Performance analysis of NOMA in pedestrian and vehicular environments

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Abstract. The ability to serve many users with high-speed transmission has made 5G as the promising candidate for the future generation of the wireless communication system. LTE could no longer support future demand with its current transmission rates. Various multiple access schemes have been proposed for 5G and NOMA as one of the candidates. Thus, this study has analysed the performance of NOMA in comparison to OMA in pedestrian and vehicular environments. To assure the Quality of Service (QoS), the metric of throughput is evaluated. The simulation was done using The Vienna 5G Link Level Simulator (LLS) and the result shows that NOMA cell centred user performed 50% better than OMA. Meanwhile, OMA outperformed NOMA in terms of cell edge user by 56%. The finding is in line with the characteristics of NOMA and OMA where NOMA users have to be in pair and share the same subcarrier while OMA users have their dedicated subcarrier for transmission.

1. Introduction
The tremendous improvements in living standards contribute to the development of wireless communication technology. The generations of wireless communication systems evolved from 1G to 4G or namely the LTE (Long Term Evolution). User peak data rate, user experience, spectral efficiency, number of connections, low latency, high reliability, and energy efficiency were some reasons for the successive evolvement of wireless communication systems. Due to the progressive growth of telecommunication industries, thus, to cope with the demand using the current transmission rates of wireless communication systems is unfeasible [1]. Therefore, the deployment of 5G is the best solution because of its capability to accommodate large number of users with high-speed transmission [2]. In addition, 5G should also go beyond the quality of experience in terms of network capacity and flexibility. Thus, the network needs to be flexible, in terms of selecting different radio resources to provide coverage based on the needs of the service.

In general, multiple accesses are the process of sharing multiple resources into a single transmission medium, which involves multiplexing techniques. The multiplexing technique is important to ensure multiple users share the same medium for simultaneous transmission. 1G to 4G are considered as the conventional multiple access scheme which is also known as Orthogonal
Multiple Access (OMA) where the previous generation of these wireless systems rely on frequency, time or code domain [3][4][5][6] to mitigate interference.

In future years, it is believed that OMA is no longer sufficient to support massive connections with different Quality of Service (QoS) requirements. The interference between the adjacent carriers and inflexibility of spectrum usage are the weak points of OMA particularly the OFDMA (Orthogonal Frequency Division Multiple Access) [7]. Thus, several multiple access schemes have been proposed such as NOMA (Non-Orthogonal Multiple Access) [8][9], SCMA (Sparse Code Multiple Access) [10][11], MUSA (Multi-user Shared Access) [12] and PDMA (Pattern Division Multiple Access) [13]. However, NOMA seems to be a promising candidate for the multiple access schemes in 5G communication systems [5][6][14]. As the name implies, non-orthogonality is how the scheme can handle multiple users in the same domain simultaneously. NOMA allows multiple users to communicate with each other by using the same frequency or code in the time domain that cannot be realized in OMA. NOMA increases the number of served users per channel as it can allocate two users per subcarrier in comparison to OMA. Instead of allowing a single user to use each of the resources in OMA, NOMA is capable of allowing two users by employing pairing and power allocation.

The main objective of this paper is to evaluate the performance of downlink transmission of NOMA in the pedestrian and vehicular environments. We simulate and analyse the performance of throughput for both access schemes. Finally, we determine the best performance in terms of user throughput. The Vienna 5G Link Level Simulator (LLS) is used to perform the simulation.

This paper is organized into several sections as the following. Section 2 describes the NOMA, system performance as well as user path loss. Section 3 introduces the network design for the NOMA scenario in The Vienna 5G LLS platform. The simulation results and discussion are presented in Section 4. Finally, the conclusion of the research findings can be found in Section 5.

2. Background

2.1. NOMA

NOMA mitigates the interference between users using the power domain (PD) [3][5][16][17] and is capable of accommodating multiple users by allocating two users per subcarrier. In NOMA, a cell consists of one base station (BS) which is located at the centre of the cell with one transceiver attached to it. Assume that there are two users (UE) in the cell; UE1 and UE2 with different channel conditions being served by the BS. UE1 is the user located near to the BS and has the strongest channel condition whereas UE2 is the user located far from the BS. It is considered that the farthest UE has the weakest channel condition. Both UEs are multiplexed together into a single carrier [3][18][19]. The BS optimizes the transmit power to a user by allocating different power according to the channel condition.

The channel condition is presented by the Signal-to-Interference-Noise-Ratio (SINR). The higher the value of SINR, the better the channel will be. User with the strongest channel condition, which in this case is UE1, is allocated with small power. More transmit power is allocated to the weakest channel condition user. The transmit signals from the BS is the composition of the Superposition Coding (SC). The process of retrieving information at the users’ receiver is done by employing the Successive Interference Cancellation (SIC). However, the SIC is done only by the receiver at UE1 since it has the strongest channel condition to cancel the UE2 signal before decoding its own information. For UE2, the receiver decoded its desired information by treating the multiplexed signal of UE1 as a noise.

2.2. System performance

In this paper, the metric of throughput has been considered to evaluate the performance of downlink NOMA. Throughput is an amount of work done in a particular period, which is normally being expressed in bits per second. Only successful packets are being considered as useful information bits. Packets that failed to arrive on time and error packets will be ignored [20]. Besides, the value of
throughput is used to determine the efficiency of the network. The higher value of throughput indicates the network works efficiently in transmitting the information and vice versa.

2.3. Path loss
The path loss value of each UE needs to be specified in order to represent the SINR value. The small-scale fading effect is considered during the simulation because its average power is determined by the path loss value. Low path loss value indicates user with strong channel condition whereas high path loss value indicates user with weak channel condition. Small-scale fading or simply known as fading is caused by interference between two or more transmitted signals received at the transmitter at different times. Different multipath propagation of these signals will affect the random frequency modulation due to varying Doppler shifts, which creates one of the effects of small scale fading [21].

3. Methodology

3.1. Network simulator
The 5G network environment is simulated using an open-source simulator, which is the Vienna Cellular Communications Simulators (VCCS) software suite or better known as The Vienna 5G LLS (Link Level Simulator). The Vienna 5G LLS is focusing on the physical layer of the communication system and can be used either in pre-defined or user-defined simulation scenarios [22].

3.2. Network design
In the simulation, two cells with one base station (BS) each have been set up. The first cell operates using OMA and the second cell is using NOMA based on the multi-user superposition transmission (MUST). MUST allows multiple users to share the same resources non-orthogonally by superimposing two users in the power domain for simultaneous transmission. The superimposed users consist of one strong channel condition user and one weak channel condition user. However, the representation of the strong and weak users is done by adjusting the corresponding path loss (PL) value to each of the user’s link. Low PL values signify the strong channel condition users whereas the high PL values represent the weak channel condition users [22].

Table 1 shows the simulation parameters for the simulation. There are four users (UEs) being configured in the simulation. The topology of the scenario is set up according to the following details. The first two users; UE1 and UE2 are attached to BS one which belongs to the first cell. UE1 and UE2 are set to have 80 dB and 110 dB of PL respectively. Meanwhile, UE3 and UE4 are attached to BS two with 80 dB and 110 dB of PL. UE1 and UE3 are set with 80 dB PL value as an indication of strong channel condition users or cell centred users. In addition, UE2 and UE4 are set with 110 dB PL and represent the weak channel condition users or cell edge users. User in the first cell and the second cell were given the same values of PL. At low SINR, UE4 interfered with UE3 and caused the performance to degrade. In order for the strong channel condition user to retrieve their own data, the receiver will perform SIC or maximum likelihood (ML). Thus, the receiver at UE3 cancelled the signal of UE4 before decoding its own information. Meanwhile, the receiver at UE4 decoded its own information by treating other signals as noise.

The bandwidth for both cells is 1.4 MHz which is carrying 72 subcarriers. Since the first cell is operating orthogonally, each user is allocated with 36 subcarriers. The users in the second cell are superimposed, thus, the allocation is set to 72 subcarriers per pair. A high value of attenuation is set so that there is no significant interference between cells during the simulation. This means that no interfering links between UEs in the first cell to BS2 or UEs in the second cell to BS1. We only considered the interference between links and BS in the same cell.

In this study, we have selected two Time Selective Fading Channel Models which are Pedestrian A and Vehicular A for analysis. The speed of the UE is set to 3 km/h for Pedestrian A while 30 km/h for Vehicular A [23] respectively. Discrete Jakes Doppler Model is being applied to model the channel’s time selectivity.
4. Results and discussions
The result of throughput is plotted over the transmit power of BSs in dBm. This unit of power is an indication of the power ratio expressed in dB with respect to milliWatt (mW).

\[ P_{\text{dBm}} = 10 \log_{10} (P_{\text{mW}}) \]  

(1)

As being regulated by the FCC (Federal Communications Commission), the peak power for the transmitter is 43 dBm [24]. Thus, the value of throughput is captured at the value of 43 dBm.

Figure 1 depicts the downlink throughput of NOMA and OMA in pedestrian and vehicular environments respectively. The throughput value for all users is summarized in Table 2. The results are categorized according to cell centred and cell edge. As aforementioned, cell centred users and cell edge users were given the value of 80 dB and 110 dB of PL respectively. It is observed that the results of throughput for NOMA and OMA for both the pedestrian and vehicular environments are similar. The different user’s speed being configured for both environments does not affect the transmission of packets.

For 80 dB of PL, the throughput for UE3 is 10 Mbps while UE1 is 5 Mbps. The performance of UE3 is 50% better than UE1. Meanwhile, for 110 dB of PL, the throughput for UE4 is approximately 2.2 Mbps and 5 Mbps for UE2. This proved that, UE2 outperformed UE4 by 56%. The throughput of UE3 is higher than UE1 and this shows that NOMA performed better than OMA in a good channel condition environment. However, for the cell edge users, OMA performed better than NOMA due to the allocation of the subcarrier to the users. In OMA, each user is allocated with a subcarrier for data transmission. On the other hand, NOMA shares the subcarrier to a pair of users. The NOMA cell edge user that is UE4 has to share the same subcarrier with UE3 for data transmission. It also can be concluded that the performance of throughput for different multiple access schemes; NOMA and OMA correlates to the PL values which correspond to the user’s channel condition.

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### Table 1. Simulation parameters.

| Parameter          | OMA                | NOMA               |
|--------------------|--------------------|--------------------|
| Cells              | OMA                | NOMA               |
| Number of users    | 2                  | 2 (1 strong, 1 cell-edge) |
| Path-loss          | 80, 110 dB         | Strong: 80 dB      |
|                    |                    | Cell-edge: 110 dB  |
| NOMA receiver      | -                  | ML                 |
| MUST power-ratio   | -                  | Fixed (second ratio) |
| Bandwidth          | 1.4 MHz (72 subcarriers) |                 |
| Waveform/coding    | OFDM, LDPC         |                    |
| MIMO mode          | 2x2 CLSM           |                    |
| Modulation/code rate| Adaptive (CQI based) |                  |
| Feedback delay     | No delay (ideal)   |                    |
| Channel model      | Pedestrian A / Vehicular A |          |
| Doppler model      | Discrete Jakes     |                    |
Figure 1. Downlink throughput per user.

Table 2. Performance of throughput for different path loss values.

| Path loss (dB) | Multiple access scheme | UE   | Environment  | Throughput (Mbps) |
|---------------|------------------------|------|--------------|-------------------|
| 80            | NOMA                   | UE3  | Pedestrian   | 10                |
|               |                        |      | Vehicular    |                   |
|               | OMA                    | UE1  | Pedestrian   | 5                 |
|               |                        |      | Vehicular    |                   |
| 110           | NOMA                   | UE4  | Pedestrian   | 2.2               |
|               |                        |      | Vehicular    |                   |
|               | OMA                    | UE2  | Pedestrian   | 5                 |
|               |                        |      | Vehicular    |                   |

5. Conclusion
In this paper, the performance of NOMA and OMA is analysed and discussed. Two network environments; pedestrian and vehicular are deployed in the simulation. Each cell consists of two users with the same path loss values, which indicate the users’ channel conditions. In general, there is no significant difference in terms of throughput for both environments. For the cell centred user, NOMA performed 50% better than OMA whereas, for the cell edge user, OMA outperformed NOMA by 56%. For future work, it is suggested to improve on the NOMA cell edge users’ throughput using pairing algorithm.

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