

# Uplink IoT Networks: Time-Division Priority-Based Non-Orthogonal Multiple Access Approach

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**Abstract**—Non-orthogonal multiple access (NOMA) has been investigated to support massive connectivity for Internet-of-things (IoT) networks. However, since most IoT devices suffer from limited power and decoding capabilities, it is not desirable to pair a large number of devices simultaneously, which encourages two-user NOMA grouping. Additionally, most existing techniques have not considered the diversity in the target QoS of IoT devices, which may lead to spectrum inefficiency. Few investigations have partially considered that issue by using an order-based power allocation (OPA) approach, where the power is allocated according to the order to the user's target throughput within a priority-based NOMA (PNOMA) group. However, this does not fully capture the effects of diversity in the values of the users' target throughputs. In this work, we handle both problems by considering a throughput-based power allocation (TPA) approach, that captures the QoS diversity, within a three-users PNOMA group as a compromise between spectral efficiency and complexity. Specifically, we investigate the performance of a time-division PNOMA (TD-PNOMA) scheme, where the transmission time is divided into two-time slots with two-users per PNOMA group. The performance of such TD-PNOMA is compared with a fully PNOMA (F-PNOMA) scheme, where the three users share the whole transmission time, in terms of the ergodic capacity under imperfect successive interference cancellation (SIC). The results reveal the superiority of TPA compared with OPA approach in both schemes, besides that the throughput of both schemes can outperform each other under imperfect SIC based on the transmit signal-to-noise ratio and the deployment scenarios.

**Index Terms**—Non-orthogonal multiple access, priority-ordering, spectrum sharing, time-division.

## I. INTRODUCTION

Recently, the wireless traffic has been growing rapidly and is expected to grow several folds in the beyond fifth generation (B5G) networks. Different promising applications and services have been proposed underlying 5G such as real-time high-definition video broadcasting, massive deployment of machine-to-machine (M2M) communications and Internet-of-Things (IoT) services [1]. With this huge demand of resources, spectral efficiency becomes a critical aspect for managing the access to the core network [2]. Several multiple access techniques have been investigated for exploiting the spectrum to face the congestion problem. In the fourth generation (4G) of wireless networks, different orthogonal multiple-access (OMA) technologies have been proposed such as orthogonal frequency division multiple access (OFDMA), time-division multiple access (TDMA), and code-division

multiple access (CDMA). However, OMA techniques provide a great improvement, they can not afford the expected massive deployment in 5G and B5G networks. To tackle this challenge, non-orthogonal multiple access (NOMA) have been proposed [3]. Unlike OMA techniques, NOMA-based networks can serve multiple users using the same resources by exploiting either the transmit power domain [4], [5] or code domain [6]–[8], which leads to better performance and spectral efficiency compared to OMA. The focus of this work is to propose a spectrum-efficient scheme for IoT systems, where users show a diversity in their QoS target throughput.

### A. Background and Related Work

In power-domain NOMA, super-position coding is used at the transmitter and successive interference cancellation (SIC) at the receiver [4]. Two types of power-domain NOMA have been investigated in literature, namely the conventional NOMA (CNOMA) and the quality-of-service (QoS) based NOMA (QNOMA), which is also known as priority-based NOMA (PNOMA). In CNOMA, users are ordered and allocated powers proportional to their channel gains [9], [10]. It is noteworthy that there are two limitations of CNOMA: (i) In the two-users CNOMA, which is the widely-used arrangement due to its reduced decoding complexity at the receiver, a cell-center (CC) user is usually paired with a cell-edge (CE) user. However, the number of CC and CE users may not be identical, which leads to a spectrum loss since some users are left unpaired and served using conventional OMA schemes, and (ii) In multi-users CNOMA, if two or more users have similar channel gains (i.e., collocated users), these users can not be paired in one group with other users [11]. The authors in [11] considered a pairing scheme at which two similar-gain CE users are paired on a time-sharing basis with a single CC user to avoid pairing two similar-gain users in one group. However, it is not possible to use CNOMA or time-sharing CNOMA if the three users have similar-gains.

On the other hand, users are assigned powers proportional to their priority or the order of their target throughput within the PNOMA group [12]–[17], which is known as order-based power allocation (OPA). However, there is a gap in the literature regarding the performance of PNOMA, specially that OPA approach does not capture the effects of the diversity in the values of the users' target throughputs. In [16], the authors

investigated the outage probability of a downlink PNOMA transmission in an overlay device-to-device (D2D) network, where a D2D transmitter is communicating with a group of collocated D2D receivers with different target rates. In [14], the secrecy performance for a two-users NOMA system is evaluated, where one user is prioritized over the other user. In [17], the authors have investigated a downlink PNOMA system with randomly deployed users. Specifically, they have investigated the asymptotic behavior of the outage probability and ergodic capacity at high signal-to-noise ratio (SNR).

### B. Motivations and Contributions

Although the work in [12]–[17] have laid foundations for PNOMA schemes, there are many gaps in the literature to fully understand the challenges and implications for adopting PNOMA. As an example, in contrast to the work in [16] that investigate PNOMA in a downlink D2D model, where all receivers have similar-gains under perfect SIC conditions, this work investigates an uplink model under imperfect SIC, where users may have similar or different-gains. It is noteworthy that the similar-gain model is applicable in a clustered IoT environment at which multiple IoT devices are collocated within a small area that can not be paired under CNOMA limitations, while the different-gain model can be used when the users are not in close proximity.

Several research work have considered  $M$ -users NOMA models as in [17], however, increasing the number of users per resource block may not be feasible due to practical implementation and hardware limitations in IoT networks. For the sake of balance between decoding complexity and improving the spectral efficiency, we analyze the performance of a time-division PNOMA (TD-PNOMA) scheme, where three-users with different target rate/throughput, namely the high, mid, and low-rate users form a PNOMA group. The transmission time is divided into two time-slots with two users sharing each slot, assuming that the high-rate user participates in both slots to achieve the higher target rate. The main contributions in this work can be listed as follows

- Investigate the performance of an uplink time-division PNOMA (TD-PNOMA), where three users with different target rates share the same resource block.
- Derive closed-form expressions of the uplink ergodic capacities (ECs) under imperfect SIC as a function of the target rates.
- Investigate the performance of the proposed scheme under different deployment scenarios to find if TD-PNOMA could pair users with different QoS target rates under similar or different gain conditions
- Investigate the performance of traditional order-based power allocation (OPA) compared to a proposed throughput-based power allocation (TPA) scheme.
- Compare TD-PNOMA to a fully-PNOMA (F-PNOMA) scheme, where all of the three users share the same resource block for the whole time.
- The accuracy of the analytical results is verified through numerical simulation.

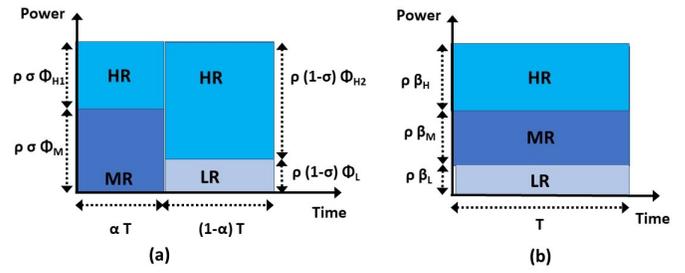


Fig. 1: (a) Time-division priority-based NOMA (TD-PNOMA) Scheme. (b) Fully priority-based NOMA (F-PNOMA) Scheme.

The rest of the paper is organized as follows: In section II, the network model of the proposed scheme is presented. Then, we derive the exact ECs for TD-PNOMA scheme. Section IV shows discussion about the feasibility of achieving NOMA gain and propose a throughput-based power allocation technique. Analytical and simulation results are introduced in section IV. Finally, the paper is concluded in section V.

## II. NETWORK MODEL

In this work, we investigate the performance of an arbitrary uplink OFDMA-based scenario at which three IoT users, with different QoS target rates, share one resource block (RB) and transmit information to a base station (BS) located at the center of the cell. Recently, many research work have investigated OFDMA-based networks, where each RB is assigned to a NOMA group of two-users to reduce the complexity associated with SIC. In this work, we assume three-users NOMA groups as a compromise between improving the spectral efficiency and increasing complexity. We assume a diversity in the QoS target rates of IoT users in the network, which can be classified into three regions represented by the high-rate (HR), mid-rate (MR), and low-rate (LR) users. We assume that  $h_H$ ,  $h_M$ , and  $h_L$  represent the channels between the BS and the three users. All channels are assumed to be independent identically quasi static with Rayleigh distribution, which are drawn according to the distribution  $\mathcal{CN}(0, d_i^{-q/2} PL_o^{1/2})$ , where  $d_i$  is the distance between the nodes and the BS,  $i \in \{H, M, L\}$ , respectively,  $q$  is the path-loss exponent, and  $PL_o$  is the path-loss constant. We also assume that perfect channel state information (CSI) is available.

In this work, we study the performance of a TD-PNOMA scheme and compare it with the F-PNOMA scheme, that are shown shown in Fig.1. In TD-PNOMA scheme, the transmission time ( $T$ ) is divided into two time-slots. HR is paired with MR and LR for  $\alpha T$  and  $(1 - \alpha)T$  seconds, respectively, while the transmit power is divided into  $\sigma P$  and  $(1 - \sigma)P$ , respectively, where  $\alpha$  and  $\sigma$  are the time and power split ratios. The justification of such arrangement is that HR needs to achieve higher target rate than MR and LR. On the other hand, the three nodes form a three-users PNOMA group, which are served using the same time and frequency in the

F-QNOMA scheme as shown in Fig. 1b. In the following, the spectral efficiency of the proposed scheme is investigated and quantified in terms of the ergodic capacity, which is derived under imperfect and perfect SIC conditions, where the ergodic capacity (EC) determines the maximum data transmission rate.

Since HR has higher target rate than both MR and LR, the power allocated to HR is larger than those allocated to both MR and LR, such that  $\phi_M < \phi_{H1}$ ,  $\phi_L < \phi_{H2}$ ,  $\phi_M + \phi_{H1} = 1$ , and  $\phi_L + \phi_{H2} = 1$ , where  $\phi_{H1}$  and  $\phi_M$  are the power allocation factors in the first time-slot,  $\phi_{H2}$  and  $\phi_L$  are the power allocation factors in the second time-slot. Consequently, the signals received at the BS during the first and the second time-slots due to the simultaneous uplink transmissions of each pair are given as follows

$$y_1 = \sqrt{P_{T1}\phi_{H1}}h_H X_{H1} + \sqrt{P_{T1}\phi_M}h_M X_M + n_1, \quad (1a)$$

$$y_2 = \sqrt{P_{T2}\phi_{H2}}h_H X_{H2} + \sqrt{P_{T2}\phi_L}h_L X_L + n_2. \quad (1b)$$

where  $X_M$ ,  $X_L$ ,  $X_{H1}$ , and  $X_{H2}$  denote the information symbols transmitted from MR, LR, and HR on the two time-slots, respectively with the expectations  $E\{|X_M|^2\} = E\{|X_L|^2\} = E\{|X_{H1}|^2\} = E\{|X_{H2}|^2\} = 1$ ,  $P_{T1} = \sigma P$ , and  $P_{T2} = (1 - \sigma)P$  are the transmit powers at the two time slots,  $n_1$  and  $n_2$  are the complex additive white Gaussian noises (AWGN) at the BS at the two time-slots. Since HR has a higher priority than MR/LR during the first/second time-slot, the BS must decode the message  $X_{H1}/X_{H2}$  first then uses SIC to decode the message  $X_M/X_L$ . Assuming an imperfect SIC, the signal-to-interference-plus-noise-ratios (SINRs) at the BS are given respectively as follows

$$\gamma_{H1} = \frac{\sigma \rho \phi_{H1} |h_H|^2}{\sigma \rho \phi_M |h_M|^2 + 1} \quad (2a)$$

$$\gamma_M = \frac{\sigma \rho \phi_M |h_M|^2}{\theta \sigma \rho \phi_{H1} |h_H|^2 + 1} \quad (2b)$$

$$\gamma_{H2} = \frac{(1 - \sigma) \rho \phi_{H2} |h_H|^2}{(1 - \sigma) \rho \phi_L |h_L|^2 + 1} \quad (2c)$$

$$\gamma_L = \frac{(1 - \sigma) \rho \phi_L |h_L|^2}{\theta (1 - \sigma) \rho \phi_{H2} |h_H|^2 + 1}, \quad (2d)$$

where  $\rho = P/N_o$  denotes the transmit signal-to-noise ratio (SNR),  $N_o$  is the AWGN noise power spectral density at the BS,  $|h_H|^2$ ,  $|h_M|^2$ , and  $|h_L|^2$  are the channels gains which follow exponential distribution with the parameter  $\Omega_i = PL_o d_i^{-\alpha}$  for  $i \in \{H, M, L\}$ , and  $\theta$  is the residual interference power ratio due to imperfect SIC, which is assumed to be the same for all users without loss of generality. Given the SINRs in (2), the achievable data rates of the three nodes at the two time slots are given as follows

$$R_{H1} = \alpha C(\gamma_{H1}) \quad (3a)$$

$$R_{H2} = (1 - \alpha) C(\gamma_{H2}) \quad (3b)$$

$$R_M = \alpha C(\gamma_M) \quad (3c)$$

$$R_L = (1 - \alpha) C(\gamma_L), \quad (3d)$$

where  $B$  is the bandwidth,  $C(x) = B \log_2(1 + x)$ , the total rate achieved by HR is given as  $R_H = R_{H1} + R_{H2}$ .

**Ergodic Capacity Analysis:** The EC of a transmission can be mathematically defined as  $C_\gamma = \int_0^\infty t B \log_2(1 + x) f_\gamma(x) dx = \frac{tB}{\ln(2)} \int_0^\infty \frac{1 - F_\gamma(x)}{1+x} dx$ , where  $t$  are the transmission time,  $f_\gamma(x)$  and  $F_\gamma(x)$  is the probability density function (PDF) and the cumulative distribution function (CDF) of the SINR  $\gamma$ , respectively. In the following, we introduce Theorem 1, which is used for deriving the ECs of the three users.

**Theorem 1:** The ergodic capacity of a transmission with SINR  $\gamma = \frac{Z_1}{Z_2+1}$  is given by

$$C_\gamma = \frac{-tB\Omega_{z_1}}{\ln(2)(\Omega_{z_1} - \Omega_{z_2})} (\eta(\Omega_{z_1}) - \eta(\Omega_{z_2})), \quad (4)$$

where  $B, t$  denote the bandwidth and duration,  $\eta(x) = e^{\frac{1}{x}} E_i\left(\frac{-1}{x}\right)$ ,  $E_i$  is the exponential integral function (8.211.1) in [18],  $Z_1$  and  $Z_2$  are exponentially-distributed random variables with parameters  $\Omega_{z_1}$  and  $\Omega_{z_2}$ , respectively.

**Proof:** The EC of the transmission can be evaluated as  $C_\gamma = \frac{tB}{\ln(2)} \int_0^\infty \frac{1 - F_\gamma(x)}{1+x} dx$ , where  $F_\gamma(x) = \Pr\{\frac{Z_1}{Z_2+1} < x\}$  is the CDF of  $\gamma$  which can be expressed as follows

$$F_\gamma(x) = \int_0^\infty \int_0^{x(1+z_2)} f_{Z_1}(z_1) f_{Z_2}(z_2) dz_1 dz_2 = 1 - \frac{\Omega_{z_1}}{\Omega_{z_1} + \Omega_{z_2} x} e^{-\frac{x}{\Omega_{z_1}}} \quad (5)$$

where  $\Omega_{z_1}, \Omega_{z_2}$  are the average power of the exponentially-distributed random variables  $Z_1$ , and  $Z_2$ , respectively,  $f_{Z_1}(z_1)$  and  $f_{Z_2}(z_2)$  are the PDFs of  $Z_1$  and  $Z_2$ , respectively. Using (5), partial fractions' expansion, and integral identity (4.352.4) in [18],  $C_\gamma$  can be re-casted into (4), which completes the proof.

By using Theorem 1, the closed-form expressions of ECs for the three nodes under imperfect and perfect SIC conditions are given in lemma 1 and lemma 2, respectively.

**Lemma 1:** The ergodic capacities of the three nodes in TD-PNOMA Scheme under imperfect SIC are given as

$$C_H^T = \frac{-B}{\ln(2)} \left( \frac{\alpha \Omega_{H1}}{\Omega_{H1} - \Omega_{Mo}} (\eta(\Omega_{H1}) - \eta(\Omega_{Mo})) + \frac{(1 - \alpha) \Omega_{H2}}{\Omega_{H2} - \Omega_{Lo}} (\eta(\Omega_{H2}) - \eta(\Omega_{Lo})) \right) \quad (6a)$$

$$C_M^T = \frac{-\alpha B \Omega_{Mo}}{\ln(2) (\Omega_{Mo} - \theta \Omega_{H1})} (\eta(\Omega_{Mo}) - \eta(\theta \Omega_{H1})) \quad (6b)$$

$$C_L^T = \frac{-(1 - \alpha) B \Omega_{Lo}}{\ln(2) (\Omega_{Lo} - \theta \Omega_{H2})} (\eta(\Omega_{Lo}) - \eta(\theta \Omega_{H2})), \quad (6c)$$

where  $T$  refers to the TD-PNOMA scheme,  $\Omega_{H1} = \sigma \rho \phi_{H1} \Omega_H$ ,  $\Omega_{H2} = (1 - \sigma) \rho \phi_{H2} \Omega_H$ ,  $\Omega_{Mo} = \sigma \rho \phi_M \Omega_M$ , and  $\Omega_{Lo} = (1 - \sigma) \rho \phi_L \Omega_L$ , respectively.

**Proof:** Since the four SINRs in (2) have similar structure as  $\gamma$ , Theorem 1 can be used to complete the proof by considering the different parameters of the SINRs.

**Lemma 2:** The ergodic capacities of the three nodes in TD-PNOMA Scheme under perfect SIC are given as follows

$$\bar{C}_H^T = C_H^T \quad (7a)$$

$$\bar{C}_M^T = \frac{-\alpha B}{\ln(2)} \eta(\Omega_{Mo}) \quad (7b)$$

$$\bar{C}_L^T = \frac{-(1 - \alpha) B}{\ln(2)} \eta(\Omega_{Lo}), \quad (7c)$$

**Proof:** By setting  $\theta$  to zero in (6), we get the proof after some simple mathematical manipulations.

### III. THROUGHPUT-BASED POWER ALLOCATION

In this section, we provide discussions on the the differences between the order-based (OPA) and the throughput-based (TPA) power allocation techniques, and feasibility of achieving PNOMA gain.

**OPA versus TPA:** In [17], the OPA coefficients for PNOMA scheme are computed based on the order of the user's throughput within the K-users PNOMA group, which are given as follows

$$\phi_i^{\text{OPA}} = \frac{K - r[i] + 1}{\mu}, \quad (8)$$

where  $K$  is number of the users in the group,  $r[i]$  is the order of the user  $i$ , and  $\mu$  is a constant which is selected such that  $\sum_{i=1}^K \phi_i^{\text{OPA}} = 1$ . In this subsection, we propose a throughput-based power allocation (TPA) technique, at which the power coefficient ( $\phi_{H1}, \phi_{H2}, \phi_M$ , and  $\phi_L$ ) rely on the actual value of the target throughput of the user not the order of its throughput. The TPA coefficients for a K-users PNOMA group can be expressed as

$$\phi_i = \frac{\bar{R}_i}{\sum_{i=1}^K \bar{R}_i}, \quad (9)$$

where  $\bar{R}_i$  is the target rate of  $i^{\text{th}}$  user. The intuition behind (9) is that the power allocation coefficients should maintain that the highest order user would have the highest SINR among all users and simultaneously reflect the diversity on the values of those target throughputs.

Intuitively, the power allocation based on both OPA or TPA can be applied in uplink scenarios if the users are collocated or the user nearer to the BS is the one with higher target throughput. However, if the near user have higher target throughput and power, this will lead to situations where the received powers from different users are comparable at the BS, which compromise the SIC process.

**Feasibility of Achieving PNOMA Gain:** In this subsection, we seek the conditions under which the pairing of two users with different target rates can be paired for uplink PNOMA scenario and achieve PNOMA gain (i.e., the sum rate of the two users in PNOMA scheme is better than the OMA scheme). By assuming two ordered uplink users,  $U_1$  and  $U_2$ , with power coefficients  $\phi_1 > \phi_2$  which are used in both PNOMA and OMA,  $U_2$  always achieves higher rate at PNOMA than OMA ( $R_2^{\text{PNOMA}} > R_2^{\text{OMA}}$ ), where  $R_2^{\text{PNOMA}} = \log_2(1 + \rho \phi_2 |h_2|^2)$  and  $R_2^{\text{OMA}} = 0.5 \log_2(1 + \rho \phi_2 |h_2|^2)$ . On the other hand,  $U_1$  can achieve gain if ( $R_1^{\text{PNOMA}} > R_1^{\text{OMA}}$ ), where  $R_1^{\text{PNOMA}} = \log_2(1 + \frac{\rho \phi_1 |h_1|^2}{\rho \phi_2 |h_2|^2 + 1})$  and  $R_1^{\text{OMA}} = 0.5 \log_2(1 + \rho \phi_1 |h_1|^2)$ . After some mathematical manipulation, the condition needed to achieve gain for PNOMA scheme is given as follow

$$1 + \rho \phi_1 |h_1|^2 > (\rho \phi_2 |h_2|^2)^2. \quad (10)$$

By investigating the gain feasibility in this subsection, we can present the following Lemma.

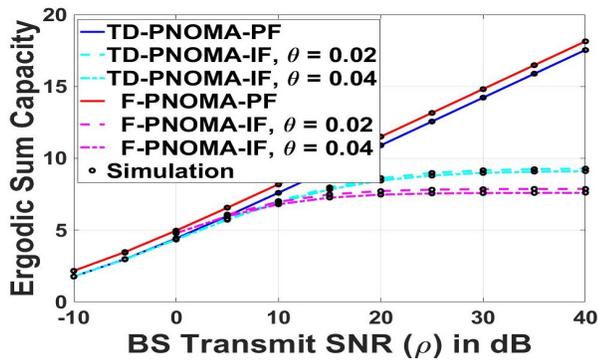
**Lemma 3:** *The possibility to achieve PNOMA gain for a two-user group not only depends on the target rates (i.e.,  $\bar{R}_1$  and  $\bar{R}_2$ ) but also on the channel gains (i.e.,  $|h_1|^2, |h_2|^2$ ).*

**Proof:** By substituting the proposed TPA coefficients in (9) into the feasibility condition in (10), we can see that the satisfaction of the feasibility condition depends on both the target rates and the channel gains not the target rates only. In other words, the previously introduced intuition, that not all deployment scenarios (i.e., the relative values of the channel gains or simply the relative distances with respect to the BS) can achieve PNOMA gain, is true.

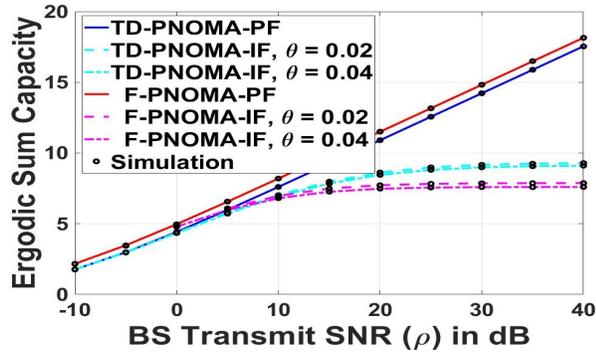
### IV. RESULTS AND DISCUSSIONS

In this section, we verify the correctness of the derived ECs and the improvement for the proposed TPA scheme compared to the OPA scheme via simulation. For the sake of completeness of the work, we provide performance analysis of the fully-PNOMA scheme for a three-users PNOMA group. Via those simulations, it is possible to identify which scheme is suitable for different deployment scenarios. Fig. 1b shows the time and power distribution of the F-PNOMA scheme. The three users are served together during the whole time period ( $T$ ), while the power is divided between the three users according to their priority/target rates (i.e.  $\beta_H > \beta_M > \beta_L$ ) and  $\beta_H + \beta_M + \beta_L = 1$ . We assume that the channels between users and BS undergo both small-scale fading and path-loss effect. Small-scale fading follows an exponential distribution with a mean value of 1. The noise signal of all channels has a Gaussian distribution with zero-mean and unit-variance. The path-loss exponent ( $q$ ) and the path-loss constant  $PL_o$  are set to 3 and 0.1, respectively. We assume a normalized bandwidth (i.e.,  $B = 1$  Hz). Unless otherwise mentioned, we assume the target throughputs of the three users to be 1, 0.5, and 0.25 bps/Hz. Under the previous assumption, the power allocation factors of the order-based power allocation (OPA) settings and TD-PNOMA scheme are  $\{\phi_{H1}, \phi_M, \phi_{H2}, \phi_L\} = \{\frac{2}{3}, \frac{1}{3}, \frac{2}{3}, \frac{1}{3}\}$ , while the coefficients of the F-PNOMA scheme are  $\{\beta_H, \beta_M, \beta_L\} = \{\frac{1}{2}, \frac{1}{3}, \frac{1}{6}\}$  according to (8). On the other hand, for the investigated throughput-based power allocation (TPA) scheme, the power coefficients of the TD-PNOMA scheme are  $\{\phi_{H1}, \phi_M, \phi_{H2}, \phi_L\} = \{\frac{2}{3}, \frac{1}{3}, \frac{4}{5}, \frac{1}{5}\}$ , while the coefficients of the F-PNOMA scheme are  $\{\beta_H, \beta_M, \beta_L\} = \{\frac{4}{7}, \frac{2}{7}, \frac{1}{7}\}$  according to (9). We assume equal sharing for the two time slots in TD-PNOMA scheme, where  $\alpha = \sigma = 0.5$ .

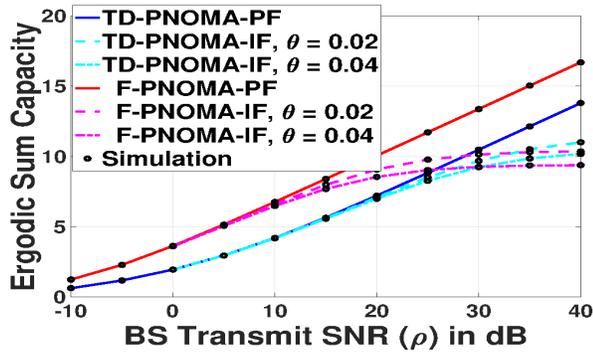
The performance of the two investigated PNOMA schemes are compared in terms of EC in a cell of 500 m radius under the following deployment scenarios: (i) HML Deployment: where HR location is the nearest to the BS, then MR, then LR is the farthest, and (ii) HLM Deployment: where HR location is the nearest to the BS, then LR, then MR is the farthest, and (iii) where LMH Deployment: LR location is the nearest to the BS, then MR, then HR is the farthest, and (iv) Co-located Deployment: where the three users are in close proximity to each others.



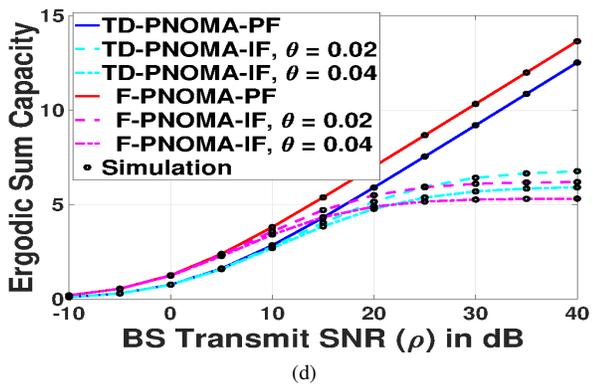
(a)



(b)



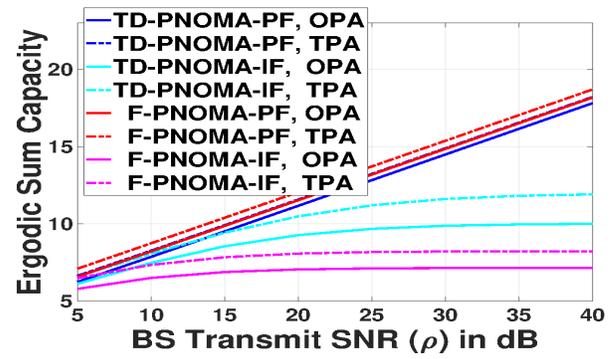
(c)



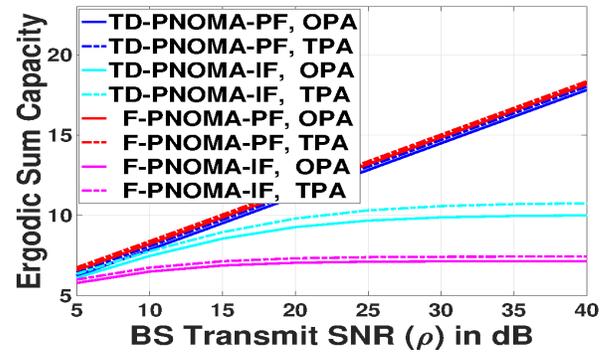
(d)

Fig. 2: Sum ergodic capacity versus the transmit SNR ( $\rho$ ) for the OPA power allocation. (a) HML (b) HLM (c) LMH (d) Co-located Deployment.

Fig. 2 shows the variations of the sum ergodic capacity



(a)



(b)

Fig. 3: Sum ergodic capacity versus the transmit SNR ( $\rho$ ) for both OPA and TPA power allocation schemes under HML deployment for  $\theta = 0.04$ . (a) Target thresholds are 1, 0.25, 0.1 bps/Hz (b) Target thresholds are 1, 0.5, 0.25 bps/Hz.

of the system, defined as the sum of the ergodic capacities of the three users, versus the BS transmit SNR ( $\rho$ ) under different deployment scenarios and different residual power factors of SIC (i.e.,  $\theta \in \{0, 0.02, 0.04\}$ ) for the two schemes (TD-PNOMA and F-PNOMA) assuming the conventional OPA power allocation. Each sub-figure represents one of the pre-mentioned deployment scenarios. Fig. 2 shows a common behavior for all deployments, where the sum ECs of both schemes under perfect SIC conditions (TD-PNOMA-PF and F-PNOMA-PF) are monotonically increasing with  $\rho$ , while under imperfect SIC conditions (TD-PNOMA-IF and F-PNOMA-IF) the sum ECs curves tend to saturate at different values, according to  $\theta$ , as  $\rho$  increases due to the residual interference. The results also show a degraded performance under imperfect SIC conditions for both schemes compared to the perfect SIC case.

Regarding choosing the suitable scheme for different deployment scenarios, we have the following observations: (i) The F-PNOMA-PF scheme outperforms all other schemes including its counterpart TD-PNOMA-PF scheme in all deployment scenarios. However, both HML and HLM scenarios shows comparable performance gap between F-PNOMA-PF and TD-PNOMA-PF in Fig.2a and Fig. 2b, while this gap shows a slight increase for the co-located deployment in Fig. 2d and becomes bigger for the LMH deployment in Fig. 2c.

(2) The performance of both F-PNOMA and TD-PNOMA under imperfect SIC conditions can outperform each other in all deployment scenarios according to the transmit SNR ( $\rho$ ). Still HML and HLM show a comparable performance, where TD-PNOMA-IF can outperform F-PNOMA-IF starting from threshold value  $\rho = 8$  dB. On the other hand, this threshold value elevates to 20:25 dB and 30:32 dB in co-located and LMH deployment, respectively according to the value of  $\theta$ . It is noteworthy that these variations in the performance, special those of LMH deployment, go along the intuition that not every deployment and target throughputs can give a good performance as mentioned in Lemma 3.

Figure 3 compares the performance of both OPA and TPA power allocation schemes in HML deployment assuming that  $\theta = 0.04$  for the imperfect SIC cases. Figure 3a shows the ergodic capacity versus  $\rho$  assuming the target rates are 1, 0.25, and 0.1 bps/Hz while Fig. 3b assumes the rates are 1, 0.5, and 0.25 bps/Hz. In both figures, we can see that the proposed TPA power allocation improves the performance under both perfect and imperfect SIC conditions. However, the performance gap increases in Fig. 3a where the target throughput differences between HR and both other users increases (i.e., (0.75, 0.9) compared to (0.5, 0.75)). This behavior is similar to traditional NOMA where the achievable gain increases with increasing the difference between the channel gains of NOMA-paired users.

**Complexity Analysis:** By grouping three IoT devices in one NOMA group, we improve the spectral efficiency of the network by slightly increasing the complexity at some of the nodes. In F-PNOMA, the low priority user (LR) is the one that needs to detect one extra message, while HR and MR retain the same complexity compared with the two-users NOMA grouping. On the other hand, HR needs to detect its own signal at the first and second time slots of the TD-PNOMA, while both MR and LR must detect HR's message first similar to the two-users NOMA grouping.

**Future Analysis:** It is imperative to consider an efficient optimization algorithm to improve the performance in the investigated TD-PNOMA system by searching optimal settings for the power allocation factors,  $\sigma$ , and  $\alpha$ . Additionally, it may be helpful to consider multi-carrier system, where users are grouped, assigned sub-carriers, and powers to improve the whole system performance.

## V. CONCLUSION

In this work, we have investigated priority-based NOMA spectrum sharing for uplink in IoT networks. Three users are allowed to use the same resource block as a compromise between spectral efficiency and decoding complexity for IoT devices with limited capabilities. We have considered two main schemes, the time-division PNOMA and the fully-PNOMA, under perfect and imperfect successive interference cancellation. Additionally, we compared two power allocation techniques, namely the order-based (OPA) and the throughput-based (TPA) power allocation techniques. The results shows that both schemes can outperform each others under different

deployments scenarios of the three users. Moreover, the simulation results show that it is not enough to consider the target rates alone to achieve a gain in PNOMA, since the deployment scenario matters too.

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