A Comparative Study of Non Orthogonal Multiple Access with Existing Orthogonal Multiple Access Schemes

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Abstract

The current generation of mobile networks is not designed to meet the future demand for high data rate, low latency communications, support a large number of users. The IMT 2020 has categorized the requirements as enhanced Mobile Broadband (eMBB), Ultra Reliable and Low Latency Communications (URLLC), massive Machine Type Communications (mMTC). The Third Generation Partnership Project (3GPP) has been actively working to define the specifications for next-generation 5G communications to address the requirements. The 3GPP is working across the Core Network (CN) and Radio Access Network (RAN) to meet the requirements. One of the proposed techniques to support a large number of users and high spectral efficiency on the radio multiple access is Non-Orthogonal Multiple Access (NOMA) scheme. This paper provides a study of NOMA, how NOMA addresses the 5G requirements, ongoing standardization efforts for NOMA and a comparative study of NOMA with other OMA schemes like OFDMA. We have also demonstrated improvements in the throughput of the users in NOMA as compared to OFDMA with the help of MATLAB simulations.

***Keywords*—** NOMA, CRNOMA, MIMO, QoS, OFDMA, SIC, IoT

I. INTRODUCTION

In past few decades, the telecommunication industry has seen drastic evolution of communication technologies starting from 1G to 4G and now 5G. While 1G was disruptive in providing mobility for the first time, it was based on analog advanced mobile phone system (AMPS) technology. Early 2G used FDMA (Frequency Domain Multiple Access) and was first digital mobile communication which also enabled operators to provide better voice quality and security on the move. 2G also provided short message service (SMS) capability to the users for the first time. In later phase, main technology used in 2G was TDMA (Time Domain Multiple Access) and 3G was mainly focused on data rather than voice and brought internet capability to mobile communications. Main technology used in 3G was CDMA (Code division multiple access). When it comes to 4G, it is an evolution of 3G in terms of bandwidth/throughput and is growing at phenomenal speed. 4G offered higher bandwidth and speed using OFDMA (Orthogonal Frequency Domain Multiple Access). 4G brought us video streaming and other high throughput applications. "Multiple Access" schemes have evolved with every generation to deliver on speed and throughput.

5G is around the corner and in 2019 many commercial deployments are expected [1] and according to the forecast from [1] by 2024, 25 percent of total global subscription and 40 percent of total mobile traffic will be on 5G networks. The advent of 5G brings together opportunities as well as challenges as it promises 1000 time faster speed than 4G [2] . This could only be possible by gaining efficiency in multiple domains following the network capacity formula which consists of primarily three factors. First is higher cell density i.e. installing more number of cells using HetNet (Heterogeneous Networks), second is spectral efficiency (technologies like MIMO coupled with evolution of 4G multiple access technology) and the third is higher frequency bandwidth or more frequency (mmWave) [3]. While there are clear research advancements in all three areas, one could speculate which multiple access technology will be able to serve the need of 5G to gain the spectral efficiency considering the 4G multi access technologies have already reached their theoretical limits. [2]. One could also ask if it is new multiple access technology then what efficiency gains could be achieved across multiple factors such as bandwidth, users and powers.

In a paper in 2013 Saito et al. [4] proposed the concept of NOMA for the first time which provides higher spectral efficiency over contemporary multiple access technologies such as OFDMA/CDMA and others by super-positioning multiple users in power domain on top of OFDMA. The concept proposed by authors used successive Interference cancellation technique (SIC) to improve both capacity and performance over OFDMA on down link. A lot of researchers have studied NOMA over past few years to conclude that NOMA is a key technology to increase the spectral efficiency in 5G. Islam et al. [5] studied NOMA and provided an overview of different variants of NOMA and its potential and challenges.

NOMA has different schemes such as power domain,code domain NOMA and some related multiple access schemes [5].Focus of this paper is power domain NOMA. We have made an attempt to compare NOMA in power domain with its closest technology

OFDMA from LTE by changing parameters in power, frequency bandwidth and no. of users domains. We attempt to visualize the improvement that NOMA in power domain as over OFDMA.

The rest of the paper is organized as follows: Section II describes the working principles of NOMA. Sections III describe combination of NOMA with Cognitive Radio (CR) and Multiple Input Multiple Output (MIMO). Section IV deals with the issues in NOMA and V discusses how NOMA is a good fit for 5G. Section VI highlights the standardization efforts related to NOMA. The section VII describes the simulation and results of comparison of NOMA with other OFDMA techniques.The Section VIII and IX summarizes the work of the authors and concludes the paper.

II. Working Principles of Power Domain NOMA

Non Orthogonal Multiple Access (NOMA), is a new dimension of multiple accessing scheme that has never been used in 2G, 3G, or 4G. NOMA permits controllable interference by allocating time, frequency, and code resource blocks to multiple users simultaneously in a non-orthogonal way but with a complex operation at the receiver. The non-orthogonality in NOMA is intentionally introduced so that an improved spectral efficiency and massive connectivity can be obtained [4], [6], [7], [8], [9].

NOMA can be mainly categorized into two schemes, power domain and code domain multiplexing [9]. However, in this study we will be focused only on power domain NOMA. The basic principle of this category of NOMA is to exploit the power domain in order to multiplex multiple signals. In this way, it accommodates multiple users via non-orthogonal resource allocation within the same resource block of time and frequency by uniquely distinguishing them with considerable amounts of power level differences. It takes advantage of the path loss variations experienced by different users in order to assign different transmission power levels to each user. Superposition coding (SC) is applied at the transmitter and successive interference cancellation (SIC) at the receiver, techniques that make power domain NOMA different from other multiple access schemes [4], [8].

A. Superposition coding (SC)

SC is one of the basic building blocks of coding schemes and was introduced by Cover in 1970 [10]. Afterwards, SC has been applied in interference, multiple access, and relay channels [11], [12], [13], [14]. The objective of SC is to transmit two signals simultaneously by encoding them into a single signal with two layers. The signal of a user with poor channel condition is encoded at a lower rate whereas that of a user with good channel condition is encoded at a higher rate and superimposed on to the signal of the user with poor channel condition [11].

B. Successive Interference Cancellation (SIC)

When employing the concept of NOMA, we can, theoretically, have a large number of users supported by a given NOMA cluster. However, practically, as the number of users increases, multiple access interference (MAI) limits the capacity of a NOMA system. Network capacity can be improved by employing better interference management techniques. There are a number of techniques used for reducing the challenges caused by interference. In the case of power domain NOMA, SIC is found to be very efficient and outperforms parallel interference cancellation (PIC) when the power level difference between paired users is large. SIC operates in an iterative manner and hence cause less hardware complexity than joint decoding approach [15].

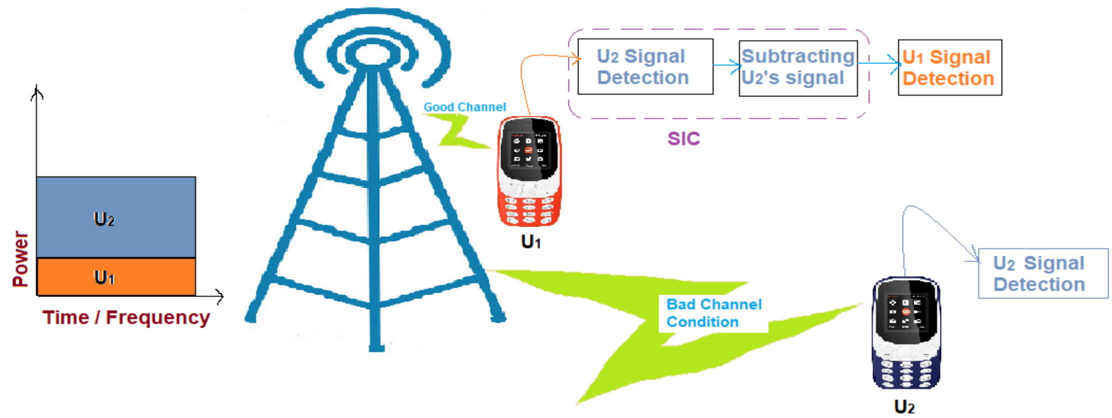

Fig 1: Illustration of Downlink power domain NOMA

During downlink, once the superimposed signal arrives at the receiver, the signal with the highest transmit power which is also the one with the smallest downlink channel gain is detected and decoded by considering other signals as noise. Then, it is subtracted from the received signal to support the recovery of subsequent signals.

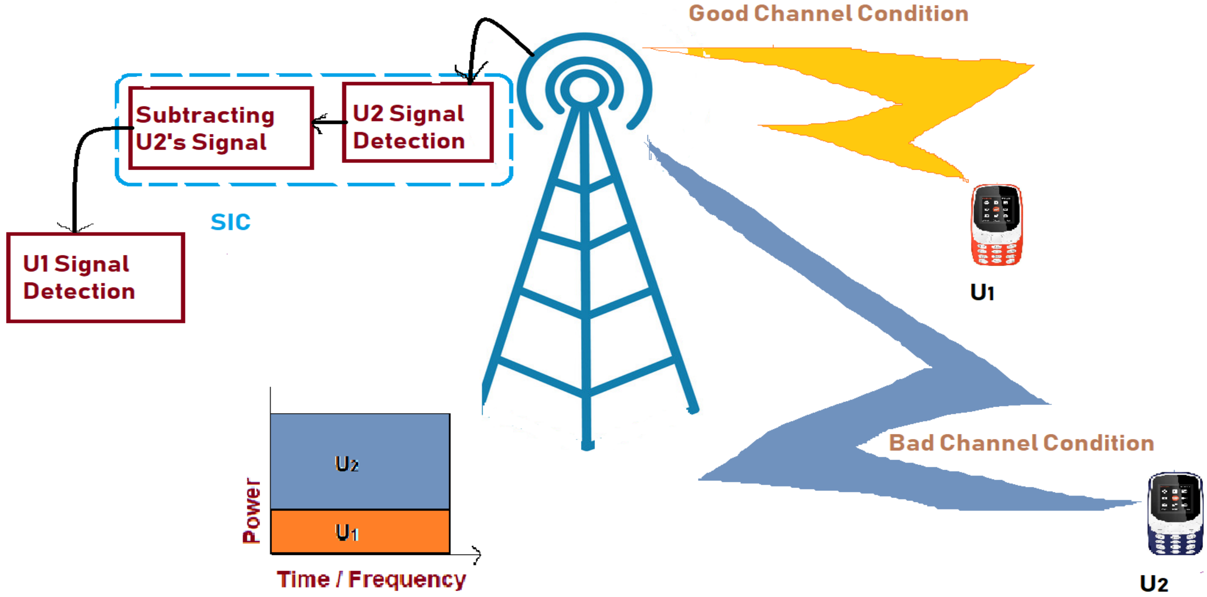

Fig 2: Illustration of Uplink power domain NOMA

As it can be observed from Fig 1, the transmit power is divided between user 1 and user 2. When allocating a transmit power for each user, careful adjustment has to be taken in order to enable better detection accuracy of individual signals at the receiver. Therefore, less power is allocated for user 1 for it has a better channel state information (CSI) whereas more power is allocated for user 2 which is with poor CSI. This helps for the user with bad CSI to experience less interference from the user with good CSI. SIC is applied to extract and decode the signal of user 1 uniquely. The reason that SIC is applied only in the case of user 1s signal detection but not in that of user 2 is because the signal of user 1 is weaker than that of user 2 and cant be recovered unless signal of user 2 is removed from the superimposed signal. Whereas in the case of signal detection of user 2, we do not need SIC as the signal of user 2 is stronger than the signal of user 1 and is not vulnerable to interference from the other signal. However, in order for an accurate SIC operation to take place at the receiving side, the transmit power difference between the signals have to be large.

For the case of uplink, the principle of SIC is similar to that of downlink NOMA in which the signal of the strong user is detected first then followed by that of the weak user as shown in Fig 2.

In NOMA, when allocating transmit power to user signals, more power is assigned to a user with poor channel condition while less power is assigned to a user with better channel condition. This enables the user with poor channel condition to decode its signal without the need for SIC while the one with good channel condition needs to apply SIC to recover its signal. Therefore, if a user is experiencing a bad channel condition, since it cannot utilize its own resource block efficiently, another user with good channel condition can take advantage of that and utilize the same resource block without causing much performance degradation to the user with poor channel condition, which improves the overall system throughput as more information is being carried in the same resource block. However, this is not possible in OMA schemes for an orthogonal resource can be used by only one user and a user with bad channel conditions wastes its resource causing spectral inefficiency.

The relationship between NOMA and OMA can be expressed mathematically by considering the example of a two-user downlink NOMA transmission. Let us denote channel coefficients of users 1 and 2 by h1 and h2. Let the transmit SNR at the base station be represented by ρ. Let us consider $|h1|^2 < |h2|^2$.

For OMA, by the principle of Shannons channel capacity theorem and when power control is employed, the normalized throughput of conventional multiple access schemes can be given for users 1 and 2 as [4]

$$R_1^{OMA} = \beta \times \log_2(1 + \frac{\alpha_1 \rho}{\beta}|h_1|^2) \tag{1}$$

$$R_2^{OMA} = (1-\beta) \times \log_2(1 + \frac{\alpha_2 \rho}{1-\beta}|h_2|^2) \tag{2}$$

Where α_1 and α_2 are the power allocation coefficients. These coefficients satisfy the condition α_1 + α_2= 1. Whereas β is a normalized parameter between 0 and 1 that stands for the resource allocation coefficient. When power control is not considered at the base station, equations 1 and 2 can be re-written into the following form:

$$R_1^{OMA} = \beta \times \log_2(1 + \rho|h_1|^2) \tag{3}$$

$$R_2^{OMA} = (1 - \beta) \times \log_2(1 + \rho|h_2|^2) \tag{4}$$

For NOMA, we have the throughput of users 1 and 2 given by [4]

$$R_1^{NOMA} = \log_2(1 + \frac{\alpha_1\rho|h_1|^2}{1 + \alpha_2\rho|h_1|^2}) \tag{5}$$

$$R_2^{NOMA} = \log_2(1 + \alpha_2\rho|h_2|^2) \tag{6}$$

When we allocate equal time or frequency resources to each of the users at very high SNRs, the overall throughput of the OMA and NOMA systems can be derived from the above equations and written as [4]:

$$R_{sum}^{OMA} \approx \log_2(\rho\sqrt{|h_1|^2|h_2|^2}) \tag{7}$$

$$R_{sum}^{NOMA} \approx \log_2(\rho|h_2|^2) \tag{8}$$

Finally, the overall throughput gain of NOMA over OMA can be expressed as:

$$R_{sum}^{Gain} = R_{sum}^{NOMA} - R_{sum}^{OMA} = \frac{1}{2}\log_2(\frac{|h2|^2}{|h1|^2}) \tag{9}$$

From equation(9), it is evident that the overall throughput of NOMA is higher than that of OMA, and this gain is achieved when the channel conditions of the two users become more different.

C. Challenges of Power Domain NOMA

1) Propagation of error in SIC:- For a reliable signal detection at the receiver when using power domain NOMA, strong interfering signals have to be removed first. When the strong signal is detected erroneously, this error has the possibility of affecting the remaining signals. Consequently, the desired signals may not be recovered very well at the receiver. It is therefore very important to allocate sufficient power to the first signal to be detected so that the probability of its detection error will be minimum. To solve the drawbacks of SIC in decoding, better ways of interference avoiding techniques should be applied [16].

2) Increased number of users degrades performance:- Power domain NOMA performs better when two or a few users share the same resource block. As the number of users increases, the power level difference among users decreases. As a result, co-channel interference will be strong and will cause a severe performance degradation of power domain NOMA. Therefore, in order to have a better performance, different approaches can be employed. The number of users in a given NOMA cluster can be limited. On top of that, dynamic power allocation can be done within a cluster so as to optimize system throughput or realize fairness among users within the cluster. Moreover, it would be recommendable to use a hybrid multiple access system in which OMA is combined with NOMA. By dividing all users into specific groups where different groups are made to have orthogonal resources, while within each group NOMA is applied [16], [17].

D. Advantages of Power Domain NOMA

Massive connectivity:- In OMA, the number of devices that can access connectivity is equal to the number of available resource blocks; whereas in NOMA, multiple devices can be supported simultaneously by each resource block, which would be highly important for massive Machine Type Communications (mMTC) as in the case of IoT, which 5G is expected to support [8].

Backward Compatibility:- Basically NOMA utilizes the same resource blocks that has been in use by OMA. What is new with NOMA is the non-orthogonality introduced into the resource utilization and power domain multiplexing. With the help of good SIC technique, NOMA can be made to inter-operate with OMA schemes [8].

Fairness:- In OMA, strong users always take advantage of the transmit power while weak users starve. However, in NOMA, more power is allocated to weak users while less power is allocated for strong users. In this regard, both weak and strong users are given the opportunity of transmitting information. The weak users signal can be accurately detected at the receiver without much interference from the strong users signal [7], [9].

Spectral efficiency:- In NOMA, by varying the power levels allocated for different users, multiple users can simultaneously utilize the available resource block. Whereas in the conventional multiple access schemes, each user occupies their own separate resource block which makes bandwidth utilization inefficient [4], [18], [19].

III. Combinations of NOMA with other techniques

A. Cognitive Radio and NOMA

Cognitive Radio (CR-NOMA) is a sub-category of power domain NOMA. The key idea is to form a special case of Cognitive radio where the power requirement demands for each user is met in a fair way in terms of their Quality of Service (QoS) requirements [20]. Therefore we may understand that this CR-NOMA basically focuses on the power domain rather than code domain multiplexing. A cognitive radio is an adaptive and smart radio system and network technology which enables us to detect the transmission parameters and channels easily thus enabling more communications to run simultaneously and improve radio spectrum allocation to a large extent, thus serving people of the same resource block such as time, frequency, and code-spectrum [21].

Interweave networks, underlay networks, overlay networks are the three main concepts that deal with CR-NOMA and present a very close relation with it. Interweave method implies that user can transmit only in the licensed spectrum, where the concurrent primary and secondary transmissions are allowed [22]. In underlay networks it is necessary that the signal causing noise is below an interference level. On the secondary user, the method of Successive Interference Cancellation(SIC) is used for the receiving technology [23]. Only one Secondary Receiver (SR) is allowed for transmission, and other SRs should wait until the current transmission is done [23]. Since the Primary Receiver (PR) receives the primary signal at both time slots, it treats secondary signals as noise signals and decodes the primary signal by using maximal ratio combining (MRC). At the Secondary Receiver, it first decodes the primary signal by using MRC, and then employs SIC to sequentially decode the secondary signal until its own signal is retrieved. This enables a efficient two-time slot communication between the sender base station and the receiver base station [24]. Whereas in overlay networks the secondary user provides relaying service to the primary network and at the same time will transmit its own signal as well [22] However, these networks naturally suffer from interference from secondary as well as primary transmitters. The SIC can cancel out the noise coming from the first user and thus enable the second user to achieve a noise-free signal.

One important point to note is that both the users have unequal power allocation. Also, differences in Successive Interference Cancellation play a major role. In CR networks many users communicate over the same network/bandwidth which is originally allocated to the primary user [25]. In such a scenario, the Base station(BS) has to decide between the throughput and the power wastage of the bandwidth allocated to the primary user. A technique to implement this is commonly used and is called the OSA (Opportunistic Spectrum Access). This makes primarily use of sensors in the spectrum which senses whether the primary user is completely turned off and only then transmits the signal. With this strategy, dynamic resource allocation (DRA) becomes essential, whereby the transmit powers, bit-rates, bandwidths, and antenna beams of the secondary transmitters are dynamically allocated based upon the channel state information (CSI) in the primary and secondary networks [25].

The following points give a detailed explanation of the latest trends in CR-NOMA, antenna allocation schemes for it, and some of the challenges that are faced by the method during the implementation:

1) Latest Trends in CR-NOMA: The trend of Multiple-input Multiple (MIMO) output antennas has been an upcoming trend for 5G Scenario. The throughput benefits have been very high as compared to the other techniques. Thus the problem of Antenna selection for use in 5G represents an important discussion in this case. The main goal behind doing this is to make sure that better spectrum efficiency is achieved while keeping the same power level for primary and the secondary user. Cognitive and NOMA both have their own ways of improving the spectral efficiency and so they can be clubbed together for a even better throughput. The physical layer security in CR-based-NOMA network is different from any single network [19]. The transmit power to the secondary user (SU) is constrained by the Signal to Noise Ratio (SNR) of the Primary user. Compared to the conventional CR systems, higher spectral efficiency can be achieved by CR-NOMA because both the PU and SU can be served simultaneously using the same spectrum. The SU is assumed to be rate adaptive and the design criterion is to maximize the SUs rate subject to the Quality of Service (QoS) requirements of 5G. [26] The techniques studied for conventional OMA techniques have been significantly different from those used in NOMA use cases. Thus a new low-complexity joint Autonomous Scheme (AS) scheme has been proposed, namely subset-based joint AS (SJ-AS), to maximize the signal-to-noise ratio (SNR) of the Secondary User SU under the condition that the QoS of the PU is satisfied [27]

2) Antenna allocation scheme for the primary user and the secondary user: If we assume that each of primary and secondary user uses a different antenna for the purpose of it's communication then we know that the power savage during the outage is less and the efficiency thus decreases [27].At each node there is a need to reduce the hardware cost, power consumption and complexity, and only the partial channel state information(CSI), i.e., the channel amplitudes, are needed at the BS(base station), which is assumed perfectly known at the BS through control signalling [28] Best Frequency combination of frequency and radio resources, is what we want from the CR or any other variant of NOMA. To keep in mind, the NOMA architecture is completely based upon the power domain phenomenon.

3) Software defined Networking based NOMA technique: SDN based NOMA works very similar to CR-based NOMA which concentrates on allocating different power levels to primary and the secondary user. Design principles of cognitive NOMA networks are perfectly aligned to the functionality requirements of 5G wireless networks, such as high spectrum efficiency, (cognitive NOMA with co-operative relaying) [20]. CR networks are based on full-duplex, device to-device, and multiple-input multiple-output (MIMO) which further increase spectrum efficiency. More particularly, existing research on the combination of NOMA and CR has the possibility to meet 5G requirements of high throughput, massive connectivity, as well as low latency. Despite these potential benefits, building efficient cognitive NOMA is a challenging issue in practice. This is because both NOMA and CR are interference-limited, and thus, coexistence of inter-network interference between the primary and secondary networks and intra-network interference (also called co-channel interference) caused by power domain multiplexing of NOMA undoubtedly results in severe performance degradation of reception reliability. [20]

4) Advantages and uses of CR NOMA: Cognitive networks can help in a number of other technologies such as Augmented Reality(AR), Virtual Reality(VR), Internet of Things (IOT) etc. Cognitive NOMA networks can guarantee improved user fairness. The Secondary User (SU) with a weak channel is allocated a higher data rate requirement, whereas a Primary User(PU) with a strong channel is allocated a lower data rate requirement. This yields a balanced trade-off between the users. Due to the coexistence of inter-network, intra-network interference in cognitive NOMA networks, as well as possible poor channel conditions of transmission links because of severe path loss and/or deep fading, outage performance in cognitive NOMA networks may be considerably degraded. [22]

5) Challenges faced by Cognitive NOMA techniques: Cognitive NOMA is a challenging issue in practice due to a number of phenomenon. Therefore, it is necessary to combine NOMA with CR in an appropriate manner for minimizing the interference and better utilization of the underlying spectrum resource. A concern which arises is that the Cognitive Radio needs to adapt to transmission and receiver parameters to avoid causing interference to the Primary User(PU) thus maximizing the spectral efficiency. To avoid causing interference, numerous techniques can be used and combined such as frequency tuning (adaptive frequency hopping, dynamic frequency selection and RF band switching), Orthogonal Frequency Division Multiplexing (OFDM) sub-channelization, channel aggregation, time multiplexing, power control, modulation and coding for Quality of Service (QoS) adaptability. Some other techniques that can be supportive towards better spectrum sharing and utilization are beam-forming and space-time coding for Multiple Input Multiple Output (MIMO) [29]. CR will be also based upon strong cross-layer interactions. For example, the cognitive spectrum management involves intelligent use of spectrum based on anticipating the demand for spectrum by the user and previous observation of user behavior [29]. Another cognitive behavior is to monitor the environment in which the CR is operating and then simultaneously manages the resource intelligently based on expectations or any experiences.

A key bottleneck in CR is that the frequency-agile RF front-ends can easily be coupled with the parts of the CR that carry out the digital processing [29]. CR transceivers should be able to use any available band, adapt to multiple access methods and adapt to modulation schemes, which switch quickly between links, and communicate with two or more points at a time. Therefore, the RF section needs to be particularly flexible [28]. This can be seen as a potential scope for improvement in the current scheme of NOMA. In addition, Cognitive Radio receiver should be able to sense the unused frequency bands, that is, if necessary. In order to solve hidden Primary User (PU) problems and eliminate the impact of these issues, co-operative spectrum sensing would be an effective method to improve the detection performance by exploiting spatial diversity in the observations of spatially located CR's (Cognitive Radios). In such a case, combining a geo-location database with spectrum sensing may be a better option provided that the CR device cost and power dissipation are decreased [22].

B. NOMA MIMO

The Anritsu white paper [30] describes NOMA and MIMO, a key technology to improve the spectral efficiency of the wireless communication systems.

In [31], the authors have put efforts to find out how NOMA can play a role in massive MIMO. They have described the scenarios where NOMA can complement MIMO systems. According to this paper, NOMA outperforms massive MIMO when $M / K = 1$ where M is the number of antennas and K is the number of active users. However, it does not perform well in common massive MIMO scheme when $M >>> K$. Hence the authors have found out the hybrid of NOMA-MIMO scenario to leverage the best of NOMA and MIMO, i.e., when two users have nearly parallel channels. The hybrid NOMA-MIMO approach groups users with similar channels under power-domain NOMA scheme and rest are served with massive MIMO because two users with the similar channel may have degraded performance under massive MIMO.

IV. Practical Issues in NOMA

The NOMA improves the overall throughput of the system, but it involves challenges like signalling overhead, design of receivers and security.

A. Signalling Overhead

The ZTE report [32] describes the NOMA adds signalling overhead in scheduling. Since NOMA works on power-domain multiplexing, the transmit power allocation can affect the throughput of the users and in turn the overall throughput of the system. The best performance can be achieved by doing the exhaustive search of user pairs and dynamic power allocation. However, this is computationally intensive and also the signalling overhead associated with the decoding and power allocation increases. The power allocation and MCS selection granularity are allocated over each subband. The overhead increases linearly as the number of sub-bands increases because power allocation and the pairing of users is done over each subband.

B. Receiver Design

The ZTE report [32] highlights that the design of the NOMA receiver is complicated because the decoding of the received signal for the cell center user needs advanced decoding techniques. As, the same time and frequency resources are shared between cell center and cell edge user, the signal of cell center user interferes with cell edge user. The two types of interference cancellation receivers are symbol-level interference cancellation (SLIC) and codeword level interference cancellation (CWIC). The CWIC decoding performance is better than SLIC. However, the resource alignment and transmission power alignment, in general, scheduler flexibility, has an impact on system performance and receiver complexity. The tradeoff of scheduler flexibility with SLIC and CWIC needs to be taken into account in the receiver's design.

C. Security Concerns

The NOMA techniques generally employ SIC to decode the multiplexed signal. The paper [33] describes how the successive decoding results into the leakage of other users data and are vulnerable to attack with the risk of getting data misused. The authors also describe the previous efforts discussed in [34] of combining international mobile equipment identity (IMEI) and media access control (MAC) address for secure transmission and is not enough to provide the full proof security over the air interface. Hence they have proposed the blockchain based secure data handover over NOMA with two-phase encryption. The parameters used for encryption are spatial information of User Equipment (UE), timestamp in-addition to MAC and IMEI. These parameters are used for key generation and provide security over spoofing and hijacking of data.

V. NOMA and 5G Requirements

The 5G technology is an umbrella technology which covers eMBB, mMTC and URLLC communication. The eMBB is suited for high data rate applications like internet services, Augmented reality, Virtual reality, video streaming. The mMTC covers massive IoT devices for various uses. The URLLC communication includes low latency communication like mission control applications, factory automation, telesurgery, tactile internet communication. This section briefly describes how NOMA is a fit for requirements of 5G.

A. eMBB

The NOMA supports a large number of devices and provides high throughput. The spectral efficiency is improved as compared to other OMA techniques like OFDMA. With these advantages, the NOMA is well suited for eMBB, and it also ensures users QoS fairness. The QoS fairness is ensured by allocating more power to the cell edge user paired with the cell center user. The improved spectrum utilization is because of sharing the same time and frequency resources among users.

B. mMTC

The devices can communicate only when the base station has allocated resources to them. The process of requesting a resource for transmission is called Random Access(RA) procedure. This procedure has challenges like collision problem, signalling overhead and different QoS requirements for the massive IoT devices outlined in the paper [35]. The NOMA removes the need of RA procedure because the devices can use the same resources for transmission. This leads to the removal of the signalling overhead problem and reduced access delay as compared to conventional existing RA procedure in cellular systems. The paper proposes random NOMA for IoT devices communication. In this technique, the devices do not need to perform RA procedure to access the network instead they can transmit on any random sub-band. The paper also discusses the practical challenges involved in considering NOMA for massive IoT like channel estimation, power allocation, traffic and load estimation, synchronisation among devices.

C. URLLC

The URLLC requires low latency of sub-millisecond and reliability of 99.999% with error rates lower than 1 packet loss in 10^5 packets [36]. The paper [37] describes the grant free NOMA as a key enabler technology for URLLC where the user can transmit data without waiting for the base station to assign the resources. The paper also studied how far the NOMA can meet the requirements of URLLC by doing the performance analysis of NOMA with short packet communications. The simulation is performed to find out the SNR for a certain error rate and latency. The simulation results show that usage of the short packet has a positive impact on the requirements of SNR to achieve error rate and latency requirements with NOMA - URLLC.

VI. NOMA Standardization Efforts

This section describes the efforts taken by standardization bodies like 3GPP regarding NOMA.

A. Downlink NOMA Standardazation

A new study item was approved in 3GPP LTE Release-13 regarding NOMA under the name of Multi-User Superposed Transmission (MUST). A Network-Assisted Interference Cancellation and Suppression (NAICS) is specified in LTE Release-12 TS 36.300 /36.331 and this work can be extended in the direction of NOMA [32].

B. Uplink NOMA Standardazation

The paper [38] describes a study item for New Radio (NR) proposed for 3GPP Release-14. It mainly deals with the UL transmissions to support massive connectivity and grant free transmission procedure for low latency and high reliability.

Also, a study item for Release-15 is approved and is discussed in [39] for the study of non-orthogonal multiple access schemes for 5G NR, including NOMA.

VII. Simulation and Results

The aim of this simulation is to prove that NOMA fulfills the requirements of 5G better than OMA techniques. In this simulation, we have compared, in a very simplified way, NOMA to OFDMA since OFDMA is the most advanced multiple access technique among OMA techniques. The programme used for this was MATLAB. The simulation case consists in a circular cell with a radio of 1 Km. In each simulation attempt, the users are randomly located inside the cell. The cell is divided in five sectors, so there are five beams. Thereby, NOMA is applied individually in each sector, as well as OFDMA. The frequency used in this simulation is 3,6 GHz since is the central frequency of one of the main frequency bands chosen for 5G in Europe (3400 3800 MHz).

In the OFDMA simplification for our simulation, the power transmitted to each user is the same and each of the user is assigned with a specific bandwidth, which is not shared inside each sector. When it comes to NOMA, every user is allowed to use all the available bandwidth. The power coefficients, in NOMA, are assigned in order to achieve a particular Signal to Interference Ratio (SIR). In this simulation, we have chosen to pursue a SIR of 3 dB for each user. However, the way in which NOMA assigns the power coefficient is vital to achieve the maximum performance and the SIR chosen for this simulations is probably not the most suitable. There is not time schedule, so all users communicate at the same time. All the same, it is enough to see if NOMA is superior to OFDMA in this simplified setup.

The capacity for each technique is the sum of the capacities of all users in the cell. The capacity for each user is calculated according to the Shannon's Law ($C = W * log_2(1 + SINR)$). For the received signal of each user, we have only taken into account the losses due to Free Space Propagation, which depend on the distance to the base station.

The following table and graphs show the results of the different iterations of the simulation code.

Table 1: Results from NOMA vs OFDMA simulation

Bandwidth (MHz)	Power (Watts)	Users	NOMA Capacity (Bits/s)	OFDMA Capacity (Bits/s)	Improvement (Bits/s) Cnoma - Cofdma
20	1	20	3,47E+09	3,19E+09	8,95%
20	10	20	3,80E+09	3,53E+09	7,72%
20	50	20	4,14E+09	3,82E+09	8,57%
20	100	20	4,30E+09	3,91E+09	9,94%
2	10	20	3,74E+08	3,82E+08	-2,00%
10	10	20	1,87E+09	1,81E+09	3,22%
20	10	20	3,73E+09	3,48E+09	7,20%
50	10	20	9,54E+09	8,38E+09	13,86%
20	10	10	2,91E+09	2,80E+09	3,59%
20	10	20	3,77E+09	3,52E+09	7,04%
20	10	30	4,04E+09	3,56E+09	13,28%
20	10	40	3,93E+09	3,51E+09	11,84%

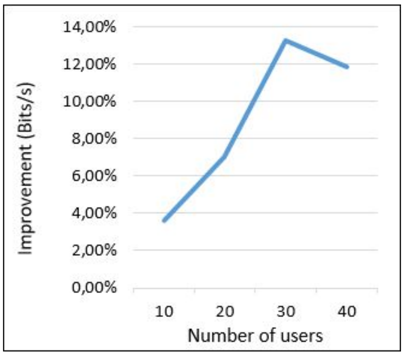

Fig 3: Progress in improvement with different number of users

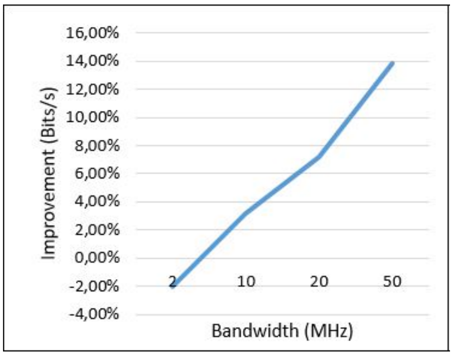

Fig 4: Progress in improvement with different bandwidths

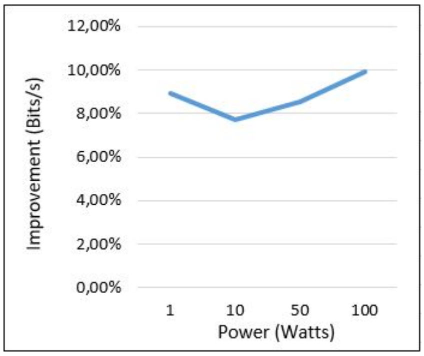

Fig 5: Progress in improvement with different available power

There are three parameters which were modified through the simulation: bandwidth per sector, available power per sector and number of total users. These parameters were modified to see their impact in the performance of both techniques. The default value of these parameters is as follows: 20 MHz of bandwidth, 10 Watts of available power and 20 users per cell.

Each of the resulted NOMA and OFDMA capacities is the average of three iterations with the same values so as to get a more reliable result. Regarding the available power, the results shows that NOMA capacity gets a higher difference with OFDMA capacity when the available power increases. This is due to how the increment in power affects the Signal to Interference and Noise Ratio (SINR) and how this is reflected in the capacity. In the case of OFDMA, each user is provided with a high SINR since there is no interference from other users. On the other hand, NOMA's users have a much lower SINR because of the interference of the other users in the sector who are using the same band of frequency. Since in the Shannon's law for the capacity the SINR is located inside a logarithm, improvements in the SINR when it is low will make a higher impact in the capacity than when the SINR is already high.

When increasing the bandwidth, NOMA manages to outperform OFDMA. In this case, the improvement when using NOMA goes higher when we increase the available bandwidth since NOMA, unlike OFDMA, assigns the same frequency band to several users by allowing a certain amount of interference, so an increment in the bandwidth will cause a more notorious improvement in NOMA capacity.

The multiple access technique chosen for 5G must sustain a great number of users as we know. Therefore, NOMA should show a better performance than OFDMA when users increase. The simulation proves that, because of the reuse of the frequency band in NOMA, the NOMA capacity keeps increasing when number of user goes up while OFDMA capacity remains the same. In the last iteration, with 40 user in the cell, we can see that NOMA capacity does not improve. This should be possible to fix with a better algorithm to assign the power coefficient more effectively. We can conclude that, in this simulation case, NOMA accomplishes to beat OFDMA in almost every iteration. Moreover, NOMA benefits to a greater extent from the increments in available power and bandwidth, even from the increase of number of users, which is the most remarkable improvement of NOMA for 5G networks.

VIII. Roles and Responsibilities

Team was self-organized and was actively involved in the research. Members divided different sections and whole team worked together to share the outcome and co-reviewed all the sections. For the writing of the paper, online sharing tools such as Overleaf and Zotero were used. Team frequently communicated over Slack to discuss the improvements.

- Ashish Sanjay Sharma - Abstract, NOMA MIMO Scheme, Practical Issues in NOMA, NOMA and 5G, NOMA Standardization Effort
- David Anguiano Sanjurjo - Simulation (MATLAB) and results
- Gebremeskel Gebremariam - Basic working principles of NOMA, emphasizing on superposition coding (SC), Successive Interference Cancellation(SIC), the challenges and advantages of power domain NOMA
- Jitendra Manocha - Introduction and Background of NOMA and Conclusion
- Shrinish Donde - Combination of NOMA with Cognitive Radio Technology(CR-NOMA), latest trends in CR-NOMA, Antenna allocation scheme of CR-NOMA and power outages in it, Software defined networking based CR-NOMA, Advantages, Uses and challenges faced during practical implementation of CR-NOMA techniques

IX. Conclusion

5G is far more superior than its previous generations when it comes to characteristics. The promise of lower latency, higher throughput and ultra reliability can only be delivered with new technologies. NOMA is one of the fundamental multiple access technology in spectral efficiency, and the benefits over its closest contemporary multiple access scheme OFDMA are significantly better.This has also been proven in the simulations done by us, where NOMA outperformed OFDMA in all three varying dimensions, such as varying power, bandwidth and no. users. Therefore, it can be concluded that NOMA together with other technologies such as MIMO will be key to deliver the 5G characteristics specially in the area of spectral efficiency. While 5G networks are being deployed in Tier-1 operators, it will take few years before it becomes main stream. In another words, 4G LTE networks will still be operational for years to come, hence there is a good possibility that NOMA could also be used to enhance the capabilities (spectral efficiency) of 4G LTE networks as well.

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