Downlink Non-Orthogonal Multiple Access (NOMA) for 5G Wireless System: A Review

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Abstract: - To ensure the sustainability of mobile communication services in the coming decades, new technology solutions are being sought for the fifth generation (5G) and beyond 5G (B5G) cellular systems. In the view of the anticipated exponential growth of mobile traffic, these technologies are expected to provide significant gains in the spectral efficiency (and hence system capacity) and improved quality of user experience (QoE).
The non-orthogonal multiple access (NOMA) is considered as a promising multiple access technology for 5G systems. By scheduling multiple users over same spectrum resources but at different power levels, NOMA can yield a significant spectral efficiency gain and enhanced QoE when compared to traditional orthogonal multiple access (OMA) systems.

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 (e.g., FDMA/TDMA/CDMA/OFDMA). The motivation behind this approach lies in the fact that NOMA can use spectrum more efficiently by opportunistically exploring users' channel conditions [6] and is capable of serving multiple users with different quality of service (QoS) requirements in the same resource slot.

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. Taking the comparison of NOMA and SCMA as an example, SCMA can be regarded as a developed technology of NOMA which integrates appropriate sparse coding, modulation and subcarrier allocation.

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.

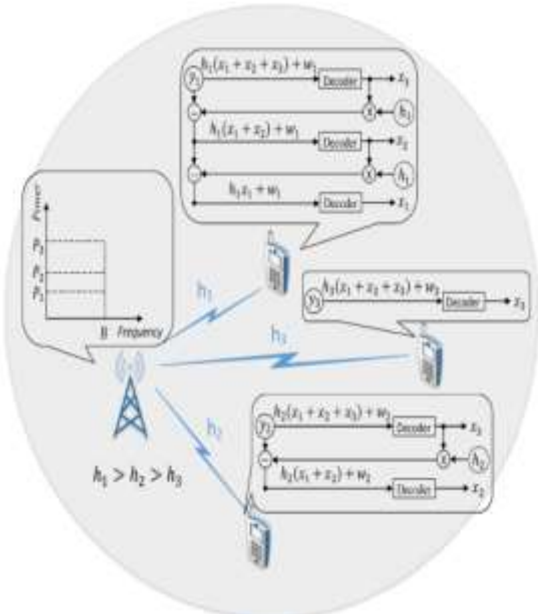

Figure 1: Illustration of a 3-user downlink NOMA transmission with SIC at user ends.

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.

IV. METHODOLOGY

The remarkable growth of smart devices has led to 1,000-fold expected traffic enhancement for the future 5G network system, compared to which the existing spectrum resource is quite constrained. To support a great number of users as well as explosively increased network capacity with limited spectrum, 5G networks depend on critical transmission technologies to provide extremely high spectrum efficiency NOMA, which provides concurrent transmissions for multiple users, is recognized as one promising solution for high spectral efficiency in 5G. In traditional OMA, messages intended for different users are transmitted in different time slots under TDMA protocol, or in different frequency bands under OFDMA protocol.

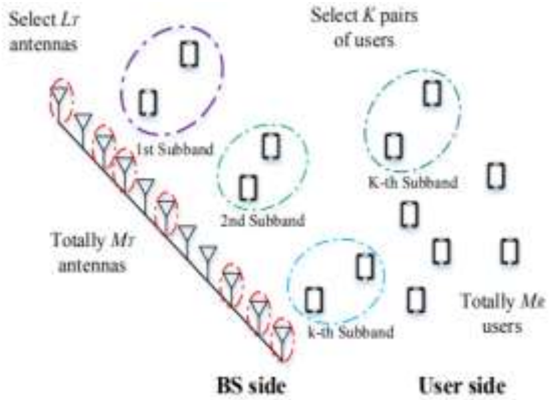

Figure 2: Massive MIMO-NOMA system with antenna selection and user scheduling

Instead, NOMA allows several users to share the same time and spectral resources. Specifically, NOMA serves different users by transmitting multiple messages at different power levels to achieve non-orthogonal reuse, which induces inter-user interference. At user side, the receivers apply successive interference cancellation (SIC) to remove the interference and separate these messages for corresponding users. The performance of NOMA system can be improved if suitable users are clustered as a NOMA group for SIC.

Massive MIMO is also a technology which archives high spectral efficiency in 5G. The very large antenna array is able to transmit massive data streams with different spatial patterns concurrently at the same frequency band to achieve spatial reuse. As a result, the throughput within the same spectrum is significantly improved. Another application is the massive antennas can transmit the same message to for the receiver side to achieve diversity gain, which increases the receive SNR. Moreover, beamforming technology in massive MIMO can potentially transmit messages in an specific angle, which is targeted at relevant NOMA user group. With the transmit power concentrated at that angle, the energy efficiency in increased and interference to other user groups is reduced.

Therefore, the integration of massive MIMO and NOMA technologies becomes a promising solution in obtaining extremely high spectral efficiency in 5G systems. However, massive MIMO-NOMA system brings certain major technical challenges at the same time. Firstly, MIMO RF chain elements, containing RF amplifier and analog-to-digital/digital-to-analog converter, increase the hardware cost along with system complexity, since each antenna should be match with one RF chain for signal processing.

So one critical scheme is to operate MIMO-NOMA with limited RF chains is to select the best subset of antennas for these RF chains. Different antennas correspond to different performance; even the same antenna subset has different performance over time due to random user distribution and user mobility. Hence, we should select the antenna subset with good performance in each time slot.

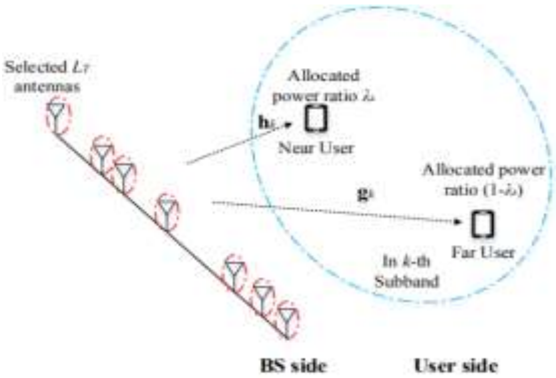

Figure 3: User service in k-th sub-band of massive MIMO-NOMA system.

Furthermore, since channel conditions vary over time and frequency, it is more cost-effective to schedule users into good channels at each time slot. Moreover, NOMA requires user pairing for SIC, where typically one near user (with strong channel gain) and one far user (with weak channel gain) are scheduled as a user pair. The inter-user channel gain different influences the SIC effect. Moreover, there will be very broad bandwidth in the future 5G, including licensed band and unlicensed band.

V. CONCLUSION

In particular, firstly, the principles of massive MIMO, NOMA to achieve high spectral efficiency and relaying technology to achieve power efficiency are introduced. Following this, relevant problems, including antenna selection, user scheduling, power allocation and relaying scheme design, are described with the necessity to be solve. A literature survey on currently available approaches is also provided. Next, the antenna selection and user scheduling strategies in massive MIMO-NOMA system is investigated. With power allocation scheme among NOMA users figured out as the basis, efficient antenna selection algorithm is proposed for single-band scenario. It searches desired antennas from candidate antennas beneficial to relevant users.

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