Performance Evaluation of Multi-Antenna Techniques in Long Term Evolution (LTE) Networks

Gerald C. Eze, Longinus S. Ezema, and Haris O. Orah, Emeka Onuekwusi

Abstract— Long Term Evolution (LTE) is the final release of third generation (3G) leading to the fourth generation (4G) network. The demand for a very high speed network connection is the driving force for this mobile network evolution. Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier Frequency Division Multiple Access (SC-FDMA) are strong multiple access scheme candidates for the downlink and uplink of the LTE and LTE-Advanced Networks with Orthogonal Frequency Division Multiplexing (OFDM) being adopted by third generation partnership project (3GPP) as the standard for modulation technique used in transmission of high data rate in LTE Networks. In this research, a Matlab and Simulink software package were used to model and design an LTE downlink physical layer simulator according to 3GPP specifications. The simulation was carried out for the single downlink, from one eNodeB to User Equipment (UE). The performance of different multi-antenna techniques (transmission modes) was exploited in Diversity scheme and mobility environment with the aim of maximizing LTE performance using Multiple-Input Multiple-Output (MIMO) Optimization. However, the result show that MIMO spatial multiplexing offers the best capacity gains at high SNR and Open Loop Spatial Multiplexing (OLSM) is more robust at high SNR followed by CLSM because of their ability to support high data throughput as well as multi-stream transmission. This research strengthens the belief that performance of different multi-antenna scheme configurations is better than single antenna scheme and that multi-stream transmission will be a practical method for improving the data throughput in LTE Networks than single stream transmission

Index Terms— *Multiple-Input Multiple-Output (MIMO), Open Loop Spatial Multiplexing (OLSM), Closed Loop Spatial Multiplexing (CLSM), Transmit diversity (TxD), Long Term Evolution (LTE), Mobile Network, SC-FDMA*.

1 INTROUDCTION

IN the last decade, the need for high speed broadband access has exponential growth and the future growth expectation continue to be high. The growth will be driven by unlimited possibilities in internet services and multimedia applications fuelled by advances in wireless technologies. To meet the current and future demands for reliable high data rates over the mobile networks, the 3GPP was created from groups of telecommunication associations to set a definition and standards for the future generation mobile system. In December 2008, the sixth version of the standard (release 8) called LTE was developed. 3GPP LTE became the de facto standard for 4G cellular networks [1], [2].

Higher data traffic rate in LTE can be attained by improving the bandwidth and by the utilisation of proficient multi-antenna transmission schemes. The limited bandwidth of mobile communication made the multi-antenna transmission an important technique in achieving higher data rate. MIMO has a better cell coverage and higher data rate. The structure of MIMO effectively realised multiple spatial layers where multiple data streams are delivered based on frequency-time resource allocation and linearly enhances the capacity of the channel. Recently, most wireless communications standards such as Wireless fidelity (Wi-Fi), Worldwide Interoperability for Microwave Access (WiMAX) and High-Speed Packet Access+ (HSPA+) support MIMO schemes. The advances in MIMO techniques allow LTE to supports wireless broadband data service as high as 1000 Mbps in the downlink and 500 Mbps in the uplink [1]. MIMO also increases cell coverage and average throughput [1]. LTE can provide high data rates, low latency, and flexible bandwidth. In order to attain these targets, OFDM and MIMO are accepted as basic technologies. The objective of this work is to carry out the performance analysis of multi-antenna scheme configuration.

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2 RESEARCH METHODOLOGY

In this research, both qualitative and quantitative approaches are used which is called mixed approach. Quantitative research is carried out by means of inquiry strategies including certain experiments and simulations which produce some form of statistical data for analysis or decisions. Qualitative research is based on the researcher knowledge through participatory and/or constructive perspectives [8]. The purpose of adopting mixed approach is to collect and review available research work and retrieve the simulation result in the field of 4G LTE. MIMO technologies have been generally employed to improve downlink peak rate, cell coverage, and cell throughput.

In order to accomplish these various set of objectives, LTE employed diverse MIMO modes technologies together with the following:

1. Single user (SU)-MIMO,
2. Transmit diversity
3. Closed loop rank-1 pre-coding
4. Multiuser (MU)-MIMO and
5. Dedicated beamforming

The LTE SU-MIMO scheme is specified for the configuration with 2 to 4 transmits antennas in the LTE downlink, which supports the transmission of multiple spatial layers with up to 4 layers to a specified User Equipment (UE).

2.1 SU-MIMO

The SU-MIMO scheme is employed to the Physical Downlink Shared Channel (PDSCH), which is the physical layer channel that transmit the information data from the network to the UE with SU-MIMO spatial multiplexing, the LTE system provides a peak rate of 150 Mbps for two transmit antennas and 300 Mbps for four transmit antennas [7], [8], [9], [10], [11]. There are two MIMO operation modes in SU and MU spatial multiplexing; the CLSM and the OLSM.

2.2 MIMO Channel Model

Consider a general MIMO system as shown in figure 1

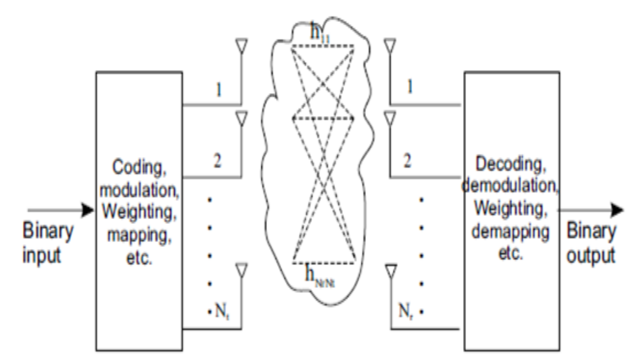

Fig. 1. Generic MIMO system structure.

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$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N_T} \\ h_{21} & h_{22} & \cdots & h_{2N_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_R1} & h_{N_R2} & \cdots & h_{N_RN_T} \end{bmatrix} \quad (1)$$

The time index is not included here for simplicity. Assuming N_T transmit antennas at eNode-B and N_R receive antennas at UE, the channel is described by an $N_R \times N_T$ matrix H the discrete signal model can be expressed as

$$y = Hx + n \quad (2)$$

The Shannon capacity expressed such a system mathematically as;

For SISO,

$$C = Blog_2\left[1+\rho\right] \quad (3)$$

B is the Bandwidth of the system and ρ is the SNR.

For SIMO

$$C = Blog_2\left[1+ N_{R\rho}\right] \quad (4)$$

The MISO capacity is expressed as

$$C = Blog_2\left[1+ g_d\rho\right] \quad (5)$$

Where $g_d = N_T \times N_R$, g_d is the full diversity gain.

And, MIMO capacity

$$C = Blog_2det\left[I_{NR} + \rho H H^H\right] \quad (6)$$

The spatial multiplexing gain of min (N_T,N_R) can be expressed as;

$$C = Bmin(N_T,N_R)log_2[1+\rho] \quad (7)$$

Full multiplexing gain can be achieved over an SU-MIMO channel if the antenna array elements at both ends are uncorrelated. As the antennas at either end become correlated, the average capacity of the channel decreases. If the antennas at either end become fully correlated, then the channel cannot support multiplexing, and the multiplexing gain is 1. Although, if sending data stream is transmitted with the same power from each of the transmit antennas N_T as the channel capacity is given as:

$$C = Blog_2det\left[I_{NR} + \frac{\rho}{N_T} HH^H\right] \quad (8)$$

2.3 LTE Link Level Throughput

The throughput theoretic bounds can be identified as the mutual information, the channel capacity, and the alleged achievable mutual information. An ideal transmission system should assume one of these bounds depending on the state of the channel information.

For the mutual information, the theoretical throughput with only SNR available at the transmitter side is;

$$C = \sum_{k=1}^{N_{tot}} Blog_2det\left(I_{NR} + \frac{1}{\sigma_n^2} H_K H_K^H\right) \quad (9)$$

Where;

B_{sub} = single subcarrier bandwidth,

$H_k = N_R \times N_T$ dimensional MIMO channel matrix of the k-th subcarrier

Where;

N_R = number of receive antennas

N_T = number of transmit antennas

σ = the energy of noise interference at the receiver

N_{tot} = number of usable subcarriers,

and I_{NR} is an identity matrix of size equal the number of receive antennas N_R.

It obvious equation (9) is independent of transmitting power and the N_T . The subcarrier bandwidth can be determined as

$$B_{sub} = \frac{N_s}{T_{sub} - T_{cp}} \quad (10)$$

Where;

N_s = the number of OFDM symbols in one subframe,

T_{sub} = the subframe duration (1 ms),

and T_{cp} = the time required for the transmission of all cyclic prefixes within one subframe. [4], [5], [14].

2.3.1 Channel Capacity of LTE Link Level

In frequency selective MIMO channel, the capacity of the channel can be determine by taking into account the singular value decomposition of the channel matrix H_k scaled by the standard deviation σ_n of the additive white Gaussian noise impairment [5, 21].

$$\frac{1}{\sigma_n} H_k = U_k \sum k\ V_k$$

$$\Sigma_k = diag\left\{\sqrt{\lambda_{k,m}}\right\} m = 1 \ldots \min\left(N_R, N_T\right) \quad (11)$$

V_k^H is optimum transmit filter, U_K is optimum receive filter and Σ_k is the diagonal eigen values of matrix H_k. k = 1. . . N_{tot}. The channel capacity is gotten by distributing the transmit power available over these parallel SISO sub-channels. The best attainable power distribution $P_{k,m}$ can be used to resolve an optimization problem.

$$C = \min_{P_{k,m}} \frac{1}{N_{tot}} \sum_{m=1}^{\min(N_R,N_T)} \sum_{k=1}^{N_{tot}} \log_2\left(1 + P_{k,m}\lambda_{k,m}\right)$$

$$subject\ to \sum_{m=1}^{min(N_R,N_T)} \sum_{k=1}^{N_{tot}} P_{k,m} = P_t$$

$$C = Blog_2det\left[I_{NR} + \rho H H^H\right] \quad (12)$$

2.3.2 Achievable Mutual Information

The achievable mutual information, in the open-loop transmission in which space-time coding technique is used at the transmitter is obtained as;

$$I_a^{OL} = \sum_{k=1}^{N_{tot}} FB_{sub} \frac{1}{N_L} log_2det\left(I_{NR\,Nl} + \frac{1}{\sigma_n^2} H_K H_K^H\right) \quad (13)$$

The achievable mutual information for closed-loop transmission can be calculated as [5, 21];

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$$I_a^{CL} = \max_{W \epsilon W} \sum_{k=1}^{N_{tot}} FB_{sub} log_2 det(I_{N_R} + \frac{1}{\sigma_n^2} H_K W W^H H_K^H) \quad (14)$$

Where;
F = correction factor
W = pre-coding matrix

3. Analysis and Simulation

3.1 DownLink Level Simulator Descriptions

This simulation is carried out in network context (system level) and on physical layer (link layer). LTE link level simulator for this research is flexible designed with a complete set of parameters configured to define the performances.

3.2 The Simulator Structure

The transmitter, channel model, and receiver in figure 2 are the link level simulator building block.

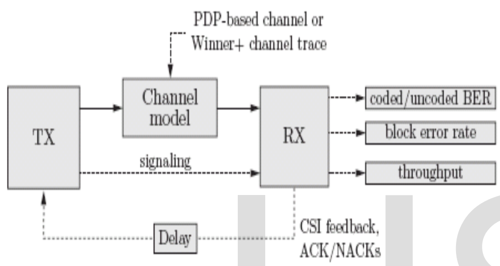

Fig. 2. LTE link level simulator structure.Magnetization as a function of applied field.

The solution is to divide the simulation into link and system levels. Link level simulation emulates all the facets of the communication involved in the link between a transmitter and a receiver. At the system level, many transmitters and receivers are found, though, individual communication links are not simulated but information from the link level simulation is used instead. The DL Link level simulator presented in this work is based on the LTE physical layer specifications [4], [12], [13] and the development framework is an open source program developed on MATLAB and C++ platforms. The C++ is used to record the computation for better efficiency and interfaced with MATLAB using MEX files.

The simulator implementation structure is shown in figure 3. At UE receiver after disassembling the resource blocks (RBs) in accordance with UE resource allocation, MIMO OFDM detection is carried out. The simulator supports Zero-Forcing (ZF), Linear Minimum Mean Squared Error (LMMSE), and soft sphere decoding as detection algorithms.

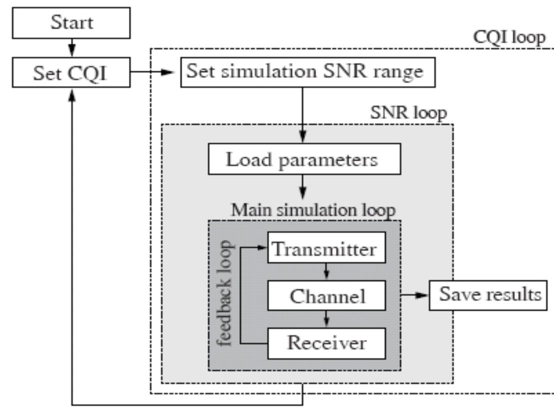

Fig. 3. Simulation scheme as implemented in the open source development platform. Magnetization as a function of applied field

3.3 Link Level Simulator Parameters

The assumption that the ideal channel estimation, a MIMO configuration of N_T and N_R, and also a SISO configuration, and Power Delay Profile (PDP) is multipath channel model [7],[8], the PDP channel gives the intensity of a signal received through a multipath channel as a function of time delay. Concerning E-UTRA turbo code block size ranges from 40 to 6144 bits and the turbo code internal inter-leaver parameters are specified in [12], and a code block sizes from 40 to 120 bits have been used for this simulation. Then, the block size for each simulation results is assigned RBs and the code rate. To analyze the baseline LTE performance, we choose the following simulation assumptions in Table 2 and Table 3. The MCS, including the CQI value used in the simulation are shown in Table 1.

Table 1: Modulation and Effective Code Rate (ECR).

CQI	Modulation	ECR	ECRx1024 [11]
1	4QAM	0.0762	78
2	4QAM	0.1172	120
3	4QAM	0.1885	193
4	4QAM	0.3008	308
5	4QAM	0.4385	449
6	4QAM	0.5879	602
7	16QAM	0.3691	378
8	16QAM	0.4785	490
9	16QAM	0.6016	616
10	64QAM	0.4551	466
11	64QAM	0.5537	567
12	64QAM	0.6504	666
13	64QAM	0.7539	772
14	64QAM	0.8525	873
15	64QAM	0.9258	948

Table 2: The Parameters assumptions used for the simula tion

Parameter	Value
Number of UEs	1
Bandwidth	1.4 MHz
HARQ	0
Retransmissions	AGWN, TU and Ped
Channel Type	B
Filtering	Block Fading
Receiver Type	Zero Forcing
Simulation	500 Subframes
Length	7 and 15
CQI	TxD 2X1 & 2X2,
Transmit Mode	OLSM 4x2 and
	CLSM 4x1 & 4x2

Table 3: Summarizes the Parameter assumptions used for the simulation

Parameter	**Value**
Carrier frequency	2.1 GHz (E-UTRA Band 4 or E-UTRA Band 10)
Transmission Bandwidth	1.4MHz
Subcarrier Spacing	15KHz
OFDM Cyclic Prefix	CP of 4.96µs (Normal), 7 modulation symbol per subframe
Number of Resource Blocks (RB)	6
Modulation Scheme	64QAM
Total number of useable subcarriers	72
Transmission Time Interval (TTI)/Subframe Duration	1ms
Simulation Length	100 Subframes
Channel Type	AGWN
Supported Channel Estimation	Perfect, LS, or MMSE
Filtering	Blocking Fading
Transmission mode (Antenna configuration schemes)	CLSM: 4x2 & 2x2, OLSM: 2x2 TxD: 2x2 & 2x1 and SISO
Precoding Type	Standard Defined Codebook
Supported Receiver Type	Zero Forcing MMSE and SSD
Supported HARQ Retransmissions	0.and 3 for retransmission

4 Results and Discussion

4.1 Multi-Antenna Channel Capacity Simulation

The equations 3, 4, 5 and 6 are executed in MATLAB for this simulation where the B value is taken as 1 with matrix elements of H (or H^H) modeled by Gaussian random variables with zero mean and unit variance that captures the stochastic nature of the wireless channel. The graphical performance analysis of SIMO, MIMO and MISO multi-antenna systems as against the SISO system is shown in figures 4 – 6.

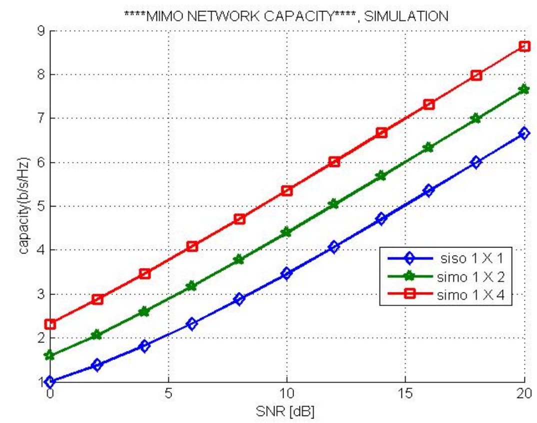

Fig. 4. Capacity of SISO and SIMO compared
The graph shows the performance analysis channel capacity of SISO and SIMO.

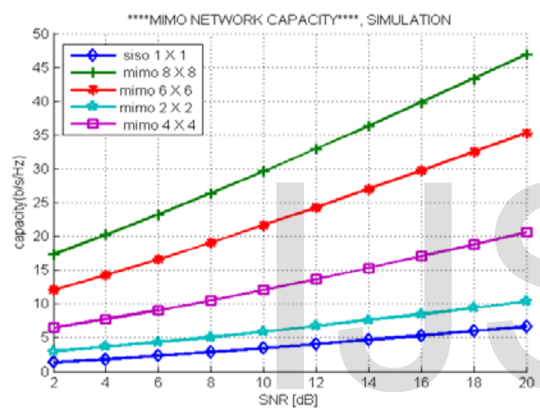

Fig. 5. Capacity of MIMO compared against SISO
The graph shows that the number of transmitting and receiving antenna is directly proportional to the channel capacity.

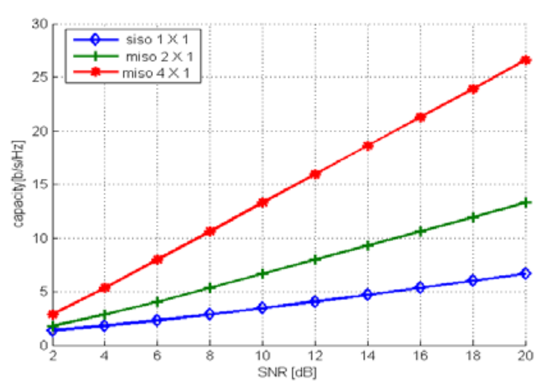

Fig. 6. Capacity of SISO and MISO compared.
As can be seen in figure 6, the MIMO system achieved higher capacity at the expense of SNR which is undesirable in mobile communication capacity.

4.2 LTE Link Level Throughput Simulation Results

The throughput for different transmit modes is shown in figure 7 and 8.

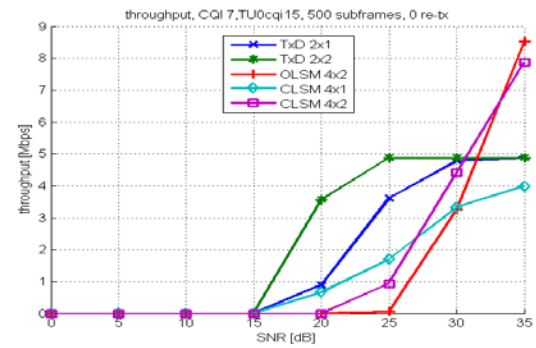

Fig. 7. LTE DL link level throughput of TxD 4x2, 2x & 2x2, OLSM 4x2, CLSM 4x2 & SISO 1x1.

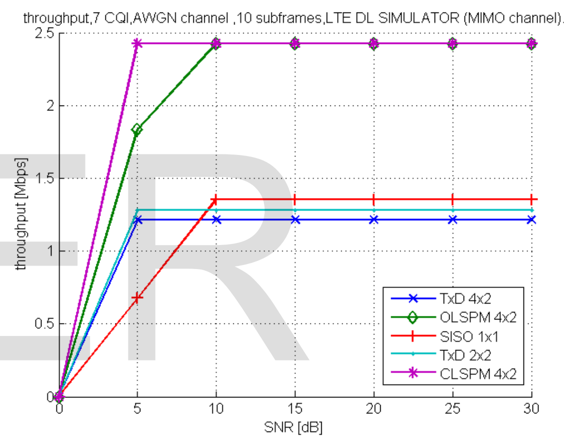

Fig. 8. AWGN channel (16-QAM) & [b] TU channel (64-QAM)

The two transmit diversity modes show the same throughput and the open-loop spatial multiplexing mode has a higher throughput at a high SNR. LTE BLER, Uncoded and Coded BER performance in this research show that the performance are in this order TxD, CLSM, SISO, and OLSM. In figure 9, the data throughput of SISO, 2x1 transmit diversity (TxD), 4x2 transmit diversity, and 2x2 Open Loop Spatial Multiplexing (OLSM) is compared when transmitting over an uncorrelated ITU Pedestrian B (PedB) channel with a simulation length of 1000 Sub-frames

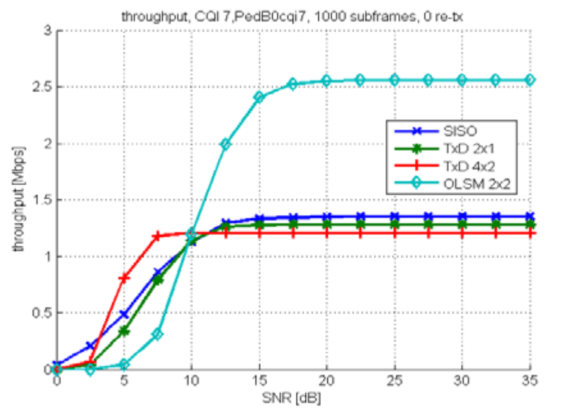

Fig. 9. LTE DL link level throughput performance of SISO, TxD 2x1, & 4x2, and OLSM 2x2 with no H-ARQ Transmission in PedB channel (Simulation Length: 1000 Sub-frames, CQI: 7 (16 QAM)).

In this simulation, the CQI value is set to 7, the 16 QAM is used as the modulation scheme and the maximum number of HARQ re-transmissions to zero.

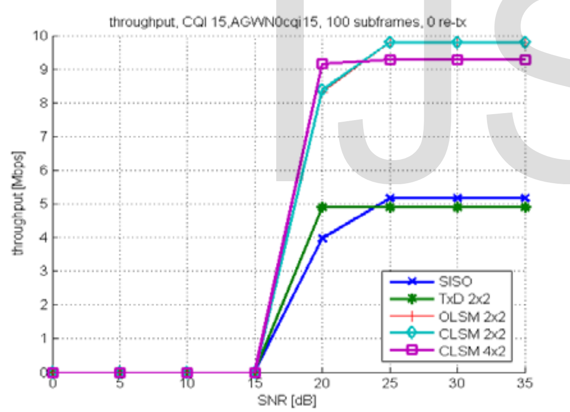

Fig. 10. LTE DL level throughput of SISO, TxD 2x2, OLSM 2x2 and CLSM 2 x2 & 4x2

The maximum throughput in MIMO scheme depends on number of transmit antennas and the number of data streams (layers). In the case of OLSM, two spatially separated data streams are transmitted thus leading to twice the maximum throughput of the 4x2 TxD system. Note that the results in figure 8 were obtained with channel adaptive pre-coding. The throughput results are shown in figures 10 and 11.

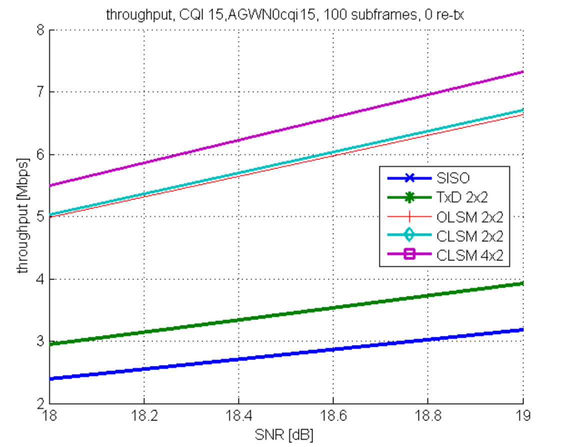

Fig. 11 Cross section of LTE DL level throughput in figure 10. CLSM 2x2 is slightly greater than OLSM 2x2 because of CSI feedback mechanism.

4.3 Comparison of Network Results with Literature

To validate this research work, the simulation results with an AWGN channel are presented in Table 4. The comparison of the network performance is often quite difficult with different assumptions and network configurations. However, the performance recorded in this work closely matched the best published literature.

Table 4 Simulation result compared against published results

Multi-antenna Scheme (Link leve throughput at 35 [dB])	SISO (1x1)	TxD (2x2)	OLSM (2x2)	CLSM (4x2)
Reference [6 (Mbits/s)	5.2333	4.9234	9.7050	9.5000
Simulation (Mbps)	5.1728	4.9024	9.8048	9.2768

5 Conclusions

This research presents the performance of multiple antenna techniques in LTE downlink transmission of a single cell setting and environment without interference. The average throughput and channel capacity are the two performance metrics used to evaluate the techniques. The results of the simulations show that CLSM has the best throughput compared to other multiple antenna schemes considered. However, MIMO spatial multiplexing offers the best capacity gains at high SNR though cellular systems typically operate at low SNR, with users at cell edges suffering from the poorest SNR, the simulation results show that OLSM is robust at high SNR followed by CLSM because of their ability to support high data throughput in addition to multi-stream transmission. This research strengthens the belief that performance of different

Multi-antenna scheme configurations is better than Single antenna scheme and that multi-stream transmission will be a practical method for improving the data throughput in LTE Networks than single stream transmission.

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