TITLE OF DISSERTATION

MICROWAVE LINK PLANNIN & TIME SERIES BASED MICROWAVE LINK CAPACITY OPTIMIZATION

A DISSERTAION

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIRMENTS

FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

Signal Processing & Digital Design

Submitted by:

[Mohammad Jawad Jahed]

(2K19/SPD/23)

Under Supervision of

[PROF. Asok De]

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

OCTOBER 2021

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road Delhi, 110042

CANDIDATE DECLERATION

I Mohammad Jawad Jahed student of M.tech in (Signal Processing and Digital Design), hereby declare that the project report titled (Microwave Link Planning and Time Series Based Microwave Link Capacity Optimization) has been prepared by me and not copied from any source without citation. This seminar report is prepared in partial fulfilment of the requirement for the award of degree of Master of Technology, under the guidance and supervision of Prof. Asoke De.

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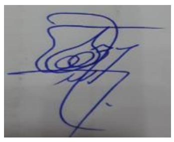
Date: — Sign: 

Electronics & Communication Engineering
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road Delhi, 110042

CERTIFICATE

I hereby, certify that the Dissertation titled (Microwave Link Planning and Time Series Based Microwave Link Capacity Optimization) that is being submitted by Mohammad Jawad Jahed, Roll No (2K19/SPD/23), Electronics & Communication Engineering Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of Dissertation work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full to the other University or Institute for any degree or Diploma.

Place: Delhi　　　　Name of Supervisor: Prof Asok De

Date:　　　　Supervisor

Abstract

For the last thirty years or so, microwave point to point link was the dominant backhaul technology in telecommunication companies. However, the development of mobile technology toward 4G & 5G and the expansion of cellular network in terms of coverage to provide mobile services for more people, has caused an unprecedented traffic growth in telecommunication companies. As a result of this unparalleled increase in traffic, telecommunication companies faced significant challenge in providing sufficient bandwidth in microwave transmission media. Cellular providers can overcome the issue of bandwidth constraint in microwave links by properly utilizing the available frequency resources and by carefully optimizing the capacity of existing microwave links in the network.

While designing the microwave link usually frequency bandwidth which is a very limited and expensive resource is wasted due to lack of accurate knowledge about the traffic of the site. Therefore, in this project we first designed a microwave backhaul link for an LTE site using Ellipse software in order to explain the planning steps required for a microwave link. We also want to illustrate in this part that why the assigned frequency bandwidth during the planning phase doesn't come out to be accurate enough and results in frequency waste.

The second part of project is microwave link capacity optimization using time series forecasting method. As traditionally, microwave link capacity was analyzed and studied manually by transmission planning and optimization team which was a time consuming process and also a difficult task to accurately analyze link throughput or utilization of every individual link.

Recently, application of machine learning provide practical solution for several challenges in cellular networks. In fact with the help of machine learning technique network operators can bring advanced automation in different parts of the network. So in the second part of this project we suggest a time series forecasting method to automatically optimize capacity and frequency bandwidth in microwave link. Historical daily average throughput of every microwave link is used to forecast future capacity in the link based on time series prediction methods. Then considering the predicted capacity an appropriate frequency channel would be selected for every microwave link. Two different prediction model, LSTM and ARIMA is used to forecast future capacity in microwave links. Moreover, MSE, RMSE and MAPE criterion are used for performance evaluation. An MAPE of less than or equal to 6 and peak to average ratio of 20% is considered for frequency channel bandwidth optimization in microwave links.

ACHNOWLEDGEMENT

I would like to express my sincere and special appreciation and a profound gratitude to my academic supervisor Professor Asoke De, for his unflagging support, constant supervision and continuous encouragement throughout this Dissertation. Without his guidance and persistence help writing this Dissertation would not have been possible for me.

I also take this opportunity to express a deep sense of gratitude to all the staff member of Electronics & Communication Engineering Department, who gave me the permission to use all the required equipment, and provided me the valuable information and cordial support which helped me in completing this Dissertation.

NAME: MOHAMMAD JAWAD JAHED

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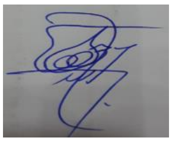

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List of Abbreviations

SBS	Small Base Station
LTE	Long Term Evolution
GSM	Global System for Mobile
mm wave	Millimeter Wave
BTS	Base Transceiver Station
PDH	plesiochronous Digital Hierarchy
SDH	Synchronous Digital Hierarchy
ATM	Asynchronous Transfer Mode
TDM	Time Division Multiple access
IP	Internet Protocol
RRH	Remote Radio Head
RRU	Remote Radio Unit
BBU	Base Band Unit
C-RAN	Cloud Radio Access Network
EHF	Extremely High Frequency
LOS	Line of Sight
NLOS	Non Line of Sight
ARIMA	Autoregressive Integrated Moving Average
LTE	Long Term Evolution
LSTM	Long Short Term Memory
IoT	Internet of Things
RMSE	Root Mean Square Error
DL	Down Link
UL	Up Link
Gbps	Giga Byte per second
Kbps	Kilo Byte per second
ANN	Artificial Neural Network

List of Abbreviations

RNN	Recurrent Neural Network
FFNN	Feed Forward Neural Network
ARMA	Autoregressive Moving Average
MA	Moving Average
AR	Autoregressive
ODU	Outdoor Unit
IDU	Indoor Unit
IF	Intermediate Frequency
RU	Rack Unit
Tx	Transmitting site
Rx	Receiving Site

Chapter 1

Introduction

Microwave point-to-point link was extensively used as a backhaul media in telecommunication companies for the past three or four decades. The incredible potentials of microwave links, like rapid deployment, low cost and ability to cross complicated train, have made this technology as a preferred transmission media in the backhaul network. In fact, microwave technology played a significant role in the establishment of 3G and 4G networks [1]. However, the evolution of cellular network toward LTE-Advanced and 5G, presents new challenges on microwave technology. One of the biggest challenge facing microwave backhaul technology is providing the appropriate capacity to transmit the huge traffic driven by the evolution of cellular network technology.

By launching 5G technology in all over the world, as its deployment is currently continuing at an unbelievable pace by telecom operators, the need for high capacity in the backhaul will soar for coming year. Based on Ericson microwave outlook report 2020, backhaul traffic will experience an incredible increase between the years (2020-2025). Backhaul capacity increase in different places like urban, suburban and rural areas is indicated in table 1.1 [2]. As a result of this unprecedented increase in traffic, microwave backhaul technology faced significant challenge in providing adequate capacity to transmit the huge traffic. To overcome these challenges, and to meet 5G high capacity backhaul demand, cellular network providers applied different techniques such as spectrum efficiency, extra spectrum, throughput efficiency and network optimization [3].

Spectrum efficiency can be achieved by applying techniques like higher order modulation, adaptive modulation, and Multiple input, Multiple output (MIMO). Based on recent study by Yao Wei (2017) an increase in modulation from 1K QAM to 2K QAM and 4QAM would result in a growth of 10% and 9% bandwidth correspondingly

Table 2 1 Mobile backhaul capacity demand between (2020 - 2025)

	3G/4G/ and Ubiquitous 5G		
Year	Urban	Suburban	Rural
2020	500Mbps - 1Gbps	200Mbps - 500Mbps	100Mbps - 150Mbps
2022	1Gbps - 10Gbps	500Mbps - 2Gbps	150Mbps - 350Mbps
2025	5Gbps - 20Gbps	1Gbps - 5Gbps	300Mbps - 2Gbps

Spectrum efficiency can be achieved by applying techniques like higher order modulation, adaptive modulation, and Multiple input, Multiple output (MIMO). Based on recent study by Yao Wei (2017) an increase in modulation from 1K QAM to 2K QAM and 4QAM would result in a growth of 10% and 9% bandwidth correspondingly. The study indicates that currently microwave equipment support up to 4096 QAM modulation and is estimated that microwave equipment should be able to manage up to 8192 QAM or even 16384 QAM in the future [4]. In addition, finding more frequency spectrum is just another method that is used to increase the capacity in microwave links. Traditional microwave frequency band (6-42) GHz has been extensively used and reach nearly to a full extent. To develop a multi-Gigabit wireless backhaul that can meet the high capacity demand of the 5G technology, higher frequency band at millimeter wave such as V-band (57-64 GHz) and E-band (71-76 GHz and 81-86 GHz) that has higher bandwidth is required [5].

Another way to boost transmission capacity in cellular networks is by precisely monitoring the capacity of the existing microwave sites in the network. Analyzing parameters like link throughput and link utilization from the key performance indicator, to specify those sites where their capacity utilization is very less or very close to the configured capacity would help us to better optimize frequency bandwidth utilization in the backhaul network. Frequency is a very limited and precious resource that must be used very carefully. By precisely monitoring microwave link throughput we can not only efficiently use the available frequency bandwidth and avoid its wastage, but can also improve the overall performance of the network.

However, in telecom companies, microwave wireless backhaul has a very complex infrastructure which consists of several hundreds of sites. By deploying 5G network more number of sites would be added to the network infrastructure as cellular network operators will densify the network and hence would leads to even more complexity of the network. Currently microwave link KPI reports are being analyzed and studied by transmission planning and optimization team which is a very time-consuming process and require a lot of energy and human resources. Moreover, accurately evaluating link throughput, link utilization and link capacity for every individual microwave sites in such a huge and complex network would be a difficult and daunting task. To tackle this problem, an automated system is required to study and analyze different KPI parameters such as link throughput and link utilization and accordingly take appropriate decision.

Recently, application of machine learning for wireless communication become one of the greatest trend in academic research area, and changed into a popular topic for researchers. Machine learning have the potential to provide practical solutions for different challenges of cellular communication networks. Several researches have been conducted to solve various problems in wireless networks. For instance, in [6], application of machine learning for spectrum access and sharing has been studied, in [7], machine learning for optimal resource allocation have been applied, and in [8], application of machine learning in energy efficiency optimization has been considered. Certainly, applying machine learning to automatically study microwave link KPI parameters, optimize capacity and frequency channel bandwidth of the link, would be helpful in efficiently using frequency spectrum in the network.

This project have two prats. In the first part we design a microwave backhaul link for an LTE site to indicate the steps and process required for planning a microwave link. In addition, in this part we also want to illustrate why the assigned frequency bandwidth during the planning doesn’t come out to be accurate enough and results in frequency waste. In the second part we use the potential and capabilities of machine learning and apply time series forecasting methods to automatically analyze microwave link throughput and take suitable decision regarding the assigned capacity of the link during the planning phase. In this phase, first long short term memory from deep learning is used to predict future throughput using the historical throughput data of every microwave link. Then, the required microwave link capacity has been determined based on the predicted throughput and was compared with the assigned capacity of the link during the planning. And finally frequency bandwidth of those microwave links whose capacity was very close or very far from the assigned capacity was adjusted.

1.1 Traditional Capacity Optimization Method and Background Research

Backhaul optimization in cellular networks refers to an ameliorative action that is required to optimize the capacity or frequency bandwidth for traffic flow so that it meets the quality of service [9]. In general, capacity optimization in cellular networks is based on monitoring of user traffic either from the radio access part or from the backhaul itself. Based on [9] three different approaches such as proactive, reactive, and active methods were used to optimize capacity in the network. All these three methods were done manually by analyzing user traffic and hence, require a lot of energy, human resource and time. In addition current equipment used in microwave links are not capable of predicting future throughput or traffic in microwave links, and therefore, cellular network providers cannot properly prepare network capacity based on the future demand.

Recently, many research papers have been written that used time series forecasting models such as statistical models, machine learning models, and deep learning models to predict future traffic in the network. For example, radio traffic of a specific cell is forecasted for a period of one week using Holt-Winters exponential smoothing technique in [10]. In [11], ARIMA and LSTM models are used to predict traffic from a base station in cellular network. In reference [12], GRU and LSTM models from recurrent neural network are compared with ARIMA model for forecasting traffic in the network. Some research paper used spatio-temporal method to forecast traffic in the network. As in [13] a deep spatio-temporal neural networks is used to forecast traffic of cellular network.

In all those research, historical traffic data from radio access part is used to forecast future traffic in the base station, however, traffic in microwave links might be aggregated from different radio access technology and some other traffic type than only traffic from LTE or 3G cell. Therefore, forecasted traffic obtained from radio access part cannot be used to evaluate capacity and find proper frequency bandwidth for microwave links. Some latest paper as in [14] used ARIMA and ANN model to predict utilization of microwave link and accordingly find the required frequency bandwidth and capacity of microwave link.

In this project we fist designed a microwave link for a real LTE site belongs to a local telecom company in Afghanistan. Considering the capacity predicted by Radio Frequency Planning team we have designed a short haul microwave link to transmit the traffic of this site to the switching center. In the second part of this project we have used long short-term memory (LSTM) and ARIMA models to predict future throughput in microwave link. Because based on several studies LSTM and ARIMA models are verified to be a suitable option for predicting historical data in cellular network. So in this part first both LSTM and ARIMA model is used to forecast future throughput in microwave link then by using predicted throughput, required capacity and frequency bandwidth were selected for the respective microwave link.

1.2 Problem Statement

Since the beginning of first generation of cellular network up to the fourth generation microwave point-to-point link was the dominant transmission technology for telecommunication companies. According to the survey done by Ericson more than 60 percent of the access links in UMTS networks was connected through microwave wireless links [15]. However the evolution of cellular network toward the current 5G technology poses significant challenges on microwave backhaul media. Because, explosion in mobile traffic during the 5G era will cause microwave technology to come under intense pressure in terms of providing enough capacity to transmit the huge traffic.

In order to handle massive mobile traffic during the 5G era and provide sufficient microwave capacity in the backhaul, a large amount of frequency bandwidth in the microwave range is required. Although, recently frequency in the V band (57-64 GHz) and E-band (71-76 GHz and 81-86 GHz) that has large bandwidth has been used in the backhaul, still telecommunication companies faces significant challenges due to the shortage of frequency band. One way to solve frequency shortage problem in telecom companies, it is required that we use efficiently the available frequency at hand.

Frequency is a very limited, scares, and costly resource that have to be used carefully. However, during the planning phase, a large amount of frequency is lost due to the improper awareness of traffic in telecommunication sites. Due to this frequency waste, telecom companies are not able to provide the sufficient capacity required for microwave backhaul media. Therefore, in this project we want avoid the frequency lost and also improve the overall performance of the network with the help of an automated capacity optimization method

1.3 Objective

Nowadays, the issue of providing sufficient microwave backhaul capacity to transmit the huge traffic resulted from the evolution of cellular technology has become a serious challenge for telecom companies. Although different ways and techniques such as spectrum efficiency, adding extra spectrum, throughput efficiency and network optimization have been suggested to solve this issue, still telecom companies are struggling with this problem. Therefore in this project we wanted to design an automated system based on time series forecasting to automatically optimize capacity utilization in microwave backhaul links and accordingly decide proper frequency bandwidth in order to avoid frequency waste.

This project has two main parts. In the first part we have designed a microwave backhaul link for an LTE site using Ellipse software in order to explain the planning steps required for a microwave backhaul link. In addition, in this part we also want to illustrate why the assigned frequency bandwidth during the planning phase doesn't come out to be accurate enough and results in frequency waste. The main objective of this part is to design and analyze a microwave point to point link for an LTE site. In this phase I would like to achieve the following specific goals.

- Specifying the required antenna height and selecting a suitable place for the site
- Finding a clear line of sight with the nearest hub site from existing network
- Selecting an appropriate frequency band and frequency bandwidth for the LTE site
- Designing the microwave LOS link while considering an availability of 99.999 %

- Calculating link budget of the site through Ellipse software (Ellipse is a microwave link planning tools used for design and analysis of microwave links)
- Selecting an appropriate equipment for the link while considering the available equipment in the stock.

The second part of this project is capacity optimization of the microwave backhaul site in the network. In this phase I would like to design an automated system based on time series forecasting methods using the historical throughput data in every microwave link. The following specific goal would be achieved in this phase

- Analyzing the dataset by using data analysis technique like plotting and visualizing the data and also applying some statistics technique in order to learn more about the dynamic of traffic and its' patterns in every microwave backhaul link
- Specifying peak to average ratio by plotting the historical throughput of microwave link and also analyzing the data to see if it has trend or seasonality
- Predicting microwave link capacity by time sires forecasting models such as Long Short Term Memory (LSTM) or ARIMA model using historical throughput data of every microwave link
- Optimizing frequency bandwidth of every microwave backhaul link by considering the predicted capacity obtained.
- Checking quality of every microwave link after optimization and seeing that how much utilization every microwave link have

1.4 Methodology

As explained this project have two main parts. The first part contains site planning and microwave backhaul link design. In this part, some important microwave link parameter like loss attenuation calculation fading and fade margins frequency planning and interference calculation are calculated by a microwave link planning software called Ellipse.

The method we developed in the second part of this project consists of automatically optimizing capacity and frequency bandwidth in microwave links and is explained in figure 1.1. In general, this phase is divided into three main parts and the algorithm used in this model is implemented in Python.

In the first step of this phase, we preprocessed the dataset in order to be prepared for time series prediction and analysis. The dataset considered in this project consists of real historical throughput of several microwave links, extracted from network monitoring system (NMS) of a local telecommunication company. First the extracted historical data of each microwave link is converted into a time series data and is passed into the model for further process.

There always exist some missing value in historical data related to microwave links either due to inaccessibility of microwave link from the NMS or due to problem in the microwave links itself. Therefore, missing values have to be handled carefully during data preprocessing. In this project, using *isnull ()* function, first the missing value were found and then were completely removed from the dataset. In addition, in this phase the dataset is rescaled in the range (-1, 1) for better accuracy and rapid convergence of prediction models. Also few outlier value that exist due to an accidently increase in microwave throughput were removed from dataset in the first phase.

The second part of this phase consists of predicting future capacity in microwave links using historical throughput data. In cellular networks mostly historical data for every microwave link is very large and composed of several past years of data. However, few microwave links might exist that would be newly install and might have a historical data of less than one year. Therefore, in this stage, first the number of past observation related to each microwave link will be checked and then an appropriate model will be selected to predict future capacity for each microwave link.

If the historical data or the number of observation for a microwave link is greater than one year, then horizon style LSTM model is used to predict future capacity. The model is evaluated based on the MSE, RMSE and MAPE evaluation criteria. If an MAPE value of ≤ 6 is achieved, then predicted throughput would be used to optimize capacity and frequency bandwidth in the link. If achieved MAPE value ≥ 6, we will modify LSTM model by changing the amount of nodes, hidden layers, regularize dropout and repeat overall process until we achieve the desired MAPE value.

In case where the historical data of a microwave link will be less than one year then we will use either ARIMA or SARIMA model to predict future capacity in the network. Historical throughput data in microwave links might be either stationary or non-stationary and may have some seasonality. If the data do not have seasonality we simply use ARIMA model to predict future capacity otherwise we use SARIMA model to forecast future capacity. We used grid search to find the best parameter in both ARIMA and SARIMA model. Again we have used MSE, RMSE and MAPE to evaluate the performance of our model. For an MAPE value of ≤ 6 we used the predicted throughput to optimize capacity, otherwise we modified our model in order to achieve the desired value of MAPE.

The final step in this phase is capacity and frequency optimization. In this stage after checking the MAPE value to ensure that it is less than or equal to 6%, the allocated capacity will be replaced with the optimized capacity based on the following formula.

$$C_{op} = C_f + X * C_f/100 \pm e_m \quad (1.1)$$

In the above equation C_{op} is optimized capacity, C_f is forecasted capacity, and e_m is prediction model error which is considered equal to or less than 6 percent in this equation. As forecasted capacity in the model is evaluated based on daily average throughput, therefore X is added in equation 10, so that the optimized capacity can handle the peak data rate during busy hour. The value of X in this equation is being evaluated based on the peak to average ratio, and according to our estimation most of the microwave links had a peak to average ratio of around 15 percent.

Hence, $X = 15$ means that 15% of extra capacity would be added with the forecasted capacity in order to support peak traffic in microwave link.

After obtaining optimized capacity from the model, a proper frequency channel and equipment configuration would be selected for each microwave link as indicated in table 1.2. Every cellular operator has specific frequency channels that are licensed by an authorized government authority

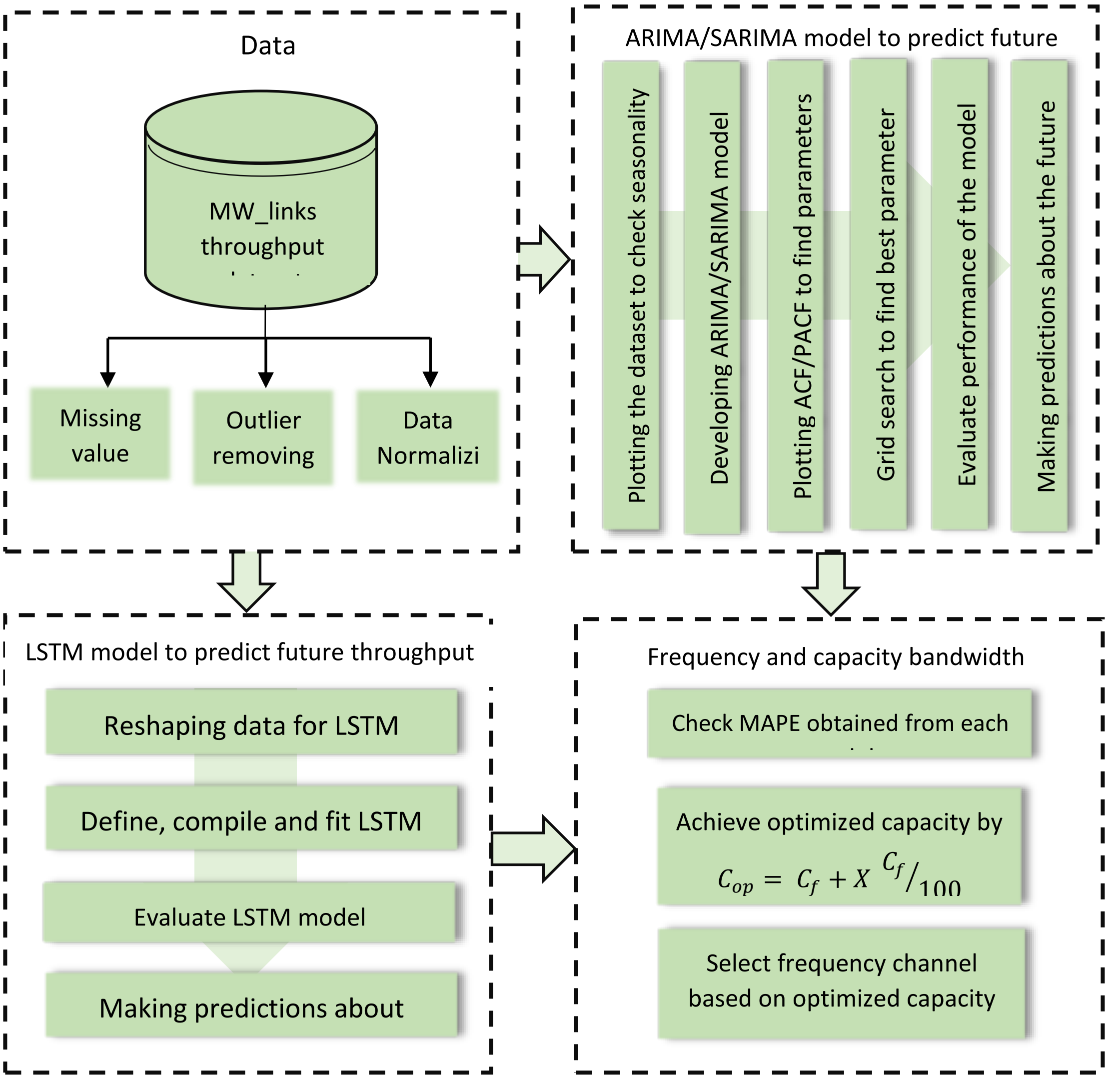

Figure 1.1 Methodology used for capacity optimization

Therefore, from the available frequency channels, an appropriate frequency bandwidth would be selected for proposed optimized capacity. An example of microwave link capacity in (MBps) at different channel bandwidth and modulation type for HUAWEI radio is indicated in table 1.2. For instance, if the anticipated optimized capacity would be 60 Mbps then 14 MHz channel with 64 QAM would be the best option for mentioned link.

Table 2. 2 Example of microwave link capacity at we GHz frequency channel

		Frequency channel bandwidth			
RTN-905 HUAWEI Radio Capacity In(MBps)	Modulation Type	Channel Bandwidth 56 MHz	Channel Bandwidth 28 MHz	Channel Bandwidth 14 MHz	Channel Bandwidth 7 MHz
	16 QAM	174	86	36	21
	32 QAM	217	110	53	26
	64 QAM	273	136	66	33
	128 QAM	323	161	78	38
	256 QAM	368	183	89	43
	512 QAM	395	196	94	45
	1024 QAM	447	217	104	52

Chapter 2

LITERATURE REVIEW

2.1 Importance of Microwave Technology as Backhaul Media in Telecommunication Companies

Microwave is a line of sight wireless communication technology that uses high frequency beams of radio waves to provide high speed wireless connection that can send and receive voice, video and data information. Microwave LOS link transmit and receive signals between two fixed terrestrial station in which electromagnetic waves are propagated in the lower part of atmosphere. Transmission in microwave links are accomplished in various frequency bands ranging from (6 GHz to 40 GHz) in licensed form and (2.4 GHz and 5.8 GHz) in unlicensed form.

Microwave point-to-point links has been an optimal technology and a preferred choice for the transmission system of cellular network for more than two decades. Microwave links was one of the dominant backhaul technology from first generation of mobile network up to the third generation. According to the survey done by Ericson more than 60 percent of the access links in UMTS networks was connected through microwave wireless links. However, the evolution of fourth generation of mobile network poses significant challenges on microwave backhaul link both in term of transmission capacity and latency. The explosion in mobile traffic caused microwave backhaul to come under intense pressure, that even some researchers feared that microwave solution would not be able to handle the huge increase in capacity demand.

With the recent development in microwave technology, like increase in microwave modulation from 1024 QAM to 4096 QAM/8192 QAM, high-speed analog to digital and digital to analog conversion, enhanced switching capabilities to handle the surge in throughput, Multiple input Multiple out technology in the antenna system, use of higher frequency like E-band and V-band and many other advancement in this area have made microwave technology to surpass the capacity and latency limits required for 4G networks. With the mentioned advancement microwave technology reached to a performance level that is only believed possible for fiber optic. Therefore, microwave LOS technology is still a preferred choice wireless backhaul connectivity of LTE network and it will continue to be a major mobile backhaul medium for the 5G and beyond.

Using microwave LOS links in LTE backhaul is cost-effective and can be rapidly installed. In addition, microwave links can cross complicated terrains which makes it an efficient means to connect two LTE cell sites that are located inside cities or in a mountainous area where practical installation of fiber optic cable is not applicable. Furthermore, latency in microwave backhaul is lower related to fiber optic as traffic in a microwave link passes only through two or three node until it reaches the final destination, but in fiber link traffic passes through many nodes till reaching the core network

2.2 Evolution of Microwave Technology to support 5G traffic

In order to overcome the challenges faced for microwave backhaul links and to meet the high capacity demand of the next generation of mobile network microwave technology have evolved in four different key area. These four key area are spectrum efficiency, throughput efficiency, extra spectrum and network optimization [3].

2.2.1 Spectrum efficiency

For a microwave link, spectrum efficiency can be achieved by applying techniques like higher order modulation, adaptive modulation, and Multiple input, Multiple output (MIMO). For instance, based on recent study by Yao Wei (2017) an increase in modulation from 1K QAM to 2K QAM and 4QAM would result in a growth of 10% and 9% bandwidth correspondingly. The study indicates that currently microwave equipment support up to 4096 QAM modulation and is estimated that with the hybrid automatic repeat request (HARQ) technique at hand microwave equipment should be able to manage up to 8192 or even 16384 QAM in the future [4]. Traffic throughput for RNT-900 HUAWEI microwave link with different QAM is indicated in figure 2.1 [5]. It is clearly visible that with the increase in modulation from QPSK to 4096 QAM the corresponding throughput also grows considerably. Figure 2.1 is an example of how throughput increases in a microwave link with the increase in modulation from QPSK to 4096 QAM. I this figure the red color indicates the maximum throughput that a microwave link can support with the given modulation type and meanwhile the blue color shows that minimum throughput in the link with the specified modulation type.

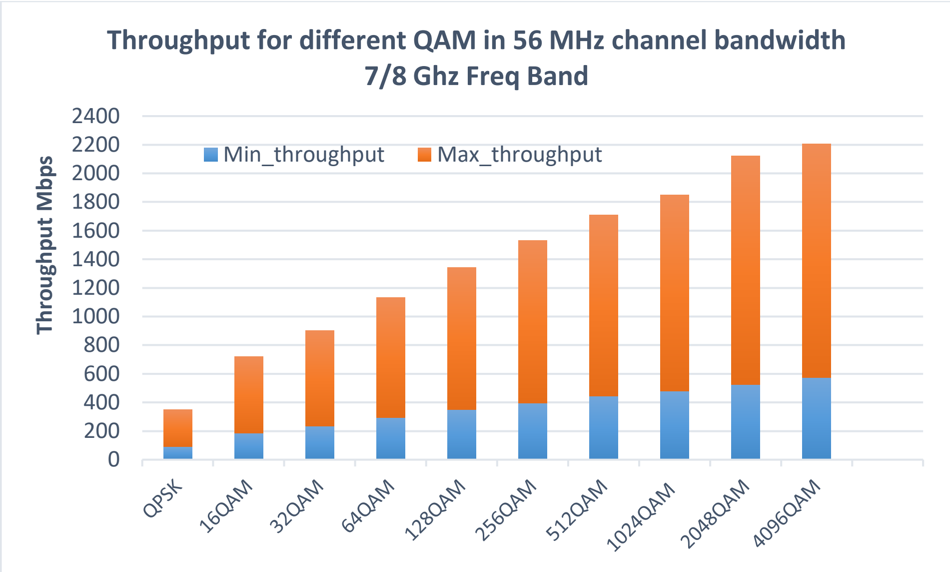

Figure 2. 1 Data throughput for different modulation scheme

2.2.2 Multiple in Put Multiply Output (MIMO)

Multiple input, Multiple output (MIMO) is a recent technique used in microwave technology to enhances capacity and throughput in the backhaul media. This technique provides a cost-effective method to improve the capacity when the available spectrum in hand is very limited. For instance, a 4x4 MIMO would improve transmission capacity of a single carrier by four-fold. MIMO will be an efficient method to scale microwave capacity further and provide high capacity backhaul solution for cellular network providers.

2.2.3 Considering More Spectrum

Traditional microwave frequency band (6-42) GHz has been extensively used and reach nearly to a full extent. To develop a multi-Gigabit wireless backhaul that meet the high capacity demand of the 5G technology with traditional microwave frequency is not feasible. Therefore, higher frequency band at millimeter wave such as V-band (57-64 GHz) and E-band (71-76 GHz and 81-86 GHz) that has higher bandwidth is required to provide high data rate in the backhaul [7].

2.2.4 Throughput Efficiency in Microwave link

It is another method that is used to increase backhaul media capacity. Throughput efficiency comprises of techniques like multi-layer header compression and radio link bonding [4]. This technique improves the throughput by considering how packet streams performs. For example in multi-layer header compression redundant information is eliminated from the data frame's header and in this way throughput will be increased.

Network optimization: densifying the existing cellular network, or deploying ultra-dense small cell base stations is just another way to deal with the high capacity backhaul demand [7].

2.3 Mobile Backhaul Background

Mobile backhaul describes the connection between any base station (BTS, Node B, eNode B) of the cellular network with the basic core network. Or strictly speaking the backhaul network portion of cellular system comprises the transitional link between the Core-Network and the small subnetworks of an existence mobile wireless communication. Previously this portion of the network was known as a transmission system, but recently the term backhaul is recognized and is used most commonly. Below figure show the basic backhaul network of a mobile communication system.

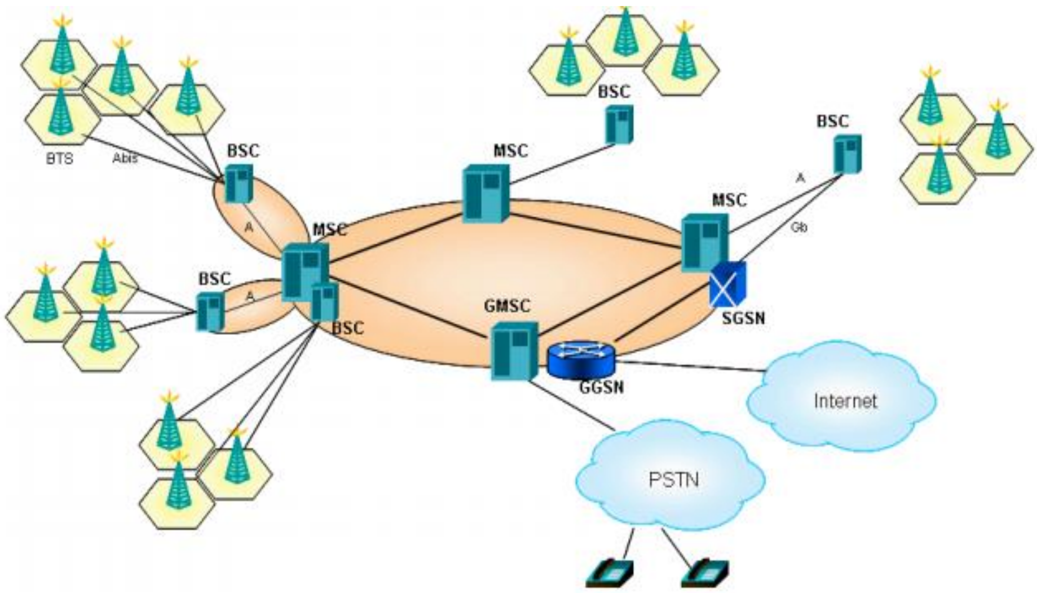

Figure 2. 2 A typical microwave backhaul in a cellular network.

The backhaul or (Transmission) interface in the GSM system were initially defined as Time Division Multiplexing (TDM) technology which is based on the 2.048 Mbps E1 circuit. Multiplexing in E1 circuits is done through plesiochronous Digital Hierarchy (PDH) and Synchronous Digital Hierarchy (SDH) standards to realize a higher order transmission system. The advent of UMTS network has brought a new technology in the backhaul which is called asynchronous transfer mode (ATM). ATM technology enable the backhaul to support different type of traffic like voice video and data [3]. Implementing the ATM in the backhaul will ensure a high quality of service (QoS) which will guarantee that different types of traffic coexistence on the same network without any detrimental behavior [16].

By executing the UMTS network, the cellular system has steadily converted from voice-centric to data-centric operation, and this development has resulted in the expansion of High Speed down Link Packet Access and advanced uplink technologies. The progresses in uplink and downlink technologies required to rise the capacity of mobile system and therefore, mobile backhauls have developed from TDM system to Carrier Ethernet. Finally, base station and network controller has shifted to the Ethernet interface and supports end-to-end transmission with a new transport layer called internet protocol (IP).

LTE was introduced with the native Ethernet and IP support, the radio interface in the LTE system offers fundamentally higher peak and mean data rate than the earlier generation of cellular network.

2.3.1 Mobile Backhaul in GSM network

When GSM network was launched for the first time devices that were used for baseband digital processing was so costly and needs a lot of money. Therefore, digital signal processing of several cell was connected to single node that was named Base Controller Station (BSC). And then was connected through a link to the Mobile Switching Center (MSC) to the core network. Later when packet switched network in the form of GPRS was added in the architecture of GSM the CS traffic was connected directly to the MSC. The PS traffic was connected to a Serving GPRS Support Node (SGSN) and it connects to the gateway GPRS Support Node (GGSN). Below figure shows the detail of GSM backhaul architecture.

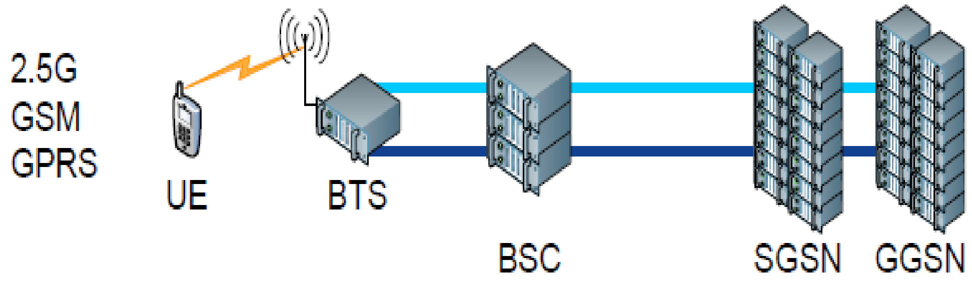

Figure 2 3 GSM backhaul architecture

2.3.2 UMTS or 3G Backhaul Architecture

In UMTS architecture both the base station and the BSC names were changed to Node B and RNC respectively. UMTS backhaul architecture is indicated in figure 2.4 which is designed based on I-HSPA standards. . In this new UMTS architecture the data path by pass the SGSN and is directly linked to GGSN, Moreover, the separate RNC in the earlier architecture of 3G network was also removed from the backhaul architecture and all its functionality is moved to Node B. This architecture greatly simplifies the network as the Iub interface is completely removed from the system. The high price of installing the RNC is saved and the network become more resilient since there is no more RNC failure. Moreover, in this architecture the latency has also reduced to certain level as the data is directly going to the GGSN.

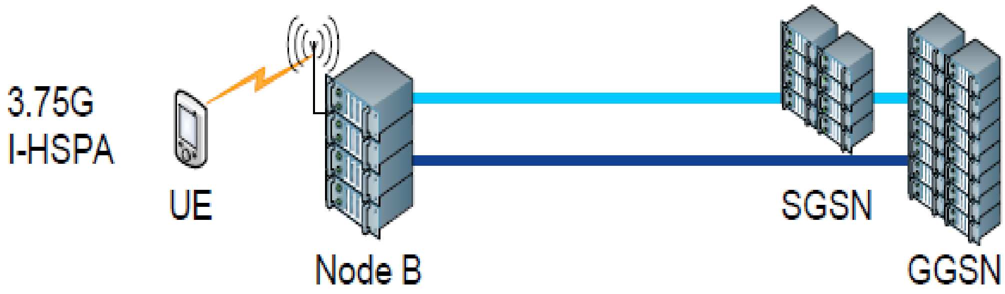

Figure 2 4 UMTS backhaul architecture

2.3.3 Backhaul Architecture of LTE network

The structure for the LTE is the same as I-HSPA, the only difference is that the Node B in LTE is called Evolved Node B (eNodeB) and in the place of SGSN there is Mobility Management Entity (MME). In addition, the gateway node has changed its name to System Architecture Evolution Gateway (SAE-GW) which is also sometimes called as serving Gateway (S-GW).

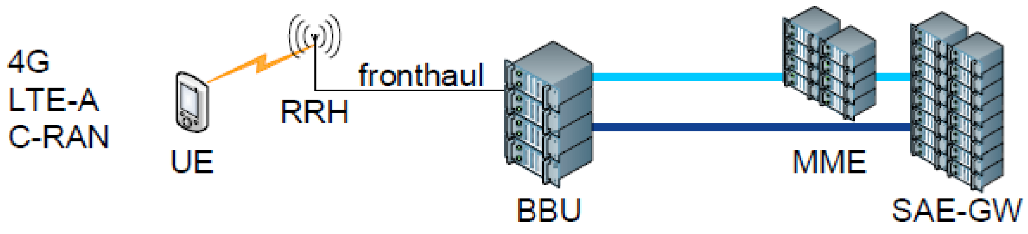

Figure 2 5 LTE backhaul architecture

Later there was a further twist in the architectural development of LTE network and this time the cloud Radio Access Network (C-RAN) was also added. In a C-RAN network, the device at the antenna is the simplest possible and all of the processing functions are performed in a more central node, that is called the digital Baseband Unit (BBU).

2.4 The Requirement for Millimeter Wave in Wireless Backhaul

The sharp increase in the number of mobile subscriber in the past few years, and simply the continuation of this condition for the next years and their parallel growth in traffic has made the world to move toward the 5th Generation of mobile cellular network. One of the requirement of the 5G network is to increase the throughput so that the upcoming demand for the capacity should be fulfilled to some extent. However, increasing the capacity in the backhaul network with the current available frequency range is not possible. Or in other words, the existing backhauling technologies cannot handle the multi gigabyte traffic of 5G network.

Using the wired backhaul to address the high capacity demand of 5G, would ensure a high reliability, but running the fiber optic cable to each and every sites in the dense small cell backhaul would be very highly costed as well as difficult to implement in populated area. While On the other hand, employing wireless backhaul as a solution for the problem of dense small cell is cost-effective and very easy to deploy. However, the main problem currently is that the traditional wireless frequency band is limited, for example, wireless spectrum in the microwave frequency bands like (6 GHz, 7 GHz, 11 GHz, …) are already fully congested in the current LTE network, and will not have enough available frequency bandwidth to address the future requirement of high capacity demand.

To meet the multi Gigabyte traffic of 5G, the world of cellular technology has no choice but to refer to the wide spectrum available in the range of (30 – 300) GHz. This new ranges of frequencies can offer 200 times greater resources then those frequency bands used currently in the cellular communication [5]. This range of frequency band is called millimeter wave spectrum (mm wave) because the wavelength corresponding to this frequency band is between 10 to 1 mm. The millimeter wave spectrum between 60 and 90 GHz is examined to be an appropriate backhauling option for the 5G networks.

The benefits related to mm wave is that wavelength in (mm wave) band is so small and thereby allows implementation of multiple antenna element in a compact form, in addition it provides huge channel bandwidth with enough unlicensed spectrum. Besides all these benefit, millimeter wave frequency band have a few propagation challenges because of its vulnerability to rain attenuation, molecular absorption, and shadowing. More over the inability in the penetration of mm Wave through building walls and other blockage forced us to consider the indoor and outdoor users separately while designing SBSs in mm Wave frequencies.

2.4 Millimeter Wave Characteristics

When looking the radio frequency spectrum table, those frequency bands whose wavelength is in the range between 10 to 1 mm is considered as millimeter wave band. Taking into account the wavelength of millimeter band we can say that these band of frequency has a larger wavelength than infrared waves and x-rays, but has a little smaller wavelength than the microwave bands that cover 3 to 30 GHz range. Millimeter wave bands are also called extremely high frequency (EHF) which occupy a frequency range of 30 to 300 GHz and a total of approximately 250 GHz bandwidth is available in this range. Due to the availability of wide range of high frequency in millimeter wave along with their great propagation characteristics such as action of interacting with the atmosphere as they traverse through the air make them suitable option for different applications, like transmission of huge amount of data, cellular communication, and radar.

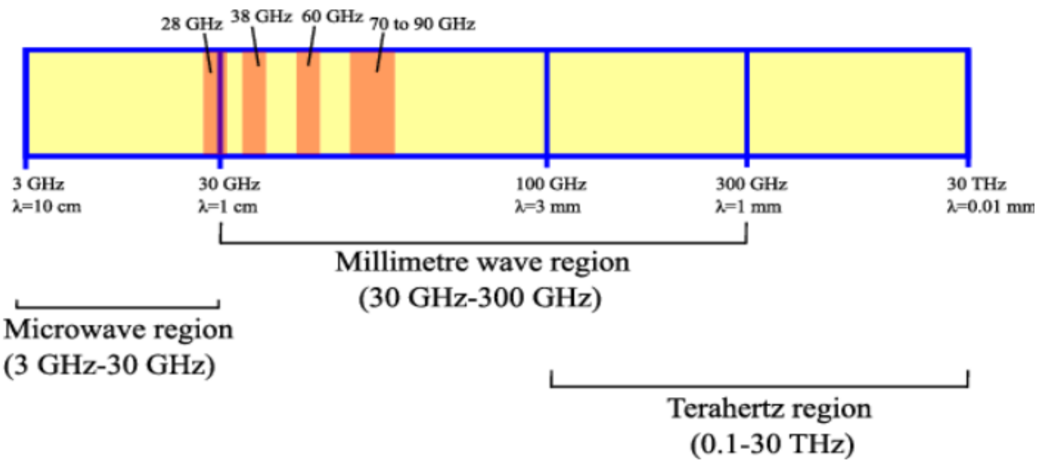

Figure 2 6 Millimeter range on radio spectrum frequency

Although the mm wave frequency band has a promising frequency bandwidth, the propagation characteristics of this band is greatly different form that of microwave frequency bands. Millimeter wave band differs from microwave band in propagation in terms of path loss, foliage loss behaviors, atmospheric absorption, diffraction and blockage, and rain attenuation. . In general, the overall loss of mm Wave systems is significantly larger than that of microwave systems for a point-to-point link [17]. The challenging characteristic of mm wave propagation will be explained in the following sections.

2.4.1 Free Space Propagation of Millimeter Wave

In the free space the power of a millimeter wave falls off as the square of its range. It means that when the range is multiplied by two, the power reaching a receiving antenna will be reduced by a factor of 4. The spherical spreading of the mm Wave when they propagate in the free space results in the reduction of the power. The following equation shows the frequency and distance dependence of the loss between two isotropic antennas in dB

$$L_{free\ space} = 20\log(4\pi\frac{R}{\lambda})\ (dB) \tag{2.1}$$

In the above equation L indicates the free space loss, λ is the given frequency wavelength and R is the range between the two antennas. From the equation 2.1 it is clearly visible that the free space loss will be increased when either of the distance or the frequency range increases [17]. In addition, it is simply visible from the equation that the free space loss is very high even in the small changes in distances. So we can conclude from this characteristics that mm Wave is best option for short distance communication links. Below table lists the path loss for a distance of R = 10m and with different frequencies.

Table 2 3 Path loss with respect to different frequency band

Frequency Band	Path Loss in dB
2.4 GHz	60 dB
5 GHz	66 dB
60 GHz	88 dB

The loss variance that exist in the frequency band of 60 GHz and the other frequency band has limited the application of mm Wave, and the only way to solve this issue and compensate this extra loss in dB of mm Wave is to use a high antenna gain.

2.4.2 Loss Factor in Millimeter Wave Propagation

The fundamental source of transmission loss in millimeter wave is free space loss, however, it is not the only source of loss in millimeter wave band. In this band there are also some other losses like absorption loss factors, such as losses due to the water vapor, rain or other gaseous constituent existing in transmission medium. Figure 2.7 shows the factor that influence mm Wave propagation.

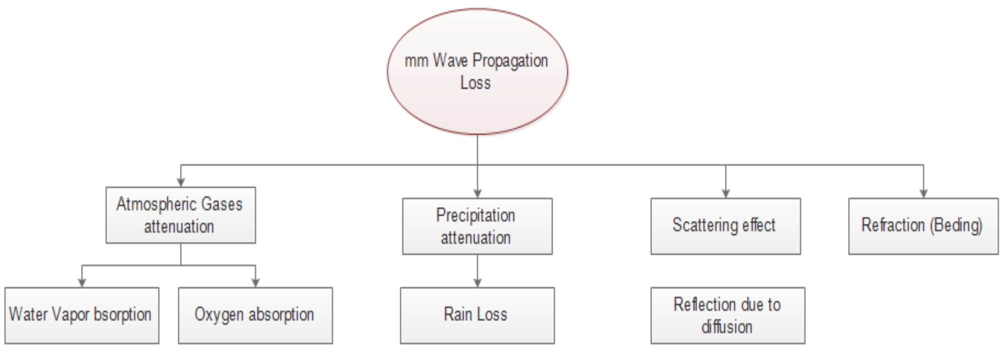

Figure 2 7 mm Wave propagation loss due to different atmospheric condition

Atmospheric loss occurs when mm Wave signal traverse through the atmosphere and are absorbed by molecules of oxygen, water vapor, and other atmospheric gaseous constituent. And these losses are greater in some frequency range due to the fact that they coincide with the mechanical resonant frequency of gas molecules [17].

2.4.3 Atmospheric Attenuation

Frequencies that exist in mm wave spectrum is highly susceptible to propagation losses resulted from rain attenuation, Oxygen and other molecular absorption. However, when we consider a short range for communication, where the distance between sending and receiving end is so small the mentioned environmental factors may not induce substantial propagation loss, such as ultra-dense small cell in 5G network [2]. During the heavy rainfall, for 28 GHz frequency the rain attenuation is only 1.4 dB over 200 m distance. The attenuation caused by atmospheric absorption is low for mm Wave spectrum especially for 28 and 73 GHz [5].

2.4.4 Penetration Loss

The frequencies in mm Wave spectrum encounters high penetration loss in the exterior of urban building while the penetration loss for indoor material is rather low. Therefore, indoor users cannot be served by outdoor BSs in mm Wave.

2.4.5 Reflection Factor

Huge amount of obstruction would influence the reflected multipath of mm Wave signals and thus would cause a large delay in both LOS and NLOS situation. Even so, signal that are strong can reach the next antenna within 200m distance in a NLOS environment [5].

2.5 Time Series Forecasting

Forecasting a time sereis data is a very significant area in machine learning, as there exist so many issues that comprises a time component. We can simply explain a time seris as the sequence of observations taken sequenctially in time[18]. When we demonstrate a time sereis data, the current time is described by (t) and the observation at the current time is given by obs(t). in time sereis the observations which are made in previous times or lag times are negative with respect to the current time and are given by (t-1) (t-2) and so on. In forecasting a time series we require time in the fututre and they are positive with respecto to the current time and are given by (t+1), (t+2) and so on. Historical throughput datasets from microwave backhaul links are also time series and therefore, we need to analyze and forecast our future throughput based on time sereis prediction and analysis techniques.

2.6 Time Series Analysis and Prediction

Analysing a time sereis data means trying to develop a model that best define the observed time sereis data for the purpose of understanding the pattern and dynamic of the data. While analysing the time series data we attempts to decompose the time sereis data into its' constituent components.

Time sereis forecasting is making prediction about future based on the historical data. Prediction procedure consists of takind the models and fitting them on the historical data and then using them to forecast future observations. We can use machine learning models and predictive statistics to forecast the future observation.

Time sereis prediction and analysis consists of several principle technique to better realize a dataset. We generally, decompose the time series data in to the following four constituent parts.

- Level: it is a baseline that defines the average value in the series
- Trend: indicates the linear decreasing or increasing behavior of a time series data
- Seasnality: indicates the reapting cycles or pattern of a series over time
- Noise: indicates the random variation in dataset that can not be defined by the model

Seasonility and trend may or may not exist in dataset but in most of the datasets there exist noise and levels. Sometimes these four techniques can be very effective for making prediction and are used in time series forecasting models.

Time series prediction is divided into the following two categories

1- Univariate Time Series: in this kind of time series dataset we only observe one varaible at each time for instance predicting the number of passenger in an airline.
2- Multivariate Time Series: here we observe two or more variable at a time for predicting the future values. For example forecasting the traffic for two LTE site at the same time

2.7 Time series prediction models used in this project

In this study two time series forecasting models namely ARIMA and LSTM are used to predict future throughput in microwave links. Both models are extensively used for predicting future value in a time series dataset.

2.7.1 ARIMA Model

ARIMA model is the most widespread and commonly used statistical means for time series prediction [19]. ARIMA is the contraction form of Auto Regressive Integrated Moving Average which is the generalization of Auto Regressive Moving Average that only adds the concept of integration. It is used both for forecasting and analyzing the time series data. it belongs to a class of models that defines an assumed time series data based on its perior values and its lag and lagged predicted errors to forecast future values

ARIMA model is not only suitable for non-linear data but it is also suitable for non-stationary. This model uses differencing and log techniques to change a non-stationary data into a stationary one [20]. There are three main parts that constitutes ARIMA model which are namely Autoregression (AR), moving average (MA), and integration or (I) parts. The Autoregression part indicates that time series is retreated on its own prior data. In equation 1, $\emptyset_p$ indicates autoregressive coefficient and ε_t shows the error term.

$$Y_t = \emptyset_1 y_{t-1} + \emptyset_2 y_{t-2} + \cdots + \emptyset_p y_{t-p} + \varepsilon_t \qquad (2.2)$$

The moving average parts uses the dependent relation between an observation and a residual error which is achieved from application of moving average on the prior observations.

$$Y_t = e_t + \emptyset_1 e_{t-1} + \emptyset_2 e_{t-2} + \cdots + \emptyset_p e_{t-p} \quad (2.3)$$

Seasonal ARIMA (SARIMA) is a technique that is used to handle the seasonal component in a time series data. In order to control seasonality in the data, it attaches three new parameters to ARIMA model which is defined as follow.

$$ARIMA\ (p, d, q)\ X\ (P, D, Q)_m \quad (2.4)$$

Where the small (p, d, q) and shows trend autoregressive, trend differencing and trend moving average order respectively, and the capital (P, D. Q) indicates seasonal autoregressive, seasonal differencing and seasonal moving average order respectively. In the formula above m indicates timestamp for one seasonal order.

The steps for applying Autoregressive Integrated Moving Average (ARIMA), is given in detail in the following sections

2.7.1.1 Stationary

Stationarity of the time series data is a requirement in order to apply ARIMA model. When a time sereis data indicates a pattern with constant mean and variance during the time interval, can be considered as stationary. Mathimatically it can be defined as

$$E(y_t) = E(y_{t-k}) \quad (2.5)$$
$$Var(y_t) = var(y_{t-k}) \quad (2.6)$$

Where y_t in the above formula shows the value of sereis at time (t) and y_{t-k} indicates the values at k time steps back which is also called as lag of k. however, this assumption can not be implemented in real life problems, therefore, a weakly stationary with the below two properties are defined.

- The mean value μ_t is constant and doesn’t depend on the time
- The autocovariance should only be related to the time lagged time k

2.7.1.2 Differencing

For a time series data with non stationary pattern, we can obtain stationarity of the data values at time t from the the value at time t-1 as

$$\acute{y}_t = y_t - y_{t-1} \quad (2.7)$$

Backshift operator is a more effective approach for expressing the order of differencing. In this method d shows the number of differneces.

$$(1-B)^d y_t \qquad (1-B)^1 y_t = y_t - y_{t-1} \qquad By_t = y_{t-1} \quad (2.8)$$

2.7.1.3 Autoregressive Process

The idea behind AR model is that in a stationary time series we can consider y_t as liner combination of prior p lagged values.

$$Y_t = \emptyset_1 y_{t-1} + \emptyset_2 y_{t-2} + \cdots + \emptyset_p y_{t-p} + \varepsilon_t \quad (2.9)$$

Where $\emptyset_p$ in the equation indicates autoregressive coefficient. And shows an error term.

2.7.1.4 Moving Averages

In the movign average approach the sereis y_t is modelled as a function of the white noise

$$Y_t = e_t + \emptyset_1 e_{t-1} - \cdots - \emptyset_p e_{t-1} \quad (2.10)$$

Where $\emptyset_p$ is the wieght that is applied to e_t.

2.7.2 Long-Short Term Memory

To better understand why LSTM model was developed and what is concept behind this model, a brief overview of artificial neural networks ANN is required. ANN model was developed to remove the drawbacks related to traditional learning and predicting algorithm [21]. This model is classified into two principle categories which are namely feed-forward neural network FFNN and recurrent neural network RNN. FFNN is mainly composed of three components that are input layers, hidden layers and output layers.

Every layer in FFNN have a few neurons and activation functions. There is no enter layer and cross layer connection between neurons in FFNN model and thereby, consider all inputs and outputs as independent of each other. Information only flow in one direction in FFNN model that is from input layer to the hidden layer and finally to the output layer. FFNN model has some constraint in internal structure and therefore cannot handle historical dependencies in time series data [22].

Recurrent neural network or RNN is another type of ANN model that has the same neural structure as that of FFNN, however, in RNN there is connection between neurons that are located in the same layer. RNN model has the potential to store input data to the internal state of the network and draw all the historical input information to the last output. The major drawback of RNN model is vanishing or exploding gradients, that make this model to learn only for a short past sequence [23]. To remove the problem of RNN, researchers have developed LSTM model.

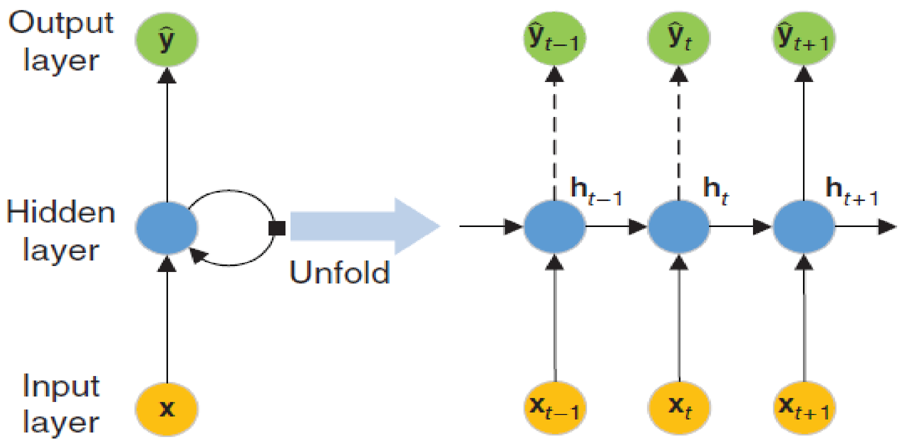

Figure 2 8 Block diagram of an RNN model

Recently long short-term memory (LSTM) as a deep learning model, is converted to a powerful means for time-series prediction [24]. LSTM is a variation of RNN model whose hidden units are changed with LSTM blocks [25]. LSTM model consists of several copies of simple memory blocks. Each memory block in LSTM model comprises a memory cell and three kinds of gates which are called input gate, forget gate and output gate. The main component in LSTM model is memory cell which is responsible for transmitting information in different time-steps. Furthermore, each of the three gates comprises a sigmoid layer to transmit information and is responsible for protecting and monitoring the cell state.

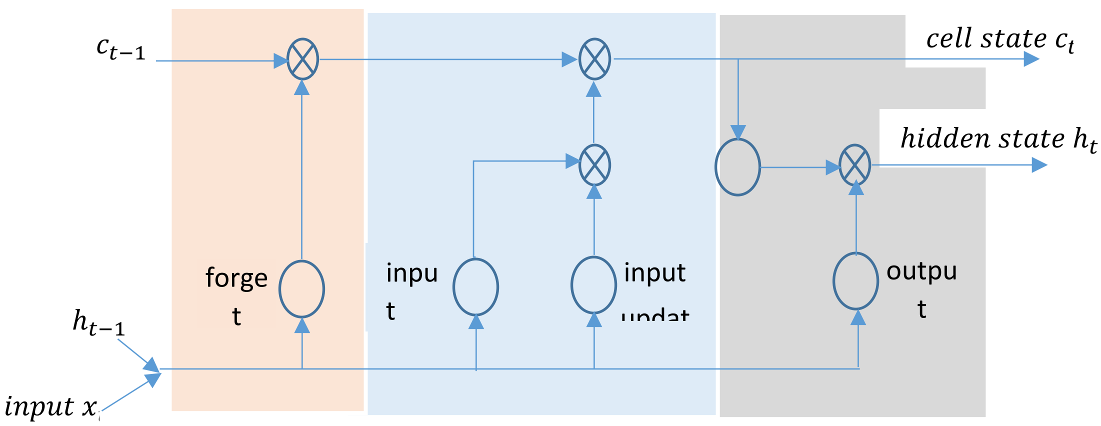

Figure 2 9 Block diagram of an LSTM model

The equation of LSTM model is given in below. In the following equations f_t, i_t, and o_t indicates the forget gate, input gate and output gate at time-step t. in addition, h_t and x_t expresses the input and output at the current time-step and h_{t-1} indicts the output at the prior time-step.

$$f_t = \sigma(W_{xf}x_t + W_{hf}h_{t-1} + b_f) \quad (2.11)$$

$$i_t = \sigma(W_{xi}x_t + W_{hi}h_{t-1} + b_i) \quad (2.12)$$

$$o_t = \sigma(W_{xo}x_t + W_{h0}h_{t-1} + b_0) \quad (2.13)$$

$$\check{C}_t = \tanh(W_{xc}x_t + W_{hc}h_{t-1} + b_c) \quad (2.14)$$

$$c_t = f_t \otimes c_{t-1} + i_t \otimes \check{C}_t \quad (2.15)$$

$$h_t = o_t \otimes \tanh(c_t) \quad (2.16)$$

Similarly σ indicates the sigmoid activation function, and $\otimes$ shows the Hamdard Product in above equations. The weight matrices is indicated by W and the three gates biases is shown by the letter b. The three superscripts f, i, and o shows forget, input and output gates for the memory cell where the subscript c illustrate the memory cell. Once the value of the three gates is evaluated, then the procedure of updating information via the gate is achieved in three steps. The first step takes decision that which part of the previous cell states c_{t-1} should be removed and this is achieved by multiplying the value of forget gate f_t with the old cell state c_{t-1}. In the next step, the value of the input gate i_t is multiplied by the new memory cell value $\check{C}_t$ in order to update information in the cell state. Finally, the output value h_t is obtained by multiplying the output gate o_t with the updated cell state c_t via a tanh function.

Chapter 3

MICROWAE LINK PLANNING & DESIGN STEPS

Planning a microwave link as a backhaul transmission media in telecommunication companies requires a set of connected activities that are used to achieve a very cost-effective and high quality transport link for every telecommunication sites. In order to efficiently design and plan a microwave backhaul link and connect it with existing transmission network the two main steps that are site planning and link design have to be done carefully. The details about microwave link planning and design is explained in the diagram below. The first step in order to build a microwave transmission link for a cellular site is site planning. Site planning contains several basic parts that will be done during the site survey. All the parts of the site planning is explained in detail in below diagram.

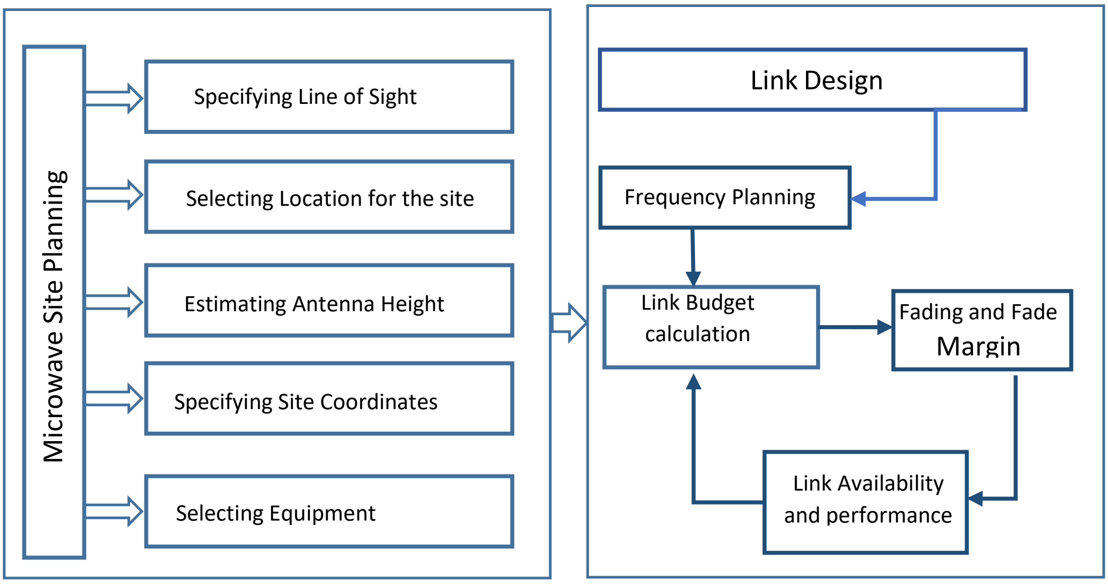

Figure 3 1 Planning and Design steps required for a microwave link

During the site survey we have to specify line of sight, selecting tower location and tower height and finally we specify the coordinate of the site chosen.

3.1 Case description and planning brief

In planning a microwave link the very first step is to obviously describe the problem and create a planning brief. In this part we will specify the type of service and the required bandwidth to be carried out over the transmission medium. Strictly speaking in planning brief we are trying to clearly define what exactly we want to achieve.

We choose the bandwidth for our new site according to the traffic estimated by the radio frequency department. Therefore, due to lack of precise knowledge about traffic in the site mostly the bandwidth for the site is selected improperly. Sometimes the frequency bandwidth selected may not be adequate for the traffic and will result in a poor performance of the site. And sometimes the traffic of the site will be less than what is estimated the will have a very less utilization that will result in frequency loss. Therefore after planning an accurate capacity optimization is required to specify the exact frequency bandwidth need for the site.

3.2 Site Location

Information of the site location is very significant in designing a microwave link. We have to check and verify all the information of the site accurately as microwave links allow a very little inaccuracy of the site coordinate because of the clearance of the beam. We have to precisely take the coordinate of the site and the exact coordinate of the antenna mounting during the site survey. Coordinates of the site taken from Global Position System (GPS) is indicated in below.

Table 3 1 Coordinate for three different options for site location

Site Location Option	Latitude	Longitude	Altitude
Site Option_1	34.501451	69.396802	1892.92 m
Site Option_2	34.501465	69.396848	1880.45 m
Site Option_3	34.501427	69.396815	1887.78 m

3.3 Tower Details for the site

While doing the site survey we have to specify the type of tower and the tower height required for the new site. In addition, we must create a tower profile for the far end sites to show number of microwave antenna, antenna diameter, azimuth angle for the direction of the antenna, and finally the antenna type that are installed on the tower. Table 3.2 shows the detailed description of tower required for the new LTE site. In this table, specification of tower for all the three options considered for the site is inserted.

Table 3. 2 Tower specification required for the microwave backhaul site

Tower Location Options	*Tower type*	*Required tower height*	*Antenna height*
Option_1	***Mono Pole tower***	***30 m***	***25m***
Option_2	***Root Top Tower on three story building***	***20 m***	***27m***
Option_3	***Guyed Mast tower on the ground***	***30 m***	***26m***

Table 3. 3 Tower specification for the selected site

Tower Height	*Antenna Type*	*Antenna Size*	*Antenna height*	*Antenna Azimuth*	*Frequency Used*
30-meter mono pole tower	*Parabolic dish*	*0.3 m*	*24 m*	*260 degree*	*28 GHz*
	Parabolic dish	*0.3 m*	*27 m*	*324 degree*	*38 GHz*
	Parabolic dish	*0.3 m*	*20 m*	*145 degree*	*23 GHz*
	Parabolic dish	*0.6 m*	*25 m*	*201 degree*	*23 GHz*
	Parabolic dish	*0.6 m*	*29 m*	*95 degree*	*28 GHz*
18-meter Roof Top	*Parabolic Dish*	*0.3 m*	*21 m*	*253 degree*	*23 GHz*
	Parabolic Dish	0.6 m	*26 m*	*121 degree*	*18 GHz*
	Parabolic Dish	0.3 m	*23 m*	*231 degree*	*18 GHz*

3.4 Antenna Selection

Antenna is the main component that is under control of a microwave link planner in terms of detailed link design. An antenna is basically a radiating element that converts electrical energy in the form of current into an electromagnetic wave in the form of oscillating electric and magnetic field. General specifications of an antenna are: antenna gain, polarization, half power beam width, and front to back ratio. We have chosen HUAWEI antenna with the following specification for our link.

Table 3 4 Antenna specification required for the microwave link

0.6 m High Performance 23 GHz frequency Band	
Antenna Model	A18S03HAC
Antenna Gain	33.0 dBi
Polarization	Single Polarization
Polarization Direction	Vertical
Beamwidth	2.0 degree

Antenna gain is calculated as

$$Gain = 20\log(d) + 20\log(f) + 17.82$$

Where d is antenna diameter in meter and f is frequency in GHz

$$Gain = 20 * \log(0.3) + 20 * \log(18) + 17.82 = 32.6\ dBi$$

And the antenna beamwidth is calculated from the following formula

$$BW = \frac{22}{f * d * 2}\ deg, \quad BW = \frac{22}{18 * .6} = 2.03\ deg$$

3.5 Frequency Band Selection

Appropriate frequency band have to be chosen according to a typical link length policy. One such typical link length policy that is explained based on the experiment is shown in the table below.

Table 3 5 Link length policy table

Frequency Link Band	Extreme Distance Permitted
7.0 GHz	> 30.00 Km
13.0/15.0/18.0 GHz	15.0 Km to 30.0 Km
23.0/26.0/28.0 GHz	5.0 Km to 15.0 Km
38.0 GHz	up to 5.0 Km

As in the case of this new microwave Backhaul link the distance is approximately 3.87 Km so we have two option for frequency selection one is in 23 GHz band and the other is in 18 GHz band. Considering the available equipment in stock and interference issue in the hub site we have selected below 18 GHz frequency for the new microwave backhaul link. The channel arrangement is based on International Telecommunication Union. Radio communication Sector (ITU-R) F.748 and Afghan Telecommunication Regulatory Authority National Frequency Allocation chart.

Table 3 6   A sample of frequency band channel classification for 18 GHz band

<table>
<tr><td rowspan="8">17874</td><td rowspan="8">18884</td><td rowspan="4">17860</td><td rowspan="4">18870</td><td rowspan="2">17853</td><td rowspan="2">18863</td><td>17849.5</td><td>18859.5</td></tr>
<tr><td>17856.5</td><td>18866.5</td></tr>
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<tr><td>17870.5</td><td>18880.5</td></tr>
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<tr><td>17874.5</td><td>18894.5</td></tr>
<tr><td rowspan="2">17885</td><td rowspan="2">18905</td><td>17881.5</td><td>18901.5</td></tr>
<tr><td>17888.5</td><td>18908.5</td></tr>
</table>

3.6 Equipment Selection for the Microwave Link

The Telecommunication where this microwave link is designed for uses microwave link equipment form two different international companies called HUAWEI and ZTE. Microwave equipment provided by these companies operate on frequency bands that are standardized by International Telecommunication Union, Radio Communication Sector (ITU-R). For This new microwave link we have considered OptiX RTN 950A microwave equipment product from HUAWEI Company. The OptiX RTN 950A is a new generation of microwave equipment that integrate TDM microwave, Hybrid microwave, and Packet microwave technologies and will provide solution according to the networking scheme for the site. This solution developed by HUAWEI Company addresses the transmission requirement of 2G, 3G, and LTE services.

OptiX RTN 950A adopts a split structure and consists of IDU 950A and ODU. Each ODU is connected to the IDU via IF cable. Below figure shows feature of IDU 950A that is considered for this new link.

Item	**Description**
Chassis height	2U
Pluggable	Supported
Number of radio directions	1 to 6
RF configuration mode	● 1+0 non-protection configuration ● N+0 non-protection configuration (N ⩽ 6) ● Nx(1+0) non-protection configuration (N ⩽ 6) ● 1+1 protection configuration ● N+1 protection configuration (N ⩽ 5) ● XPIC configuration
Service interface type	● E1 interface ● STM-1 optical/electrical interface ● FE optical/electrical interface ● GE optical/electrical interface

Figure 3 2 A view of microwave IDU used in for the new Microwave backhaul

ODU is the outdoor unit for OptiX RTN 950A. Tt converts frequencies and amplifies signals. Below table shows feature of OptiX RTN 950A ODU. We have used 18 GHz band with 16-QAM modulation scheme. As indicated in the table 3.2 this microwave ODU supports frequency ranges from 6 GHz up to 42 GHz. This ODU also support different modulation schemes from QPSK up to 1024 QAM. As indicated in below table different frequency channels such as 3.5, 7, 14, 28, 40 and 56 MHz are applicable with this ODU.

Item	**Description**		
	High-Power ODU		**Low Capacity ODU**
ODU type	XMC-2	XMC-2H	XMC-1
Frequency band	6/7/8/10/10.5/11/13/15/18/23/26/28/32/38/42 GHz	6/7/8/11 GHz	7/8/11/13/15/18/23 GHz
Microwave modulation scheme	QPSK/16QAM/32QAM/64QAM/128QAM/256QAM/512QAM/1024QAM (6/10/10.5/11/13/15/18/23/26/28/32/38/42 GHz, 7/8 GHz XMC-2E) QPSK/16QAM/32QAM/64QAM/128QAM/256QAM (7/8 GHz Normal)	QPSK/16QAM/32QAM/64QAM/128QAM/256QAM/512QAM/1024QAM	QPSK/16QAM
Channel spacing	3.5/7/14/28/40/50/56 MHz **NOTE** The 10.5 GHz frequency band does not support 40/50/56 MHz channel spacing.	7/14/28/40/50/56 MHz	3.5/7/14/28 MHz

Figure 3 3 Specification of the Microwave out door unit

3.7 Network Diagram for the New Microwave Backhaul

The new microwave link is located in south of Kabul the capital of Afghanistan. The distance of this site with KAB371 Hub site is about 3.87 Km. KAB371 hub site is considered as the far end for the new microwave link. This hub site has a 30 m monopole tower installed on the ground and three other microwave links are also connected in this tower. Therefore, while designing the new microwave link interference with existing site should be considered. As shown in figure 3.5 traffic of this new LTE site will reach to the core network through two different media. First traffic from this new site will go to KAB371 hub site via microwave link and then it will reach the core network through fiber optic rings. The connectivity of KAB138 site with KAB371 hub site and finally to the core network is drawn in google earth and its topology is shown in figure 3.23.

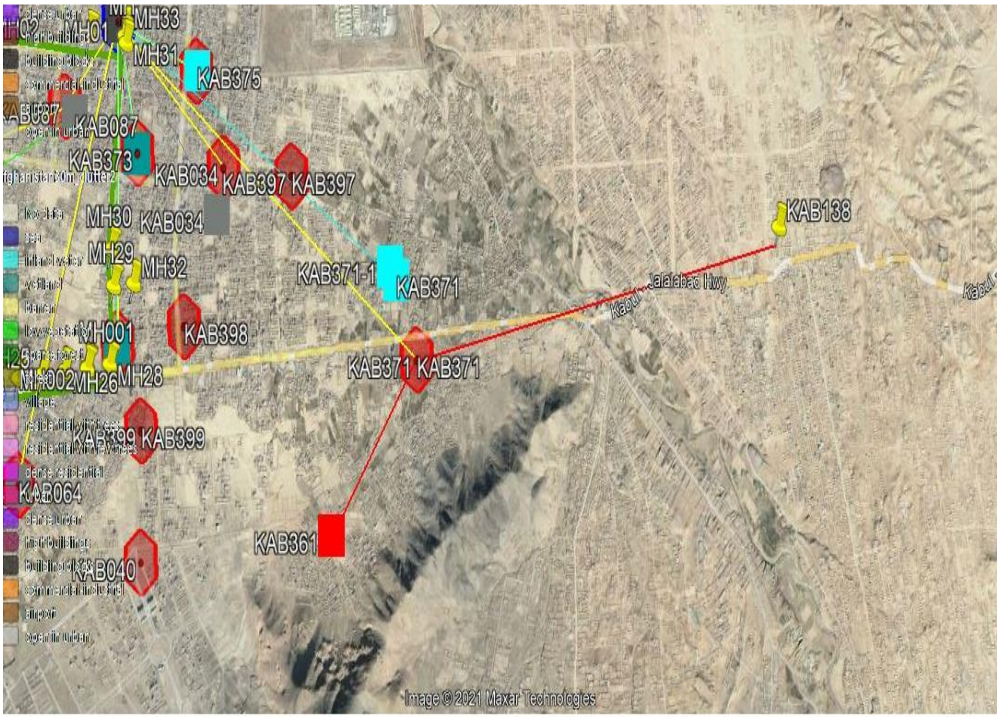

Figure 3 4   Microwave link connectivity drawn in google earth

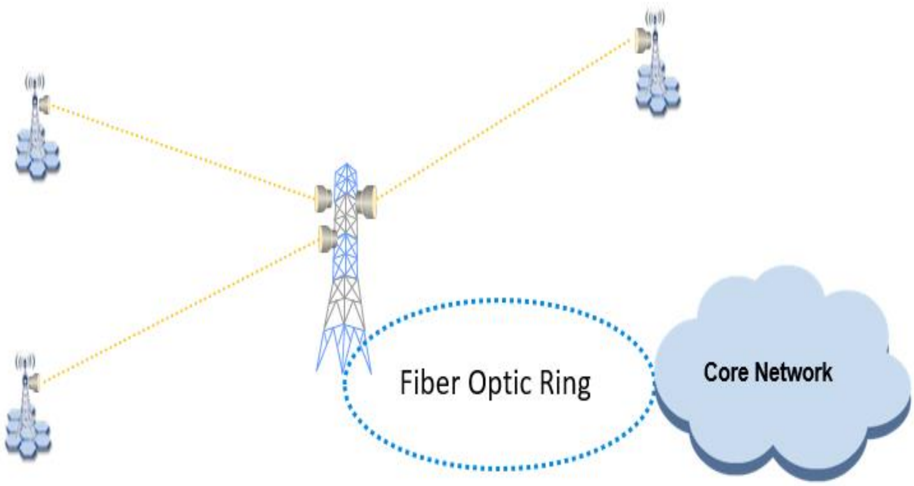

Figure 3 5   A sample of network diagram for the link connectivity

3.8 Microwave Link Design

Link design is nothing but precisely estimating the outage period that a radio link will suffer and ensuring that it doesn't surpass the quality objectives considered for the link. It is an organized process that comprises the steps explained in the figure 2.1. We have used Ellipse software to in order to design the microwave link

Ellipse is a software application used for planning dimensioning and optimization of microwave links and wired backhaul networks. This software integrates all the latest ITU specifications required for precise network design. We use Ellipse software in transmission planning department for the following purposes.

- To proactively plan and manage large microwave networks
- To design reliable line-of-sight (LOS) and non-line-of-sight (NLOS) links
- To manage combined wired and wireless backhaul networks
- To reduce backhaul CAPEX via accurate dimensioning
- To efficiently manage networks and optimize frequency use to reduce OPEX

3.8.1 Checking Line-of-sight (LOS) for the microwave link

The coordinate of the sites was taken by handheld GPS during the survey. These coordinates were used in the Ellipse to check LOS possibility with the minimum antenna height required. Although line-of-sight (LOS) was checked by binocular during site survey but in order to insure that there is no obstacle and the LOS is clear we have used Ellipse. Moreover, Ellipse software was also used for specifying Fresnel zone and exact antenna height. We have tested the possibility of LOS with three different sites and choose KAB371 hub site as the far end for our link. We have selected KAB371 hub site as the far end because it has minimum distance and it was interference free.

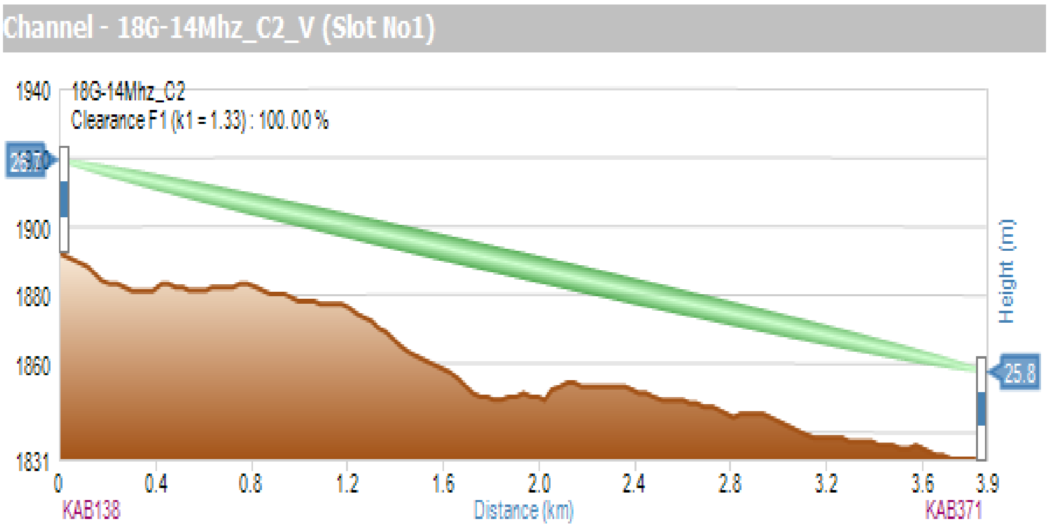

Figure 3 6 Line of Sight picture taken from Ellipse

As it is shown in figure 3.6 it is clearly visible that the line of sight (LOS) is clear between the two sites and there is no obstacle between them.

The details of the site is given in table 3.7 . The distance between the two sites is about 3.87 Km. Frequency channel bandwidth selected for the site is 14 MHz and with this frequency bandwidth the capacity of the link is about 42 Mbps. Also as can be seen from the table there is no TDM capacity and it means that no E1 is configure for this link.

Table 3 7 new microwave site details

Link	Unit	Value
Distance	km	3.87
Channel Bandwidth	MHz	14
Duplex Mode	MHz	Full
TDM Capacity	Mbit/s	0.000 (-)
IP Throughput	Mbit/s	42
Total Link Capacity (TDM + IP)	Mbit/s	42

3.8.2 Site Descriptions

During the site survey done for this link, we have taken some of the required data that was necessary for the link design and add them in Ellipse in order to design the microwave link that would be efficient, cost effective and with good quality and performance.

All the site data taken from Ellipse is shown in table 3.1. The new microwave backhaul link name is KAB138 and the far end where this site is connected with is KAB371. In both sides of this microwave link the tower type are monopole tower. The Elevation from the sea level for both sites are also added in the table 3.8. KAB138 is about 1892.2 m above sea level and KAB371 which is the far end site for the new microwave backhaul link has an elevation of 1831.9 m. as this site is not located on the roof top so no building height is considered for this link. Moreover, the frequency used is from 18 GHz band and polarization of the antenna is considered as vertical. For this microwave backhaul link no microwave radio and antenna loss is considered, since loss due to radio and antenna is very less that can be negligible.

Table 3 8 Site description

TX	Unit	A->B	B->A
Site	-	KAB138	KAB371
Towers	-	twr	twr
Tower Coordinates	Degrees	69.396802 | 34.501451	69.35507 | 34.49649
Tower Coordinates (Dms)	DMS	069 E 23 48.487 | 034 N 30 05.224	069 E 21 18.252 | 034 N 29 47.364
Elevation (AMSL)	m	1892.92	1831.9
Building Height	m	0	0
Tower Height	m	30	30
Frequency	MHz	18091	19101
Polarization	-	V	V
Clearance	%	100	100
Microwave Radio Loss	dB	0	0
Coupling Device Loss	dB	0	0
Antenna System Loss	dB	0	0
TX Radio	-	18GXMC216Q14M	18GXMC216Q14M

3.8.3 Antenna Specification for Transmission and Receiving Ends

High performance single polarization parabolic antenna is used for both transmission and receiving ends of this link. Antenna height on the tower for transmission end is about 27 m above the ground and in the receiving end it is about 26m. Azimuth angle is about 261.62 deg from the north. For both the receiving and transmission ends antenna diameter is selected to be 0.3 m. During the design process which is performed by Ellipse software, different antenna diameter was given for the link and based on the desired signal receive level 0.3 antenna was selected as the best option. Result of report from Ellipse software for the antenna is given in table 3.9

As shown in table 3.9 Azimuth angle for the receiving end is about 81.6 deg from the north. And also antenna gain is 34.2dB in the receiving end.

Table 3 9 Antenna specification for the new microwave link

TX Antenna	-	A18S03HAC	A18S03HAC
TX Height On Tower	m	26.68	25.84
TX Elevation (AMSL)	m	1919.6	1857.74
TX Azimuth	deg	261.62	81.62
TX Azimuth (Geographical North)	deg	261.84	81.82
TX Tilt	deg	-0.92	0.92
TX Antenna Gain	dB	34.2	34.2
TX Antenna Diameter	m	0.3	0.3

RX	Unit	A->B	B->A
RX Antenna	-	A18S03HAC	A18S03HAC
RX Height On Tower	m	25.84	26.68
RX Elevation (AMSL)	m	1857.74	1919.6
RX Azimuth	deg	81.62	261.62
RX Azimuth (Geographical North)	deg	81.82	261.84
RX Tilt	deg	0.92	-0.92
RX Tilt (Factor K Contribution)	deg	0.9	-0.93
RX Antenna Gain	dB	34.2	34.2

3.8.4 Propagation Loss calculation via Ellipse

If microwave signal pass through in free space it would cross in straight line and would have only free space loss. Yet, radio signal travel through troposphere that different parameter impacts the path trajectory and signal absorption and therefor, leads to different signal degradation and attenuation. All the propagation loss for this link was calculated in Ellipse software and the result of the report is given out in the table 3.10. Based on the following table the free space loss for this microwave backhaul link is about 129.3 dB. The absorption and detraction loss is zero because there is no obstacle and vegetation in the path between the receiving and transmission ends. The distance to first Fresnel zone as indicated in the table 3.10 is about 18.9 m and distance to the loss considering the k factor is about 23m.

Table 3 10 Propagation loss calculation with Ellipse

Propagation	**Unit**	**A->B**	**B->A**
Free Space Loss	dB	129.31	129.78
Absorption Loss	dB	0.23	0.31
Diffraction (Obstacle) Loss	dB	0	0
Foliage Loss	dB	0	0
Total Loss	dB	129.53	130.09
K Value (K1)	-	1.33	-
Worst Obstacle Distance (K1)	km	1.18	2.69
AMSL Height (K1)	m	1877.97	-
AGL Height (K1)	m	0	-
Clutter Code (K1)	-	undefined	-
Distance To Los (K1)	m	22.59	-
Los Clearance (K1)	%	100	-
Distance To First Fresnel Area (K1)	m	18.9	-

The worst possible obstacle distance is about 1.18m from the transmission end.

3.8.5 Attenuation due to rain

There are several factor the impacts the attenuation due rain such as the rain drop size and form, intensity of the rain in region, and finally the frequency of raining. As rain attenuation affects the overall availability of link hence, the unavailability of the link is calculated with Ellipse and the result is given in the table below.

Table 3 11 Loss attenuation calculation with Ellipse

Rain			
Interference TD	dB	0	0
Other Margin	dB	-	-
Flat Margin	dB	45.37	44.81
Rain (Year)	Unav. %	0.00E+00	0.00E+00
Rain XPD (Year)	Unav. %	0.00E+00	0.00E+00
Year	Unav. %	0.00E+00	0.00E+00
Worst Month	Unav. %	0.00E+00	0.00E+00

3.8.6 Multipath fading calculation with Ellipse

Multipath fading is divided into two important parts: Flat Fading and Frequency Selective Fading. Usually thermal noise and interference causes flat fading in a microwave link while the properties of radio electric system such as Modulation scheme, and capacity will cause frequency selective fading in a microwave transmission link [26].

Table 3 12 Multipath fading calculation with Ellipse

Multipath			
Flat Margin	dB	45.37	44.81
Flat Fading (Worst Month)	Unav. %	3.13E-11	3.84E-11
Frequency Selective Fading (Worst Month)	Unav. %	0.00E+00	0.00E+00
Clear-Air XPD (Worst Month)	Unav. %	0.00E+00	0.00E+00
Worst Month (Unprotected)	Unav. %	3.13E-11	3.84E-11
Worst Month (Protected)	Unav. %	3.13E-11	3.84E-11
Improvement Factor (Worst Month)	-	1	1
Year (Unprotected)	Unav. %	2.61E-12	3.20E-12
Year (Protected)	Unav. %	2.61E-12	3.20E-12

3.8.7 Capacity planning and link budget calculation

Based on traffic estimation and prediction done by radio frequency department the required capacity for this microwave link is about 40 Mbps. Therefore 14 MHz frequency channel bandwidth with 16-QAM modulation is selected for this microwave backhaul link. The detail about link budget of the microwave site is given in table 3.13

Table 3 13 Link budget calculation with Ellipse

Radio Data : 42Mbps-16QAM			
BER 1E-3	**Unit**	**A->B**	**B->A**
TX Power	dBm	23	23
Transmitted Power	EIRP(dBm)	57.2	57.2
RX Level	dBm	-38.13	-38.69
RX Level (Diversity)	dBm	-	-
Threshold	dBm	-85.5	-85.5
Thermal Margin (Fade Margin)	dB	47.37	46.81

As indicated in the following table with TX power of 23 dBm the receiving for the far end would be around -38.13 dBm which is a very good receiving level for microwave links.

As this site was a normal site therefor, no protection link was considered for this microwave link. It is also indicated in table 3. That RX power and receiving power level is zero for the diversity antennas.

3.8.8 Link performance calculation based on UTR

The performance of the link was calculated based on UTR and the results taken out from Ellipse is given in table 3.14

Table 3 14 Link performance calculation with Ellipse

KAB138-KAB371 Performance						
Channel - 18G-14Mhz_C2_V (Slot No1)						
UTR						
Scheme	**UTR Rain (Ratio)**	**UTR Multipath (Ratio)**	**UTR Refraction (Ratio)**	**UTR Hardware (Ratio)**	**UTR Total (Ratio)**	**UTR Objective (Ratio)**
	Annual / Worst Month	**Annual / Worst Month**	**Annual / Worst Month**		**Annual / Worst Month**	
42Mbps-16QAM	AB: 0.000E+000 / 0.000E+000	AB: 1.624E-014 / 1.949E-013	Not computed	AB: -	AB: 0.000E+000 / 0.000E+000	AB: 2.000E-003
	BA: 0.000E+000 / 0.000E+000	BA: 1.992E-014 / 2.390E-013		BA: -	BA: 0.000E+000 / 0.000E+000	BA: 2.000E-003
ESR						
Scheme	**ESR Rain (Ratio)**	**ESR Multipath (Ratio)**	**-**	**-**	**ESR Total (Ratio)**	**ESR Objective (Ratio)**
	Annual / Worst Month	**Annual / Worst Month**			**Annual / Worst Month**	
42Mbps-16QAM	Not computed	Not computed	-	-	Not computed	AB: 7.500E-002
(Missing radio parameters for Q&A calculation)						BA: 7.500E-002

3.8.9 Link Unavailability Calculation

The principle attention when designing a microwave link is link unavailability. Mostly for microwave links, a link availability of 99.999 or five nine is considered in order to have a stable link. Availability of five nine means that a microwave link is allowed to drop 315 or fewer second or 5,3 minutes for a year in an growth of ten second only. Or strictly speaking a microwave link has an availability of 99.999 percent if the outage in the link has not occurred for more than second at a time and 315 second for a year.

The following table shows the link unavailability for this microwave links during a year.

Table 3 15 Link unavailability calculation with Ellipse

KAB138-KAB371 UTR Objectives (Unavailability Time Ratio)						
Channel - 18G-14Mhz_C2_V						
BER 10-3						
Scheme	UTR Rain (Ratio) Annual / Worst Month	UTR Multipath (Ratio) Annual / Worst Month	UTR Refraction (Ratio) Annual / Worst Month	UTR Hardware (Ratio)	UTR Total (Ratio) Annual / Worst Month	UTR Objective (Ratio)
42Mbps-16QAM	AB: 0.000E+000 / 0.000E+000	AB: 1.624E-014 / 1.949E-013	Not computed	AB: -	AB: 1.624E-014 / 1.949E-013	AB: 2.000E-003
	BA: 0.000E+000 / 0.000E+000	BA: 1.992E-014 / 2.390E-013		BA: -	BA: 1.992E-014 / 2.390E-013	BA: 2.000E-003
BER 10-6						
Scheme	UTR Rain (Ratio) Annual / Worst Month	UTR Multipath (Ratio) Annual / Worst Month	UTR Refraction (Ratio) Annual / Worst Month	UTR Hardware (Ratio)	UTR Total (Ratio) Annual / Worst Month	UTR Objective (Ratio)
42Mbps-16QAM	AB: 0.000E+000 / 0.000E+000	AB: 2.610E-014 / 3.132E-013	Not computed	AB: -	AB: 2.610E-014 / 3.132E-013	AB: 2.000E-003
	BA: 0.000E+000 / 0.000E+000	BA: 3.196E-014 / 3.835\E-013		BA: -	BA: 3.196E-014 / 3.835E-013	BA: 2.000E-003

CHAPTER 4

CAPACITY OPTIMIZAITON OF MICROWAVE BACKHAUL LINKS

Backhaul optimization in cellular networks refers to an ameliorative action that is required to optimize the capacity or frequency bandwidth for traffic flow so that it meets the quality of service [9]. In general, capacity optimization in cellular networks is based on monitoring of user traffic either from the radio access part or from the backhaul itself.

Dataset

In telecommunication companies all microwave links are controlled and monitored by network management system (NMS). Basically, network management system save permanently historical data related to fault management, performance management and configuration management. Therefore, KPI performance report can keep historical data of microwave links for long period of time. As there are enough historical data saved for every microwave link therefore, applying time series forecasting models like ARIMA and LSTM is suitable.

The dataset used in this project is a real throughput data obtained from KPI report of a local telecommunication company in Afghanistan. In this part of the project daily average throughput of several microwave link was traced from NMS system and was used to predict the future throughput in the microwave links. Moreover, based on predicted throughput, future capacity utilization and required frequency bandwidth was selected for the mentioned links.

Analyzing capacity utilization of microwave links

In cellular networks initially capacity planning and frequency bandwidth dimensioning in microwave backhaul is done based on maximum predicted capacity in the air interface during radio planning process. Usually traffic and capacity predicted during radio planning phase does not come out to be accurate enough and require several iteration in the planning process until it meet the QoS. Therefore, most of the time initial planed capacity and the assigned frequency bandwidth in the backhaul is not precise. For some microwave links the assigned capacity and frequency bandwidth would be insufficient that will leads to poor link performance while for other links the assigned frequency bandwidth might exceeds the required capacity and will result in frequency loss. To avoid frequency waste and improve link performance in microwave links, an accurate capacity analysis is needed in the network.

To analyze capacity utilization in microwave backhaul network, nearly two hundreds microwave site was considered from whole network. Fig.4.1 is drawn as a result of capacity analysis of mentioned frequency sites. We can see from Fig.1 that more than half of the microwave links from that total amount of 200 sites have used less than 50% of their planned capacity. About 26 microwave links have used only up to 10% of their assigned capacity and another 23 and 33 microwave links have used up to 20 and 30 percent of their planned frequency respectively. Totally 82 microwave links which is slightly less than the half total microwave links have used only up 30% of their frequency.

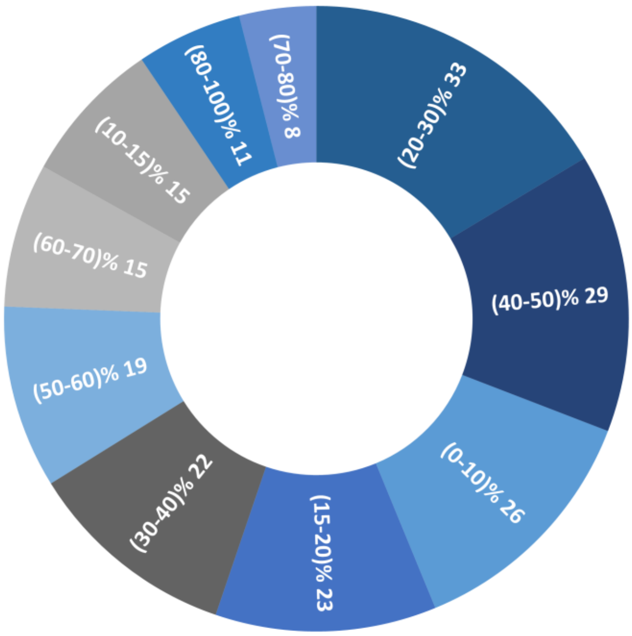

Figure 4 1 Capacity Utilization in different microwave link s

In addition, it is clearly visible from Fig.1 that only 19 microwave links that equals approximately 10 percent of total links have used eighty or more than eighty percent of their capacity, the rest 90 percent have used less than 75 percent that is a huge waste in frequency resource. Therefore, by developing a model that can predict the future throughput and can determine required network capacity accordingly, we are able avoid frequency bandwidth losses, that is a very a valuable and limited resource in telecom companies.

Analyzing the Dataset

The dataset used in this project is a collection of historical throughput obtained from several active microwave links. The historical data of each microwave links is different from other links, and has its own characteristics like level, trend, seasonality and noise. Based on the characteristics of the dataset we considered whether we should apply ARIMA or SARIMA model to predict future throughput. Therefore, we first decomposed the historical throughput data into its time series component to specify if our data is smooth or has trend or seasonality. Then based on decomposition of the data we select the appropriate model to predict future capacity.

A sample of the dataset used in this project is shown in table 4.1. In this table C_A shows the actual capacity, C_P is the planned capacity C_f indicates forecasted capacity and finally C_{op} shows optimized capacity in every microwave link and are shown in formula 11, 12 & 13 respectively

$$C_A = \{c_{at}\ ,\ c_{a(t-1)},\ c_{a(t-2)}, \dots\ ,\ c_{a(t-n)}\} \tag{4.1}$$

$$C_f = \{c_{a(t+1)},\ c_{a(t+2)},\ c_{a(t+3)}, \dots\ ,\ c_{a(t+n)}\} \tag{4.2}$$

$$C_{op} = \{c_{t-n}, \dots\ ,\ c_{t-2},\ c_{t-1},\ c_t,\ c_{t+1},\ c_{t+2}, \dots\ ,\ c_{t+n}\} \tag{4.3}$$

In equation 4.1, c_{at} is indicating capacity at the present time and $c_{a(t-1)}$, $c_{a(t-2)}$, indicates the capacity at the previous time steps. In equation 4.2, C_f is the forecasted capacity that is obtained from time series forecasting models used in this project and $c_{a(t+1)}$ shows the predicted capacity at one time step ahead.

In addition, in equation 4.3, C_{op} is the optimized capacity or the capacity of the microwave link which is obtained after optimization is applied on the microwave link.

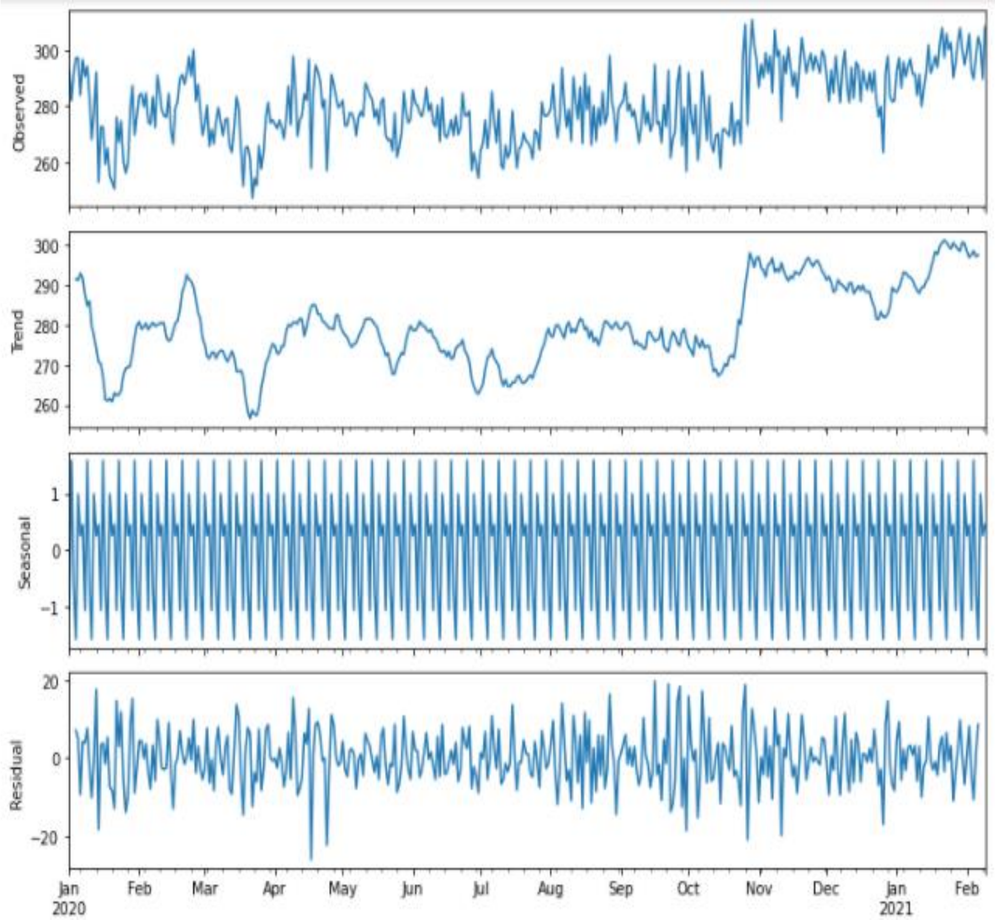

Figure 4 2 Decomposing the data to specify seasonality in the dataset

Moreover, in our model we have used daily average throughput data in order to find forecasted capacity in the network.

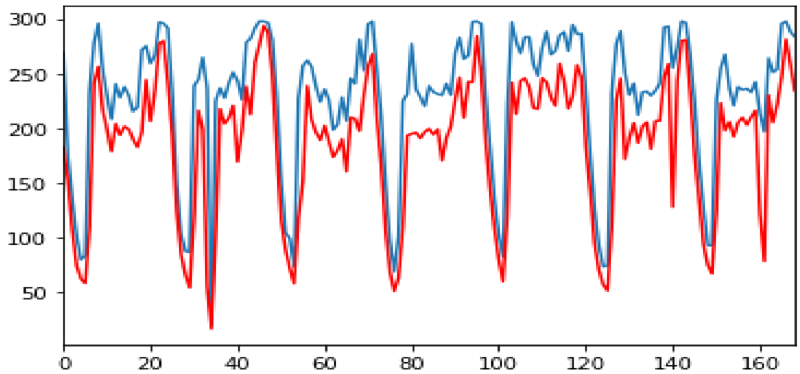

Figure 4 3 graph of peak vs average throughput for MW_link 9

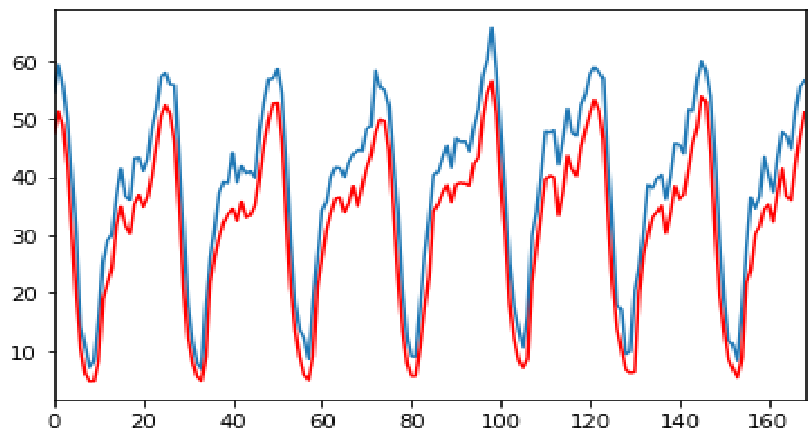

Figure 4 4 Graph of peak vs average throughput for MW_link 3

Therefore, when evaluating optimized capacity form the forecasted capacity we add X value in the formula so that the optimized capacity can handle peak data rate during busy hour. The value of X is evaluated based on peak to average ratio and according to our estimation peak to average ratio was around 15 % for most of the microwave link. Figure 4.3 & 4.4, is an hourly graph of peak throughput vs average throughput for one week. These graphs clearly indicates that the ratio between peak value and average don't exceed 15%.

Table 4 1 example of dataset capacity and utilization

Link name	Planned Capacity (C_P)in Mbps	Actual Capacity (C_A) in Mbps	Capacity Utilization in percentage
MW Link_1	368.00	278.65	75.7 %
MW Link_2	136.00	56.36	41.44 %
MW Link_3	89.00	33.85	38.03 %
MW Link_4	183.00	98.71	53.94 %
MW link_N	78.00	25	32 %

As the peak to average ratio calculated from most of the microwave link was around 15 percent therefore, we add another 15 percent of the predicted capacity so that our model can handle the peak data rate during the busy hours.

The data file is collected from real microwave links that are used as a transmission backhaul medium in cellular networks. Some changes have been made for the collected dataset because data in telecommunication companies are confidential and cannot be shared.

Results and Discussion

The model used in this project was constructed and executed in python. For the ARIMA and SARIMA models, Pmdarima, which is a statistical library in python was used to find the best parameter for the two models. Then prediction was done based on the parameter found from the Auto-ARIMA. LSTM model was developed using Keras library. Best output from LSTM model was achieved when the number of lag observation was considered 9 for most of the microwave link data. Sigmoid was used as an activation function with the backpropagation method. The performance of the models are evaluated based on MSE, RMSE and MAPE criteria. The details of the parameters for each model and the achieved results after defining, fitting and evaluating the models are indicated in detail in table 4.2.

Considering the characteristics and the number of past observation of the dataset, three different models were developed in order to forecast future capacity in each microwave link. After predicting future capacity then the result of each model was found based on the performance criteria, and finally optimized capacity was calculated according to the formula given in the table 4.2.

Let’s start explaining in detail our first experiment which has microwave link name (MW_link-1). This microwave link has about 4 months or 120 days of historical data so the best model to predict future capacity is either ARIMA or SARIMA. After decomposing the signal we found that the data has no seasonality and therefore based on our methodology the best model for this microwave links is ARIMA.

Applying ARIMA model with parameters (0, 1, 1), an MAPE value of 3.636 with forecasted capacity of 51 Mbps is achieved. As MAPE value is less than 6 percent so the next step is to find the optimized capacity for this microwave link. Considering peak to average ratio of 15 Mbps for the link our optimized capacity for this link is in the range of (55.59 – 61.71) Mbps.

Table 4 2   Result obtained from capacity and frequency optimization model

Link Name	Number of Past Observation	Performance Criterion	Models					Optimized Capacity in (Mbps) When *X = 15*
			ARIMA (p,d,q)	Result	SARIMA (p,d,q)(P,D,Q)(S)	Result	LSTM Result	$C_{op} = C_f + X * C_f/100 \pm e_m$
MW_Link-1		MSE	(0,1,1)	8.95	NA			55.59 - 61.71
		RMSE		5.014			NA	
		MAPE		3.636				
MW_Link-3		MSE	NA		NA		6,54	321.65 – 333.85
		RMSE					3.42	
		MAPE					2.13	
MW_Link-5		MSE	NA		NA		5.276	53.05 – 55.05
		RMSE					2.564	
		MAPE					1.89	
MW_Link-9		MSE	(1,1,1,)	11.687	NA			18.67 – 20. 43
		RMSE		6.345			NA	
		MAPE		5.180				
MW_link-15		MSE	NA		(1,1,0)(1,0,1)(7)	9.123		32,63 – 34. 07
		RMSE				4.352	NA	
		MAPE				2.48		
⋮								

Figure 4.5 indicates the actual and predicted trace of MW_link 1. The x-axis illustrates the number of days the average throughput is plotted and the y-axis indicates the capacity utilization or average throughput in Mbps. The blue line shows the actual plot of the data, the green line shows the fitted and the orange line shows the predicted plot of data.

Similarly, microwave link 3 has about 400 day of historical data and based on our methodology the best model to predict future capacity for this link is LSTM model. Applying LSTM model for this microwave link achieved an MAPE value of 2.13

percent. Again considering the peak to average ratio as 15, the optimized capacity for this link is in the range (321.65 – 333.85) Mbps.

Figure 4.6 is plotted as a result of applying LSTM model for MW_link 3. Again the x-axis indicates the time in days that the average throughput is plotted and the y-axis shows utilization in Mbps.

The blue line shows the actual plot of the historical data and green line shows the fitted and the green line shows the predicted throughput in this microwave link. From the result obtained in table 4 and graphs in figure 7 and 8 as a result of the the models, it is clearly visible that our model is able to optimize capacity utilization in microwave links and is a good propose for capacity planning in telecom companies.

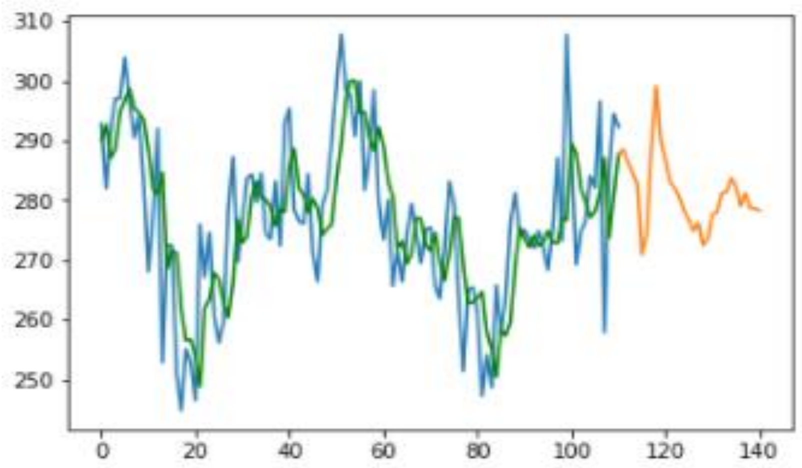

Figure 4. 5 Graph of predicted capacity vs actual capacity of MW_1 using ARIMA model

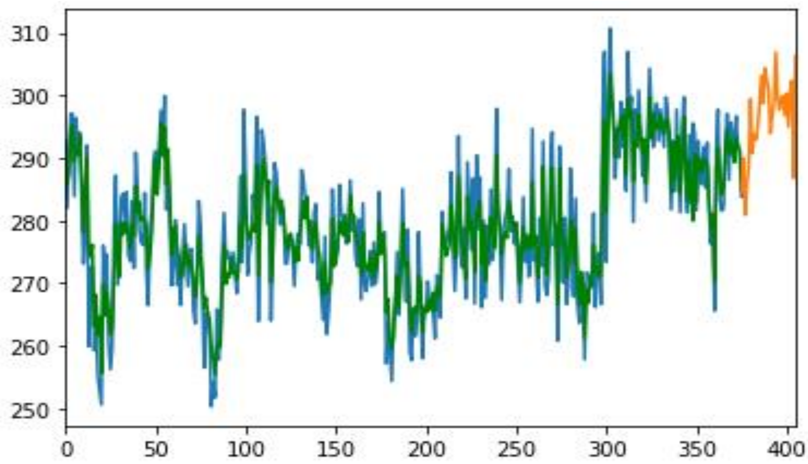

Figure 4. 6 Graph of predicted capacity vs actual capacity of MW_5 using LSTM model

Conclusions

As discussed, this project has two main parts. In the first part of this project we designed a microwave link for an LTE site in order to explain the planning and design steps required for a microwave backhaul link. Moreover, through this link planning, we also wanted to indicate that mostly the capacity assigned for every microwave backhaul link during the planning does not come out to be accurate enough and require some capacity optimization in order to improve the link performance and avoid frequency bandwidth loss.

It should be noted that in Afghanistan generally most of the microwave link are used as backhaul media for cellular sited due to the limitation of fiber optic growth. This link was designed by considering the existing equipment in the stock, available licensed frequency in hand, and other limitation affecting the link.

A step by step design process was followed while planning the site. First a complete site survey was done for specifying the site location, tower type, antenna height, power availability, site coordinates and all other equipment required for the link. Then the link was systematically designed by calculating all the parameter of the link by a microwave planning software called Ellipse was used in order to accurately design and analyze the link.

The result obtained from the Ellipse was implement on the site and all the parameters like link receiving level, link capacity was achieved based on the calculation from the software. After the installation we monitor the site utilization and found that the utilization of the site was very less then what was predicted from RF planning department and therefore, require a capacity optimization process in order to avoid frequency waste which is a very limited and costly resources.

In the second part of this project we wanted to develop an intelligent system to automatically study past throughput in microwave links, and accordingly predict future throughput in order to optimize capacity and frequency in transmission links in cellular networks. The main objective of this part of our project was to automate capacity optimization process in the backhaul system in telecommunication companies in order to avoid frequency waste and improve quality of the overall network.

With the help of time series forecasting models and the historical data of microwave backhaul links obtained from NMS system we were able to develop a model that has the capability to optimize capacity and frequency in transmission media in telecom companies. Two forecasting models were used to predict future capacity in every microwave link and then using the predicted capacity or throughput we were able to assign an appropriate frequency bandwidth for every link. In this way we not only improve the overall performance of the network but also avoid a huge amount of frequency waste in the network.

As an example we have selected few microwave link in table 4.3 to indicate how frequency waste is avoided in the network. Let's start from first row of table 5 which is microwave link 2 (MW_link 2). Prior to the optimization process this microwave link had only about 41 % utilization and 28 MHz frequency bandwidth. In this link a large amount of frequency bandwidth which is a scarce and expensive resource is wasted. After optimization process frequency bandwidth of the link was decreased to 14 MHz and modulation was increased to 256 QAM. Utilization of the link after optimization was around 63 % which is counted as a good utilization for microwave links.

Table 4 3 utilization and frequency bandwidth after optimization

	Capacity utilization and frequency bandwidth before optimization			Capacity utilization and frequency bandwidth after optimization		
Link Name	Utilization in percentage	frequency BW in (MHz)	modulation type in QAM	frequency BW in (MHz)	Modulation type in QAM	Utilization in percentage
MW_link 2	41.44	28	64	14	256	63
MW_link 3	38.03	14	256	7	512	75.5
MW_link 5	73.4	56	512	56	256	79.4
MW_link 9	57.83	28	64	14	512	83.6

For the microwave link 3 (MW_link 3) that had also low utilization, again 7 MHz of frequency bandwidth was saved and had a good utilization of 75 % after optimization. This process was done for the whole microwave links considered in this project that results in not only saving a huge amount of frequency bandwidth but also improving the overall performance of the network.

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