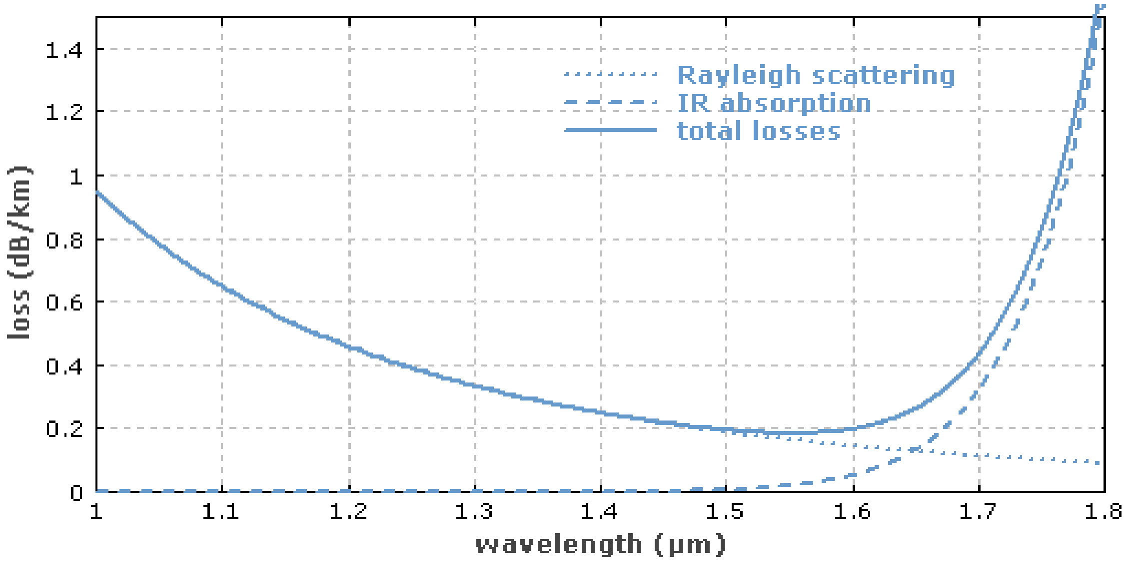

Figure 3.4: Different Intrinsic Losses in Pure Silica

3.11. Transmission Losses In Fibers

The transmission loss or attenuation of the signal in an optical fiber is a very important quantity to consider in optical fiber communication. The attenuation of the signal transmitting through the fiber results from absorption and scattering and is measured in dB/km and is a function of wavelength as shown in figure 3.3 The optical communication wavelengths are 0.8, 1.3 and 1.55µm [19].

Attenuation can be classified into two types:

(1) Intrinsic losses

(2) Extrinsic losses.

Mechanisms generating intrinsic losses

1. Tail of infrared absorption by SiO coupling—it is present at higher wavelengths around 1.4µmto1.6µm.
2. Tail of ultraviolet absorption due to electron transition—it is present at lower wavelengths near 0.8µm. This will produce a loss of 0.3dB/km.
3. Rayleigh scattering due to spatial fluctuation of refractive index and is inversely proportional to λ^4 —it produces a maximum loss in the ultraviolet region only. In the wavelength region around 0.8µmto1µm, it gives a loss of 0.6dB/km [19].
4. Absorption by molecular vibration of OH impurity—fundamental absorption due to hydroxyl (OH) ions is present at λ=2:8µm. But its harmonics occur at wavelengths 1.38µm and 0.95µm respectively. This kind of absorption is almost eliminated by the modified chemical vapor deposition process adopted for the fiber perform production reducing the water content in the fiber to below 10 parts per billion.
5. Absorption by transition metal impurities likes Cr, V, Fe, Mn and Ni—this absorption produces a loss at wavelengths greater than 0.8µm. In ultra low loss fibers, this absorption is practically negligible.
6. Thus it is found that in the case of pure silica fibers the transmission losses are reduced to a minimum value at 1.55µm wavelength. At 1.3µm also, the transmission losses are minimum but the net attenuation is slightly greater with respect to the wavelength 1.55µm [19].

Mechanisms generating extrinsic losses:

1. Geometrical non-uniformity at the core-cladding boundary.
2. Imperfect connection or alignment between fibers.
3. Micro bending.
4. Radiation of leaky modes.

Extrinsic losses are very small when compared to intrinsic losses and can be minimized by proper care during the manufacturing and installation of the fibers [19].

Chapter Four

RADIO OVER FIBER NETWORK

4.1 Introduction

Radio over fiber (RoF) is a type of analog transmission over fiber technology which refers to a light that is amplitude modulated by a radio signal and transmitted over an optical fiber link to centralize the wireless access technology, for example 3G,Wimax communication, WiFi.

In other words radio signals are carried over fiber optic cables. A single antenna can receive any and all radio signals such as 3G, WiFi, cell etc carried over a single fiber cable to a central location where equipment then converts the signals; this is opposed to the traditional way where each protocol type such as 3G, WiFi, cell etc requires separate equipment at the location of the

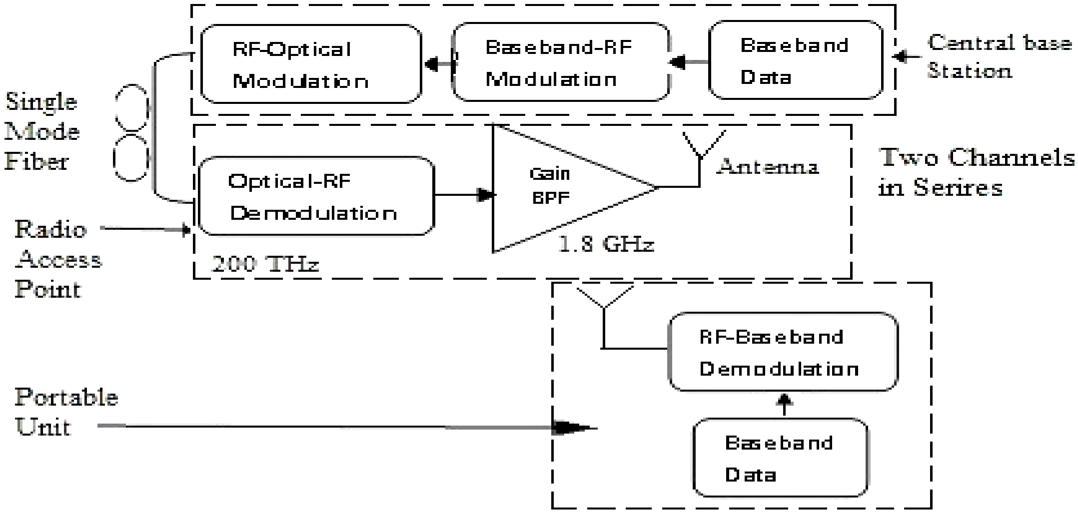

Figure 4.1: Radio over Fiber Concept.

antenna. In this RoF technology wireless signals are able to transport long distance with high fidelity in optical form between a central base station and a set of base stations or a cluster. Fiber optic links can reach at dead zones such as manmade obstacles, mountains area, secluded places, tunnels [34][35][36]. In optical fiber microcell system where microcells in a wide area are connected by optical fibers and radio signals are transmitted over an optical fiber links among base stations and central base station. This microcell system attracted much interest in the telecommunication system just because of low loss and huge bandwidth of optical fiber [37]. The demand of network coverage is increasing rapidly with low loss. In this system, each microcell radio port would consist of a simple and compact optoelectronic repeater connected by and radio frequency fiber optic link to centralized radio and control equipment, possibly located at a preexisting microcell site. Now-a-days RoF systems are widely being used for enhanced cellular network coverage for example offices, shopping malls, rail station, air port terminals, and underground subway station [38]. RoF has a huge number of applications in telecommunication sector. One of the important applications is; it provides a wide range wireless network and many channels.

4.2 Benefits of RoF Technology

Some of the advantages and benefits of the RoF technology compared with electronic signal distribution are given below.

4.2.1 Low attenuation loss

Electrical distribution of high frequency microwave signals either in free space or through transmission lines is problematic and costly. In free space, losses due to absorption and reflection increase with frequency [40]. In transmissions lines, impudence rises with frequency as well, leading to very high losses [41]. Therefore, distributing high frequency radio signals electrically over long distances requires expensive regenerating equipment. As for mm-waves, their distribution via the use of transmission is not feasible even for short distances. The alternative solution to this problem is to distribute baseband signals or signals at low intermediate frequencies from the switching center to the BS [42]. The baseband and intermediate signals are up converted to the required microwave or mm0-waves frequency at each base station, amplified and then radiated. Since high performance Los would be required for up conversion at each base station, this arrangement leads to complex base stations with tight performance requirements. However, since optical fiber offers very low loss, RoF technology can be used to achieve both low-loss distributions of mm-waves, and simplification of Remote Antenna Units (RAUs) at the same time. Commercially, available standard Single Mode Fibers (SMFs) made from glass (silica) have attenuation losses below 0.2dB/km and 0.5dB/km in the 1550nm and the 1300nm windows, respectively. Polymer Optical Fiber, a more recent kind of optical fiber exhibits higher attenuation ranging from 10-40dB/km in the 500-1300nm regions [43] [44]. These losses are much lower than the encountered in, say coaxial cable, whose losses are higher by three orders of magnitude at higher frequencies. For instance, the attenuation of a 1/2inch coaxial cable (RG-214) is > 500dB/km for frequencies above 5GHz [45 ROF(14)]. Therefore, by transmitting microwaves in the optical form, transmission distances are increased several folds and the required transmission powers reduced greatly [38] [39].

4.2.2 Immunity to radio frequency interference

Immunity to Electromagnetic Interference (EMI) is very attractive property of optical fiber communications, especially for microwave transmission. Thus is so because signals are transmitted in the form of light through the fiber. Because of this immunity, fiber cables are preferred even for short connections at mm-waves. Related to EMI immunity is the immunity to eavesdropping, which is an important characteristic of optical fiber communications, as it provides privacy and security [39].

4.2.3 Large bandwidth

Optical fiber offers enormous bandwidth. There are three main transmission windows, which offer low attenuation namely the 850nm, and 1550nm wavelength. For a single SMF optical, the combined bandwidth of the three windows is in the excess of 50THz [46]. However, today’s state of the art commercial systems utilize only a fraction of this capacity (1.6THz). But developments to exploit more optical capacity per single fiber are still continuing. The main driving factor towards unlocking more and more bandwidth out of the optical fiber include the availability of low dispersion (or dispersion shifted) fiber, the Erbium Doped Fiber Amplifier (EDFA) for the 1550nm window, and the use of advance multiplex techniques namely Optical Time Division Multiplexing (OTDM) in combination with Dense Wavelength Division Multiplexing (DWDM) techniques.

The enormous bandwidth offered by optical fibers has high capacity apart from the high capacity for transmitting microwave signals. The high optical bandwidth enables high speed signals. The high optical bandwidth enables high speed signals processing that may be more difficult or impossible to do in electronic systems. In other words, some of the demanding microwave functions such filtering, mixing, up and down conversion, can be implemented in the optical domain [47]. For example, mm-wave filtering can be achieved by first converting the electrical signal to be filtered into an optical signal, then performing the filtering by using the optical components such as the Mach Zehnder Interferometer (MZI) or Fiber Bragg Gratings (FBG), and then converting the filtered signal back into electrical form [48]. Furthermore, processing in the optical domain marks it possible to use cheaper low bandwidth optical components such as laser diodes and modulators and still be able to handle high bandwidth signals [49].

The utilization of the enormous bandwidth offered by optical fibers is severely hampered by the limitation of electronic systems, which are the primary sources and receivers of transmission data. This problem is referred to as the ‘electronic bottleneck”. The solution around the electronic bottleneck lies in effective multiplexing. OTDM and DWDM techniques mentioned above are used in digital optical systems. The analogue optical system including RoF technology, Sub-Carrier Multiplexing (SCM) is used to increase optical fiber bandwidth utilization. In SCM, several microwave subcarriers, which are modulated with digital and analog data, are combined and used to modulate the optical signal, which is then carried on a single fiber [50] [51]. This makes RoF systems cost-effective.

4.2.4 Reduction power consumption

Reduction power consumption is a consequence of having simple RAUs with reduced equipment. Most of the complex equipment is kept at the centralized headend. In some applications, the RAUs are operated in passive mode. For instance, some 5GHz Fiber-radio systems employing pico-cells can have the RAUs operate in passive mode [52]. Reduced power consumption at the RAU is significantly considering that RAUs are sometimes placed in remote locations not fed by the power grid [39].

4.2.5 Multi-operator and multi-service operation

RoF offers system operational flexibility. Depending on the microwave generation technique, the RoF distribution system can be made signal-format transparent. For example, the Intensity Modulation and Direct Detection (IM-DD) technique can be made to operate as a linear system and therefore as a transparent system. This can be achieved by using low dispersion fiber (SMF) in combination with pre-modulated RF subcarriers (SCM). In that case, the same RoF networks can be used to distribute multi-operator and multi-service traffic, resulting in huge economic savings [53].

4.2.6 Dynamic resource allocation

Since the switching, modulation, and other RF functions are performed at a centralized headend, it is possible to allocate capacity dynamically. For example, in a RoF distribution system for GSM traffic, more capacity can be allocated to an area (e.g. office, shopping mall, university) during peak times and then re-allocated to other areas when off-peak times (e.g. to populated residential areas in the evenings). This can be achieved by allocating optical wavelengths through Wavelength Division Multiplexing (WDM) as need arise [54]. Allocating capacity dynamically as need for it arises obviates the requirement for allocating permanent capacity, which would be a waste of resources in cases where traffic loads very frequently and by large margins [53]. Furthermore, having the centralized headend facilities the consolidation of other signal processing functions such as mobility functions and macro diversity transmission [54].

4.3 Application of RoF

4.3.1 Access to dead zones

An important application of RoF is its use to provide wireless coverage in the area where wireless backhaul link is not possible. These zones can be areas inside a structure such as a tunnel, areas behind buildings, Mountainous places or secluded areas such as jungles [61].

4.3.2 Fiber To The Antenna (FTTA)

By using an optical connection directly to the antenna, the equipment vendor can gain several advantages like low line losses, immunity to lighting strikes/electric discharges and reduced complexity of base station by attaching light wave Optical-to-Electrical (O/E) converter directly to antenna [61][39].

4.3.3 Satellite communication

One of the first applications of RoF technology was satellite communication. One of the applications involves the remoting of antennas to suitable locations at satellite earth stations. In this case, small optical fiber links of less than 1km and operating at frequencies equipment can be centralized.

The second application involves the remoting of earth stations themselves. With the use of Radio over Fiber technology the antenna can be positioned many kilometers away for the purpose of improved satellite visibility or reduction in interference from other terrestrial system [38].

4.3.4 Wireless LANs

As portable devices and computers have become more and more powerful as well as widespread, the demand for mobile broadband access to LANs we be increasing. This will lead to higher carrier frequencies to meet the demand for capacity. Higher carrier frequencies in turn lead to microcells and pico-cells, and all the difficulties associated with coverage discussed above arise. A cost effective way around this problem is to deploy RoF technology [38].

4.3.5 Vehicle communication and control

Vehicle communication and control is another potential application of Radio over Fiber technology. Frequencies between 63-64GHz and 76-77GHz have already been allocated for this service within Europe. The objective is to provide continuous mobile communication coverage on major roads for the purpose of Intelligent Transport Systems (ITS) such as Road-to-Vehicle Communication (IVC). ITS systems aim to provide traffic information, improve transportation efficiency, reduce burden on drivers, and contribute to the improvement of the environment. In order to achieve the required coverage of the read network, numerous base stations are required. These can be made simple and of low cost by feeding them through RoF systems, thereby making the complete system cost effective and manageable [38].

4.4 Limitations of RoF

Since RoF involves analogue modulation, and detection of light, it is fundamentally an analogue transmission system. Therefore, signal impairments such as noise and distortion, which are important in analogue communication systems, are important in RoF systems as well. These impairments tend to limit the Noise Figure (NF) and

Dynamic Range (DR) of the RoF links [55]. DR is a very important parameter for mobile (cellular) communication systems such as GSM because the power received at the BS from the Mobile Unites (MUs) varies widely (e.g. 80dB) [53]. That is the RF power received from a MU which is close to the BS can be much higher than the RF power received from a MU which is several kilometers away, but within the same cell.

The noise sources in analogue optical fiber links include the laser's Relative Intensity Noise (RIN), the laser's phase noise, the photodiode's shot noise, the amplifier's thermal noise, and the fiber's dispersion. In Single Mode Fiber (SMF) based RoF, systems chromatic dispersion may limit the fiber link lengths and may also cause phase de-correlation leading to increased RF carrier phase noise [40]. In Multi-Mode Fiber based RoF systems, modal dispersion severely limits the available link bandwidth and distance. It must be stated that although the RoF transmission system itself is analogue, the radio system being distributed need not be analogue as well, but it may be digital (e.g. WLAN, UMTS), using comprehensive multi-level signals modulation formats such as xQAM, or Orthogonal Frequency Division Multiplexing (OFDM) [39].

4.5 RoF Multiplexing Techniques

4.5.1 Subcarrier multiplexing in RoF systems

Optical Subcarrier multiplexing (SCM) is a scheme where lots of signals are multiplexed in the radio frequency (RF) domain and transmitted by a single wavelength. SCM has an advantage that microwave devices are more matured than optical devices.

A popular application of SCM technology in fiber optic systems is analog cable television (CATV) distribution system. Because of the simple and low-cost implementation, SCM has also been proposed to transmit multichannel digital optical signals using direct detection for local area optical networks [38].

The basic configuration of Sub-Carrier Multiplexing and Wavelength Division Multiplexing.

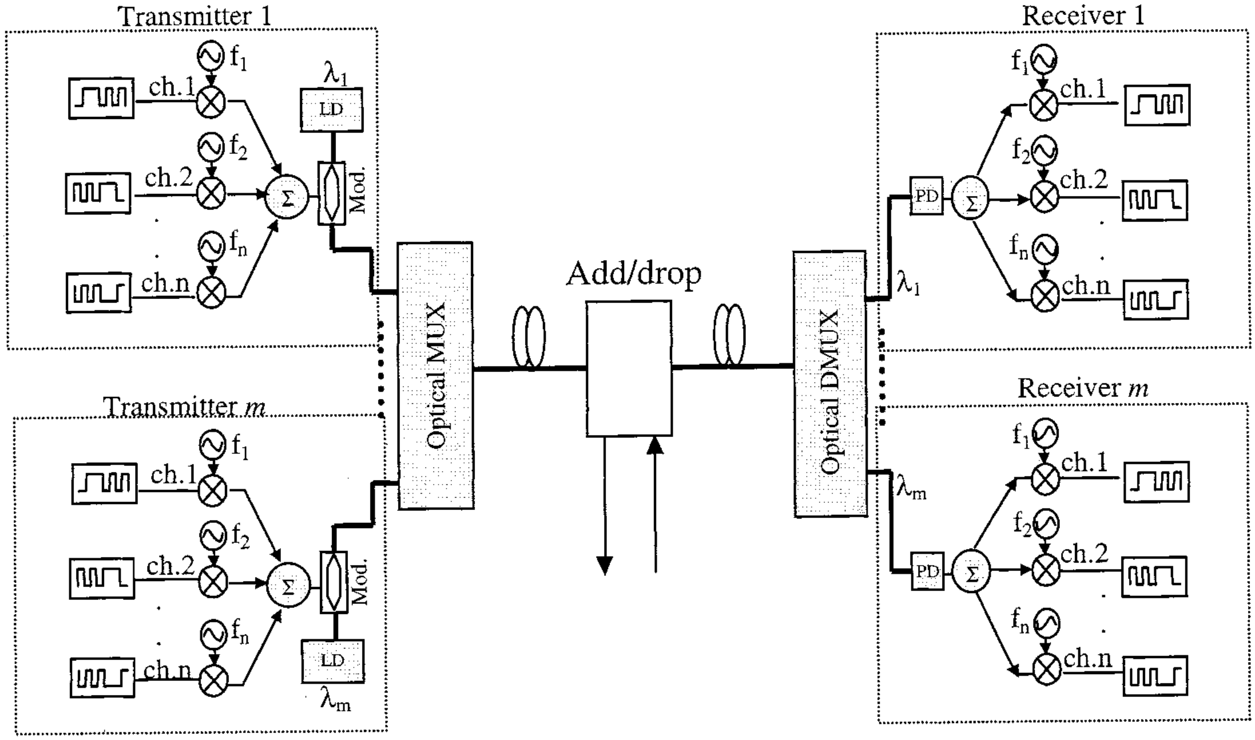

Figure 4.2: The basic configuration of SCM and WDM Optical system [56].

In this example n independent high speed digital signals are mixed by N different microwave carrier frequencies $f_{i.}$ These are combined and optically modulated onto an optical carrier. m wavelengths are then multiplexed together in an optical WDM configuration. At the receiver an optical demultiplexer separates the wavelengths for individual optical detectors. To separate digital signal channels Radio Frequency coherent detection is used.

SCM is less sensitive to fiber dispersion because the dispersion penalty is determined by the width of the baseband of each individual signal channel. Compared to conventional

WDM systems, on the other hand, it has better optical spectral efficiency because much narrower channel spacing is allowed [38].

Conventional SCM generally occupies a wide modulation bandwidth because of its double-sideband spectrum structure and, therefore, is susceptible to chromatic dispersion. In order to reduce dispersion penalty and increase optical bandwidth efficiency, optical SSB modulation is essential for long-haul SCM–WDM optical systems. Fortunately, optical SSB is relatively easy to accomplish in SCM systems. This is because there are no low-frequency components, and the Hilbert transformation is, thus, much simpler than OSSB in conventional TDM systems [38].

4.5.1.1 Advantages of sub-carrier multiplexing

One of the main advantages of SCM is that it supports mixed mode data traffic. Each sub-carrier may transport a signal having an independent modulation format. Therefore, it can be used for wide range of applications such as CATV, wireless LANs and mm-wave applications to name but a few. This is a consequence of the fact that the modulation technique used and data carried on each sub-carrier are at low frequencies, components required for SCM-based systems are readily available. Modulators, mixers and amplifiers employed in cable (or community) TV (CATV) and other satellite systems can still be used in SCM systems leading to low system costs [39].

4.5.1.2 Disadvantages of sub-carrier multiplexing

The disadvantage of SCM is that being an analogue communication technique, it is more sensitive to noise effects and distortions due to non-linearities. This places stringent linearity requirements on the performance of components especially for applications such video, where a Carrier-to-Noise-Ratio (CNR) > 55 dB may be required. The light source’s Relative Intensity Noise (RIN) is the major source of noise and should be kept as low as possible [53][55].

4.5.2 Wavelength division multiplexing in RoF systems

The use of Wavelength Division Multiplexing (WDM) for the distribution of RoF signals has gained importance recently. WDM enables the efficient exploitation of the fiber network’s bandwidth. However, the transmission of RoF signals is seen as inefficient in terms of spectrum utilization, since the modulation bandwidth is always a small fraction of the carrier signal frequency. Therefore, methods to improve the spectrum efficiency have been proposed [40]. RoF on WDM systems have been reported. Carriers modulated with mm-waves are dropped from and added to a fiber ring using Optical Add-Drop Multiplexers (OADM). The OADM are placed at base stations and tuned to select the desired optical carriers to drop [57][58][59][60].

Chapter Five

CONGESTION CONTROL IN RAN USING RADIO OVER FIBER NETWORKS

It is clear that our focus area is congestion control. In congestion issues the MSC cannot take real time decisions about traffic control. This happens because every RBS is an individual unit of information center. It gives the information about that particular cell zone but the picture of the whole locality or the neighboring is not provided.

A MSC does not have information such that if a user is getting strong service signals from the neighboring RBS's, comparison of congestion rates of the neighboring RBS's etc. it happens because the information is sent to the MSC in the electrical media via wires. The other reason is all the RBSs are connected to single MSC. This is a problem considering that in an urban area the congestion rate is always high. This condition will make the decision making capability of the MSC in real time near to impossible.

For the reasons above we proposed a model of which will be a remedy to the congestion problem. We also tried to provide architecture and mathematical explanations to the proposal.

5.1 System Architecture

As stated earlier that the probable cause for congestion problem is that the MSC does not have the real time information of the local areas. In our proposal we emphasized the importance of a secondary control unit. This secondary control unit can be called Central Base Unit (CBS).

The central base unit will be connected to the RBSs and MBS by optical fiber. In this way the data and control information will be available to the CBS and MBS in real time.

We also assumed that all RBS cell zones will have overlapping areas. The overlapping areas will give user of one cell zone the membership to other cell zone and RBS network. This overlapping region will facilitate rerouting of the calls and service requests to other RBS's. The expiations of these features in the proposed system and their inner workings will be provided in the following chapter.

5.1.1 Physical Region

The physical regions of our proposed system include Antenna, Radio Base Station (RBS), Central Base Station (CBS), Optical to Electrical Signal converter and optical fiber.

The antenna will serve as the wireless signal transverse. It will transmit and receive the modulated wireless signal. To this tower there will be a signal converter which will change that wireless analogue signal to electrical signal. In the conventional wireless communication system the converted electrical signal will be modulated, filtered and ready for call processing. It will also give forward and reverse control massage to the mobile device. This forward and reverse control massages help the antenna determine the user location. This feature will come very handy in the proposed operation of the model.

The Radio Base Station (RBS) is the processing unit of the mobile service system. It is used co-ordination to the MSC. As per instructions from the MSC in assigns channels and performs handoffs. These units also perform filtering, call processing and informs the MSC about the presence of users in its cell zone. Although the congestion report sent by the RBS is singular. The word singular in this context means that the report informs the congestion population of a particular cell zone. The MSC does not get information of the whole integrated locality. This problem is of the conventional communication model. In our model several RBSs, most probably 4 or 5 will be connected CBS via optical fiber. Before the information is sent by the optical fiber the electrical signal is converted to optical signal.

Electrical to optical converter is a device used now in communication sector to send massage to the MSC. This device turns the electrical signal provided by the antenna into optical signal with the help of Laser LEDs and highly sensitive optical sensors. Then the converted signal is sent through the Optical fiber.

Optical fiber is used simply for the purpose that it is highly immune to Electro-Magnetic Interference. This optical fiber also ensures high data speed and band width. As stated before that one of our objectives as a research group is to find a model which will be efficient for all coming mobile advances. For this very reason higher bandwidth and higher data speed is needed in our proposed model.

Finally we will need Central Base Station (CBS). CBS is a secondary control device. This control device will be monitoring 4 or 5 RBSs. These RBSs will be connected to the CBS through optical fiber. In our proposed model these RBS will be sending the congestion information, user information to the CBS instead of MSC. As CBS is responsible for one particular location it can take a better decision of the handoff and rerouting solutions within the monitoring RBSs. As it is also responsible for several RBSs it can receive the information about the RBSs'. This information will help the CBS make a better assumption of the congestion issues of the locality. Not only will it help get a better congestion report of the locality. The information of user presence in the area will help make better call request probability assumption. It will also give CBS a comparative congestion ratio of different cell zones so that it can reroute service request as it pleases.

Our major assumption in making this system model is that there are some overlapping regions in the cell zones. It is explained broadly in the next section.

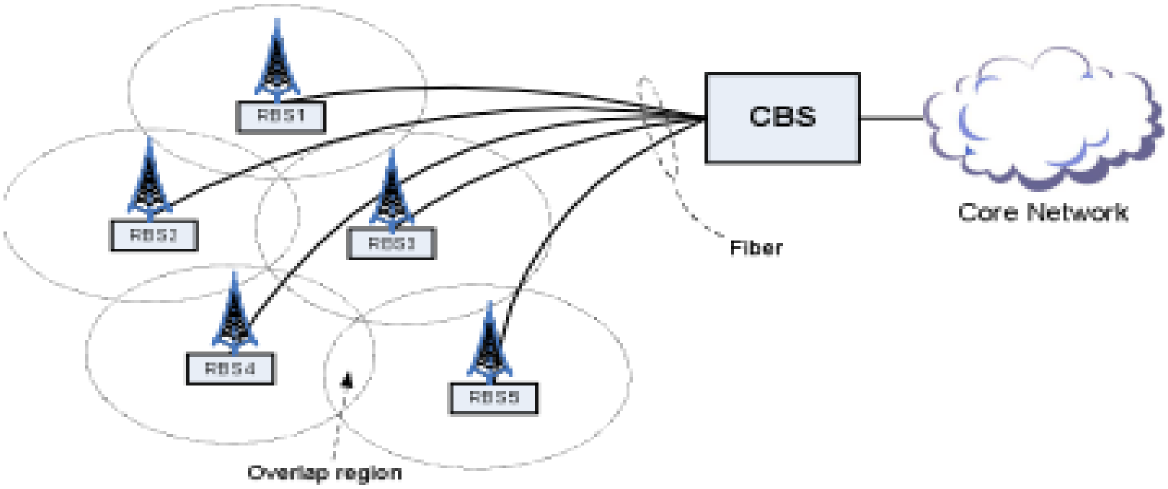

Figure 5.1: Radio over Fiber networks concept.

5.1.2 Overlapping region

The most important assumption in the research is the overlapping regions. We assumed that all cell zones have overlapping regions with each other.

Let us assume that there is a cell zone 1 which is under RBS1. Now if a user is present at cell zone 1 he or she will get the strongest service signal from the RBS1. In the conventional system we had assumed that all cell zones are independent of each other. One cell will not have any overlapping common region to any other cell zone. Because of this very reason the MSC has a very difficult time to create a complete congestion profile of an area.

In our proposed model there will be several overlapping regions. It is our assumption that a cell zone will have overlapping regions with 4 other cell zones. Due to these cell zones the cell zones can cover one active user by several RBS's.

Let us give an example, assuming that one of the cell zones in our proposed system model. In this example an active user is present in one cell zone. Now due to overlapping regions the user will have access to many other RBSs. The user will have the strongest service signal from its home cell zone. Home cell zone is the cell zone from whose RBS user is nearest to.

Although the user will receive very strong service signals from the neighboring overlapping cell sites. This creates a coverage area with no blank spots. A user will get service signal from anywhere in te service area. It might even be possible that the user might get more than one service signal from neighboring RBS. This is a very important feature in the sense that if for any reason the home cell zone is not able to give requested service than the other neighboring cell zones will provide for it.

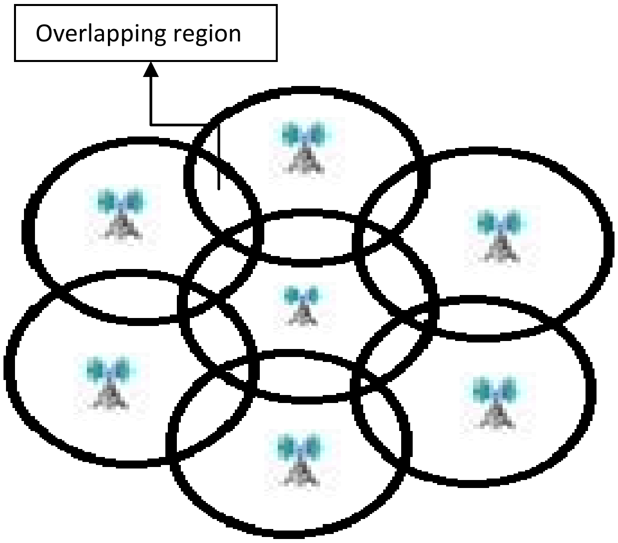

Figure 5.2: Overlapping cell zones

5.2 Mathematical Model

Before we get into the mathematical expirations we must know about some assumptions that we took to make the model valid. We have taken the noise created by the congestion in the consideration. The other noises will be considered as White Gaussian Noise. In case of RBS the Gaussian noise and other noises will have commutative effect on the total Signal to Noise Ratio (SNR). For our consideration we will take the SNR of the optical noises and show how it can be reduced.

The overall signal to noise ratio (SNR) in RoF system is a cumulative SNR which is a weighted sum of Optical SNR (OSNR) at the optical channel and RF SNR at the wireless RF channel. This cumulative SNR is expressed by the equation (5.1)[62]

$$\text{SNR}=\frac{OSNR}{1+\frac{10^{L/10}}{G_{op}}} \qquad (5.1)$$

Where,

$$\text{OSNR}=\frac{m^2 I_D^2 E[s^2(t)]10^{-\frac{L_{op}}{10}}}{\langle I_{sh}^2\rangle+\langle I_{RIN}^2\rangle+\langle I_{th}^2\rangle} \qquad (5.2)[62][63][64]$$

G_{op} is optical amplifier gain, L_{op} is RoF link loss, I_D is photo detector current, s(t) is the RF signal, m is modulation index and the term $I_{shot}^2 + I_{RIN}^2 + I_{th}^2$ is RoF link noise. In RoF link noise, the component $\langle I_{RIN} \rangle$ is known as the Relative Intensity Noise (RIN) which significantly depends on RF signal power $\langle s^2\langle t\rangle\rangle$ at each sub carrier multiplexing point.

$$\langle I_{RIN}^2\rangle = P_{RIN}\,\Re^2 P_o^2 B\left[1+\sum_{i=1}^{n} m_i^2\langle s^2\langle t\rangle\rangle\right] \qquad (5.3)[62]$$

In the equation above P_o is the mean optical power, B defines the Bandwidth of the signal, P_{RIN} is the Relative Intensity Noise (RIN) power.

From the equation above, we see that RIN nonlinearity by the RF signal power at the Sub Carrier Multiplexing (SCM) link. With more active users in the cell site SCM contribution to RIN increases and in turn it reduces the OSNR as stated in equation (5.2). A reduced OSNR eventually reduces the overall SNR of the RoF system as shown in equation (5.1).

By defining a capacity threshold for SCM link at CBS, CBS can maintain the RIN at low value so the OSNR level is increased. Therefore, the overall SNR of the RoF system can be maintained at an acceptable range so that the calls within an RBS do not get congested.

We know that short noise is generated by active electronic components. It might be a very prominent noise in wireless communication. Although in our proposed model the most the communication is done in optical media so the short noise will be very little for consideration making it less dominant.

The other noise is Thermal noise which is generated by temperature change. The mathematical expiration of thermal noise is given below

$$P_n=kTB$$

Where P_n is the power of thermal noise, B is the shot noise variance, T is temperature in Kelvin and k is Boltzmann constant. Now it is prominent that the thermal noise is dependent on temperature. In optical communication the temperature does not rise beyond a certain level. So the Thermal noise is not going to increase very much.

On the other hand Relative Intensity Noise (RIN) is dependent on the number of users. If we return to the equation (5.3) we can see that RIN depends on P_o .This is mean optical power. This power increases with the increase of users. So in the situation where there is congestion the RIN can be so dominating that it can make RBS drop or block service requests.

Returning to the equation (5.2) we can see that, denominator has the term $I_{shot}^2 + I_{RIN}^2 + I_{th}^2$ where $\langle I_{shot} \rangle$ is the short circuit noise and $\langle I_{th} \rangle$ is the thermal noise. Now it can be seen by their definition that $\langle I_{RIN} \rangle$ is going to be a much larger factor than other noises, so it can be assumed that

$$I_{RIN}^2 \gg I_{Shot}^2 + I_{th}^2$$

So the reduced OSNR equation will stand

$$\text{OSNR}=\frac{m^2 I_D^2 E[s^2(t)]10^{-\frac{L_{op}}{10}}}{I_{RIN}^2} \qquad (5.4)$$

Which farther more adds to the fact that if the $\langle I_{RIN} \rangle$ increases than the OSNR will decrease. Now for the sake of signal clarity there has been set a pre-determined level by the RBS about the capacity of the call traffic it can process. Now call traffic increases beyond that capacity level than $\langle I_{RIN} \rangle$ will increase which will make OSNR decrease and in turn make SNR drop beyond the signal quality level which will make the call noise enough to drop the call.

5.3 Proposed Congestion Control Scheme

In our proposed model, we emphasized on the fact that MBS does not have real time information on the RBS congestion issues. So we introduced the CBS. CBS is a intermediary secondary control unit. It is linked between RBS and CBS. The entire data and control signal between RBS, CBS and MBS is done by optical signals via optical fiber.

In this model a user is served with service signals from more than one RBS. So there is always network coverage provided to the mobile device.

Now let us assume an situation, an active user is in the cell zone 01. The user is getting service signal from home RBS which is RBS1. As stated before the mobile device will get service signals from other neighboring RBS's. This strong service signals are gotten by the overlapping regions of the cell zones.

As showed in the mathematical expirations beforehand that all RBSs have a certain threshold. This threshold value is taken from the equation (5.4). It is said before that Relative Intensity Noise $\langle I_{RIN} \rangle$ increases with the increase of congestion. It can be seen that if the congestion rate is 85% the OSNR below the acceptable level. From the equation (5.1) it is shown that if OSNR drops, the SNR drops too. At 85% congestion rate the SNR drops to a level that RBS cannot take any new service requests from the active users. This causes the RBS to block and drop calls. This causes the reduction of the service quality.

Now if the user in cell zone 01 is trying to make a call, then the RBS will user information to the CBS. The user information will additionally contain the RBS's congestion rate, user location and what RBS’s other than the home RBS service signal is available to the user.

If CBS sees that the congestion rate is less than the threshold level for the RBS which is 85% then the CBS will patch the call through to the user.

If the congestion of the home RBS has reached threshold value then the CBS will seek which of the other RBS’s have strong service signal provided to the user. If it finds such a RBS, CBS will reroute the call through that RBS. This rerouting to the new RBS will make the congestion rate of the home RBS stay at the same level. On the other hand, the new RBS will take the call. The new RBS will have less call congestion. Making the SNR of the RBS never go beyond that threshold value. This causes the service quality much superior to others.

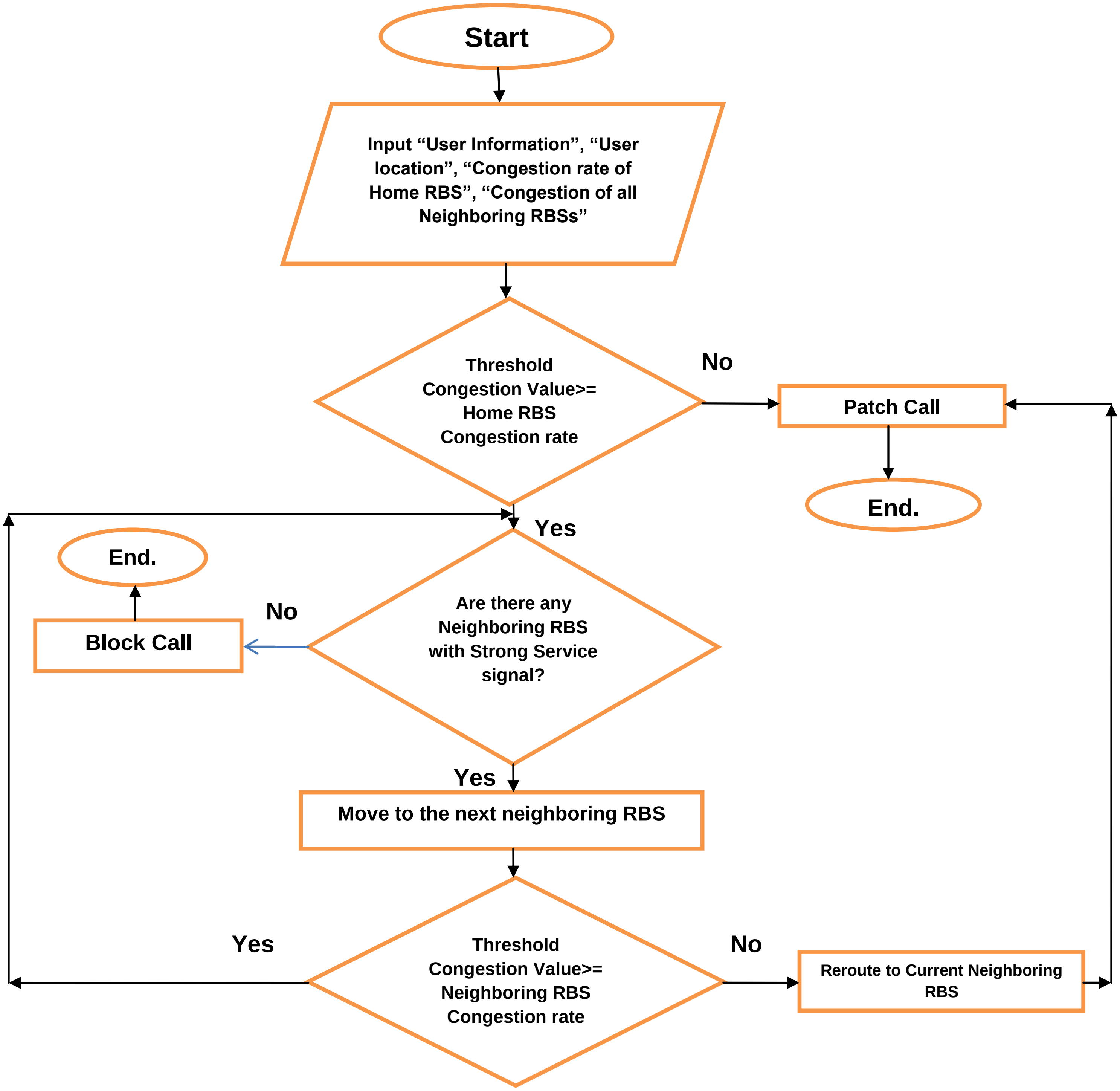

Figure 5.3: Flowchart of Proposed System Model.

5.4 Simulations

We have done some simulations in MATLAB to examine the proposed model. We have used some assumption on the simulation to get the results. The simulation figure and the results of the experiments are explained in the next chapter. The next chapter is titled “Simulation and Results”.

Chapter Six

SIMULATION RESULTS AND ANALYSIS

Considering 5 neighboring RBSs connected with one CBS via optical fiber the proposed congestion control system was simulated. In the simulation, each user radio signal was considered as one individual SCM channel in the SCM link. We also considered that *RIN* is the dominating noise factor in RoF link noise. Our simulation focus was to compare the overall received SNR in RoF empowered wireless systems with proposed congestion control and without congestion control. Figure 6.1 depicts the simulation results below.

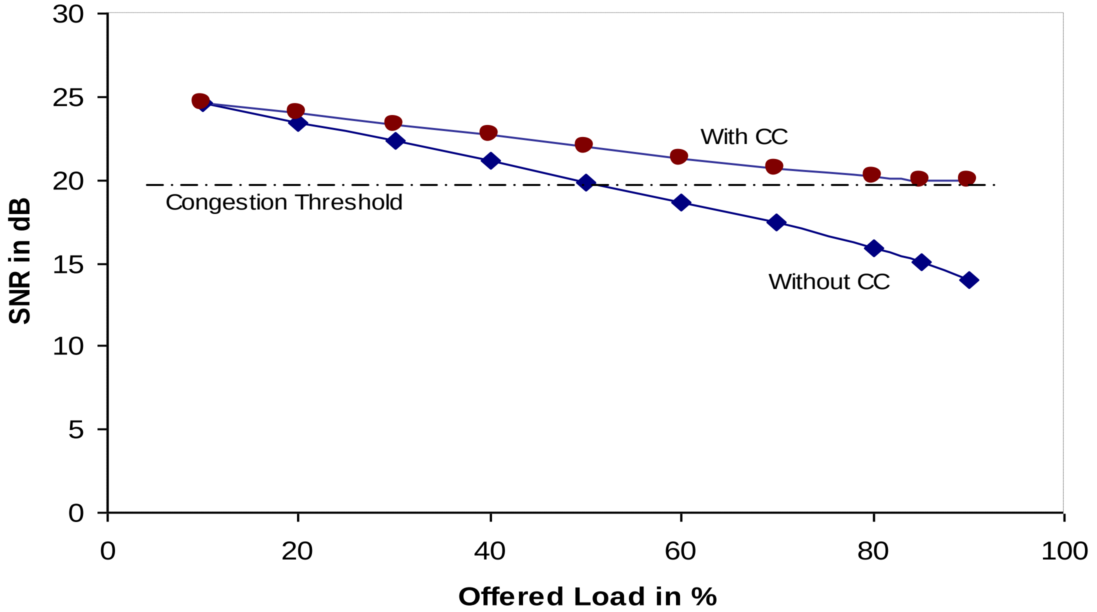

Figure 6.1: Performance comparison between RoF based RAN with congestion control and without congestion control.

In Figure 6.1, we notice that overall SNR in RoF based RAN with congestion control is maintained above the acceptance threshold even when the offered traffic load is more than 90%. While on the other hand, the SNR in RAN without congestion control drops below the acceptance threshold when the traffic load is at about 52%. The performance improvement with RoF based wireless system using congestion control is significant.

In another simulation we focused on the comparison between the overall SNR received in RoF and the call dropping probability. Figure 6.2 shows the simulation results below.

In the figure 6.2, we notice that with increasing SNR in RoF, a parabolic fall in call drop is noticed. As stated in the figure before the RoF based RAN has a flatter gradient of decay. Thus it is a safe assumption that the SNR will not fall below a certain level. We know from the previous chapters that call drop probability is a function of noise. From the figure 6.1 the system that SNR never drops below 20 dB. Now if we take look at the figure 6.2 we will see that with the increase of SNR the call drop probability fall. More importantly when the SNR is at 20 dB the call drop probability is at 38% which is better considering all the existing models and as the SNR never drops 20 dB. This indicates that the call drop probability never rises above 38%.

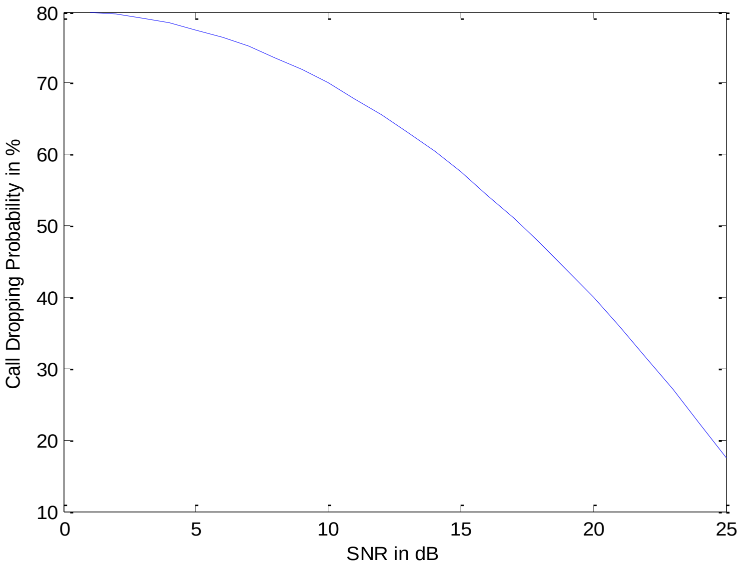

Figure 6.2: Performance comparison between call dropping probability and SNR received in RoF.

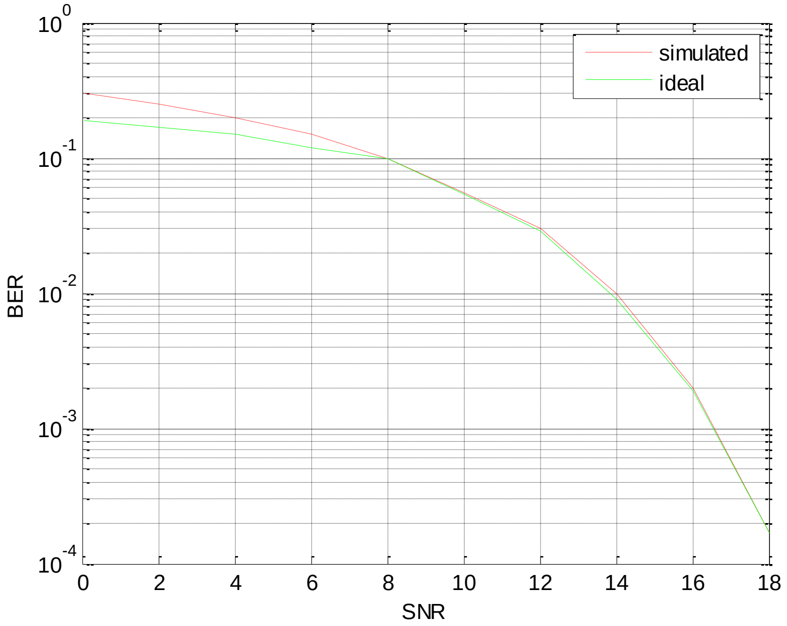

Figure 6.3**:** Performance comparison between SNR and BER

Now from the figure 6.3 it is clear that with the increase of SNR the BER is decreasing to a factor that the system model becomes one with the ideal situation. It is explained before that the SNR never drops below 20 dB so the BER will be very low which is so negligible that it cannot be showed in the figure. So the System has very low BER.

Thus from the simulations we can see that with the increase of SNR call drop probability falls and BER also falls. This proves that it is a better replacement to the existing communication models. In the next chapter we will conclude our thesis with our overall findings on the subject and future research possibilities in this field.

Chapter Seven

Conclusion

Communication sector is one of the fast growing sector and also most challenging as well. It is fast growing because day by day the cost of different communication medium like-Mobile, Internet, telephone is decreasing and at the same time the invention and implementation of new technologies are going at the same pace. One other factor that is also play a part is the competition among different communication service providers. All the factors are responsible for the fast growth of the users. As the users are growing fast some quality issues arise like-call drop, congestion etc. In this paper we extensively study the call drop due to congestion in the network and propose a resolution to avoid this problem.

Call drop happen due to many reasons congestion is one of main cause. RAN is one of the main components of wireless communication system. It provides connection to the mobile terminal device to the core that means it connects user devices like-mobile, Tab, Computer, Laptop to the core network. RAN is designed to establish certain number of calls with the core network and if it happens that it gets call establishment request beyond its designed capacity because of increased user then it can’t serve the incoming request and congestion occurred.

There are a good number of resolution techniques to avoid congestion in network. But in this paper we extensively study the problem and come with the idea that RoF is a very potential solution to resolve the congestion issue. In our proposed model, we give importance on the fact that MBS does not have real time information on the RBS congestion issues. So we introduced the CBS. CBS is an intermediary secondary control unit. It is linked between RBS and CBS. The entire data and control signal between RBS, CBS and MBS is done by optical signals via optical fiber. In this model a user is served with service signals from more than one RBS. So there is always network coverage provided to the mobile device. As user can get signal from different RBS so if one of the RBS get congested then the user mobile device can get access to the core network through other RBSs, and thus can avoid congestion.

This analysis is a primary study on how congestion control using RoF technology can mitigate call drop issues in wireless cellular networks. It can be used for further research on leveraging benefits of Radio over Fiber technology in modern communications.

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