Non-Orthogonal Multiple Access in 5G

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Abstract: The increasing demand of mobile Internet and the IoTs poses exacting requisites for 5G wireless communications, like high spectral efficiency. Hence, a promising technology, non-orthogonal multiple access (NOMA), is discussed. Unlike standard orthogonal multiple access technologies, NOMA can serve much more users via non-orthogonal resource allocation. The most striking attribute of NOMA is to serve multiple users at the same time/frequency/code, but with different power levels, which produces a remarkable spectral efficiency gain. There are mainly two types of NOMA techniques, power-domain and code-domain. This paper primarily focuses on power-domain NOMA that utilizes superposition coding (SC) at the transmitter and successive interference cancellation (SIC) at the receiver. Also, this paper discusses how NOMA performs when it is combined with other wireless communication techniques, for example cooperative communications, multiple-input multiple-output (MIMO). Furthermore, this paper discusses several important issues on NOMA implementation and provides some avenues for future research.

Keywords: NOMA, OFDMA, SC, SIC, C-NOMA, MIMO-NOMA.

Introduction

From analog phone calls to the IP services, including voice and messaging, each alteration has been encouraged by the need to meet the requirements of the new generation of mobile technology. With a large scope for both consumers and industry, 5G is expected to rise by 2020. It requires a change in data speed and a notable reduction in end-to-end latency.Many of the industry resources which have advanced with work on 5G profess that the network data rate in 5G should be 10-20 Gbps (i.e., 10-20 times the peak data rate in 4G), and the user-experienced data rate should be 1 Gbps (100 times the user-experienced data rate in 4G). They also set the latency (end-to-end round-trip delay) at 1 millisecond (one-fifth of the latency in 4G).The design of a suitable multiple access technique is one of the most important aspects in improving the system capacity. Multiple access techniques can broadly be categorized into two different approaches, orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA). An orthogonal scheme allows a receiver to separate unwanted signals from the desired signal using different basis functions. In other words, signals from different users are orthogonal to each other in orthogonal schemes. Time division multiple access (TDMA), and orthogonal frequency-division multiple access (OFDMA) are examples of OMA schemes. In TDMA, several users share the same frequency channel on a time-division basis. The users communicate in rapid succession, one after the other, each using their assigned time slots. OFDMA allows multi-user communications through an orthogonal frequency-division multiplexing (OFDM) technique in which subcarrier frequencies are chosen so that the subcarriers are orthogonal to each other. Unlike OMA, NOMA allows allocating one frequency channel to multiple users at the same time within the same cell and offers a number of advantages, like improved spectral efficiency (SE), higher cell-edge throughput, relaxed channel feedback (only the received signal strength, not exact channel state information (CSI), is required), and low transmission latency (no scheduling request from users to base station is required). The available NOMA techniques can broadly be divided into two categories, power-domain and code-domain NOMA.

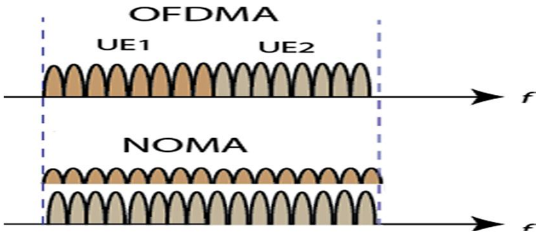
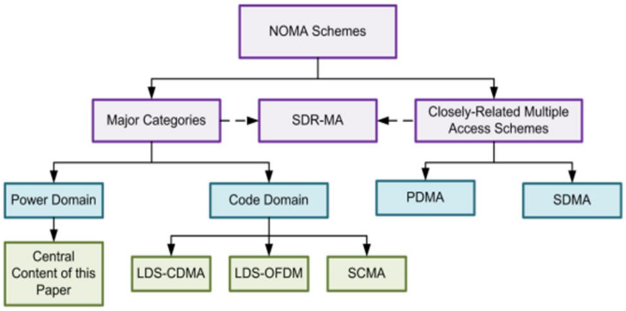


Fig 1: Spectrum sharing for OFDMA and NOMA

This paper focuses on the power-domain NOMA that superimposes multiple users in power domain and exploits the channel gain difference between multiplexed users. At the transmitter side, signals from various users are superimposed and the resulting signal is then transmitted over the same channels (i.e., the same time-frequency resources). At the receiver side, multiuser detection (MUD) algorithms, such as successive interference cancellation (SIC) are used to detect the desired signals. NOMA achieves superior spectral efficiencies by SC at the transmitter with SIC at the receiver. Over the past few years, the demand for NOMA has increased substantially in order to meet 5G requirements.

Basic Concepts Of Noma

Figure presents a simple classification of the existing NOMA techniques. Unlike power-domain NOMA, which attains multiplexing in power domain, code-domain NOMA achieves multiplexing in code domain. Like the basic code division multiple access (CDMA) systems, code-domain NOMA shares the entire available resources (time/frequency). In contrast, code-domain NOMA utilizes user-specific spreading sequences that are either sparse sequences or non-orthogonal cross-correlation sequences of low correlation coefficient. This can be further divided into a few different classes, such as low-density spreading CDMA (LDS-CDMA), low-density spreading-based OFDM (LDS-OFDM), and sparse code multiple access (SCMA) . The use of low-density spreading sequences helps LDS-CDMA to limit the impact of interference on each chip of basic CDMA systems. LDS-OFDM can be thought of as a combination of LDS-CDMA and OFDM, where the information symbols are first spread across low-density spreading sequences and the resultant chips are then transmitted on a set of subcarriers. SCMA is a recent code-domain NOMA technique based on LDS-CDMA. In contrast to LDS-CDMA, the information bits can be directly mapped to different sparse codewords, because both bit mapping and bit spreading are combined. When compared to LDS-CDMA, SCMA provides a low complexity reception technique and offers improved performances. There exist some other multiple access techniques, which are also closely-related to NOMA, including pattern division multiple access (PDMA) and spatial division multiple access (SDMA). PDMA can be realized in various domains. At the transmitter side, PDMA first maximizes the diversity and minimizes the overlaps among multiple users in order to design non-orthogonal patterns. The multiplexing is then performed either in the code domain, spatial domain, or a combination of them. For SDMA, the working principle is inspired by basic CDMA systems. Instead of using user-specific spreading sequences, SDMA distinguishes different users by using user-specific channel impulse responses (CIRs). This technique is particularly useful for the cases where the number of uplink users is considerably higher than the number of corresponding receiving antennas in BS. However, accurate CIR estimation becomes challenging for a large number of users. The concept of software defined radio for multiple access (SDR-MA) allows various forms of NOMA schemes to coexist. This technique provides a flexible configuration of participating multiple access schemes in order to support heterogeneous services and applications in 5G. It is worth noting that while the aforementioned list provides some insights into different forms of NOMA, it is not exhaustive, and the primary focus of this paper is on power-domain NOMA. In the following, a brief note about SC and SIC is presented This paper refers to power-domain NOMA simply by NOMA.



Superposition Coding And Successive Interference Cancellation-Sc

at the transmitter and successive interference cancellation (SIC) at the receiver makes it possible to utilize the same spectrum for all users. At the transmitter site, all the individual information signals are superimposed into a single waveform, while at the receiver, SIC decodes the signals one by one until it finds the desired signal. In the illustration, the three information signals indicated with different colors are superimposed at the transmitter. The received signal at the SIC receiver includes all these three signals. The first signal that SIC decodes is the strongest one while others as interference. The first decoded signal is then subtracted from the received signal and if the decoding is perfect, the waveform with the rest of the signals is accurately obtained. SIC repeats the process until it finds the desired signal. The success of SIC depends on the perfect cancellation of the signals in the iteration steps. The transmitter should accurately split the power between the user information waveforms and superimpose them. The methodology for power split differs for uplink and downlink channels.

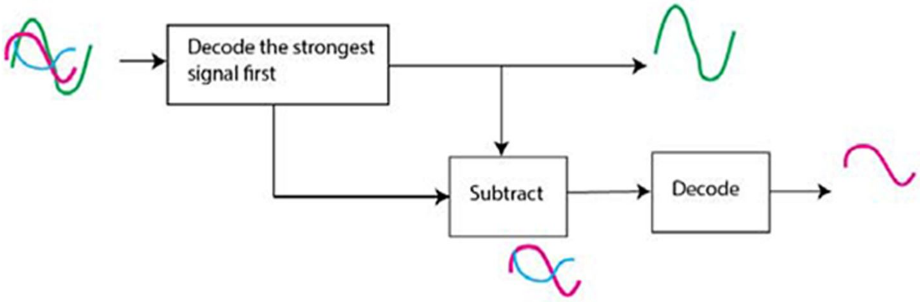


Fig:3 Successive interference cancellation

Noma For Downlink

In NOMA downlink, the base station superimposes the information waveforms for its serviced users. Each user equipment (UE) employs SIC to detect their own signals. Figure shows a BS and K number of UEs with SIC receivers. In the network, it is assumed that the UE_1 is the closest to the base station (BS), and UE_K is the farthest.

The challenge for BS is to decide how to allocate the power among the individual information waveforms, which is critical for SIC. In NOMA downlink, more power is allocated to UE located farther from the BS and the least power to the UE closest to the BS. In the network, all UEs receive the same signal that contains the information for all users. Each UE decodes the strongest signal first, and then subtracts the decoded signal from the received signal. SIC receiver iterates the subtraction until it finds its own signal. UE located close to the BS can cancel the signals of the farther UEs. Since the signal of the farthest UE contributes the most to the received signal, it will decode its own signal first.

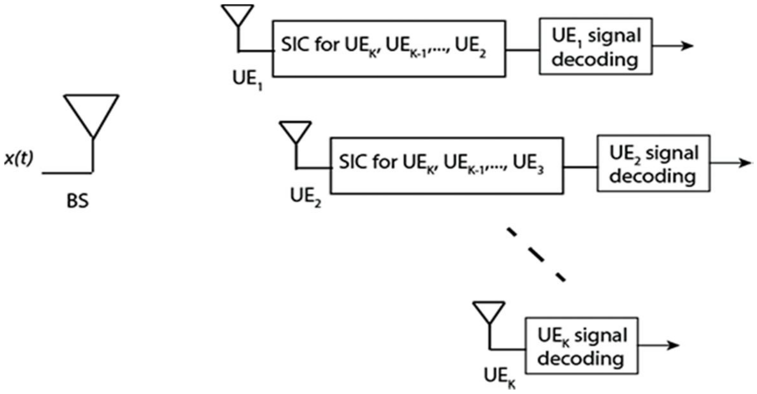


Fig:4 Downlink NOMA for K users.

Noma For Uplink

Uplink implementation of NOMA is slightly different than the downlink. **Figure 4** depicts a network that multiplexes *K* UEs in the uplink using NOMA. This time, BS employs SIC in order to distinguish the user signals.

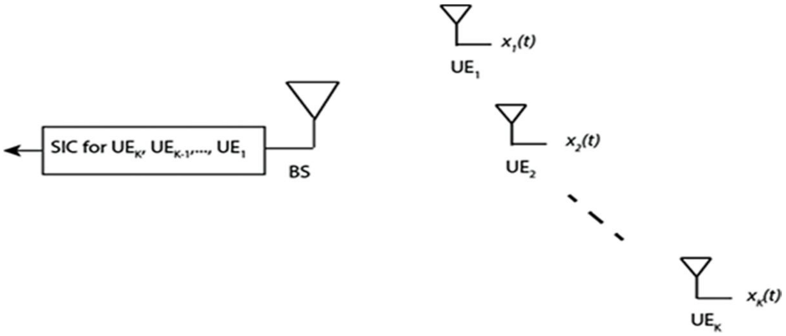


Fig:5 Uplink NOMA for K users.

Imperfectness In Noma

Our discussions so far in the previous sections assume perfect cancellation in the SIC receiver. In actual SIC, it is quite difficult to subtract the decoded signal from the received signal without any error. In this section, we revisit the NOMA concept with cancellation error in the SIC receiver.

Here, we consider the downlink only; however, the discussions can easily be extended for the uplink. Recall that SIC receiver decodes the information signals one by one iteratively to obtain the desired signal. In SIC, after decoding the signal, one should regenerate the original individual waveform in order to subtract it from the received signal. Although it is theoretically possible to complete this process without any error, in practice, it is expected to experience some cancellation error.

Results

Rate Pairs

We assume that there are two users in the network and analyze the boundaries of the achievable rate regions for these two users. We consider a symmetric downlink channel so that the users are at equal distance to the BS. $SNR_1=SNR_2=10Db$. As illustrated ,NOMA achieves higher rate pairs than the OFDMA except at the corners points (where the rates are equal to the single user capacities). When the fairness is high, both users experience 1.6 bps/Hz throughputs with both NOMA and OFDMA. However, when the fairness is lower, both sum capacity and individual throughputs are higher with NOMA. It is shown in the figure that the rate pairs when the channel is asymmetric, that is, $SNR_1=20dB$ and $SNR_2=0dB$. NOMA achieves much higher rate pairs than OFDMA, particularly for the farther user, UE_2.

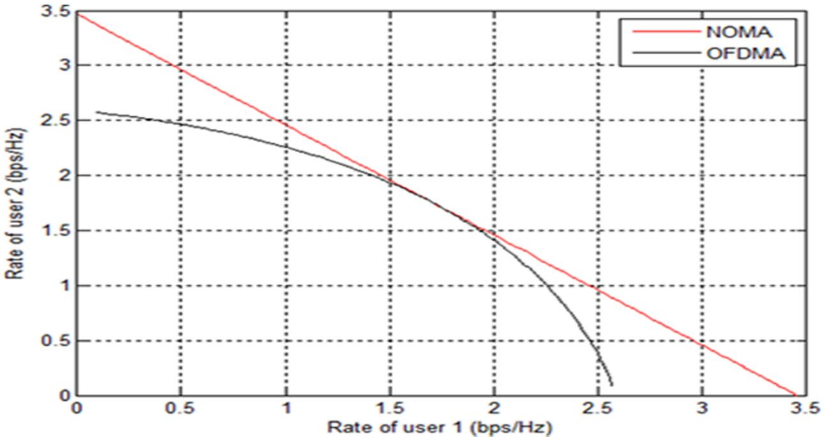


Fig:6 Rate pairs with OFDMA and NOMA for downlink NOMA

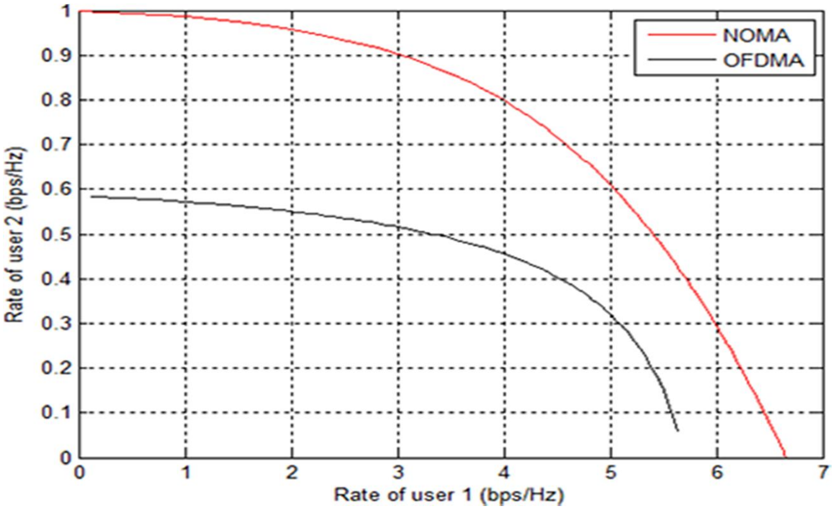


Fig:7 Rate pairs with OFDMA and NOMA for downlink NOMA

Impact Of Imperfect Cancellation

Here, we repeat the same conditions for the asymmetric downlink channel in the previous section with imperfectness in SIC. The case for perfect cancellation is given as reference. We then analyze the impact of imperfect cancellation by setting the cancellation error term (ϵ) at 1, 5 and 10%. For instance, when ϵ=1%, UE_1 cannot perfectly cancel the signal for UE_2 in the first iteration, and 1% of the power of the second user's signal still remains as interference. When ϵ=1%, the individual rate pairs and accordingly overall capacity slightly reduce. When ϵ=10%, on the other hand, the reduction is more distinct.

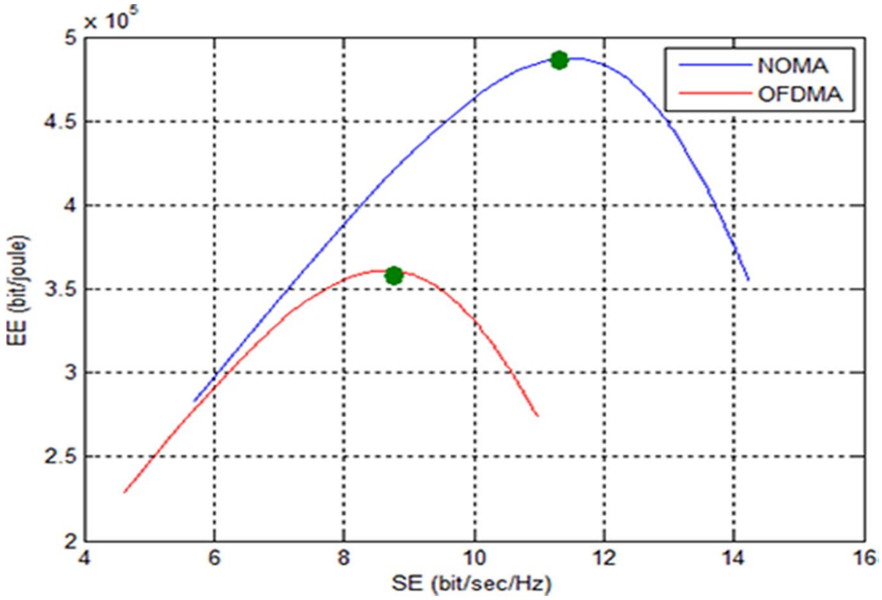


Fig:8 Impact of imperfect cancellation in SIC

Se-Ee Trade-Off With Noma

We compare the EE and SE of NOMA with OFDMA. We again consider the downlink. The system bandwidth is taken asW=5 MHz. The channel gains for UE_1 and UE_2 are, respectively, taken as g_1^2=−120dB and g_2^2=−140dB. Noise density (N_0) is taken as −150 dBW/Hz. We assume that the static power consumption at the BS is P_{static}=100W. It is seen that NOMA achieves higher EE and SE than OFDMA system. The green-points occur for NOMA and OFDMA when P_T is at 17 W and 18 W, respectively. At these points, both systems achieve their maximum EE. NOMA clearly dominates OFDMA at green point and beyond for both EE and SE.

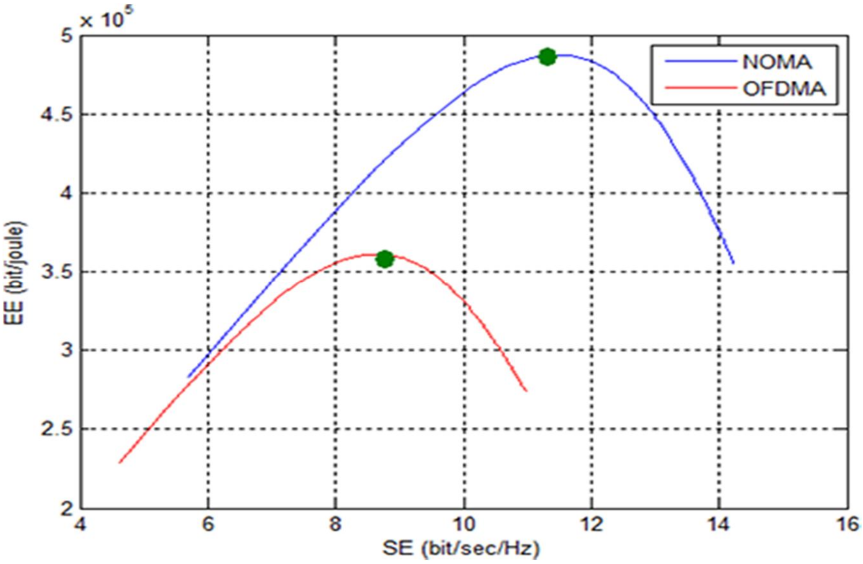


Fig:9 EE-SE trade-off curves for NOMA an OFDMA

Performance Of Mimo Noma

It is indicated that the MIMO NOMA system outperforms MIMO with OMA, particularly at high SNR values. By comparing the slopes of the performance curves, it can be concluded that the diversity gain of MIMO NOMA is the same as MIMO OMA. However, MIMO NOMA provides better SE, since this gain is achieved by allowing both users from the same cluster to utilize the same BW.

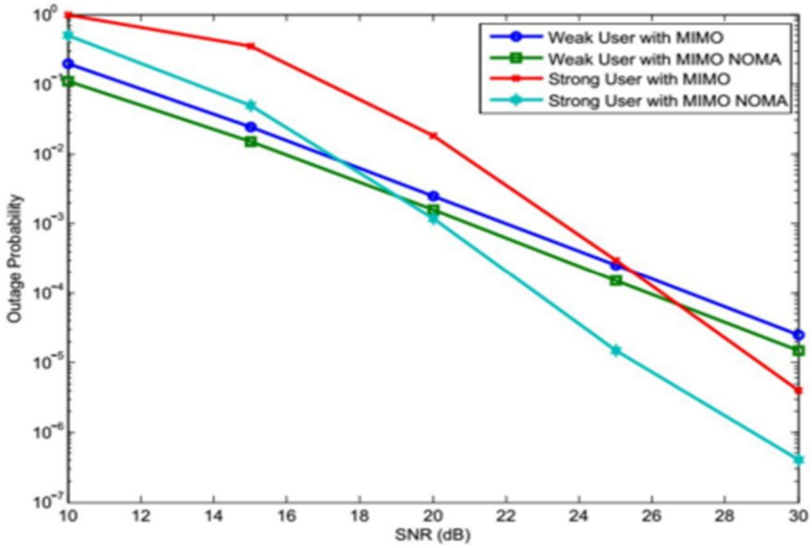


Fig:10 Outage performance of a MIMO NOMA system

Performance Of Cooperative Noma

The outage probability that is achieved by non-cooperative NOMA and cooperative NOMA is a function of SNR. It shows that cooperative NOMA surpasses the comparable scheme, since it ensures that the maximum diversity gain is achievable by all users. Under C-NOMA, users with the worst channel condition get assistance from the other users, along with their own direct links to the source. Although non-cooperative NOMA can attain only a diversity order of for the i^{th} ordered user, C-NOMA ensures that a diversity order of is achievable for all users by exploiting user cooperation.

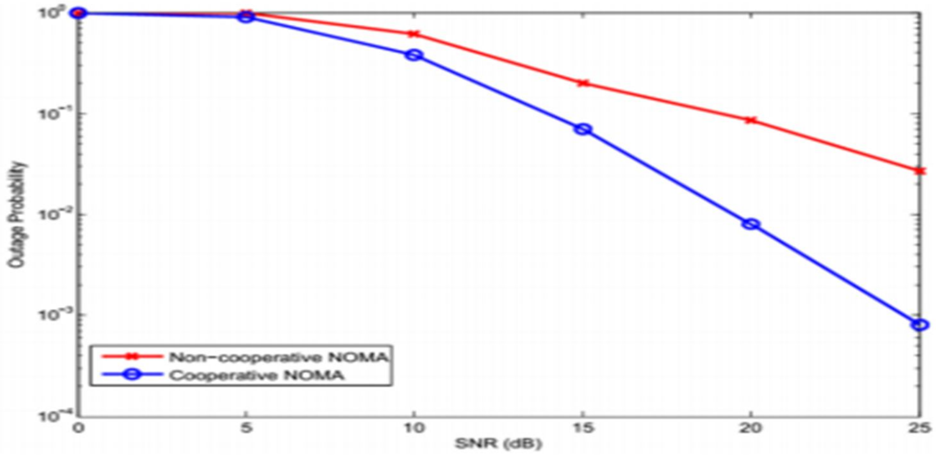


Fig:11 Outage performance of a cooperative NOMA.

Conclusion

The basic principles of NOMA and its superior performance over conventional OFDMA in terms of sum capacity, energy efficiency and spectral efficiency are corroborated. The impact of imperfectness at the SIC receiver on the system performance is discussed. NOMA has given a new dimension in the newly emerging era of 5G. There are, however, still some drawbacks for successful implementation of NOMA. First of all, it requires high computational power to run SIC algorithms particularly for high number of users at high data rates. Second, power allocation optimization remains as a challenging problem, particularly when the UEs are moving fast in the network. Finally, SIC receiver is sensitive to cancellation errors which can easily occur in fading channels. It can be implemented with some other diversity techniques like multiple-input-multiple-output (MIMO) or with coding schemes in order to increase the reliability and accordingly reduce the decoding errors.

In addition, this paper discusses how NOMA works with various standard wireless technologies, including cooperative communications and MIMO. For a deeper understanding of NOMA, this paper provides a discussion on how inter-cell interference in a network can be mitigated, and explains how a trade-off between energy efficiency and spectrum efficiency can be achieved. The current state of the art for NOMA, however, is still far from its potential and requires further investigation.

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