Performance Analysis of Channel Condition & Channel Model of LTE in various Transmission Mode in Bangladesh

A thesis submitted to the Department of Electronic & Communication Engineering of East West University in partial fulfillment of the requirements for the Degree of

Masters of Science in Telecommunication Engineering

By

Rashedul Haque Chowdhury

Moutosi Rahman

Under the Supervision of

Mr. Mustafa M. Hussain

Assistant Professor

Department of Electronic & Communication Engineering

East West University

A/2,Jahurul Islam Avenue, Jahurul Islam City, Aftabnagar, Dhaka-1212

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Declaration :

It is hereby declared that, this thesis titled **"Performance Analysis of Channel Condition & Channel Model of LTE in various Transmission Mode in Bangladesh"** has been accepted in partial fulfillment for the requirement of the degree of **Masters of Science in Telecommunication Engineering** on 23rd August..

Supervisor:

Mr. Mustafa M.Hussain

Assistant Professor

Department of Electronic & Communication Engineering

EWU,Dhaka-1212,Bangladesh

Students:

Rashedul Haque Chowdhury

ID: 2014-02-98-007

Moutosi Rahman

ID: 2014-02-98-013

Dedicated

- To our Parents

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Abstract :

Long Term Evaluation(LTE) is an emerging 4G wireless technology. Multiple-Input Multiple-Output (MIMO) systems are a primary enabler of the high data rate south to be achieved by LTE .

In LTE /LTE -advanced standards, the physical layer is mapped into multiple transmission modes(TM) and each TM should be dynamically selected depending on the time-varying MIMO channel. Besides the single antenna SISO transmission (TM1), multi element antenna (MIMO) technology such as Open Loop Spatial Multiplexing (OLSM) and Close Loop Spatial Multiplexing (CLSM) transmission are also specified by the 3GPP standard for LTE downlink transmission. According to LTE Release 9 there are 7 MIMO configurations from mode 2 to 8. An LTE base station is expected to select and switch among these transmission modes based on channel quality feedback like Channel Quality Indicator (CQI) . In this paper we have investigated the effect of different channel conditions at different SNR levels on the performance achieved through transmission mode 1 to 4 . The simulation output shows that the mode 3 and 4 which are open loop and close loop spatial multiplexing respectively using 4 transmitting antenna outperforms all other mode in terms of high throughput at very reasonable BLER.

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Chapter - 1

Introduction :

1.1 : LTE Overview:

LTE, short for Long Term Evolution, is considered by many to be the obvious successor to the current generation of UMTS 3G technology, which is based upon WCDMA, HSDPA, HSUPA, and HSPA. LTE (Long Term Evolution) is a global success with 635 million subscriptions by Q1 2015[1] LTE is not a replacement for UMTS in the way that UMTS was a replacement for GSM, but rather an update to the UMTS technology that will enable it to provide significantly faster data rates for both uploading and downloading. Verizon Wireless was the first U.S. carrier to widely deploy LTE, though MetroPCS and AT&T have also done so, and Sprint and T-Mobile USA both have plans for LTE. In fact, Sprint is phasing out its WiMAX network in favor of LTE. Verizon Wireless and AT&T currently have incompatible LTE networks, even though they both make use of 700MHz spectrum. AT&T and Verizon Wireless LTE customers often see download speeds that exceed 15Mbps, and upload speeds in the 10Mbps range.

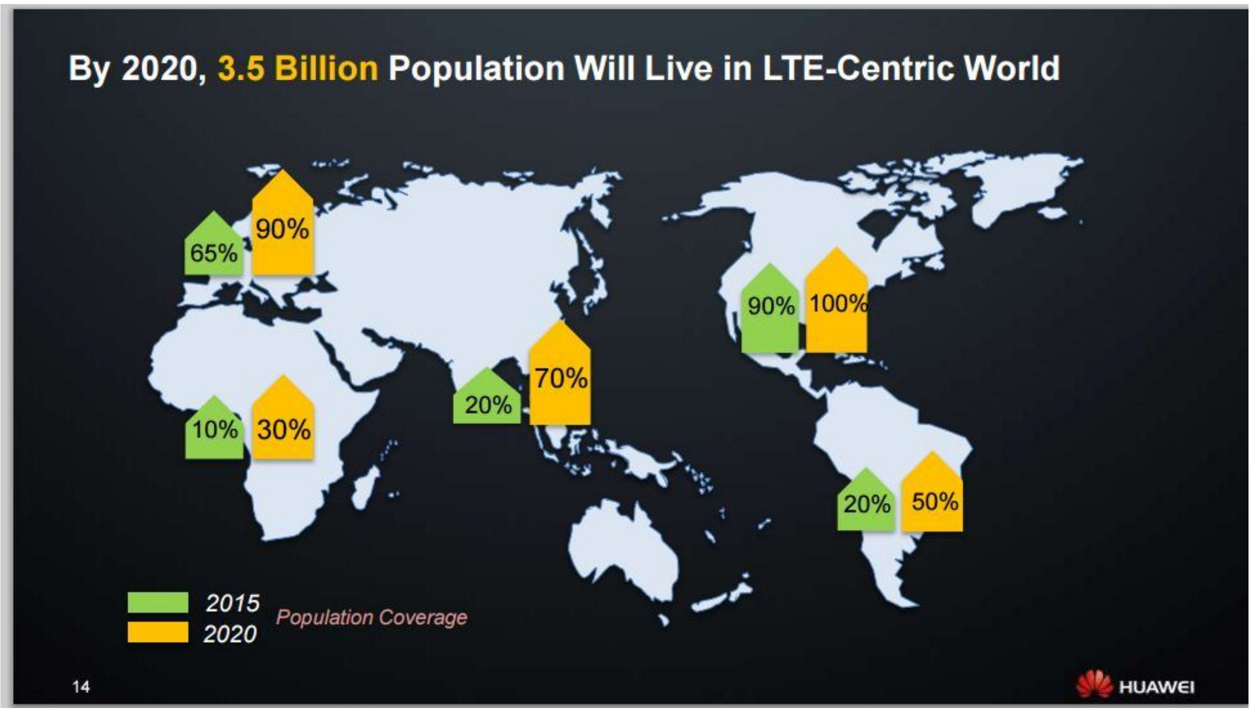

Figure 1: LTE Coverage

Standards development for LTE continued with 3GPP Release 9 (Rel-9), which was functionally frozen in December 2009. 3GPP Rel-9 focuses on enhancements to HSPA+ and LTE while Rel-10 focuses on the next generation of LTE for the International Telecommunication Union's (ITU) IMT-Advanced requirements and both were developed nearly simultaneously by 3GPP standards working groups. Several milestones have been achieved by vendors in recent years for both Rel-9 and Rel-10. Most significant was the final ratification by the ITU of LTE-Advanced (Rel-10) as IMT-Advanced in November 2010.

The first commercial LTE networks were launched by Telia Sonera in Norway and Sweden in December 2009; as of July 2015, there were 442 commercial LTE networks of 142 countries are in various stages of commercial service.

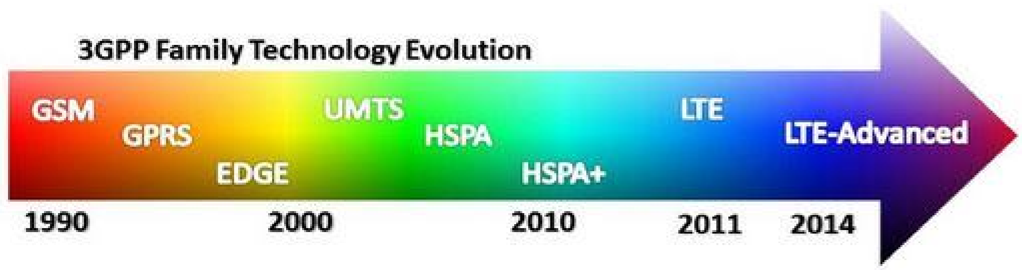

Figure 2: 3GPP Family Technology Evolution

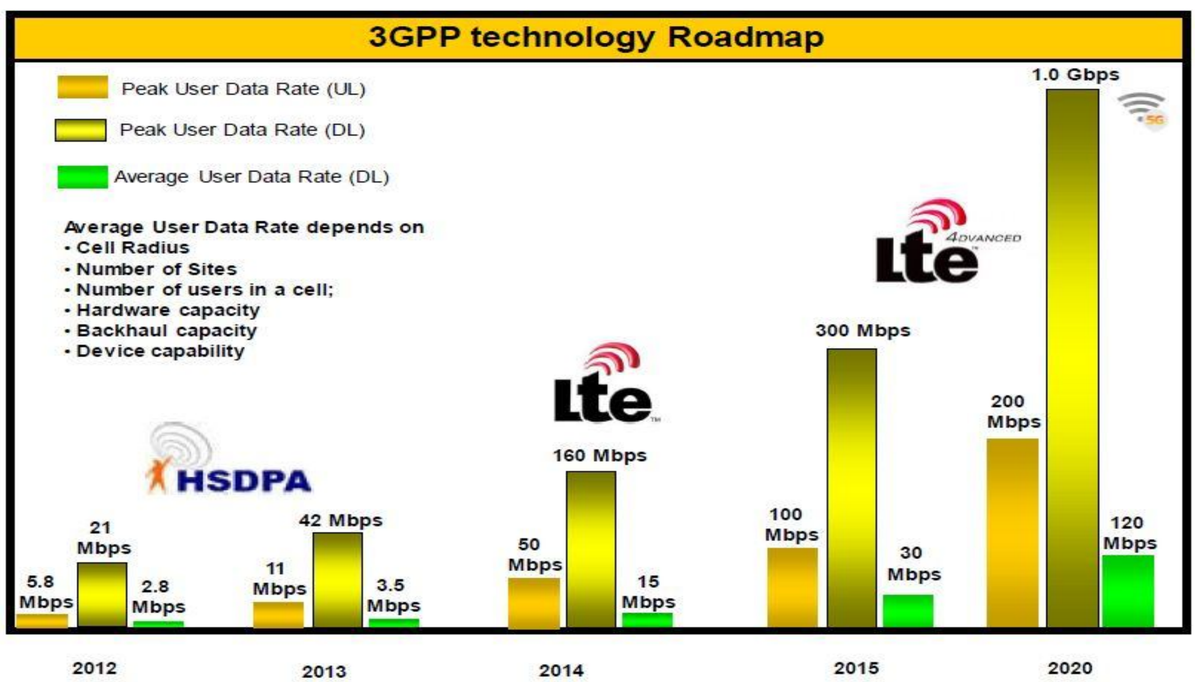

Figure 3: 3GPP Family Technology Roadmap

For many years now, a true world cellular standard has been one of the industry's goals. GSM dominated 2G technologies but there was still fragmentation with CDMA and TDMA as well as iDEN. With the move to 3G, nearly all TDMA operators migrated to the 3GPP technology path. Yet the historical divide remained between GSM and CDMA. It is with the next step of technology evolution that the opportunity has arisen for a global standard technology. Many operators have converged on the technology they believe will offer them and their customers the most benefits. That technology is Long Term Evolution. Most leading operators, device and infrastructure manufacturers, as well as content providers support LTE as the mobile technology of the future. Operators, including leading GSM-HSPA and CDMA EV-DO operators as well as newly licensed and WiMAX operators, are making strategic, long-term commitments to LTE networks. *All roads lead to LTE.*

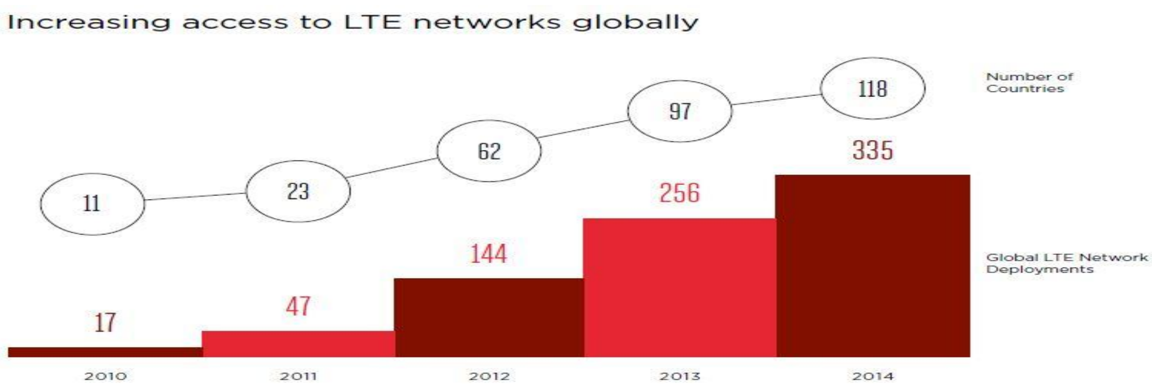

Figure 4: Increase of LTE Network

In June of 2008, the Next Generation Mobile Networks Alliance (NGMN) selected LTE as the first technology that matched its requirements successfully. 4G Americas, GSMA, UMTS Forum, and other global organizations have reiterated their support of the 3GPP evolution to LTE. Additionally, the LSTI Trial Initiative has provided support through early co-development and testing of the entire ecosystem from chipset, device and infrastructure vendors.

LTE capabilities include:

- Downlink peak data rates up to 326 Mbps with 20 MHz bandwidth
- Uplink peak data rates up to 86.4 Mbps with 20 MHz bandwidth
- Operation in both TDD and FDD modes
- Scalable bandwidth up to 20 MHz, covering 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz in the study phase
- Increased spectral efficiency over Release 6 HSPA by two to four times
- Reduced latency, up to 10 milliseconds (ms) round-trip times between user equipment and the base station, and to less than 100 ms transition times from inactive to active

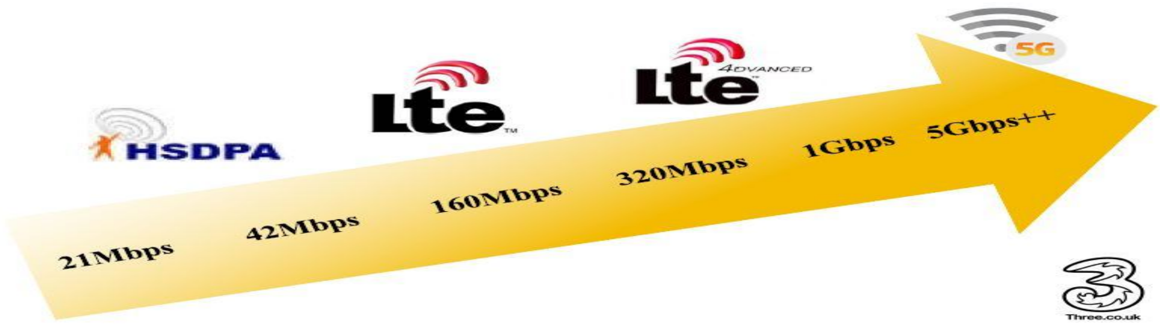

Figure 5 : Advancement of LTE

In This Paper we have investigated the effect of channels as CQI on the performance of LTE Release 9 through LTE link level simulator developed by the Institute of Communications and Radio Frequency Engineering, Vienna University of Technology[4].

This paper is made for Bangladeshi Environment, so that it can be used as a helping manual. That's why transmission mode 1-4 are simulated in high multipath fading environment and the superiority of the open loop and close loop spatial multiplexing were demonstrated.

1.2: Thesis Motivation:

In 8th September 2013,Bangladesh Government had sold 35Mhz Frequency Band under 2.1GHz Frequency Band to 5 Mobile Operators. Meanwhile South Asian Telecom Regulatory Council announced in May 2013 that Bangladesh adopted the APT700 FDD band plan[2].According to Bangladesh Telecommunication Regulatory Authority (BTRC) officials: The telecom regulator will allow the cellular phone operators to run LTE (Long Term Evolution) service along with the 3G or third generation cellular phone license[3].BTRC will conduct auction of unused 450MHz frequency (including 700Mhz,1800MHz & 2.1GHz) for LTE later part of this year.

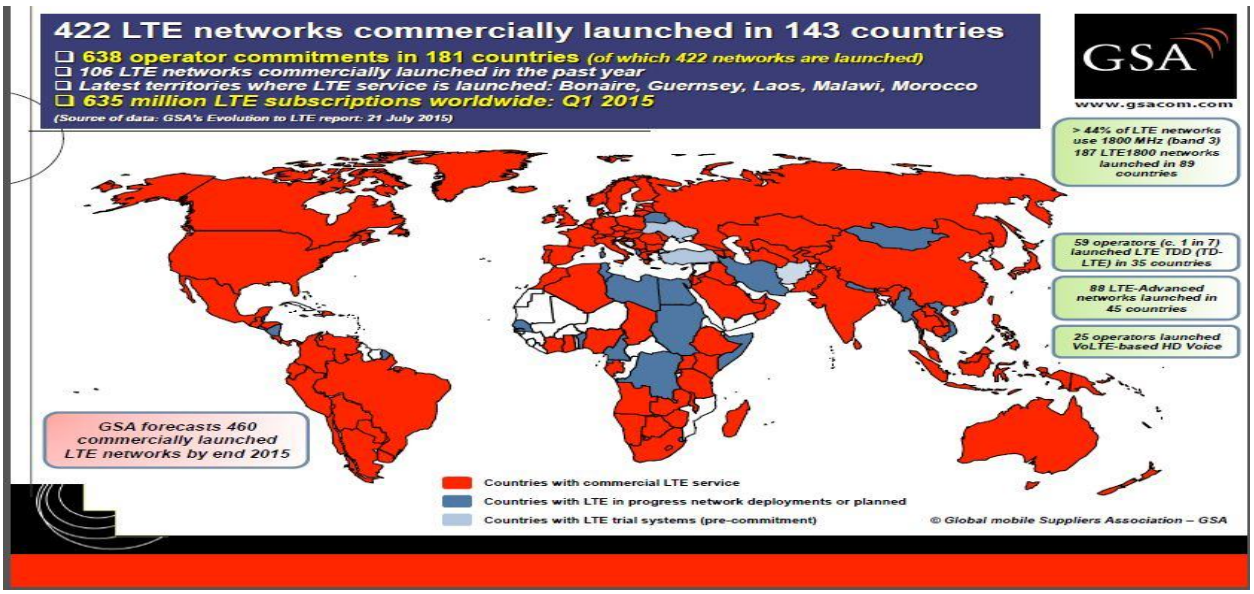

Figure 6: LTE Commercial Network

Internet Subscribers in Bangladesh September, 2013

The total number of Internet Subscribers has reached **36533.572 thousand** at the end of **September, 2013**.

The Internet subscribers are shown below:

Category	Subscribers
Mobile Internet	34995.983
ISP + PSTN	1223.12
WiMAX	314.469
Total	**36533.572**

Figure 7: Internet Subscriber of Bangladesh in September 2013

Internet Subscribers in Bangladesh June 2015

The total number of Internet Subscribers has reached **48.347 million** at the end of **June, 2015**.

The Internet subscribers are shown below:

OPERATOR	SUBSCRIBER
Mobile Internet	46.899
WiMAX	0.180
ISP + PSTN	1.268
Total	**48.347**

Figure 8: Internet Subscribers of Bangladesh in June 2015

From Figure 7 & 8 it can easily observed that the number of Mobile Internet Subscribers are increased in a huge amount after the launching of 3G.And it is expected to be triple after the launching of LTE in Bangladesh.

1.3: Thesis Organization :

The paper is organized in following section. In section two we have presented the brief over view of LTE transmission modes. In Release 8 , Long Term Evaluation(LTE) [5] was standardized by 3GPP as the successor of the Universal Mobile Telecommunication System (UMTS). The targets for downlink and uplink peak data rate requirements were set to 100Mbits/sec and 50Mbits/sec, respectively when operating in a 20MHz spectrum allocation [6].As few of telecom operators have bought 5MHz Bandwidth in 3G,Channel evolution in 5MHz Bandwidth is also performed.

First performance evaluations show that the throughput of the LTE physical layer and MIMO enhanced WCDMA [7] is approximately the same [8-12] . However, LTE has several other benefits of which the most important are explained in the following.

The LTE downlink transmission scheme is based on Orthogonal Frequency Division Multiple Access (OFDMA) which converts the wide-band frequency selective channel into a set of many flat fading sub-channels. The flat fading sub-channels have the advantage that even in the case of MIMO transmission – optimum receivers can be implemented with reasonable complexity , in contrast to WCDMA systems .OFDMA additionally allows for frequency domain scheduling , typically trying to assign only "good" sub-channels to the individual users . This offers large throughput gains in the downlink due to multi-user diversity [13,14].

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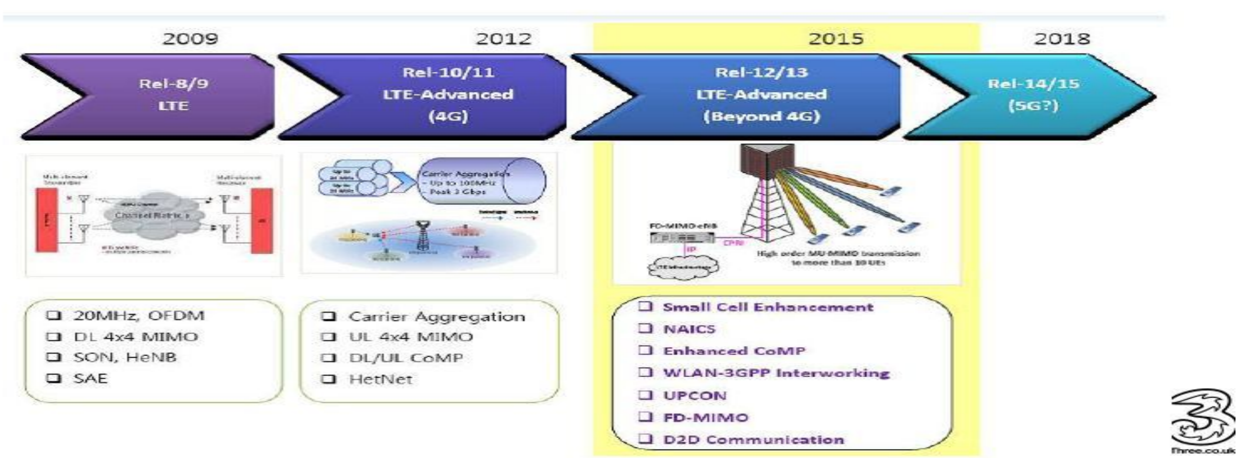


Figure 9: LTE Advancement

Chapter - 2

LTE Uplink & Downlink Channel:

2.1: LTE Uplink & Downlink Physical Channel:

LTE defines a number of channels in the downlink as well as the uplink. Table 1 and Table 2 provide an overview.

Downlink		
LTE downlink physical channels		
Name	**Purpose**	**Comment**
PDSCH	Physical downlink shared channel	user data
PDCCH	Physical downlink control channel	control information
PCFICH	Physical control format indicator channel	indicates format of PDCCH
PHICH	Physical hybrid ARQ indicator channel	ACK/NACK for uplink data
PBCH	Physical broadcast channel	information during cell search
LTE downlink physical signals		
	Primary and secondary synchronization signal	information during cell search
RS	Reference signals	enables channel estimation

Table 1: Overview of LTE downlink physical channels and signals

Uplink		
LTE uplink physical channels		
Name	**Purpose**	**Comment**
PUSCH	Physical downlink shared channel	user data
PUCCH	Physical uplink control channel	control information
PRACH	Physical random access channel	preamble transmission
LTE uplink physical signals		
DRS	Demodulation reference signal	channel estimation and demodulation
SRS	Sounding reference signal	uplink channel quality evaluation

Table 2: Overview of LTE uplink physical channels and signals

2.2: Downlink Reference Signal :

The downlink reference signal structure is important for channel estimation. It defines the principle signal structure for 1-antenna, 2-antenna, and 4-antenna transmission. Specific pre-defined resource elements (indicated by R0-3) in the time-frequency domain carry the cell-specific reference signal sequence. One resource element represents the combination of one OFDM symbol in the time domain and one subcarrier in the frequency domain. Figure 3 shows the principle of the downlink reference signal structure for 1 antenna and 2 antenna transmission.

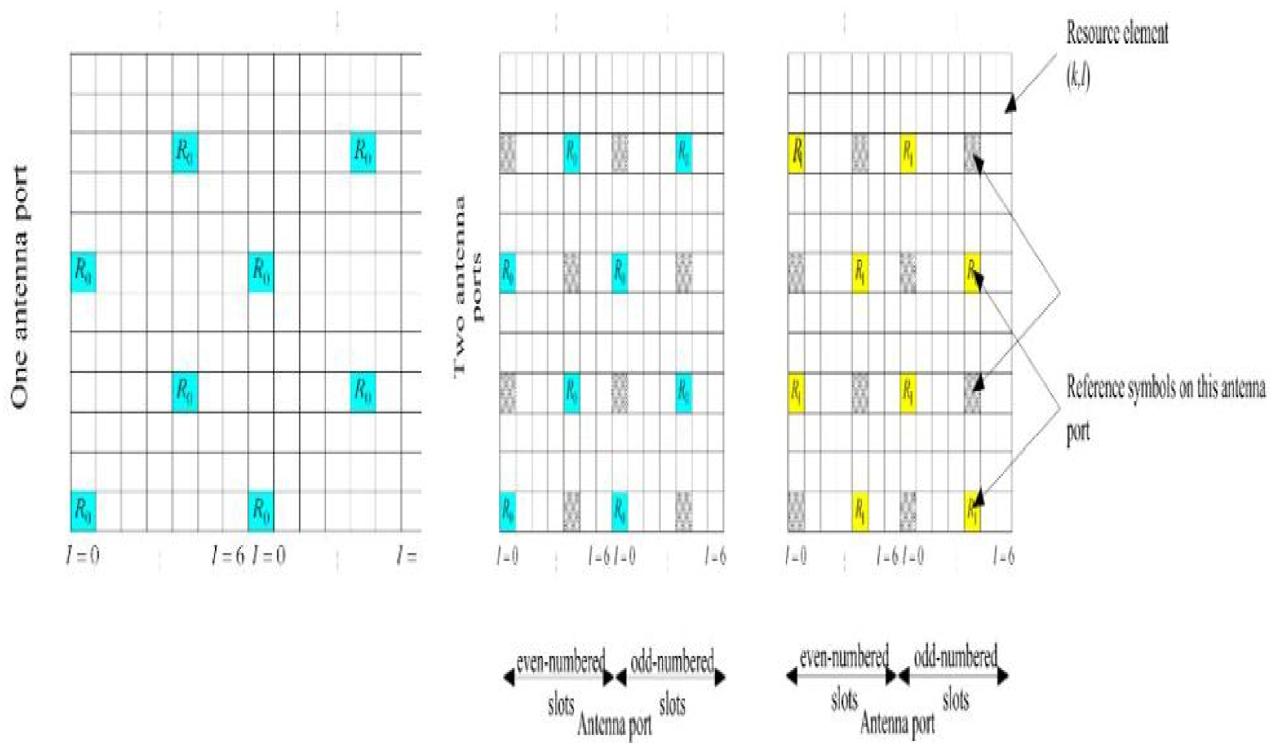


Figure 10: Distribution of the downlink reference signals in LTE

A different pattern is used for beam forming (see section 3.2.7). UE-specific reference signals are used here. These are needed because whenever beam forming is used, the physical downlink shared channel for each UE is sent with a different beam forming weighting. The UE-specific reference signals and the data on the PDSCH for a UE are transmitted with the same beam forming weighting.

LTE TDD UEs must (mandatory) support UE-specific reference signals, while it is optional for LTE FDD UEs. Beam forming is of particular interest for LTE TDD because the same frequency is used in the downlink and uplink.

In TM 8 also UE-specific reference signals (RS) are used. Since the same elements are used for both streams, the reference signals must be coded differently so that the UE can distinguish among them.

Chapter - 3

LTE Transmission Modes:

In the downlink, LTE uses technologies such as MIMO, transmit diversity or SISO, Beam forming etc are used to achieve high data rates. In the Release 9 specification [11], up to four antennas are defined in the base station and up to four antennas in the UE.

Transmission Modes in LTE Release 9		
Transmission Mode	**Description**	**Comment**
1	Single transmit antenna	Single antenna port; port0
2	Transmit diversity	2/4 antennas
3	Open loop spatial multiplexing with cyclic delay diversity(CDD)	2/4 antennas
4	Close loop spatial multiplexing	2/4 antennas
5	Multi-user MIMO	2/4 antennas
6	Close loop spatial multiplexing using a single transmission layer	1 layer (rank 1), 2/4 antennas
7	Beamforming	Single antenna port; port 5
8	Dule-layer beamforming	Dule-layer transmission, antenna ports 7 or 8

✓ TM 1 – Single transmit antenna

This mode uses only one transmit antenna.

✓ TM 2 – Transmit diversity:

It sends the same information via various antennas, whereby each antenna stream uses different coding and different frequency resources. This improves the signal-to-noise ratio and makes transmission more robust.

For two antennas, a frequency-based version of the Alamouti codes (space frequency block code, SFBC) is used, while for four antennas, a combination of SFBC and frequency switched transmit diversity (FSTD) is used

✓ TM 3 – Open loop spatial multiplexing with CDD:

This mode supports spatial multiplexing of two to four layers that are multiplexed to two to four antennas, respectively, in order to achieve higher data rates. It requires less UE feedback regarding the channel situation (no precoding matrix indicator is included), and is used when channel information is missing or when the channel rapidly changes, e.g. for UEs moving with high velocity.

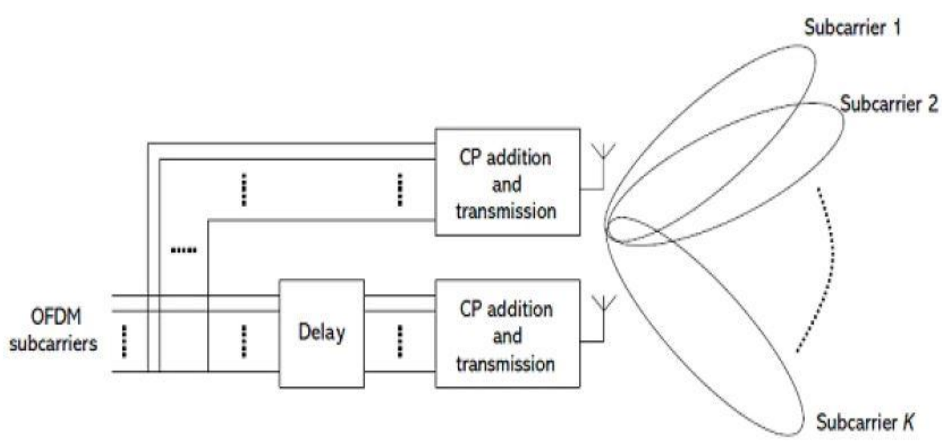


Figure 11: TM 3, Spatial multiplexing with CDD; the individual subcarriers are delayed artificially

✓ TM 4 – Closed loop spatial multiplexing:

This mode supports spatial multiplexing with up to four layers that are multiplexed to up to four antennas, respectively, in order to achieve higher data rates. To permit channel estimation at the receiver, the base station transmits cell-specific reference signals (RS), distributed over various resource elements (RE) and over various timeslots

Spatial multiplexing LTE		
Codebook index	Number of layers υ	
	1	2
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-

Table 3: Codebook indices for spatial multiplexing with two antennas, green background for two layers; yellow background for one layer or TM 6 [11]

✓ TM 5 – Multi-user MIMO:

It uses codebook-based closed loop spatial multiplexing, however one layer is dedicated for one UE.

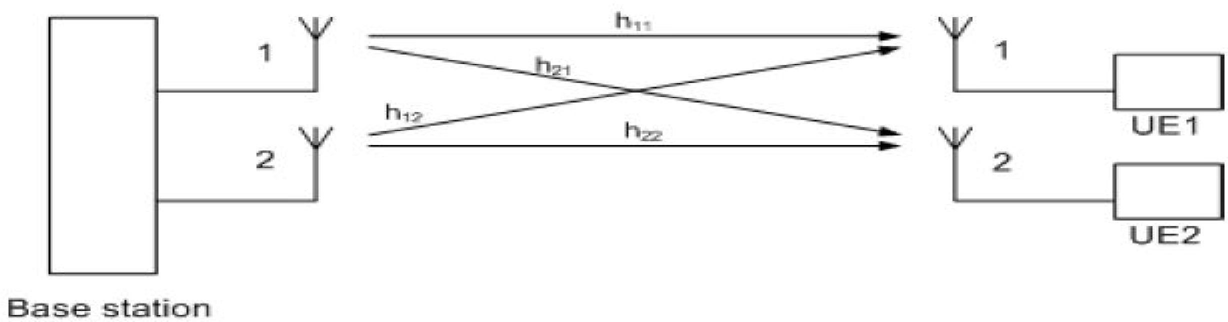


Figure 12 : TM 5: Multi-user MIMO; the two data streams are divided between two UEs

✓ TM 6 – Closed loop spatial multiplexing using a single transmission layer:

This mode is a special type of closed loop spatial multiplexing (TM 4). In contrast to TM 4, only one layer is used (corresponding to a rank of 1). The UE estimates the channel and sends the index of the most suitable precoding matrix back to the base station. The base station sends the precoded signal via all antenna ports. The codebooks from Table 4 are used, but only the 1-layer variants .

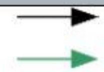
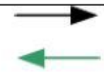
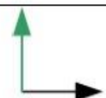
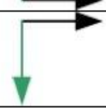
Weights for 1 Layer			
Codebook index	**Matrix**	**Weights**	**Phase**
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$		0°
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$		180°
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$		90°
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$		270°

Table 4 : Precoding/weighting for a 1-layer scenario using the codebook index (the phase column indicates the phase difference between the two antenna signals)

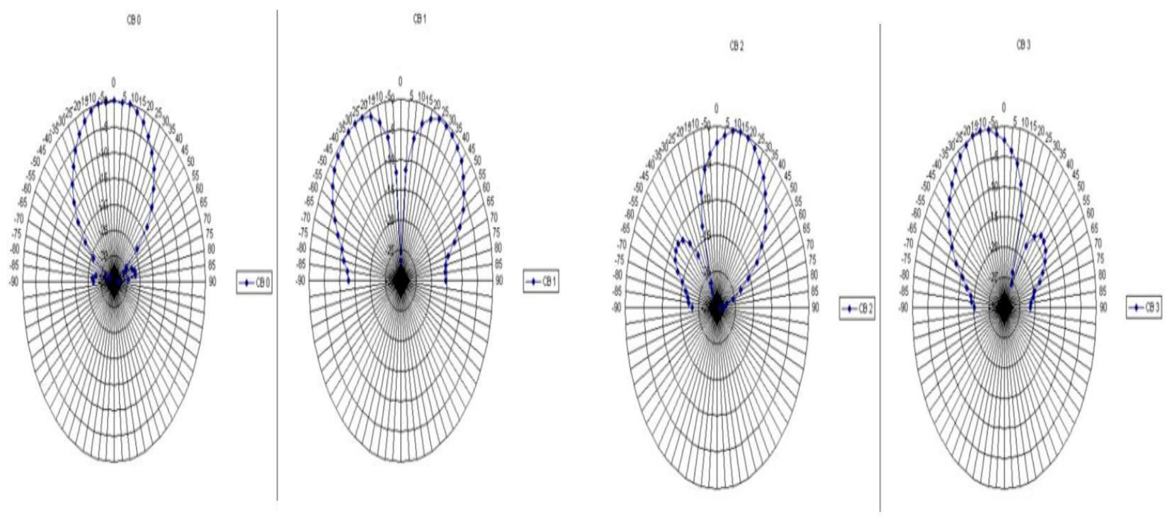


Figure 13: Schematic representation of TM 6 implicit beamforming for two antennas, codebook index 0…3

✓ TM 7 – Beamforming (antenna port 5):

This mode uses UE-specific reference signals (RS). Both the data and the RS are transmitted using the same antenna weightings. This transmission mode is also called "single antenna port; port 5". The transmission appears to be transmitted from a single "virtual" antenna port 5.

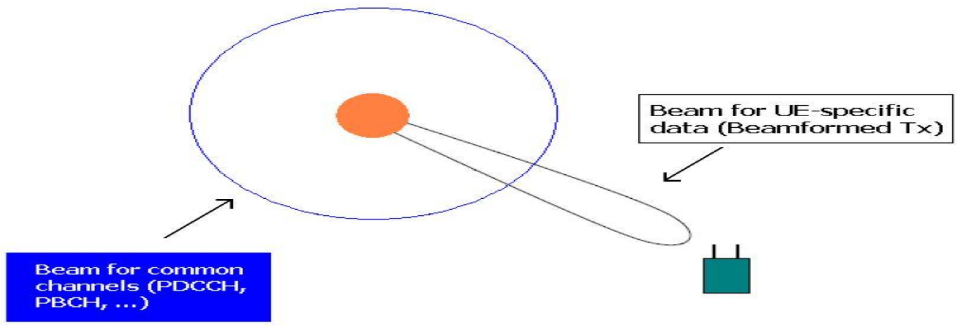


Figure 13.a: Beamforming in TM 7; use of UE-specific RS; the common channels use transmit diversity

✓ TM 8 – Dual layer beamforming (antenna ports 7 and 8)

As in TM 7, UE-specific reference signals (RS) are also used here. Since, as can be seen in Figure 14, the same elements are used, the reference signals must be coded differently so that the UE can distinguish among them.

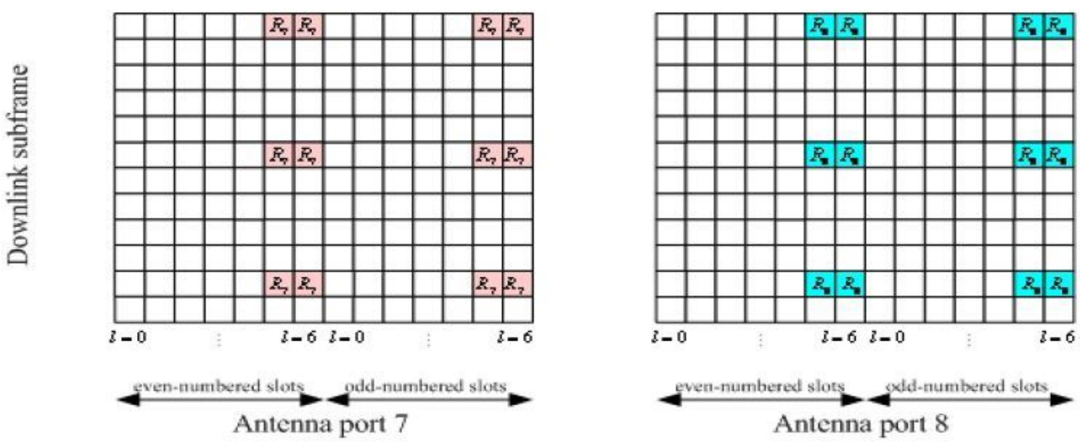


Figure 14: Distribution of reference signals for transmission mode 8 (antenna ports 7 and 8) [11]

Chapter - 4

LTE Channel Quality:

Channel Quality Indicator (CQI) is an indicator carrying the information on how good/bad the communication channel quality is. In LTE, there are 15 different CQI values ranging from 1 to 15 and mapping between CQI and modulation scheme, transport block size is defined as follows:

CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

Table 5 :4Bit CQI Table

Path Loss Model

The European Telecommunications Standards Institute (ETSI) has proposed several path loss models, depending upon various environments for LTE system [15]. These models assist in simulations based on channel models for wireless system evaluation. The various environments models specified by ETSI are discussed below:

Outdoor to Indoor and Pedestrian Test Environment

The outdoor to indoor and pedestrian test environment also consists of small cells with antennas transmitting at low power. The base stations are equipped with low height antennas and are normally placed outdoors. The mobile users can move without any restrictions indoor and outdoor.

Vehicular Test Environment

The vehicular test environment consists of large cells with antennas transmitting at high power. It is used while user needs minimal throughput during mobility

Chapter - 5

Simulation Results & Analysis:

In this paper, we have worked with transmission mode 1,2,3 & 4 at 5MHz & 20MHz Bandwidth.

5.1: Simulation Result:

In LTE we have seen the variation in Throughput & BER with the change of Transmission mode & CQI. Ideally it seems like the picture below :

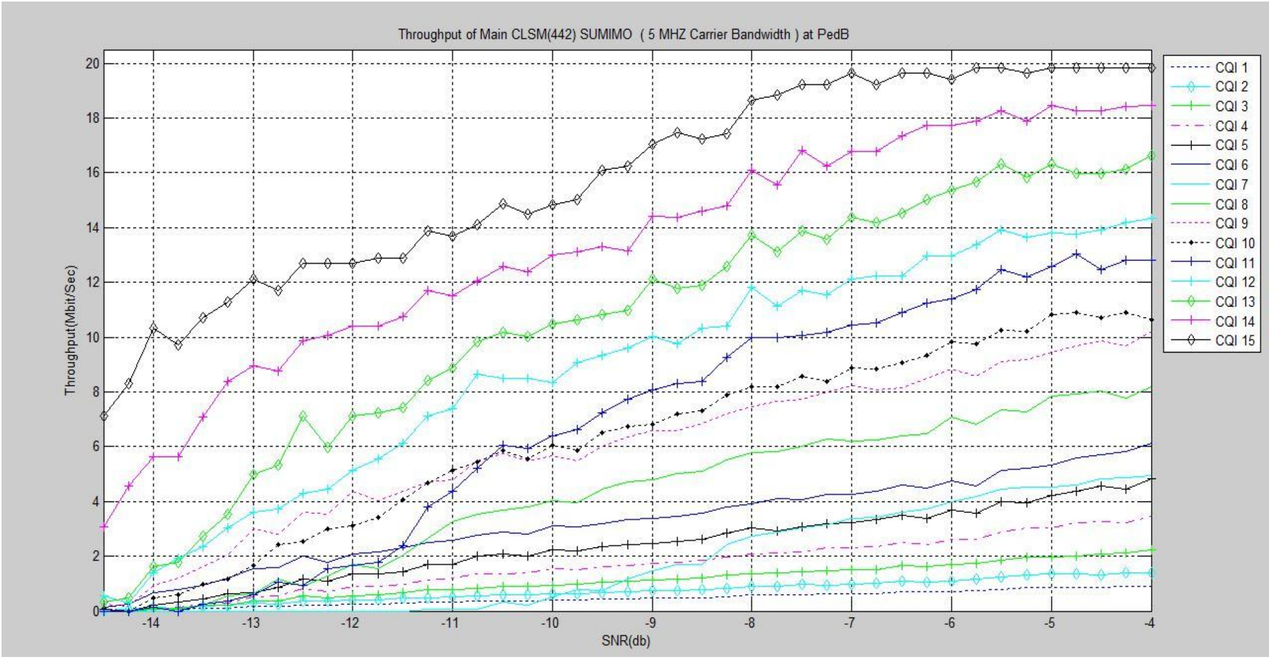


Figure 15 :Ideal variation in throughput with the change of CQI at PedB

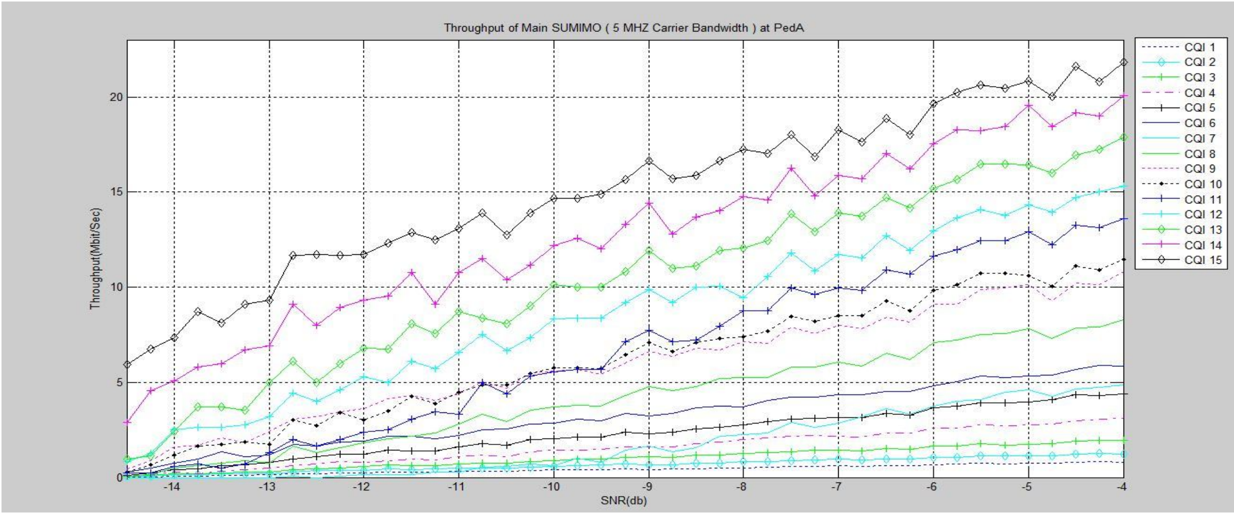


Figure 16 :Ideal variation in throughput with the change of CQI at PedA

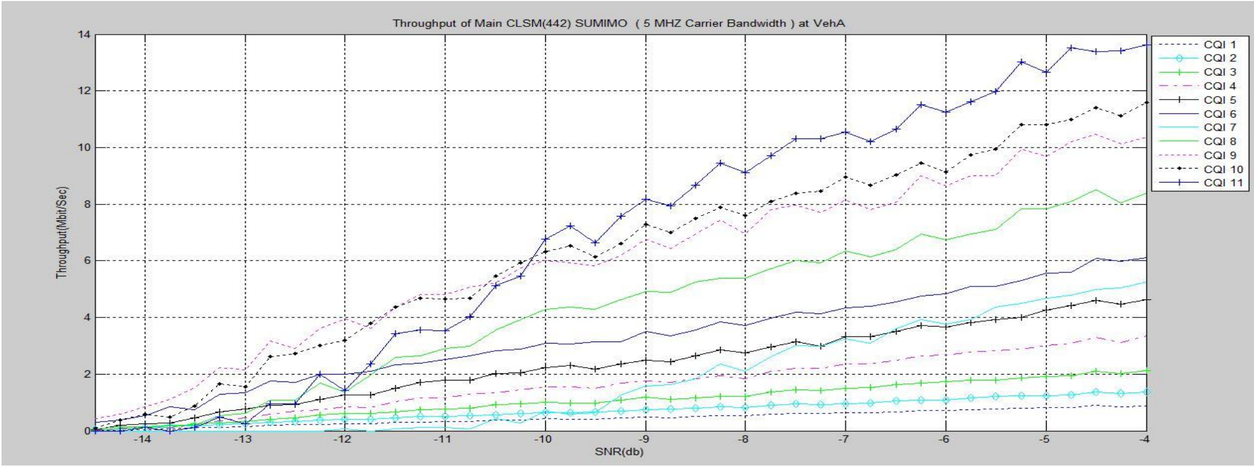


Figure 17 :Ideal variation in throughput with the change of CQI at VehA

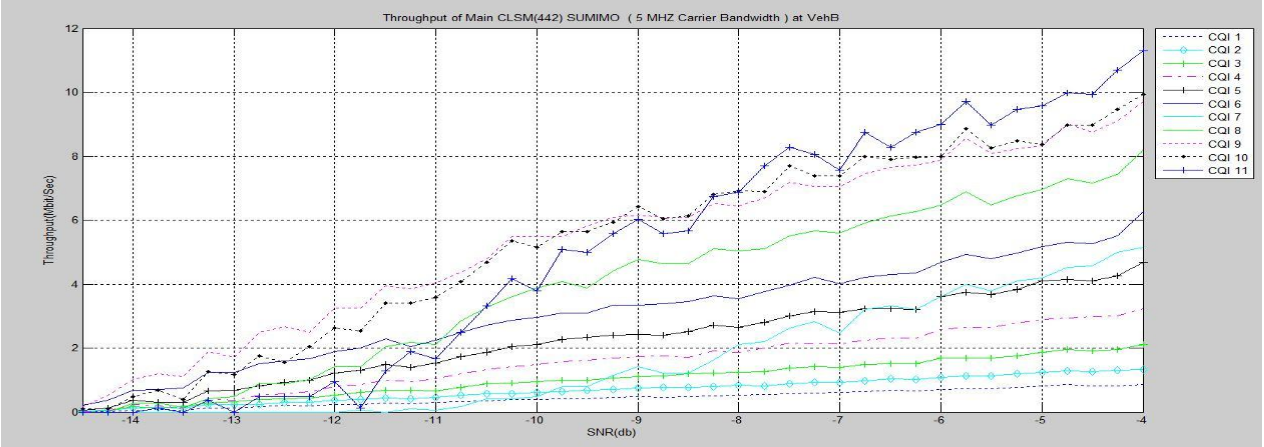


Figure 18 :Ideal variation in throughput with the change of CQI at VehB

But practically, the variation doesn't happen in this way.The throughput & BER varies differently for each types of transmission mode.every transmission mode follows a definite rate to vary the parameter (Throughput & BER).Here Transmission mode 1,2,3,4 are discussed.

We can observe the variaton rate through the table below:

CQI	Transmission Mode (Transmission mode,nTx,nRx)	Peak throughput (M bit/Sec) for Pedestrian & Vehicular Model	
		5 MHz Bandwidth	20 MHz Bandwidth
1	1	0.5	2.00
	221	0.5	1.90
	242	0.4	1.50
	342	1.0	3.80
	442	1.25	4.80
2	1	0.75	2.80
	221	0.90	3.50
	242	0.80	3.10
	342	1.5	5.50
	442	1.60	5.80
3	1	1.75	6.80
	221	1.75	6.80
	242	1.60	6.50
	342	2.60	9.60
	442	2.75	10.20
4	1	2.25	9.80
	221	2.25	9.75
	242	2.10	8.20
	342	4.20	15.75
	442	4.40	16.20

5	1	3.50	13.30
	221	3.40	13.00
	242	3.20	12.80
	342	6.5	25.75
	442	6.4	25.60
6	1	4.75	18.80
	221	4.75	18.80
	242	4.20	16.60
	342	8.20	32.40
	442	8.00	31.80
7	1	5.80	21.50
	221	5.80	21.50
	242	5.20	20.80
	342	10.50	41.90
	442	10.50	41.80
8	1	7.60	30.20
	221	7.60	30.20
	242	6.80	27.50
	342	13.80	52.50
	442	13.80	52.50
9	1	9.80	39.80
	221	9.30	38.50
	242	8.80	34.00
	342	17.00	66.80
	442	17.00	67.00
10	1	10.80	42.80
	221	10.20	41.00
	242	10.10	40.50

	342	19.50	76.50
	442	19.80	76.90
11	1	13.00	51.50
	221	12.50	49.80
	242	11.90	47.50
	342	23.50	90.50
	442	24.00	92.00
12	1	16.00	63.80
	221	14.80	59.60
	242	13.50	53.80
	342	28.00	110.50
	442	28.00	110.50
13	1	18.00	71.50
	221	17.00	68.75
	242	16.50	66.20
	342	32.50	125.80
	442	32.50	125.80
14	1	20.00	81.5
	221	19.50	79.60
	242	18.60	75.00
	342	38.00	142.50
	442	38.00	142.50
15	1	20.00	80.00
	221	18.50	73.50
	242	9.50	38.00
	342	35.00	136.00
	442	36.00	138.50

Table 5 : Variation Rate of Transmission Mode with the change of CQI

5.2: Simulation Analysis:

From the graph we have seen that, Transmission Mode 3 & 4 have highest throughput rate.At the same time we have observed that each transmission mode has a peak value for a fixed CQIS.After that it tends to decrease . we can compare all the four transmission modes (1,2,3,4) by taking graphs showing all transmission mode for some CQI.

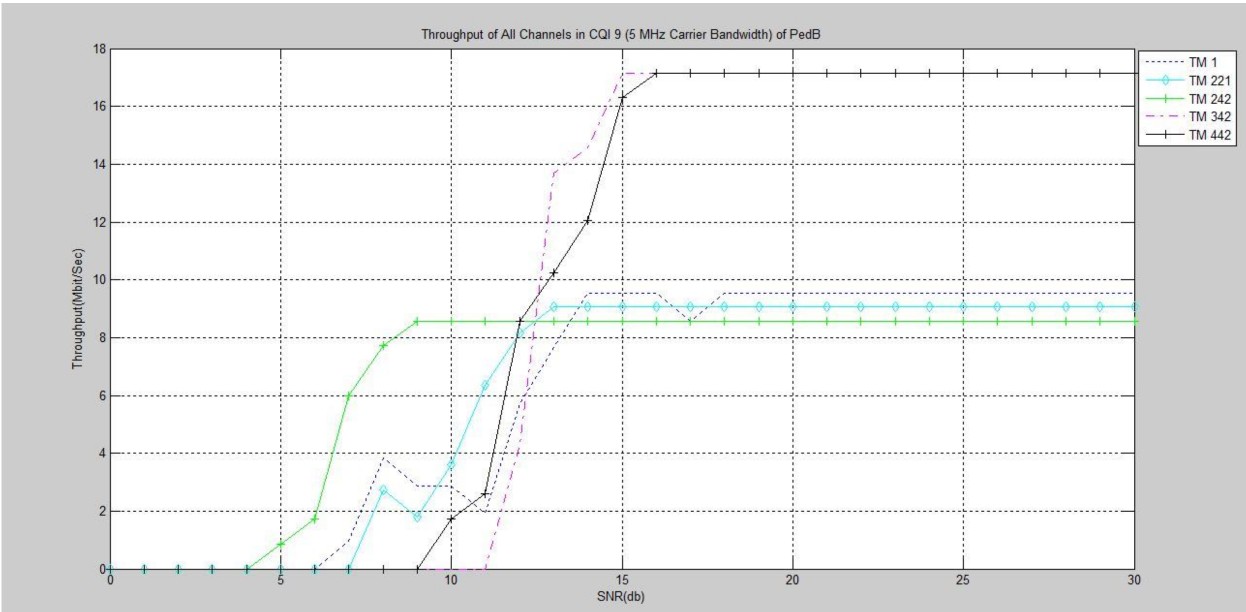


Fig. 19: All TM of CQI 9 at PedB (5MHz Bandwidth)

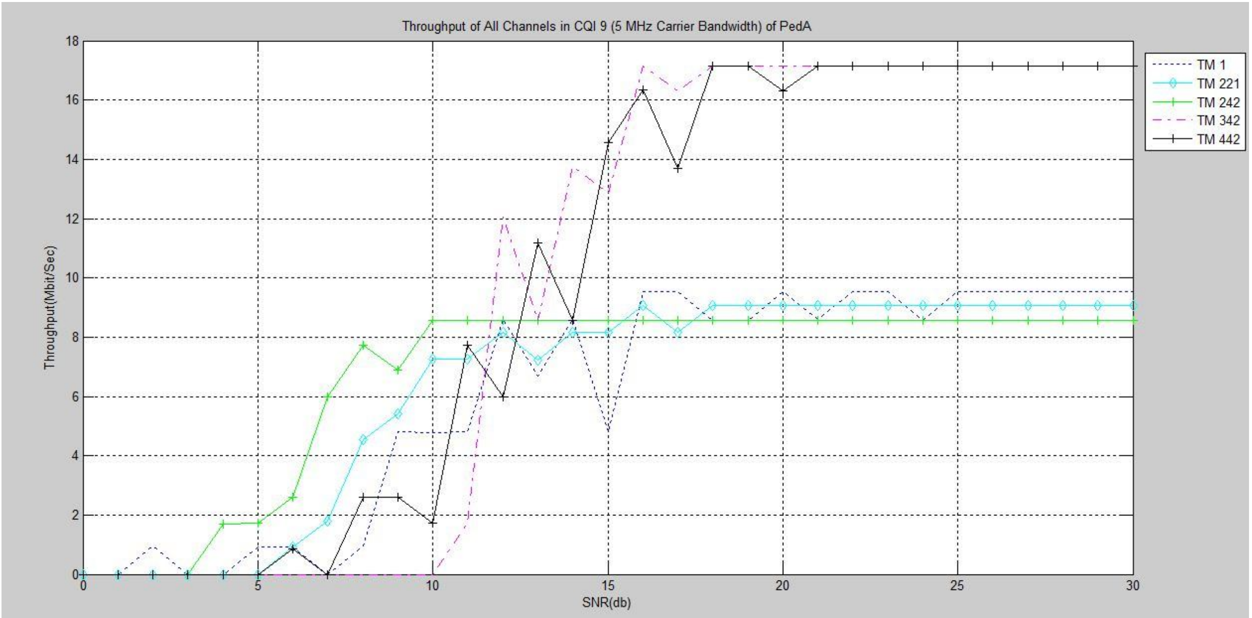


Fig. 20: All TM of CQI 9 at PedA (5MHz Bandwidth)

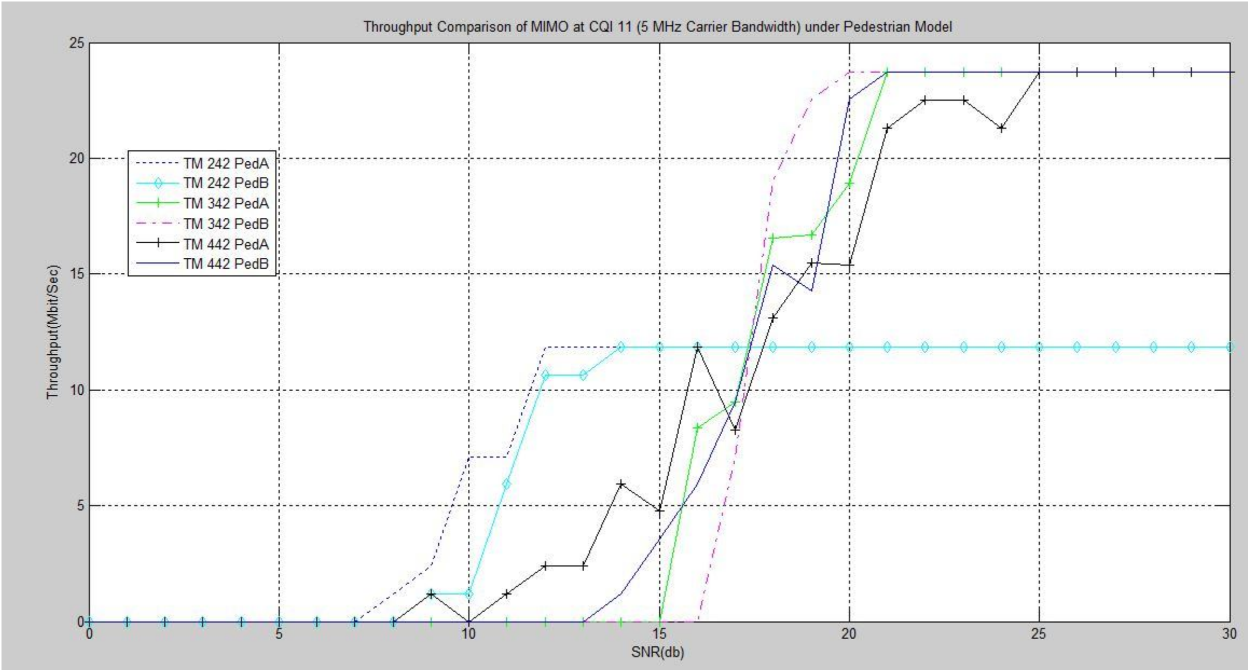


Fig. 21: Throughput Comparison of MIMO at Pedestrian Model (5MHz Bandwidth)

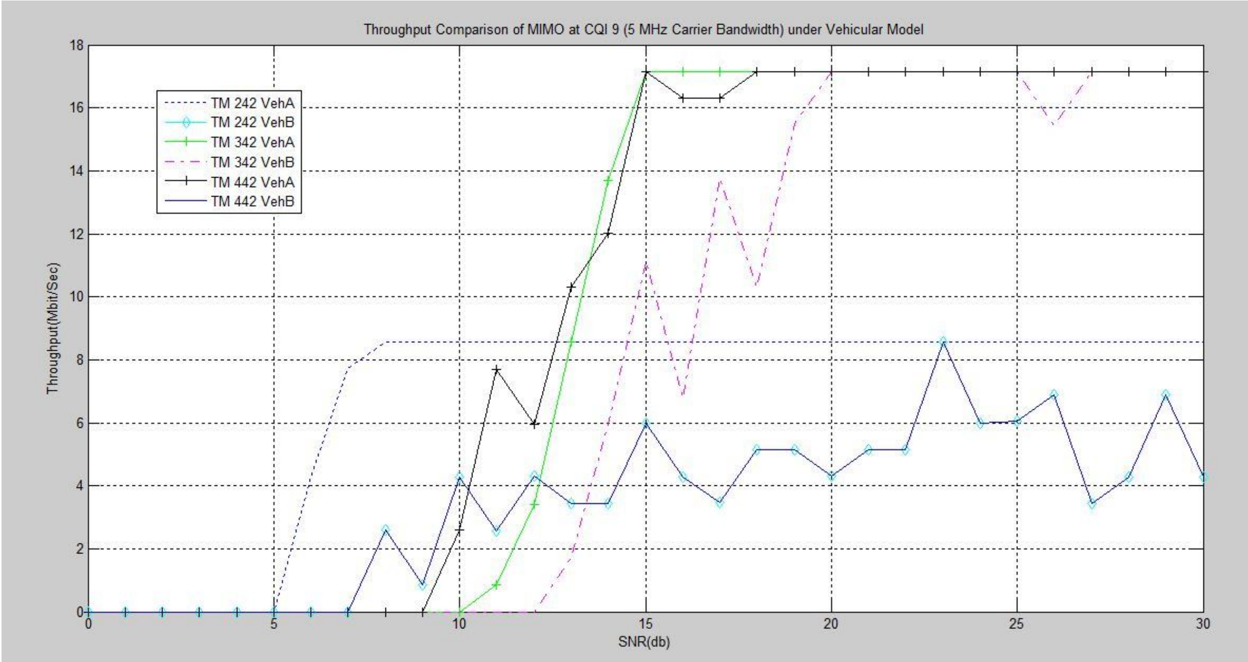


Fig. 22: Throughput Comparison of MIMO at Vehicular Model (5MHz Bandwidth)

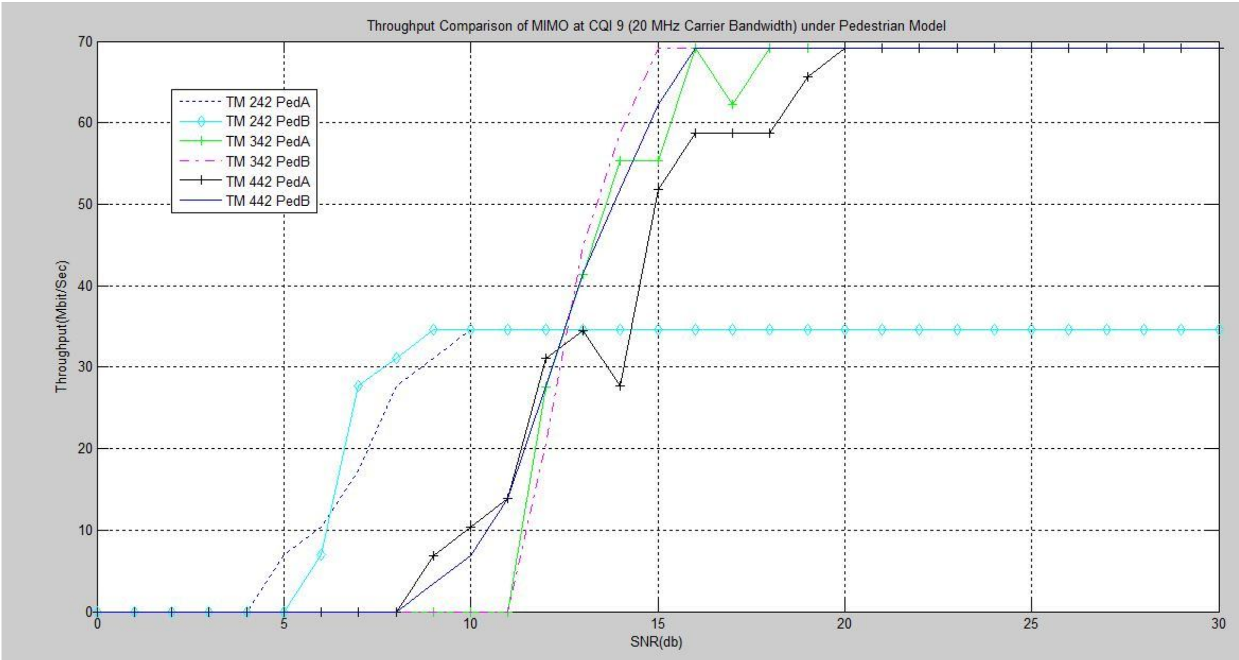


Fig. 23: Throughput Comparison of MIMO at Pedestrian Model (20MHz Bandwidth)

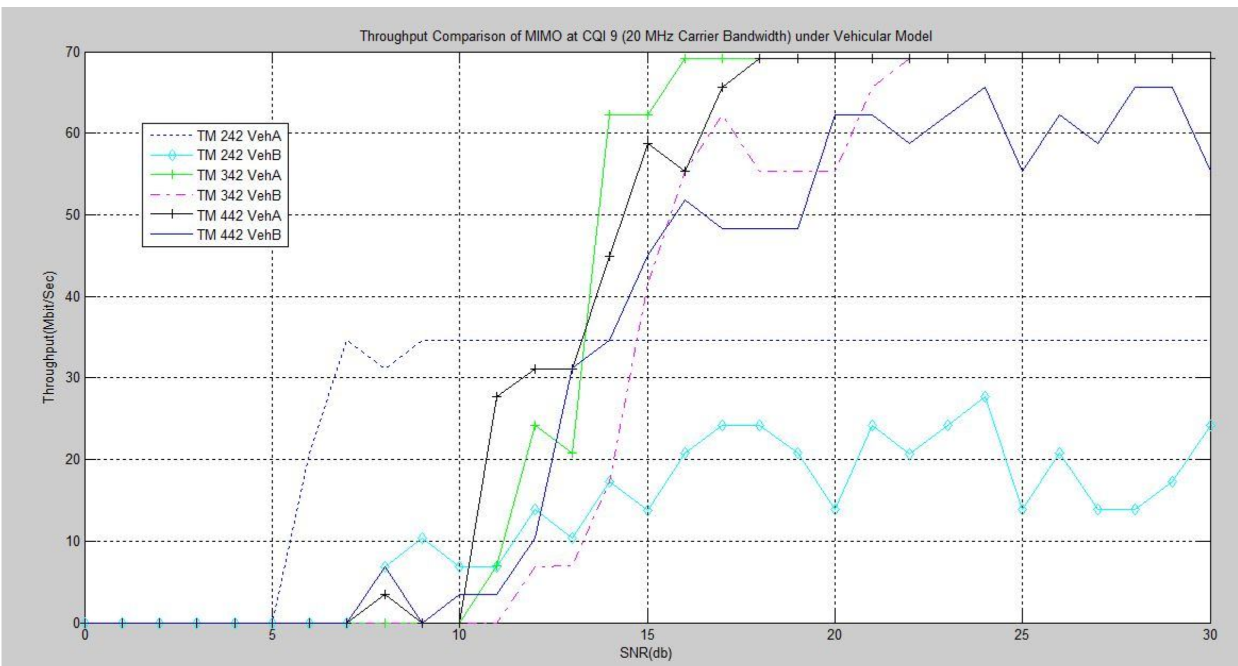


Fig. 24: Throughput Comparison of MIMO at Vehicular Model (20 MHz Bandwidth)

Chapter - 6

Conclusion:

5.1: Conclusion

For **transmit diversity**[3], Space Time Block Codes (STBC) are used to provide improvement against the channel deteriorating effects. Alamouti STBC are considered to be the simplest space time block codes. It is well known that Alamouti codes [4] can achieve full diversity and full code rate simultaneously. That's why it can be used to get minimal throughput gain at low SNR.

For this reason it is used in **noisy channel**.

Spatial Multiplexing[3] provides extra gain as compared to TxD [5].Independent data streams are transmitted from the NT transmit antennas in spatial multiplexing. Two classes of spatial multiplexing, open and closed loop spatial multiplexing Figures 3 and 4, are discussed. OLSM transmits the independent data streams without deploying any feedback algorithm. In CLSM essential amount of CSI is used as feedback which enables us to achieve high throughput

That's why in less **noisy channel Spatial Multiplexing** (Transmission Mode 3 & 4) is used for getting high throughput.

In **Pedestrian Environment** it is observed that PedB needs less SNR to get minimal throughput gain. That's why in **"Outdoor to Indoor" Environment, PedB is used**

In Vehicular Environment it is observed that VehA needs less SNR to get minimal throughput gain. That's why in **"Mobility" Environment, VehA is used**

5.2: Recommendation for Future Research

LTE Advanced,5G are the future technology. Among them LTE-Advanced is already launched in 43 Countries. And 5G rollout project is running by few countries

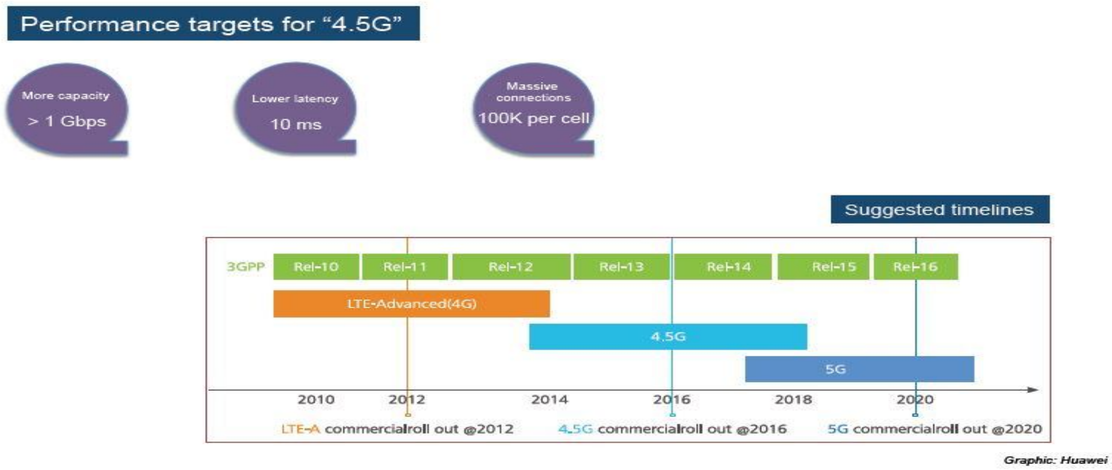


Figure 25: LTE Advance Performance Roll Out

5.3: LTE Based Project

5.3.1: Project "Loon" :

In 2008, Google had considered contracting with or acquiring Space Data Corp., a company that sends balloons carrying small base stations about 20 miles (32 km) up in the air for providing connectivity to truckers and oil companies in the southern United States, but didn't do so.[16]

Unofficial development on the project began in 2011 under incubation in Google X with a series of trial runs in California's Central Valley. The project was officially announced as a Google project on 14 June 2013.[17]

On 16 June 2013, Google began a pilot experiment in New Zealand where about 30 balloons were launched in coordination with the Civil Aviation Authority from the Tekapo areain the South Island

On 28 July 2015, Google signed an agreement with officials of Sri Lanka, to launch the technology on a mass scale.[18] As a result, Sri Lanka will be the first country in the world to get full coverage of 4G internet, using this technology.

Figure 25: Project Loon in Srilanka

As a result, Sri Lanka will be the first country in the world to get full coverage of 4G internet, using this technology.

5.3.2: Facebook Drone "Acquila" :

Facebook has revealed its first full-scale drone, which it plans to use to provide internet access in remote parts of the world.

Code-named "Aquila", the solar-powered drone will be able to fly without landing for three months at a time, using a laser to beam data to a base station on the ground.

The company plans to use a linked network of the drones to provide internet access to large rural areas. However, as with its Internet.org project, Facebook will not be dealing with customers directly, instead partnering with local ISPs to offer the services.

Jay Parikh, Facebook's vice-president of engineering, said: "Our mission is to connect everybody in the world. This is going to be a great opportunity for us to motivate the industry to move faster on this technology."

Facebook said it would test the aircraft, which has the wingspan of a Boeing 737, in the US later this year.

Figure 26: Drone Acquila

Yael Maguire, the company's engineering director of connectivity, said that the plane will operate between 60,000ft (18km) and 90,000ft (27km) – above the altitude of commercial airplanes – so it would not be affected by weather.

It will climb to its maximum height during the day, before gliding slowly down to its lowest ebb at night, to conserve power when its solar panels are not receiving charge.

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[2]“ Evolution to LTE report” by GSA at 21 July 2015: Page 26

[3]“The Daily Star” : 9th September 2013:Page 1

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3g-internet/

Appendix A:

LTE Sim Batch Main File:

```
% Basic batch simulation script
% (c) 2009 by INTHFT
% www.nt.tuwien.ac.at

clear
clear global
close all
clc

 %% DEBUG level
global DEBUG_LEVEL;
DEBUG_LEVEL = 1; % Now set to highest level.

%% SNR setting
SNR_30percent = [-7, -5, -3, -1, 1, 3, 3, 7, 9, 11, 13, 14.5, 16, 17.75, 19.5];
SNR_stepsize = 0.25;
SNR_window = 3;

%% Actual simulations
%for cqi_i = 1:15

for cqi_i=9
   N_subframes = 100;
   % SNR_vec = 100;
   % LTE_load_parameters_SUMIMO;  % Single User Multiple Input Multiple Output
   % LTE_load_parameters_MUMIMO;  % Multi User Multiple Input Multiple Output
    LTE_load_parameters_SUSISO;  % Single User Single Input Single Output
   % LTE_load_parameters_MUSISO;   % Multi User Single Input Single Output
   SNR_vec = SNR_30percent(LTE_params.scheduler.cqi)-
SNR_window*2.5:SNR_stepsize:SNR_30percent(LTE_params.scheduler.cqi)+SNR_window;

   % See comments in LTE_sim_main for using parfor
   LTE_sim_main;

   % Code to generate the output filename
   output_filename = LTE_common_generate_output_filename(LTE_params,N_subframes)
   filename_suffix = [];

   save(fullfile('./results',[output_filename filename_suffix '.mat']));
   %close all;
end
```

Appendix B:

Result of CQIS 13 of Transmission Mode 442.

% Modify expression to add input arguments.
% Example:
%   a = [1 2 3; 4 5 6];
%   foo(a);

LTE_Sim_Batch_quick_test_experiment1
LTE Link Level simulator
(c) 2008, INTHFT, TU Wien
 This work has been funded by Mobilkom Austria AG and the Christian Doppler Laboratory for Design Methodology of Signal Processing Algorithms.

  By using this simulator, you agree to the license terms stated in the license agreement included with this work
  Contains code from:
    - pycrc (CRC checking)
    - The Coded Modulation Library (convolutional coding & SISO decoding)
  Convolutional coding & SISO decoding MEX files under the GNU lesser GPL license
*************** SNR = 0dB, value 1 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: NaNmin
  BLER UE1, stream 1: 1.00
*************** SNR = 1dB, value 2 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 3.063min
  BLER UE1, stream 1: 1.00
*************** SNR = 2dB, value 3 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 2.893min
  BLER UE1, stream 1: 1.00
*************** SNR = 3dB, value 4 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 2.795min
  BLER UE1, stream 1: 1.00
*************** SNR = 4dB, value 5 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 2.688min
  BLER UE1, stream 1: 1.00
*************** SNR = 5dB, value 6 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 2.598min

BLER UE1, stream 1: 1.00
*************** SNR = 6dB, value 7 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 2.497min
BLER UE1, stream 1: 1.00
*************** SNR = 7dB, value 8 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 2.382min
BLER UE1, stream 1: 1.00
*************** SNR = 8dB, value 9 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 2.267min
BLER UE1, stream 1: 1.00
*************** SNR = 9dB, value 10 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 2.154min
BLER UE1, stream 1: 1.00
*************** SNR = 10dB, value 11 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 2.060min
BLER UE1, stream 1: 1.00
*************** SNR = 11dB, value 12 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 1.963min
BLER UE1, stream 1: 1.00
*************** SNR = 12dB, value 13 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 1.857min
BLER UE1, stream 1: 1.00
*************** SNR = 13dB, value 14 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 1.757min
BLER UE1, stream 1: 1.00
*************** SNR = 14dB, value 15 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 1.653min
BLER UE1, stream 1: 1.00
*************** SNR = 15dB, value 16 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 1.552min
BLER UE1, stream 1: 1.00
*************** SNR = 16dB, value 17 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 1.454min
BLER UE1, stream 1: 0.90
*************** SNR = 17dB, value 18 of 31 ***************

```
  processing subframe #1 of 10
---> remaining simulation time: 1.354min
  BLER UE1, stream 1: 1.00
*************** SNR = 18dB, value 19 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 1.255min
  BLER UE1, stream 1: 0.90
*************** SNR = 19dB, value 20 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 1.158min
  BLER UE1, stream 1: 0.70
*************** SNR = 20dB, value 21 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 1.055min
  BLER UE1, stream 1: 0.90
*************** SNR = 21dB, value 22 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 0.957min
  BLER UE1, stream 1: 0.30
*************** SNR = 22dB, value 23 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 0.856min
  BLER UE1, stream 1: 0.50
*************** SNR = 23dB, value 24 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 0.757min
  BLER UE1, stream 1: 0.20
*************** SNR = 24dB, value 25 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 0.655min
  BLER UE1, stream 1: 0.00
*************** SNR = 25dB, value 26 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 0.555min
  BLER UE1, stream 1: 0.20
*************** SNR = 26dB, value 27 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 0.457min
  BLER UE1, stream 1: 0.00
*************** SNR = 27dB, value 28 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 0.360min
  BLER UE1, stream 1: 0.00
*************** SNR = 28dB, value 29 of 31 ***************
  processing subframe #1 of 10
---> remaining simulation time: 0.265min
```

BLER UE1, stream 1: 0.00
*************** SNR = 29dB, value 30 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 0.173min
BLER UE1, stream 1: 0.00
*************** SNR = 30dB, value 31 of 31 ***************
processing subframe #1 of 10
---> remaining simulation time: 0.081min
BLER UE1, stream 1: 0.00