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Massive MIMO Exploitation to Reduce HARQ Delay in Wireless Communication System

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***Abstract*—As recommended by 5th generation Public-Private Partnership (5G-PPP) and Next Generation Mobile Networks (NGMN), one of the most important 5G requirements is to minimize the delay within the network for delay-sensitive services. Main objective of this work is to exploit massive MIMO technology to reduce Hybrid Automatic Repeat Query (HARQ) retransmission delay. Massive MIMO indoor environment is created by a 3D ray-tracing tool to simulate the received power, phase, delay, and angle of arrival of each ray in the channel. Two sizes of rectangular antenna array are used to evaluate the performance of beamforming in enhancing the bit error rate. This reflects directly on the mean and maximum numbers of packet retransmission. The angle between user-equipments is considered to evaluate the effect of inter-user interference on HARQ. This work opens the door to develop smarter resource allocation algorithms in 5G for delay-sensitive services based on the location and the angle of arrival of the users.**

I. Introduction

Although the increasing demand for high data rates and the exploiting of new advanced technologies to achieve those data rates, the communication delay still has major influence on user experience for several services. Next Generation Mobile Networks (NGMN) alliance has defined the main technical requirements that 5G network has to fulfill in order to provide users with the promised services and application [1], such as conversational services (Voice Over IP and video telephony), real-time gaming [2], relay networking, M2M communication, and the most promising application: Internet of Things (IoT). All of the aforementioned applications and services are considered as delay-sensitive cases which urge to minimize the delay. Several solutions and techniques were proposed to reduce the delay in MAC and physical layers, like shorten the packet and minimize Time Transmit Interval (TTI), Semi-persistent scheduling, improving error protection of ACK/NACK (Acknowledgement/Negative-Acknowledgement) messages for HARQ (Hybrid automatic repeat query), and other techniques. Some of these techniques are explained and experimented in LOw LAtency (LOLA) FP7 project focusing on Long-Term Evolution (LTE) systems [3].

With the significant reduction of delay in the core of mobile networks due to structure simplification (e.g. System Architecture Evolution SAE in 3GPP LTE system), the delay reduction in wireless part is still a challenge. HARQ schemes cause the major part of this delay, in particular when the links, on which losses occur, have long path delay [4]. The trade-off between throughput, diversity, multiplexing gain and delay for MIMO ARQ systems was studied in [5], [6] and [7]. For example, in 3GPP technical report for Universal Terrestrial Radio Access Network (UTRAN) [8], an estimation of 5 msec retransmission time is used in user-plane with HARQ different values of retransmission probability (Probability of packet rejection) 30% or 10%. Fig.1 shows the delay components of LTE Frequency-Division Duplexing (FDD) in user-plane [8], which can be expressed in msec as:

$$T(N) = 1 + 1.5 + 1 + 5(N-1) = 3.5 + 5(N-1) \quad (1)$$

where N is the total number of packet transmissions ($N-1$ unsuccessful then 1 successful). Similar result for LTE Time-Division Duplexing (TDD) also is given. This shows how much it is important to limit the number of retransmissions to reduce delay, adding to this the fact that the smaller number of HARQ retransmissions the less processing time wasted for decoding. For 5G, both 5G-PPP and NGMN are leading discussions about the requirements of HARQ delay as in [9] and [10].

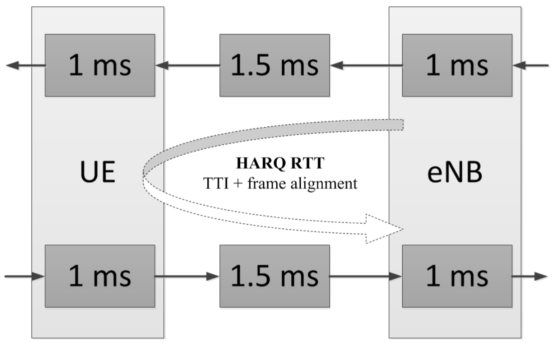

Figure 1: User-plane delay components of LTE FDD in 3GPP standards

Generally, HARQ schemes are used when channel state information (CSI) is not perfectly known at the transmitter side. More knowledge about CSI means improving the system performance, subsequently minimizing HARQ retransmissions [11]. Also improving the wireless channel conditions and the diversity will assure that too, reflecting on maximum required number or retransmissions. For example, normally in 802.11 WiFi system the number of maximum allowed retransmissions is $L = 7$ (for short packets), meanwhile some literature suggests to limit it for LTE in the downlink to save the radio resources for user-equipments (UE) with poor radio link [12]. In the last few years Massive MIMO (also known as very large Multiple-Input Multiple-Output, or full-dimension MIMO) has been an interesting technology to enhance wireless system performance, especially by using beam-forming to reduce the interference among users. Massive MIMO is an emerging technology which is similar to traditional MIMO systems but on much larger scale [13]. The number of base station antennas is much larger than the number of UEs. This enables the

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system to communicate with many users in the same time-frequency resources; and that reflects positively on system capacity and spectral efficiency. Several works have been done to illustrate massive MIMO benefits like [14], [15] and [16]. The new contribution of this paper is to study the improvement, that can be achieved by massive MIMO, on the number of HARQ retransmissions in indoor environments, subsequently reducing the delay in low layers (L1 and L2). The variation of inter-user interference, affected by changing the angle between the users and the antenna array size, plays a major role in the performance.

The remainder of this paper is organized as follows: Section II explains the system model and analyses it within two parts, Massive MIMO and HARQ delay. The simulation setup is introduced in Section III. Section IV presents the results of massive MIMO channel simulation and HARQ mechanism performance. Finally, the conclusion is drawn in Section V.

II. System Model

A. Massive MIMO system

The wireless model is a narrow band massive MIMO system operating in an indoor environment at 5 GHz. The base station uses the narrow beams of massive antenna array to transmit to several user-equipments with space-division multiple access SDMA, within the same time-frequency resources (Fig.2). The number of antenna array elements N_{Arr} is much larger than the number of user-equipments K. The received signal by the k^{th} user-equipment is expressed as:

$$\mathbf{Y}_k = \mathbf{H}_k\mathbf{X}_k + \sum_{j=1, j\neq k}^{K} \mathbf{H}_j\mathbf{X}_j + \mathbf{W}_k \quad (2)$$

where: $\mathbf{H}_k\mathbf{X}_k$ is the useful signal for the k^{th} user-equipment, $\sum_{j=1,j\neq k}^{K} \mathbf{H}_j\mathbf{X}_j$ is the interfering signal and $\mathbf{W}_k$ is the AWGN noise matrix for user-equipment k. $\mathbf{H}_k$ is the channel matrix between the transmitter and user-equipment k and can be expressed as a matrix as below:

$$\mathbf{H}_k = \begin{bmatrix} h_{11} & h_{21} & \dots & h_{m1} \\ h_{12} & h_{22} & \dots & h_{m2} \\ \vdots & & \ddots & \vdots \\ h_{1n} & h_{2n} & \dots & h_{mn} \end{bmatrix} \quad (3)$$

where h_{mn} is the channel coefficients between the n^{th} base station transmit antenna and the m^{th} receive antenna of a user-equipment k, and can be calculated as [17]:

$$h_{mn} = \sum_{r=1}^{R} \sqrt{p_r}.e^{j\theta_r}.e^{j2\pi f_\circ \tau_r} \quad (4)$$

where p_r, θ_r and τ_r are the received power, phase shift and time delay of the r^{th} propagation path respectively. R is the total number of paths and $f_\circ$ is the carrier frequency.

The bit error rate of massive MIMO downlink channel can be derived as in [18].

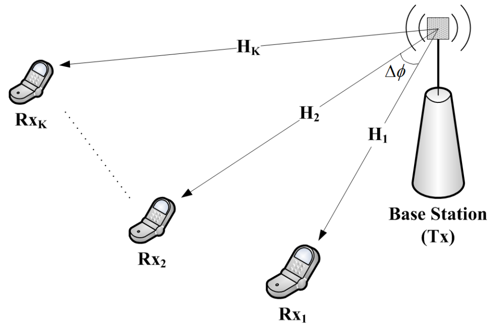

Figure 2: Wireless System Model

B. HARQ Delay

A Hybrid ARQ (HARQ) error control mechanism is modelled to study the retransmission delay, where stop-and-wait (S/W) ARQ scheme is used. This scheme is normally inefficient in case of long separation between the time when a packet is transmitted and the time when ACK or NACK feedback message is received (round-trip delay). However, the advantage that it is easy to implement, moreover, the transmitter or the receiver needs to store only one packet at any given time [11]. The channel coding scheme is BCH(n,k), "Bose-Chaudhuri-Hocquenghem-Codes" [19], which is able to correct t bits of error. Hence the probability of packet retransmission is:

$$P_{ret} = 1 - P_{acc} = 1 - \sum_{i=0}^{t} \binom{n}{i} P_b^i (1 - P_b)^{n-i} \quad (5)$$

Where P_b is the bit error probability.

The mean delay which is caused by HARQ for a certain packet is given as [20]:

$$T = (\frac{P_{ret}}{1 - P_{ret}})T_u + T_s \quad (6)$$

Where T_s and T_u are the times for successful and unsuccessful transmission attempts respectively. Meanwhile this delay can be also written in terms of N the total number of transmission for a packet:

$$T(N) = (N - 1)T_u + T_s \quad (7)$$

$$N = \frac{1}{1 - P_{ret}} = \frac{1}{\sum_{i=0}^{t} \binom{n}{i} P_b^i (1 - P_b)^{n-i}} \quad (8)$$

Changing N with L (Maximum allowed number of retransmissions) in (7)

$$T_L = (L - 1)T_u + T_s \quad (9)$$

and probability of T_L is

$$Prob\{T_L\} = (P_{ret})^L = [1 - \sum_{i=0}^{t} \binom{n}{i} P_b^i (1 - P_b)^{n-i}]^L \quad (10)$$

III. Simulation Setup

The simulation consists of two parts, Massive MIMO indoor channel simulation, and Hybrid ARQ delay evaluation.

For channel simulation a 3D ray-tracing method is used. Modelling MIMO channels based on ray-tracing has been evaluated in various research works. An early work to model MIMO channels based on ray-tracing can be found in [21]. In [22], it was proven that 3D ray-tracing can characterize several channel parameters such as delay spread, Doppler spread and angular spread, with high accuracy. Hence, this simulation uses Wireless InSite [23], a 3D ray-tracing tool, to get the received power, phase, delay and angle of arrival of each ray as described in (4). The simulation includes one transmitter base station with uniform rectangular antenna array (with 100 or 49 antenna), and two receiver user-equipments moving in a line-of-sight (LOS) indoor environment. The UE antennas are omni-directional. Phased array system toolbox in Matlab is used to form the antenna array beams of the base station by adapting the weights of each array element. The spacing between the isotropic elements is half of the wave length of the carrier frequency 5 GHz. Fig.3 shows a 3D view of the office design.

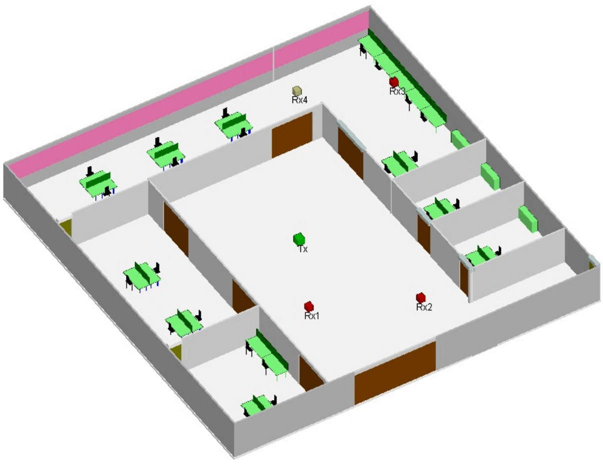

Figure 3: Typical office area

For the evaluation of Hybrid ARQ delay, Matlab is used to simulate a QPSK narrow band wireless communication system with ARQ stop-and-wait mechanism and forward error block coding BCH with $n = 63$, $k = 10$ and correction capability $t = 13$. For simplification, the feedback channel that carries ACK/NACK messages is considered free of error.

IV. Simulation Results

The simulation results focus on the number of retransmissions of a packet when the following variables are changing:

SNR: Signal to Noise Ration in wireless channel

$\Delta\Phi$: Angle between the two user-equipments

Size of antenna array: 100 (10x10) or 49 (7x7)

The simulation results are averaged over 1000 channel response simulations.

A. Channel Simulation

Fig. 4 shows the interference power normalized to useful signal power when the angle between user-equipments changes between 2° and 20°. It can be seen from the figure that the beam width of 10x10 array main lobe is about 2x12° meanwhile it is about 2x16° for 7x7 antenna array.

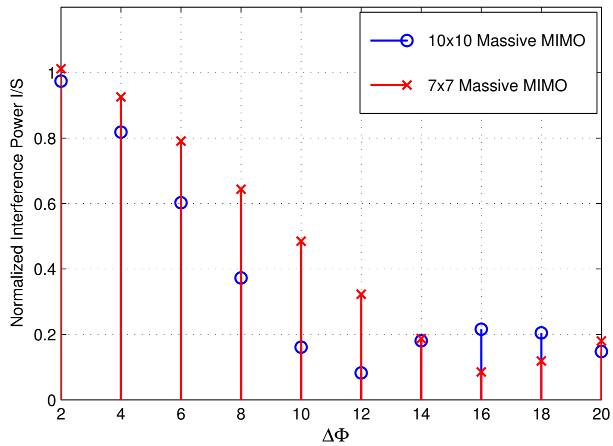

Figure 4: Interference power normalized to useful signal power

The bit error rate (BER) is shown in Fig. 5 for both antenna array sizes with different SNR and angle separation values. When the angle $\Delta\Phi$ between the two receivers Rx_1 and Rx_2 is smaller than half of main lobe beam width ($\Delta\Phi < 14°$), the larger antenna array size the less bit error rate, meanwhile for angles equal or greater than 16° the two arrays show almost the same performance.

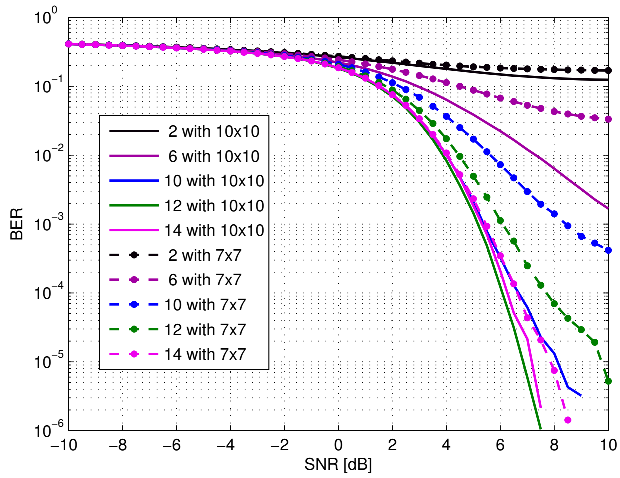

Figure 5: BER in both cases (49 and 100 antenna) when the angle between the two users changes in the range [2° 14°]

B. HARQ Delay Performance

Fig. 6 shows the mean number of HARQ retransmissions based on the achieved bit error rate by the simulation, in

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comparison with the theoretical analysis which is done in (8). To get the probability of packet retransmission from (5) in this analysis, a packet of 10 bits is considered with maximum 1 error per packet acceptance. With large enough number of simulation bits, BER could be close to theoretical probability of error.

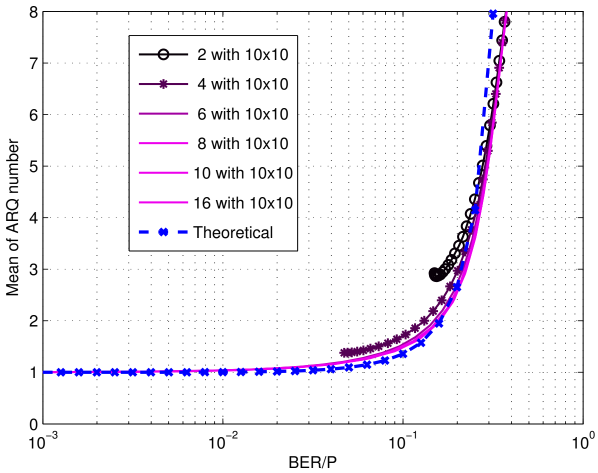

Figure 6: Mean number of HARQ packet retransmissions with different values for $\varDelta\Phi$. (The curves of $\varDelta\Phi$ between 6° and 16° are almost the same)

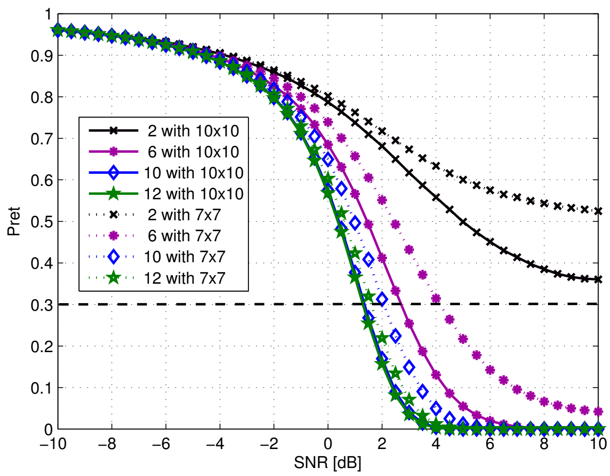

Figure 7: Probability of packet retransmission in terms of SNR considering 30% of packet retransmission probability as a requirement, with different values for $\varDelta\Phi$

The probability of packet retransmission (or the probability of packet rejection) is shown in Fig. 7. This is calculated based on (5) with SNR and BER extracted from the simulation. For example, considering 30% of packet retransmission suggested in [2] and $\varDelta\Phi = 6^{\circ}$, the threshold can be reached by the 100 antenna array with 1.5 dB lower SNR compared to the 49 array antenna.

Finally, to show the summarized result of massive MIMO benefit in reducing HARQ delay, Fig. 8 and Fig. 9 show respectively the mean and the maximum numbers of retransmissions when SNR and $\varDelta\Phi$ change. The figures depict the reduction of the number of HARQ retransmissions especially when $\varDelta\Phi$ is between 4° and 12° (within the main lobe). The later figure, which considers the peaks during simulation, indicates the expected maximum delay because it is more critical in delay-sensitive services.

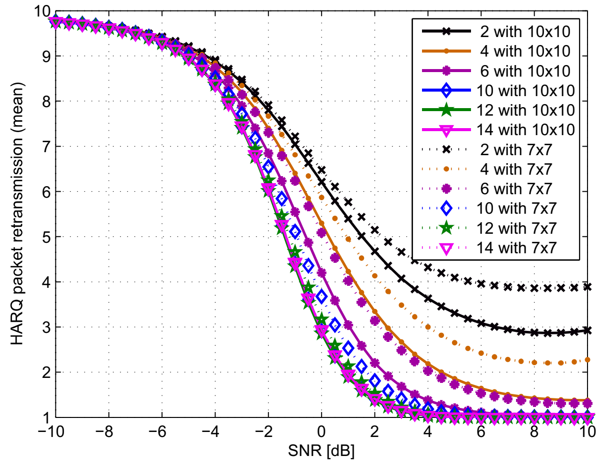

Figure 8: The mean number of HARQ packet retransmission with different values for $\varDelta\Phi$ where L=10

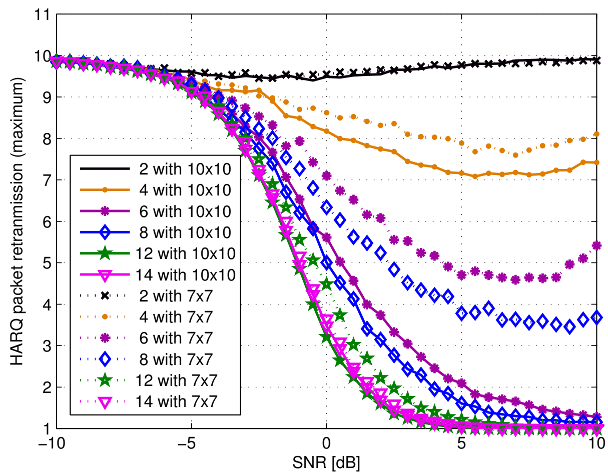

Figure 9: The maximum number of HARQ packet retransmission with different values for $\varDelta\Phi$ where L=10

V. Conclusion

The paper investigated the benefit of exploiting massive MIMO to reduce HARQ delay in an indoor wireless environment. Packet retransmission probability and number of retransmissions (mean and maximum) were analysed and simulated by Matlab and 3D ray-tracing tool with different SNR values. The angle between the two user-equipments was considered to evaluate the performance of beamforming in decreasing the inter-user interference. The results showed the improvements in the system performance in terms of delay by using larger number of antenna, as an extended conclusion from traditional MIMO systems. The simulation was confined to a simple setup (two users, QPSK, S/W ARQ algorithm, fixed packet length), hence many works can be done to develop the solution in LTE and other standards. This gives the ability to suggest smarter resource allocation algorithms in 5G network for delay-sensitive services based on the location and the angle of arrival of the users.

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