MEASUREMENT OF QoS PARAMETERS AND COMPARATIVE PERFORMANCE ANALYSIS OF THE MAJOR MOBILE NETWORKS IN BANGLADESH

M. Engg.Thesis

in

Electrical and Electronic Engineering

Department of Electrical and Electronic Engineering, BUET

March, 2017

MEASUREMENT OF QoS PARAMETERS AND COMPARATIVE PERFORMANCE ANALYSIS OF THE MAJOR MOBILE NETWORKS IN BANGLADESH

A THESIS SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING, BUET IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
M.Engg. IN ELECTRICAL AND ELECTRONIC ENGINEERING

Submitted by
Md. Zafar Sadiq
Student no: 0411062233

Supervised by
Dr. Md. Saifur Rahman
Professor, Dept. of EEE, BUET

March, 2017

The thesis titled "**MEASUREMENT OF QoS PARAMETERS AND COMPARATIVE PERFORMANCE ANALYSIS OF THE MAJOR MOBILE NETWORKS IN BANGLADESH**", submitted by Md. Zafar Sadiq, Roll No: 0411062233, Session: April 2011 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of M.Engg. in electrical and electronic engineering on 11th March 2017.

Board of Examiners

Dr. Md. Saifur Rahman
Professor
Department of Electrical and Electronic Engineering
Bangladesh University of Engineering and Technology, Dhaka-1205, Bangladesh

Chairperson
(Supervisor)

Dr. Satya Prasad Majumder
Professor
Department of Electrical and Electronic Engineering
Bangladesh University of Engineering and Technology, Dhaka-1205, Bangladesh

Member

Dr. Md. Forkan Uddin
Associate Professor
Department of Electrical and Electronic Engineering
Bangladesh University of Engineering and Technology, Dhaka-1205, Bangladesh

Member

Declaration

I do, hereby declare that the content of this dissertation is my original work. No part of this work has been submitted elsewhere partially or fully for the award of any other degree or diploma. Any material reproduced in this article has been properly acknowledged.

....

Md. Zafar Sadiq
Student No: 0411062233

Acknowledgement

This thesis and the entire M. Engg. Program has been made possible through the strength and wisdom bestowed on me by the Almighty Allah. I am convinced that without Him I could not have reached this stage.

I would like to express my profound gratitude to my supervisor Professor Dr. Md. Saifur Rahman for his meticulous guidance which paved the way for this final output. His orientation, discipline, availability, constant support, and guidelines, were a key factor to finish this work with the demanded and desired quality.

I am very grateful to my company, for giving me the opportunity to use technical tools necessary for the thesis work.

I owe many thanks to my family, especially my parents and my wife for their enormous patience, understanding and unconditional love, for giving me the strength and motivation, without which, the completion of this work would have been a more difficult task.

Abstract

The main purpose of this thesis is to study the mobile network, in terms of coverage and quality of service. Mobile communication played a vital role in changing the social, economic and technological change in Bangladesh over last 2 decades. Mobile operators use Key Performance Indicators (KPIs) to judge their network performance and evaluate the Quality of Service (QoS) to understand end user perceived quality. The KPIs are derived with the help of some counters using different formulations. On the other hand, KPIs sometimes misled about network quality perception of users as there are some specific network problems that cannot be identified through KPI measurement. In some cases, KPI gives a general idea about a problem rather than pinpoint the problem location or specific reason causing the problem. Therefore, operators perform drive test periodically in different locations to understand the actual network scenario experienced by the users. Benchmarking drive test is the standard procedure to measure competitive network scenario among operators. Drive test tool is used to collect the network data. Coverage, different quality parameters like CSSR, CDR, FER, C to I can be calculated from the drive test data. The drive test log can also be used for further dig down to find out the actual reason that caused the network problems; for example, why the call drop occurred in a specific location- can be found out. Benchmarking is mostly important in city area, where all the major mobile operators exist and quality of the service is very important to the users. On the other hand, few operators are present in rural area and coverage is the deciding factor to comment on the network of rural area. In this study, we have measured 2G network scenario in 5 thana (of 3 city, namely- Dhaka, Chittagong and Sylhet). From the benchmarking drive test, we have found that Banglalink is the best operator followed by ROBI. Airtel stood the last where Grameenphone secured the third place. It should be noted that, the performance difference among the 4 mobile operators is very marginal. Several recommendations have been placed to improve the network condition.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AUC	Authentication Center
BER	Bit Error Rate
BS	Base Station
BSC	Base Station Controller
BTRC	Bangladesh Telecommunication regulatory Authority
BTS	Base Transciever Station
C to I	Carrier to Interference Ratio
CEPT	Conference of European Post and Telecommunications
CRC	Cyclic Redundancy Check
CS	Circuit Switch
ECU	Error Concealment Unit
EGPRS	Enhanced General Packet Radio Service
EIR	Equipment Identity Register
EIRP	Effective Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
FDMA	Frequency Division Multiple Access
FER	Frame Eraser rate
GMSC	Gateway Mobile Switching Center
GPS	Global Positioning System
GSM	Global System for Mobile
HLR	Home Location Register
IBS	In Building Solution
ISC	International Switching Center
ISDN	Integrated Service Digital Network
ITU	International Telecommunication Union
IWF	Interworking Function
KPI	Key Performance Indication
LEA	Law Enforcing Authority
MOS	Mean Opinion Score
MS	Mobile Station
MSC	Mobile Switching Center

NMS	Network Management System
NO	Network Operators
OMC	Operation and Maintenance Center
PS	Packet Switch
PSTN	Public Switched Telephone Network
QoS	Quality of Service
QoSE	QoS Experienced (by the user)
QoSP	QoS Perceived (by the user)
RX Level	Received Signal Level
RX Qual	Received Signal Quality
SACCH	Slow Associated Control Channel
TBF	Temporary Block Flow
TDMA	Time Division Multiple Access
TRAI	Telecom Regulatory Authority of India
TRx	Transceiver (Transmitter and Receiver)
TSP	Telecom Service Provider
UMTS	Universal Mobile Telecommunications System
VLR	Visitor Location Register

CHAPTER 1

INTRODUCTION

We live in the age of modern wireless digital communication, where the earth has become a global village. In Bangladesh cellular mobile communications play a vital role in person to person communication, which promotes the rapid development of business and the overall progress of the country. Currently there are five GSM mobile operators and one CDMA operator in Bangladesh, who offer cellular mobile communication services to the subscribers. The current research aims at determining the QoS parameters of the major mobile networks in Bangladesh and carry out a comparative performance analysis so that the subscribers may come to know about the actual quality of services the mobile operators offer to them. This chapter first outlines the present scenario on the issue. Then it describes the motivation for the current work, the scope of the work, the objectives and the possible outcomes. Finally, it gives a brief description of the contents of this dissertation.

1.1 Present Scenario

Network performance and QoS assessment are significant for mobile operators because customer satisfaction is directly dependent on the quality and the performance of the mobile operator's network [1]. Regardless of service type, all operators in a country or area have to verify their service quality against some acceptable and recognized standard. Observation and optimization of the network quality and performance are necessary in order to meet increasing customer demands. Operators has to make sure that the Key Performance Indicator (KPI) values e.g., Call Drop rate, Call Setup Success Rate, Call Block Rate, Handover Success Rate, etc., are within the specified threshold values and provide the QoS criteria required by both the authorities and customers, and they compare the performance of their competitors as well to serve the users in a better manner. Furthermore, all mobile operators use KPIs to judge network performance and evaluate QoS. The KPIs are derived with the help of some counters using various formulations. On the other hand, KPIs sometimes mislead the network quality perception of users as there are some specific network issues that cannot be identified through KPI. To gather network benchmarking data [2], drive tests are the only way using which mobile network operators can collect accurate competitive data that may indicate the true levels of technical performance and quality of their networks.

Data collection [3] based on the drive tests is an essential method to evaluate the service quality and to assess the performance of a mobile network [4]. Mobile operators perform drive tests individually to assess the QoS parameters of their own network, but those are not revealed outside. On the other hand, each operator claim that it's offered services are better than those of any other mobile operator.

1.2 Motivation for the Work

Measuring the QoS parameters of the mobile operators, followed by analysis and comparison can provide a useful insight about QoS scenario of mobile service in Bangladesh. This will also help us understand whether the QoS meet the standard set by the regulator, where the QoS parameters stand with respect to the international standard. Analysis of the possible causes to the QoS degradation can help us reveal the applicable solution to improve the QoS. However, relevant data representing the QoS indicators of any specific area for the services of various mobile networks of Bangladesh are neither published by the BTRC for the end-users nor from any impartial and independent source.

1.3 Scope of the Work

In this thesis, we have described how to obtain and analyze data from field by drive test, how to calculate the KPIs from drive test data, what are the important KPIs to describe QoS scenario, why QoS degrades and the impacts of degradation of the QoS parameters. Some recommendations have also been made on how to improve the QoS scenario in a particular area. From the drive test data, coverage problems can be identified and appropriate solutions can be suggested and carried out. The methods for making comparisons between the network operators according to the KPIs are explained.

Prior to the result and discussion section, a detailed discussion has been presented on what QoS means, standard definitions of QoS by the international organization like ITU, ETSI etc. QoS standardization in different countries are also discussed with an elaborate QoS guidelines in Bangladesh. Benchmarking through drive test is also compared with the benchmarking through NMS statistics.

1.4 Objectives and Possible Outcomes

Objectives:

The main objectives of the current study/research are:

a) To measure the important data, relevant to the performance on coverage and quality of the various mobile radio networks of Bangladesh in some selected areas,
b) To determine the QoS parameters based on the measurement log and assess/evaluate the comparative performance ranking of the major mobile operators of Bangladesh.

Possible outcomes:

The expected outcomes of the proposed research are:

a) Performance comparison, on the basis of the QoS parameters, would be possible for the major mobile networks in Bangladesh.
b) The measured data would provide necessary qualitative information relevant to the mobile radio networks of Bangladesh, which could be used by BTRC and/or the specific operator(s) to ensure and optimize the network performance, and thus help improve the overall quality of the mobile networks.

1.5 Organization of this Dissertation

This dissertation contains the following chapters

Chapter 1 is the introductory chapter which describes problem definition, motivation of the work, scope of the thesis, Objectives and possible outcomes and organization of the dissertation.

Chapter 2 is on the quality of service in GSM system. In this chapter the QoS are defined, standard QoS parameters are discussed, national and international QoS requirement are presented. Specific KPIs are mentioned with calculation formula, causes responsible for the QoS degradation are also discussed. Benchmarking term is elaborated.

Chapter 3 describes the two measurement procedure of the QoS parameters, the question of why drive test is taken as the benchmarking is answered. The equipment used for this work is also elaborately described in this chapter.

Results are discussed in chapter 4. Here the drive test result are presented in a greater detail. Possible causes for the problems are identified and their possible solutions are suggested.

Finally, chapter 5 summarizes the outcome of the benchmarking drive test and the QoS comparison among various mobile operators of Bangladesh. It also suggests the extension to the current research to improve the overall QoS of GSM system based on this dissertation.

References are included at the end of this dissertation.

This chapter has provided the introductory information relevant to the current research. The next chapter describes the Quality of Services (QoS) parameters in a GSM system and importance of their performance analysis.

CHAPTER 2
QUALITY OF SERVICE IN GSM SYSTEM

The motivation for measuring the QoS parameters and conducting the comparative performance analysis of the major mobile networks in Bangladesh were described in previous chapter. This chapter first gives an overview of a GSM system, then it goes on to define the various QoS parameters of a mobile network. It also describes the factors that influence the QoS parameters.

2.1 GSM System Overview

In the early 1980s, analog cellular telephone systems expanded across Europe. However, as each country developed its own system, interoperability across borders became a limiting factor. In 1982, the Conference of European Post and Telecommunications (CEPT), an association of telephone and telegraph operators in Europe, established a working group to develop a new public land mobile system to span the continent. In 1989, the responsibility for GSM development was passed on to the European Telecommunications Standards Institute (ETSI), and phase 1 of the GSM specification was published in 1990. The first commercial service was launched in 1991. When the official language of the GSM group changed from French to English, GSM was changed from Groupe Speciale Mobile to Global System for Mobile Communications. GSM uses a combination of both the time division multiple access (TDMA) and frequency division multiple access (FDMA) technologies so that, more channels of communications are available, and all channels are digital.

A GSM system basically consists of 2 parts-

a) Radio Network/Access Network and

b) Core Network

Fig. 2.1 shows the fundamental components of a GSM system [5]. In a GSM system, a user carries a Mobile Station (MS) which can communicate over the air with a base station, called Base Transceiver Station (BTS). The BTS contains transmitter and receiver equipment, such as antennas and amplifiers, as well as a few components for signal and protocol processing. For example, error protection coding is performed in the BTS, and the link-level protocol for signaling on the radio path is terminated here. In order to keep the base stations small, the essential control and protocol intelligence resides in the Base Station Controller (BSC). It contains, for example, protocol functions for radio channel allocation, channel setup and management of handovers. Typically, several BTSs are controlled by one BSC. In practice, the BTS and BSC are connected by fixed lines or P2P (point to point) radio links. BTS and BSC together form the Radio Access Network.

The combined traffic of the users is routed through a switch, called the Mobile Switching Center (MSC). It performs all the switching functions of a switching node in a fixed telephone network, e.g., in an Integrated Services Digital Network (ISDN). This includes path search, data forwarding and service feature processing; main difference between an ISDN and an MSC is that the MSC has to consider the allocation and administration of radio resources and the mobility of the users. The MSC therefore has to provide additional functions for location registrations of users and for the handover of a connection in the case of changing from a cell to cell. A cellular network can have several MSCs with being responsible for a part of the network. Calls originating from or terminating to the fixed network are handled by a Gateway MSC (GMSC). The internetworking of a cellular network and a fixed network (e.g., PSTN, ISDN) is performed by the Interworking Function (IWF). It is needed to map the protocols of the cellular networks on to those of the respective fixed network. Connections to other mobile or international networks are typically routed over the International Switching Center (ISC) of the respective country.

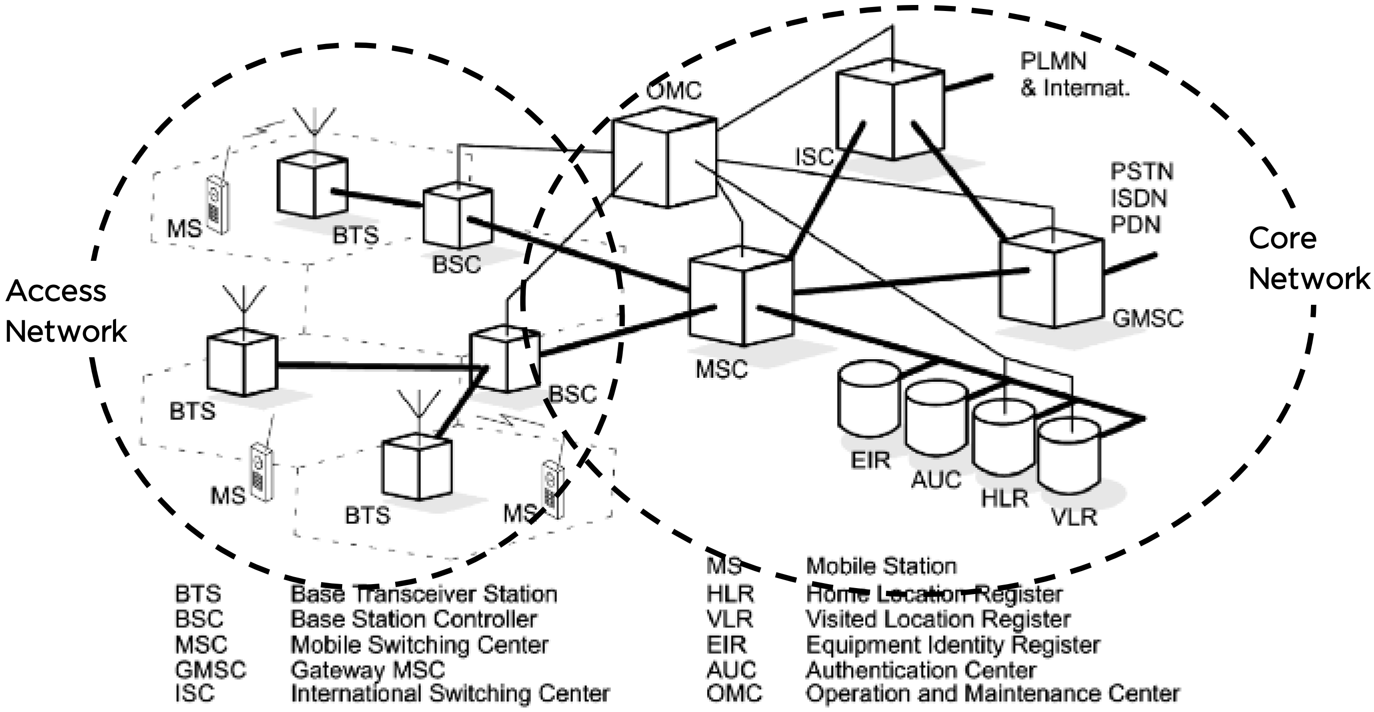


Fig. 2.1: GSM System Architecture

A GSM network also contains several types of databases. The Home Location register (HLR) and the Visitor Location register (VLR) stores the current location of the user. This is needed since the network must know the current cell of a user to establish a call to the correct base station. In addition, these registers store the profile of the users, which are required for charging and billing and other administrative issues. Two further databases perform security functions: the Authentication Center (AUC) stores security-related data such as keys used for authentication and encryption; the Equipment Identity Register (EIR) registers equipment data rather than subscriber data. The network management is organized from a central place, the Operation and Maintenance Center (OMC). Its function include the administration of the subscribers, terminals, charging data, network configuration, operation, performance monitoring and network maintenance.

2.2 Quality of Service: ITU Standardization

QoS is defined by International Telecommunication Union (ITU) as "*Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service.*" [6]

In earlier version of ITU recommendation [7], we get more elaborated idea on QoS definition of telecommunication: the serveability performance is the most generally affected. It is further subdivided into three terms:

a) service accessibility performance;

b) service retainability performance;

c) service integrity performance.

Serveability performance depends on trafficability performance and its influencing factors of resourcing and facility, dependability and transmission performance (of which propagation performance is a subset), as shown in Fig. 2.2 below. The numbers in each box show the reference number of ITU recommendations. These definition boxes support a set of QoS standards.

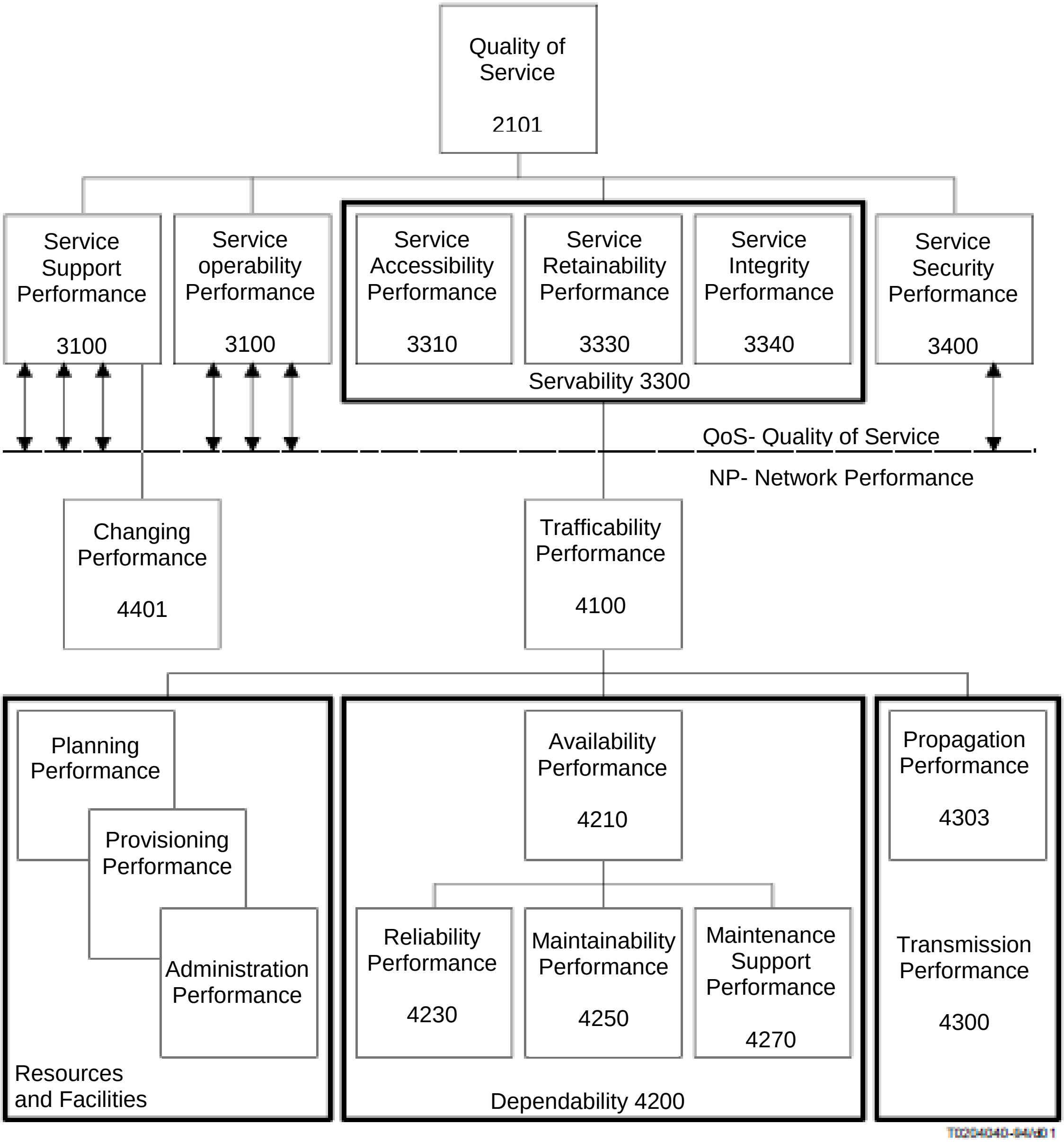


Fig. 2.2: Quality of service (ITU recommendation)

From the figure above, it is evident that Quality of Service depends on many factors. It is quite difficult to conclude on service quality. Therefore, we have considered the 'Servability' part, as part of the project which is directly measurable through drive test.

In the updated version [6] of ITU recommendation, the Quality of Service is simplified. End – to-end quality is shown in figure Fig. 2.3:

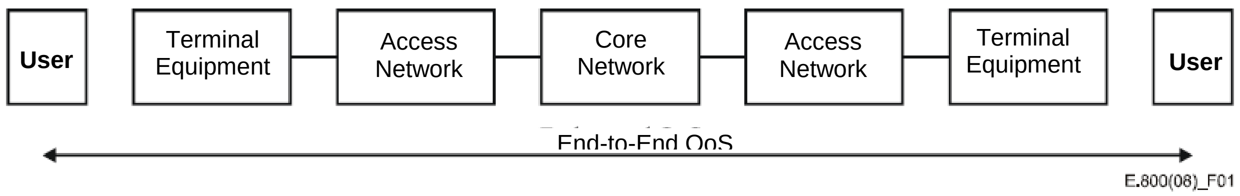


Fig. 2.3: Schematic contributions to end-to-end QoS

To specify the end-to-end QoS, it is necessary to state the specified operating conditions in which a service is supported over a connection (connectionless or connection oriented) that takes place. The QoS could also be altered for a given set of specified operating conditions by environmental conditions, such as traffic and routing.

Two main dependent of quality are Network and non-network segment [6]. Fig. 2.4 illustrates the relationship between QoS and network performance. QoS comprises both network performance and non-network related performance. Examples of network performance are bit error rate, latency, etc., and for non-network performance provision time, repair time, range of tariffs and complaints resolution time, etc. The list of QoS criteria for a particular service would be dependent upon the service and their relevance could vary among the segments of the customer population.

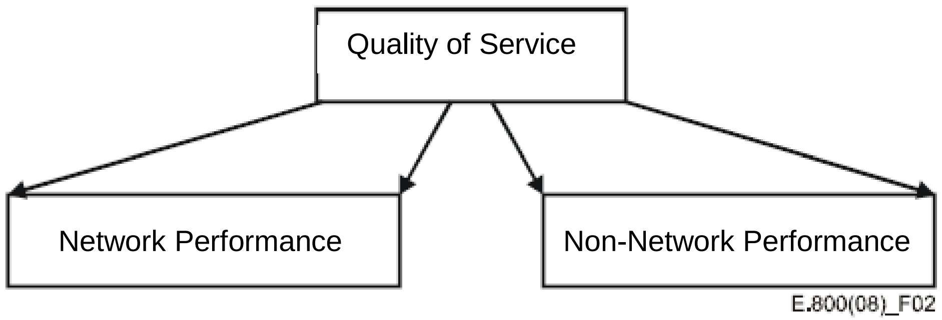


Fig. 2.4: Quality of service comprises network and non-network criteria

At a more detailed level, QoS can be divided into four viewpoints as illustrated in Fig. 2.5 below. This Concept is described further in [ITU-T G.1000]. A generic definition of QoS is derived from a definition of quality and is given in clause 2. Of particular interest is QoS experienced by the user (expressed by QoSE or QoSP – QoS perceived). QoSE is influenced by the delivered QoS and the psychological factors influencing the perception of the user. Understanding of the QoSE is of primary importance to help optimize revenue and resources of the service provider.

User experience or Quality of service basically depends on radio part. Improving radio network is always the main challenge to the mobile operators. Maintenance of a large number of BTSs

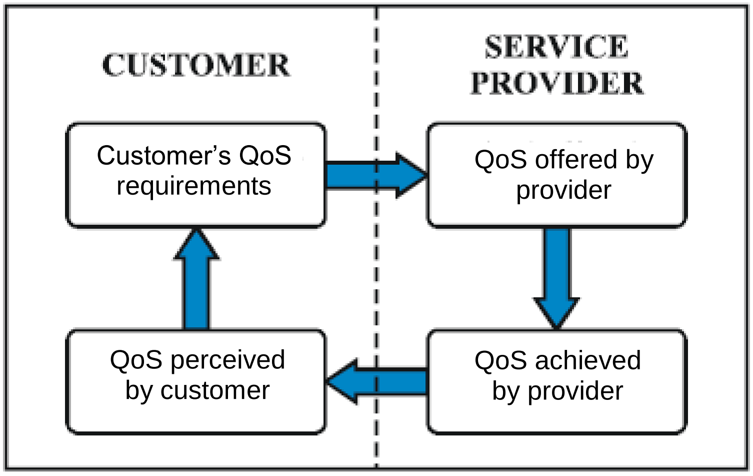


Fig. 2.5: Four viewpoints of quality of service

is the key challenge, while dynamic wireless environment is another challenge to be addressed. Regular health check of network elements like physical blocking issue of the antenna, performance management of the whole antenna system (antenna, feeder cable, connector, jumper etc) of so many BTSs is a mammoth's task.

Even with numerous number of BTS. Indoor solution (IBS- In Building Solution with Distributed Antenna System) is the best solution to improve indoor coverage, yet mass deployment of IBS is not feasible due to high cost. Therefore, operators have to choose optimum resource deployment for providing indoor solution up to certain level.

Quality problem comes after user is able to access the network. User can face multiple types of problem such as silent call (one sided call), call drop, broken voice during conversation, poor voice quality, poor data speed, data latency, etc.

2.3 QoS Standardization in Mobile Telephony

The task of standardization is done by the regulatory authority. Different countries set QoS range differently based on their requirement. For example, in African countries like Nigeria and Libya- QoS demand is much strict than that in Bangladesh. Bangladesh Telecommunication regulatory Authority (BTRC) sets the standards for QoS to be met by the mobile operators. In the last QoS directives by BTRC [8] states clear demand of each QoS to be met. Also, a timeline is proposed with which window it has to be measured. The best part of the directive is, to set an expectation for long-term as well, which helps the operators to set their QoS goal accordingly. Table 2.1 next lists the QoS parameters to be met by the mobile operators in Banglasdesh.

Parameters that are averaged over a period of 1 month can be obtained from the NMS or other statistics; for a localized area- drive test can help to obtain this. All the KPIs except section 4 listed in table 2.1 can be obtained from NMS statistics.

Parameters that are averaged over a period of 1 quarter usually obtained from the benchmarking drive test; Section 4 KPIs (benchmarking KPI) represents this type of KPIs.

Table 2.1: QoS recommendation for the Mobile Operators in Bangladesh

No.	QoS Parameters	Benchmarks		Averaged over a period of
		Short Term (<2 years)	**Long Term (>2 years)**	
1.0	**CS KPI**			
1.1	Call set-up success rate	>= 95%	>= 97%	One Month
1.2	Congestion due to SDCCH	<=3%	<=2%	One Month
1.3	Congestion due to Paging Channel	<=3%	<=2%	One Month
1.4	Congestion due to TCH	<=3%	<=2%	One Month
1.5	Call drop rate	<=3%	<=2%	One Month
2.0	**PS KPI**			
2.1	EGPRS TBF Throughput (GSM Cells only)	DL >=100 kbps UL >=25 kbps	DL >=100 kbps UL >=25 kbps	One Month
2.2	Average Throughput for PS R99 Service (UMTS Cells only)	DL >= 256 kbps UL >= 80bps	DL >= 275 kbps UL >= 100 kbps	One Month
3.0	**SMS Service**			
3.1	Completion Rate for SMS service	>= 80%	>= 85%	
4.0	**Benchmarking KPI**			
4.1	Rx Level (90% samples)	>= -95dBm(Indoor) >= -75dBm(Outdoor)	>= -95dBm(Indoor) >= -75dBm(Outdoor)	One Quarter
4.2	MOS(90% samples)	>=3	>= 3.5	One Quarter
4.3	Call Setup Time	<= 8 sec	<=7 sec	One Quarter
5.0	**Operational KPI**			
5.1	Accumulated Down Time Of BTSs	<= 2%	<= 1%	One Quarter
6.0	**Customer Complain Management**			
6.1	No of complaints per 100 customers	<= 2.5	<= 1	One Month
6.2	Response Time to customer for assistance in Customer Care: a. Electronically b. Voice to voice (Through an Operator)	100 % within 20 sec 95 % within 30 sec 100% within 90 sec	100 % within 20 sec 95 % within 30 sec 100% within 90 sec	One Month

A sample comparison of QoS is shown in Table 2.2 below that clearly articulates the QoS standards among different countries [8] [9]. The comparison shows that the QoS target set by the regulatory authority is a bit relaxed for the mobile operators in Bangladesh compared to that of Nigeria and Libiya.

Table 2.2: QoS recommendation comparison among different countries

QoS Parameter	Bangladesh	Nigeria	Libya
Call Setup success Rate	>95%	≥98% (BH)	99% Local (BH) 98% International (BH)
Call Drop Rate	<=3%	<=1% (BH)	<=1% (BH)
Call set up time	<= 8 sec.	<=6 sec. (BH)	<=5 sec Local <=10 sec. (International)

The following paragraphs will describe the various QoS parameters in a greater detail.

RX Level

'RX Level' stands for 'Received signal level' by the mobile station, it is measured in dBm. Usually the received power ranges from micro watt to pico watt level (10^{-6} watt to 10^{-12} watt level), due to very low value, signal level is converted to dBm. RX level measured with mobile always show the negative value because the received signal is lower than 1 mW.

Following category for RX level are used in telecommunication to define mobile signal Strength. The difference between categories depends on the penetration loss. To explain- for example, if a person is in outdoor environment there will be no penetration loss (other than body loss) and the user can use service up to the RX sensitivity of his user device-

Minimum RX sensitivity of the handset = -102 dBm

Minimum C/I requirement for GSM voice = 9 dB

Body loss= 1.5 dB

Minimum required signal level = -102 dBm +1.5 dB + 9 dB= -91.5 dBm

In case of absence of external/other interference, -91 dBm is sufficient for voice conversation in an outdoor scenario.

In a similar way, "In-car" level is assumed considering 10 dB penetration loss, while indoor is defined with a 20 dB penetration loss. Table 2.3 shows the RX level ranges categorization.

Table 2.3: RX Level ranges categorization.

Category	RX level
Deep Indoor	up to-65 dBm
Indoor	-65 dBm to -71 dBm
In car	-71 dBm to -81 dBm
outdoor	-81 dBm to -91 dBm

RX Qual

RxQual is represented by a numeric value between 0 and 7, where each value corresponds to an estimated number of bit errors in a number of bursts. Each RxQual value corresponds to the estimated bit-error rate according to the following table 2.4, which is taken from GSM technical specification 05.08 section 8.2.4:

Table 2.4: RX Qual vs Bit Error Rate (BER) ranges.

RX Qual value	Bit Error Rate (BER Range)	Remarks
0	BER < 0.2%	Good
1	0.2% < BER < 0.4%	Good
2	0.4% < BER < 0.8%	Good
3	0.8% < BER < 1.6%	Good
4	1.6% < BER < 3.2%	Moderate
5	3.2% < BER < 6.4%	Moderate
6	6.4% < BER < 12.8%	Bad
7	BER > 12.8%	Bad

After the channel decoder has decoded a 456 bits block, it is coded again using the convolutional code in the channel coder and the resulting 456 bits are compared with the 456 input bits. Fig. 2.6 shows the channel coding scenario in GSM for a full-rate traffic speech channel. The number of bits that differs between those two 456 bits block corresponds to the number of bit errors in the block (at least up to a rather high number of bit errors). The number of bit errors is accumulated in a BER sum for each SACCH multi-frame. The BER sum is then divided by the total number of bits per SACCH multi-frame and the result is classified 0 -7

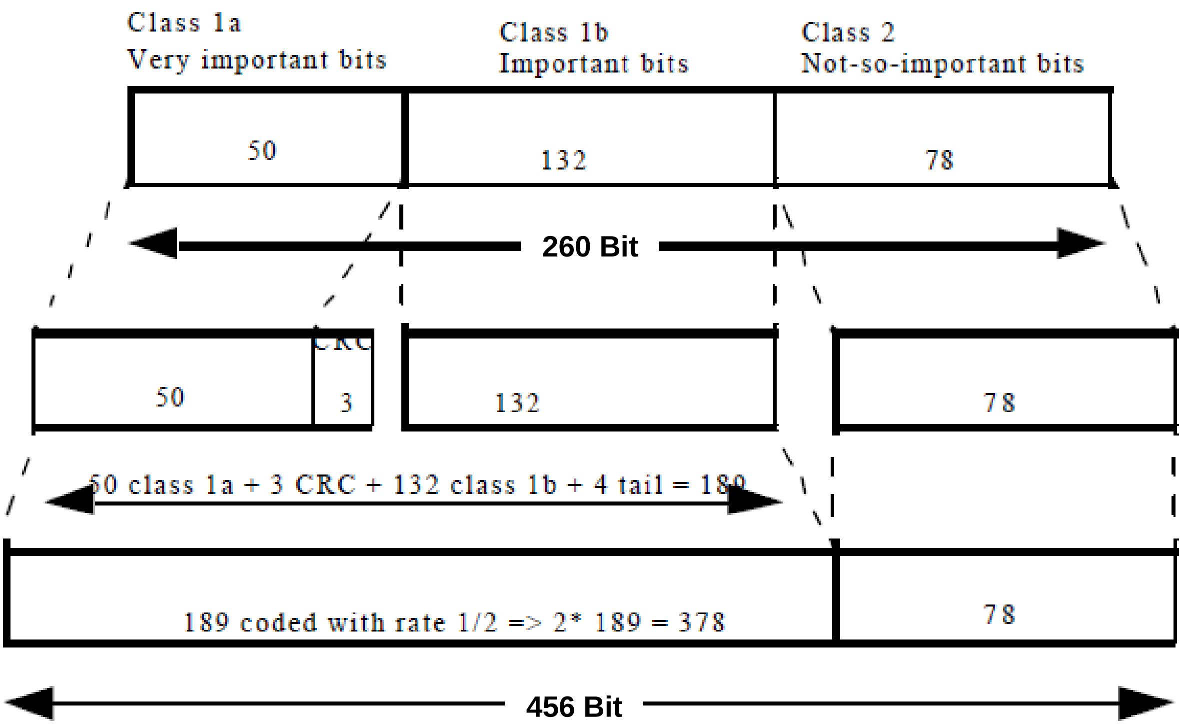


Fig. 2.6: Channel coding in GSM for a full-rate traffic speech channel

according to the BER to Rx Qual conversion table above. Note that the BER calculation will not take into consideration whether the block shall be discarded due to error in the CRC protecting the class 1a bits. Also note that even if the CRC indicates a valid speech block, the speech quality is not necessarily good. Bit errors can still remain in the class 1 bits and especially in the unprotected class 2 bits.

It should be noted that the BER calculation will not take into consideration whether the block shall be discarded due to error in the CRC protecting the class 1a bits. Even if the CRC indicates a valid speech block, the speech quality is not necessarily good. Bit errors can still remain in the class 1 bits and especially in the unprotected class 2 bits.

FER (Frame Eraser Rate)

Three CRC bits protect the 50 class 1a bits. CRC stands for cyclic redundancy check and works as a parity control and is used for error detection in the class 1a bits. When the channel decoder has decoded a 456 bits block, the CRC is checked and, if it is wrong, the whole block is discarded. GSM technical specification 06.11 gives an example of how this should be handled in the receiver by an error concealment unit (ECU). The FER value is based on the number of blocks that has been discarded due to error in the CRC:

FER (%) = (no. of blocks with incorrect CRC / total no. of blocks)*100………………. (2.1)

As with the RxQual and RxLev values, two types of measures are needed, FER FULL based on all frames and FER SUB based on the two mandatory blocks only. FER value should be less than 4% in a mobile network.

The FER values in which different speech codecs will begin to experience MOS degradation, and the rate of such degradation is quite uniform. Therefore, FER can be efficiently used as a speech quality performance indicator. The traditional problem associated with the usage of FER as a KPI in GSM systems has been the lack of FER-based NMS statistics. Therefore only drive test data have been available to measure the FER of the system. FER is, however, available to the network in the uplink (UL), and the downlink (DL). FER could be estimated from the available information in the network. Rel'99 specification includes the enhanced measurement report, which together with other enhancements brings the DL PER reporting. With this enhancement, terminals will report DL FER, thus permitting the network to generate DL FER statistics based on these reports.

Finally, it is important to define how FER data should be analyzed, both in terms of the averaging to apply to the raw data and the threshold values that define the occurrence of bad quality samples. The impact of frame erasures in the speech quality degradation will not only be related with the average FER value but with the frame erasure distribution as well. The FER associated with real connections has a bursty nature. Once the channel coding is not able to restore the original information, the FER degradation is easily very high. [10]

C to I (Carrier to Interference Ratio)

GSM is an interference restricted system. Carrier-to-interference ratio (C to I), also called interference protection ratio, refers to the ratio of all useful signals to all useless signals. This ratio is relevant to the instantaneous location and time of MS due to irregular landform, different shape, type and number of surrounding scatterer, different type, direction and height of antenna, as well as different number and intensity of interference source, etc.

The intensity of the interference is essentially a function of co-channel interference depending on the frequency reuse distance. From the viewpoint of a mobile station, the co-channel interference is caused by base stations at a distance from the serving base station with the same frequency.

In a GSM system, a 200 KHz channel is used for communication. Adjacent Channel Interference refers to the interference from all adjacent signals around the serving cell (carrier offset 200 KHz) to serving cell channel under the frequency reuse condition.

The noise is typically a broadband signal with stochastic variation, comparable to an AWGN (average white Gaussian noise) signal. The level of the noise floor in a GSM mobile is determined by two parameters. The first is the thermal noise, which is dependent on the nature of the GSM RF channel (the temperature and the bandwidth of the signal). The second parameter is the amount of noise generated in the mobile station's hardware.

The carrier to interference ratio is the ratio between the signal strength of the current serving cell and the signal strength of undesired (interfering) signal components. Here interference refers to all Co-channel, Adjacent Channel interference as well as Noise.

C to I= Carrier power/ (Co Channel Interference + Adjacent Channel Interference + Noise)

………………. (2.2)

Therefore, in a given radio environment, the C to I depends essentially on the ratio R/D (where, R is the cell radius and D is the frequency reuse distance). From these considerations it follows that for a desired or required C to I value at a given cell radius, one must choose a minimum distance for the frequency reuse, above which the co-channel interference falls below the required threshold. [11]

Minimum C to I requirement [12] is given below:

a) For Co-Channel Interference, C/I_c = 9 dB
b) For adjacent (200 KHz) Channel Interference, C/I_{a1} = - 9 dB
c) For adjacent (400 KHz) Channel Interference, C/I_{a2} = - 41 dB
d) For adjacent (600 KHz) Channel Interference, C/I_{a2} = - 49 dB

Voice Conversation can be conducted with even 6 dB C to I. Anything above 15 dB is considered very good C to I.

Call Drop and Call Completion Rate:

Call drop is defined as an event that shows the abnormal disconnection during call setup or during conversation. From a subscriber point of view, the most serious dropped calls are those that interrupts an ongoing conversation, i.e. a call dropped on the TCH. Long calls are used during drive test to check for dropped calls. By definition of ETSI, call drop is the proportion of incoming and outgoing calls which, once they have been correctly established and therefore have an assigned traffic channel, are dropped or interrupted prior to their normal completion by the user, the cause of the early termination being within the operator's network.

Finding reasons for call drops and solving them are one of the most challenging job in mobile network. Main reasons for a call drop are

a) Poor signal strength (Uplink or downlink or both),
b) Interference,
c) Resource limitation during call handover, and
d) Hardware or software problem of network element.

In a recent technical publication by TRAI (Telecom Regulatory Authority of India) shows the factors affecting call drops in Delhi and Mumbai area [13]. Fig. 2.7 shows the statistics of the factors affecting call drop in Delhi and Mumbai Area in India.

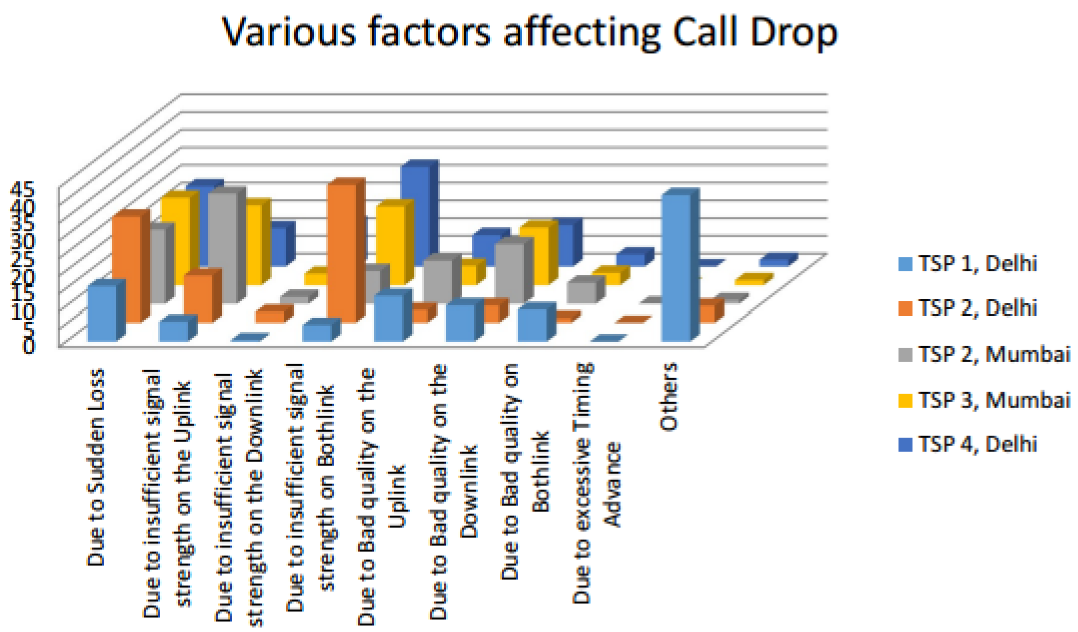


Fig. 2.7: Factors affecting Call drop in Delhi and Mumbai Area- August 2015

It can be seen that insufficient signal strength on both links is one of the prominent causes of dropped calls. Other factors like sudden loss of signal and insufficient signal strength on the Uplink also play a vital role in the call drop.

ETSI defined call drop rate as "The percentage of calls which, once they have been correctly established and therefore have an assigned traffic channel, are interrupted prior to their normal completion by the user, the cause of the early termination being within the operator's network" [14]

Call drop rate = Number of call drops /Number of Total call x 100% ………………. (2.3)

In case of benchmarking, few hundreds calls are generated, based on this- drawing a conclusion is very difficult (several thousand calls are generated in each cell every day).

Call Setup Time

The call setup time is considered to be the time from pressing the "send" button to the point at which the called party, or at least one called party in the case of a multi-party, voice group or voice broadcast call, can receive information.[15]

The call setup time is the time it takes for the user to get into a call. Different operators worldwide define call setup time differently. A common requirement is that call setup time is the time measured from when the user presses the 'dial' button to when the ring tone is heard. Call setup time can be measured by both drive tests or by the system itself. Owing to the current trend of having different vendors supplying different sub-systems (e.g. the radio and the switching parts supplied by different vendors), drive testing seems to be the test relied on for this. To improve accuracy of measurement and to remove ambiguities, the call set-up time is defined as 'the interval between the dial command to the mobile and the receiving of the layer-three message 'alerting' for 2G GSM networks. Similar definitions can be arrived at for other 2G and 3G systems. Current trends seem to indicate a call set-up time of 4 seconds for a mobile to PSTN call and about 8 seconds for a mobile-to-mobile call. The mobile-to-mobile call takes longer since the called or 'B party' mobile has to be authenticated by the network.

According to ETSI, There are three classes of set-up time performance and examples of the call setup times are:

a) Class 1 fast set-up 1-2s;

b) Class 2 normal set-up < 5s (but greater than 2 sec.);

c) Class 3 slow set-up < 10s (but greater than 5 sec.);

Handset Power

User equipment can generate 0 dBm to 33 dBm power, but usage of handset power depends on link budget balance. The Handset uses low power if it is in good radio condition and the link budget is balanced.

The range is defined with 2 categories:

a) Handset power less than 30 dBm (1 watt)
b) Handset power greater than 33 dBm (2 watt)

This is not a KPI that is monitored regularly to improve the performance. However, this KPI has a significance in understanding Link budget scenario and cell edge coverage scenario. A Typical link budget is shown in Fig. 2.8 below.

Allowable path loss at downlink = 60 – (-102) = 162 dBm and Allowable path loss at uplink = 33 + 17 -2- (-110)= 158 dBm

Therefore, we can see that even with the highest power from handset, the link budget cannot be balanced in 2 TRx scenario. With 4 TRx, it is nearly close (allowable path loss: uplink 158 dBm and downlink 159 dBm).

The significance of this calculation is that, the mobile tries to communicate with minimum possible power. If the mobile is in bad condition, it will dissipate more power to reach the BTS. If it is in good condition, it will dissipate less power. Therefore, the more the users are at poor coverage or cell edge, the higher the power dissipation from user mobile which will eventually increase the uplink interference level.

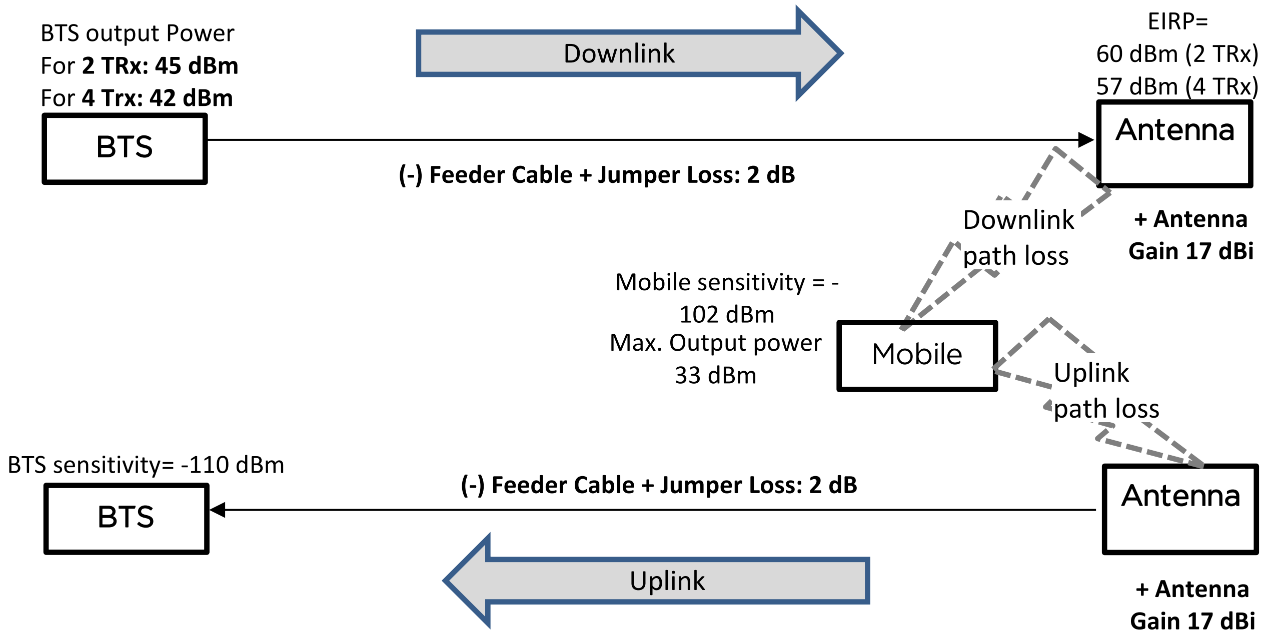


Fig. 2.8: Typical link budget (Uplink and downlink)

Use of high gain antennas can improve the scenario. High gain antennas improve downlink coverage level as well as add gain in uplink path that requires less power. Using booster or amplifier in the uplink path is another way to improve the scenario.

2.4 Basic Reasons Responsible for Network Problems:

The basic reasons responsible for network degradation are described in section 2.4.1 to 2.4.4

2.4.1 Path Loss due to distance

Path loss is the main reason for indoor coverage issues. For rural area, Path loss is due to the distance whereas penetration is the main accountable for path loss in city area.

The basic formula of path loss used for wireless communication [16] is

$$L_{Path} = (4\pi)^2 (d/\lambda)^2 \ldots\ldots \quad (2.4)$$

Where, d stands for distance between transmitter and receiver, λ is wavelength.

However, different models are used to calculate path loss in complex environment.

Two forms of the Okumura-Hata model are available. In the first form, the path loss (in dB) can be written as

$$PL = PL_{freespace} + A_{exc} + H_{cb} + H_{cm} \ldots\ldots \quad (2.5)$$

Where, $PLf_{reespace}$ is the free space path loss, A_{exc} is the excess path loss (as a function of distance and frequency) for a BS

Height h_b = 200 m, MS height h_m = 3 m, H_{cb} and H_{cm} are the correction factors shown.

The more common form is a curve fitting of Okumura's original results. In that implementation, the path loss is written as

$PL = A + B \log(d) + C$ ……………………………………………………………..…. (2.6)

where A,B, and C are factors that depend on frequency and antenna height.

$A = 69.55 + 26.16 \log(f_c) - 13.82 \log(h_b) - a(h_m);$ ………………………………….. (2.7)

$B = 44.9 - 6.55 \log(h_b)$ ……………………………………………………..……….. (2.8)

Where, f_c is given in MHz and d in km.

The function $a(h_m)$ and the factor C depend on the environment:

a) Small and medium-size cities:

$a(h_m) = (1.1 \log(f_c) - 0.7)h_m - (1.56 \log(f_c) - 0.8)$ …………….…….... (2.9)

$C = 0$.

b) Metropolitan areas

$$a(h_m) = \begin{cases} 8.29(\log(1.54\, h_m)^2 - 1.1 & \text{for } f \leq 200 \text{ MHz} \\ 3.2(\log(11.75\, h_m)^2 - 4.97 & \text{for } f \geq 400 \text{ MHz} \end{cases} \quad \text{……...} \quad (2.10)$$

$C = 0$.

c) suburban environments

$C = -2[\log(f_c/28)]^2 - 5.4$ …...(2.11)

d) Rural area

$C = -4.78[\log(f_c)]2 + 18.33 \log(f_c) - 40.98$ ....(2.12)

The function $a(h_m)$ in suburban and rural areas is the same as for urban (small and medium-sized cities) areas.

Range of validity for the Okumura-Hata model:

carrier frequency	f_c	150...1500 MHz
effective BS-antenna height	h_b	30...200 m
effective MS-antenna height	h_m	1...10 m
distance	d	1...20 km

It is noteworthy that the parameter range does not encompass the 1800 MHz frequency range most commonly used for second-and third generation cellular systems. This problem was solved by the COST 231 – Hata model, which extends the validity region to the 1500 - 2000 MHz range by defining $A = 46.3 + 33.9 \log(f_c) - 13.82 \log(h_b) - a(h_m)$ ....(2.13)

$B = 44.9 - 6.55 \log(h_b)$ ....(2.14)

C is 0 in small and medium-sized cities, and 3 in metropolitan areas.

Other path loss models (The COST 231–Walfish–Ikegami Model, The COST 207 GSM Model, The ITU-R Models) are also used to predict path loss [17].

When operators plan to extend coverage in certain area, they plan site number, type, height, parameter based on path loss calculation which is done by simulation in the planning tool. Site position is critical to choose because it can affect the initial planning to a great extent. Even with perfect execution of initial plan, lots of factors can affect the path loss, i.e., blocking by adjacent building, an increased subscriber number, antenna and other equipment faults etc.

2.4.2 Number of Site

Number of site has direct impact on coverage (RX Level- received signal level). However, there are some other factors that have impact on coverage. Each site has certain transmitted power. Due to different loss factors (Fading, penetration loss, etc) coverage became limited. In urban area, penetration loss is the main factor that limits the coverage. In rural area, usually there is no establishment; signal can propagate through open space.

2.4.3 Number of Subscriber

In GSM environment, numbers of subscriber have indirect impact over network coverage, output power of the BTS depends on number of TRx (which is subsequently depends on number of subscriber). BTS power is inversely proportional with the increasing number of TRx. For example, we can have 46 dBm power from the BTS if 2 TRx is active, on the other hand BTS output power reduces to 43 dBm in case of 4 active TRx. The loss is due to combiner+ duplexer loss. Therefore, more number of sites is required in more populated area.

2.4.4 Area Type (clutter and Terrain)

Clutter data can play a significant of role in designing wireless communication systems. It can be used to improve predictions of signal attenuation and other radio propagation effects and to assist in finding the optimal location of network base stations and other wireless system transmitters. It can also be utilized when projecting usage (traffic) trends in any type of mobile or nomadic system.

Clutter data can be used in several ways to enhance the resolution of the signal level calculation to return more accurate point-specific results. Fig. 2.9 shows the clutter map of Bangladesh. The most straightforward approach is to use the method alluded to above where the attenuation at a particular receiver location is a direct function of the clutter type at that location. If for example, a remote unit is located in a suburban area containing single-story houses and mature trees, one might apply an additional attenuation of 20dB at 2.5GHz; for relatively open Parklands 10dB might be used. The ongoing challenge in using clutter is determining the appropriate attenuation values for each clutter category.

One option is to use the Telecommunications Industry Association resources. This group has classified clutter losses based on ten clutter categories appropriate to RF planning and documented them as part of the TSB-881 document. Ultimately the most accurate value will be based on received signal measurements (i.e. drive test) within each market area that take into account the type of vegetation and man-made structures present in that area.

A second approach is to assume that the clutter represents a hard, non-transparent blockage to the radio signal. The clutter data is then used to effectively raise the terrain elevation used by the planning tool so that the propagation calculation will see the clutter as obstacles along the path rather than a "bare earth" condition. Here, the clutter data is categorized as having an above-the-ground height value representing the average height for each type of clutter. This method is most effective at the higher frequencies, especially above 5GHz where almost any clutter type represents a high-loss obstacle to the radio signal. This can be extremely useful in urban areas where buildings represent the primary obstacles to the signal. Rather than investing in a high cost vector database.

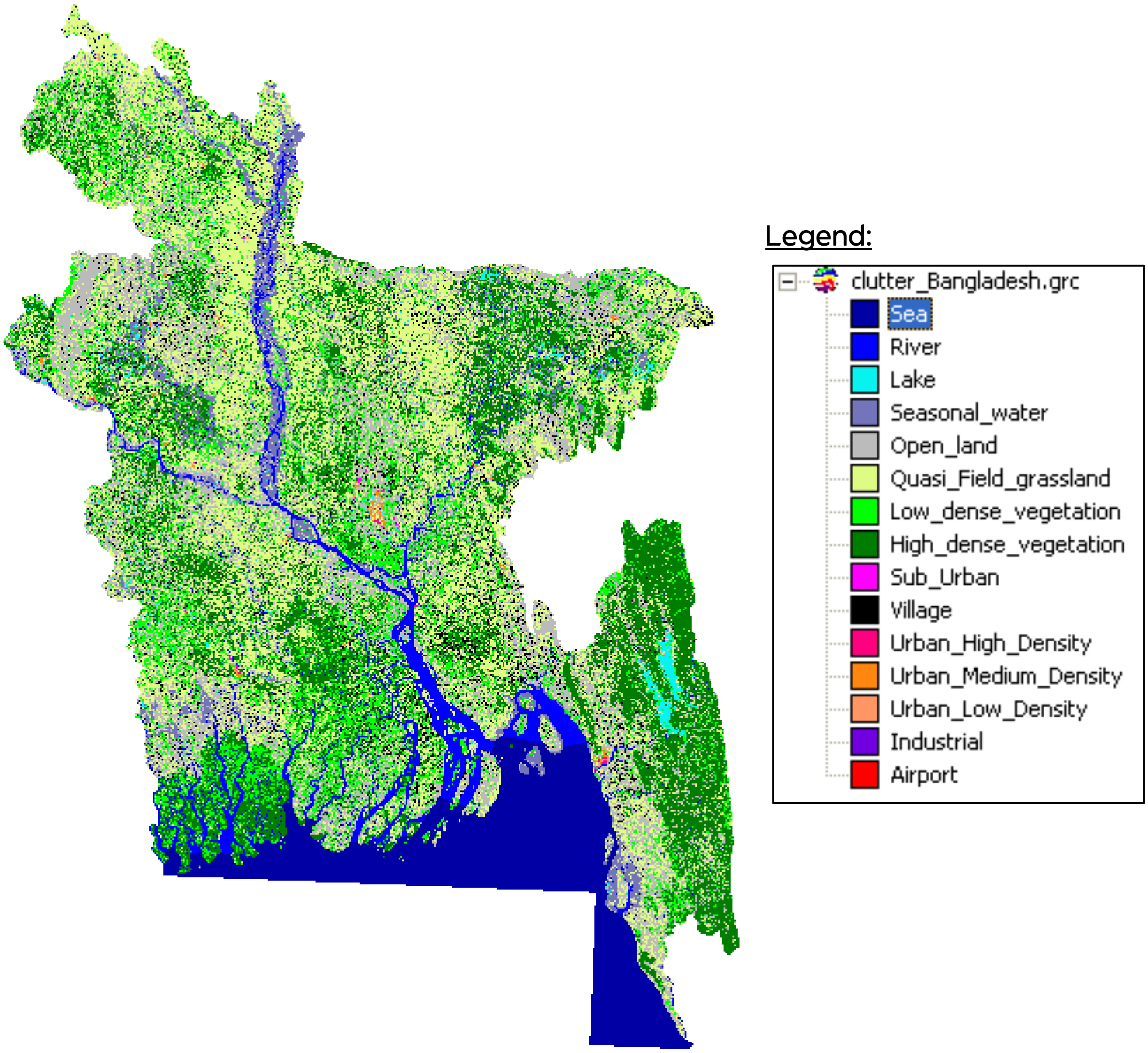


Fig. 2.9: Bangladesh clutter map and corresponding legend

Terrain data used to predict signal penetration changed due to natural landline height. The basic difference between clutter and terrain data is that, the clutter data can be changed within a short time (due to man-made structure), but terrain data usually do not change over time. For example, in the Chittagong terrain map (shown in Fig. 2.10 next), the color difference represents surface heights from sea level. It shows there is high land in the middle and right part of the block which is also clearly visible in the corresponding google map. It should be noted that despite of dense building in the center of the block, terrain data is not changed. Both the clutter and terrain data are processed from satellite images through some processing engines.

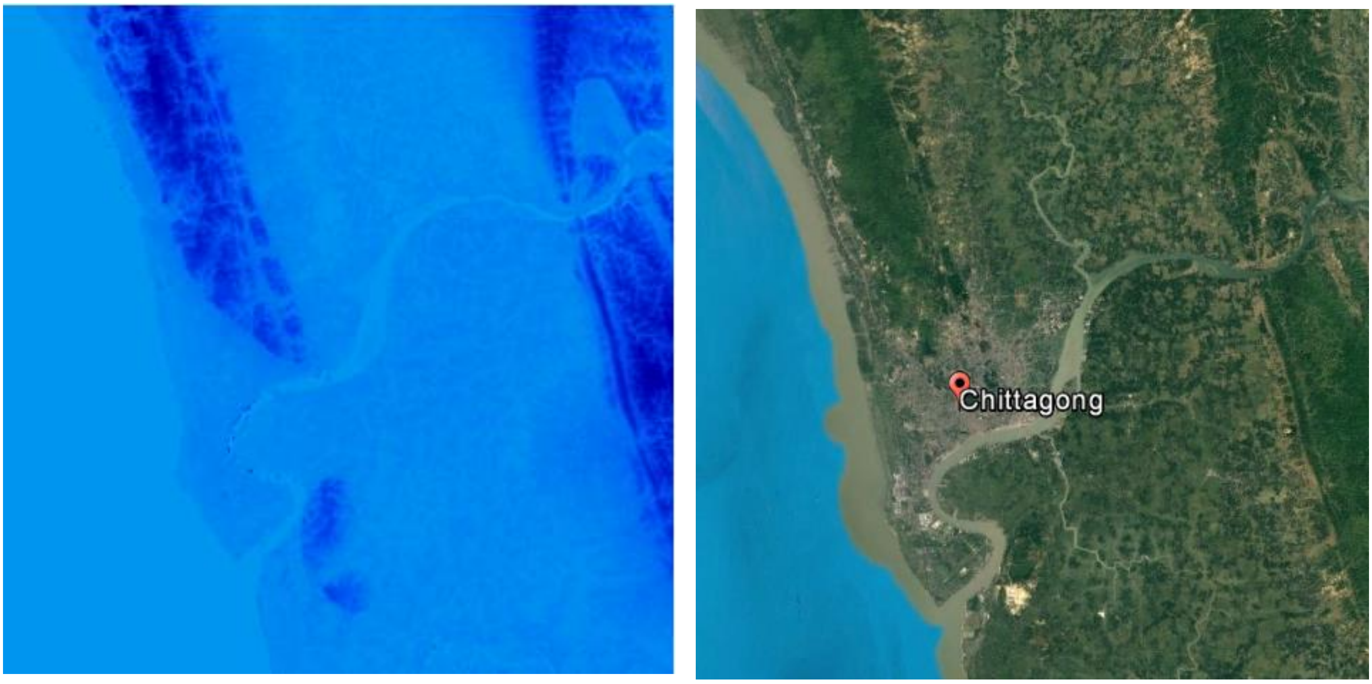


Fig. 2.10: Terrain map: zoom in view of Chittagong shows hilly area in the middle and right

2.5 Benchmarking

Benchmarking has been defined as the comparison of performance of one company with the same of the competitor in the like business. For mobile network operators, knowledge of their strengths and weaknesses provides the basis for identifying options to maximize revenue and business potential. Benchmarking characterizes important aspects of mobile network operations in terms of Key Performance Indicators (KPIs) of technical performance.

Benchmarking is the process of comparing the companies according to performance metrics. It is mostly used to measure performance using a specific indicator resulting in a metric of performance that is then compared to those with others. In a sense, we can also define benchmarking as the observation of service quality. Benchmarking is performed following the determination of the service quality parameters.

Drive testing for gathering network benchmarking data is the only way mobile network operators can collect accurate competitive data on the true level of their own and their competitor‘s technical performance and quality levels.

Quality criteria for benchmarking may be categorized as speed, accuracy and dependability. Speed denotes the time-related quality criterion; accuracy indicates the quality criterion that benchmarks the degree of correctness with which the service function is performed. In addition, dependability denotes the quality criterion that benchmarks the degree of certainty. Benchmarking characterizes important aspects of mobile network operations. For benchmarking the mobile networks in terms of QoS parameters, it is deemed necessary to focus on some particular KPIs.

In order to benchmark the performance of various operators, it is required that overall performance score can be calculated as a weighted score or an equivalent weighted score.

Equivalent weighted score is calculated by accepting the indicators that form the table as equally weighted. Second alternative is to calculate the weighted score according to the different weighted percentages that weight has been assigned to different KPI.

This chapter has defined the QoS parameters of a GSM network. Next chapter will describe how these QoS parameters can be measured by collecting relevant data from the drive test conducted in the field.

CHAPTER 3

MEASUREMENT OF QUALITY OF SERVICE

The QoS parameters of the GSM network were defined in the previous chapter. This chapter elaborates the process of measuring the QoS parameters of a mobile network and describes how the benchmarking data collection is accomplished.

3.1 Service Level to the Users

To measure the service level, mobile phone operators use 2 methods:

1. **Central Node statistics**- contains overall visibility to the service. It can be generated from different nodes, i.e., BSC, MSC etc.
2. **User experience measurement through drive test-** This represents real user experience. Usually costlier than any other method and can identify to the maximum details of a user's problem and issues.

There are also some simulation based user experience measurement process. The simulation depends on information in different nodes and spreads the sample data over the serving area through statistical method (example- Monte Carlo technique). The simulation cannot have even close accuracy to drive test data. Therefore, we have considered all simulation based techniques under category 1.

3.2 User Experience Measurement Through Central Node Statistics (NMS Statistics)

Most network vendors have counters to count the events occurring in a network. These counters are then collected by Network Management System (NMS) for the particular subsystem. In a typical multi-vendor solution, the statistics from different vendors' equipment are collected into a special reporting tool to give an idea of the performance of the system as a whole [18] in Bangladesh, all telecom operators have multi- vendor network equipment. Fig. 3.1 depicts the scope of the NMS system.

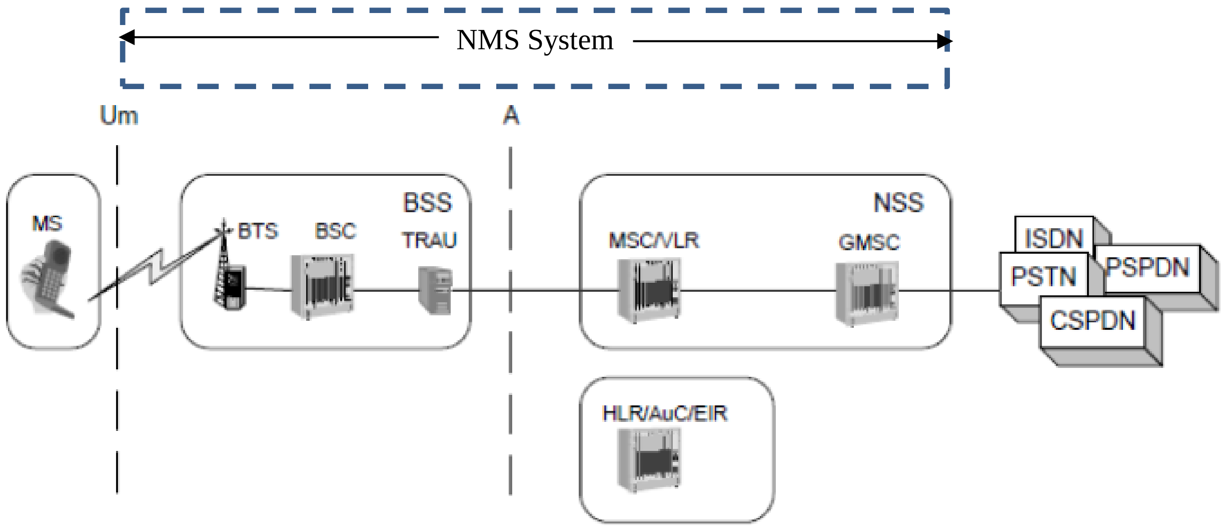


Fig. 3.1: Scope of the NMS system

Network element counters have not been standardized, so both the amount of counters available and their trigger points differ widely among vendors. For example: one vendor has only about fifty counters available to the user while another has close to thousand.

When using such counters from a different vendor, the user has to be aware of the differences in counter availability as well as their trigger points. In a typical multi-vendor scenario it is not usual to have different values reported for the same KPI depending on the sub system used for the reporting.

Network statistics give a more comprehensive picture of network performance since it includes all geographical area covered. The disadvantage of network statistics is that precise geographical information is missing. That is where drive test comes into scenario to pinpoint the localized problem.

3.3 User Experience Measurement Through Drive Test

Performing a drive test is the best way to analyze a problem with geographically separated area. Fig. 3.2 shows the organization of a benchmarking equipment for the drive test. While statistics give an idea about the real behavior faced by all end users regardless of their geographical location, drive testing or walk testing bring a simulation of end user perception of the network on the field from one call perspective. The drawback of this method is complexity and cost. In fact, drive testing can model the behavior of up to five mobiles (mobile operators); however in order to analyze objectively a scenario, many attempts should be performed under the same conditions.

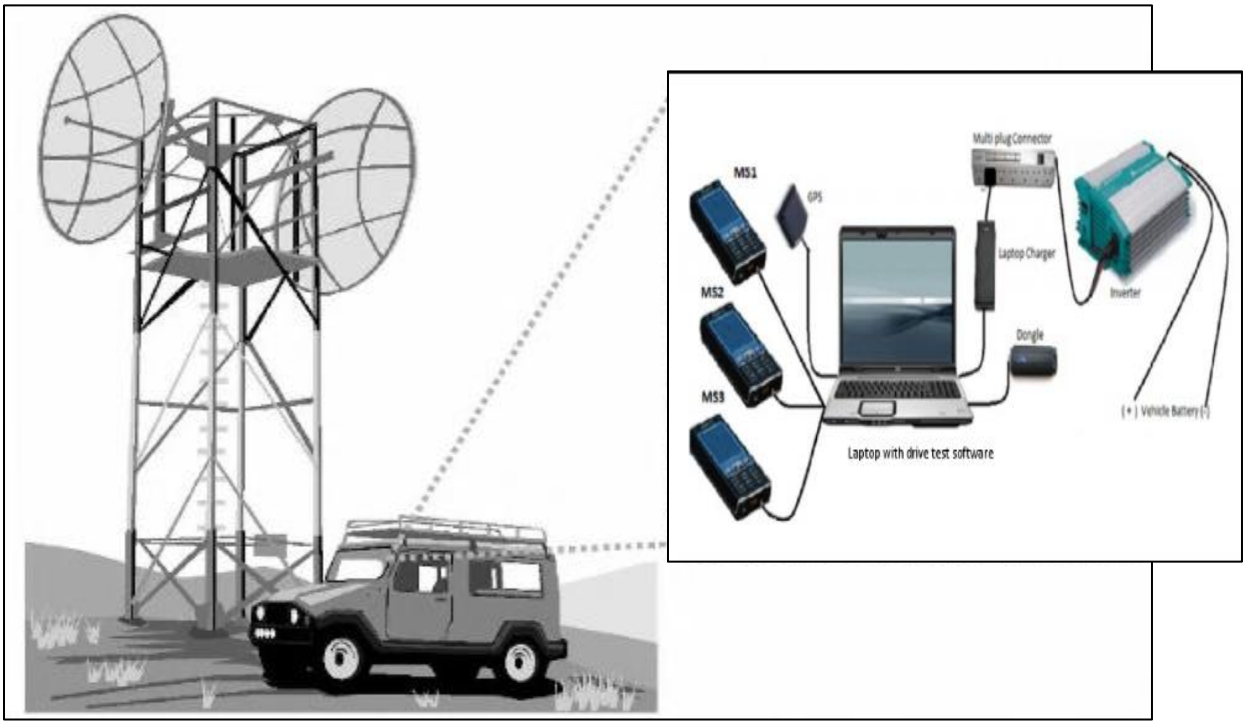


Fig. 3.2: Organization of a benchmarking equipment

For logistics reasons, this cannot be performed on the entire network, which is why drive tests and statistics are complementary methods. Both of them are necessary for optimization engineers to assess the network performance. Outdoor drive tests are also used to assess indoor coverage. Therefore, in a dense urban area, by assuming a certain building penetration loss (in general 20 dB is considered), the indoor signal is estimated to be 20 dB less than the outdoor level. If -80 dBm is then accepted as a good indoor level, the outdoor level should be at least -60 dBm.

The advantage of drive test described in [19] are given below.

a) It measures the performance of the network from the point of view of a user and it does not depend upon any program/algorithm within the network.
b) While Network Counters do not take into account the user who has no coverage, such situations are fully taken into account by Drive tests.
c) Even though a simple drive test may not be representative of the performance of the whole network, it can give a snapshot of the performance of a network on the limited routes chosen for the test. The major issues observed during these drive tests are
    a. In cities/towns there are patches of poor coverage for some of the operators.
    b. On highways and major roads, complete coverage is not available for many operators.

In the market, many tools exist where the idea is almost the same (as shown in Fig. 3.2). One or more handsets, configurable on different technologies like GSM 900/1800/1900, IS95.15136 and AMPS, mounted on a car kit and connected via a cable to a laptop, report measurements for specific software. This application permits online visualization on a map or a graph of different parameters (level, quality, serving cell identity, etc.). A global positioning system (GPS) is also required to identify the position of quality degradation precisely. The overall system is mounted on a vehicle. The first installation of the equipment requires some operations like calibration of the GPS. In fact, manually calibrated GPSs contain an odometer and a gyroscope, which may require going through specific routes with various distances and various speeds. In some cases, an attenuator is used on the antenna chain in order to cancel antenna gain and have a 0 dBm chain. The performance of the tool depends on the ability of the handset, to report or not, some specific data. Each mobile can be in one of three modes: idle, call generator or frequency scan. The same set can also be used for benchmarking several networks. Some tools bring additional features such as channel lock, layer 3 message decoding and online sound warnings for events and GPS signal loss. Log files of the measurements can then be recorded and reviewed later. They can also be used to plot some data on maps or graphs. Generally each tool has a specific software application to analyze the measurements further. Drive testing is necessary in many phases of network evolution. Before sites are installed and after BTS roll out, frequency plan implementation, etc., every time that a change is performed on the network in terms of site engineering and/or parameters, drive tests should be performed.

3.3.1 Tools Used for the Drive Test

SwissQual was the first company to introduce specialized wireless network benchmarking equipment. SwissQual AG is a telecommunications company specializing in wireless network service quality benchmarking and network optimization. The company is a contributor to ITU-T standards for speech and video quality assessment.

To cut costs for logistics and transport, without compromising the reliability and quality of the measured QoS performance indicators, Rohde & Schwarz Mobile Network Testing and SwissQual developed the Benchmarker II Go. The highly scalable and flexible benchmarking solution uses the same base components as the industry's leading mobile network testing system, the Benchmarker II. It achieves the same accurate, stable, and reproducible test results, but in an easily transportable and lightweight format, optimized for adhoc measurement campaigns. Benchmarker II Go is powered via a standard car cigarette lighter socket and runs the measurements directly from the transport case, using unmodified smartphones and their internal antennas. With this, operators and service providers not only save time but also substantially reduce the costs for installing and customizing the system in any vehicle, including rental cars.

Standard equipment

The standard configuration of a benchmarking equipment is shown in Fig. 3.3 below.

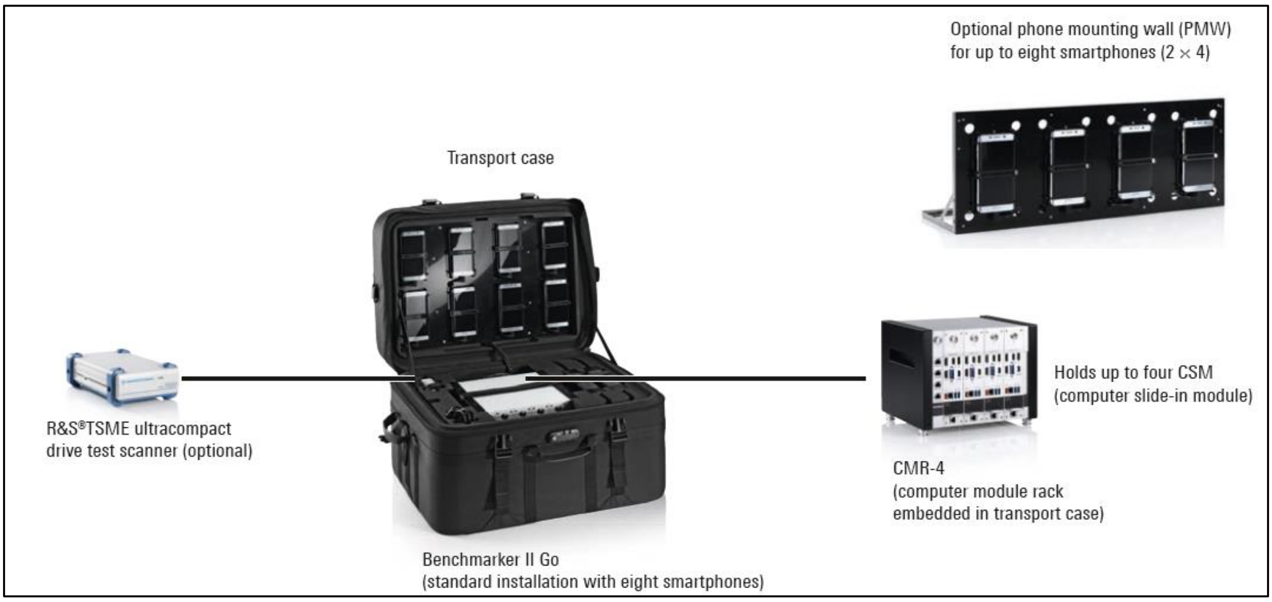


Fig. 3.3: Benchmarking equipment

Technical Specification:

The dimensions and technical specifications of the benchmarking equipment is shown next.

Specifications in brief		
Transport case (check-in luggage)		
Dimensions 1)	W × H × D	approx. 60 cm × 45 cm × 45 cm (23.6 in × 17.7 in × 17.7 in)
Weight	including four CSM (computer slide-in module) and one R&S®TSME ultracompact drive test scanner	max 23 kg (50.7 lb)
Satellite bag (carry-on luggage)		
Dimensions 2)	W × H × D	approx. 48 cm × 35 cm × 13 cm (18.9 in × 13.7 in × 5.1 in)
Weight	Depending on content, e.g. laptop, cables, etc.	
CMR-4 (computer module rack)		
Voltage		12.5 V to 16.8 V DC
Power consumption		240 W max. powers up to 16 smartphones with the max. configuration of 4 CSM, powered by either one 16 A or two 10 A cigarette lighter sockets

3.4 Drive Test Procedure

In this project, drive test was carried out with SwissQual equipment mounted in a microbus. The full set of transport case was not available, therefore we used some local racks to hold the mobile phones in fixed positions. As the target is to measure CS KPI, we have tried to perform the test in 'busy hour' as much as possible. The usual 'busy hour' in mobile network is typically 5 to 11 pm. The mobile phones of the 4 mobile operators of Bangladesh were connected simultaneously, therefore similar condition was ensured for all.

Drive test needs to be performed twice in each road, one is for 'idle mode' (to measure RX Level), and another is for 'dedicated mode' (to measure other parameters like Call Drop Rate, RX Qual, and FER etc).

The following measures were taken care of while performing the drive test:

Neutrality: Because of consistency, the measurements were made at the same time, at the same location for all of the network operators. This was essential to compare the performances of network operators in a fair and impartial manner. Same device was used, and intra-operator call has been made for each operator.

Objectivity: The measurements were taken by automatic systems and personal interventions were not allowed. It is not possible to interfere manually with the data logs.

End-to-End measurement: It was aimed at measuring any kind of events affecting the QoS. During end-to-end measurement, the system acts like an end-user.

This chapter has described the process of measuring the QoS parameters of the majoe mobile networks of Bangladesh. The next chapter will describe the results for each operator and provide a comparative performance analysis.

CHAPTER 4

RESULTS AND DISCUSSION

The previous chapter described the process of measuring the QoS parameters of a mobile network and how the drive test has been performed. This chapter extracts the results of the findings and provides the comparative performance analysis of the major mobile networks in Bangladesh.

4.1 Project Area

The benchmark area for the current study is selected by thana boundary. Three thanas were selected within Dhaka city (Dhanmondi, Gulshan and Pallabi) and other two thanas were selected from outside Dhaka (Sylhet Sadar and Comilla Sadar). Fig. 4.1 shows the five benchmarking thanas that were selected for the drive test. Rural areas were excluded from our measurement for the following reasons:

a) All operators do not have their network in rural areas

b) Very few roads to check network performance.

c) Lack of roads with good condition (for vehicle movement)

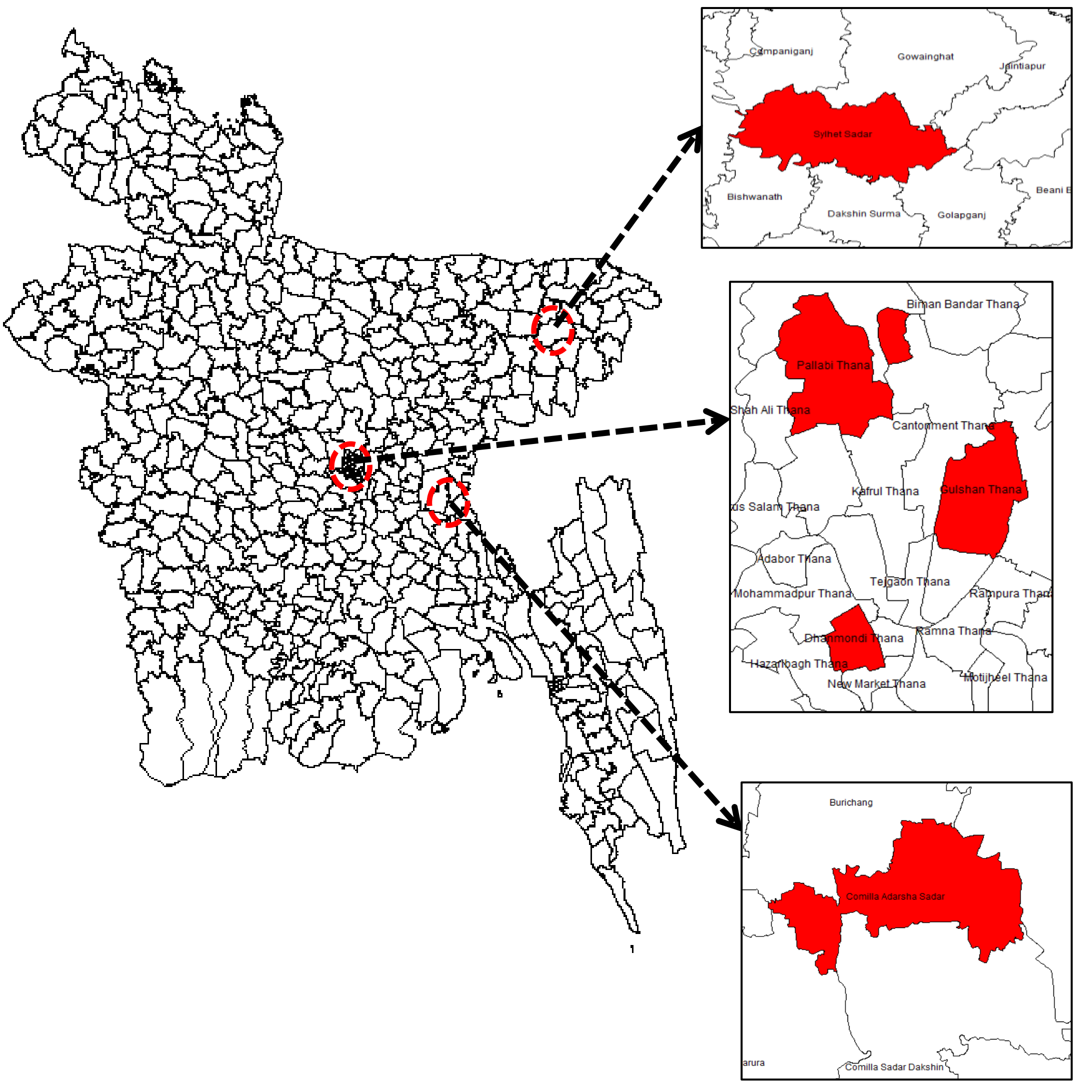


Fig. 4.1: Five benchmarking thanas selected for the drive test

4.2 Results

The benchmarking data that was collected from the drive test was first analyzed using Actix Analyzer and the result obtained from the analysis are discussed in sections 4.2.1 and 4.2.2. To interpret the result, color Legends are provided. Several QoS plots (RX Level, RX Qual, C to I, FER) of each operator are shown for each thana.

4.2.1 Site map & RX Level

All the areas considered in our study are city area. Therefore the site density is higher in the selected area. Number of sites is directly related to the indoor coverage (RX Level). The more the number of sites, the better indoor coverage we can expect. Of course site placement, frequency plan and parameter plan have an important role to play in defining the quality of service in that area, as our primary concern is the coverage, we are placing it first.

<u>**Comilla Sadar:**</u>

Number of sites: ROBI has the highest number of sites in Comilla sadar followed by Grameenphone. Banglalink has third highest site while Airtel is close to Banglalink with least site count in Comilla sadar. The site positions of the 4 mobile operators in Comilla sadar is shown in Fig. 4.2 below.

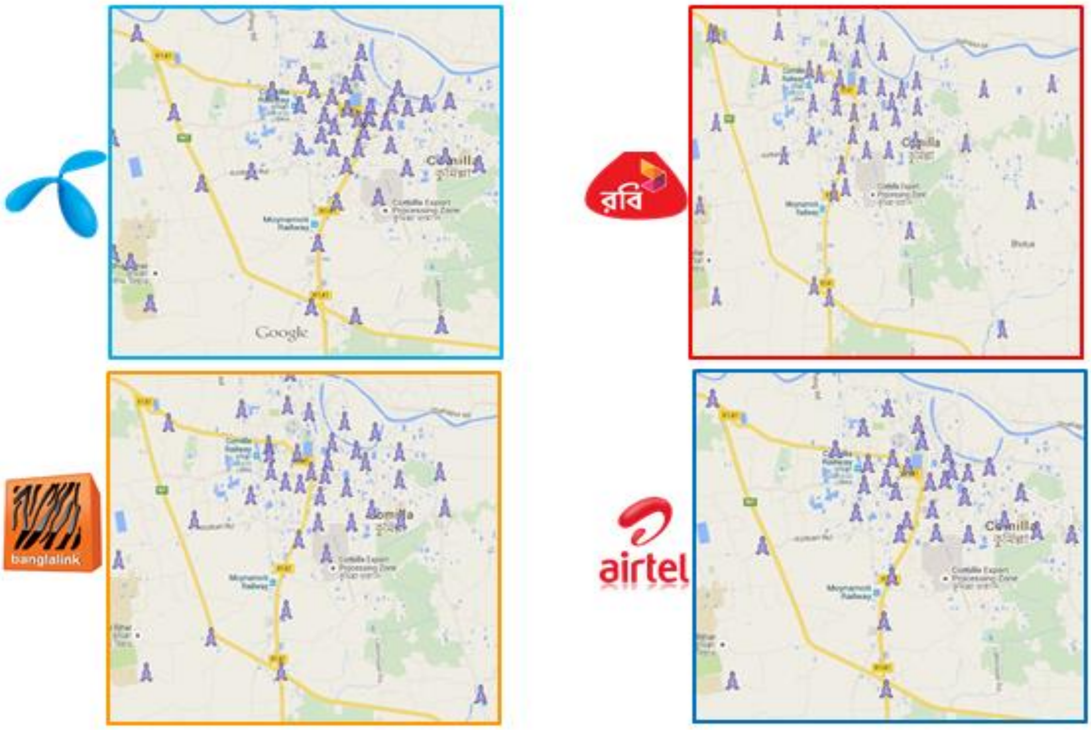
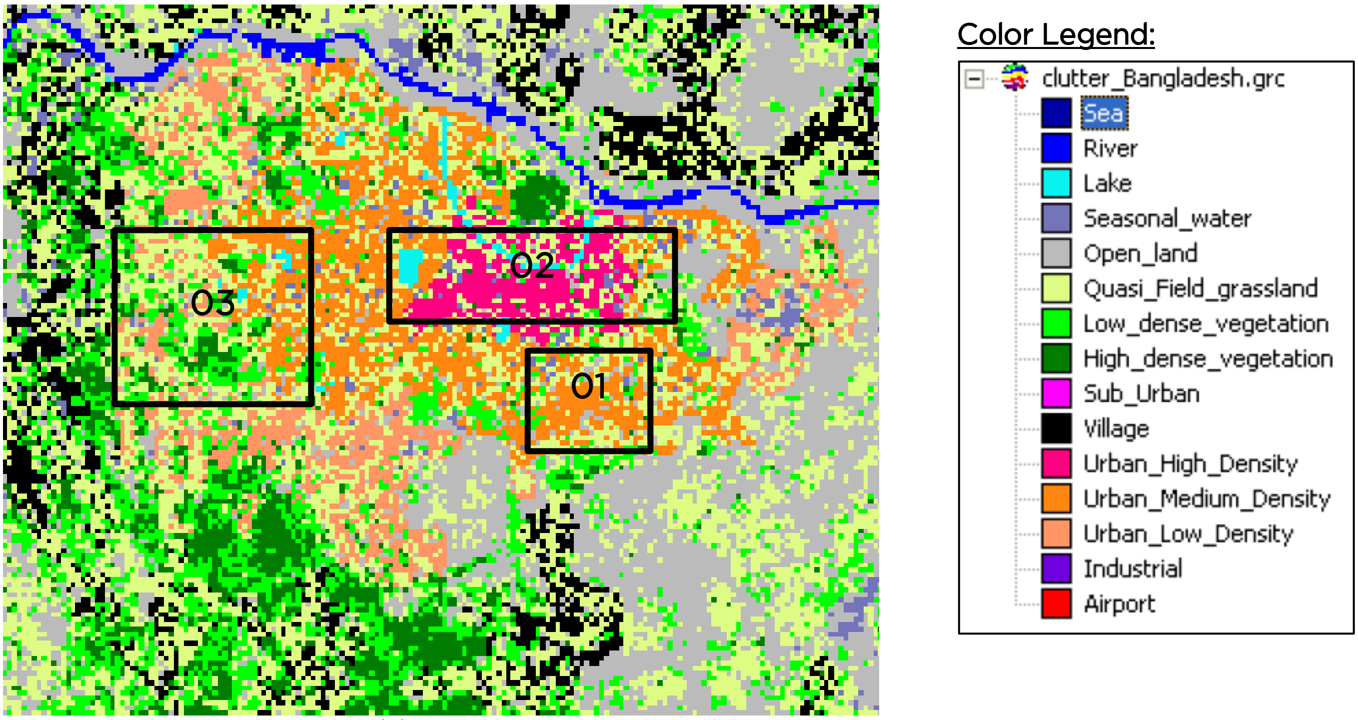
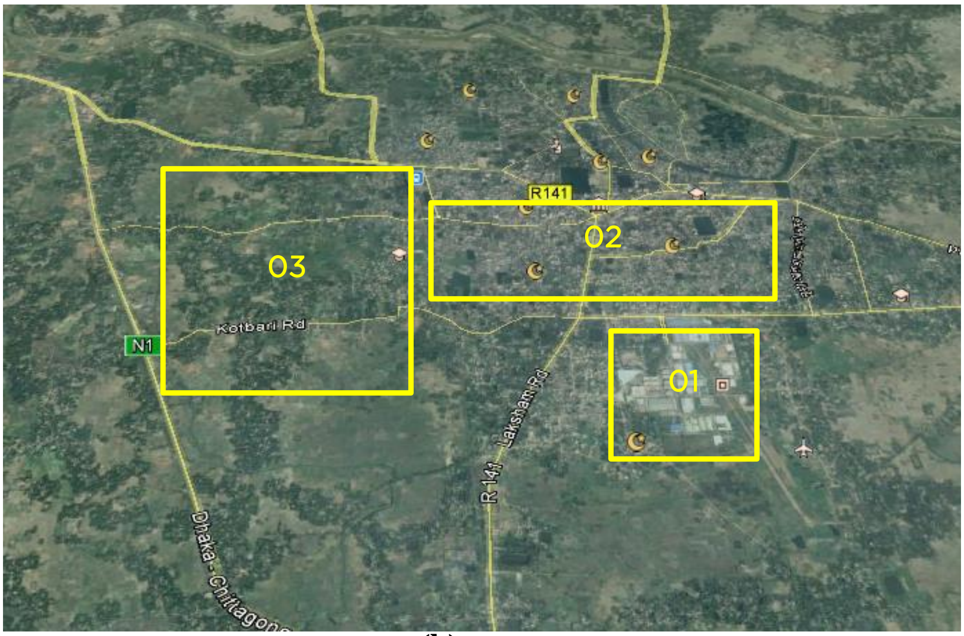


Fig. 4.2: Site positions of the 4 mobile operators in Comilla Sadar area

Area Type (clutter and Terrain): Comilla Sadar is a flat land. Therefore we can avoid the terrain factor for this area. Consideration of clutter is important in understanding the coverage level. In Fig. 4.3, the clutter map of Comilla sadar along with google earth view is shown. Now we shall explain these 2 maps in brief next.



(a)



(b)

Fig. 4.3: (a) Clutter map of Comilla Sadar with color legend. (b) Google Earth view of Comilla Sadar area

Area 1 (the rectangle marked with 01) is a tin-shed industrial area with a density of suburban type (different definitions are followed by different companies for representing suburban/urban, we have followed the standard one). We can expect good coverage in this part with few sites as the clutter loss is comparatively lower than that of urban area.

Area 2 (the rectangle marked with 02) is the urban area with dense building structures. Population density of this portion is high as well. Here, more number of sites are required to provide good coverage due to higher clutter loss.

Area 3 (the rectangle marked with 03) is also a suburban area; it has even fewer establishments than area 1. We can expect good coverage with even fewer sites as the clutter loss is comparatively lower than that of urban area.

RX Level of Comilla sadar area: Fig. 4.4 shows the RX level plot of the 4 mobile operators in Comilla sadar area.

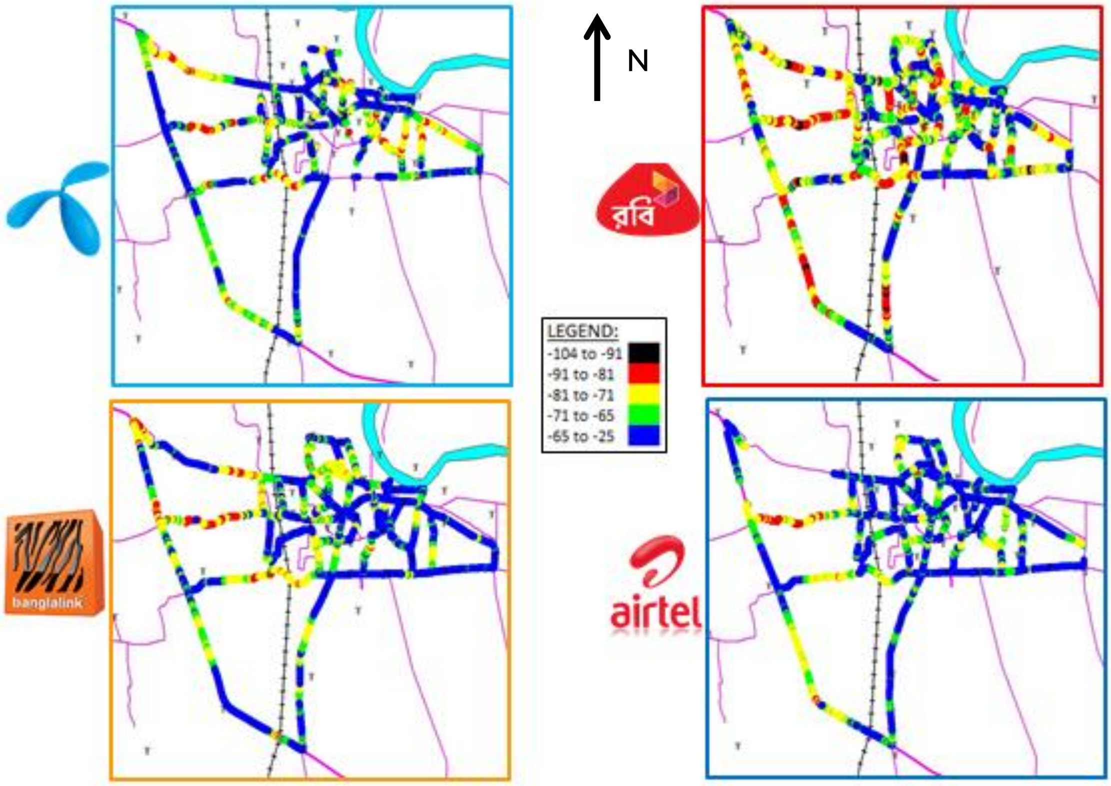


Fig. 4.4: RX Level plot of the 4 mobile operators in Comilla Sadar area

It has been noted that, all the operators have absolute outdoor coverage all over Comilla sadar area. The difference is distinguishable with the indoor coverage. The sample percentage of indoor coverage is shown in Table 4.1

Table 4.1: RX Level sample percentage in Comilla sadar area

Operator	**Indoor Coverage (Sample >-71 dBm)**
ROBI	53.4%
GP	75.3%
BL	81.9%
AT	85.7%

It has been noted that Grameenphone has good indoor coverage in the urban part (central part), while suffering with the suburban area in the east and west part of Comilla City.

On the other hand, it has been found that Banglalink has good indoor coverage in the city area as well as in the suburban part on the eastern side of the city, but it suffers with bad indoor coverage in the western suburban part. In the eastern part, Grameenphone has higher number of sites than Banglalink, yet Banglalink has better coverage. This is due to better site positioning, a low number of user accessing the network and usage of high gain antenna by Banglalink.

The survey reveals that ROBI has the worst indoor coverage level in Comilla. ROBI has a higher number of subscriber than Banglalink and Airtel, hence the BTS output power should be lower. The scattered conditions of the recorded RX level represent a serious issue either with site positioning or with physical parameters. It should be noted here that Grameenphone and ROBI has the same number of sites in Comilla Sadar.

Airtel has the least number of subscribers in Comilla Sadar. They have new equipment supported by good design and perhaps better site positioning. Only the western suburban part of Comilla city is facing poor RX level, where Airtel has only 1 site in that location.

Dhanmondi

Number of sites: Grameenphone has the highest number of sites in Dhanmondi followed by ROBI. Banglalink has third highest site while Airtel is close to Banglalink with the least site count. The site positions of the 4 mobile operators in Comilla sadar is shown in Fig. 4.5 below.

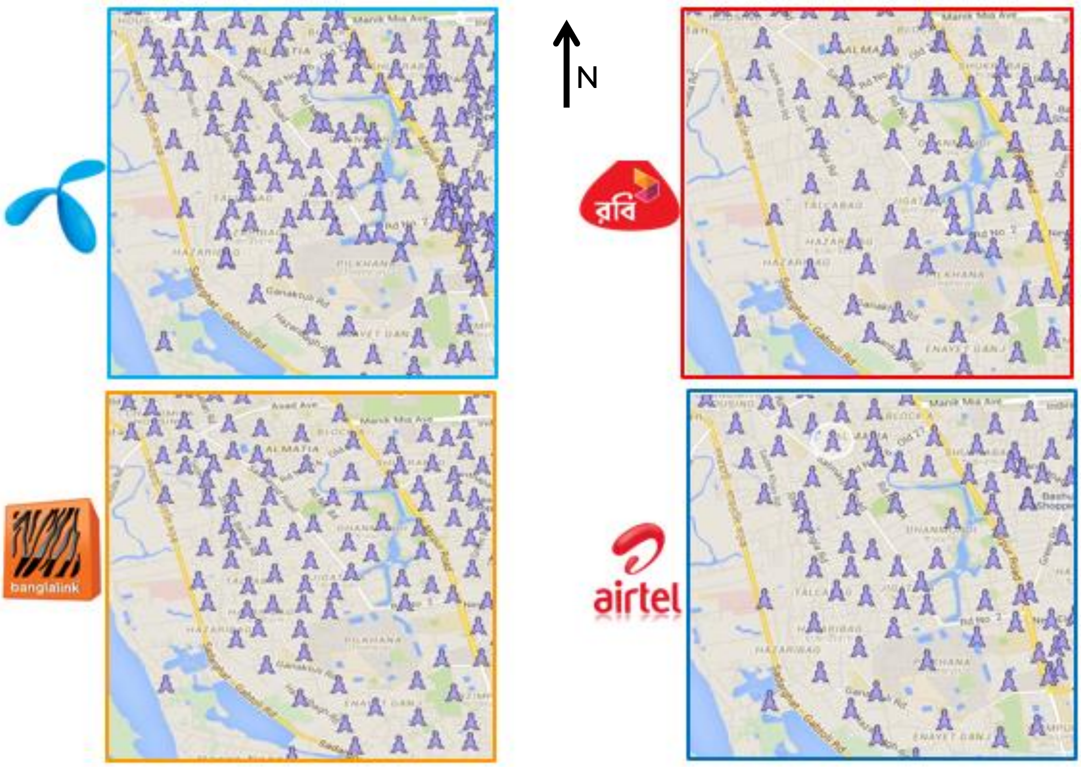
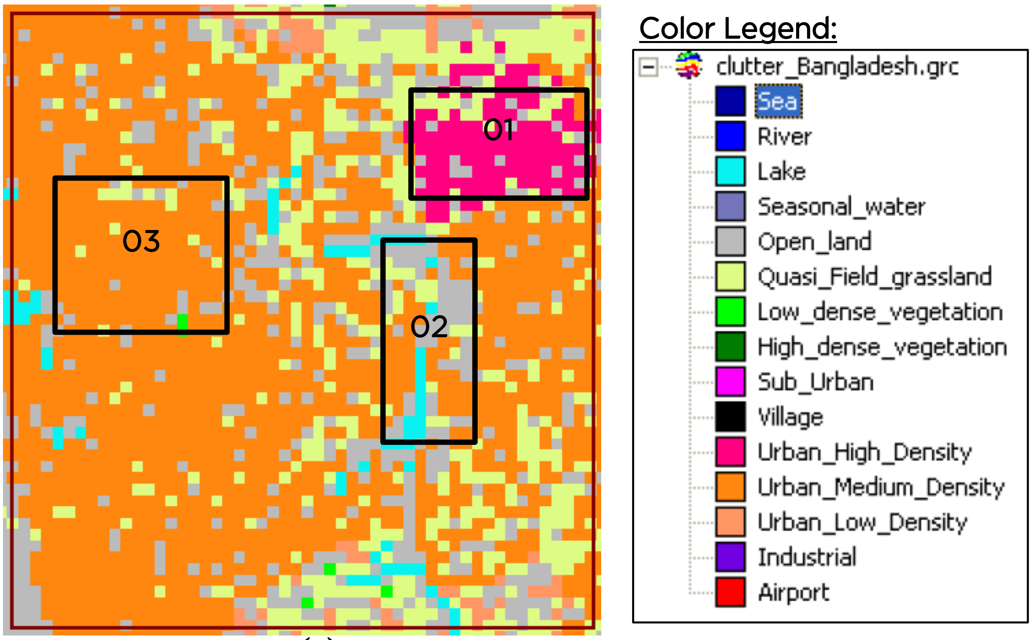
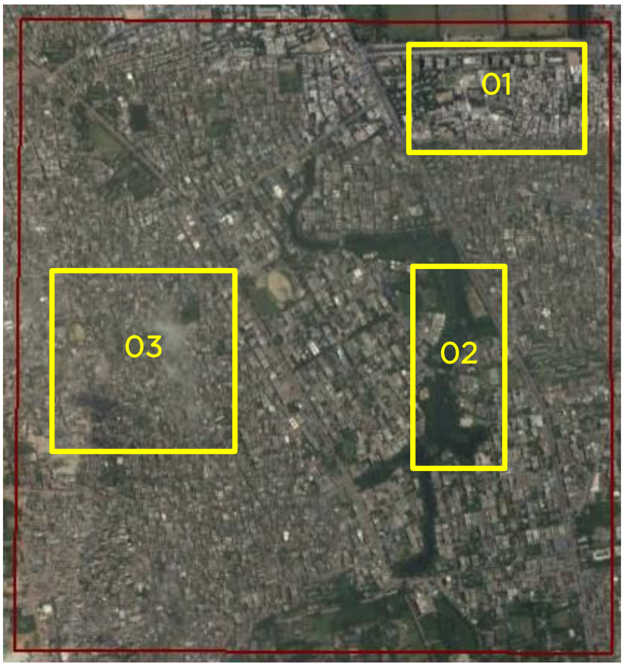


Fig. 4.5: Site positions of the 4 mobile operators in Dhanmondi area

Area Type (clutter and Terrain): Fig. 4.6 shows the clutter map of Dhanmondi area and the corresponding Google earth view



(a)



(b)

Fig. 4.6: (a) Clutter map of Dhanmondi with color legend and (b) Google Earth view of Dhanmondi area

Area 1 (the rectangle marked with 01) is a dense urban area with tall urban building infrastructures. Building penetration is higher in these area. Upper floors of these buildings are usually affected by interference by the signal coming from distant locations.

Area 2 (the rectangle marked with 02) is the lake and the surrounding open area. This area should have good coverage, but if multiple sites are placed to cater for higher number of subscribers, this might cause an increased interference.

Area 3 (the rectangle marked with 03) is a typical urban area; compared to area 1, building heights are lower. Overall, users of this area will get good network if sufficient sites are placed; interference issues are not devastating here due to lower building height.

RX Level of Dhanmondi area: The RX Level plots of the 4 mobile operators in Dhanmondi area is shown in Fig. 4.7

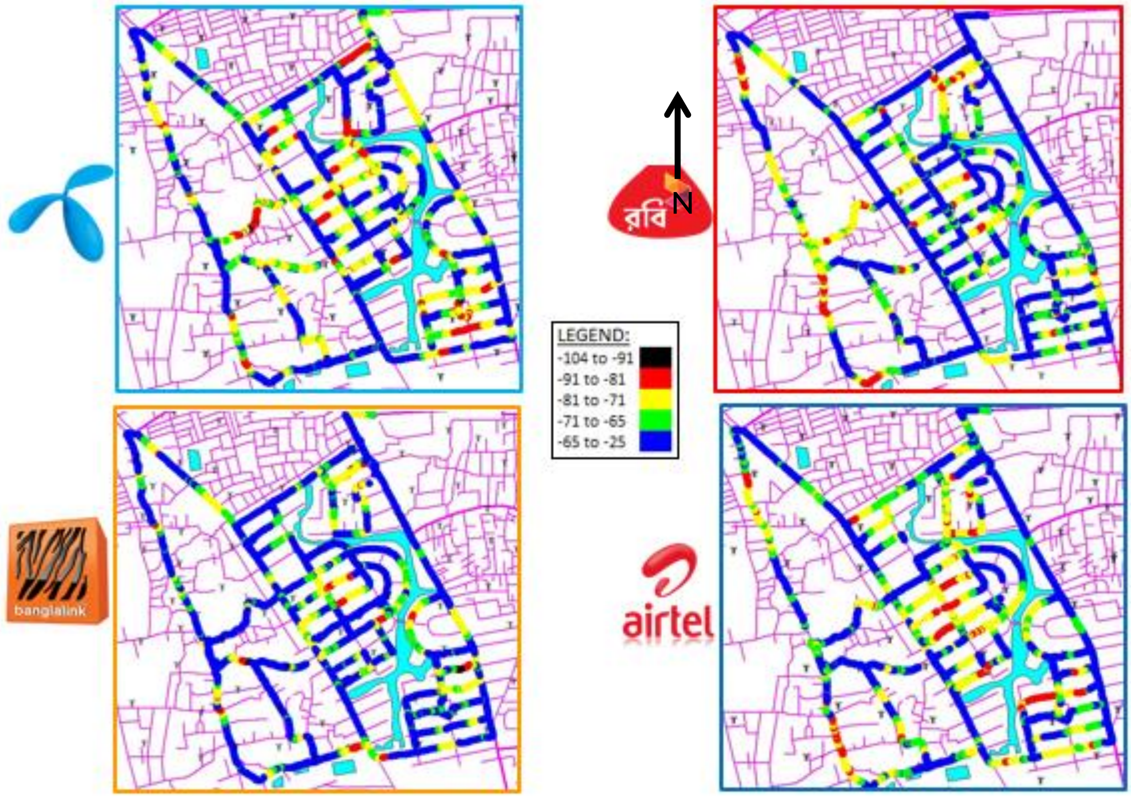


Fig. 4.7: RX Level plot of the 4 mobile operators in Dhanmondi area

The RX level sample percentage in Dhanmondi area is summarized in Table 4.2

Table 4.2: RX Level sample percentage in Dhanmondi area

Operator	**Indoor Coverage (Sample >-71 dBm)**
ROBI	77.01%
GP	72.36%
BL	86.77%
AT	78.15%

Here, Banglalink has the best coverage level among the 4 mobile operators. Banglalink has few coverage issues at the center which can be solved by placing a new site.

Grameenphone has the highest number of sites. However, they do not have the best coverage, clearly some coverage issues have been identified during the drive test. This might be related to site positioning blocking issue or the problems related to the physical parameter which are responsible for the coverage issues of Grameenphone in Dhanmondi area.

ROBI has apparently insufficient number of sites in Dhanmondi area which has resulted in poor samples distributed all over the area.

Airtel has the least number of sites compared to its competitors. Their coverage is not good at all in Dhanmondi area. Poor coverage samples are identified, especially at central part of Dhanmondi area.

Gulshan

Number of sites: Grameenphone has the highest number of sites in Gulshan area followed by Banglalink. ROBI has the third highest site while Airtel is close to ROBI with least site count. Fig. 4.8 shows the site positions of 4 mobile operators in Gulshan area.

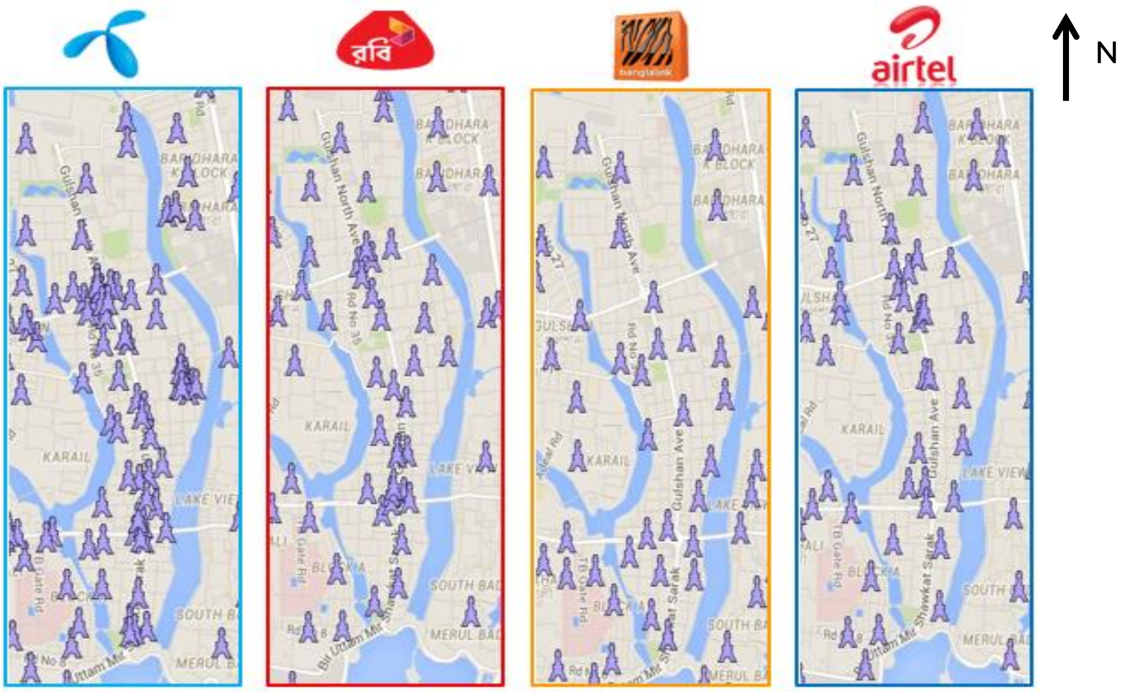
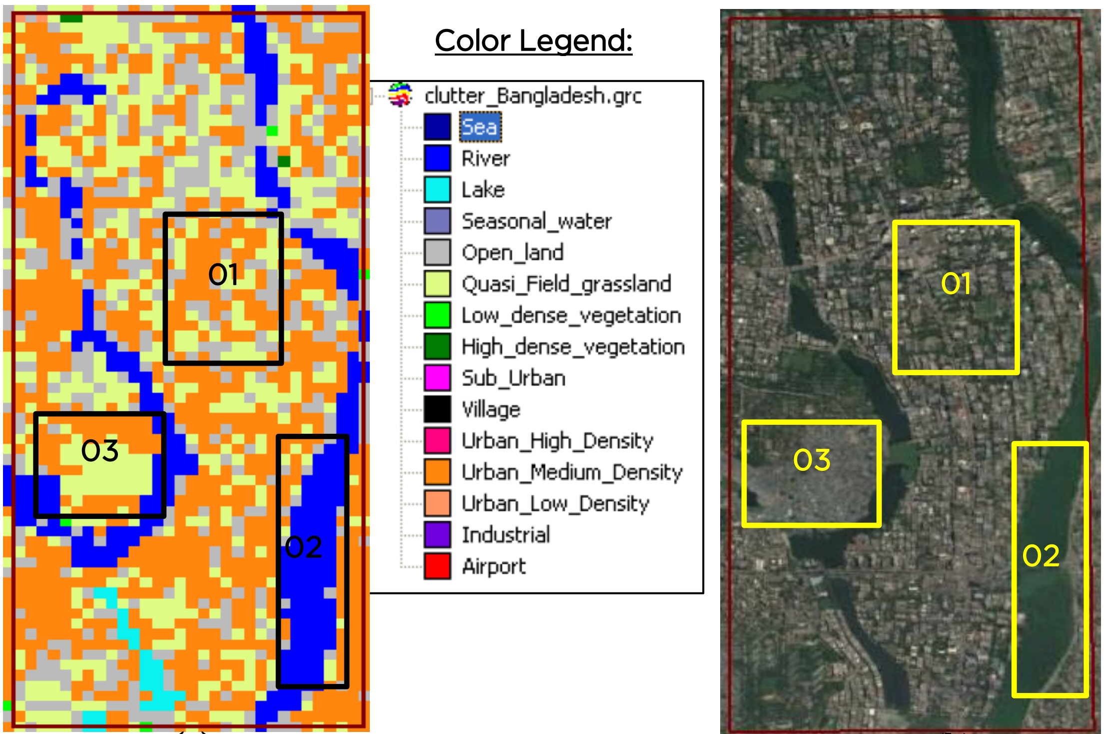


Fig. 4.8: Site positions of the 4 mobile operators in Gulshan area

Area Type (clutter and Terrain): The clutter map of Gulshan area and the corresponding Google earth view are shown in Fig. 4.9.



(a) (b)

Fig. 4.9: (a) Clutter map of Gulshan area with color legend and (b) Google Earth view of Gulshan area

Area 1 (the rectangle marked with 01) is a medium dense urban area with tall urban building infrastructure. Building penetration is higher in these area, but lower than Gulshan dense area. Upper floors of these buildings are usually affected by interference by the signal coming from distant location.

Area 2 (the rectangle marked with 02) is lake and surrounding open location. This are should have good coverage, but if multiple sites are placed to cater higher subscriber, there might be interference issue.

Area 3 (the rectangle marked with 03) is an open area (slam area); there is no place to provide a site here (due to socio-economic reason). Users of these area should face interference and capacity issues.

RX Level of Gulshan area: The RX level plots of 3 mobile operators in Gulshan area are shown in Fig. 4.10.

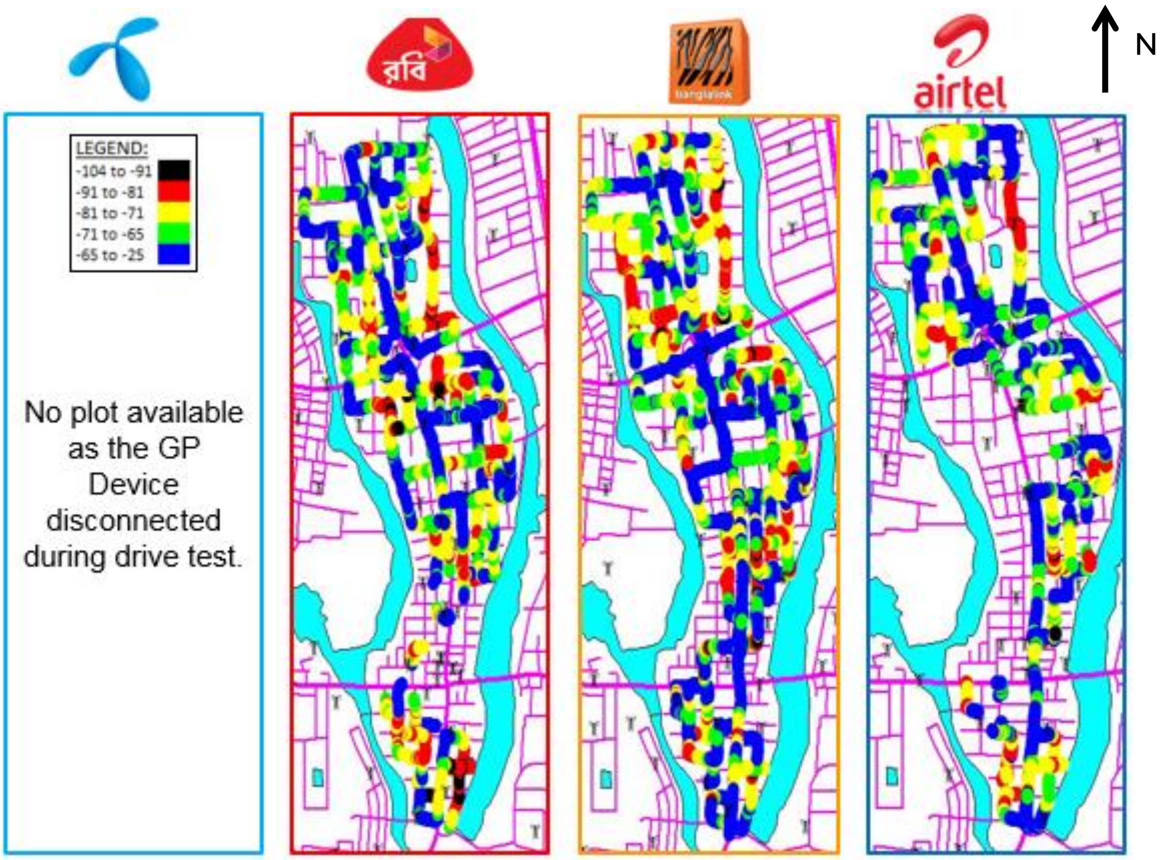


Fig. 4.10: RX Level plots of the 3 mobile operators in Gulshan area

It should be noted here that the drive test equipment with Grameenphone connection unfortunately remained disconnected during the drive test without knowledge. We found the error in the analyzing stage when the benchmarking tool had already been occupied with some regular activities and remain blocked for a long time. Individual drive test was possible (Only for Grameenphone), but that would not fulfil the benchmarking objective. Therefore, we had to compare the performance of only ROBI, Banglalink and Airtel for the Gulshan area.

The RX level sample percentage in Gulshan area is summarized in Table 4.3.

Table 4.3: RX Level sample percentage in Gulshan area

Operator	Indoor Coverage (Sample >-71 dBm)
ROBI	63.02%
GP	Not Available
BL	70.65%
AT	62.94%

All three operators have mixed samples all over Gulshan area. Compared to other areas, where we have performed benchmarking, Gulshan has significantly higher number of bad coverage samples. Considering performance of the three operators, Banglalink has the best coverage samples in Gulshan area. However, it has some coverage problem in the northern part. The coverage is better in central and southern part. On the other hand, Airtel and ROBI have almost equal bad samples; ROBI has some coverage blackspots and some coverage discontinuities as well.

A practical problem in Gulhsan area is that operators could not deploy any site in their best desired location. This is a rich area, tenants of this area are less interested to provide space for erecting tower on their roof-tops. Also, some part of it has Law Enforcing Agency (LEA) restriction owing to its being a diplomatic zone.

Pallabi

Number of sites: Grameenphone has the highest number of sites in Pallabi followed by ROBI. Banglalink and Airtel have equal number of sites in Pallabi area. Fig. 4.11 shows the site positions of the 4 mobile operators in Pallabi area.

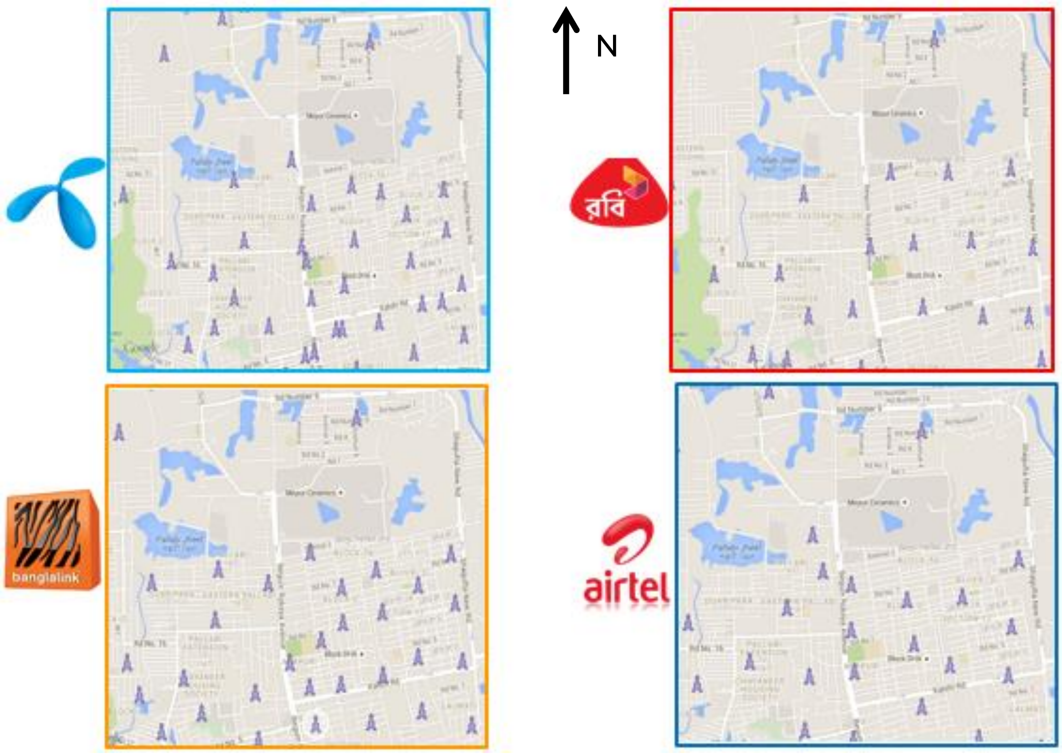
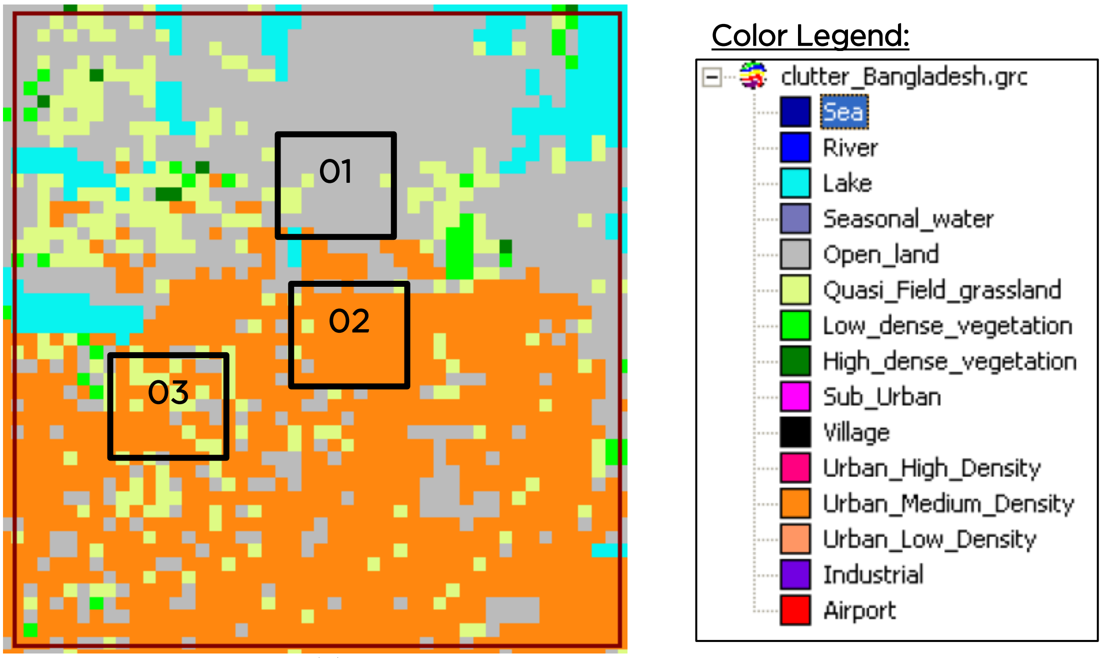
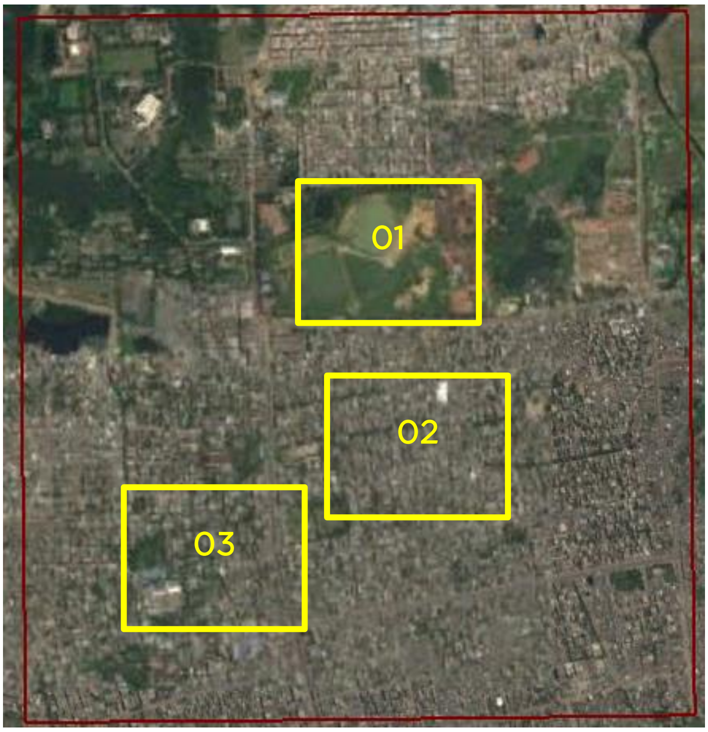


Fig. 4.11: Site positions of the 4 mobile operators in Pallabi area

Area Type (clutter and Terrain): Fig. 4.12 shows the clutter map and corresponding Google earth view of Pallabi area.



(a)



(b)

Fig. 4.12: (a) Clutter map of Pallabi area with color legend and, (b) Google Earth view of Pallabi area

Area 1 (the rectangle marked with 01) is an open area where signal can propagate easily, only faces free space propagation loss. Users of this area should have good coverage.

Area 2 (the rectangle marked with 02) is the urban area with dense building structures. Population density of this portion is higher also. More number of sites are required to provide good coverage here.

Area 3 (the rectangle marked with 03) is a suburban area; it has even fewer establishments than area 01. Similar kind of building structure, but a fewer buildings with marshy lands. We can expect good coverage with fewer sites here as the clutter loss is very low.

RX Level of Pallabi Area: The RX Level plots of the 4 mobile operators in Pallabi area are shown in Fig. 4.13

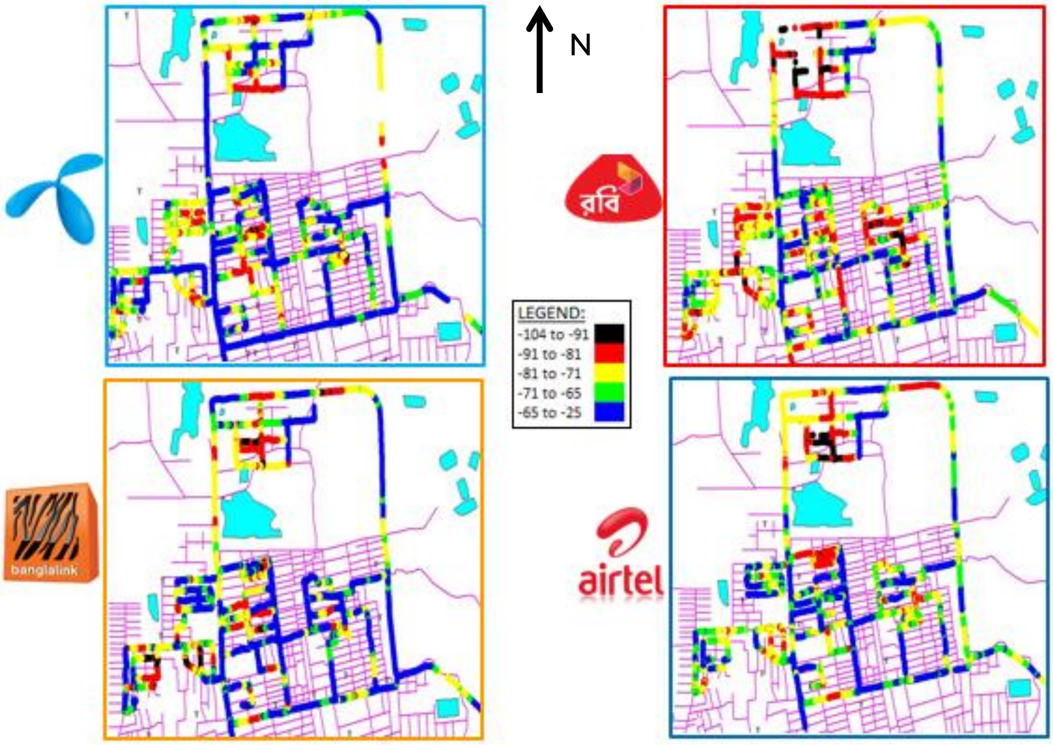


Fig. 4.13: RX Level plot of the 4 mobile operators in Pallabi area

Grameenphone has the best coverage in Pallabi area. The remaining three operators face coverage gap especially, in the northern part. ROBI and Banglalink have coverage gap in the south-west part of Pallbi. ROBI also faces coverage problem in south-east part along with Airtel. In a nutshell, ROBI has the worst coverage in Pallabi area.

Pallabi is a new residential area compared to Mirpur; a large number of buildings are still under construction. Here, clutter pattern changes every 6 months due to addition of new structures. Therefore, a complete optimization is required from the operator's side from time to time.

The RX level sample percentage in Pallabi area is summarized in Table 4.4.

Table 4.4: RX Level sample percentage in Pallabi area

Operator	Indoor Coverage (Sample >-71 dBm)
ROBI	47.29%
GP	68.34%
BL	64.38%
AT	63.78%

Sylhet Sadar

Number of sites: Grameenphone has the highest number of sites in Sylhet sadar followed by Airtel. Banglalink has the third highest site while ROBI has the least number of sites in Sylhet sadar. Fig. 4.14 shows site positions of the 4 mobile operators in Sylhet sadar area.

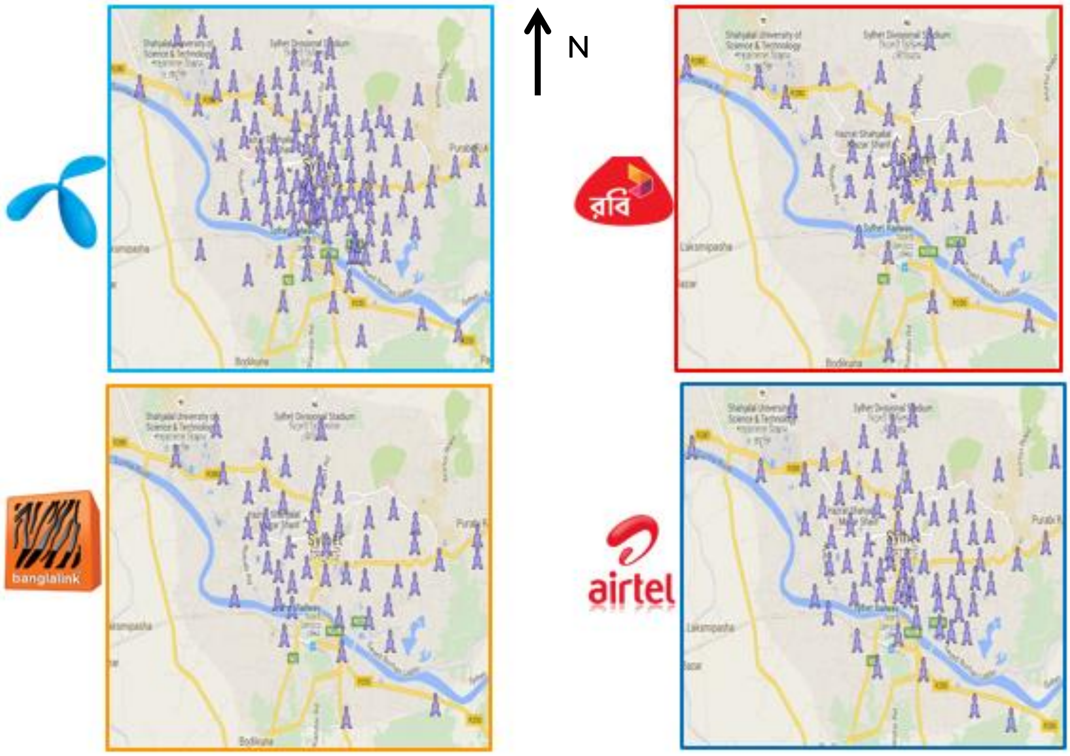
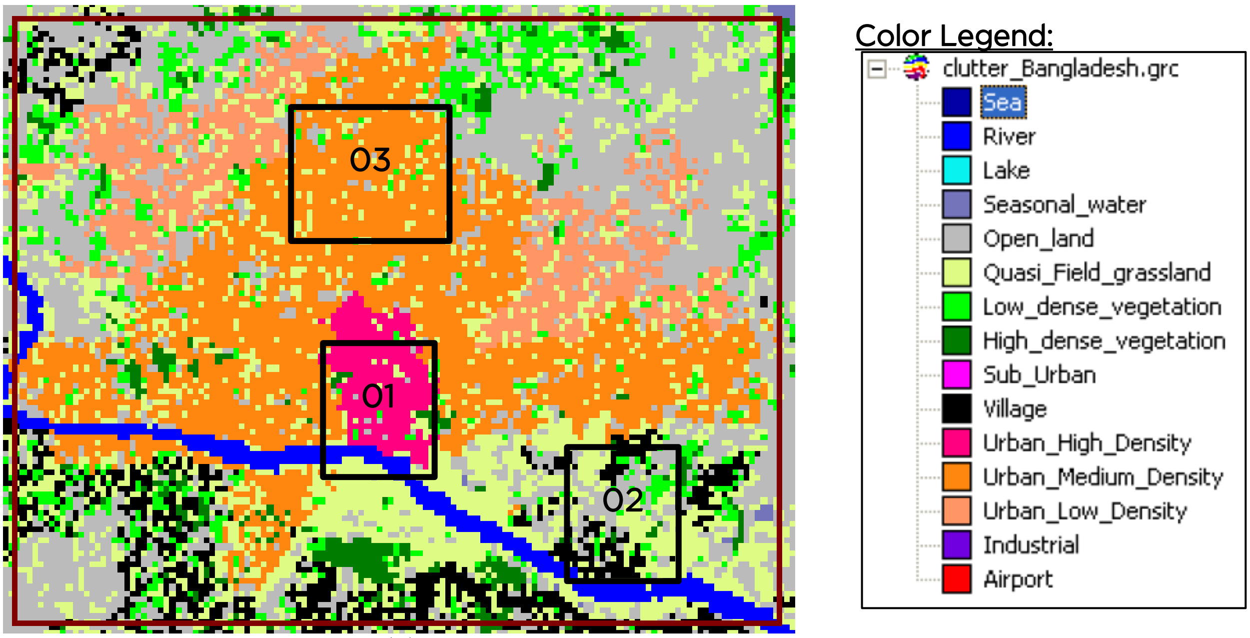
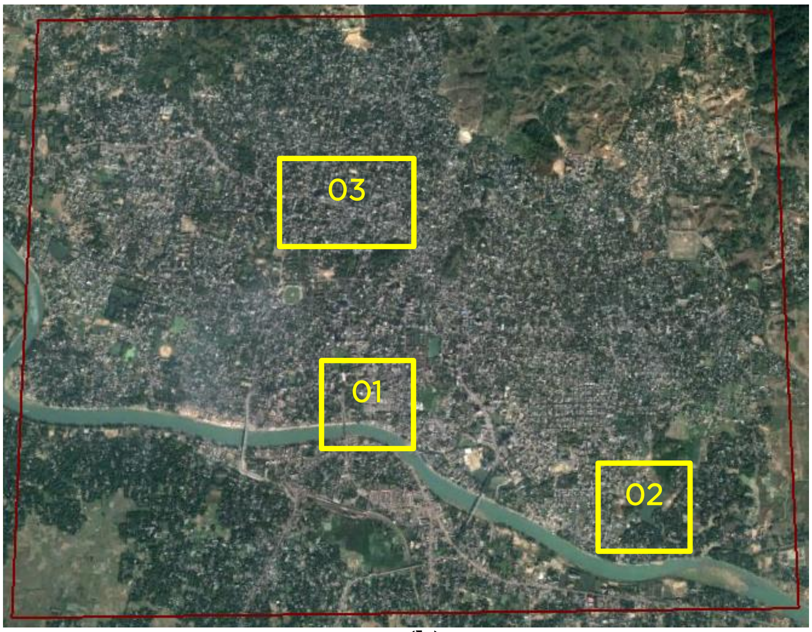


Fig. 4.14: Site positions of the 4 mobile operators in Sylhet Sadar area

Area Type (clutter and Terrain): The clutter map of Sylhet sadar area and the corresponding Google earth view is shown in Fig. 4.15



(a)



(b)

Fig. 4.15: (a) Clutter map of Sylhet Sadar with color legend and, (b) Google Earth view of Sylhet Sadar area

Area 1 (the rectangle marked with 01) is a dense urban area with tall urban building infrastructure. Building penetration is higher in these area. Upper floors of these buildings are usually affected by interference by the signal coming from distant location.

Area 2 (rectangle marked with 02) is open location. This area should have good coverage, but if multiple sites are placed to cater higher subscriber, there might be interference issue.

Area 3(rectangle marked with 03) is a typical urban area; compared to area 1, building heights are lower. Overall, user of this area will get good network if sufficient sites are placed; interference issues are not devastating here due to lower building height.

RX Level of Sylhet Sadar area: The RX level plots of the 4 mobile operators in Sylhet sadar area are shown in Fig. 4.16.

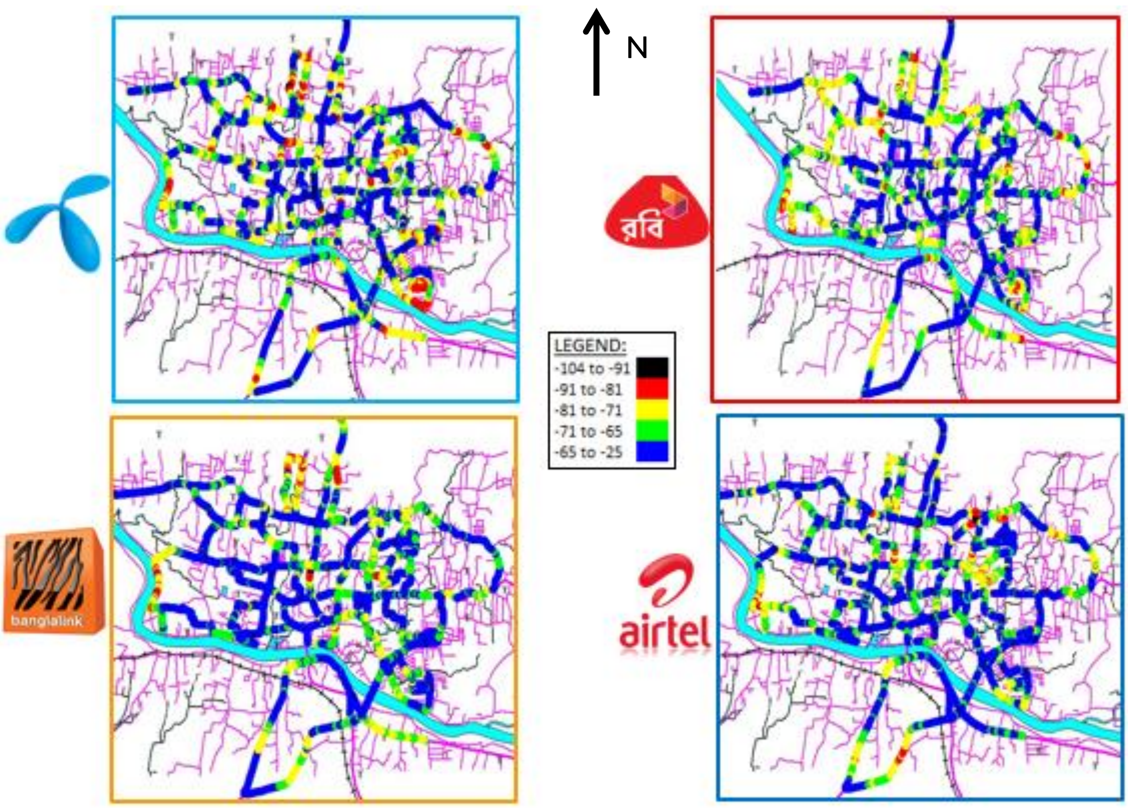


Fig. 4.16: RX Level plot of the 4 mobile operators in Sylhet Sadar area

All the four mobile operators have good coverage level in Sylhet sadar area. Grameenphone has some discrete bad samples in the central part, which might have been caused by high penetration loss due to dense urban structures. By the riverside (western part) all operators are facing bad coverage.

However, in the northern part (airport road and its surrounding), all the three operators have bad coverage except Airtel.

ROBI has a fewer number of sites in the western part, consequently the coverage is not good in that part.

On the other hand, Banglalink has good coverage, especially, in the central part. They require a couple of sites in the eastern side of the central part to solve the coverage problem of that area.

Airtel has coverage problems from the central to the eastern part of this particular area. They need to erect additional sites to solve the problem.

Grameenphone has bad samples in the south-eastern part, a new site in that location can immediately solve the coverage problem of the area. Grameenphone has the highest number of sites in Sylhet, but it has bad RX level samples scattered all over the area. Regular optimization work can improve the situation.

The RX level sample percentage in Sylhet sadar area is summarized in Table 4.5.

Table 4.5: RX Level sample percentage in Sylhet sadar area

Operator	**Indoor Coverage (Sample >-71 dBm)**
ROBI	77.06%
GP	73.51%
BL	84.89%
AT	83.35%

4.2.2 Quality parameters

From the drive test log file analysis, we can draw some conclusion on quality parameters. We can measure RX Qual (range 0 ~7), Frame Erasure Rate (FER), Carrier to Interference Ratio (C to I), handset power measurement etc.

<u>Comilla Sadar</u>

RX Qual: Fig. 4.17 shows the RX qual plots of the 4 mobile operators in comilla sadar area.

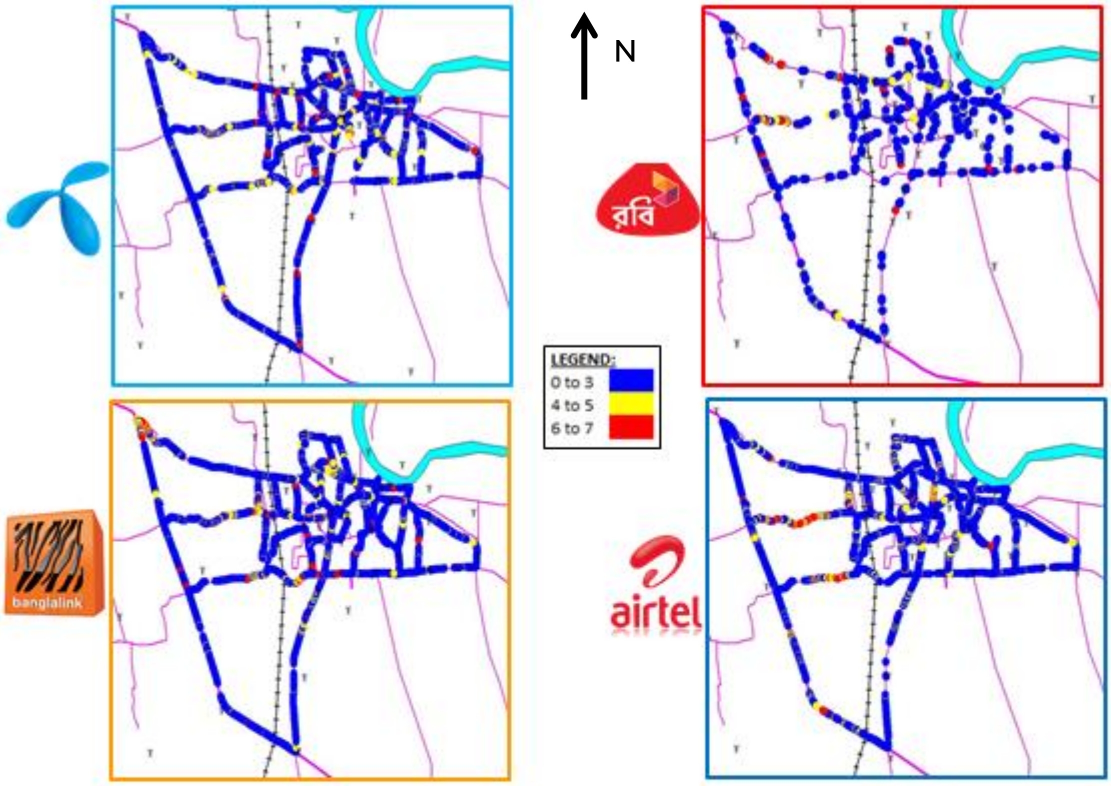


Fig. 4.17: RX Qual plot of the 4 mobile operators in Comilla Sadar area

From the RX Qual above comparing with RX level plot (Fig. 4.4- RX Level represents carrier power- Indoor coverage was discussed on previous section), it is evident that, coverage is not the deciding factor for good RX Qual values. Frequency plan, usage of antenna gain, number of sites, sector planning are other factors that have impact on the interference level.

Grameenphone and Banglalink have intermittently bad RX Qual samples irrespective of the RX Level. ROBI samples are discrete as the samples are taken from short call. Airtel has good RX Qual all over Comilla Sadar area except for the west suburban part where their RX level is also poor.

The findings prove that, all the 4 operators have good frequency plan and the plan for other parameters as well because, good RX Qual proves that wherever they have bad coverage (bad RX Level), interference level is equally down to maintain a moderate RX Qual level.

Table 4.6 summarizes the RX Qual sample percentage of Comilla Sadar area. Banglalink has the highest number of good RX Qual samples followed by Grameenphone. Airtel stands 3rd while ROBI comes at last with less than 90% good RX Qual samples.

Table 4.6: RX Qual sample percentage in Comilla Sadar area

Operator	RX Qual (1 ~ 3)
ROBI	89.50%
Grameenphone	92.90%
Banglalink	95.08%
Airtel	90.78%

FER: FER plot of Comilla sadar area is shown in Fig. 4.18 for the 4 mobile operators.

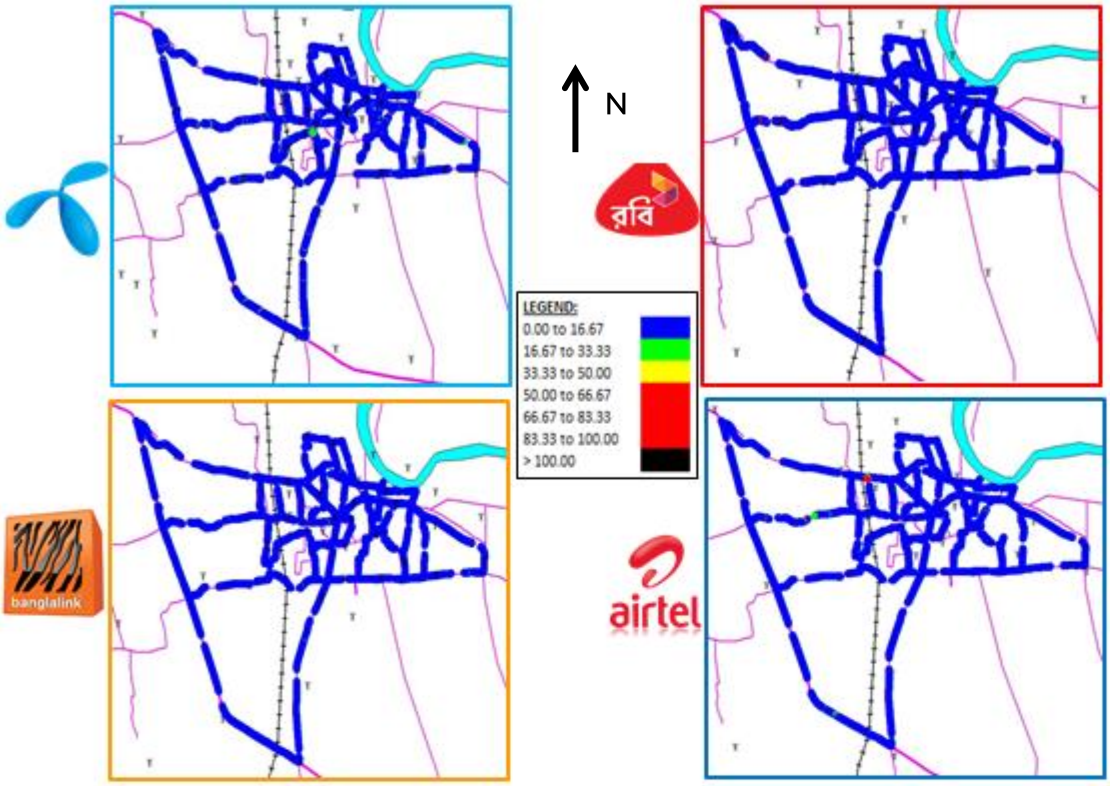


Fig. 4.18: FER plot of the 4 mobile operators in Comilla Sadar area

It has been observed that, all the mobile operators have almost 100% sample values with an FER <16.67%. Grameenphone has relatively low performance in FER measurement. High FER leads to call drop, low speech quality etc. However, high FER is resulted from the extremely bad wireless network condition here.

Table 4.7 gives the FER percentage in Comilla sadar area.

Table 4.7: FER in Comilla Sadar area

Operator	FER (0- 16.67%)
ROBI	99.62%
Grameenphone	97.58%
Banglalink	99.55%
Airtel	99.45%

Carrier to Interference Ratio (C to I): Fig. 4.19 shows the C to I plots of the 4 mobile operators in comilla sadar area.

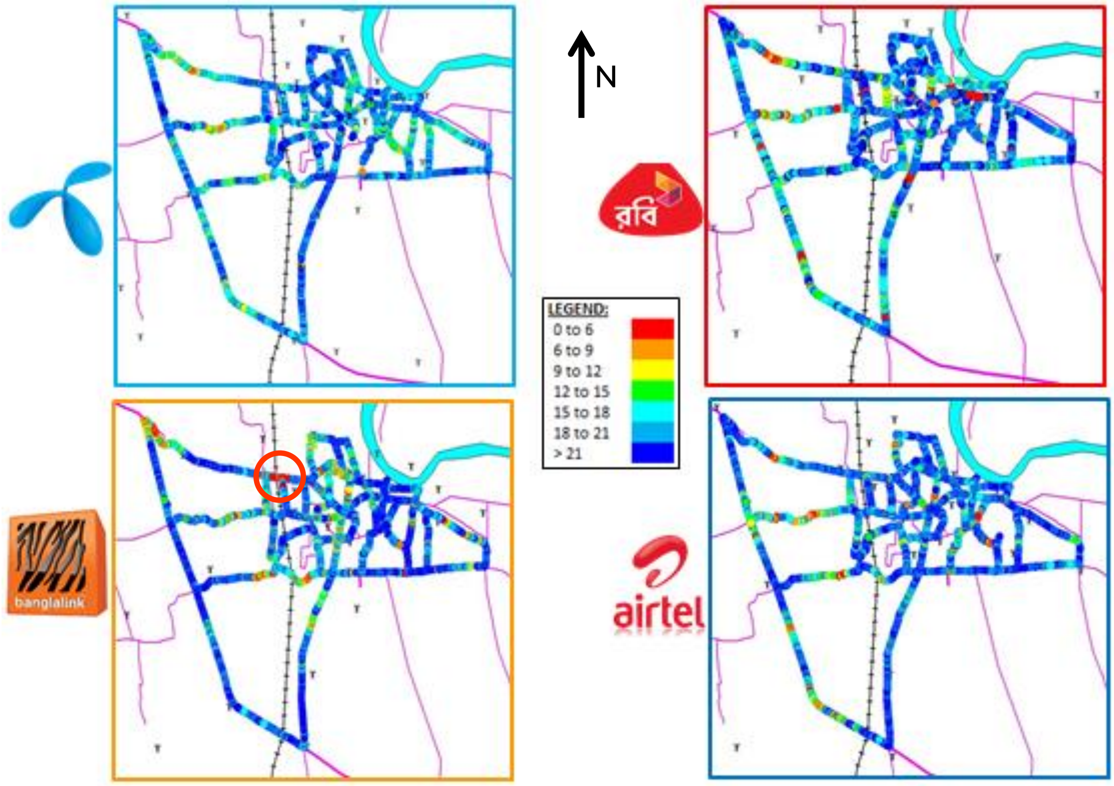


Fig. 4.19: C to I plot of the 4 mobile operators in Comilla Sadar area

The C to I ratio (in percentage) of the 4 mobile operators in Comilla sadar area is summarized in Table 4.8. Airtel has the highest number of good C to I samples followed by Banglalink. ROBI comes to the third, while Grameenphone performs the least. The red circle in the Banglalink C to I plot represents samples with zero C to I value.

Table 4.8: C to I in Comilla Sadar area

Operator	C to I (>12)
ROBI	89.09%
Grameenphone	88.23%
Banglalink	92.28%
Airtel	94.10%

One major reason behind poor C to I is the number of users. The more the users, the closer the frequency reuse distance; this will lead to an increased co-channel interference. Site design parameter is another important issue to be taken care of.

Among the 4 mobile operators, Banglalink uses mostly high gain antennas, but the better C to I proves that they had done the planning very intelligently to control the interference level.

Airtel has low number of users, hence their reuse distance is high enough to keep C to I level at the best possible value. ROBI does not have any specific pattern, it has shown poor C to I ratio all over the city in a scattered manner.

Call Drop and Call Completion rate: Table 4.9 gives the summary of call drop and call completion rates for the 4 mobile operators in Comilla sadar area.

Table 4.9: Call Drop and Call Completion rates in Comilla Sadar area

Operator	**Total Call**	**Successfully completed**	**Call dropped**	**Call Drop**	**Call completion rate**
ROBI	146	145	1	0.68%	99.32%
Grameenphone	146	145	1	0.68%	99.32%
Banglalink	147	147	0	0.00%	100.00%
Airtel	145	144	1	0.69%	99.31%

It can be concluded from the above table that all the mobile operators have deployed sufficient capacity, and hence no significant call block is found.

Call setup time: Table 4.10 shows the call setup time of the 4 mobile operators in Comilla sadar area.

Table 4.10: Call setup time of the 4 mobile operators in Comilla Sadar area

Operator	**Average Call setup time (Sec.)**
ROBI	5.53
Grameenphone	4.83
Banglalink	6.47
Airtel	7.71

This is a very important parameter as it cannot be obtained from any counter or network node. How much time user have to wait after dialing a number represents the 'Call setup time'. The lower call setup time, the better.

We can see from the above table that, Grameenphone has the best call setup time followed by ROBI. Airtel stands as the last while Banglalink is placed on 3rd. It is a common practice among the operators to keep the call setup time below 6 seconds though the value falls under 'Slow setup' as per ETSI definition.

Handset Power: The handset power distribution of the 4 mobile operators in Comilla sadar area is shown in Table 4.11

Table 4.11: Handset power distribution of the 4 mobile operators in Comilla Sadar area

Operator	**Handset Power (uplink, <=30 dBm)**
ROBI	92.05%
Grameenphone	97.91%
Banglalink	97.79%
Airtel	94.91%

It has been noted from the above table that, Grameenphone and Banglalink have the highest number of samples with a handset power distribution within 30 dBm. ROBI has the lowest performance in this parameter with having a 3% gap with Airtel. Airtel secured the 3rd position scoring about 95% better handset power level in the uplink.

Dhanmondi

RX Qual: Fig. 4.20 shows the RX Qual plot of the 4 mobile operators in Dhanmondi area

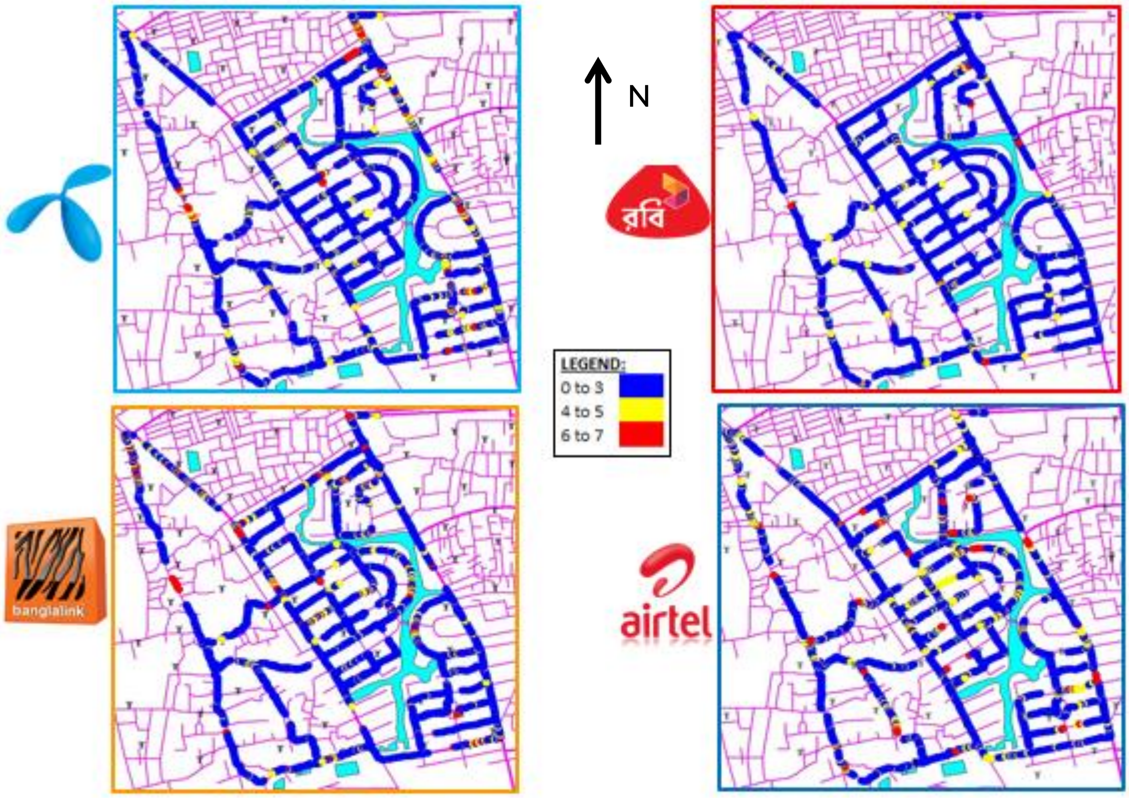


Fig. 4.20: RX Qual plot of the 4 mobile operators in Dhanmondi area

Grameenphone has good RX Qual samples except in the eastern part. ROBI has good RX Qual samples all over the area except a few bad samples scattered here and there. Banglalink has some quality problems in central Dhanmondi area while Airtel suffers with bad RX Qual samples all over the area.

Table 4.12 summarizes the RX Qual sample percentage of the 4 mobile operators in Dhanmondi area.

Table 4.12: RX Qual sample percentage in Dhanmondi area

Operator	**RX Qual (1 ~ 3)**
ROBI	94.91%
Grameenphone	88.90%
Banglalink	91.30%
Airtel	87.43%

ROBI has the best RX Qual (the highest number of good RX Qual samples) among the four mobile operators in Dhanmondi area. Banglalink stands second with just over 91%, while Grameenphone becomes the 3rd with less than 89% score. Airtel has the worst RX Qual in Dhanmondi area. It should be noted that both Grameenphone and Airtel have at least 10% bad RX Qual sample here.

FER: Fig. 4.21 shows the FER plot of the 4 mobile operator in Dhanmondi area.

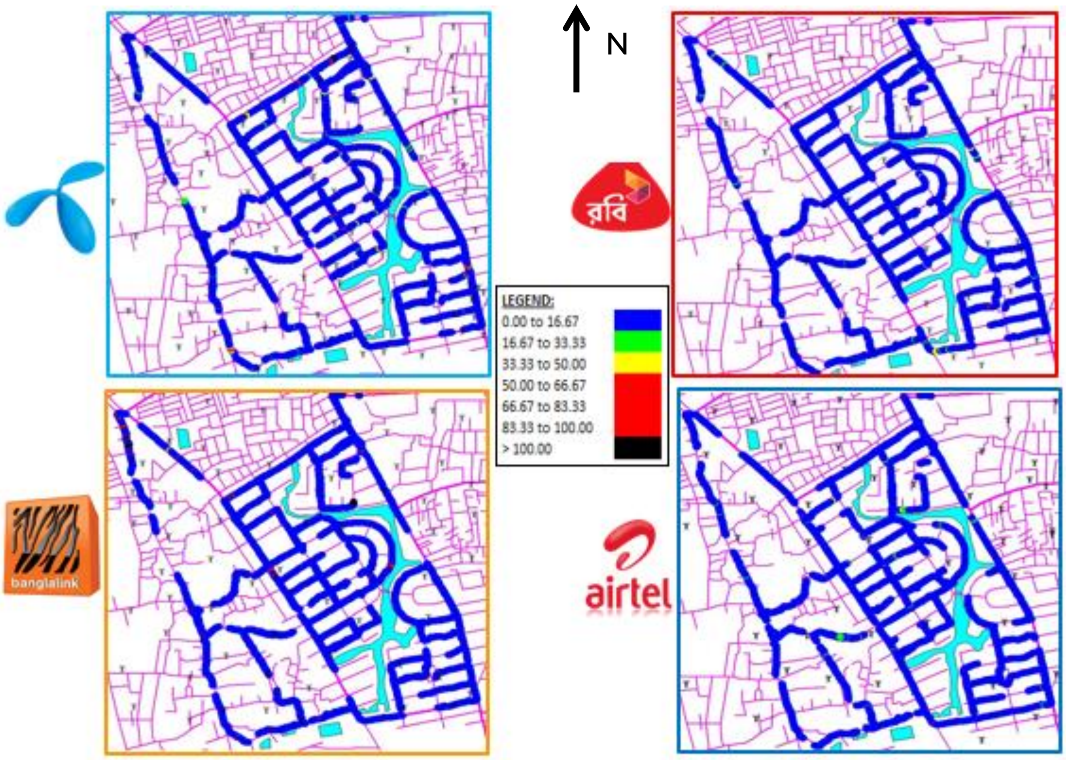


Fig. 4.21: FER plots of the 4 mobile operators in Dhanmondi area

FER scenario is similar for all the four operators. With more than 98% good FER samples for all the operators Banglalink stands the first, ROBI is second marginally, while Airtel and Grameenphone becomes the 3rd and 4th respectively.

Table 4.13 gives FER percentage of Dhanmondi area.

Table 4.13: FER in Dhanmondi area

Operator	**FER (0- 16.67%)**
ROBI	98.71%
Grameenphone	98.27%
Banglalink	98.94%
Airtel	98.65%

Carrier to Interference Ratio (C to I): Fig. 4.22 represents the C to I plots of the 4 mobile operator in Dhanmondi area.

Referring to Fig. 4.22, ROBI has the best C to I ratio in Dhanmondi area followed by Grameenphone. Banglalink is marginally behind Grameenphone securing the 3rd position. Airtel becomes the last with the worst C to I ratio among the four. Airtel subscribers would face problems in the call quality in Dhanmondi area.

Similar to the RX Qual scenario, Grameenphone is facing C to I problem in the eastern part, while Banglalink is facing problem mainly in the central part. Airtel has bad C to I ratio all over Dhanmondi area.

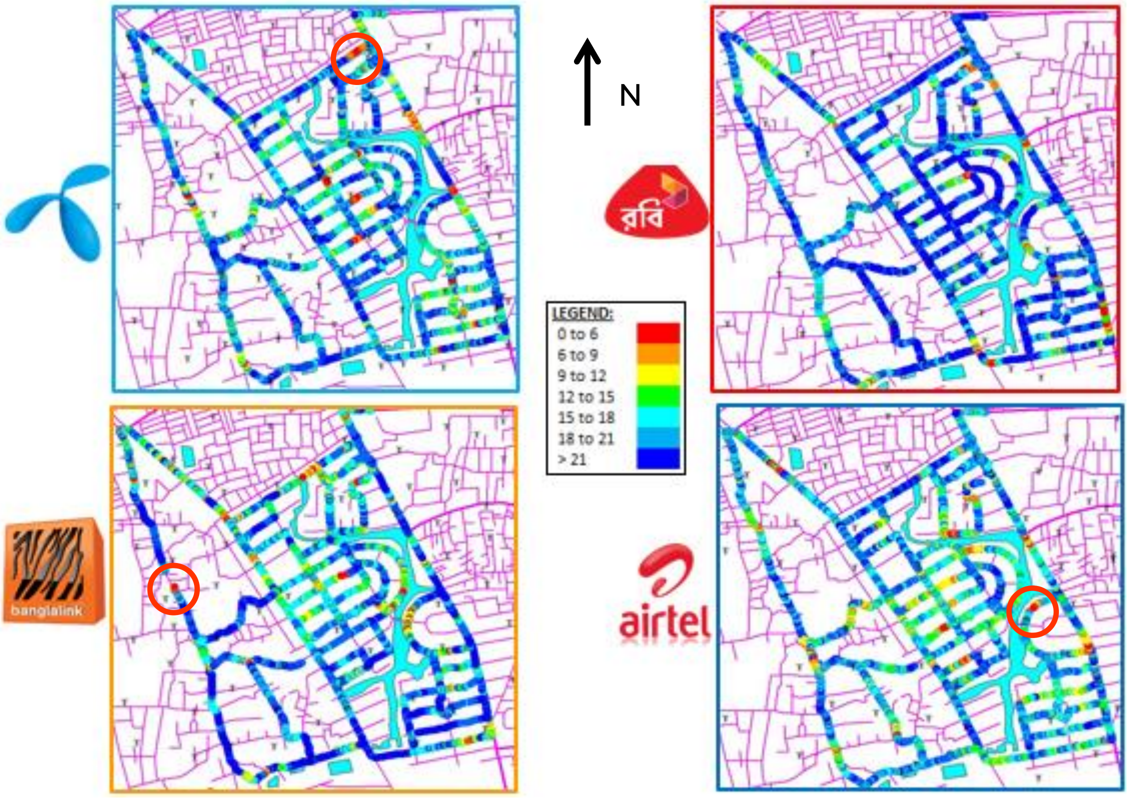


Fig. 4.22: C to I plot of the 4 mobile operators in Dhanmondi area

Table 4.13 shows the C to I ratio of the 4 mobile operators in Dhanmondi area. The red circle in the Grameenphone, Banglalink and Airtel C to I plot represents samples with zero C to I value.

Table 4.14: C to I ratio in Dhanmondi area

Operator	**C to I (>12)**
ROBI	94.85%
Grameenphone	92.61%
Banglalink	91.51%
Airtel	89.84%

Call Drop and Call Completion rate: Table 4.15 shows the summary of call drop and call completion rates for the 4 mobile operators in Dhanmondi area

Table 4.15: Call Drop and Call Completion rate in Dhanmondi area

Operator	**Total Call**	**Success fully completed**	**Call dropped**	**Call Drop**	**Call completion rate**
ROBI	48	47	1	2.08%	97.92%
Grameenphone	48	48	0	0.00%	100.00%
Banglalink	51	50	1	1.96%	98.04%
Airtel	47	47	0	0.00%	100.00%

Both ROBI and Airtel faced a single call drop during the benchmarking drive test. It should be noted that despite having good network quality (good RX Qual, best FER and best C to I), ROBI faced a call drop while Airtel did not face any call drop though Airtel has the worst network quality compared to the other three mobile operators. This also reflects the fact that call drop can be occurred due to several reasons apart from the radio interface problem. For example, BTS equipment problem, Transmission problem etc.

Call setup time: Table 4.16 shows the average call setup time of the 4 mobile operators in Dhanmondi area

Table 4.16: Call set up time of the 4 mobile operators in Dhanmondi area

Operator	Average Call setup time (Sec.)
ROBI	5.21
Grameenphone	6.39
Banglalink	6.52
Airtel	7.92

ROBI has the best call setup time followed by Grameenphone. Banglalink is very close to Grameenphone ahead of Airtel. The reason of higher call setup time is not having sufficient access channels for all of its users.

Handset Power: The handset power distribution of the 4 mobile operators in Dhanmondi area is shown in Table 4.17

Table 4.17: Handset power of the 4 mobile operators in Dhanmondi area

Operator	Handset Power (uplink, <=30 dBm)
ROBI	87.25%
Grameenphone	97.38%
Banglalink	95.51%
Airtel	95.24%

Lower handset power represents more balanced link budget and less users at the cell edge with poor downlink signal. As a general rule, the higher the number of sites, the lower the signal path loss from BTS to user end; hence the lower the handset power required to reach the BTS from a user in the uplink.

Grameenphone has the best scenario in handset power followed by Banglalink and Airtel, who have marginally lower performance. However, ROBI is miles away behind the other three.

Gulshan

RX Qual: Fig. 4.23 shows RX Qual plots of the 3 mobile operator in Gulshan area.

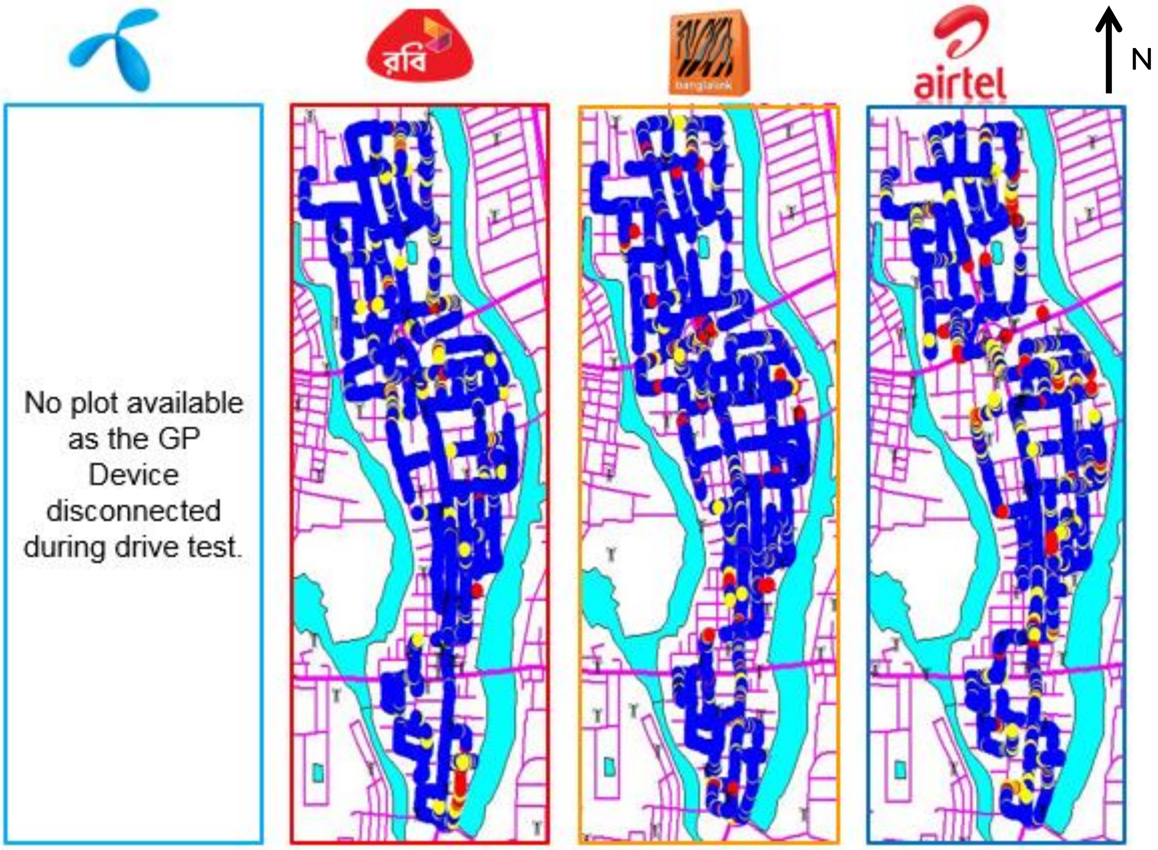


Fig. 4.23: RX Qual plot of the 3 mobile operators in Gulshan area

(Drive test equipment with Grameenphone connection was disconnected during drive test, hence Grameenphone is excluded from the comparison in Gulshan)

ROBI has the highest number of good RX Qual samples among the three operators. Considering the RX Qual performance, Banglalink has just over 90% good samples while Airtel is far away behind ROBI and Banglalink. Airtel suffers with more than 15% bad RX Qual samples, which represents comparatively bad voice quality for the Airtel users.

All three operators have bad samples distributed all over Gulshan area

Table 4.18 gives the summary of RX Qual sample percentage of the 3 mobile operators in Gulshan area.

Table 4.18: RX Qual sample percentage in Gulshan area

Operator	RX Qual (1 ~ 3)
ROBI	92.99%
Grameenphone	Not Available
Banglalink	90.56%
Airtel	84.90%

FER: Fig. 4.24 shows the FER plot of the 3 mobile operators in Gulshan area

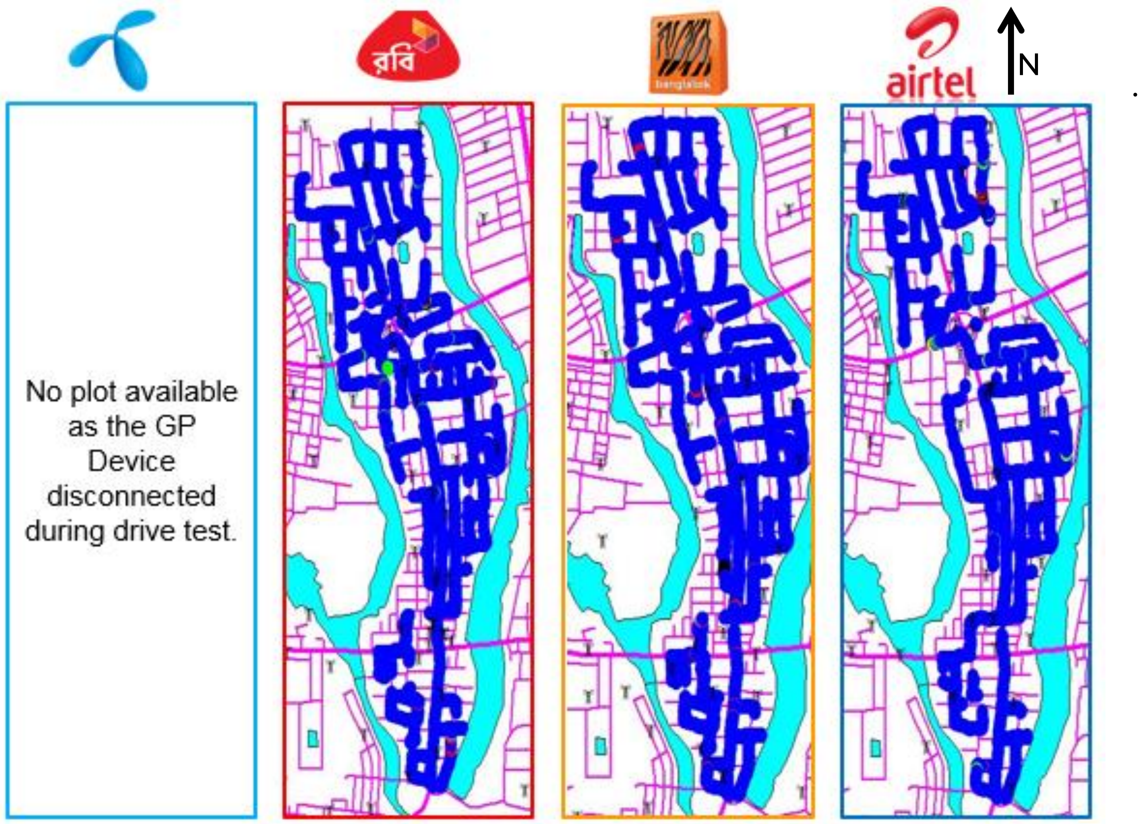


Fig. 4.24: FER plot of the 3 mobile operators in Gulshan area

All the operators have good FER performance in Gulshan area. Among the three operators, Banglaink has the best FER performance with more than 99% correct frame. ROBI and Airtel perform almost equally with just below 99% accuracy.

Table 4.19 gives the summary FER in Gulshan area.

Table 4.19: FER in Gulshan area

Operator	FER (0- 16.67%)
ROBI	98.71%
Grameenphone	Not Available
Banglalink	99.39%
Airtel	98.82%

Carrier to Interference Ratio (C to I): Users of Gulshan area suffer from bad voice quality. Airtel is performing worst with more than one-fourth samples with bad C to I ratio(C to I less than 12). Banglalink and ROBI are performing close to 90% samples with good C to I ratio. Banglalink is better than ROBI by 3% in the C to I measure. C to I plot of 3 operators are shown in Fig. 4.25 next.

All the operators should seriously think of improving the network quality in Gulshan area. Placing couple of new sites in the central-east part, north end and south end will improve the situation a lot, because all the operators have bad samples in these three areas in common.

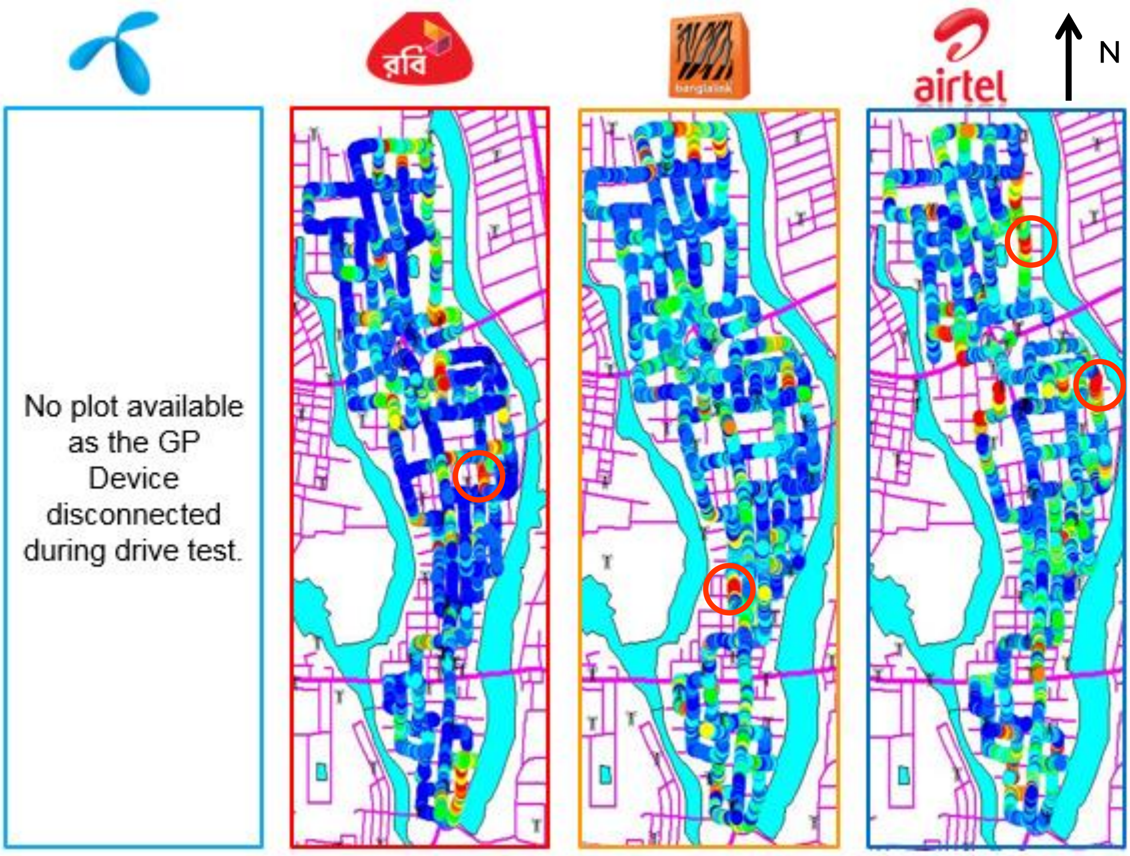


Fig. 4.25: C to I plot of the 3 mobile operators in Gulshan area

The red circle in the Robi, Banglalink and Airtel C to I plot represents samples with zero C to I value.

Table 4.20 shows the C to I ratio of the 3 mobile operators in Gulshan area

Table 4.20: C to I in Gulshan area

Operator	C to I (>12)
ROBI	88.46%
Grameenphone	Not Available
Banglalink	91.72%
Airtel	74.08%

Call Drop and Call Completion Rate: Table 4.21 next shows the call drop and call completion rate of Gulshan area.

As reflected in the coverage and quality parameters, 2 call drops experienced in Airtel. No call drop observed in Banglalink, while a single call drop was noticed in ROBI. Grameenphone information was not available.

Table 4.21: Call Drop and Call Completion rate in Gulshan area

Operator	Total Call	Success fully completed	Call dropped	Call Drop	Call completion rate
ROBI	65	64	1	1.54%	98.46%
Grameenphone	Not Available				
Banglalink	65	65	0	0.00%	100.00%
Airtel	51	49	2	3.92%	96.08%

Call setup time: Table 4.22 shows the call setup time of the 4 mobile operators of Gulshan area.

Table 4.22: Call setup time of the 3 mobile operators in Gulshan area

Operator	Average Call setup time (Sec.)
ROBI	5.46
Grameenphone	Not Available
Banglalink	6.80
Airtel	9.12

ROBI has the best call setup time among the three operators. Banglalink stands second. Airtel needs almost 80% more time compared to ROBI to establish a call. The measurement strengthens the fact that Airtel does not have sufficient access channels and their network strength is really poor compared to its competitors.

Handset Power: The handset power distribution of the 4 mobile operators are shown in Table 4.23.

Table 4.23: Handset power of the 3 mobile operators in Gulshan area

Operator	Handset Power (uplink, <=30 dBm)
ROBI	84.24%
Grameenphone	Not Available
Banglalink	96.71%
Airtel	92.04%

ROBI holds the lowest position in this measure, which reflects the fact that ROBI link budget is not balanced, user equipments need to dissipate more power to communicate with the BTS.

Banglalink uses high gain antennas and their link budget is more balanced. Therefore, Banglalink performed the best in this parameter. Airtel performs moderately in between Banglalink and ROBI with a 92% score.

Pallabi

RX Qual: Fig. 4.26 shows the RX Qual plot of the 4 mobile operators in Pallabi area

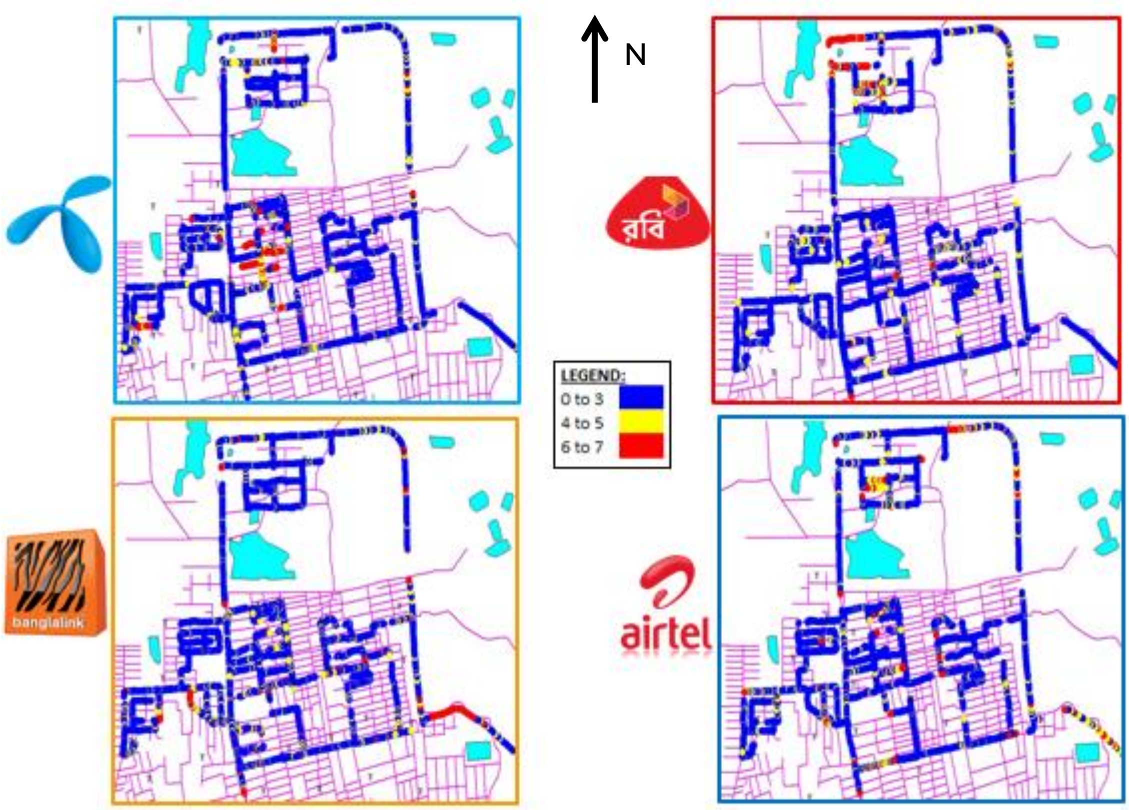


Fig. 4.26: RX Qual plots of the 4 mobile operators in Pallabi area

ROBI has the best RX Qual (highest number of good RX Qual samples) among the four operators in Pallabi area. Grameenphone stands second with just a near 0.5% margin over Airtel. Banglalink has the worst RX Qual in Pallabi area with almost 86% good RX Qual samples. It should be noted that all four operators have at least 10% bad RX Qual samples, which reflects the necessity of network quality improvement of all the operators in Pallabi area.

Table 4.24 summarizes the RX Qual percentage of Pallabi area.

Table 4.24: RX Qual sample percentage in Pallabi area

Operator	RX Qual (1 ~ 3)
ROBI	89.49%
Grameenphone	87.54%
Banglalink	85.93%
Airtel	87.07%

Grameenphone has bad RX Qual mainly at the central part, with some scattered bad samples in the north. ROBI suffers in the northern part as well, while Banglalink faces bad RX Qual distributed all over the area. Airtel has a similar plot like Banglalink, except a relatively worse scenario in the northern part.

FER: Fig. 4.27 shows the FER of the 4 mobile operators in Pallabi area

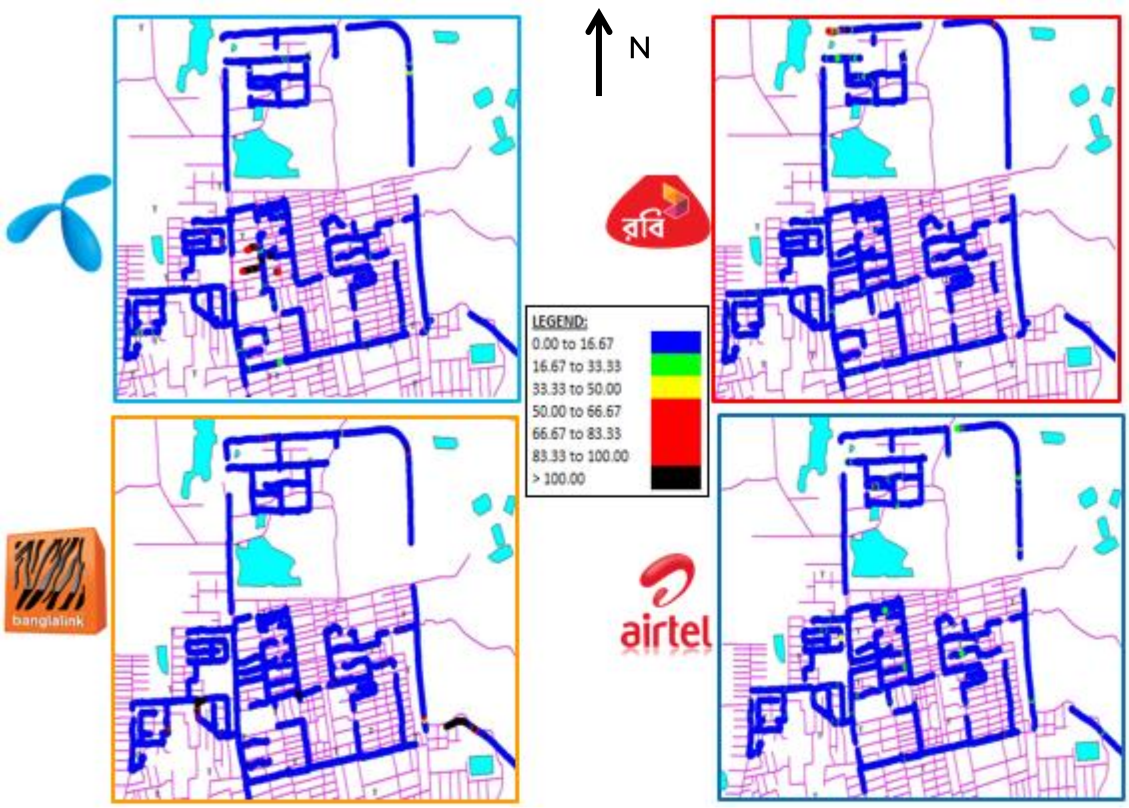


Fig. 4.27: FER plot of the 4 mobile operators in Pallabi area

FER scenario is similar for all the four operators here. With more than 97% good FER samples for all the operators Banglalink stands first, Airtel becomes second with a narrow margin, while ROBI and Grameenphone, becomes the 3rd and 4th , respectively.

Table 4.25 shows the FER statistics of Pallabi area.

Table 4.25: FER in Pallabi area

Operator	FER (0- 16.67%)
ROBI	97.40%
Grameenphone	97.16%
Banglalink	98.29%
Airtel	98.02%

Carrier to Interference Ratio (C to I): Fig. 4.28 shows the C to I plot of Pallabi area.

Banglalink has the best C to I ratio in Pallabi area followed by ROBI. Grameenphone is marginally behind ROBI securing the 3rd position. Airtel becomes the last with the worst C to I ratio among the four operators.

Similar to the RX Qual scenario, Grameenphone is facing C to I problems in the central part. All the operators faces C to I problems in the eastern part of Pallabi area. ROBI and Airtel have some bad samples in the northern part. Banglalink has relatively low bad samples concentrated mainly in the central-west part.

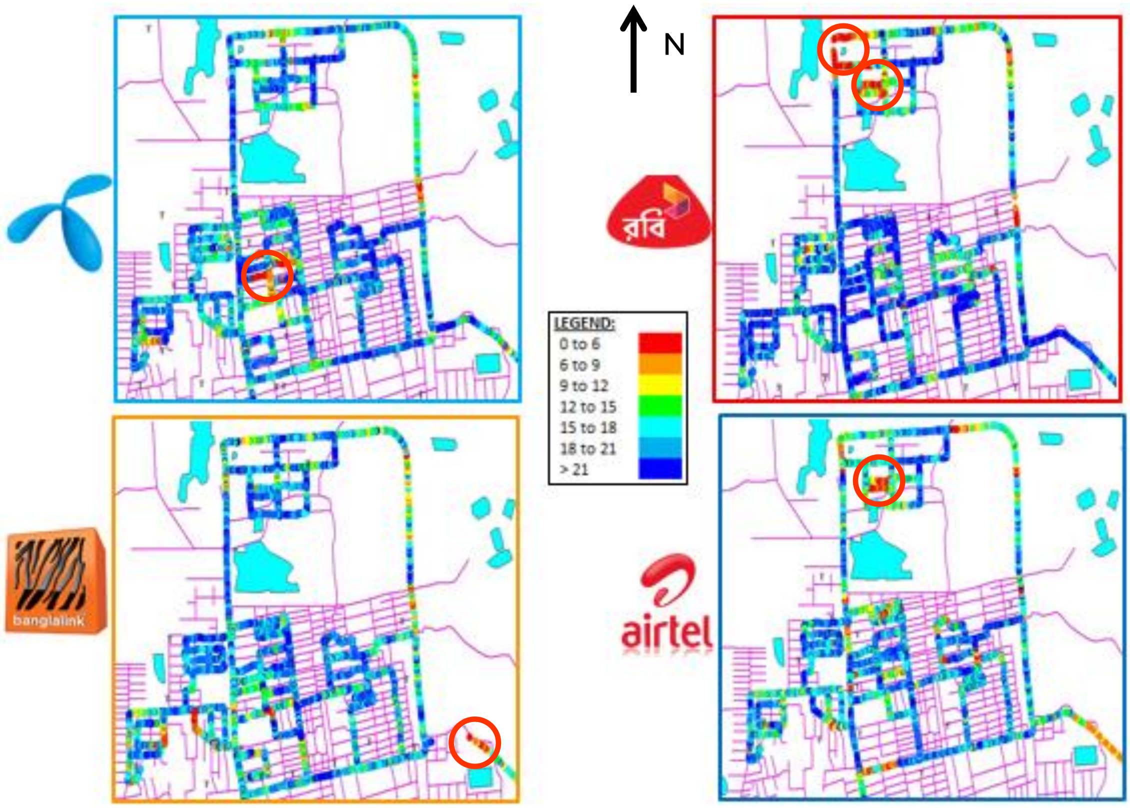


Fig. 4.28: C to I plot of the 4 mobile operators in Pallabi area

The red circle in the 4 operators' C to I plot represents samples with zero C to I value.

Table 4.26 summarizes the C to I good smaple percentage of Pallabi area.

Table 4.26: C to I in Pallabi area

Operator	**C to I (>12)**
ROBI	87.43%
Grameenphone	87.31%
Banglalink	88.55%
Airtel	84.46%

Call Drop and Call Completion rate: Table 4.27 shows the call drop rate and call completion rate of the 4 mobile operators in Pallabi area.

Table 4.27: Call Drop and Call Completion rate in Pallabi area

Operator	**Total Call**	**Success fully completed**	**Call dropped**	**Call Drop**	**Call completion rate**
ROBI	58	55	3	5.17%	94.83%
Grameenphone	57	52	5	8.77%	91.23%
Banglalink	54	53	1	1.85%	98.15%
Airtel	53	52	1	1.89%	98.11%

Grameenphone suffered with 5 call drops during the benchmarking drive test. All of this happened in the central part, where C to I ratio is extremely bad. 3 call drops were also noticed in ROBI network. Banglalink and Airtel have single call drop in Pallabi area during the benchmarking. It should be noted here that some spots have been identified with extremely low C to I ratio where call cannot be sustained, and call drop is obvious.

Call setup time: Table 4.28 listed the call setup time of the 4 mobile operators in Pallabi area.

Table 4.28: Call setup time of the 4 mobile operators in Pallabi area

Operator	Average Call setup time (Sec.)
ROBI	5.15
Grameenphone	5.49
Banglalink	6.92
Airtel	7.39

ROBI has the best call setup time among the four operators. Grameenphone stands second. Airtel needs almost 40% more time compared to ROBI to establish a call. Banglalink stands 3rd with requiring almost 7 seconds to establish a call. The measurement strengthens again the fact that Airtel does not have sufficient access channels and their network strength is really poor compared to its competitors.

Handset Power: Table 4.29 shows the power dissipation by Handsets of the 4 mobile operators in Pallabi area.

Table 4.29: Handset power of the 4 mobile operators in Pallabi area

Operator	Handset Power (uplink, <=30 dBm)
ROBI	80.31%
Grameenphone	95.37%
Banglalink	95.85%
Airtel	94.56%

ROBI holds the lowest position in this measure, which reflects the fact that ROBI link budget is not balanced, user equipment need to dissipate more power to communicate with the BTS.

Banglalink uses high gain antennas and their link budget is more balanced. Therefore, Banglalink performed the best in this parameter. Grameenphone is marginally behind Banglalink. Airtel is closer to the top 2, with a significant distance with ROBI.

Sylhet Sadar

RX Qual: Fig. 4.29 shows the RX Qual plot of the 4 mobile operators in Sylhet sadar area.

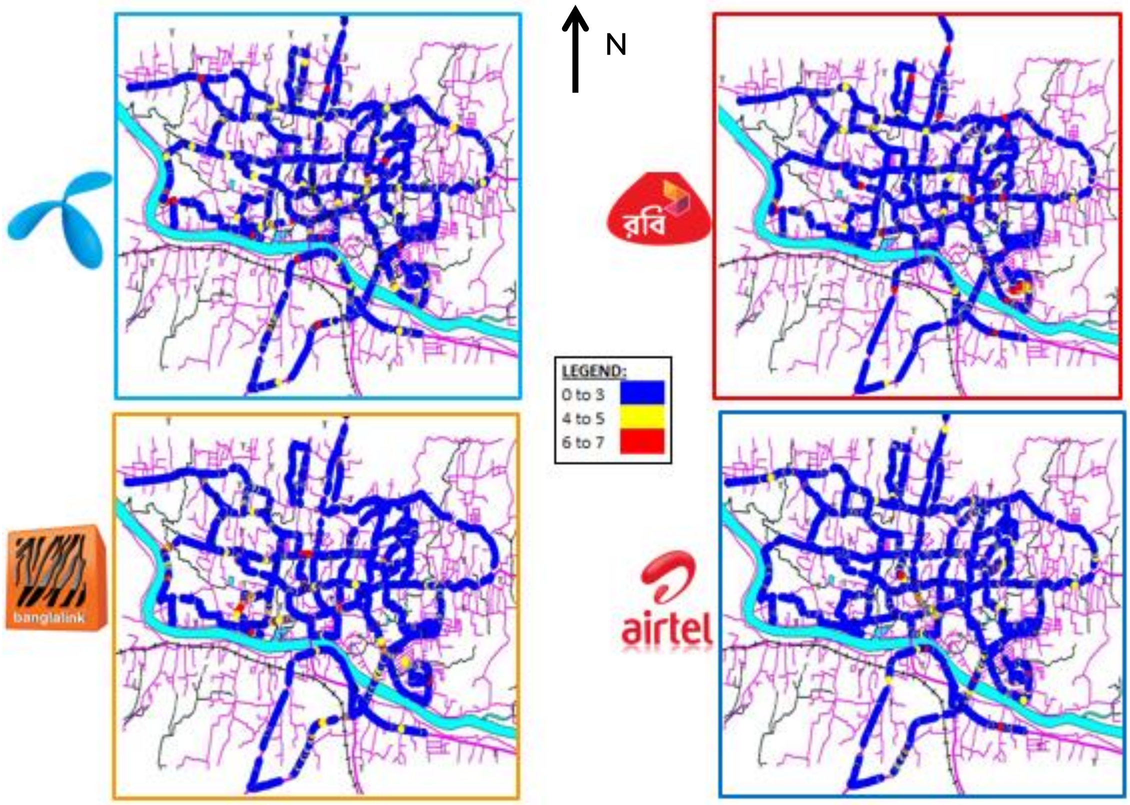


Fig. 4.29: RX Qual plot of the 4 mobile operators in Sylhet Sadar area

ROBI has the best RX Qual (highest number of good RX Qual samples) among the four operators in Sylhet sadar area. Banglalink stands second with just a 0.05% margin over Grameenphone. Airtel has the worst RX Qual in Sylhet sadar area with almost 92% good RX Qual samples. It should be noted that all four operators have almost over 92% good samples which presents the best scenario among the current benchmarking drive test areas.

Grameenphone and ROBI have scattered bad samples all over Sylhet sadar area. Banglalink has some problems especially at the central part. Airtel faces problem in the southern part. All the operators have some quality problems in the roads by the side of the river.

Table 4.30 shows the RX Qual scenario in Sylhet Sadar area

Table 4.30: RX Qual sample percentage in Sylhet Sadar area

Operator	RX Qual (1 ~ 3)
ROBI	94.07%
Grameenphone	92.96%
Banglalink	93.01%
Airtel	91.82%

FER: Fig. 4.30 next represents the FER plots of the 4 mobile operators in Sylhet sadar area.

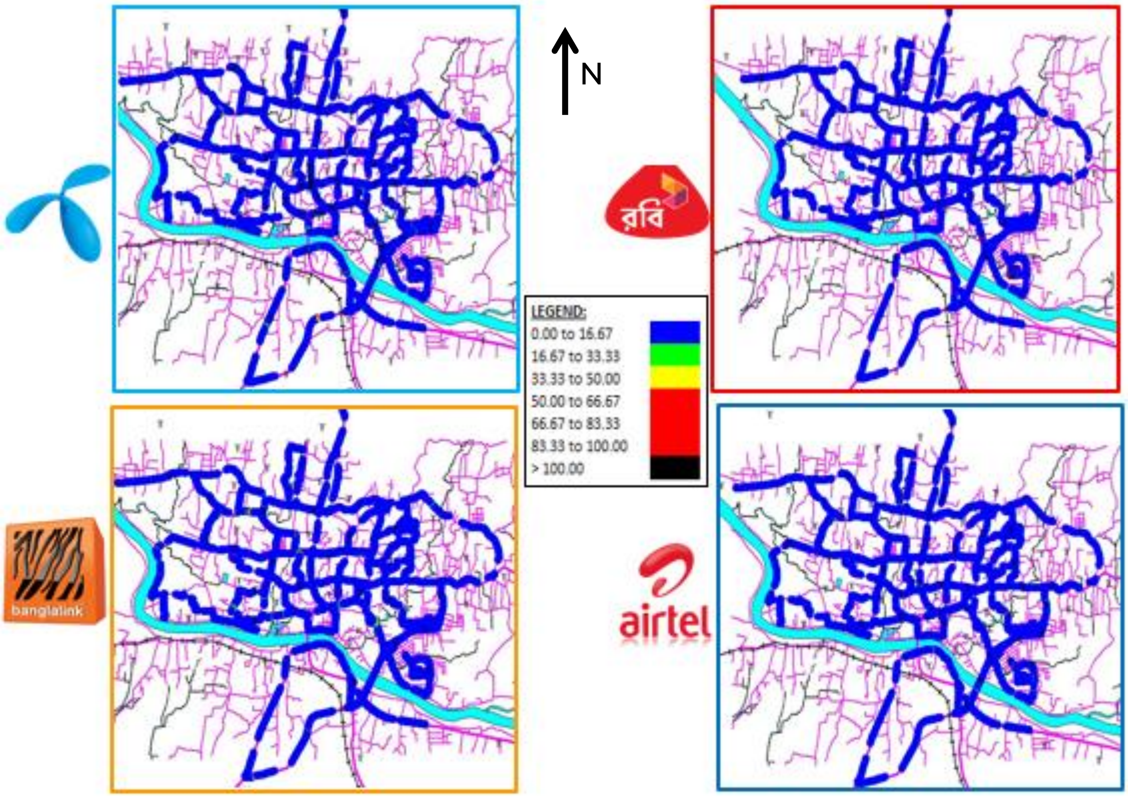


Fig. 4.30: FER plots of the 4 mobile operators in Sylhet sadar area

FER scenario is relatively better for all the four operators in Sylhet sadar area compared to the other benchmarking drive test areas. With nearly 99% good FER samples Grameenphone stands the last among the four operators. ROBI, Airtel and Banglalink, secured the 1st , 2nd and 3rd, respectively with having more than 99% score.

Table 4.31 listed the FER scenario of the 4 mobile operators in Sylhet sadar area

Table 4.31: FER in Sylhet Sadar area

Operator	FER (0- 16.67%)
ROBI	99.60%
Grameenphone	98.78%
Banglalink	99.20%
Airtel	99.50%

Carrier to Interference Ratio (C to I): Fig. 4.31 shows the C to I ratio of the 4 mobile operators in Sylhet sadar area.

Airtel has the best C to I ratio in Sylhet sadar area followed by Grameenphone. ROBI is marginally behind Grameenphone securing the 3rd position. Banglalink performed the last with the worst C to I ratio among the four. Banglalink is almost 8% behind the other 3 competitors with 86.4% good C to I samples.

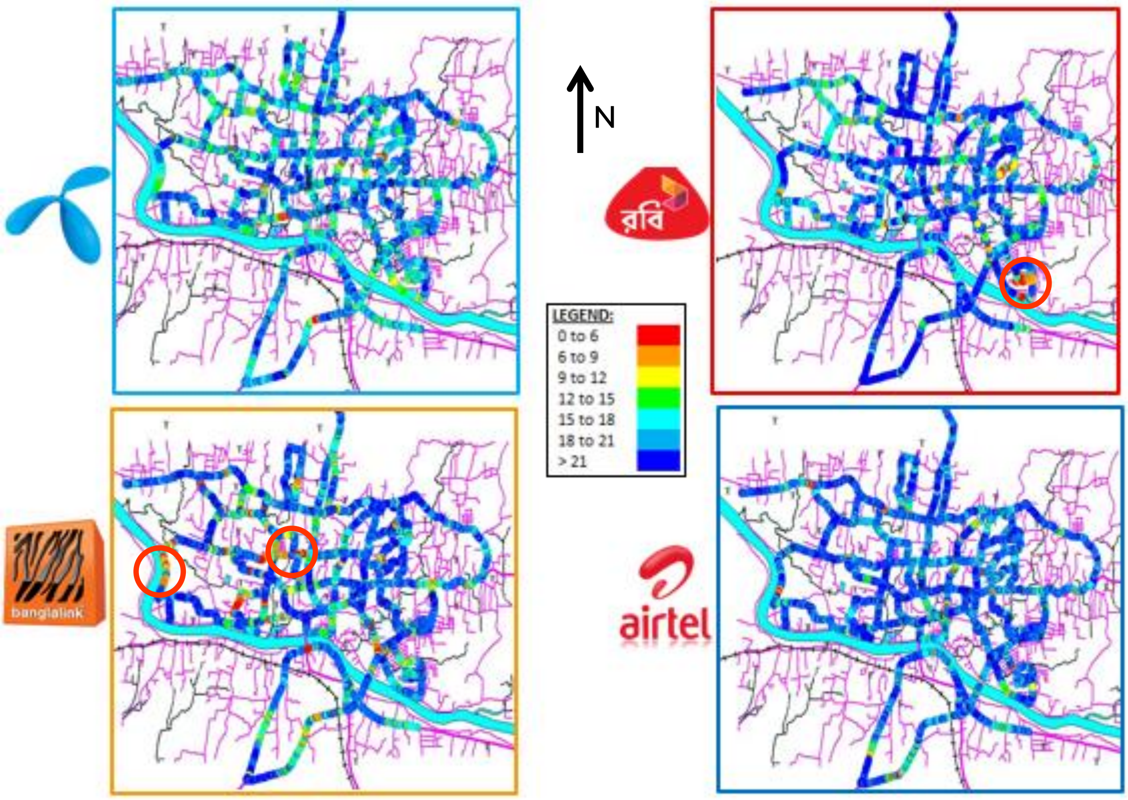


Fig. 4.31: C to I plot of the 4 mobile operators in Sylhet sadar area

Similar to the RX Qual scenario, Grameenphone and ROBI are facing C to I issues scattered all over Sylhet sadar. Banglalink has a number of red sample (with C to I < 6) in the west part of Sylhet. Airtel bad samples are found in the central area and by the riverside road. The red circle in the Robi and Banglalink C to I plot represents samples with zero C to I value.

Table 4.32 summarizes the C to I ratio of Sylhet sadar area.

Table 4.32: C to I in Sylhet Sadar area

Operator	C to I (>12)
ROBI	94.26%
Grameenphone	94.47%
Banglalink	86.43%
Airtel	96.89%

Call Drop and Call Completion rate: Table 4.33 listed the call drop and call completion rate of the 4 mobile operators in Sylhet sadar area

Table 4.33: Call Drop and Call Completion rate in Sylhet Sadar area

Operator	Total Call	Success fully completed	Call dropped	Call Drop	Call completion rate
ROBI	151	151	0	0.00%	100.00%
Grameenphone	156	155	1	0.64%	99.36%
Banglalink	162	162	0	0.00%	100.00%
Airtel	153	153	0	0.00%	100.00%

No call drop experienced in Sylhet except a single drop for Grameenphone. All calls are successfully completed.

Call setup time: Table 4.34 shows the call setup time of the 4 mobile operators in Sylhet sadar area

Table 4.34: Call setup time of the 4 mobile operators in Sylhet Sadar area

Operator	Average Call setup time (Sec.)
ROBI	5.72
Grameenphone	5.70
Banglalink	5.62
Airtel	6.63

Banglalink has the best call setup time among the four operators. Grameenphone and ROBI are marginally behind Banglalink with 0.02 second difference between each other. Airtel is 4th with 1 second lag in performance.

Handset Power: Table 4.35 shows the power dissipated by the user equipment of the 4 mobile operators in Sylhet sadar area

Table 4.35: Handset Power of the 4 mobile operators in Sylhet Sadar area

Operator	Handset Power (uplink, <=30 dBm)
ROBI	86.83%
Grameenphone	98.05%
Banglalink	94.77%
Airtel	95.38%

ROBI holds the bottom position in this measure, which reflects the fact that ROBI link budget is not balanced, user equipment need to dissipate more power to communicate with BTS.

Grameenphone has the highest performance in this parameter, it performs exceptionally well with 98% scoring. Airtel is second with 95% while Banglalink follows Airtel by 0.6% gap.

4.3 Summary of the Results

The overall result of the benchmarking drive test data is presented in Table 4.36

Table 4.36: The overall result of the benchmarking drive test data

Operator	Coverage (Sample >-71 dBm)	Call Drop	RX Qual (1 ~ 3)	FER (0-16.67)	Call completion rate	C to I (>12)	Handset Power (uplink, <30 dBm)	Average Call setup time (Sec.)
ROBI	64.47%	1.28%	92.96%	99.14%	98.72%	91.08%	87.33%	5.41
Grameenphone	73.17%	1.55%	91.66%	98.07%	98.45%	90.98%	97.55%	5.60
Banglalink	80.06%	0.42%	92.34%	99.20%	99.58%	89.83%	96.22%	6.47
Airtel	79.99%	0.89%	89.69%	99.12%	99.11%	90.87%	94.73%	7.75

The combined result of the benchmarking drive test data is also shown in bar diagrams for the 4 mobile operators in Fig. 4.32

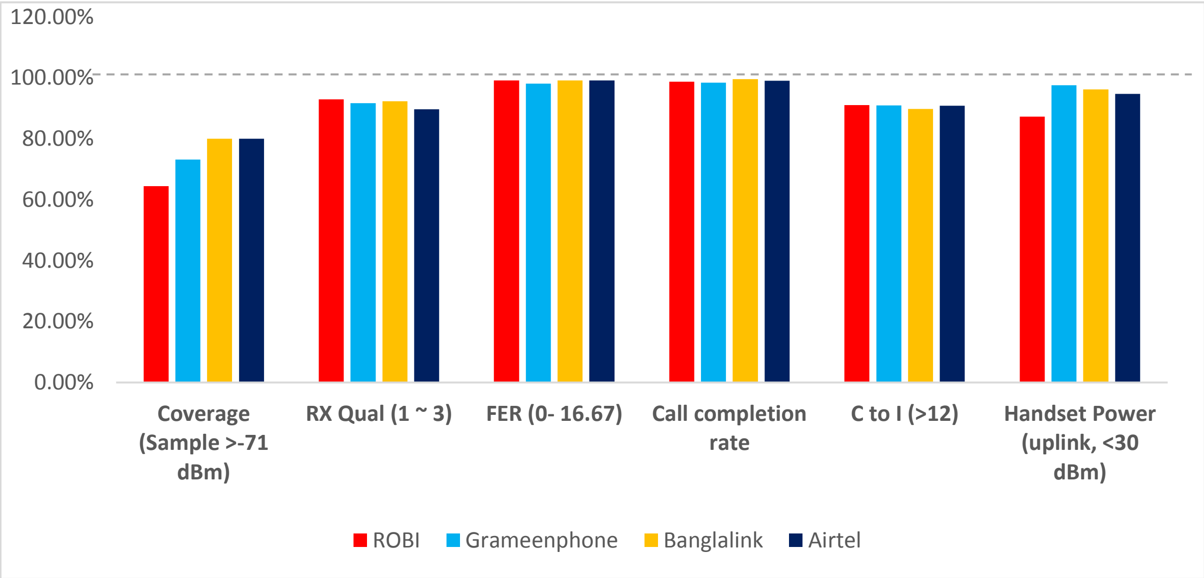


Fig. 4.32: Combined results obtained from the benchmarking drive test data

The plots reveal that ROBI serves with poor RX Level compared to its competitors. They have less number of sites. They do not use high gain antenna in their network as well. As a result, their RX Level is poor. This fact is also reflected in Handset power dissipation scenario, where almost 13% of ROBI samples are coming from the cell edges, with an extremely low RX level environment, which in turn drives the handsets to dissipate more power to continue communication with the BTSs.

Despite the poor RX Level, RF condition of the ROBI network is good. One of the reasons behind this is an appropriate spectrum distribution (refer to Fig. 4.33):

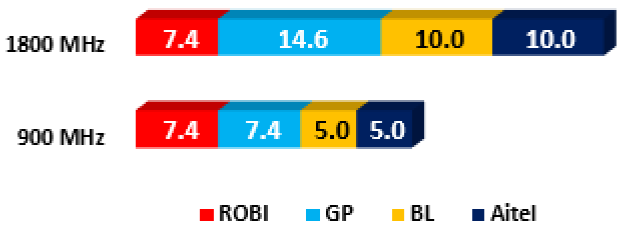


Fig. 4.33: Spectrum holding of the 4 mobile operators in Bangladesh

ROBI has the higher spectrum holding compared to subscriber distribution (with similar subscribers, higher spectrum than Banglalink). Therefore, their frequency re-use distance is high. In addition, absence of high gain antenna in the ROBI network keeps the interference level low, which results in a better C to I, better RX Qual and low FER. Their call drop rate is increased due to 3 call drops in Pallabi area. In Dhanmondi, call drop occurred not owing to radio condition rather some equipment problem was involved. ROBI holds the best call setup time among the 4 mobile operators, which represents sufficient resources to access the network.

Proposed solution for ROBI to improve the quality of their network:

1. Improve RX level through
    a. New site installation (preferred option)
    b. Use of antennas having different gain (high/ medium gain)
    c. Optimizing the existing BTS equipment or by installing improved BTS equipment.
2. In Sylhet sadar, the riverside coverage should be checked and improved by taking appropriate measures.
3. Solve blackspot and coverage hole by placing new sites or by properly tuning the existing sites with the nearby sites.
4. Cluster optimization can improve performance as we have noticed scattered bad samples distributed all over the selected area.

It can be said that, Grameenphone serves with moderate RX level although they have the highest number of sites. Grameenphone also uses medium gain antennas. As a result, their RX Level is moderate. Despite the lower RX level, they performed best in handset power dissipation. This reveals the fact that, even having poor RX level, if the path loss is low (which can be achieved by densifying the site positions) handset power dissipation can be made low.

Grameenphone suffers in call drop rate due to 5 call drops in Pallabi area because of radio problems in one location. Grameenphone has the highest spectrum resources, but they also have the highest subscriber base. Therefore, their frequency re-use distance is low compared to ROBI. They have good level of RX Qual, FER and C to I samples in the benchmarking by drive test. Grameenphone has the 2nd best call setup time among the 4 mobile operators, which represents sufficient resources to access the network.

The proposed solution for Grameenphone to improve the quality of their network are as follows:

1. Improve the RX level by using antennas with different gains (high/ medium gain)
2. In Sylhet sadar, the riverside coverage should be checked and improved by taking appropriate measures.
3. Cluster optimization can improve the performance as we have observed scattered bad samples distributed all over area (especially in Pallabi area)

Banglalink serves with the best RX level among the 4 mobile operators. Despite having lower number of sites than Grameenphone and ROBI, they have good coverage owing to their use of high gain antennas. Banglalink has the best FER performance and the best call drop rate, which reflect their network is of good quality network as well. In handset power dissipation, they are 2nd in rank. RX Qual performance of Banglalink is better than Grameenphone and Airtel. Banglalink requires almost 1 second more to establish a call, which reflects the need of parameter optimization on their part.

The proposed solution for Banglalink to improve their network performance are as follows:

1. Improve the RX Qual and C to I ratio through using antennas having different gains (high/ medium gain).
2. In Sylhet sadar, the riverside coverage should be checked and improved by taking appropriate measures.

3. Solve blackspot and coverage holes through placing new sites or by appropriately tuning with existing sites nearby.
4. Cluster optimization is needed as it has been observed that bad samples are distributed all over the selected area in a scattered fashion.
5. To reduce call setup time, parameter optimization and allocation of sufficient resources in the network access end are needed.

Airtel is a new comer in the telecom market, primarily they hold the license for 1800 MHz frequency band only. Therefore, they have built their network in city area more carefully so that their coverage can penetrate even with 1800 band. Later, they got 900 MHz license and deployed 900 which gave them extra mileage. Same thing is reflected in benchmarking statistics; with the lowest number of sites, they are almost number 1 (jointly with Banglalink) in the RX Level.

Airtel quality is also good in terms of FER, C to I ratio and call drop rate. Their RX Qual is poor, one of the reasons is that they have the 900 E-GSM band. Some part of it interferes with the CDMA and it also encounters external interference (Ref. to Fig. 4.34 below):

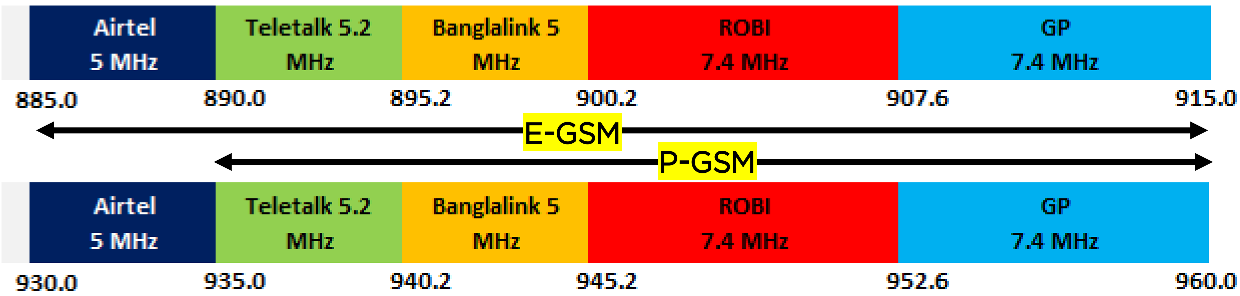


Fig. 4.34: The 900 MHz spectrum scenario in Bangladesh

Airtel is the last among the 4 mobile operators in call setup time, which represents insufficient resources on their part to access the network.

The proposed solution for Airtel to improve their network performance are given below.

1. Improve the RX level by installing new sites.
2. In Sylhet sadar, the riverside coverage should be checked and appropriate measures should be taken to improve the network performance.
3. Solve blackspot and coverage holes through placing new site or proper tuning of existing sites nearby. Especially, they need to consider whole area optimization for Gulshan and Dhanmondi.
4. Cluster optimization is required as it has been observed that bad samples are distributed all over the selected area in a scattered manner.
5. Parameter optimization and allocation of sufficient resources in network access end to reduce call setup time is required.

The results of the benchmarking drive test data were processed, analyzed and discussed in this chapter. The next chapter concludes the summary of the findings and suggests some recommendations for future work.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The results of the benchmarking drive test data were compared and discussed in the previous chapter. This chapter concludes the results and suggests some extensions to the current work that may be undertaken in future.

5.1 Conclusions

In this thesis, benchmarking of the major mobile networks of Bangladesh has been discussed. QoS terms are explained as per ITU definition, and its scope in telecommunication has been presented. Service quality standardization by BTRC has also been presented. QoS regulation has been discussed country-wise to have an idea about QoS standardization in different countries.

KPI's are explained in detail. Coverage KPI (RX Level) and quality KPI (RX Qual, FER, Carrier to Interference ratio, call drop rate, call setup time etc) and relevant calculation methods have been shown. Basic causes for KPI degradation are also discussed. In order to understand wireless signal propagation and path loss, basic idea on clutter, terrain, impact of site density, subscriber count etc are also presented.

Benchmarking methods are discussed in details. Comparison between drive test and other methods are also given. Drive test setup and procedure are explained.

In the benchmarking area (5 thana, namely- Comilla sadar, Dhanmondi, Gulshan, Pallabi, and Sylhet sadar), drive test was performed for the 4 mobile network simultaneously. For coverage KPI, idle mode log was collected while dedicated mode log was collected for quality KPIs. Then the log files were processed through analyzer tool to obtain necessary result.

A detail discussion has been presented with the KPI scenario. Clutter and terrain view of each area and expected KPI level is mentioned along with the site count. Actual result of benchmarking drive test was shown, problem areas were identified, and possible remedial measures were recommended to solve the network problems.

It has been found that, ROBI has the quickest call setup time along with the best performance in the RX Qual and carrier to interference ratio. However, the coverage performance is poor, link budget is not balanced- improvement of these parameters are required by ROBI.

Grameenphone has the most balanced link budget, it has performed up to the standard level in all the other parameters though not performed as the best in any of the sectors. Some optimization is required for Grameenphone, as well as spot coverage problems need to be solved.

Banglalink has the best RX level, best Frame Erasure Rate, and the best call drop rate. Banglalink needs to reduce the interference level by improving the carrier to interference ratio and to reduce call setup time as well.

Being last entrant in the mobile market, Airtel has performed pretty well in the benchmarking drive test. Airtel must have to look at the call setup time to improve it. Another necessary action from Airtel is required to improve the interference scenario, which will eventually result in better performance in the RX Qual and carrier to interference ratio.

5.2 Recommendations for Future Work

In this dissertation, we have performed benchmarking in some selected areas, presented the results and recommend possible solutions. However, the proposed solutions are not implemented yet. We cannot check the improvement of the actions until the mobile operators implement the solutions and further drive tests are conducted and subsequent analysis are carried out. In future, more intensive data may be collected and analyzed for providing more specific recommendations to solve each single problem. Furthermore, the following scopes were not covered in this work, which can be undertaken in future:

Pre and Post Benchmarking: Impact of the suggested solutions cannot be checked in the current work as they have not been implemented yet. The benchmarking can be done in collaboration with the mobile operators, and then solutions can be recommended and implemented after identifying the network issues. Its impact could then be checked afterwards. In that case, 2 benchmarking drive tests will be required, one to check the scenario first (similar to the case as studied in the present work), and another after taking action for checking the improvement.

Data Benchmarking: QoS of the mobile data connection was not covered in the scope of the current work. Mobile data is heavily dependent on local tower (serving cell) loading and on the number of simultaneous users, as data capacity is shared among various users. For data benchmarking, ‘busy hour for data’ for all the operators need to be identified first; then data benchmarking drive test can be performed.

KPI Comparison between Benchmarking Drive Test and NMS Statistics: This would be an interesting task to compare benchmarking output with NMS statistics output. It is very much possible that NMS statistics can give similar, dissimilar or even completely opposite KPI scenario compared to the benchmarking test results. Together, these two KPI sources may provide a complete and comprehensive network scenario in a specific area.

Benchmarking in Rural Areas: In rural areas, there are no sufficient road to perform the benchmarking drive test, hence researchers may need to perform the walk test for obtaining benchmarking test data. Sample size should be higher in number, because lack of roads will result in insufficient samples to decide on the network condition.

Benchmarking in highway, railway or waterway: The ultimate goal of communication is mobility- to communicate from anywhere with anyone at any time. It is important to check the mobility scenario in highways, railways or waterways where vehicles usually move fast. Maintaining the KPI in railway or waterway is another challenge to the mobile operators, as the scenarios in these cases are quite different from those of the densely populated area.

Radiation Measurement: To provide coverage in dense area, more number of sites are required. Increasing number of site in locality increases the chance of radiation. Higher radiation may cause health hazard. Radiation measurement of the mobile network can be a good option as it has two-fold benefit. First benefit is, if the radiation level is high the operator will be bound to control the radiation. Secondly, exact measurement of radiation (which should be much lower than safe radiation threshold) from independent source will make people convinced about the actual radiation scenario and end to some anxiety due to radiation. SAR value measurement (Radiation from the handset- usually measured in laboratory condition) is another option to work with.

This chapter has highlighted the conclusions of the current work and recommended some suggestions for future work. References that have been used in the current dissertation are included next.

REFERENCES

[1] Thomas J.O. Afullo, “Quality Of Service in Telecommunications- Customer‘s Perspective”, published in AFRICON, 2004. 7th AFRICON Conference in Africa (Volume:1) pp 101 - 106 IEEE.

[2] Oliver Nipp, Marc Kuhn, Armin Wittneben, and Thomas Schweinhuber, “Speech Quality Evaluation and Benchmarking in Cellular Mobile” presented in IEEE Mobile and Wireless Communications Summit, 2007.

[3] SwissQual specification: Retrieved on 5th October, 2016 from http://www.swissqual.com/en/products/benchmarking/benchmarker-2-go/#

[4] Actix analyzer: Retrieved on February 29, 2016 from http://www.actix.com/analyzer.html

[5] Eberspächer Jörg Eberspächer, Vögel Hans-Joerg Vögel, Bettstetter Christian Bettstetter, Hartmann Christian Hartmann “GSM - Architecture, Protocols and Services John Wiley & sons, 2008, 3rd Edition, pp 43.

[6] Rec. ITU-T E.800 (09/2008) ”Terms and definitions related to the quality of telecommunication services”,2008, pp 1-3

[7] Rec. ITU-T E.800 (08/1994) ”Terms and definitions related to the quality of service and network performance including dependability”,1994, pp 2

[8] BTRC ” Interim Directives on Quality of Service (OoS) for Mobile Operators”,2014, pp 2-3

[9] Federal Republic of Nigeria Official Gazette ” Nigerian Communications Act (No. 19 of 2003), Quality of Service Regulations, 2012”,2012, section B101

[10] Halonen Timo (Editor), Romero Javier (Editor), Melero Juan (Editor) ” GSM, GPRS and EDGE Performance: Evolution Towards 3G/UMTS”,2003, 2nd Edition, page 161

[11] Eberspächer Jörg Eberspächer, Vögel Hans-Joerg Vögel, Bettstetter Christian Bettstetter, Hartmann Christian Hartmann “GSM - Architecture, Protocols and Services”, John Wiley & sons, 2008, 3rd Edition, pp 24-25.

[12] Mishra Ajay R. (Editor) “Advanced Cellular Network Planning and Optimisation: 2G/2.5G/3G... Evolution to 4G”, John Wiley & sons, 2007,pp 76.

[13] Telecom Regulatory Authority of India “Technical Paper on Call Drop in Cellular Networks”, 2015, pp 12

[14] ETSI EG 202 057-3 V1.1.1 (2005-04) “Speech Processing, Transmission and Quality Aspects (STQ); User related QoS parameter definitions and measurements; Part 3: QoS parameters specific to Public Land Mobile Networks (PLMN)”, 2005, pp 13-16

[15] GSM 02.67 version 5.0.1: July 1996 ” Digital cellular telecommunications system (Phase 2+); enhanced Multi-Level Precedence and Pre-emption service (eMLPP) - Stage 1 (GSM 02.67)”,1996, pp 9-10

[16] Black Bruce A., DiPiazza Philip S., Ferguson Bruce A., Voltmer David R., Berry Frederick C., “Introduction to Wireless Systems”, Pearson Education Inc. (Prentice Hall), 2008, 1st Edition, pp 30.

[17] Molisch Andreas F. “Wireless Communications”, Pearson Education Inc. (Prentice Hall), 2010, 2nd Edition, pp 127-144.

[18] Mishra Ajay R., “Fundamentals of Cellular Network Planning and Optimisation:2G/2.5G/3G…Evolution to 4G” John Wiley & Sons, 2004. pp. 263-264

[19] Mishra Ajay R. (Editor) “Advanced Cellular Network Planning and Optimisation: 2G/2.5G/3G...Evolution to 4G” John Wiley & Sons, 2006. pp. 107-108