https://doi.org/10.1109/BlackSeaCom.2014.6849019

Challenges of Using MIMO Channel Technology in 5G wireless Communication Systems

Dr.Intisar Al-Mejibli
Informatics Systems Management Dept.,
University Of Information Technology and Communications,Baghdad,Iraq
Dr.intisar.almejibli@gmail.com

Dr.Salah Al-Majeed ,Senior member IEEE,Srilatha Pamuri
Systems Engineering Dept.,
Military Technological College,
Muscat,Oman
Salah.almajeed@mtc.edu.om

Abstract—**Multiple input multiple output (MIMO) systems, which are suitable for mmWave communications, facilitate building large arrays of communication channel with Reasonable form factors indoor and outdoor communications. In both, indoors and outdoors communications a reasonable coverage can be achieved by the high gains of array. Deploying MIMO systems in frequency-division duplex mode faces the issue of high feedback overhead of channel state information (CSI) to the transmitter. This issue is attributed to the used multiplexing algorithm. From other hand, it is expected that by 2020, all new 5G technologies will be in operation. Hence, it is crucial to investigate and analyze using the MIMO system with orthogonal frequency-division multiplexing OFDM modulation in 5G technology. This research sheds light on the potential challenges of implementing MIMO- OFDM in 5G technology. It proposed four models with different number of transmitter and receiver antenna elements in the array. All proposed model used 2 elements per row in transmitter and receiver antenna. The four models are implemented in two cases Line of sight LOS and Non Line of Sight NLOS. The channel rank and condition number of channel matrix are regarded as significant and accurate mathematical indicators which can be used to evaluation MIMO channel technology. The condition number is calculated from the obtained results of four models with rank of channel metrics.**

Keywords—***5G; Channel Coefficient*** $\mathbf{h_{(m,k)}(f)}$ ***; MIMO ; NLOS; OFDM; SISO.***

I. INTRODUCTION

The demand on higher data rates, services with better quality and fully mobile and connected wireless network is increased. 5G technology satisfies the previous demands as it is anticipated that 5G wireless networks will achieve 10 times higher than 4G in spectral efficiency and energy efficiency. That required significant changes in the layers design of 5G communication systems. Multiple input multiple output (MIMO) technologies is one of candidate for the physical layer design of 5G networks. MIMO based on transmitting different signals over multiple antennas to gain capacity. During the mid-1990s, Research studies showed that, though combining MIMO with popular air interfaces for instance time-division multiple access (TDMA) and code-division multiple access (CDMA) improves communications quality, using MIMO and OFDM is most effective at higher data rates [1]. Using OFDM modulation with MIMO will provide more reliable communications at high speeds because OFDM divides a radio channel into a large number of sub channels that are closely spaced [2].

Soon, 5G will impact all people lives in multiple areas such as education, healthcare, transportation and banking. 5G technology will developed these industries technically, in the same time, the network specialists must work hard to make this technology commercially viable and to overcome any challenges may appear. One of the significant aspect is ensuring the cost of using the 5G mobile network reasonable regardless the implemented industries. As the vast range of 5G industries, specialists will need to identify and manage several new commercial arrangements and cost structures [3]. Moreover, great effort must be made by scientists and specialists to study, analyze implementing 5G technology using current wireless communication techniques and technologies.

This research investigates and evaluates using MIMO-OFDM in 5G wireless communication system by implementing four models, each with distinct parameters. These models calculate and compare the condition number and rank of channel matrix from the resulting models files.

The rest of this paper is organized as follows: section two presents the 5G technology, and MIMO channel is described in section three. Evaluate MIMO channel is explained in section four. Section five introduces the simulated models. Conclusion is described in section six.

II. 5G TECHNOLOGY

Although, the current status of the 5G technology is its early development stages, the 5G technology and its services have attracted the attention of specialists and researchers. Currently, the researches that study, analyze and investigate 5G technology from different aspects are still few and needs more effort from the researchers to enrich this field. Generally, advanced technologies could be used to become part of a new 5G system because of that several companies are looking into these technologies. Additionally, 5G research units that focus on developing the 5G technologies, have established in many universities.

There are a common challenges that faced 5G technology such as research methodology, lack of infrastructure, and cost. From the other hand, standardization is regarded as the main challenging in 5G technology as it it's critical to ensure universal interoperability of this new technology [3]. From the point of view commentator state: 5G is ubiquitous access to services with high & low data rate.

III. MIMO CHANNEL

MIMO technologies are the key variables of state-of-the-art mobile radio systems and are essential to accomplish extremely ambitious objectives of capacity such as giving stable data rates [4].

MIMO channel is the channel that use both multiple transmit and multiple receive antennas. MIMO channel provides extra spatial dimension for communication, results in a degree-of- freedom gain via beam forming and increase reliability. These additional degrees of freedom can be exploited to spatially multiplexing many of data streams onto the MIMO channel which results in increasing the capacity. The n transmit and receive antennas in such MIMO channel capacity is proportional to n [5]. A basic 2x2 spatial multiplexing is showed in Fig. 1.

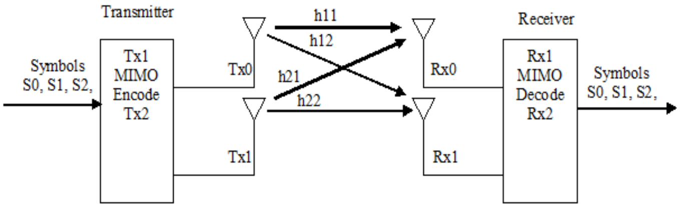

Fig. 1. MIMO configuration of 2x2 spatial multiplexing with the associated four complex channel coefficients.

A continuous evaluation of complex matrices is required to evaluate the status of a MIMO channel. The channel rank and condition number are viewed as generally straightforward mathematical indicators that can be used to measure the quality of MIMO channel [5].

The maximum channel capacity is calculated by using the bandwidth B and the effective signal-to-noise ratio (SNR). In accordance with the Shannon-Hartley theorem for single input single output (SISO), the maximum channel capacity C is calculated as expressed in formula 1 [6] : $C = B * \mathrm{Log}_2\ (1 + \frac{P}{N})$ (1)

where P is the received signal power and N is the noise power. Achieving the targeted peak data rates essentially depend on the available channel bandwidth B because B has a directly proportionate effect on the channel capacity.

In wireless communication, the signal-to-noise ratio is a function of the physical distance between the receiver (such as a smart phone) and the base station, so it is location-dependent value. The performance or transmission quality is mainly affected by SNR which is decisive for it and therefore for the actual data throughput in a wireless cell [7].

These two channel attributes can be improved by using designed MIMO system and without increasing the bandwidth or transmit signal power. Diversity of transmit and/or receive antenna can improve the channel performance. Increasing the channel capacity can be achieved by apply spatial multiplexing. Consequently, apply spatial multiplexing alone results a significant increase in the channel capacity because it offers the possibility of multilayer data signals transmission. Calculating the MIMO channel capacity will become very complicated process compared to the aforementioned Shannon-Hartley theorem for (SISO). However, calculating the SISO channel capacity as M-times by Shannon can be used to estimate the greatest possible MIMO channel capacity as M-layer data transmission [8]. Better channel conditions and higher SNR than an equivalent SISO system are required for successful spatial multiplexing.

IV. EVALUATE MIMO CHANNEL

Evaluate the MIMO characteristics of a mobile radio channel requires an appropriate mathematical model that includes set of linear equations [7]. Transmit and receive signal vector form are used to represent the transmitter and receiver respectively. The real transmission feature, or the present channel state, is summarized in a matrix which is useful in assessing the MIMO channel [7].

The condition number is characterized as the proportion of the largest to smallest singular value in the singular value decomposition of a matrix. Additionally, in the context of wireless communications, it is a metric to characterize the quality of MIMO channels [9].

A well-conditioned system of linear equations has small condition number value (e.g., below 20 dB) where small errors in the matrix coefficients result in small errors in the solution. A well-conditioned system indicates that each sub-channel usually has a distinct spatial direction. An ill-conditioned system of linear equations has high condition number value (e.g., over 20 dB) where small errors in the coefficients may have a large detrimental effect on the solution [10].
The following formula represents how the condition number K(H) of matrix H is calculated:

$$K(H) = \frac{\sigma_{max}}{\sigma_{min}} \geq 1 \quad (2)$$

where σ_{max} represents the largest singular value and σ_{min} represents the smallest singular value in matrix.

The rank of a matrix is the dimension of the vector space generated (or spanned) by its columns (or rows), so it represents the number of singular values not equal to zero. Thus the rank of the channel matrix is an indicator of how many data streams can be spatially multiplexed over the channel in the context of MIMO communications [6][9].

V. SIMULATED MODELS

NYUSIM simulator is used to simulate millimeter-wave channel for the four proposed models. It provides precise measurements in terms of time and space. These measurements includes rendering of actual channel impulse responses and realistic signal levels [9].

This simulator provides several output files that includes information of each resolvable multipath component. The conducted measurements from simulator can be used to generate the MIMO channel coefficient for an OFDM sub-carrier. The following equation (3) [11] is used to compute the channel coefficient

$$h_{m,k}(f) = \sum_{p} \Big(a_{m,k,p} e^{j\emptyset_{m,k,p}} e^{-j2\pi f T_{m,k,p}} \times e^{-j2\pi f d_T \operatorname{m} \sin(\emptyset_{m,k,p})} \times e^{-j2\pi d_R \operatorname{k} \sin(\varphi_{m,k,p})}\Big) \quad (3)$$

Where the MIMO channel coefficient is represented by $h_{m,k}(f)$. The m^{th} transmit antenna and the k^{th} receive antenna represent the range of MIMO channel coefficient for the sub-carrier f. The parameters in equation 3 are explained in Table 1.

Table 1. The Meaning of Equation 3 Parameters

Parameter	Meaning
p^{th}	resolvable multipath component
α	the amplitude of the channel gain
ϕ	multipath component phase
φ	departure azimuth angle and arrival angle
d_T	antenna element spacing of transmitter
d_R	antenna element spacing of receiver

All these parameters can be extracted from the NYUSIM simulator files after executing the model. In a MIMO-OFDM system, there exists an $N_t * N_r$ channel matrix that named as H. Where N_t represents the number of transmitter (TX) antenna elements and Nr represents the number of receiver (RX) antenna elements. The elements of H matrix are $h_{m,k}(f)$, where m = 1,…,N_t and k = 1,…,Nr . Thus, it is possible to obtain the condition number of H.

The simulated model based on using the aforementioned approach, where table 2 shows the used values as input parameters in the NYUSIM GUI.

Four simulated model are implemented which are different in number of N_t and N_r values. The 1^{st},2^{nd},3^{rd},and 4^{th} simulated models use different sizes of communication channel arrays described by these values: (1*2) =2, (2*2) =4, (3*2) =6 and (4*2)= 8, where number of columns takes the value of (1,2,3, and 4) and the antenna elements per row is fixed (2) in transmitter and receiver.

The simulated model takes into consideration the weather factors of Baghdad city in July. So the used values in simulated model are as following: temperature =43^o, rainfall= 0mm/hr, pressure= 998.5 mbar, and humidity= 12% [12]. The used weather values represent the mean values in July at Baghdad.

Table 2. The values of input parameters on the NYUSIM GUI

Parameter	**Value**
Frequency	28 GHz
RF bandwidth	800 MHz
environment	outdoor in urban microcell (UMi)
Environment	Line of sight (LOS) and Non Line of sight (NLOS)
Lower Bound of T-R & R-T Separation Distance	100 meter
TX Power	30 dBm
Number of RX Locations	100 locations
TX Antenna Azimuth and Elevation HPBW	10^o Celsius
RX Antenna Azimuth and Elevation HPBW	10^o Celsius
Number of TX and RX Antenna Elements Per Row Wt and Wr	2,2 respectively
TX and RX antenna array type	Uniform Linear Array (ULA)
TX and RX Antenna Spacing	0.5 wavelength

The simulated models assign the frequency interval between adjacent sub-carriers to 500 kHz, as this value is corresponds to 800 MHz/500 kHz and equal to1600 sub-carriers. Each simulated model is performed 100 time (because the number of RX locations is set to 100), results in emulating 100 random MIMO channel realizations. Empirical cumulative distribution function (CDF) used to compute the probability measure which is implicitly specified by the frequency counts in the obtained condition numbers [13].

Figure 2, 3, 4 and 5 illustrates the empirical CDF of the condition number of channel matrices when Nt and Nr values =2, 4, 6, 8 respectively.

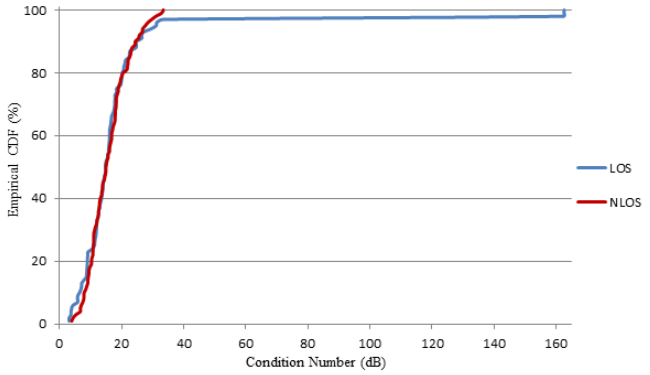

Fig. 2. Empirical CDF of the condition number of channel matrices when Nt =2 and Nr =2

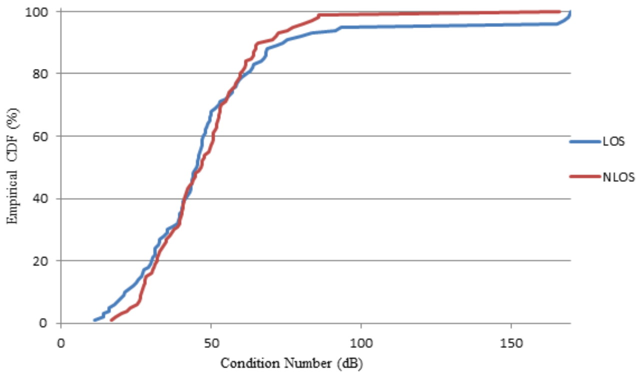

Fig. 3. Empirical CDF of the condition number of channel matrices when Nt =4 and Nr =4

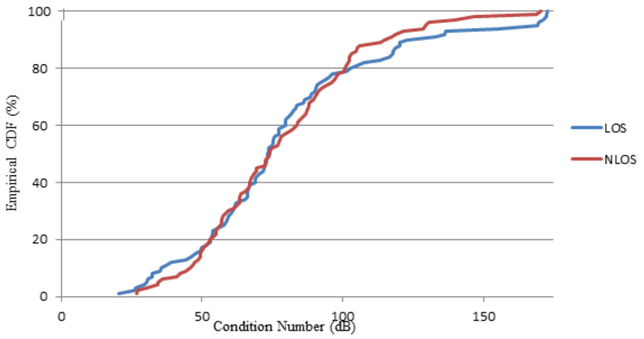

Fig. 4. Empirical CDF of the condition number of channel matrices when Nt =6 and Nr =6

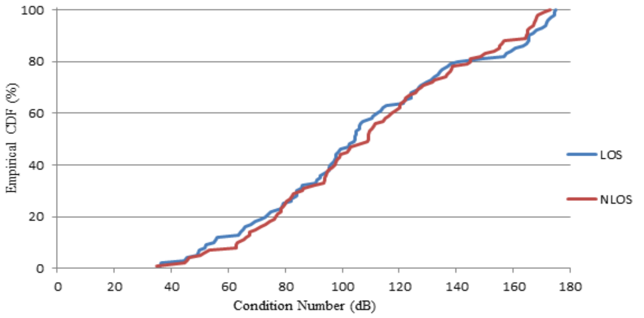

Fig. 5. Empirical CDF of the condition number of channel matrices when Nt =8 and Nr =8

Physically, good orthogonality can be achieved when condition number value is small (e.g., below 20 dB) of different sub-channels. Usually, a distinct spatial direction is specified for each sub-channel, additionally the channel gains can be compared in different spatial directions.

It is apparent from Fig.2, 3, 4, and 5 that when the Nt and Nr increased the condition number is increased too which results in bad orthogonality.

The differences in condition numbers of the individual OFDM sub-carriers between the 4 matrices in the case of LOS and NLOS are described in table 3.

Table 3. The differences between Matrices

Matrices Size	Difference
1*2	4.7 dB
2*2	6.2 dB
2*3	5.41 dB
2*4	3.57 dB

These differences are attributed to the fact of matrix rank deficient as the results shows that the probability of achieving full rank is decreased as the number of Nt and Nr increased. For example in LOS case, the average median value of the condition number is 19 dB when both TX and RX antenna elements equal to 2. This number is increased when TX and RX antenna elements increased. Consequently, the average median value of the condition number is: 50 dB, 79 dB, 107 dB when the numbers of TX and RX antenna elements are 4, 6, and 8 respectively. As a result, the spatial multiplexing technique can be used effectively to send the spatial streams simultaneously when TX and RX antenna elements less than or equal to 2.

Table 4, shows the average differences between LOS and NLOS. There is a slightly difference in two cases.

Table 4. The Average differences between LOS and NLOS

Matrices	LOS Difference	NLOS Difference
Between 1*2 and 2*2 matrices	31 dB	32 dB
Between 2*2 and 2*3 matrices	29 dB	31 dB
Between 2*3 and 2*4 matrices	27 dB	30 dB

VI. CONCLUSION

Using Multiple-input, multiple-output with orthogonal frequency-division multiplexing (MIMO-OFDM) is regarded as dominant air interface for 5G wireless communication systems. MIMO facilitates transmitting different signals over multiple antennas to multiply capacity. Orthogonal frequency- division multiplexing (OFDM) provides more reliable communications at high speeds by dividing a radio channel into a large number of sub channels which are closely spaced. The results of combining the technology of MIMO and OFDM is expanding the capacity and achieving more reliable communications at high speeds. MIMO-OFDM is the base for many advanced wireless local area network and network standards of mobile broadband. This combination delivers the highest data throughput and capacity by achieving the greatest spectral efficiency.

It is expected that 5G wireless networks will be deployed in next few years to satisfy the increased demand on more efficient communication system in terms of maximal data rates, service in better quality, fully mobile and connected wireless networks. Accordingly, it is significant to study deployment of MIMO with OFDM in 5G wireless networks. This research proposed four different models to study and analyze implementing MIMI and OFDM technologies in 5G. It takes into its consideration the LOS and NLOS environments. Two mathematical indicators are used to measure the quality of MIMO channels, which are condition number and rank of the matrix. The results show that the relation between the condition number and number of TX and RX antenna elements is positive relation, while the achieving full ranking matrix and number of TX and RX antenna elements are related with contraryrelationship.

REFERENCES

[1] Ms. Komalpokale, Prof.S. Ahirwar, and Prof. G. Ramalakshmi, “VLSI Implementation of MIMO”, International Journal of Computer Application (2250-1797) Volume 5– No. 6, October 2015.

[2] Long Bao Le, Vincent Lau, Eduard Jorswieck, Ngoc-Dung Dao, Afshin Haghighat, DongInKim, Tho Le-Ngoc, “Enabling 5G mobile wireless technologies”, Sipringer Leet al. EURASIP Journal on Wireless Communications and Networking, (2015) 2015:218, DOI 10.1186/s13638-015-0452-9.

[3] Ilia Abramov, product director and security expert, Xura, “5G Rising: Changes and Challenges in the Next-Generation Network”, 2016,. [4] Stefan Schindler, Heinz Mellein, “Assessing a MIMO Channel”, Rohde & Schwarz, 2011

[5] David Tse and Pramod Viswanath, “Fundamentals of Wireless Communication”, Cambridge University Press, 2005.

[6] Olivier Rioul, and José Carlos Magossi, “On Shannon’s Formula and Hartley’s Rule: Beyond the Mathematical Coincidence”, journal of Entropy 2014, 16, 4892-4910; doi:10.3390/e16094892.

[7] Rohde & Schwarz: "Introduction to MIMO", Application Note 1MA142, 2009

[8] Foschini, Gans: "On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas", Wireless Personal Communications 6, 311-335, 1998.

[9] New York University and NYU WIRELESS, “NYUSIM User Manual”, New York USA, 2017

[10] Keysight Technologies, “MIMO Performance and Condition Number in LTE Test”, USA, 2014

[11] A. Adhikary, E. A. Safadi, M. K. Samimi, R. Wang, G. Caire, T. S. Rappaport, and A. F. Molisch, “Joint spatial division and multiplexing for mm-wave channels”, IEEE Journal on Selected Areas in Communications, vol. 32, no. 6, pp. 1239–1255, 2014.

[12] Baghdad International (sda) Monthly Climate Average, Baghdad.

[13] Rui Castro, “Introduction and the Empirical CDF”, 2013, http://www.win.tue.nl/~rmcastro/AppStat2013/files/lecture1.pdf