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Average Spectrum Efficiency of Non-Orthogonal Multiple Access (NOMA) for 5G Wireless Systems

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Abstract— Investigating NOMA for conventional downlink and uplink systems, the application of NOMA is investigated in downlink multiuser multiple-input multiple output (MIMO) systems, by proposing a novel MIMO-NOMA model with linear beamforming technique. In this MIMO-NOMA system, users' receive antennas are dynamically grouped into a number of disjoint clusters, and within each cluster a single beam is shared by all the receive antennas those adopt NOMA. The superiority of the proposed model is illustrated through extensive performance evaluations. Finally, the application of coordinated multi-point (CoMP) transmission technique is investigated in downlink multi-cell NOMA systems, considering distributed power allocation at each cell. In the proposed CoMP-NOMA model, CoMP transmission is used for users experiencing strong receive-signals from multiple cells while each cell independently adopts NOMA for resource allocation. The applicability and necessary conditions to use different CoMP schemes are identified under various network scenarios, and the corresponding throughput formulas are derived. The spectral efficiency gains of the proposed CoMP-NOMA model are also quantified.

Keywords: - Non Orthogonal Multiple Access (NOMA), Fifth Generation, Spectral Efficiency, 5G Wireless System

I. INTRODUCTION

As the long-term evolution (LTE) system is reaching maturity and the fourth generation (4G) has commercially deployed, a certain number of researchers have pondered over the ways and means for the coming fifth generation (5G) cellular network [1]. The 5G networks is with high expectation on making substantial breakthrough beyond the previous four generations, especially on the provision of at least 1,000 times higher system capacity, 10 times higher spectrum efficiency and 10 times lower energy efficiency per service than 4G networks [2]. Towards these direction, several key technologies and approaches such as ultra-densification, millimeter wave (mm Wave), massive multiple-input multiple-output (MIMO), device-to-device (D2D) and machine-to-machine (M2M) communication, full duplex (FD) communication, energy harvesting, cloud-based radio access networks (CRAN), wireless network visualization (WNV), and software defined networks (SDN) were identified by researchers.

Apart from the aforementioned approaches, multiple access (MA) technology is also regarded as one of the most fundamental aspect in physical layer, which have significantly varied in each generation wireless networks and affected the definition of technical feature to a large extent. Looking back on the development of the MA formats, in the first generation (1G), the MA is frequency division multiple access (FDMA), which is an analog frequency modulation based technology. From the secondary generation (2G), the MA began to transform into a digital modulation format—time division multiple access (TDMA) by exploiting time multiplexing. Then the code division multiple access (CDMA), which was proposed by Qualcomm [3], became the dominant MA standard in the third generation (3G) networks. In an effort to overcome the limitations of CDMA which is not capable of supporting high-speed data rates, orthogonal frequency division multiple access (OFDMA) was dominantly adopted in 4G networks [4].

Due to the fact that the unprecedented expansion of new Internet-enabled smart devices, applications and services is expediting the development of the 5G networks, the MA technology is also required to be reconsidered. Non-orthogonal multiple access (NOMA), which has been recently proposed for 3GPP Long Term Evolution (LTE) [5], is expected to have a superior spectral efficiency. It has also been pointed out that NOMA has the potential to be integrated with existing MA paradigms, since it exploits the new dimension of the power domain. The key idea of NOMA is to ensure that multiple users can be served within a given resource slot (e.g., time/frequency /code), by applying successive interference cancellation (SIC), which is fundamentally different from conventional orthogonal MA technologies.

II. ADVANTAGE OF NOMA

High spectrum efficiency:

Spectrum efficiency is one of the well accepted performance metrics in wireless networks. NOMA exhibits a high spectrum efficiency to improve the sum system throughput, which is attributed to the fact that NOMA allows one resource block (RB) (e.g., time/ frequency/code) to be occupied by multiple users [7].

Fairness-throughput tradeoff:

One key feature of NOMA is to allocate more power to the weak user, which is different from the conventional popular power allocation (PA) policies such as water filling PA1. By doing so, NOMA is capable of guaranteeing a good tradeoff between the fairness among users and system throughput.

Ultra-high connectivity:

The future 5G systems are envisioned to support the connection of billions of smart devices (e.g., Internet of Things (IoT)). The existence of NOMA offers a promising approach to efficiently solve this non-trivial task by fully exploiting the non-orthogonal characteristic. More specifically, unlike conventional orthogonal multiple access (OMA) which requires equal number of RBs to support these equal number devices; NOMA is able to serve them with occupying much less RBs.

Good compatibility:

From the theoretic perspective, NOMA can be an “add-on” technique to any exiting OMA techniques (e.g., TDMA/FDMA/CDMA/OFDMA), due to the fact that it exploits a new power dimension. Also, with the mature development of superposition coding (SC) and SIC technologies both in theory and practice, it is very promising that NOMA is capable of achieving good compatibility with the existing MA techniques.

Open flexibility:

Compared to other existing techniques for MA, such as multiuser shared access (MUSA), pattern division multiple access (PDMA), sparse code multiple access (SCMA), NOMA provides an easy-understanding and low complexity design [8]. In fact, the fundamental principle of the aforementioned MA schemes and NOMA are very similar, which is to allocate multiple users in a single RB.

III. NOMA IN DOWNLINK TRANSMISSION SCENARIOS

Let us consider a downlink NOMA transmission with a single antennas BS and single antenna m number of users with distinct channel gains. In such m-user downlink NOMA, the BS transmitter non-orthogonally transmits m different signals by superposing them over the same spectrum resources; whereas, all m UE receivers receive their desired signals along with the interferences caused by the messages of other UEs.

To obtain the desired signal, each SIC receiver first decodes the dominant1 interferences and then subtracts them from the superposed signal. Since each UE receives all signals (desired and interfering signals) over the same channel, the superposing of different signals with different power levels is crucial to diversify each signal and to perform SIC at a given UE receiver.

Let us also consider that the messages of NOMA users are superposed with a power level which is inversely proportional to the their channel gains, that is, a particular user is allocated for low power than the users those have lower channel gain while that allocated power is higher than all the users those have higher channel gain than the particular user. As such, the lowest channel gain user (who receives low interferences due to relatively low powers of the messages of high channel gain users) cannot suppress any interference. However, the highest channel gain user (who receives strong interferences due to relatively high powers of the messages of low channel gain users) can suppress all interfering signals.

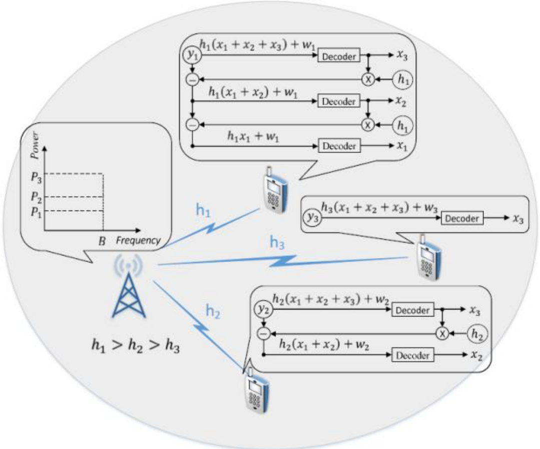

Figure 1: Illustration of a 3-user downlink NOMA transmission with SIC at user ends.

NOMA in Uplink Transmission Scenarios

The working principle of uplink NOMA is quite different from the downlink NOMA. In uplink NOMA, multiple transmitters of different UEs non-orthogonally transmit to a single receiver at BS over same spectrum resources. Each UE independently transmits its own signal at either maximum transmit power or controlled transmit power depending on the channel gain differences among the NOMA users. All received signals at the BS are the desired signals, though they make interference to each other. Since the transmitters are different, each received signal at SIC receiver (BS) experiences distinct channel gain. Note that, to apply SIC and decode signals at BS, we need to maintain the distinctness among various message signals. As such, conventional transmit power control (typically intended to equalize the received signal powers of all users) is not feasible in NOMA-based systems.

Let us consider a general m-user uplink NOMA system in which m users transmit to a common BS over the same resources, at either maximum transmit power or controlled transmit power. The BS receives the superposed message signal of m different users and applies SIC to decode each signal. Since the received signal from the highest channel gain user is likely the strongest at the BS; therefore, this signal is decoded first. Consequently, the highest channel gain user experiences interference from all other users in the NOMA cluster. After that, the signal for second highest channel gain user is decoded and so on. As a result, in uplink NOMA, the achievable data rate of a user contains the interference from all users with relatively weaker channels. That is, the highest channel gain user experiences interference from all users and the lowest channel gain user enjoys interference-free data rate.

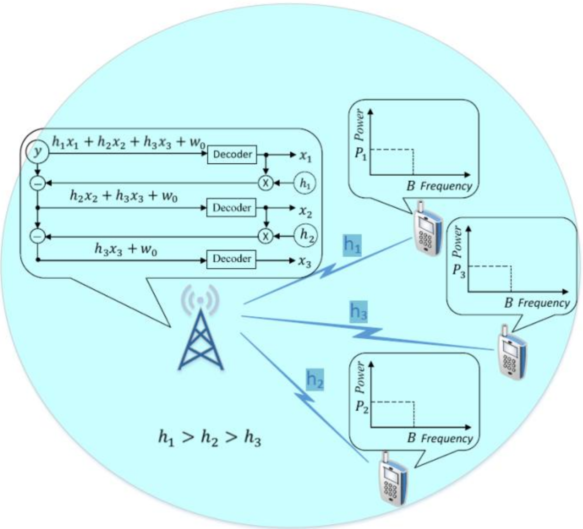

Figure 2: Illustration of a 3-user uplink NOMA transmission with SIC at user ends.

IV. BASIC PRINCIPLE OF COMP

The fundamental principle of CoMP utilizes multiple transmit/receive antennas from multiple antenna site locations, which may or may not belong to the same physical cell, to enhance the received signal quality and effective coverage area by exploiting the co-channel interferences [7] [8]. CoMP mainly has been targeted to improve cell-edge user's experience, but regardless the location it improves throughput performance to the users those experience strong signals of different BSs/cells. CoMP mainly categorized as inter-site CoMP and intra-site CoMP. In inter-site CoMP, the coordination is performed between BSs located at separated geographical areas. On the other hand, intra-site CoMP enables the coordination between sectors of the same BS, where the coordination is performed through multiple antenna units that allow the coordination between the sectors.

In the CoMP-NOMA framework, CoMP transmission is used for users experiencing strong receive-signals from multiple cells while each cell adopts NOMA for resource allocation to its active users.

V. PROPOSED METHODOLOGY

In this purposed CoMP-NOMA model for downlink transmission, CoMP transmission is used for users experiencing strong receive-signals from multiple cells under a downlink co-channel homogeneous network. Various CoMP schemes are applied to the CoMP-users experiencing inter-cell interference under two-cell coMP set, while distributed power allocation for NOMA users is utilized in each coordinating cell. This model first determines the users requiring CoMP transmissions from multiple cells and those requiring single transmissions from their serving cells. After that, different NOMA clusters are formed in individual cells in which the CoMP-users are clustered with the non-CoMP-users in a NOMA cluster.

In the proposed CoMP-NOMA model, I utilize the NOMA throughput formula in a different order than previous chapters but the working principle is exactly same. Here, in each NOMA cluster, the CoMP-users are defined prior than the non-CoMP-users regardless their respective channel gains, in order to ensure the clustering of a CoMPuser at multiple cells in a the CoMP set. First I define the achievable throughput for a NOMA user according to their decoding order under the proposed COMP-NOMA model. After that, different CoMP schemes are discussed considering single antenna

BS and user equipment (UE), and identify their applicability for a NOMA-based transmission model.

Let us assume a downlink NOMA cluster with n users and the following decoding order: UE1 is decoded first, UE_2 is decoded second, and so on. Therefore, UE_1's signal will be decoded at all the users' ends, while UE_n's signal will be decoded only at her own end. Since UE_1 can only decode her own signal, it experiences all the other users' signals as interference, while UE_n can decode all users' signals and removes inter-user interference by applying SIC. Therefore, the achievable throughput for the i-th user can be written as follows:

$$R_i = B\log_2(1+\frac{p_i y_i}{\sum_{j=i+1}^{n} p_i y_i + 1}) \qquad (1)$$

Where y is the normalized channel gain with respect to noise power density over NOMA bandwidth B_i, and p_i is the allocated transmit power for UE_i. The necessary condition for power allocation to perform SIC is:

$$(p_i - \sum_{j=i+1}^{n} p_j)\ \ y_j \ge p_{tol} \qquad (2)$$

Where ptol is the minimum difference in received power (normalized with respect to noise power) between the decoded signal and the non-decoded inter-user interference signals.

VI. SIMULATION RESULT

The average spectral efficiency (in bits/sec/Hz) is evaluated for all the serving cells in a CoMP. For all simulations, the non-CoMP-users are considered at a fixed distance within their distribution areas, while a random distance is considered for CoMP-users outside the non-CoMP-user's coverage areas (measured in terms of the cell-edge coverage distance). Perfect channel state information (CSI) is assumed to be available at the BS ends.

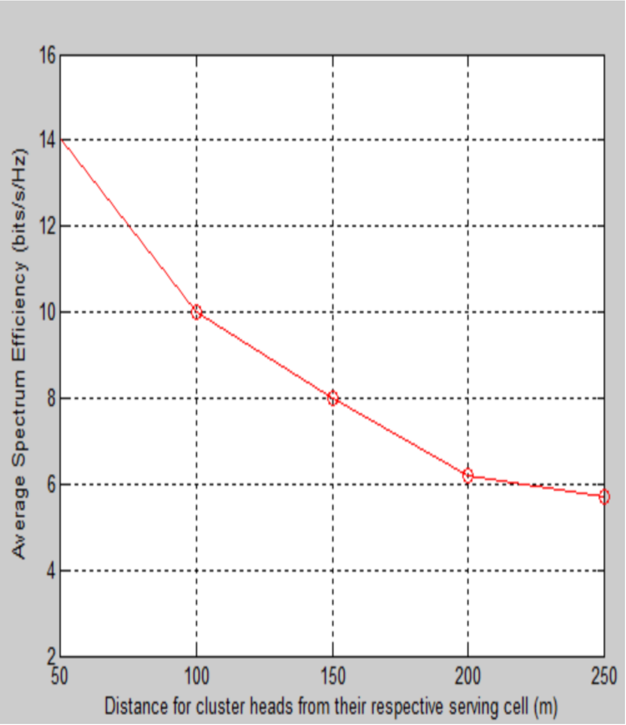

Figure 3: Average Spectrum Efficiency for MIMO 2×2 System

From the above simulation results, the following observations can be made: X Sum-throughput of downlink NOMA is observed to be always better than OMAnat any channel conditions. However, a significant throughput gain can be achieved for more distinct channel conditions of users in a cluster.

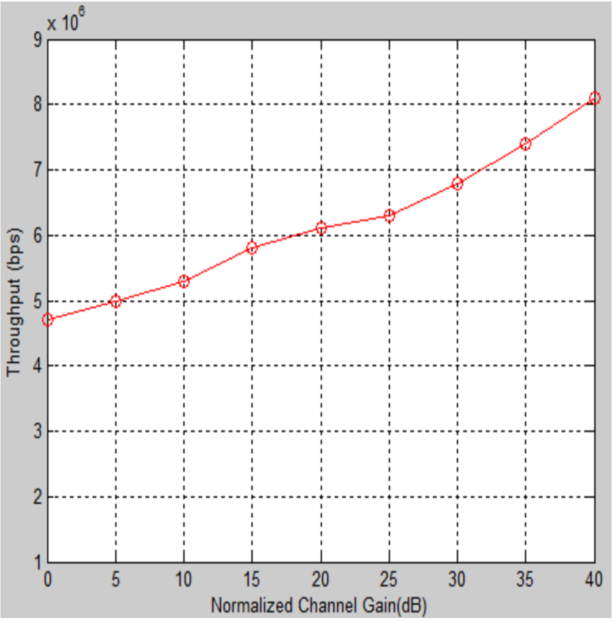

Figure 4: Throughput for MIMO 2×2 System

Individual throughput of the highest channel gain user in a NOMA cluster is significantly higher than in OMA. However, the lowest channel gain user's throughput is limited by its minimum rate requirements. To overcome this issue in NOMA, minimum rate requirements of different users can be dynamically adjusted (by the system) to enhance the fairness among users.

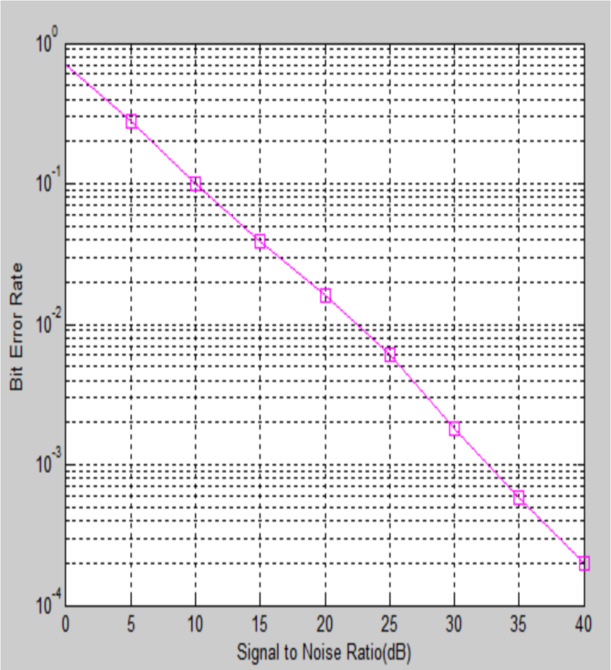

Figure 5: BER for MIMO 2×2 System

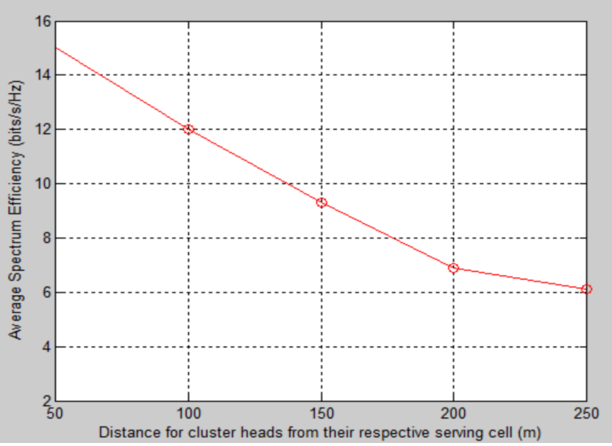

Figure 6: Average Spectrum Efficiency for MIMO 4×4 System

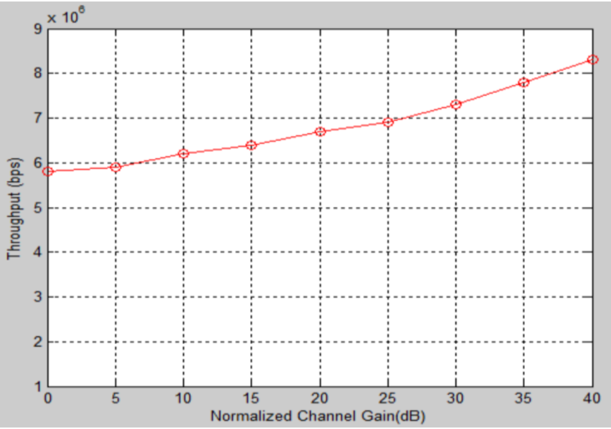

Figure 7: Throughput for MIMO 4×4 System

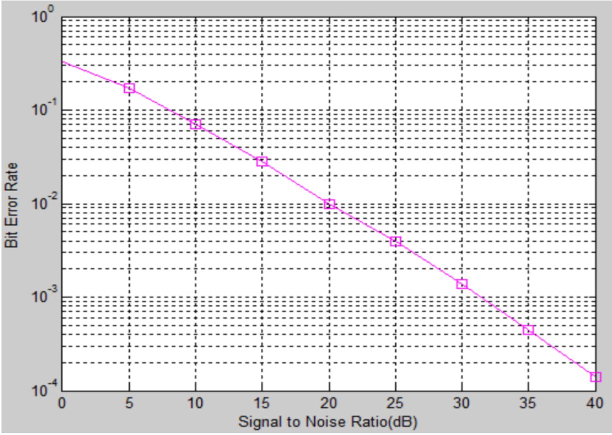

Figure 8: BER for MIMO 4×4 System

VII. CONCLUSION

General framework is proposed to use CoMP transmission technology in downlink multi-cell NOMA systems considering distributed power allocation at each cell. In this framework, CoMP transmission is used for users experiencing strong receive-signals from multiple cells while each cell adopts NOMA for resource allocation to its active users. I also have identified the necessary conditions required to perform CoMP-NOMA in downlink transmission under distributed power allocation. Different CoMP-NOMA schemes have been numerically analyzed under various network deployment scenarios. All of the simulation results reveal the superior spectral efficiency performance of CoMP-NOMA systems over their counterpart CoMP-OMA systems.

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