Non-Orthogonal Multiple Access for Future Emerging Ad-Hoc Networks

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Abstract
Non-orthogonal multiple access (NOMA) has convincing potential to replace the conventional orthogonal frequency division multiple access (OFDMA) and single-carrier orthogonal division multiple access (SC-OFDMA). NOMA would therefore increase the spectrum efficiency and capacity of 3G and 4G/LTE networks either to 5G. Power allocation band multiple access amongst subscribers is the core concept behind NOMA. This article discusses numerous Ad hoc networks employing a variety of communication tools. We briefly go over Micrometers (MM) waves, Li-Fi communication (also known as visible light communication or VLC), and NOMA. Furthermore, NOMA adopting Successive Interference Cancellation (SIC) subsequent interference cancellation and power allocation principle are analyzed. Additionally, a detailed comparison of NOMA with OFDMA and NOMA is provided. The prospective areas for NOMA's future work in terms of Wireless Sensors Network (WSN) and the Internet of Things (IoT) are presented in the conclusion.

Keywords:
Ad-Hoc Networks, NOMA, Successive Interference Cancellation.

1. Introduction

The exponential advancement in electronic, communication and networks lead to the design of an instant, fully autonomous, peer-to-peer emerging mobile Ad Hoc network. Such networks are the combination of wireless moving nodes having temporary architectures. An Ad-hoc network is a wireless network in which nodes directly communicate with each other [1]. Ad-hoc network architecture is either centralized or decentralized. Centralized networks have a static ground-based infrastructure. The designing of such networks is an expensive approach. Whereas the nodes communicate by the static infrastructure which needs fixed hardware. Due to the complexity of the network, this is an expensive topology. To overcome this difficulty selected node will communicate with a centralized network. While other nodes will communicate with each other or at sleep mode to save power consumption [2]. Decentralized Ad-hoc networks are inexpensive because they need no static infrastructure. It can be easily implemented and disassembled when required. This type of network is more popular in Flying Ad-Hoc Networks (FANET). Based on the mobility of nodes there are two types of Ad-hoc networks, a Single hop Ad-hoc network, and a Multi hop Ad-hoc network [3].

The single-hop Ad-hoc network is one of the simplest types of Ad-hoc networks. While mobile nodes are within range of radio communication. This type of network is also named a peer-to-peer network. The single-hop Ad-hoc network has limited coverage. There is a minimum of two nodes. In a multi-hop, Ad-hoc network destination nodes are farther apart than single hop. Hence single-hop communication fails here. Multi-hop network topology covers a larger area compared with single-hop topology. Multi-hop topology always has more than two nodes. In multi-hop networks, intermediate nodes act as a router/repeater. After passing through different nodes information reach the destination [4].

Furthermore, an Ad-hoc network is divided into three different categories as Mobile Ad-hoc network (MANET), Vehicular Ad-hoc Network (VANET), and Flying Ad-hoc network (FANET). Each ad-hoc network category is designed for different modes of mobility features (i.e. Fast/Slow mobility, Slow/Higher Data rate, etc.). Whereas, MANET is one of the most important and widely used networks. In this type of Ad-hoc network nodes move on certain terrain. Node mobility is slowest compared to the other Ad-hoc networks. As users in MANET are cellular phones, laptops, PC, and Tablet users. These users move randomly. So MANET is implemented by the random waypoint mobility model [5]. It is quite effective to use with speedy and the direction of the nodes randomly in the Ad-hoc network.

VANET is the combination of moving vehicles equipped with a wireless communication infrastructure that can exchange information with each other VANET nodes moves on roads or highways. Due to their fixed path VANET model is highly predictable [6]. In the present era, VANET has drawn consideration by researchers. As a result, novel and fascinating solutions in vehicle safety, traffic management, the efficiency of traffic control, design of intelligent transportation systems (ITS).

FANET, with the advancement of electronic, mechanical, control systems, and communication

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technology, it is possible to design an Unmanned Arial Vehicle (UAV) that can be operated without a pilot. Due to their versatile design, flexibility, low operating cost, and easy installation FANET opened new arenas in civilian and military applications, like find and destroy operations [7] surveillance of borders, remote location sensing [10] monitoring of traffic, controlling of wildfire, estimation of wind, and monitoring of disasters [8]. FANET is an Ad-hoc network established between nodes flying in the sky. Node mobility is the highest of all aforementioned topologies. Due to the highest mobility of node topology the network changes frequently. In FANET distance between nodes is much greater than in MANET and VANET. A potential area of FANET includes TV coverage. The communication between nodes of FANET is one of the most challenging tasks due to the rapid mobility of nodes.

2. Multiple Access Techniques in Ad-hoc Networks:

Traditionally, there are three types of access modes in communication. These are Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), and Orthogonal Frequency Division Multiple Access (OFDMA).

2.1 Time Division Multiple Access (TDMA)

In TDMA time Division Multiple Access on a time-sharing basis, several clients share the same frequency channel. The clients communicate in fast progression, one after the other, each utilizing their allotted time slots. During each time slot entire capacity of the channel is available for use and then the user must release the channel. TDMA is a collision-free technique because the entire channel is available to one user for a fraction of the time. As the number of users increases TDMA faces difficulties in the synchronization of time slots among users because such a technique needs perfect synchronization with independent users. To cope with this issue one of the proposed solutions is the Guard band for the effects of propagation delay between the users. The guard band is a time interval during which the channel is not given to any user. Although this time interval is small cumulative sum is significant . TDMA is a half-duplex scheme in which the only sender sends data from one end and at the other end; the receiver receives data (single-way communication). To overcome these issues, give birth to OFDMA.

2.2 Code Division Multiple Access (CDMA)

In this technique, Transmitter sends information by using spreading code in a wide frequency band signal. At the receiver, information is retrieved by using the same code. By using this technique we can send and receive information simultaneously to the different devices. This technique is used to reuse the channel bandwidth and minimize interference [9]. CDMA uses shared code that can be given to each group of nodes. Many codes have the same channel, but nodes only have a peculiar code that can understand each other. If there is any bit error caused by nearby channel interference is corrected by forwarding error correction, but this correction scheme is only used when codes are orthogonal or near to it. In CDMA each node should know its code which is used to send or receive a peculiar information packet. The same code is used for sending and receiving information. The number of codes available has a limit, so it is not possible to allocate different codes for each transmitter and receiver. To solve this challenge spatial code reuse technique is used in this technique two or more clusters placed far from each other can be assigned the same code.

2.3 Orthogonal Frequency Division Multiple Accesses (OFDMA)

OFDMA is used in 3G and 4G LTE communication technologies. Single Carrier OFDMA (SC-OFDMA) is used in 4G LTE have good performance over OFDMA. The OFDMA allows multi-client communication through an orthogonal frequency division multiplexing strategy in which subcarrier is selected orthogonal to one another. All fourth-generation communication and 4G LTE system adopt OFDMA Orthogonal Frequency Division Multiple Access [10]. In the OFDMA division of the entire channel is into sub-channel in the frequency domain and these subdivided channels are orthogonal to each other. In this technique, different frequency provides for different users to avoid interference between the users all frequencies are orthogonal to each other [11]. This increases the capacity of the channel and improves the Quality of Service (QoS) more than any technique in use.

In the OFDMA communication network, there is a uniform distribution of power. It means there is an equal amount of power distributed through the cell. Due to this draw, back more power is utilized and cell end users are affected in terms of service quality and availability. Now, researchers are trying to implement a scheme that has control over power by improving power utilization and enhancing service quality to end-user cells [12]. This technique will also improve data rate and improvement in QoS. This technology is called 5G cellular communication technology. The below table shows that in 5G communication technology, the data rate will be greater than 1Gbps, 5G technology will be updated in the future by artificial intelligence (AI) to enhance its efficiency [13].

Table 1: Comparison of FDMA, TDMA, OFDMA, SC-OFDMA and NOMA

Multiplexing	*Technology*	*Bandwidth*	*Service*
FDMA	1G	2kbps	Voice
TDMA/ CDMA	2G/2.5G	14-64kbps	Digital voice, SMS
OFDMA	3G	2Mbps	Integrated high-quality audio, video and data
SC-OFDMA	4G	200Mbps	Dynamic information access, variable device
NOMA	5G	>1Gbps	Dynamic interconnection access, variable devices with AI capabilities

3. Theme of NOMA for 5G/6G Networks.

It is expected that mobile traffic will increase beyond 500-fold in the next 10 years. So, future radio access (FRA) aims to enhance the gain in channel capacity and overall throughput of the system till 2020 [14]. LTE, (Long Term Evolution) has just accomplished a 3-4 crease upgrade in the range proficiency contrasted with 3G High-Speed Packet Access HSPA our objective is to increase will be more than 10 overlays contrasted with the 3G. To upgrade the range effectiveness, Non-Orthogonal Multiple Access (NOMA) is proposed. This is a promising solution to communication issues to face in the future [13].

5G/6G cellular communication systems are focusing on extending the capacity of the channel accessible for distinctive sorts of gadgets [15]. In 5G/6G cellular communication data rate ought to be in Gbps i.e 10-20 Gbps at the network level (10-20 times more than 4G peak data rate) and 1Gbps at the user side (100 times more than in 4G) and latency set to be 1millisecond Besides 5G frameworks are imagined decreasing the utilization of power and expense [16]. In 5G cellular communication, there are three candidate technologies, Millimeter waves (Mm), Light fidelity (Li-Fi) communication, and Non-orthogonal Multiple Access (NOMA).

3.1 Millimeter waves (Mm):

The millimeter-wave band is between 30-300GHz and is used for the 5G cellular network in the uplink. In Mm, the wave path loss is enhanced with the square of the frequency [17]. They cannot penetrate through many indoor and outdoor objects like the human body, etc [13]. The Mm waves can be used for only short-range communication because their high path loss makes it impractical for long-range communication. In the future, Mm waves have a strong potential to take place of Wi-Fi [18].

3.2 Light Fieldtly (Li-Fi):

Li-Fi uses visible monochromatic light for the transmission of data. We can also use white light for data transmission. Color of light effect data rate and range. LED is used as a transmitter. Lights flicker at a rate of Nanosecond human eye cannot detect such rapid fluctuation of light. Light ON OFF sends data in the form of digital data. ON equal to 1. OFF equal to 0. Light is collected by a photodiode which again converts it into a digital signal. Li-Fi is also called VLC(visible light communication) VLC is extensively used in the literature on Li-Fi. It is expected that Li-Fi is the end of advancement in light communication. We cannot go beyond the visible light spectrum because it is dangerous to human skin and cause cancer.

3.3 Non-Orthogonal Multiple Access (NOMA)

The conservative resources allocation schemes such as orthogonal multiple accesses (OMA) allocate resources orthogonally in code, time, and frequency. On the other hand, the NOMA is different from the aforementioned schemes as it allocates resources in a non-orthogonal way. In the NOMA grid resources are distributed among multiple users with different levels of power [19]. Hence, NOMA emerges as one of effective technology as well as it captures the attention of researchers. NOMA resources allocation technique has strong potential to improve spectral efficiency and energy efficiency, to achieve sustainable radio access in the future [3]. In [20], a low complexity algorithm based on NOMA is proposed for improving energy efficiency. The energy efficiency in NOMA at downlink via imperfect channel state information (CSI) is proposed. In [21], the authors proposed energy efficiency optimization based on cognitive radio with downlink NOMA in multi-user cases. In [3], the authors shed light on NOMA in MANET for future radio access.

NOMA Non-Orthogonal Multiple Access is an emerging technique as multiple access (MA) scheme, it has remarkably improved the efficiency of cellular communication in power, channel capacity, data rate, and Quality of services (QoS). This is the only candidate in 5G/6G cellular communication that has control over the power. The traditional cellular communication schemes are based on Time Division Multiple Access TDMA, code division (CDMA), and frequency division (FDMA and OFDMA). While NOMA is only one technique that works on different power allocation according to the different user's locations. The edge of NOMA over all aforementioned techniques is this NOMA can use combinations with OFDMA, TDMA, and CDMA with various users according to the users' location and Received Signal Strength (RSS). Recently NOMA is also used in Li-Fi for SIC successive interference cancelation [13].

Therefore, for the decoding of superposed signals at every receiver, the SIC technique is proposed. In [22] less-complex SIC with MMSE for MIMO detection is discussed. SIC is a powerful scheme for exploiting superposed signals based on signal strength. When one client's signal is interpreted, then the interpreted signal is subtracted from the combined signal before the next client's signal.

4. Successive Interference Cancellation in NOMA

In this section, we will discuss the simple NOMA downlink technique applying to two users UE1 and UE2. This technique is also applicable in uplink NOMA. The simple NOMA using the SIC scheme for one transmitter, two users UE1 and UE2 as a receiver in the downlink is shown in Fig 1. UE-1 receives signals from BS. The power of the signal transmitted from BS is P1.

The sum of power is P. Where $E\ [|xi|^2]\ =\ 1$ in NOMA superposition of signals $x1$ and $x2$ are denoted in equation form as

$$Y = \sqrt{P_1 x_1} + \sqrt{P_2 x_2} \qquad (1)$$

The equation shows signals transmitted from BS. The equation of the received signal at UE-i is

$$y_i = H_i x + G_w \qquad (2)$$

Here is the received signal, which is a complex channel between the transmitter and UE-i. is based on white Gaussian noise including inter-cell and co-channel interference according to the power density.

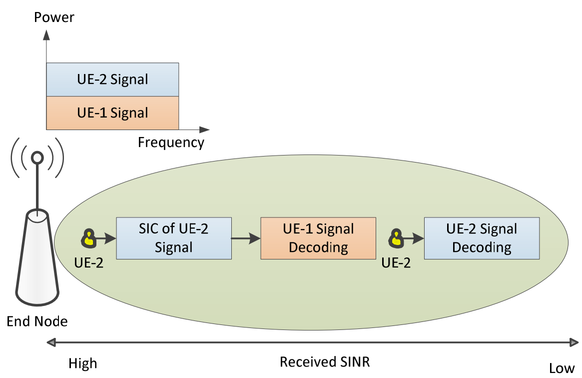

Fig.1. Basic NOMA scheme applying SIC for UEs in downlink

In NOMA downlink as shown in Fig 2, the SIC scheme is implemented on the client-side UE. The order of decoding composite signal is based on a high gain of the channel that is brought to normalize the channel state. The co-channel and inter-cell interference power is based on coding systems that can decode precisely signals at the users. In our case, there are only two users UE1, and UE2 with power and respect. Now suppose is greater than UE1 decodes the first signal and performs inference cancellation on the second signal and then subtracts component from the received signal.

$$R_1 = \log_2\left[1 + \frac{P_{1|}|h_1|^2}{N_{0,1}}\right] \qquad (3)$$

$$R_2 = \log_2\left[1 + \frac{P_{2|}|h_2|^2}{P_{1|}|h_2|^2 + N_{0,2}}\right] \qquad (4)$$

Here, as mentioned in the above equation the allocation of power determines the efficiency of the user throughput performance, Modulation, and Coding Scheme (MCS) used is for the transmission of data for each user. Carefully allocating the ratio of the power of each UE, the base station has to control overall throughput. The power allocation technique is an efficient control over cell-edge throughput, the overall cell throughput, and user fairness. Hence, for using the potential gain of the NOMA designing a flexible radio interface is required [23].

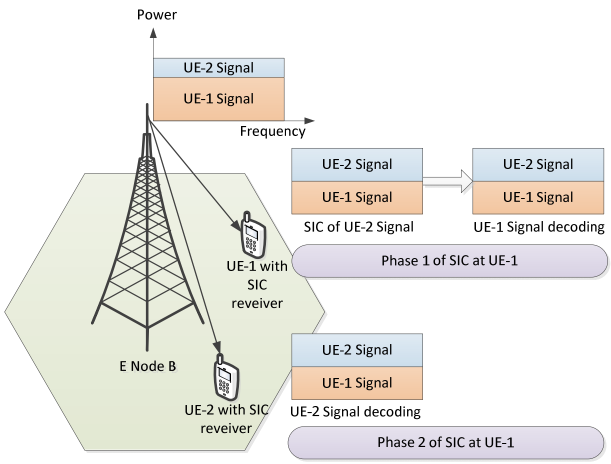

Fig.2. Illustration of downlink NOMA based SIC (two UEs case)

5. Performance Analysis of NOMA

Traditional multiple access techniques such as OFDMA and SC-OFDMA in the communication system are based on orthogonally resource allocations to each user. Whereas, the changes in frequency (orthogonal) for the individual user. While the problem with this method is power for the near and cell-edge users is the same as a result for cell-edge users to overcome the bandwidth and network coverage issues [24]. Whereas, NOMA has control over power which is one of the main differences between NOMA and other traditional schemes used in communication. Till now NOMA is the only discovered scheme that works on power allocation. In NOMA near the user and given less power while the cell-edge user signal is provided with greater power so that the cell-edge user enjoys the same data rate and coverage. NOMA has proven to solve issues that face traditional multiple access schemes. For the NOMA transceiver, the OFDMA transceiver is replaced instead of the NOMA transceiver. While, the proposed model has a wide range of practical applications in the ad-hoc network (MANET, VANET, FANET) and any other network that uses NOMA for data exchange [16].

Now, wideband scheduling and power allocation scheme is used to measure the performance of NOMA over OFDMA. Furthermore, at the system level performance does not depend merely on selective channel frequency information, but is also important for practical deployment for a wide area network. Due to this fact, Figure 3 shows the Cumulative Distribution Function (CDF) of the user's throughput of OFDMA and NOMA with SIC capabilities. Fractional Transmission Power Allocation (FTPA) is used for NOMA in [25]. These results are plotted for a simple scenario, where the 100 UEs are randomly distributed in the 1Km range of a macro–Base Station (BS). The BS is operating in the downlink. Two different multiple access techniques OFDMA and NOMA are assumed for each simulation. All the sub-carriers are assumed to be transmitted with equal power in OFDMA, whereas in NOMA, the cell edge UEs are transmitted with a high power compared to the UEs at the cell center. The results show that the NOMA-based resource allocation has outperformed the traditional OFDA in terms of UE achievable throughput.

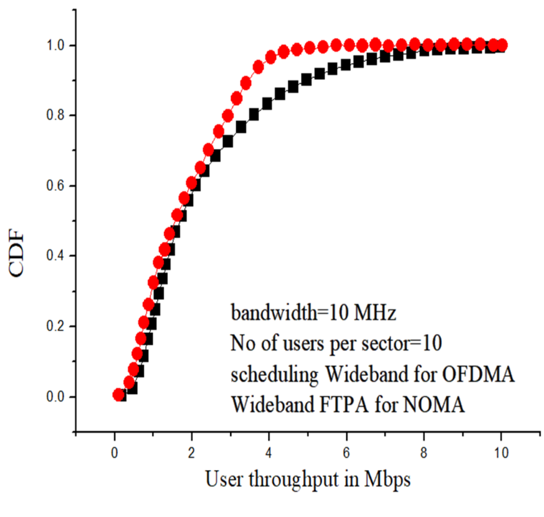

Fig 3. Throughput Analysis of OFDMA and NOMA

6. Conclusions

The number of mobile devices is increasing every day since mobile communication is launched. As a result, the lack of bandwidth is faced. To overcome this issue we move from TDMA to CDMA to OFDMA to SC-OFDMA and then to NOMA. This paper sheds light on different types of Ad-hoc networks on basis of radio access single-hop multi-hop, on basis of node mobility of nodes MANET, VANET, and FANET. Modes of communication in Ad-hoc networks like TDMA, CDMA, OFDMA, and SC-OFDMA that are currently in use or used in past. We discuss challenges we face in OFDMA 3G and SC-OFDMA 4G LTE like allocation of resources, and effective distribution of power among cell center and cell-edge users. Then to solve these issues we discuss 5G technology and its different candidates like Mm waves Li-Fi and NOMA. In this paper, we focus on NOMA in the Mobile Ad-hoc network, which is extendable to FANET, and VANET. We proposed a physical model for the NOMA transceiver. In comparison, NOMA performance over OFDMA NOMA performance is superior then OFDMA. Then NOMA MIMO at downlink with different MIMO combinations SU-NOMA and MU-NOMA are briefed, at the end of this section NOMA and OFDMA performance in the MIMO scenario is compared, and NOMA outperforms in MIMO.

The potential research areas of NOMA based future networks include power allocation code complexity, error propagation mitigation in SIC, power allocation when no of users increases, NOMA standardization, etc. In future work, this concept is extendable in VANET, FANET as well as the internet of everything (IoE), biomedical engineering, and automation.

Although NOMA is capable to compete with the challenges those are facing in near future with OFDMA and SC-OFDMA. But there is room for improvement in NOMA. Many potential areas need the attention of researchers to contribute their contribution. Whereas, the NOMA signal decoding is different at a level of complexity compared with other OMA techniques. In the NOMA SIC technique user have to decode other user signals before their signal. As the number of users increases the complexity of decoding is also increasing. To cope with this issue users can be divided into several clusters and SIC is performed on each cluster. This technique is a tradeoff performance over the complexity of implementation.

While the propagation of error occurs in SIC first time then all remaining users' information is decoded with error. This effect can be compensated at the expense of a stronger code. The researcher needs to develop some nonlinear code detection algorithms to cope with the issue of error propagation in NOMA. Furthermore, The basis of NOMA is on power allocation according to the users. This technique works well when the numbers of users are small but when the number of users is increased then the dynamic power allocation is needed

NOMA is effective during massive connectivity with near and far users effect is high. But OMA (Orthogonal Multiple Access) more effective than MONA when the number of users is small and the near-far user effect is not prominent. Due to this fact for best performance, we need a platform where NOMA and OMA coexist. Hence there is a need to design SODOMA (Software Design Multiple Access) that can respond quickly according to changes in the aforementioned situation.

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