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Extensive Spectrum Efficiency of Massive MIMO Channels for 5G Mobile wireless Communication System

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Abstract— In this work, an analytic extension of massive MIMO capacity for 5G mobile communication systems is firstly developed. Then, the capacity limit and multiplexing gain are investigated in simulations for different massive MIMO configurations. Furthermore, the two calculated metrics are performed as a function of SNR taking into account the transceiver impairments. On the one hand, an analytic expression of the capacity under uncorrelated Rayleigh fading channel is developed as a function of SNR and OFDM subcarriers number. On the other hand, simulation results are carried out based on the deterministic and uncorrelated fading Rayleigh channel showing that the capacity limit is up bounded by [50-57] bit/s/Hz for a multiplexing gain equal to 256. Finally, three metrics are used to characterize the massive MIMO for the uncorrelated fading channel with a multiplexing gain of (256,256). The proposed analysis to minimize error rate in wireless communication system compared to state-of-art methods. Likewise, a trade-off is observed between the capacity limit and the tolerable SNR value for massive MIMO transmission while increasing the multiplexing gain.

Keywords-Massive MIMO; OFDM;5G; Mobile Communication.

I. INTRODUCTION

Today, the migration from 4G to 5G mobile communications is mandatory and motivated by the exponential demand for users regarding bandwidth and integrating new kinds of services. This kind of service covers dynamic information access, wearable devices, Internet-of-Things (IoT) and HD streaming. This motivation will be true while introducing advanced technology based on new multi-carrier waveforms, such as orthogonal frequency division multiplexing (OFDM), filter bank multi-carrier (FBMC) and universal filtered multicarrier (UFMC) for 5G and beyond applications [1]. The most important targets for Mobile 5G applications are raising user data rates (i.e., at least 1 Gb/s achievable data rate across the coverage area), reducing latency, enhancing the energy saving with reducing cost, higher system capacity and increasing the massive device connectivity. In order to improve the system capacity, among effective methods is the use of multiple-input multiple-output (MIMO) technology in mobile communication. In fact, MIMO is an antenna technology for wireless communication in which multiple antennas are used at both transmitter and receiver sides. Furthermore, MIMO is an emerging technology that can be potentially useful in bursty traffic as well as in railways environment characterized by high speed and impulsive noise [2,3]. However, massive MIMO is the extension of MIMO in which, a massive scale of the antenna (i.e., typically more than 64) is assigned to each base station (BS). In addition, large MIMO grant to a vast number of users to be served simultaneously. Thus, the main benefits of massive MIMO are providing a huge spectral efficiency of cellular networks and high energy efficiency [4- 6]. Likewise, massive MIMO is successfully deployed in many standards, such as LTE, 802.16 (WiMax) and 802.11 (WiFi). However, it suffers mostly from pilot contamination and pilot overhead while estimating the channel in timedivision duplexing (TDD) and frequency-division duplexing (FDD) paradigm, respectively [7]. In literature, various studies have been done regarding the capacity analysis of massive MIMO. For instance, the reservation-based random access wireless

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network capacity was investigated with addressed upper and lower bound expressions [8]. Recently, the random matrix theory (RMT) tools are intensively noticed and have been vastly used to tame the performance of massive MIMO systems. The majority work of RMT focused on the closed-form expressions for critical parameter analysis, such as the ergodic capacity, higher-order capacity moments, and outage probability [9,11]. Among the various mathematical tools provided by RMT, the equivalent deterministic method was introduced by [10,12-14]. In which, Shannon transform method [10-15], Gaussian method [16], and three product channels based on probability theory plays critical role in approximating the channel model [17]. On the other hand, the statistics and probability analysis method were widely applied for capacity and outage probability analysis in massive MIMO systems [8], but still difficult to be adopted to the more complicated massive MIMO systems, especially with the non-orthogonal multiple access (NOMA) decoding scheme. The present paper is a significant extension of the authors' paper reported in [18] related to the analytic expression of the massive MIMO capacity limits as a function of signal-to-noise ratio (SNR) and OFDM subcarrier number. Then, an extensive simulation is performed based on the water-filling algorithm for the power allocation of the massive MIMO transmitter antenna to determine the limit in terms of average finite SNR, capacity and the maximum tolerable SNR for MIMO configurations (4,4), (16,16), (64,64), (128,128) and (256,256), respectively.

II. SYSTEM ARCHITECTURE

The massive MIMO architecture is composed of a transmitter, a matrix channel and a receiver as shown in Fig.1. On the one hand, the transmitter design includes a pre-coder with closed-loop MIMO system, cooperative beamforming schema (i.e., in low SNR case, the best strategy is to use the largest eigen-mode only) and time-reversal for frequency channel [19].

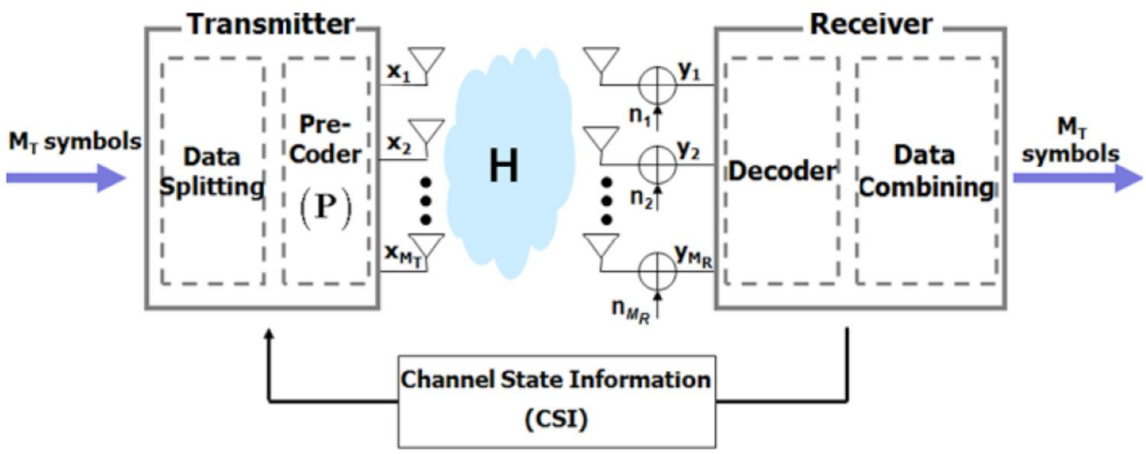

Figure 1. Massive MIMO architecture.

On the other hand, receiver design involves a decoder and a data combining sub-component. In addition, channel state information (CSI) knowledge can enhance the MIMO system spectral efficiency and reduce potentially the receiver complexity [20]. In the state-of-the-art, there are three different kind of situations concerning the quantity and quality of the CSI available at the transmitter side can be identified: i) No CSI: the transmitter does not have any knowledge of any parameter concerning the channel or the interferences at the receiver. In this case, a reasonable transmitter strategy consists in utilizing space-time codes; ii) Perfect CSI: the transmitter has full knowledge of the instantaneous channel realization and, possibly, of the interference's statistics at the receiver. In this case, since complete information is available, there are many possible strategies and optimization criteria to carry out the design depending on the detection method at the receiver or on the performance metric; iii) Imperfect CSI: the transmitter has inaccurate knowledge about the parameters describing the channel. For example, the transmitter may be informed of an erroneous channel ( ). For the case of imperfect CSI, two main strategies can be considered, either the transmitter is designed to attain the maximum performance level for the worst possible situation of the channel among the ones that are compatible with the CSI (i.e., maximin or worst-case approach) or the transmitter is designed to have the best mean performance averaged over the unknown parameters of the CSI (statistical or Bayesian approach) [21]. In this paper, we consider the case of an imperfect CSI.

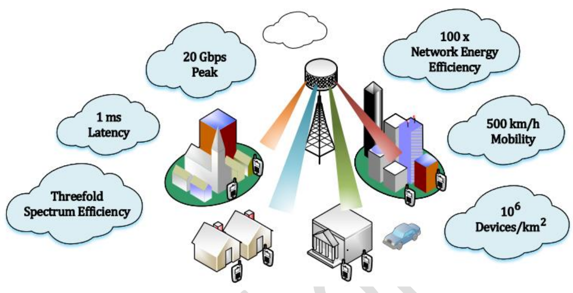

Figure 2. 5G major goals massive MIMO deployment illustration.

III. Proposed Traditional MIMO technology

MIMO technology was first proposed by Marconi in 1908. It is equipped with multiple antennas on both sending and receiving end to improve the capacity of communication system, transmission rate of system data and transmission reliability. 3GPP LTE Release10 can already support 8 antenna ports for transmission, that is, 8 single-stream users or 4 dual-stream users for simultaneous transmission. The MIMO technology standardization process in LTE/ LTE-A is shown in table 1. It is limited by mobile terminal size, power consumption and appearance. If you want to further improve the data transmission capacity, an intuitive way is to increase the number of data streams that are transmitted in parallel or increase the number of base station antenna ports.

Table1. MIMO technology standardization process

Standard	MIMO technology	Characteristic
Rel-8	Transmit diversity	Support up to 4 layers of transport
	Space division multiplex beamforming	Only support single layer transport
	MU-MIMO	Up to two rank1 UE
Rel-9	Double stream beamforming	SU/ MU flexible switch
		Up to 4 data streams (up to 2 levels per UE) Use the transmission mode of non-code book
		Support channel reciprocity based feedback
Rel-10	High order MIMO	Support up to 8 layers of transport
		High precision feedback based on two level multiparticle codebook
	Uplink MIMO	Support up to 4 layers of transport
Rel-11	CoMP	Multi-cell coordination MIMO
Rel-12	CoMP/3DMIMO	Multi-cell coordination MIMO/ 3D
Rel-13	3DMIMO	Expanded into a three-dimensional (3D) antenna array

In 2010, Marzetta, a scientist in Bell laboratory, proposed the concept of massive MIMO in the context of multiple cell and TDD scenario[2]. Thus, some different features of the limited number of antennas in single cell were found. massive MIMO technology refers to that the base station is equipped with a large number of antennas [3], usually a hundred or several hundred antennas, which is several orders of magnitude higher than the number of antennas in the existing communication system. It serves multiple users simultaneously on the same time-frequency resource, and mobile terminals generally adopt the communication mode of single antenna reception. The theoretical channel model of massive MIMO system can be effectively verified through the channel measurement in the actual wireless communication environment, and the performance of the entire communication system can be improved by measuring the actual channel [5]. (1)The distributed MIMO channel is measured under the condition of 2.6ghz micro cell. The measurement method is mainly to use three base stations under distributed MIMO to be equipped with four groups of antenna units, so that the height of its space meets the condition of co-directional polarization. The last base station is used to configure an antenna unit. A mobile platform consists of a uniform cylindrical array with 64 pairs of dual-polarization antenna units. By analysing the cross correlation of the massive fading of communication links between different base stations, the massive fading values of the channels at different locations are obtained. (2) Measurement method of linear array with 128 units. Literature [6] described 26 users transmitting at different stadia under 2.6ghz and 10 users transmitting at non-stadia, and deployed 128 unit antenna array at the base station terminal, and set half wavelength as the antenna spacing, with 7.3m as the length of the antenna array. By verifying the massive MIMO channel under the above configuration, it can be known that the massive antenna array is a wireless communication channel when some invisible scattered or highly variable scattered power values exist, and cannot be regarded as a generalized stationary process. However, since the non-stationarity of the antenna array and the effect of near field can remove the correlation between the users, thus providing a relatively stable and low-interference channel environment. Due to the rapid development of 5G technology, massive MIMO channel modelling shows some new features. For example, in the deployment of massive antenna array at the base station terminal, spherical waves should be used to replace plane waves [7] and channel energy should be concentrated in limited space. The channel is no longer independent and identically distributed. With the increasing antenna array at the base station terminal, only different antenna units can see different scatterers, and the fading is characterized by non-static characteristics [8].

$$C = B \cdot \log_2\left(1 + \frac{p|h|^2}{B \cdot n_0}\right), \quad (1)$$

where c is the channel capacity in bits per second, b is the bandwidth of the channel in hertz, p is the symbol power, h is the channel gain, and n0 is the noise variance [19]. Considering the theoretical upper limit, where E[|h| 2] = 1, and removing the fixed channel bandwidth, we can then simplify the expression as

$$C = \log_2(1 + \mathrm{SNR}), \quad (2)$$

where the capacity C is now measured in bits/hertz and SNR = 1/Np n0 is the signal-to-noise ratio at the receiver. As we will have R × T channel responses and multiple signals, it is convenient to represent this model using vectors and matrices. The model can be then represented with

$$\begin{bmatrix} Y_1 \\ \vdots \\ Y_R \end{bmatrix} = \begin{bmatrix} H_{1,1} & \cdots & H_{1,T} \\ \vdots & \ddots & \vdots \\ H_{R,1} & \cdots & H_{R,T} \end{bmatrix} \begin{bmatrix} X_1 \\ \vdots \\ Y_T \end{bmatrix} + \begin{bmatrix} N_1 \\ \vdots \\ N_R \end{bmatrix} \quad (3)$$

It was already shown in [17] that the optimal power allocation is given by the waterfilling method, which will assign higher powers to channels with better conditions. It can be defined as

$$q_k^{opt} = \max\left(\mu - \frac{N_0}{s_k^2}, 0\right). \quad (4)$$

Taking advantage of the fact that, for massive MIMO systems with R 1 and a small correlation between the channels associated with different transmit and receive antennas.

IV. Simulation Results

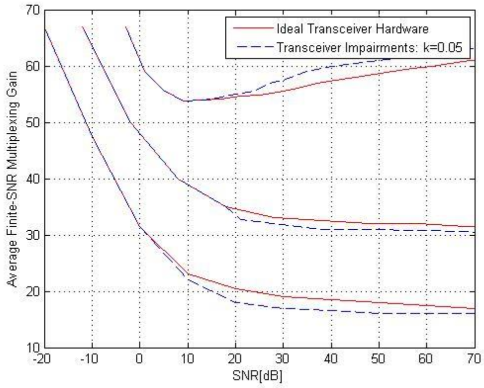

Figure 3. Aerage finite-SNR multiplexing gain of deterministic channels with different Nt and Nr=64 configurations

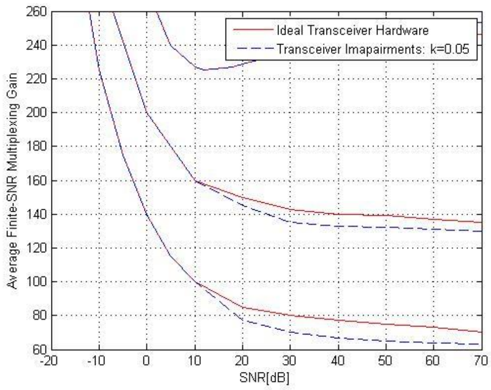

Figure 4. Average finite-SNR multiplexing gain of uncorrelated Rayleigh fading channels with different Nt and Nr=256.

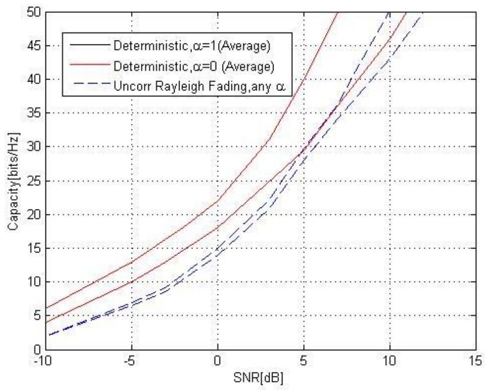

Figure 5. The capacity of uncorrelated Rayleigh fading channels with different Nt and Nr=16.

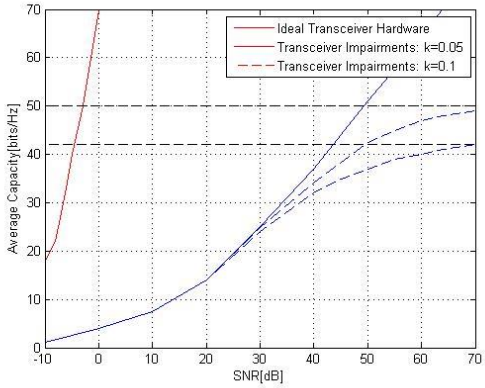

Figure 6. *The* average *capacity of massive MIMO as a function of SNR for Nt=64 and Nr=64.*

V. CONCLUSION

In this paper, an investigation of the massive MIMO system model was presented for both deterministic and uncorrelated Rayleigh fading channels in the context of 5G mobile communications systems. An extension of analytic capacity expression was demonstrated for the uncorrelated Rayleigh fading channels taking into account SNR and subcarrier number. Moreover, two metrics are used in simulation to characterize massive MIMO; average finite SNR multiplexing gain and average capacity. It was demonstrated also that there's saturation of the massive MIMO system under the high SNR region and the finite capacity limit is independent of the channel distribution. Additionally, the massive MIMO capacity is proportional to the multiplexing gain over the whole SNR range, thus leading to an upper bound of capacity limit equal to 41 bit/s/Hz and 57 bit/s/Hz for a multiplexing gain of 4 and 256, respectively. Finally, three metrics were presented to determine the limit of massive MIMO in terms of average finite SNR, capacity and the maximum tolerable SNR is (256,256) configuration, respectively. Therefore, by increasing the multiplexing gain a trade-off between capacity limit and tolerable SNR value is observed.

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