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A Study On Non Orthogonal Multiple Access (NOMA) For 5G

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ABSTRACT:*Many multiple access techniques have emerged based on the technology used in mobile devices. In this paper a brief description of the multiple access techniques used from 1G to 5G is given and finally a detailed overview of the latest Non Orthogonal Multiple Access technique (NOMA) for 5G is presented. NOMA research challenges and future trends in 5G are also discussed.*

KEYWORDS: *Cooperative NOMA, MIMO NOMA, mmWave, Multi carrier NOMA, OMA, Single Carrier NOMA, Wireless Networks.*

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I. INTRODUCTION:

One of the most challenging constraints in wireless communications is the bandwidth that is the amount of frequency range available for communication is limited. It must be somehow allowed for multiple users to communicate simultaneously in the given frequency range. Multiple access techniques allow multiple users to access the single channel to make the efficient usage of bandwidth there by providing multiple users access a single channel. There are many channel-based (or reservation based) multiple access techniques. Broadly these multiple access techniques are classified as 1. Frequency Division Multiple Access (FDMA), 2. Time Division Multiple Access (TDMA) and 3. Code Division Multiple Access (CDMA) [1]-[2].

In FDMA, the whole frequency band or frequency range is divided into small frequency channels and each of the channels is allocated to a specific user. Here user can access the individual channels simultaneously.

In TDMA, the total frequency band is available to a user but only for a short period of time i.e. each user can transmit the data only in a specified time slot with a common frequency. Multiple users can transmit using the same frequency but only in their specified time slot.

In CDMA, multiple users can transmit simultaneously using the same frequency band over a single common channel but each with a different code. In many mobile communication applications a combination of FDMA, TDMA & CDMA is used as multiple access techniques. Table 1. gives the multiple access techniques and their usage in a cellular system [1]-[2].

Multiple access techniques Random based (Packet based) are divided into two as Random with and without reservation. Random without reservation multiple access techniques are ALOHA, CSMA & ISMA. Random with reservation multiple access techniques are Reservation ALOHA & PRMA.

First Generation till third generation of mobile communication uses a combination of CDMA, TDMA & FDMA techniques and is single carrier systems. Fourth generation of mobile communication was started by ITU-R from 2008 and supports mobile web access, IP telephony, Mobile on-line gaming services, HD mobile TV, Video Conferencing, 3D TV, Cloud Computing and so on. 4G systems use OFDM with multi carrier transmission. Example of 4G systems commercially deployed is Mobile WiMAX & LTE standard [1]-[2].

Table 1: Various multiple access techniques in cellular systems

S.No	Cellular System	Multiple Access Technique
1	AMPS	FDMA/FDD
2	GSM	TDMA/FDD
3	USDC	TDMA/FDD
4	DECT	TDMA/FDD
5	IS-95	CDMA/FDD
6	CDMA 2000	CDMA/FDD & CDMA/TDD
7	UTRA	DS- CDMA/FDD & CDMA/TDD
8	W-CDMA/NA	DS- CDMA/FDD & CDMA/TDD

9	W-CDMA/JAPAN	DS- CDMA/FDD & CDMA/TDD
10	WIMS/W-CDMA	DS- CDMA/FDD & CDMA/TDD
11	CDMA I	TDMA/FDD
12	WC 136	TDMA /TDD
13	TD-SDMA	DS-CDMA/TDD
14	LTE/WiMax	MIMO-OFDM
15	5G	CDMA/BDMA

The rest of the paper is organized as follows. Section 2 gives NOMA introduction. Section 3 & 4 describes the design of Single–Carrier NOMA and Multi Carrier NOMA respectively. Section 5 focus on Multiple Input Multiple Output (MIMO) NOMA and Co-operative NOMA respectively. Section 6 gives a study on the combination of NOMA with mmWave and Section 7 concludes the paper.

II. NON ORTHOGONAL MULTIPLE ACCESS TECHNIQUE

Fifth generation wireless networks uses Non Orthogonal Multiple Access (NOMA) as the Multiple Access Technique [3]. NOMA is considered as the most essential multiple accesses enabling technology for the 5th generation (5G) wireless networks which meets the demands like low latency, high throughput, high reliability, good connectivity and improved fairness. NOMA schemes are basically proposed to improve the efficient usage of limited network sources. The key challenge is to serve multiple users with the same resources such as the time slot, frequency channel, the sub carrier and the spreading code.

Many 5G multiple access techniques are proposed in literature such as Power domain NOMA, SCMA, PDMA LDS, LPMA and all these techniques are based on the same concept where multiple users are served with the same time slot, frequency channel and spreading code [4]. It is Possible to integrate NOMA with the present and future wireless systems due to its compatibility with other communication technologies. NOMA can be compared with the conventional Orthogonal Multiple Access (OMA) techniques such as OFDMA & TDMA. NOMA ensures that two users can be served simultaneously on the same OFDMA subcarrier. Recently, NOMA is included in Layered Division multiplexing (LDM) which is the forthcoming digital TV standard (ATSC3.0) [5]. By using the NOMA principle and super imposing multiple data streams, the spectral efficiency of TV broad casting can be improved. Thus, NOMA not only serves the 5G networks but can also has a large potential for other upcoming & existing wireless systems.

III. SINGLE CARRIER NOMA

NOMA can be classified into two as Power Domain NOMA and Cognitive Radio NOMA (CR-NOMA).

3.1 Power-domain NOMA

It serves multiple users in the same time slot, spreading code, and OFDMA subcarrier and also the multiple access can be realized by assigning different power levels to each user. For example, MUST which is a power domain NOMA is a two user downlink NOMA scheme, wherein two single antenna users are served simultaneously at the same OFDMA subcarrier. In this power domain NOMA, in order to achieve high system performance, multiple users are connected to single transmitter by superimposing their information signals. Each user is assigned a different power coefficient according to their channel conditions. Successive interference cancellation (SIC) is applied at the receiver to decode these signals one by one unless the desired user's signal is obtained. Thus, the method provides a good tradeoff between the systems throughput and user fairness. For example, if there are two users in a system then the base station superimposes the user's messages by assigning different power coefficients to each. The key principle of power domain NOMA is to assign more power to the user with poor channel conditions. In order to decode one's message, a user breaks the other's message as noise. For example, if user1 decodes its message by treating user 2 message as node, whereas the user2 performs SIC in it initially and then decodes user1 message and then removes it from the observation before decoding its own message. It is found that the performance of NOMA is far better compared to OMA in terms of gain. Also use of NOMA supports massive connectivity and meets diverse QOS requirements of the users [7].

3.2 CR NOMA

In order to ensure user fairness, more power is allocated to users with power channel conditions in case of conventional power domain NOMA. Inspite of this, conventional power domain NOMA cannot guarantee the QoS to the users strictly. An alternative method is to use Cognitive Radio (CR) NOMA which ensures some or all of the QoS requirements of the users. The main idea behind CR-NOMA is to consider NOMA as a special case of cognitive radio and is designed in such a way that the users QoS requirements are met. CR-NOMA uses the NOMA principle [8] where a single base station serves two users through downlink. The primary user is one with poorer channel condition. Thus the primary user is always served with sufficient power in order to meet the QoS requirements. Secondary user will be served with the left out power later. In [8], the outage & rate performance of CR-NOMA is analyzed and in [9], the energy efficiency of CR NOMA is studied. Also in [9], the concept of CR-NOMA is extended to systems with multi-antenna nodes. It is not always required to consider the user with poorer channel conditions as the primary user. In [10], in order to meet all the users QoS requirements in a flexible manner, a more general cognitive radio with power allocation policy for uplink and downlink NOMA scenarios is proposed.

IV. MULTI CARRIER NOMA

In Multi carrier NOMA the user s are divided into multiple groups in a network. User belonging to a group is served with the same orthogonal resource block which follows the NOMA principles and different resource blocks are allocated to different groups. Multi carrier NOMA is considered as a special case of hybrid NOMA. The key idea behind hybrid NOMA is to reduce the system complexity. It is possible to assign all users in the network to a single group with one orthogonal resource block, but this could be problematic, as the user with good channel conditions before decoding its own message would have to decode other user's messages resulting in high decoding delay and increased complexity. Thus, Hybrid NOMA would be a better alternative to have a balanced tradeoff between complexity and system performance

In multi carrier NOMA, all users are divided into multiple groups. Same sub carrier is assigned to all users within one group. Other groups are assigned other sub carriers in order to avoid inter group interference. Thus massive connectivity can be realized using this scheme. But this overloading supports many users than the number of available sub carriers and is realized at lesscomplexity as the number of users at each subcarrier is limited.

It is also demonstrated in [3] that if two users with most different channel conditions are grouped then it gives the highest gain performance over OMA. In [8] user pairing is studied i.e., two users are assigned to a single orthogonal resource block. It is studied in [3] that use of NOMA results in different effects on the two different users. A user with stronger channel conditions use NOMA as this gives a higher data rate than with OMA. In contrast, user with poorer channel conditions with NOMA may have smaller rate than with OMA. This performance loss can be mitigated by using CR based approach. However, when there are two users with different channel conditions and if these two users are paired then the total data rate achieved with NOMA is quite large compared to that with OMA.

Many other practical forms of multicarrier NOMA have been proposed for 5G as multi carrier NOMA achieves a favorable trade off between system performance and complexity. These other practical forms of multi carrier NOMA are LDS, SCMA & PDMA.

In LDS & SCMA, single user information is spread over multiple sub carriers [11]-[12]-[13]-[14]. The number of sub carriers which are assigned to a single user is much smaller than available total number of sub carriers. Also the number of users using the same sub carrier is not too large so that the complexity of the system remains manageable. In FDMA, a type of multi carrier NOMA, low density, sparse spreading feature is no longer present. i.e., number of sub carriers for each user need not be necessarily smaller than the total number of sub carriers.

V. MIMO NOMA

MIMO-NOMA design is more challenging compared to that of single input single output (SISO) NOMA. MIMO-NOMA [15] gives better performance compared to MIMO-OMA but still it is not very clear whether MIMO-NOMA reaches the optimal system performance. In [16] it is shown that NOMA achieves larger individual & larger sum rates than OMA. SISO-NOMA can realize a part of the capacity region of the broadcast channel. In [17] authors used the concept of quasi degradation for the evaluation of MIMO-NOMA. In this, two user downlink scenario is considered with single antenna users and a multi antenna base station. It is a challenging task to evaluate the performance of MIMO-NOMA. If users channels are quasi degraded then according to [17] the use of MIMO-NOMA gives the same performance as dirty paper coding (DPC).

Also another difficult task in MIMO-NOMA scenario is ordering. Ordering the users according to their channel conditions is straight forward in SISO case as the user channels are scalars. But when nodes are equipped with multiple antennas i.e. user channels are in the form of vectors or matrices and then ordering them according to their channel conditions becomes difficult. In [18], random beamforming for NOMA was considered which avoids the user ordering issue by asking the base station to order the users according to their channel quality feedback. In [19], the users with large distances from the base stations are treated as weak users and their messages are decoded first at all the receivers.

VI. COOPERATIVE NOMA

In cooperative NOMA, user acts as a relay to the other users as shown in figure.1. Thus the users cooperate among themselves. In a two user case, the strong user has to decode the weak user's information before it decodes its own signal and thus acts as a relay by assisting the weak user.

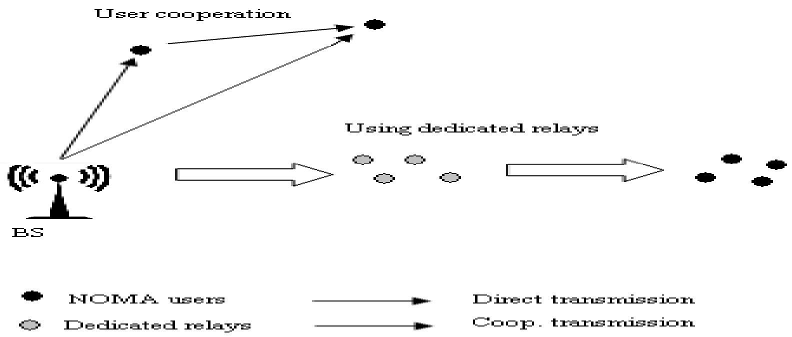

Figure 1 Cooperative NOMA illustration

Cooperative NOMA protocol relying on cooperation among the NOMA users is proposed in [20]. This is explained with an example wherein a downlink transmission is considered with two users. The cooperative NOMA transmission is performed in two phases. In phase one, the superimposed mixture of the user's signals is broadcasted by the base station. In phase two, the strong user forwards the weak users message to the weak user by acting as a relay. The strong user uses the short range communications such as Wi-Fi or blue-tooth. Even if the short range communication is not used, the cooperative NOMA performs better than cooperative OMA. Cooperative NOMA requires two time slots only whereas cooperative OMA needs three time slots; where two time slots are used by the base station to deliver the two messages to the two users and the third time slot is used by the strong user to assist the weak user. By using full duplexing relaying, the spectral efficiency of cooperative NOMA can be improved further. In full duplexing, strong user receives the signals from the base station and simultaneously carriers out the relay transmission. Thus the dedicated time slot for relay transmission (as is required in half duplexing relaying) is avoided. The concept of full duplexing can be applied to non co-operative NOMA scenarios. In [21] it is shown that this full duplexing concept applied to non co-operative NOMA is very effective in order to improve the spectral efficiency of the joint design of uplink and downlink.

One variant of cooperative NOMA is to employ dedicated relays to the NOMA users. This results in spectrally efficient reach to the users that are close to the edge. Considering an example where there is only one dedicated relay which should help two users that are close to the cell edge. With cooperative OMA, four time slots are required for transmission. Two time slots are used by the base station to deliver the two users information to the relay and the other two slots are used by the relay to deliver the messages to the two users.

With cooperative NOMA, instead of four, only two time slots are required, one for NOMA broadcasting from the base station to the dedicated relay and one for the transmission from relay to the two users. Thus, cooperative NOMA has much spectral efficiency as the number of time slots are reduced from four to two.

When multiple relays are available then the problem of relay selection arises. This problem was studied in [22] and a two stage relay selection protocol was proposed where users are ordered according to their QoS requirements and are grouped in one subset. In stage two, a relay is selected from the qualified relay subset that can give the largest rate to the other user. The overall outage probability is minimized using their relay section strategy as is proved in [22].

VII. MILLIMETER NOMA

MillimeterWave (mmWave) communications are brought into use based on the fact that the spectrum resources are limited below 6 GHz for wireless communications. NOMA increases the spectrum efficiency where as mmWave utilizes the less occupied mmWave frequency bands. Federal Communications Commission (FCC) has approved a spectrum in mmWave bands which is more than 10GHz above 24 GHz and made it available for 5G wireless communications in July 2016.

NOMA in mmWave networks provides an important tool which supports massive connectivity. Due to the increase in the demand for emerging data services like augmented and virtual reality, the gain obtained from using the mmWave bands will dwarf quickly. NOMA ensures a large number of users to be served simultaneously with different QoS requirements each, which is not possible with OMA. Users in mmWave networks will have strongly correlated channels due to the directionality of mmWave transmission. As shown in figure.2 if a network has densely deployed users then several users can be expected to share the same normalized LOS direction due to strong correlated channels. Whereas in OMA based networks such channel correlation reduces the throughput of the systems as well as the multiplexed gain. In [23] it is illustrated with the principle of quasi degradation that the use of NOMA yields the optimal performance for MIMO transmissions if the channels are strongly correlated. Thus, NOMA is well aligned with mmWave transmission characteristics and results in improved system throughput. Practically, a combination of massive MIMO and mmWave transmission is used as it is possible to pack a large number of antenna elements in a small area with the use of mmWave communications.

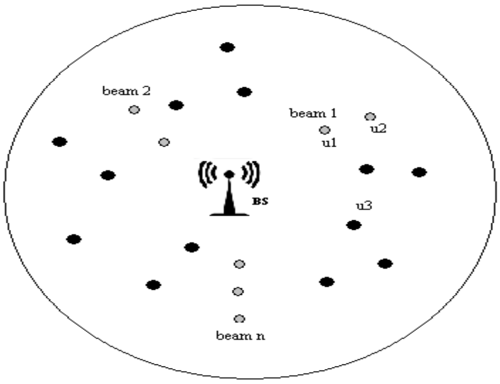

Figure 2 Random beamforming in mmWave NOMA

In [24] the authors have proposed the use of random beamforming for mmWave NOMA networks so that the system overhead cam be reduced. Base station generates the random beamforming vectors and each user has to feed back only the scalar effective channel gain to the base station, not the whole channel vector. Also by exploiting the directionality of mmWave transmission, the system overhead can be reduced further. It is also shown in [24] that all the users need not feed back their channel conditions for a given beam. For example for beam1 only the users 1 & 2 of figure. 5 need to feed back their channel conditions. The other users need not feed back their channel gains as their effective channel gains for the beam will be very small.

VIII. FUTURE CHALLENGES

The following is a list of few future research challenges for NOMA.

1. Wireless power transfer to NOMA
2. Combination of cognitive radio networks and NOMA
3. Realizing transmission security in NOMA
4. NOMA applications to other 5G communication techniques
5. NOMA applications to beyond 5G

IX. CONCLUSIONS

In this paper, a brief description of Multiple Access techniques is presented followed with their usage in a cellular system for the various generations of wireless networks. Later the paper is totally focused on NOMA which is used for 5G networks. It is concluded that NOMA is one of the most enabling technology to achieve the performance requirements of 5G such as high system throughput, low latency and massive connectivity. It is also studied that compared to OMA, NOMA utilizes the bandwidth resources more efficiently as it exploits the users heterogeneous channel conditions & QoS requirements. Also, massive connectivity can be realistically achieved with NOMA as multiple users can be served simultaneously. NOMA networks can reduce the delay as users are not forced to wait till the resource block becomes available. It is also proposed to include NOMA in 5G, LTE-A and Digital TV Standards in future generation wireless networks according to the recent industrial efforts by the research engineers.

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