Power Domain Non Orthogonal Multiple Access: A Review

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Abstract— This paper highlights the fundamentals of the strong candidate Power Domain Non-Orthogonal Multiple Access (PD-NOMA) technique, and how it can best fit the requirements of fifth Generation (5G) in practical applications. PD-NOMA ensures flexibility in radio resource to improve user's access performance. Multiple Users share the same radio resources in PD-NOMA, and therefore better spectrum efficiency can be achieved. The practical system design aspects of PD-NOMA are considered in this paper by exploring different network scenarios. Optimal performances of PD-NOMA system can be obtained by suitable power allocation schemes, with reduce the computational complexity, and advanced user pairing strategy. Theoretical formulation and solutions are also explained prior to the concept of downlink PD-NOMA. Challenges and future research windows are discussed before conclusion of this paper.

Keywords—Power domain, NOMA, 5G, successive interference cancellation, user pairing.

I. INTRODUCTION

It is a recognized fact that approximately every 10 years a new wireless communication network standard emerges to cope with the massive growth of digital devices worldwide. So far, the current wireless communication network standard, 4G LTE has been found not to possess enough capabilities to cope with the required massive connectivity that will come into play in the years to come with the surge in development of computational devices, mobile devices, IOTs as well large-scale cloud connectivity.

The 5G wireless network standard is not an incremental upgrade to 4G but as an entirely new implementation, it is currently being proposed as a solution to addressing these issues and ongoing researches have been ongoing to come up with various solutions to address the following challenges:

1. High data rate 1000x of current 4G.
2. Enhanced user quality of experience (QoE).
3. Low round trip transmission (1ms latency)
4. Lower energy consumption.
5. Massive connectivity with diverse quality of service (QoS) million devices/square km

An all-encompassing vision of 5G wireless networks can outlined as such:

- A highly efficient mobile network that guarantees optimal performance at lower investment rate. It should meet the highly desirable need for unit cost of data transportation varying inversely as the volume of data demanded which happens to be a most pressing need for mobile network operators
- An ultra-fast mobile network consisting of the next generation of small cells tightly assembled together to give constant coverage over, urban areas (in the worst case scenario).
- Provide the millimeter wave bands (20 – 60 GHz) which allow higher bandwidth and the speeds of up to 10 Gbit/s data access.

In order to concretize a roadmap to achieving the 5G network vision, enhanced research efforts have been ongoing in the field of 5G wireless networks, most especially in the area of Multiple Access Techniques as a means to achieving large scale connectivity more efficiently.

Until recently, Orthogonal Multiple Access (OMA) techniques have always been the default approach for achieving a decent level of throughput performance in packet domain services with a simplified receiver design, which has characterized the radio access technologies for cellular mobile communication [1, 2]. Initiatives on 5G research are currently being carried out extensively worldwide in order to take a step further in shaping the future of mobile and wireless networks beyond 2020. Moreover, 5G networks should have the ability to support communications for certain special scenarios that are not supported by 4G networks. As such, 5G is expected to provide high data rates (network level 10-20Gbps and user

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experience data rate of 1Gbps), improve the user Quality of Experience (QoE), enhance latency (1ms round trip latency), and lower energy consumption [3,4].

Despite of all these benefits, a typical challenge facing 5G is the spectral efficiency in handling heavy traffic from mobile internet usage. Another challenge is with the development of Internet of things (IoT) specifically, how to connect users and devices in such a way to ensure low latency and diverse service types. In conventional OMA schemes, the overall amount and the scheduling granularity of orthogonal resources determines the maximum number of supported users, therefore, several radio access techniques are proposed in the literature to increase the system capacity in 5G networks [5].

NOMA is one of the potential solutions for the future of the next generation mobile networks. It could be relies on new domain which it doesn't get to utilized in previous systems before. Power-Domain NOMA capable enough to allow many users have access to all frequency and time resources therefore improves the spectral efficiency. Compared with OMA, NOMA meets the demanding 5G requirements of ultra-low latency and ultra-high connectivity because it enables users with strong channel state information to have access to those with poor channel state information [6]. Several NOMA schemes have been investigated for 5G showing that NOMA enables significant performance improvements in system throughput and capacity of connecting mobile devices when compared to OMA in Long Term Evolution (LTE). Moreover, the non-orthogonal design provides good backward compatibility with orthogonal frequency division multiple access (OFDMA) and sparse-code frequency division multiple access (SC-FDMA).

There are two main categories of NOMA techniques, namely code-domain multiplexing (CDM) and power domain multiplexing (PDM). The CDM-NOMA facilitates user separation at the receiver by introducing redundancy via coding/spreading. Whereas, PDM-NOMA is able to perform successive interference cancellation (SIC) for users with better channel conditions [7]. In this sense, PDM-NOMA ensures flexibility in resource allocation to improve NOMA performance. Nevertheless, comprehensive knowledge of the recent research achievements is extremely desirable since NOMA is still in its early stage in 5G. In this regard, this paper primarily focuses on PD-NOMA in the facets of power control, channel allocation and user pairing aspects in PD-NOMA, which is believed to be the most important technical issue to be considered so as to meet the requirements of 5G real-world applications.

In this paper, Section II introduces a typical PD-NOMA scheme. Section III explains the PD-NOMA power control, channel allocation and user pairing aspects. Challenges and future research are discussed in Section IV. Finally, Section V concludes this paper.

II. A TYPICAL PD-NOMA SCHEME

A. PD-NOMA Single Cell Scenario

As a technology, NOMA has the potential to adequately meet 5G network requirements. NOMA mechanisms mainly relies on multiplexing different users by allocating different power level to each of them according to their channel conditions to ensure maximum gain in the system performance [8]. Recently research efforts have been undergone to ascertain the potential advantages of PD-NOMA for both downlink and uplink transmissions in different aspects and scenarios. It is essential to consider the practical system design aspects in order to ensure that the PD-NOMA features are feasible in real networks.

To better understand the theory behind the concept of PD-NOMA, a typical single-cell PD- NOMA scheme in the power domain is considered with two users UE outlining how the transmitter and receiver operates.

Fig. 1 shows that both users, $UE1$ and $UE2$ belong to the same cell, scheduled on the same radio resources, frequency and time, with their modulated symbols directly superposed.

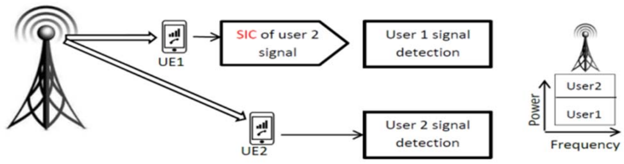

Fig. 1. PD-NOMA Transmitter Setup

The base station transmission symbols can be expressed as [9]:

$$X(i) = \sqrt{\alpha} X_{UE1}(i) \sqrt{1 - \alpha X_{UE2}}\,(i) \quad (1)$$

The complex valued symbol resulting from the linear superposition is represented by $X(i)$, a symbol index i, the complex-valued modulated symbols of $UE1$ and $UE2$ denoted by $X_{UE1}\,(i)$ and $X_{UE2}(i)$ respectively and α referring to the ratio transmission power allocated to the first user, $UE1$. Assuming that this user $UE1$ is located at the cell center and allocated less power compared to the second user located far away $UE2$ at the cell edge, thus assigned more power. Such power allocation makes it easy for signal separation at the receiver. In this case α is assumed to be less than 0.5 ($\alpha < 0.5$) and the sum of both users' powers is dependent on the constraint of the BS maximum transmission power.

Decoding the desired signal for each user $UE1$ requires the reconstruction and cancellation of the signal of $UE2' s$ first at the receiver side. If the modulation and code scheme (MCS) of $UE2$ is selected prior to its own channel conditions, and the channel conditions of $UE1$ is better than that of $E2$, then the possibility that $UE1$ obtains the right $UE2$ signal is high. In such case, the signal of $UE2$ is assumed to be completely cancelled and the received signal-to-interference plus noise power ratios ($SINRs$) by $UE1$ in both PD-NOMA and OMA can be expressed as follows:

$$SINR_{PD-NOMA,UE1} = \alpha \times SINR_{OMA,UE1} \quad (2)$$

On the other hand, for $UE2$ at the receiver side, $UE2$ is able to treat $UE1$ signal as noise and correctly decode its desired signal. Therefore, the received $SINRs$ by $UE2$ in both PD-NOMA and OMA can be as such:

$$SINR_{PD-NOMA,UE2} = 1 - \alpha/(\alpha + \frac{1}{SINR_{OMA,UE2}}) \quad (3)$$

Fig. 2(a) and 2(b) illustrate the transmitter and receiver operations in the downlink PD-NOMA.

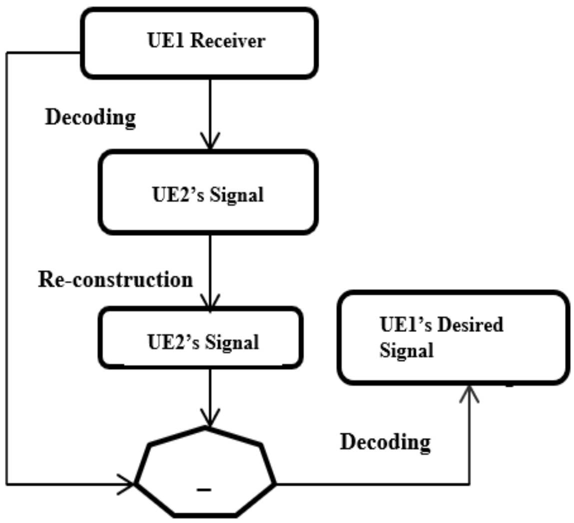

Fig. 2 (a) UE1 Receiver Operation

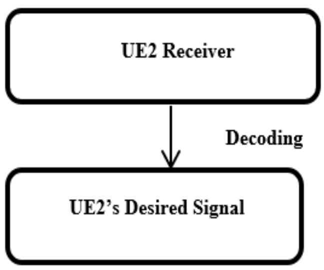

Fig. 2 (b) UE2 Receiver Operation

The cell-center users and cell-edge users are broadly categorized at the base station depending on their channel gain conditions. Users are co-scheduled onto the same radio resource by setting a threshold coupling loss to complete PD-NOMA user pairing. The cell center or cell edge UEs are identified by comparing the coupling loss with the configured threshold. This process reduces the computation complexity for the practical scheduler followed by the allocation of power to the co-scheduled PD-NOMA users. Finally, the base station runs the scheduling decision, for instance, in the case of determining proportional fairness for multiple users. This step results in selection of the set of users and the associated power allocation ratio prior to the selected scheduling algorithm. The interference cancellation (IC) receivers are introduced in LTE-Advanced Released 12 to handle inter-cell and intra-cell interference. The IC therefore makes it feasible for user implementation to reduce the intra-cell and inter-user interference in NOMA systems.

B. PD-NOMA in Multi Cell Scenario

PD-NOMA is favorable over the OFDMA scheme in which one user is assigned one sub-channel, by having the feature of allowing more than one user to be multiplexed on the same sub-channel [8]. The key advantage of this feature is to improve spectrum efficiency. Nevertheless, in downlink PD-NOMA, users located at the cell edge are allocated more power which results in an interference to neighboring cells. To explain this situation, a cellular system with two cells and four users is considered. Fig. 3 depicts a multi-cell PD-NOMA scenario comprising a two-user structure for each cell. Users 1 and 2 are served by $BS1$, whereas $BS2$ serves user 3 and 4. Here, a strong interference is expected between users 1 and 3, which may cause degradation in the performance of PD-NOMA. Joint pre-coding of PD-NOMA users' signals across neighboring cells is then needed to reduce the inter-cell interference. In [10], a precoding scheme with reduced complexity is proposed for PD-NOMA, the multi-cell precoder is applied to the cell edge users, e.g. to user 1 and user 3 in Fig. 3.

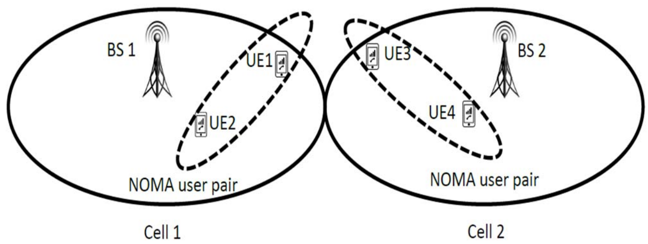

Fig. 3. PD-NOMA in Multi Cell Scenario

The performance of PD-NOMA system can be optimized by using suitable power allocation schemes with low complexity. In PD-NOMA, the achievable throughput of other users is affected when power is allocated to one user due to power-domain multi-user multiplexing. In [11], a Fractional Transmit Power Allocation (FTPA) is proposed. In FTPA, the instantaneous channel conditions of multiplexed users are considered and power is apportioned to the users proportional to their path-loss raised to the power αFTPA. This maximizes the performance evaluation metric targeted. An exhaustive user selection is avoided by proposing a predefined user grouping grounded on channel conditions and fixed per-group power allocation (FPA). This facilitates the achievement of a considerable amount of PD-NOMA gains with reduced overhead.

An iterative sub-optimal power allocation algorithm is another low complexity method based on Difference of Convex (DC) programming [12]. In this method, the objective function for optimal power allocation is broken down into difference of convex functions, which is then iteratively solved with successive convex approximation to arrive at an efficient sub-optimal solution. Similar to FTPA and FPA, a tree-based search and reversed SIC order is a sub-optimal reduced complexity method from weighted sum rate maximization perspective as user weights have not been considered during power allocation among the multiplexed users [13].

C. *Formulation of basic PD-NOMA system model*

Typical consideration of a single cell scenario, transmitter and receiver antennas is assumed in [14] to explain the concept of downlink PD-NOMA, N users' equipment U_i, with $i \in N = \{1,2,3, \ldots\ldots N\}$ and one base station (BS) and applying a (SIC) at the users' receivers. Users simultaneously receive data from the BS, subject to the constraint of total power. Channels are sorted as:

$$0 < |h_1|^2 \leq |h_2|^2 \ldots \leq |h_i|^2 \ldots\ldots \leq h_N|^2$$

With the help of super-positioning coding (SC) at the BS and SIC decoding techniques to the users, PD-NOMA scheme achieves concurrent serving of all users by means of utilizing the entire system bandwidth (BW) to transmit data. The BS transmits a linear superposition of N users' data by allocating β_i, a fraction of the BS power P to each user U_i, ($Pi = \beta_i P$), where, P_i is the power allocated to U_i. On the other hand, each user decodes the signal of the weaker users at the receiver side, i.e., the signal can be decoded by U_i for each user U_m with $m < i$. The signals for weaker users are then derived from the received signal to decode the signal of user U_i, while processing the signals of the stronger users, U_m, with $m < i$, as interference. The received signal at user U_i can be represented as:

$$y_i = h_i x + w_i \tag{4}$$

Where $x = \sum_{i=1}^{N} \sqrt{P\,\beta i}\, S_i$ is the superimposed signal transmitted by the BS, with S_i being the signal for user U_i, w_i is the additive white Gaussian noise (AWGN) of user U_i with zero mean and variance σ_n^2. If signal superposition at the BS, and SIC at U_i, are performed effectively, the data rate attainable for user U_i for 1 Hz system BW is given by:

$$R_i = log_2\,(1 + \frac{\beta i P\ |h_i|^2}{P\ |h_i|^2 \sum_{k=i+1}^{N} \beta_k + \sigma_n^2}) \tag{5}$$

The data rate for user U_N is denoted by the expression:

$R_N = log_2\,(1 + \ \beta_N P\ |h_N|^2/\sigma_n^2)$, [12].

Before decoding its own signal, this user sequentially decodes and cancels out all other users' signals. Although a strong user experiences better channel conditions, it does not correlate to a stronger signal strength. In fact, a low transmit power is allocated to a strong user, and a weak user is allocated high power resulting in good SINR. Therefore, PD-NOMA aligns with the basic concept of SIC, where the strongest signal is decoded first.

The entire BW is simultaneously used by two users by assuming a 1Hz overall system transmission bandwidth. Owing to the fact that user 1 has a higher channel gain than user 2 it first performs SIC to decode the signal for user 1. The decoded signal is then deducted from the received signal of user 2. The resultant signal is applied in decoding the signal for user 2. Since SIC is not executed for user 1, the signal is directly decoded. Thus, the achievable data rate for users 1 and 2 are given by (6) and (7), respectively.

$$R_1 = log_2\,(1 + P_2\ |h_2|^2/\sigma_n^2) \tag{6}$$

$$R_2 = log_2\,(1 + \frac{P_1\ |h_1|^2}{P_2\ |h_1|^2 + \sigma_n^2}) \tag{7}$$

When OMA is applied, user 1 uses α Hz and the remaining (1-α) Hz is assigned to user 2. Here, the achievable data rate for user 1 and user 2 are given by (8) and (9), respectively:

$$R_1 = \alpha log_2\,(1 + \frac{P_2\ |h_2|^2}{\sigma_n^2}) \tag{8}$$

$$R_2 = (1 - \alpha) log_2\,(1 + P_2\ |h_2|^2/\sigma_n^2) \tag{9}$$

It is evident in (6) and (7) that PD-NOMA scheme regulates the throughput of each user by varying the power allocation ratio P_1/P_2. This makes the overall throughput and user fairness a derivative power allocation scheme used. Assuming an asymmetric channel, where signal-to-noise ratios (SNRs) of the two users are at a variance, and the numerical values of R_1 and R_2 calculated from (6) and (7) respectively, are substantially much greater than those of R_1 and R_2 calculated from (8) and (9). However, this numerical comparison is basically a special case of the multi-user channel capacity analysis. Therefore, PD-NOMA is seen to be highly effective in terms of system-level throughput when the channels are different for two users.

III. NOMA CHALLENGES AND FUTURE RESEARCH

Despite the vast literature in NOMA system, there are still some challenges and future research needs to be considered. Some of the challenges include:

A. Resource Allocation

Meeting the 5G requirements of very high data rates coupled with low latency so as to cover a diverse range of traffic requirements is a difficult one mainly due to the limited resources available. Based on this premise, it becomes quite apparent that the key to effective utilization and allocation lies in inventing new techniques of Wireless resource management. As a sequence of processes that need to take place in order to determine the timing and quota of resource allocation to users, Wireless resource management takes into factor the specific kind of resource. According to Shannon's theorem, bandwidth is one of the important characteristic in wireless resources to look into in this particular scenario. As part of the Wireless resource management process in a communication system, the total bandwidth is first broken up into chunks. Each set of chunks is assigned to different users or group of users (as in the case of NOMA). Therefore, user-pairing and optimal power allocation among users in NOMA is wholly dependent on the availability of efficient algorithm(s) to provide the most optimal performance with minimal resource requirement.

B. SIC implementation

SIC is a core part of the NOMA scheme. Unfortunately, SIC is beset by various practical issues, as described below.

- SIC requires the decoding of each user's information in order of priority determined by the SIC decoding order. This results in the signal decoding complexity scaling with as total user count in the particular cell grows. To address this complexity issue, we can split the total amount of users into multiple groups and encode/decode on each group basis. By doing so, the amount of complexity would be brought down to a reasonable level enough to be handled properly.
- Error propagation refers to a scenario where an error occurs in decoding a certain user's signal, thereby causing the error to cascade down in the SIC decoding order to other users who will be affected and their signal decoding likely to be error-prone. This difficult issue can be addressed through the utilization of stronger codes as long as the number of users is not very large.

Another topic of future research is evaluating the performance of NOMA in the presence of beam-formers and MU-MIMO. NOMA is expected to yield more gains when co-existing with MU-MIMO. In this case, the user multiplexing in power domain using NOMA is orthogonal to the user multiplexing in the spatial domain using MU-MIMO. The co-scheduled UEs in NOMA are assumed to use the same beam-former so that the cell-center UE can decode the transmissions to the cell-edge UE. Another future topic can be the performance analysis of a cooperative NOMA scheme especially in the existing dynamic interfering environment.

The combination of PD-NOMA with other types of MA schemes, including not only the conventional OMA schemes but also newly developed 5G MA techniques is also worth studying [15]. Furthermore, since user pairing/clustering is believed to reduce system complexity, new low-complexity algorithms need to be developed in order to realize optimal user clustering.

IV. CONCLUSION

In this paper, the concept of PD-NOMA is introduced as a potential multiple access candidate for future radio access technology (RAT) in 5G mobile and wireless communication. The main idea of PD-NOMA is that multiple users are served simultaneously over the same radio resources with minimal inter-user interference involved. When compared to the conventional (OMA), where each user is served based on pre-allocated radio resources, PD-NOMA superposes the message signals of multiple users in the power domain and is then decoded (through SIC) at the receivers in a multi-user scenario. Relying on power domain, NOMA contributes to better spectral efficiency by allowing each user access to all subcarriers channels. The PDM-NOMA is able to perform (SIC) at users with better channel conditions. Power domain is not utilized in the previous systems which make NOMA as multiplexing scheme suitable for 5G technologies.

In a single cell scenario, the transmitter and receiver antennas are assumed to explain the concept of down link PD-NOMA. In multi cell scenario, PD-NOMA allows more than one user to be multiplexed on the same sub-channel in order to improve spectrum efficiency. The performance of PD-NOMA systems can be optimized by using less complicated power allocation schemes. The throughput of other users achieved is affected when power is allocated to one user due to power-domain multi-user multiplexing.

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