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Peak-Throughput of LTE-Release 10 for Up/Down Link Physical Layer

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ABSTRACT

Long Term Evolution (LTE) Release 8 of the Universal Mobile Telecommunications Systems (UMTS) was developed to provide extensive support for deployment in a variety of spectrum allocations, ranging from 1.4 MHz to 20 MHz, for both paired and unpaired bands. For system bandwidth beyond 20 MHz, the only reasonable way to achieve LTE-Advanced highest target peak-throughput rate is to increase the transmission bandwidth, relative to Release 8. In order to provide the necessary bandwidth, LTE-Advanced specifies spectrum allocations of up to 100 MHz using “carrier aggregation”, where multiple component carriers are combined. Therefore, to configure all component carriers that are LTE Release 8 compatible, at least when the aggregated numbers of component carriers in the Uplink (UL) and the Downlink (DL) must be the same. However, not all component carriers are necessarily Release 8 compatible. The main aim of this paper is to investigate a comprehensive analysis of physical layer throughput of LTE-Advanced (DL) and (UL) using Multi Input Multi Output channel (MIMO) 2x2 based on standard parameters for different channel bandwidths.

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1. INTRODUCTION

An important metric for quantifying network throughput performance is data throughput but unfortunately, the ways in which various organizations quote throughput statistics vary tremendously which often leads to misleading claims. The proposed solution to address the issue of improved data throughput, LTE-Advanced is implementing relay technologies which have great application potential. The performance of relay transmissions however, is greatly affected by the collaborative strategy, which includes the selection of relay types and relay partners. UMTS target for LTE-Advanced was set considering tha gain of 1.4 to 1.6 from Release 8 LTE performance [1]. The 3rd Generation Partnership Project (3GPP) introduced LTE as the 3rd generation of mobile communication standards, where LTE Release 8 describes a mobile communication standard which supports up to 300 Mbps of data transmission in downlink using the Orthogonal Frequency Division Multiplexing (OFDM) scheme as well as up to 75 Mbps throughput for uplink using the Single Carrier-Frequency Division Multiple Access (SC-FDMA) modulation. Therefore this paper present, an in-depth study of LTE throughput performance based on Release 10 which is conducted for uplink and downlink under different scenarios.

In addition this paper also highlight the Frequency Division Duplex (FDD) operation mode which, shows that the maximum throughput for downlink data is 299.122 using 4 antenna ports with the least possible control overhead (one OFDM symbol assigned to Physical Downlink Control Channel-PDCCH), 64-QAM data modulation scheme, the maximum code rate (0.92), and the maximum channel bandwidth (20 MHz). The throughput result presented is based on Physical Downlink Share Channel PDSCH which is used for data transmission only and does not include control information (PDCCH, PHICH, and Physical Control Format Indicator Channel-PCFICH), broadcast channel (PBCH), reference signals, and Synchronization Signals (P-SS and S-SS). This study also shows that the maximum uplink throughput for the FDD operation is 71.97 Mbps excluding control channel information (PUCCH), and reference signals (demodulation reference signals and sounding reference signal). This maximum throughput result simulated is based on assuming 64-QAM data modulation with a maximum bandwidth of 20 MHz and 0.85 code rates.

This research study also presents other throughput results based on different parameters. In summary this research, provides a comprehensive investigation of the LTE performance analysis based on detailed physical layer parameters to fill the existing gap in current literature in the performance study of LTE [2]. Figure 1 shows the increasing throughput from the first cell phones till LTE-Advanced.

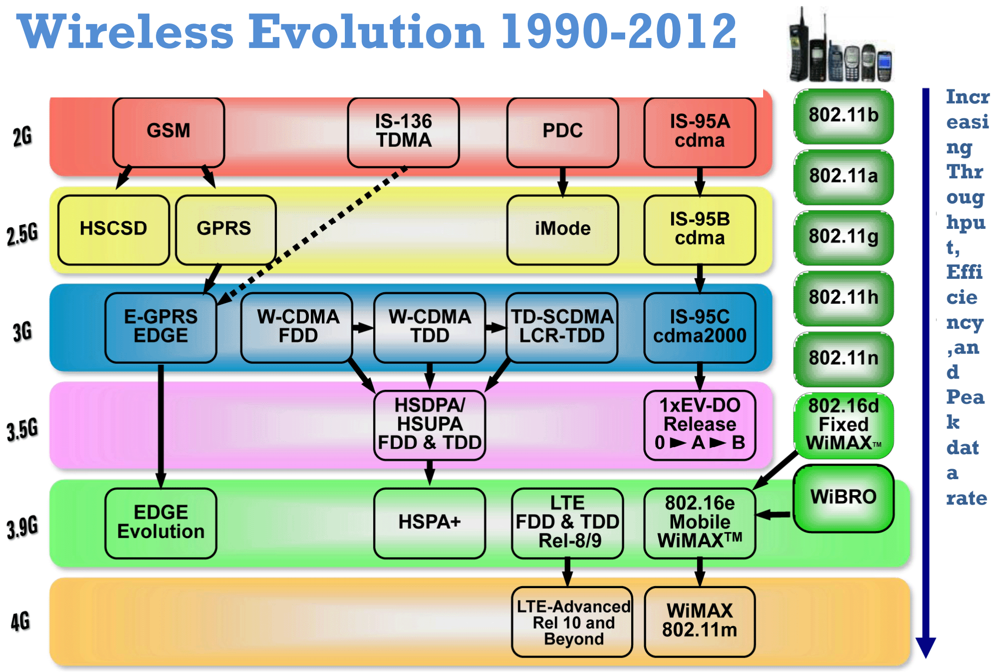


Figure 1: Brief history of Throughput [3]

In addition, this paper also presents an average spectral efficiency of LTE-Advanced in section 2, physical downlink of LTE-Advanced System is explained in details in section 3. Physical uplink of LTE-Advanced System is discussed in section 4, and finally all the simulation results of LTE-Advanced downlink multi input/multi output (MIMO) with 2X2 Throughput and LTE-Advanced uplink multi input/multi output (MIMO) with 2x2 throughput discussions and conclusions are shown in sections 5, 6 and 7 respectively.

2. LTE-Advanced

LTE-Advanced features are designed in a backwards-compatible way where LTE Release 8 terminals can be used on the same carrier where new LTE-Advanced Release 10 features are activated[4]. LTE-Advanced can be considered as a toolbox of features that can be flexibly implemented on top of LTE Release 8. The main technology components in Release 10 LTE-Advanced are as follows:

- Carrier aggregation up to 40MHz total band, and later potentially up to 100 MHz;
- MIMO evolution up to 8×8 in downlink and 4×4 in uplink;
- Relay nodes for providing simple transmission solution;
- Heterogeneous networks for optimized interworking between cell layers including macro, micro, pico and femto cells.

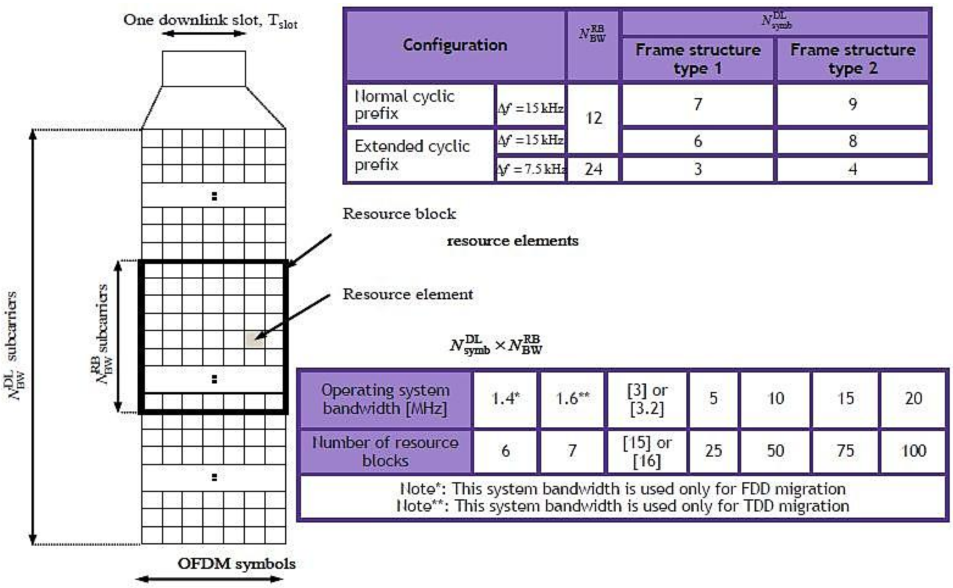
Cell-edge User Equipment (UE) throughput and average spectral efficiency are the main challenging indicators for LTE-A to fulfill the International Telecommunication Union – Radio communication Sector (ITU-R) requirements for LTE-Advanced systems. In order to address these challenges, multi-antenna techniques in LTE-A have been improved targeting efficient single user (SU) - and multi user (MU-MIMO) transmissions. The main driver in designing MIMO schemes for LTE Rel-10 comes from the requirment to consider different antenna configurations at the eNodeB (eNB), where it will be possible to deploy 2, 4 and 8 antennas. The main antenna deployment configurations have been identified as:

- Closely spaced (e.g. 0.5 to 0.7 times carrier wavelength) cross-polarized antenna scenario (closely spaced Clustered Linear Array (CLA)).
- Widely spaced (e.g. 4 or even 10 times carrier wavelength) cross-polarized antenna scenario (widely spaced CLA).
- Uniform Linear Array (ULA) scenario.

Operators indicate the case of closely spaced CLA as the one with the highest priority. However, they also emphasize the need for optimizing the other possible scenarios. Another driver is the availability starting from Release 9 (Rel-9) of dedicated reference signals that allow the use of non-predefined beamforming weights for downlink transmissions. Dynamic SU/MU-MIMO switching has been recognized to be an important feature, for which codebook design and feedback reporting should be optimized. Low computational complexity at the UE side, is another reason behind some of the choices made in 3GPP. In the following a summary of reference signal design and multi-antenna transmission schemes is given, for downlink and uplink transmissions [5][6].

3. LTE-A Maximum Throughput

In LTE-A, a physical Resource Block (RB) is 0.5 ms (7 OFDM symbols, short cyclic prefix) and 12 subcarrier as shown in Figure 2. Since every subcarrier is 15 KHz, the RB has a dimension of 7x12=84 symbols, which leads to 84 / 0.5 ms= 168000 symbols/second.



Configuration		N_{BW}^{RB}	N_{symb}^{DL} Frame structure type 1	N_{symb}^{DL} Frame structure type 2
Normal cyclic prefix	$\Delta f = 15$ kHz	12	7	9
Extended cyclic prefix	$\Delta f = 15$ kHz	12	6	8
	$\Delta f = 7.5$ kHz	24	3	4

Operating system bandwidth [MHz]	1.4*	1.6**	[3] or [3.2]	5	10	15	20
Number of resource blocks	6	7	[15] or [16]	25	50	75	100

Note*: This system bandwidth is used only for FDD migration
Note**: This system bandwidth is used only for TDD migration

Figure 2: The OFDMA Frame Structure [7]

The following figure explains the three types of modulations,

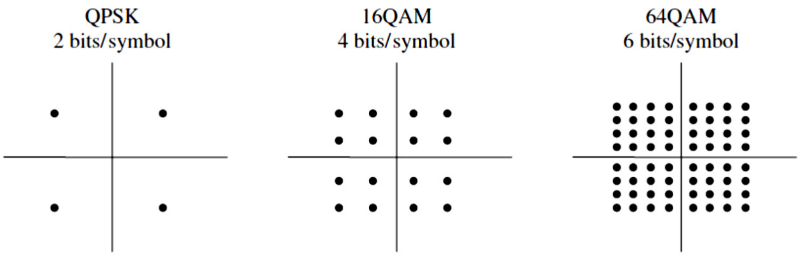


Figure 3: LTE-A modulation constellation

In the case of QPSK modulation (2 bits/symbol). The RB throughput is 168000 x 2=336 Mbps. Assuming a Forward Error Correction (FEC) of 5/6, then this throughput becomes 5/6 x 336 Mbps= 280 Mbps. In the case of 16QAM modulation (4 bits/symbol), The RB throughput is 168000 x 4=672 Mbps. Assuming a FEC of 5/6, then this throughput becomes 5/6 x 672 Mbps= 560 Mbps. In the case of 64QAM modulation (6 bits/symbol), The RB throughput is 168000 x 6=1.008 Mbps. Assuming a FEC of 5/6, then this throughput becomes 5/6 x 1.008= 0.84 Mbps. Now for a 20 MHz carrier, nRB is 100. Therefore, for a 20 MHz carrier, the total maximum cell throughput is 84 Mbps (obviously less because the reference symbols must be removed). For a 2x2 MIMO, that corresponds to 168 Mbps.

4. Physical Downlink of LTE-Advanced System

Figure 4 shows a block diagram for a downlink (eNB to UE) connection. The configuration shown is for full 2×2 MIMO. In the downlink, regular OFDMA is used. On the transmitter side two Transport Blocks (TBs) are prepared for transmission, assuming spatial multiplexing. A CRC is added to the TB to allow integrity checking. The TB is segmented or appended into Coding Blocks (CB) and another CRC is added for HARQ purposes. A turbo encoder or a convolutional encoder is used to encode the data at 1/3 coding rate. The output coding rate is matched to the desired coding rate by puncturing. The data is then mapped to the modulation constellation, according to the estimated path requirement for a 10% BER (Block Error Rate). A pre-coder is applied according to the antenna configuration chosen for the path. The signal is then mapped directly onto the sub-carriers in one or more Resource Blocks (RBs). Each Resource Block is a set of 12 sub-carriers by one symbol.

The Reference Signal (RS), known also as pilot is inserted in specific sub-carriers. An IFFT (Inverse Fourier Transform) is then applied to the sub-carrier in the transmission bandwidth. Finally, a CP (Cyclic Prefix) is inserted according to the sector configuration (normal or extended CP). The signal is then sent to each of the antenna's RF equipment. On the receiver side, the signal is received by two RF equipment and the CP is removed. An FFT (Fast Fourier Transform) is applied to the whole bandwidth and the sub-carriers are extracted. The sub-carrier content is then de-mapped from the constellation states to a sequence of bits. The MIMO receiver equalizes and processes these bits, sending them to the two receive branches. The RBs are de-mapped and a Likelihood Receiver Generator (LRG) sends the most likely streams to the turbo decoder for error correction. The CRC is then checked and, if it fails, an HARQ request is sent. The information is stored until the receiver received correctly or it will be discarded, up to 8 HARQ tries are done. The data is finally re-assembled or disassembled and each TBs CRC is checked. A failed CRC triggers

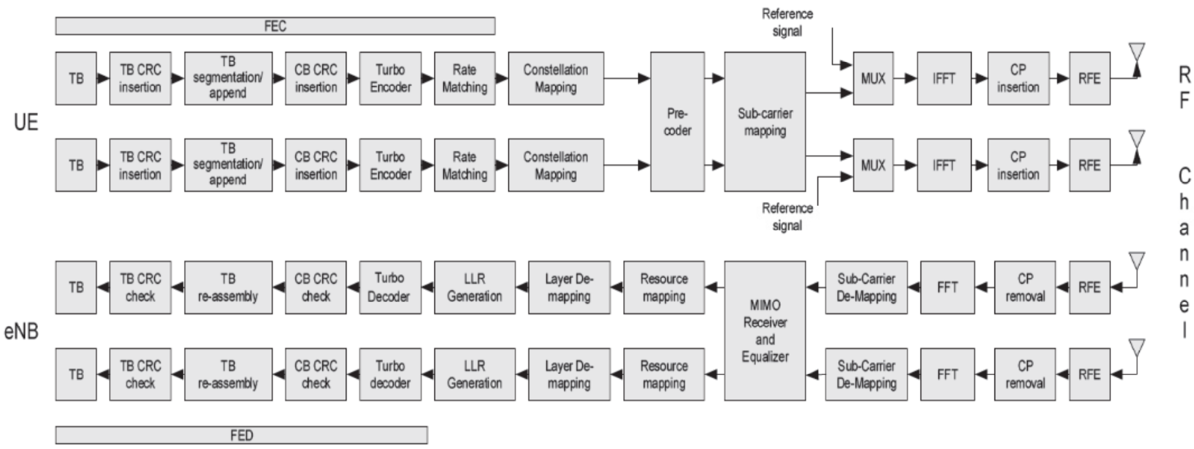


Figure 4: Downlink PHY block diagram for 2 X 2 MIMO [8]

This procedure assures that the number of errors passed to the higher layers is small, although the RF part works at a 10% BER. The advantage of this procedure is a higher throughput and the drawback is the processing time jitter. Therefore applications that require a low delay have to target lower BERs [8].

5. Physical Uplink of LTE-Advanced System

Figure 5 shows a block diagram for an uplink (UE to eNB) connection. The configuration shown is for full 2×2 MIMO. In the uplink, DFT-S-OFDMA is used. On the transmitter side, two Transport Blocks (TBs) are prepared for transmission, assuming spatial multiplexing. A CRC is added to the TB to allow for integrity checking. The TB is segmented or appended into Coding Blocks (CB) and another CRC is added for

HARQ purposes. A turbo encoder or a convolutional encoder is used to encode the data at 1/3 coding rate. The output coding rate is matched to the desired coding rate by puncturing. The data is then mapped to the modulation constellation, according to the estimated path requirement for a 10% BER (Block Error Rate). The signal is then sequenced in time and passed through an FFT (Fast Fourier Transform) that decomposes it into frequencies that coincide with the sub-carriers. A pre-coder is applied according to the antenna configuration chosen for the path.

The signal is then mapped directly to the sub-carriers in one or more Resource Blocks (RBs). Each Resource Block has a set of 12 sub-carriers by one symbol. The Reference Signal (RS), also known as a pilot, is inserted into specific sub-carriers. An IFFT (Inverse Fourier Transform) is then applied to the sub-carrier in the transmission bandwidth. Finally a CP (Cyclic Prefix) is inserted according to the sector configuration (normal or extended CP). The signal is then sent to each of the antenna's RF equipment. On the receiver side, the signal is received by two RF equipment and the CP is removed. An FFT (Fast Fourier Transform) is applied to the whole bandwidth and the sub-carriers are extracted. The sub-carrier content is then de-mapped from the constellation states onto a sequence of bits. The MIMO receiver equalizes and processes these bits, sending them to the two receive branches. An IFFT is applied to restore the original signal, which has the modulated signals aligned in time. The RBs are de-mapped and a Likelihood Receiver Generator (LRG) sends the most likely streams to the turbo decoder for error correction. The CRC is then checked and, if it fails, an HARQ request is sent. The information is stored until received correctly or it is discarded, and up to 8 HARQ tries are done. The data is finally re-assembled or disassembled and each TBs CRC is checked. A failed CRC triggers an ARQ request [8]. The decision to use the DFT-S-OFDMA was proposed to reduce the PAPR, but in practice the reduction is of about 2.5 dB for QPSK and about 0.5 dB for 64QAM. On average we can say that a reduction of 1.5db can be expected. Therefore this gain is lost by a similar loss in frequency diversity.

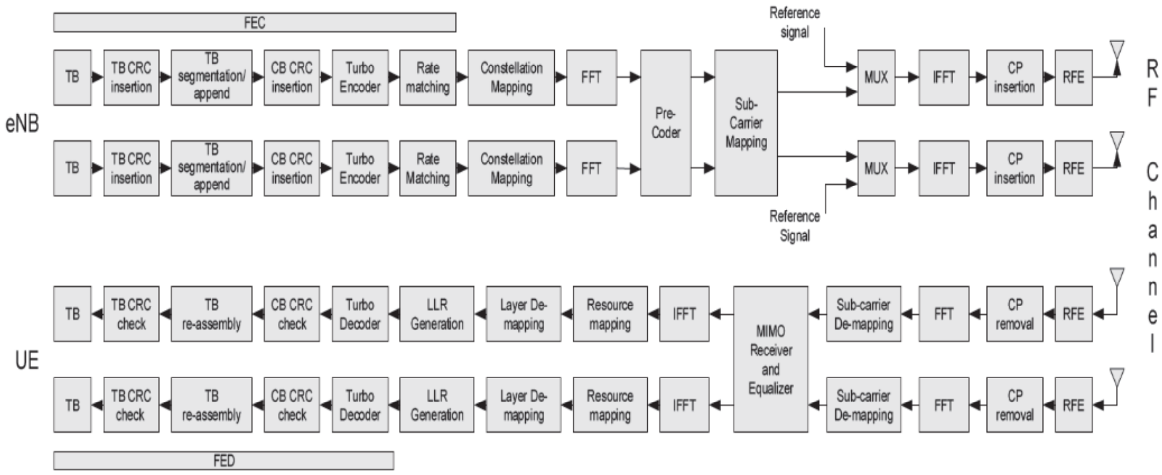


Figure 5: Uplink PHY block diagram for 2 X 2 MIMO[8]

6. LTE-Advanced DL MIMO 2X2 Throughput

The simulation workspace demonstrates a close loop throughput measurements for LTE Advanced downlink 2x2 system with spatial multiplexing in a fading environment. The Agilent SystemVue MIMO channel builder is an optional block set that provide LTE-Advanced MIMO channel models for BER/FER and throughput fading simulation of LTE, LTE-Advanced, where Figure 6 shows an LTE-Advanced system broadcasting over MIMO channel [9].

Based on the reference parameters for LTE-Advanced as tabulated in Table 1 and using SystemVue 2011 program to implement LTE-A (FDD-DL) using MIMO by 2X2 channel with fading throughput. Figure 7 shows the results that have been reached after implementing for throughput fraction; this shows the relationship between the throughput and SNR.

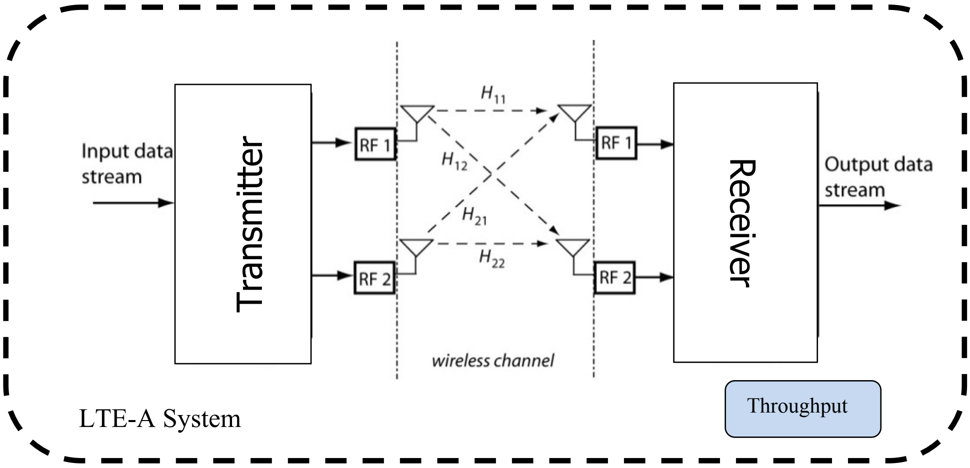


Figure 6: LTE-A Downlink 2x2 MIMO Throughput diagram

Table 1: The Reference Data of LTE-A DL MIMO

Extended Vehicular A models (EVA) channel with 5Hz max Doppler shift
The bandwidth is 10 MHz
21 RBs are allocated for UE1 PDSCH (Release 10)
The mapping type is 16QAM
The code rate is 1/2
5000 subframes are simulated

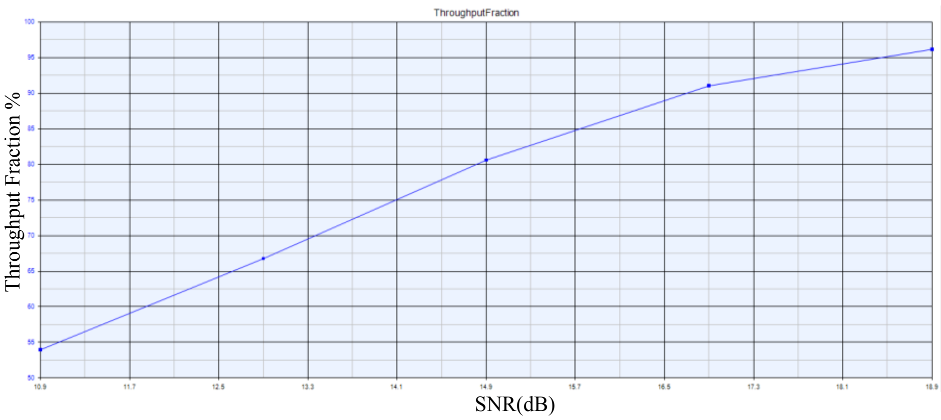


Figure 7: Throughput Fraction in Downlink 2x2 MIMO

7. LTE-Advanced UL MIMO 2X2 Throughput

This simulation workspace demonstrates a close loop throughput measurements for LTE Advanced uplink 2x2 with HARQ retransmission in a fading environment, so that the closed-loop HARQ simulation for PUSCH is enabled. The delay part (with the delay of (NumHARQ-1)) is placed between these two 'HARQ_Bits' ports in the receiver and the source. Note that the two input ports should come from the receiver corresponding output ports, and the measurement should at least begin with the second subframe. Figure 8 shows LTE-Advanced system broadcasting over MIMO channel with HARQ ACK/NACK.

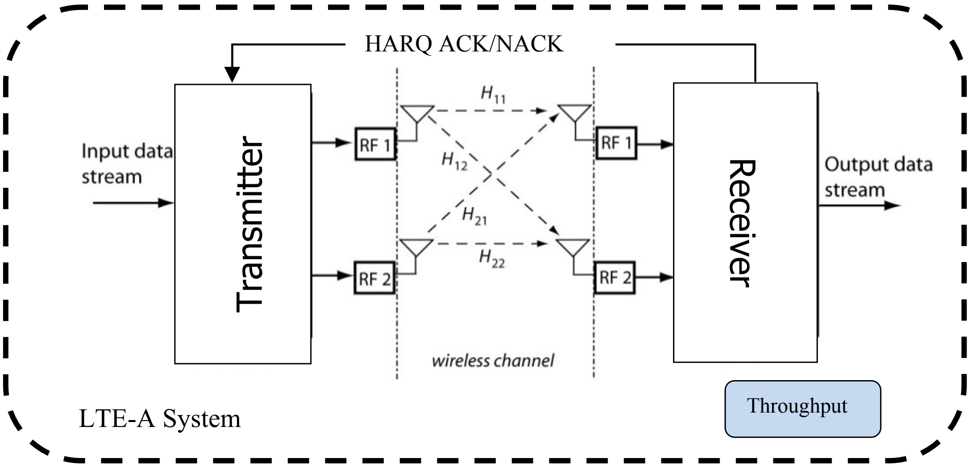


Figure 8: LTE-A Uplink 2x2 MIMO Throughput diagram

Table 2: The Reference Data of LTE-A UL MIMO

FDD LTE-A uplink 2x2 system
The bandwidth is 5MHz
All 25RBs are allocated for PUSCH
The mapping type is QPSK
The code rate is 1/3
2000 subframes are simulated in InH channel with 5Hz max Doppler shift

Based on the reference parameters for LTE-Advanced as tabulated in Table 2 using SystemVue 2011 program to implement the LTE-A (FDD-UL) for MIMO 2X2 channel with fading throughput. Figure 9 shows the result that have been reached after implementation for throughput fraction; the result shows the relationship between throughput and SNR.

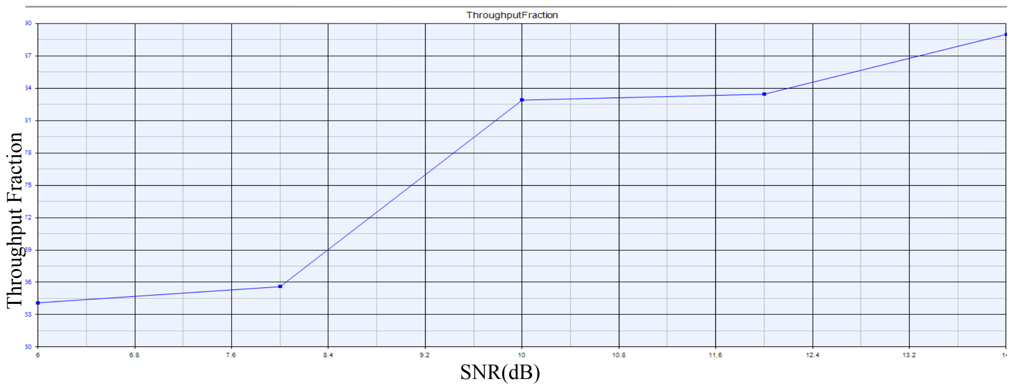


Figure 9: Throughput Fraction in Uplink 2x2 MIMO

The normalized user throughput is defined as the number of correctly received bits by a user at the data link layer over a certain period of time, divided by the total spectrum. The cell edge user spectral efficiency is defined as 5% point of Cumulative Distribution Function (CDF) [10] of the normalized user throughput. Control-plane latency is defined as the transition time from idle-state to connected state.

The transition time (assuming downlink paging latency and core network signalling delay are excluded) of less than 100 ms is required for LTE-Advanced systems. The user-plane latency (also known as transport delay) is defined as the one-way transit time between a packet being available at the IP layer of the origin (user terminal in the uplink or base station in the downlink) and the availability of this packet at IP layer of the destination (base station in the uplink or user terminal in the downlink). Table 3 shows the throughput of DL MIMO 2x2 for different values of SNR.

Table 3: Relationship between throughput and SNR in Downlink 2x2 MIMO

SNR (dB)	-2.8	-3	-4.3	-7	-8.3
Throughput (%)	54	70	83	93	97

While Table 4 shows the throughput of UL MIMO 2x2 for different values of SNR.

Table 4: Relationship between throughput and SNR in Uplink 2x2 MIMO

SNR (dB)	6	7	10	12	14
Throughput (%)	64	65	82	83	87

8. CONCLUSION

Throughput is an important measurement for characterizing LTE receiver performance. Receiver sensitivity is another important measurement based on the throughput measurement to test the throughput; where a test system needs a golden reference receiver and certain auto-configuration capability. In this research for the developing period, a physical “golden” receiver is not available. Therefore the test approach offered here is an integrated test solution with embedded LTE reference receiver (that serves as a “golden” receiver) and an auto-configuration capability Agilent SystemVue software is used to integrate and control all test instrument hardware such as signal sources and signal analyzer as well as instrument software together as a test system.

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