Performance Evaluation of Adaptive MIMO Switching in Long Term Evolution

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Abstract— In a race towards 4G technologies, future cellular network like Long Term Evolution (LTE) is competing with high data rates and improved spectrum efficiency. The target of this paper is to evaluate performance of Adaptive MIMO Switching (AMS) in LTE in terms of cell throughput and throughput gain with respect to other antenna configuration. The impact of different intersite distance on the performance of AMS was also investigated in this paper. The assessment was based on simulations using analytical channel model. Kronecker channel model without any Channel State Information (CSI) at transmitter was used for the simulation purposes. Adaptive MIMO switching works on the principle of switching among transmit diversity, receive diversity, and spatial multiplexing in accordance to SINR level. Simulation results reveal that significant improvement in cell throughput can be achieved by applying AMS technique. However, utilization of standard MIMO transmission techniques also improves channel capacity.

Keywords— Adaptive modulation and coding, Adaptive MIMO switching, Long term evolution, Channel capacity

I. INTRODUCTION

Cellular networks with Single-Input-Single-Output (SISO) systems offer limited channel capacity. Nowadays, interactive services are able to produce sufficient network traffic to create bottlenecks at radio interface. Multi Input Multi Output (MIMO) stands for multiple number of antennas at transmitter and receiving side. In transmit diversity multiple antennas are used at transmitting side; in receive diversity multiple antennas are used at receiver side. Transmit and receive diversity helps in improving the signal to interference noise ratio, but it does not directly improves the throughput [1]. Spatial multiplexing is another form of MIMO system, in which independent data stream are sent on each transmit antenna, roughly doubling the throughput.

LTE system categorized as an evolved cellular network and MIMO is important feature of LTE system. LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) in downlink and Single Carrier-Frequency Division Multiple Access (SC-FDMA) in uplink direction [2]. Mentioned access schemes can significantly improve spectral efficiency, but multiple antenna transmission further improves the spectral efficiency. LTE can be considered as a system with high spectral efficiency as a result of flexible radio interface [3]. In this paper MIMO transmission modes can be distinguished as transmit diversity with single receiving antenna (TD), receive diversity using Maximum Ratio Combining (MRC), and spatial multiplexing (SM) with equal number of multiple antennas at transmitting and receiving side. Transmit diversity is a basic MIMO setup, where each antenna is transmitting the same copy of data [2]. In MRC, the signals from the independent channel are combined at the receiver. Each branch signal is multiplied by weight factor such that branch with strong signal is further amplified, while weak signals are attenuated to provide better SINR. Third case is of SM, it means that each antenna is transmitting independent and different data stream. With SM data rates can be improved with higher efficiency comparing with TD and MRC [2].

This paper provides comparison between different transmission modes with different modulation and coding schemes. Emphasis was given on finding the average cell throughput in LTE, with different transmission modes. Performance of AMS with different intersite distance was investigated. Aim of this paper was to highlight the gain achieved by AMS. Research work of this paper was carried out by performing simulations in MATLAB environment.

The rest of the paper is organized as follows. Section II deals with LTE system features. In section III, detail about Shannon capacity, channel model along with channel capacity is presented. Description of simulation environment and simulation parameters is given in section IV. Section V is about simulation results and their analysis. Finally section VI concludes the paper.

II. LTE SYSTEM FEATURES

In this section, brief description of adaptive modulation and coding schemes, multiple antenna configuration, LTE physical layer, and adaptive MIMO switching is presented.

A. LTE Physical Layer

Essential improvement introduced in LTE system are new system access techniques i.e. OFDMA and SC-FDMA adopted in downlink and uplink directions, in reference to prior cellular system. It supports different bandwidth ranging from 1.25MHz to 20MHz, while sub-carrier spacing of 15 kHz remains constant [2]. Flexible bandwidth deployment made LTE system an attractive choice for the operators. Radio resources are being assigned to users dynamically which leads to higher flexibility.
Radio resources are allocated in reference to user demand. Resource block is considered as grid in time and frequency domain. Smallest data unit which can be allocated to a single user is a pair of resource block. Resource Block (RB) consists of 12 consecutive subcarriers in frequency domain for half ms in time domain. The transmission time interval (TTI) is one ms for LTE. There is parallel transmission of data with multiple subcarriers in downlink direction [3], [4].

In uplink transmission, as mentioned previously, SC-FDMA is used. This approach sustains low level of Peak to Average Power Ratio (PAPR) [4]. MU-MIMO transmission can be used in uplink direction as virtual multiple antenna transmission.

B. Adaptive Modulation and Channel Coding Rate

The data rate is adjusted by changing the modulation scheme and the channel coding rate. The process of adjusting the modulation scheme and coding rate is adaptive to instantaneous channel condition. In the downlink direction, the amount of transmitted data is directly dependent on high data rates over band limited system. Therefore, higher order modulation scheme is used. In uplink direction 64QAM is supported with certain channel coding rate. Coding rate shows the amount of bits used for channel coding purpose. Lower order modulation scheme e.g. QPSK is more robust to the errors compared with higher order modulation schemes. Therefore, higher order modulation such as 64QAM can be employed only when the channel conditions are good and have high signal to interference noise ratio. Modulation and coding schemes with their respected spectral efficiency used for the simulation purpose of this paper are presented in Table I.

<table>
<thead>
<tr>
<th>Modulation Scheme</th>
<th>Channel Coding Rate</th>
<th>Spectral Efficiency [bps/Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>1/3</td>
<td>0.67</td>
</tr>
<tr>
<td>QPSK</td>
<td>1/2</td>
<td>1.0</td>
</tr>
<tr>
<td>QPSK</td>
<td>2/3</td>
<td>1.33</td>
</tr>
<tr>
<td>QAM16</td>
<td>1/2</td>
<td>2.0</td>
</tr>
<tr>
<td>QAM16</td>
<td>2/3</td>
<td>2.67</td>
</tr>
<tr>
<td>QAM16</td>
<td>5/6</td>
<td>3.33</td>
</tr>
<tr>
<td>QAM64</td>
<td>2/3</td>
<td>4.0</td>
</tr>
<tr>
<td>QAM64</td>
<td>5/6</td>
<td>5.0</td>
</tr>
</tbody>
</table>

C. Multiple Antenna Configurations

Adaptive modulation and coding schemes, reduced transmission time interval (TTI) and advanced medium access technique helps in improving the spectral efficiency of LTE system. Still, spectral efficiency of the system can be further improved by multi antenna technique (MIMO). Previously advanced reception and transmission diversity techniques were implemented in UMTS. Reception diversity with single transmitting antenna is known as Single Input Multiple Output (SIMO) system [1]. Transmission with multiple antennas on transmitting end and single antenna at receiving end is known as Multiple Input Single Output (MISO) system, which is an example of transmit diversity [1]. Interference between antennas can be significantly reduced by applying spatial separation between antennas. Spatial separation between the antennas may decrease the correlation factor between the received signals coming from different antennas. In this paper, MIMO system with the same number of antennas on each transmitting and receiving side are considered as MIMO with spatial multiplexing (SM).

D. Adaptive MIMO Switching

To cope with increasing user demand of throughput, additional advanced antenna techniques are required from cellular systems. Adaptive MIMO switching (AMS) is a scheme of switching among different antenna transmission modes to maximize the user throughput with improved coverage and quality of service (QoS) [4]. In radio environment, channel conditions are continuously changing, transmission mode is selected by switching from diversity to spatial multiplexing or vice versa to provide maximum throughput. The target of AMS is to efficiently utilize the radio resources, maximizing the spectral efficiency. When the user experiences high signal to interference noise ratio e.g. near the eNodeB, spatial multiplexing is used and diversity techniques are used for the users at cell edge or with low SINR value. SINR threshold value for switching between the transmission modes depends upon the throughput [4].

III. CHANNEL CAPACITY

This section deals with capacity formulation for different antenna transmission modes.

A. Shannon Capacity

Shannon’s capacity mathematical formula presented in equation (1) is the basis for the research work of this paper. Shannon capacity theorem defines the theoretical upper bound for the maximum rate of data transfer considering white Gaussian noise. It states that channel capacity is proportional to the bandwidth W, and a logarithmic function of signal to noise power ratio SNR. It also shows that data rates are limited by the noise power [6].

\[ C = W \cdot \log_2(1 + SNR) \]  

If we consider bandwidth equals to 1 Hz, then equation (1) gives us the spectral efficiency of the channel as bits per second per hertz (bps/Hz). Shannon provided upper bound for capacity with respect to additive white Gaussian noise (AWGN) however practical channels differ much from the characteristics of AWGN channel. Shannon’s formula needs to be reconsidered for Rayleigh fading channel. Actual capacity of network is always less than Shannon capacity [6].
B. Kronecker Channel Model

Kronecker channel model is analytical channel model and belongs to the family of random channel matrix model. This model is applied to radio channels where Channel State Information (CSI) is not known at the transmission side. Propagation mechanism in the Kronecker model considers signal scatters located in the vicinity of transmitter and receiver [5]. Rayleigh fading is often used to model the non line of sight (NLOS) channel assuming scatters near the transmitter and receiver. Channel matrix is modelled by the Kronecker product of transmit and receive covariance matrix. MIMO channel can be modelled by Kronecker as given in equation (2) [5].

\[ H = R_T^{1/2} H_{IID} (R_R^{1/2})^T \]  

In equation (2), \( R_T \) and \( R_R \) are the transmit and receive covariance matrices respectively, \( (\cdot)^T \) performs the transpose operation of matrix. \( H_{IID} \) is a random fading MIMO channel matrix whose entries are independent and identically distributed (i.i.d). Each entry has Gaussian distribution with zero mean and unit variance. Kronecker model is inaccurate compare to Weichselberger model but simpler regarding computation [5].

C. Channel Capacity for Transmission Modes

In random matrix models all the factors affecting the input output relationship of the MIMO system are put together in random matrix \( H \). Factors like fading, interference between transmit and receive antennas, constructive and destructive interference caused by physical obstacles are taken into account while modelling the channel. Without CSI at transmitter, assuming equal power at all transmitting antennas, MIMO channel capacity can be given by the equation (3)

\[ C_{Gen} = \min(M_T,N_R) \log_2 \det \left( I_{n_R} + \frac{E_x}{M_T \sigma^2} H R_{xx} H^H \right) \]  

In equation (3), \( C_{Gen} \) represents capacity of general MIMO channel when CSI is unknown at the transmitter. Total average energy at the transmitter side is denoted by \( E_x \), and it is equally divided among all transmit antennas. \( M_T \) and \( N_R \) represents number of transmission and receive antennas respectively. \( H \) represents random channel matrix where \( H^H \) is Hermitian’s transposition of matrix \( H \). \( I_{n_R} \) refers to identity matrix, whereas \( R_{xx} \) stands for covariance matrix at transmitter. Average Gaussian noise power is expressed by \( \sigma^2 \). Assuming perfect flat channel, with unity covariance matrix and total transmission power is equally divided among all transmit antennas, equation (3) can be transformed for different transmission mode as [7]

\[ C_{SISO} = C_{MISO} = \log_2 \det \left( 1 + \frac{E_x}{\sigma^2} \right) \]  

\[ C_{SIMO} = \log_2 \det \left( 1 + \frac{E_x \cdot N_R}{\sigma^2} \right) \]  

From equation (4) it can be seen that MISO system does not offer any increase in capacity, because there is no diversity at the receiver. At one time only one data pipe is active, and transmission power is equally divided among all transmit antennas [7]. However, MRC helps in improving the SINR which practically increases channel capacity as seen in equation (5). Equation (6) shows that ideally capacity can be doubled compare to SISO system by increasing 3 dB transmission power in case of 2 transmit and receive antennas.

\[ C_{MIMO_{nax}} = n \log_2 \det \left( 1 + \frac{E_x}{n \cdot \sigma^2} \right) \]  

IV. SIMULATION ENVIRONMENT AND SIMULATION PARAMETERS

MATLAB was used as simulation tool for performing simulations for the research work of this paper. Impact of different antenna transmission modes over the throughput of LTE system with different inter site distance was analyzed. These simulations were done with seven sites, with three cells on each site. Single site was interfered by six other sites. Users with full traffic buffer were assumed i.e. they always have data to transmit. Every user tries to get as much throughput as possible. Cell resources were equally divided among all active users in cell, leaving no unused resources at any TTI. Therefore cell loading of 100% was assumed along with 100% other cell loading in neighboring cells. Number of users supported in any TTI was fixed, and users were homogenously distributed over the cell area. Location of users was random, with flat distribution over the coverage area of the cell.

COST231 Hata model was used as radio propagation model for calculating the path loss between the user and the eNodeB. Only modulation and coding schemes presented in Table I were assumed for simulation purpose. General parameters of LTE used for the simulation are presented in Table II.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downlink</td>
<td>Area type</td>
<td>Urban</td>
</tr>
<tr>
<td>Operating frequency band</td>
<td>MHz</td>
<td>2600</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>MHz</td>
<td>20</td>
</tr>
<tr>
<td>Carrier spacing</td>
<td>kHz</td>
<td>15</td>
</tr>
<tr>
<td>Total resource block (RB)</td>
<td>No.</td>
<td>100</td>
</tr>
<tr>
<td>Transmission power</td>
<td>dBm</td>
<td>43</td>
</tr>
<tr>
<td>Antenna gain</td>
<td>dBi</td>
<td>18</td>
</tr>
<tr>
<td>Antenna height</td>
<td>m</td>
<td>25</td>
</tr>
<tr>
<td>Cyclic prefix</td>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>Number of users per TTI</td>
<td>No.</td>
<td>5</td>
</tr>
<tr>
<td>Cell loading</td>
<td>%</td>
<td>100</td>
</tr>
<tr>
<td>UE noise figure</td>
<td>dB</td>
<td>8</td>
</tr>
<tr>
<td>Data activity factor</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
V. SIMULATION RESULTS AND ANALYSIS

In Fig.1 required SINR value against spectral efficiency per antenna for different antenna configuration is shown. For more than one antenna at transmit side, same modulation and coding scheme was assumed for all antennas. SIMO and MISO are providing receive and transmit diversity respectively. MIMO2x2 and MIMO4x4 are working on the principle of spatial multiplexing. It can be seen that SIMO system performs best in low SINR condition among all other antenna configurations. SIMO system performs very similar to SISO system as total transmission power was divided between the transmit antennas; therefore advantage of channel gain is not significant. MIMO 4x4 has highest SINR requirement and works well in good SINR condition. In adaptive MIMO switching, different antenna configuration is selected on the basis of achieved maximum throughput.

In Fig.2 average cell throughput against intersite distance for different antenna configuration is shown. It can be seen that the average cell throughput achieved by using AMS is better than average cell throughput by any individual antenna configuration. In Fig.2 AMS2x2 considers adaptive MIMO switching with maximum two antennas at transmitting and receiving side, with AMS4x4 maximum of 4 transmit and receive antennas were considered. Average cell throughput achieved by SIMO system was found similar to MIMO2x2, while keeping the total transmission power fixed and constant in both cases. In Fig.2 highest cell throughput was achieved with lowest intersite distance. By analyzing the results presented in Fig.2 it was found that by increasing the intersite distance average cell throughput is decreased.

In Fig.3 relative throughput gain for different antenna configurations against intersite distance is shown. Relative throughput gain with respect to single input and single output (SISO) system is plotted in Fig.3. It was found that although average cell throughput achieved by AMS decreases with increasing intersite distance as shown in Fig.2, but relative throughput gain increases with increasing intersite distance. It can be seen by adopting spatial multiplexing with two transmit and receive antennas (MIMO2x2), relative throughput gain does not improve by 100% with respect to SISO system. Only 20% gain was observed by adopting spatial multiplexing for MIMO2x2 with 1000m intersite distance. With AMS2x2 and AMS4x4 relative gain of 50% and 75% can be achieved respectively at 1000m intersite distance. It was found that AMS performs better with large intersite distance.

Fig.4 shows the cumulative distribution functions (CDF) of cell throughput for different intersite distances, achieved by using adaptive MIMO switching (AMS) with maximum two antennas at transmitting and receiving side in LTE system. There is high probability of no data transfer with large intersite distance, because of limited transmission power at eNodeB for downlink direction. Better results are achieved with smaller intersite distance. Probability of having cell throughput above 50Mbps is 34%, 23%, 9.5% and 1.5% with 1000m, 2000m, 3000m and 4500m correspondingly. Mean value of cell throughput with AMS for different intersite distance can be seen from Fig.4.
Fig. 5 shows the cumulative distribution functions (CDF) of cell throughput for different intersite distances, achieved by using adaptive MIMO switching (AMS) with maximum four antennas at transmitting and receiving side in LTE system. By comparing results presented in Fig. 4 and Fig. 5 it was found that upper part of CDF curves of throughput with different intersite distances shifts to right in Fig. 5, which shows enhanced throughput results with AMS4x4 compared to AMS2x2. Performance of AMS4x4 is similar to AMS2x2 in low SINR condition, actual throughput gain from AMS4x4 is attain in good SINR condition.

![Fig. 4. CDF plot of AMS 2x2 throughput for different ISD](image)

![Fig. 5. CDF plot of AMS 4x4 throughput for different ISD](image)

Fig. 6 shows the cumulative distribution functions (CDF) of cell throughput with 1000m intersite distance for different antenna configuration in LTE system. CDF of cell throughput for MISO system seems to follow the similar behaviour when compared with SISO system. But performance of SIMO was found better. It can be seen that the activation of adaptive MIMO switching enhances the cell throughput significantly. Effective utilization of spatial multiplexing in good SINR condition and exploiting diversity techniques in bad SINR condition improves the overall cell throughput by adaptive MIMO switching. Probability of having cell throughput above 30Mbps is 57% with MIMO4x4, whereas probability of having cell throughput above 30Mbps is 86% with adaptive MIMO switching. Similarly, probability of having throughput above 70Mbps is only 12%, 5.5%, and 20% with MIMO4x4, AMS2x2 and AMS4x4 respectively.

VI. CONCLUSION

Adaptive modulation and coding scheme along with multiple antennas transmission improves spectral efficiency, but the analysis of results shows that average cell throughput can be further enhanced by adopting adaptive MIMO switching. Significant improvement in cell throughput was observed with AMS. It was found that average cell throughput decreases but the relative throughput gain achieved by AMS increases with the increase in intersite distance. A noticeable gain was observed by AMS in small cells as well as in large cells. AMS efficiently utilizes the radio resources, and improves the overall spectral efficiency of LTE system.

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REFERENCES


![Fig. 6. CDF of throughput with 1000m ISD for different transmission mode](image)