Analysis of Channel Capacity using MIMO-OFDM for 4G Applications

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***Abstract*: To reach and connect people all around, unlike previous generations, 4G is a set of evolved network technologies which aim to provide dramatically fast data rates. This can be best achieved using Multiple Input Multiple Output (MIMO) Antenna system, as MIMO has the potential to enhance the system capacity of wireless communication. This paper focuses on increasing the channel capacity, reliability i.e., lowering the Bit Error Rate(BER) and improving the spectral efficiency for MIMO systems. Since the technology behind is Orthogonal Frequency Division Multiplexing (OFDM), the above advantages are achieved at a very low transmitted power in the entire system which makes it smart yet state of the art.**

Keywords- MIMO, BER, OFDM, LTE (Long Term Evolution), PAPR (Peak to Average PowerRatio),CSI (Channel State Information).

I. INTRODUCTION

The recent advancement in the domain of wireless communication has accelerated through the growth of Long Term Evolution (LTE), commonly marketed as 4G LTE. The main acceptance from the entire 4G system in future is to have the potential to drive high data rates for a large number of users at every corner and at any time in the world. Here, a further goal has been re-designed to simplify the network architecture from a partially IP based network of 3G system to a complete IP based system so as to have a reduced transfer latency, so as to have a maximum utilisation of radio spectrum with complete security and high end user experience. For providing maximum data rates with complete channel utilisation, Worldwide Interoperability for Microwave Access(Wi-MAX) is the backbone of 4G LTE [1]. There was a need to increase the capacity of the Wi-MAX system to a large extent and thus the concept of MIMO antennas came into the picture. To achieve the most significant technological breakthrough in modern wireless mobile communication MIMO can be considered to be the ultimate trendsetter[2]. However due to modernisation there was sudden rise in mobile network traffic and there was a bottleneck of solving the problem of approximate same high speed internet access to all the User Equipment (UE) coming under a definite coverage area. In MIMO systems the transmitted signals from one end of multiple transmitting (Tx) antennas and the receiving (Rx) antennas on the other side are combined to achieve spatial multiplexing which provides a seamless connection to the existing network such as GSM, CDMA and WCDMA to achieve a low bit error rate with significant high data rates for the user. The priority of MIMO system is to have a key feature of "space-time" signal processing and an ability to turn multipath propagation into an advantage of the network architecture[3]. The concept of enabling high multiplexing gain is achieved by simultaneous operating on parallel channels [4]. To nullify the various drawbacks faced earlier, a robust system comes into realisation with high spectral efficiency, increasing capacityand coverage improvements through the multiplexing gain of MIMO pattern of antennas. A boost in the system performance is further advantageous as the above parameters are achieved at a very low transmitted power even though neglecting the complexity of MIMO receivers [5]. Higher capacity gain, interference management capabilities, efficient spectrumand to combat multipath feeding Orthogonal Frequency Division MultipleAccess (OFDMA) is the promising tool for the evolution of high speed communication network achieved through MIMO system. The fading coefficients needs to be independent for each user in the entire OFDMA system alongwith Channel State Information (CSI) at the transmitter end helps in further increase of the capacity of the channel by having concept of Selectivity of the best user for each subcarrier and accordingly the allocation of the transmitted power is done. All this is achieved through two different frame structures which are Frequency Division Duplexing (FDD)and Time Division Duplexing (TDD). LTE supports scalable carrier bandwidths from 1.4 MHz to 20 MHz. With increased spectrum stability alongwith low data transfer latencies (sub-5ms latency for small IP packets in optimal conditions), the handover and connection setup time has been reduced alongwith improved support for mobility which provides a good Quality of Service (QoS) with a good end user experience.

II. MIMO SYSTEM MODEL

To have a uniform coverage along with signal strength and signal quality, omni-directional antennas are used for MIMO system so as to transmit and receive well equally in all directions.

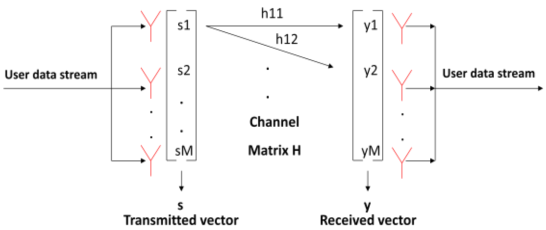

Fig 1. MIMO antenna configuration

To establish a linear link model the vector notations of the transmitting and receiving antennas of a narrow band single user MIMO system is as follows [6]:

$$\mathbf{y=Hx+n} \quad (1)$$

where y is $\mathbf{N_R \times 1}$ is the received signal vector , x is the transmitted signal vector represented by $\mathbf{N_T \times 1}$ and n is the complex Gaussian noise vector having equal variance and zero mean. The channel matrix H is represented by:

$$H = \underset{MR}{\left[\begin{array}{cccc} h11 & h21 & \ldots\ldots & hM1 \\ h12 & h22 & \ldots\ldots & hM2 \\ . & . & \ldots\ldots & . \\ h1M & h2M & \ldots\ldots & hMM \end{array}\right]}^{MT} \quad (2)$$

$\mathbf{h_{ij}}$ is a Complex Gaussian random variable that models fading gain between the $\mathbf{i^{th}}$ transmit and $\mathbf{j^{th}}$ receive antenna.

The downlink data transmission of a cellular system is based on the multi-user MIMO model. The resource allocation and transmission of downlink data to the users is done through by the usage of N_T transmit antennas and N_R receives antennas which is controlled and monitored by the base station. To achieve optimal performance at two ends of transmission and reception two schemes are proposed below:

A. Maximal Ratio Combining Scheme

To improve signal strength for MIMO antenna systems Maximal Ratio Combining (MRC) Schemeis a promising technique. The methodology used here involves multiplication by a weight factor to each signal branch which is proportional to the signal amplitude. Here the concept is to amplify the stronger signal and attenuate the weaker signal.

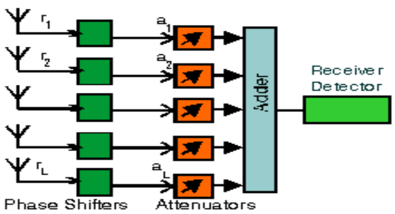

Fig2. MIMO Receiver using MRC scheme

In the above figure the phase shifters plays the role of converting the out of phase signals to in-phase signals.

```
Command Window
>> mrc
SNR on channel 1 is supposed to be 20 dB.  Actually is 20.11 dB
SNR on channel 2 is supposed to be 15 dB.  Actually is 15.00 dB
SNR on channel 3 is supposed to be 12 dB.  Actually is 12.13 dB
SNR after MRC    is supposed to be 21.7 dB.  Actually is 21.82 dB
>> mrc
SNR on channel 1 is supposed to be  3 dB.  Actually is 2.98 dB
SNR on channel 2 is supposed to be 15 dB.  Actually is 15.01 dB
SNR on channel 3 is supposed to be 12 dB.  Actually is 12.12 dB
SNR after MRC    is supposed to be 16.9 dB.  Actually is 16.99 dB
fx >>
```

Fig 3.Simulation output of MRC scheme

From the above output it is observed that when the signal is strong further amplification to the nearest level is done and after combining all the signals the overall output is closer to the strongest signal. Similarly for the weaker signals attenuation is done so as to nullify their effect on the system.

B. Spatial Multiplexing Scheme

To have a higher data rate in the same channel the configuration of multiple independent links between the transmitter and the receiver has to be done in a cross-path design between the antennas. Decoupling by digital signal processing is done having fine correlation.

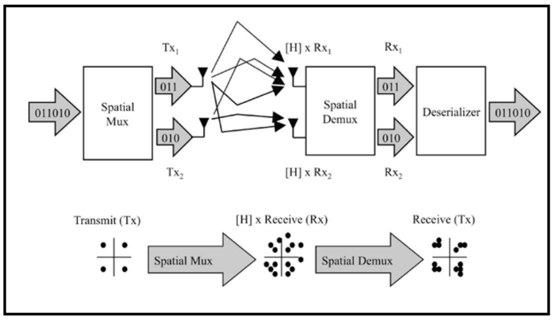

Fig 4. MIMO system to implement spatial multiplexing

The incoming data is divided into multiple independent sub streams so as to have a high spectral efficiency through the MIMO transmit technique where the divided data is simultaneously transmitted. Channel dependent linear processing of the data substreams is only possible where there is an availability of perfect Channel State Information (CSI) at both sides of the link. Here the reliability of the data substreams are improved by adapting transmitted signal of the Eigen-structure to the instantaneous channel where different parallel channels are established through the strongest channel Eigenmodes. For Spatial multiplexing of MIMO system the average bit error rate and the signal to noise ratio are characterized by the parameters diversity and array gain.

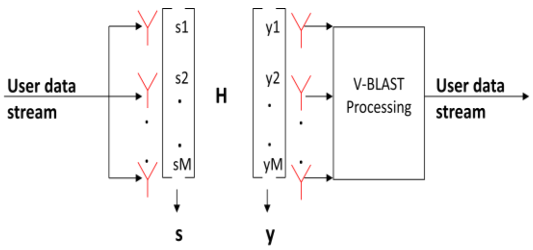

Fig 5. V-BLAST Spatial Multiplexing

This is the only architecture that provides the maximum data rate. The brief process is summarized below:

1. The data is split into MT data stream →map to symbols →send
2. Assuming receiver knows H
3. Uses old technique of ordered successive cancellation to recover signals
4. Sensitive to estimation errors in H

5. rs = MT because in one symbol period, we are sending MT different symbols.

III. MIMO CHANNEL CAPACITY

To increase capacity and keeping bandwidth and transmitting power same is now a well accepted fact by just putting more antennas at the transmission and reception side. MIMO capacity is best understood through the channel matrix having j^{th}(j = 1, 2 ,..., n_t) transmit antenna and i^{th} (i= 1, 2 ,......, n_r) receive antenna referring to the above channel matrix from equation (1). The Rayleigh model is the random channel that has been used. A complex matrix that has identically independent distributed entries with unit variance and zero mean is used to approximate a channel in the frequency domain. A lower bound generalized capacity formula that is applicable for any MIMO system:

$$C = \log_2(\det [I_{n_r} + (\rho/n_t) H H^T]) b/s/Hz \quad (3)$$

In the above equation, determinant is symbolized by " det ", Identity matrix (I_{n_r}) having dimension $n_r \times n_t$, and " H^T " is the transpose conjugate for the channel matrix H. Lower bound capacity for the (n,n) in terms of independent chi-squared variable with second degree of freedom is as follows:

$$C > \sum_{k=1}^{n} \log_2 [1 + (\rho/n).\chi_{2k}^2] b/s/Hz \quad (4)$$

Optimum ratio combining or receive diversity(n_r=n_t=n) for the capacity formula is:

$$C = \log_2[1+\rho.\chi_{2n}^2] \text{ b/s/Hz} \quad (5)$$

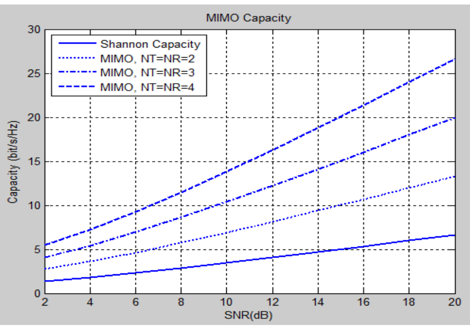

Fig 6. Capacity vs SNR plot for MIMO system

On increasing the number of antennas the SNR of the system increases hand in hand which refers to the increase in capacity of the MIMO system.

IV. PEFORMANCE ENHANCEMENT OF MIMO USING OFDM

The LTE physical layer is based on"Orthogonal Frequency Division Multiplexing(OFDM) technology" and the fundamental principle of OFDM is to use a large number of narrowband, orthogonal subcarriers to carry data transmission instead of using a single wideband carrier.It should be noted that in case of independent modulation in OFDM transmission, it is possible for each subcarrier to be independently modulated and the techniques that can be used are: QPSK, 16-QAM, 64 QAM.

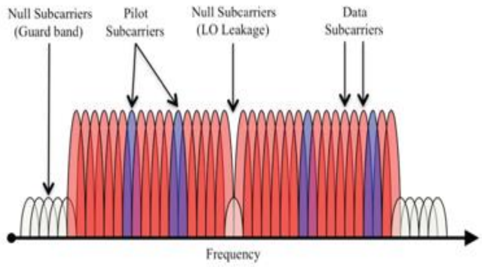

Fig 7. OFDM signal in frequency domain

Here the overlapping &orthogonality of subcarriers allows a better spectral efficiency than single carrier modulation scheme. Also a significant number of subcarriers at the band edge are kept null as guard band to reduce the inter-symbol interference (ISI) which is thus a great application in mobile-wireless communication. OFDM is used for downlink for the LTE standard.In OFDMA scheme, the multiple subcarriers are grouped into resource blocks that can be dedicated to individual users.

A. LTE Downlink Channel Structure

The fundamental design of the LTE downlink signal is orthogonal frequency division multiple access(OFDMA) and is based on multicarrier frequency division access(FDMA) where users are assigned orthogonal sets of subcarriers.OFDMA enables OFDM transmission to benefit from multi-user facility.

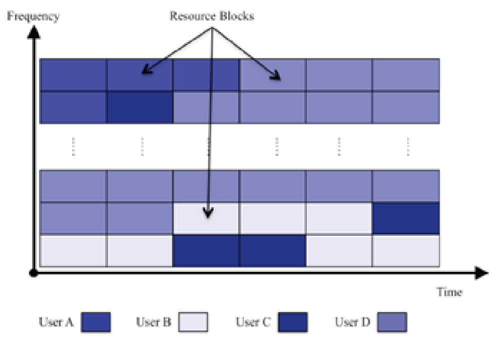

Fig 8:Allocation of resource blocks to various users

Each resource grid can be described by the following parameters: number of downlink resource blocks, the number of subcarriers in each resource block, number of OFDM symbols in each block.

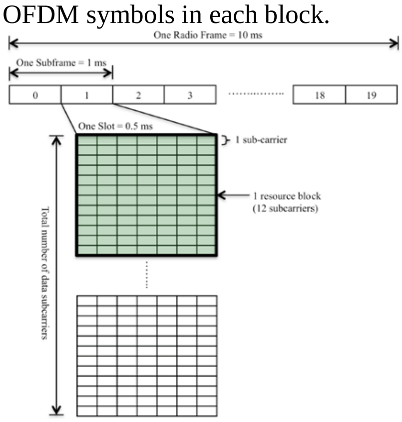

Fig 9: Assignment of orthogonal sets of subcarriers

B. LTE Uplink Channel Structure

The LTE Uplink uses SC-FDMA(Single Carrier Frequency Division Multiple Access). Here SC-FDMA is unique as it uses a special signal processing to reduce the peak to average power ratio(PAPR)of the signal [7].Due to sufficient low PAPR of the transmitted waveform the battery life is enhanced.

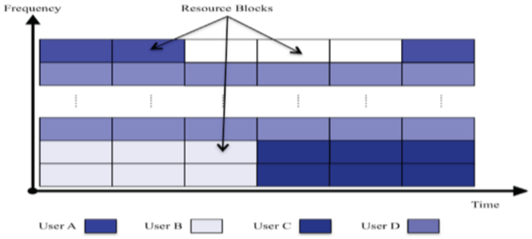

Fig 10: Uplink frequency allocation of resource blocks

V. CONCLUSION

In this paper the performance evaluation of MIMO OFDM has been studied with respect to its channel structure and frequency allocation. All the simulations have been performed using MATLAB. The practical variation in the channel has been studied with respect to the varying SNR and considering the AWGN with Rayleigh fading.It was found that by increasing the number of transmitting and receiving antennas the channel capacity of the MIMO system substantially increases. A recent trend in the research activities and observations with respect to antennas and propagations in MIMO system architecture have been reviewed.

REFERENCES

[1] Integrated AP for Seamless Interworking of Existing WMAN and WLAN Standards S. Frattasi, E. Cianca, and R. Prasad,-An, Wireless Personal Communications, vol. 36, no. 4, pp. 445–459, 2006 .

[2] Broadband wireless access with WiMAX/802 Current performance benchmarks and future potential A. Ghosh, D. Wolter, J. Andrews, and R. Chen,IEEE Communications Magazine, vol. 43, no. 2, pp. 129–136, 2005

[3] Multipath signal effect on the capacity of MIMO, MIMO-OFDM and spread MIMO OFDMUthansakul, P.; Bialkowski, M.E.Microwaves, Radar and Wireless Communications, 2004. MIKON-2004. 15th International Conference on Year: 2004, Volume: 3 Pages: 989 - 992 Vol.3, DOI: 10.1109/MIKON.2004.1358536.

[4] MIMO wireless channels: capacity and performance prediction D. Gesbert, H. Bolcskei, D. Gore, and A. Paulraj, in IEEE Global Telecommun Conf. (GLOBECOM'00), vol. 2, 2000.

[5] CDMA Dynamic Downlink Power ControlLei Song and Jack M. Holtzman, In Proceedings of the Vehicular Technology Conference (VTC'98), volume 2, pages 1101{1105, Ottawa, Canada, 1998.

[6] Compressive spectrum sensing for MIMO-OFDM based Cognitive Radio networksShan Jin; Xi ZhangWireless Communications and Networking Conference (WCNC), 2015 IEEE Year: 2015 Pages: 2197 2202, DOI: 10.1109/WCNC.2015.7127808.

[7] PAPR Analysis and Mitigation Algorithms for Beamforming MIMO OFDMkSystemsYing-Che Hung; Shang-Ho Tsai, 2014, Volume: 13, Issue: 5Pages: 2588, 2600, DOI: 10.1109/TWC.2014.031914. 130347.

[8] Implementation of MIMO-OFDM using adaptive multiuser detection in wireless communicationParveen, N.; Venkateswarlu, D.S.Communications, Devices and Intelligent Systems (CODIS), 2012 International Conference on Year: 2012 Pages: 381 - 384, DOI: 10.1109/ CODIS.2012.6422218.

[9] Financial analysis of 4G network deploymentYanjiao Chen; LingjieDuan; Qian ZhangComputer Communications (INFOCOM), 2015 IEEE Conference onYear: 2015Pages: 1607 - 1615, DOI: 10.1109/INFOCOM.2015.7218540.

[10] MIMO filter-bank multicarrier system using unique word OFDMMohammadi, Z.; Zamiri-Jafarian, H.Electrical Engineering (ICEE), 2015 23rd Iranian Conference onYear: 2015Pages: 483 - 488, DOI: 10.1109 /Iranian CEE.2015.7146263.

[11] **A** road to future broadband wireless access: MIMO-OFDM-Based air interfaceHongwei YangCommunications Magazine, IEEEYear: 2005, Volume: 43, Issue: 1Pages: 53 - 60, DOI: 10.1109/MCOM.2005.1381875.