Power Minimization of Downlink Spectrum Slicing for eMBB and URLLC Users

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Abstract—A critical task in 5G networks with heterogeneous services is spectrum slicing of the shared radio resources, through which each service gets performance guarantees. In this paper, we consider a setup in which a Base Station (BS) should serve two types of traffic in the downlink, enhanced mobile broadband (eMBB) and ultra-reliable low-latency communication (URLLC), respectively. Two resource allocation strategies are considered, non-orthogonal multiple access (NOMA) and orthogonal multiple access (OMA). A framework for power minimization is presented, in which the BS knows the channel state information (CSI) of the eMBB users only. Nevertheless, due to the resource sharing, it is shown that this knowledge can be used also to the benefit of the URLLC users. The numerical results show that NOMA leads to a lower power consumption compared to OMA for every simulation parameter under test.

Index Terms—NOMA, RAN slicing, eMBB, URLLC, Power saving

I. INTRODUCTION

5G technology is conceived as a connectivity platform that is capable to support flexibly a plethora of services with heterogeneous requirements. To address the complexity of such a vast connectivity space, 5G has opted to define three generic service types: enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), and ultrareliable low-latency communications (URLLC). These generic types should not be seen as exclusive to a device or a service; there will be composite services that use any combination of the aforementioned generic service types.

In this context, *spectrum slicing* is a fundamental task in a 5G Radio Access Network (RAN): how to utilize a given chunk of spectrum to serve users with heterogeneous requirements. This terminology is motivated by the more general concept of *network slicing*: partitioning the physical network infrastructure in different end-to-end isolated virtual networks, i.e. *slices*, each one able to support a different service requirement for different use cases [1]. In that sense, we can also refer to spectrum slicing as RAN slicing.

The general problem of resource allocation for network slicing is discussed in [2]. Several prior works treated the problem of resource allocation algorithms to multiplex eMBB and URLLC services. In [3], the joint resource allocation problem for eMBB-URLLC slicing is addressed employing different puncturing models. The authors of [4] and [5] propose dif-

ferent deep reinforcement learning techniques to allocate the resource to the two services, employing orthogonal resources and pre-emption/puncturing, respectively. All these works consider the standard application of dynamic resources sharing between eMBB and URLLC, i.e. by means of puncturing or nonoverlapping time/frequency resources [6]. However, power domain non-orthogonal multiple access (NOMA) has proven to outperform the orthogonal multiple access (OMA) [7]. Spectrum slicing can be realized by these two principal approaches, OMA and NOMA, as introduced in the framework presented in [8]¹. The use of NOMA is also been investigated in [9] for URLLC devices with different latency requirements. In [10], a reinforcement learning algorithm decides whenever to use OMA or NOMA for dynamic multiplexing of eMBB-URLLC data streams, setting the transmission power based on the information about the channel gain.

In this paper, we consider spectrum slicing for downlink transmissions of eMBB and URLLC traffic. This is depicted in Fig. 1, which illustrates the two principal ways for sharing the radio resources. The eMBB service aims to maximize the throughput, while not having a latency requirement. On the contrary, the URLLC service demands mission critical, reliable communication, where a hard latency constraint must be fulfilled. Considering the intermittent nature of URLLC and the stringent latency constraints, the estimation of channel state information (CSI) is infeasible, while it can be done for the eMBB device. Accordingly, we assume that perfect CSI is known at the BS towards the eMBB devices, while for the URLLC devices only statistical CSI is available. We investigate the minimization of power for the eMBB-URLLC spectrum slicing problem for both the NOMA and OMA downlink paradigms. The analysis shows that the overall performance, including the URLLC devices, can benefit from the knowledge of the CSI of the eMBB devices. Reserving orthogonal resources to each user allows transmitting URLLC data stream without interference. However, the price to pay

¹Note that the terms OMA and NOMA are commonly used to denote the sharing of wireless resources among services with the same type of requirement, e.g., rate maximization. In [8] the terms H-OMA (heterogeneous OMA) and H-NOMA (heterogeneous NOMA) are used to emphasize the heterogeneous requirements; here we will use NOMA and OMA without any risk of confusion.

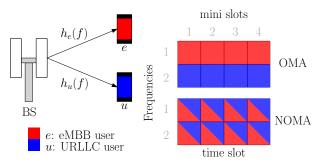


Fig. 1: Toy example of the system model with available frequencies F=2 and available mini slots M=4.

is a non-negligible increase of the power spent for eMBB transmission. Using NOMA, we tolerate a certain amount of interference for the URLLC data stream to reduce the power employed for eMBB transmission. Numerical results show that NOMA attains a lower power consumption than OMA.

II. SYSTEM MODEL

We consider a downlink communication scenario where the base station (BS) transmits eMBB and URLLC traffics. To capture the nature of the dynamics of the slicing problem, our study is focused on a simplified scenario with only two users: an eMBB user e and a URLLC user u.

Following a 5G-like model, the available resources are organized in a time and frequency grid. The time axis is organized in time slots, each divided into M mini slots collected in the set \mathcal{M} . We assume that channel coherence time is always greater than the duration of a single time slot. In the frequency domain, there are F orthogonal frequency resources (FR) collected in the set \mathcal{F} . We further denote as $\mathcal{F}_e \subseteq \mathcal{F}$ and $\mathcal{M}_e \subseteq \mathcal{M}$ the sets of frequency and temporal resources reserved to user e, and with $\mathcal{F}_u \subseteq \mathcal{F}$ and $\mathcal{M}_u \subseteq \mathcal{M}$ the sets of resources reserved to user u. The cardinality of these sets is F_e, M_e, F_u, M_u , respectively. When we follow the NOMA paradigm the resource grid is shared between URLLC and eMBB, i.e. $\mathcal{F}_u \times \mathcal{M}_u = \mathcal{F}_e \times \mathcal{M}_e$. For the OMA configuration the resources are mutually exclusive, i.e. $\mathcal{F}_u \times \mathcal{M}_u \cap \mathcal{F}_e \times \mathcal{M}_e = \emptyset$.

Our goal is to show the effectiveness of the NOMA paradigm when applied to the problem of spectrum slicing. To do so, we employ as the term of comparison the overall transmitted power, a well-recognized optimization parameter. Accordingly, the eMBB user is modeled as transmitting with a target rate r_e and with a minimum transmitted power. The requirements for the URLLC user are formulated in terms of latency and reliability. In particular, we assume that a packet with target rate r_u bit/Hz/s must be delivered within T_u seconds with an outage probability lower than ϵ_u . The URLLLC latency constraints are expressed as a function of the *edge delay*, i.e. the delay between the time at which the message arrives at the transmitter and the time at which the message is effectively transmitted, assuming that all other delay terms have already subtracted from T_u [11]. Without

loss of generality, we define the tolerable latency in terms of the number of mini slots. Hence, each packet should be correctly decoded by the receiver within latency l^{\max} . Even if the instantaneous CSI for URLLC cannot be estimated, due to the time-critical nature of the communication of this service, we assume that the mean channel gain Γ_u , accounting for large-scale fading, is known.

A. Signal model

We consider an OFDM-like transmission, focused on the coexistence of data streams of eMBB and URLL. We denote as n the number of symbols contained in a mini slot. Due to the latency requirements, the length of each URLLC codeword is assumed equal to n, so each mini slot contains a different codeword. On the other hand, a codeword of e may span over multiple mini slots, e.g. $L \leq M$, assuming that its duration is exactly a multiple of n. Let us consider a single resource (t, f), i.e. a single mini slot $t \in \mathcal{M}$, and a single FR $f \in \mathcal{F}$. Therefore, the vectors of transmitted symbols in a resource are denoted as $\mathbf{s}_u(t,f) = [s_u(1,f),\ldots,s_u(n,f)]^T$ for u, and $\mathbf{s}_e(t, f) = [s_e((t-1)n+1, f), \dots, s_e(tn, f)]^T$ for e. We assume that symbol vector chosen are orthonormal, i.e. $\mathbb{E}\left\{||\mathbf{s}_{i}(t,f)||^{2}\right\} = 1, i \in \{e,u\}, \mathbb{E}\left\{\mathbf{s}_{e}^{H}(t,f)\mathbf{s}_{u}(t,f)\right\} = 0.$ The BS transmits both eMBB and URLLC data stream using superposition coding. The transmitted signal in a single resource (t, f) is:

$$\mathbf{x}(t,f) = \sqrt{P_e(t,f)}\mathbf{s}_e(t,f) + \sqrt{P_u(t,f)}\mathbf{s}_u(t,f) \tag{1}$$

where $P_e(t,f)$, $P_u(t,f)$ are the power coefficient used to transmit the symbols of e and u on resource (t,f), respectively. It is worth noting that this formalization implies the possibility of the transmission of the data stream of a single user $i \in \{u,e\}$ in an OMA fashion, by imposing the other coefficient equal to 0. We further denote with $P^{\text{tot}} = \sum_{t \in \mathcal{M}} \sum_{f \in \mathcal{F}} P(t,f)$ the overall power spent. Finally, we denote as \mathbf{P}_u the vector collecting all the URLLC power coefficients, and with \mathbf{P}_e the vector collecting all the eMBB power coefficients.

On the receiver side, we can model the signal received by user $i \in \{e, u\}$ as

$$\mathbf{y}_i(t,f) = h_i(f)\mathbf{x}(t,f) + \mathbf{n}_i \tag{2}$$

where $h_i(f)$, $i \in \{e, u\}$, is the channel gain, and specifically $h_e(f)$ is assumed known, while $h_u(f) \sim \mathcal{CN}(0, \Gamma_u)$; $n_i \sim \mathcal{N}(0, \sigma_i^2 \mathbf{I}_n)$, $i \in \{e, u\}$, is the noise at the receiver. We denote the instantaneous normalized channel gain at the receiver as $i \in \{e, u\}$ as

$$\gamma_i(f) = \frac{|h_i(f)|^2}{\sigma_i^2},\tag{3}$$

where it is worth noting that $\gamma_e(f)$ is a deterministic value and it is known, while $\gamma_u(f) \sim \text{Exp}(\rho_u)$, where $\rho_u = \mathbb{E} \{\gamma_u(f)\} = \Gamma_u/\sigma_u^2$ is the normalized average channel gain.

In the case of OMA, the two data streams are orthogonal in time or frequency, and thus the usual decoding actions can be employed. In the case of NOMA, each user may employ successive interference cancellation (SIC) to cancel the data stream of the other user and recover its data stream with virtually no error. However, the cancellation of a user data stream depends on the reception of the whole codeword, but the eMBB codewords are assumed spanned over multiple mini slots. If the URLLC user waits for the reception of a whole e codeword it may incur a violation of the latency requirement respect its own packet. Therefore, we concentrate on a NOMA communication paradigm where the eMBB user is the only one that can employ the SIC.

Having considered a quasi-static fading channel, the channel dispersion defined in [12] is zero, as demonstrated in [13], [14]. Hence, the description of the maximum available rate for short packets may be done in terms of mutual information and outage capacity.

According to the previous definitions, the mutual information of u data stream at receiver u is denoted as [15]

$$I_u = \sum_{t \in \mathcal{M}_u} \sum_{f \in \mathcal{F}_u} \log_2 \left(1 + \frac{\gamma_u(f) P_u(t, f)}{1 + \gamma_u(f) P_e(t, f)} \right), \quad (4)$$

while the mutual information of u data stream at receiver e is denoted as

$$I_{u,e} = \sum_{t \in \mathcal{M}_u} \sum_{f \in \mathcal{F}_u} \log_2 \left(1 + \frac{\gamma_e(f) P_u(t, f)}{1 + \gamma_e(f) P_e(t, f)} \right), \quad (5)$$

and the mutual information of e data stream at receiver e after the SIC process is

$$I_e = \sum_{t \in \mathcal{M}_e} \sum_{f \in \mathcal{F}_e} \log_2 \left(1 + \gamma_e(f) P_e(t, f) \right). \tag{6}$$

Given the above terms of information is easy to define the outage events that may occur during the transmission.

III. OUTAGES AND THE PROBLEM OF POWER MINIMIZATION

In this section, the definition of outage events for both users is outlined. Then, we describe the optimization problems for the minimum power allocation.

A. eMBB outages

Let us start from the outage events occurring at e. The data stream transmitted to e is incorrectly decoded if: the SIC process is not successful, or the data stream of e is erroneously decoded after the SIC. If NOMA is not applied, the SIC process is considered always successful to give a uniform formulation. The SIC process cannot be successfully employed if $r_u > I_{u,e}$. In this case, we say that the outage event denoted as $\mathcal{O}_{u,e}$ is occurred, and its probability is

$$P(\mathcal{O}_{u,e}) = \Pr\{I_{u,e} < r_u\}. \tag{7}$$

Assuming that the SIC process, if present, has been successful, the data stream of e is wrongly decoded at its own receiver if $r_e > I_e$. Thus, the outage event denoted as \mathcal{O}_e is occurred with probability

$$P(\mathcal{O}_e) = \Pr\{I_e < r_e\}. \tag{8}$$

It is important to note that the assumption of complete knowledge of the CSI for the eMBB user constraints $P(\mathcal{O}_{u,e})$ and $P(\mathcal{O}_e)$ to be either 1 or 0.

B. URLLC outages

Let us now focus on the outage event for u. According to our model, the data stream intended for u is not successfully decoded if: the URLLC packet is wrongly decoded at receiver u, or the URLLC packet is not entirely received before the latency requirement l^{\max} . A packet transmitted toward u is wrongly decoded if $r_u > I_u$. In this case, we denote the event as \mathcal{O}_u having probability

$$P(\mathcal{O}_u) = \Pr\left\{ I_u \le r_u \right\} \le \epsilon_u, \tag{9}$$

which must be upper bounded by ϵ_u , i.e. the URLLC reliability constraint. The violation of the latency requirement, denoted as \mathcal{L} , occurs if the transmission is not successful within l^{\max} . Defining as Δ_u the number of mini slots between the arrival and the first transmission of the URLLC packet, the probability of \mathcal{L} can be formalized as [14]

$$P(\mathcal{L}) = \Pr\{I_u \le r_u \cup \Delta_u + M_u > l^{\max}\},\tag{10}$$

which can be upper bound by

$$P(\mathcal{L}) \le \Pr\{I_u \le r_u\} + \Pr\{M_u > l^{\max} - \Delta_u\}$$

$$\le \epsilon_u + \Pr\{M_u > l^{\max} - \Delta_u\}.$$
 (11)

Hence, the latency constraint can be always satisfied choosing a reasonable value of M_u , such as

$$M_u \le l^{\max} - \Delta_u, \tag{12}$$

providing that the probability of outage event \mathcal{O}_u fulfill the reliability requirement.

C. Optimization process

Given the previous definition of outage events, we can formalize the OMA power allocation problem as

$$\min_{\mathbf{P}_e, \mathbf{P}_u} P^{\text{tot}} \tag{13}$$

s.t.
$$P(\mathcal{O}_u) \le \epsilon_u$$
, (13.a)

$$P_u(t, f) = 0 \text{ if } P_e(t, f) > 0, \forall t \in \mathcal{M}, f \in \mathcal{F}$$
 (13.b)

$$P_e(t, f) = 0 \text{ if } P_u(t, f) > 0, \forall t \in \mathcal{M}, f \in \mathcal{F} \quad (13.c)$$

$$P(\mathcal{O}_e) = 0, (13.d)$$

$$\mathbf{P}_u \succeq 0, \mathbf{P}_e \succeq 0, \tag{13.e}$$

where constraints (13.b)-(13.c) denote the orthogonality of the allocation process. On the other hand, the minimization problem for the NOMA case is the following

$$\min_{\mathbf{P}_{o}, \mathbf{P}_{o}} P^{\text{tot}} \tag{14}$$

s.t.
$$P(\mathcal{O}_u) \le \epsilon_u$$
, (14.a)

$$P(\mathcal{O}_{u,e}) = 0, \tag{14.b}$$

$$P(\mathcal{O}_e) = 0, \tag{14.c}$$

$$\mathbf{P}_u \succeq 0, \mathbf{P}_e \succeq 0. \tag{14.d}$$

Problem (13) and (14) are not convex w.r.t. both power coefficients. Moreover, the evaluation of (13.a) and (14.a) are not known, and only bound or approximations can be used, e.g. see [16], [17]. Unfortunately, optimize the power coefficient using these approximations is an hard task. In the following Section, we describe a simplified solution to the problems.

IV. SIMPLIFIED SOLUTION OF (13) AND (14)

The general idea is to split the problem for e and then for u, to solve simple convex problems. Having considered a single coherence time, the power analysis can be made assuming that $P_u(t,f)$ and $P_e(t,f)$ will not change on different mini slots. Moreover, given (12), the time resources of URLLC transmissions are already defined. Thus, we can impose $P_i(t,f) = P_i(f), \ \forall t \in \mathcal{M}_i, \ i \in \{e,u\}.$

A. eMBB constraints

Let us start with the eMBB decoding process. Following the definition (6), we can obtain the minimum power spent that guarantees that $P(\mathcal{O}_e) = 0$, solving the following problem

$$\min_{\mathbf{P}_e \succeq 0} \sum_{f \in \mathcal{F}_e} P_e(f)$$
s.t.
$$\frac{1}{F_e} \sum_{f \in \mathcal{F}_e} \log_2 \left(1 + \gamma_e(f) P_e(f) \right) \ge \bar{r}_e.$$
(15)

where $\bar{r}_e = r_e/M_e/F_e$ is the average target rate obtained when the informative bits are spread onto the resources available for e. The solution of problem (15) can be computed through the well-known water-filling approach [15], obtaining the desired power coefficients \mathbf{P}_e .

In a similar way, following the definition (5), the minimum power spent constraint to $P(\mathcal{O}_{u,e}) = 0$ can be obtained by solving the following problem

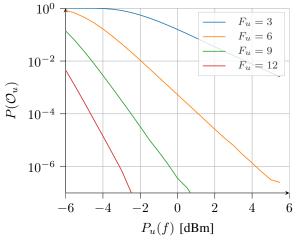
$$\min_{\mathbf{P}_{u} \succeq 0} \sum_{f \in \mathcal{F}_{u}} P_{u}(f)$$
s.t.
$$\frac{1}{F_{u}} \sum_{f \in \mathcal{F}_{u}} \log_{2} \left(1 + \frac{\gamma_{e}(f) P_{u}(f)}{1 + \gamma_{e}(f) P_{e}(f)} \right) \ge \bar{r}_{u}.$$
(16)

where $\bar{r}_u = r_u/M_u/F_u$ is the average target rate obtained when the informative bits are spread onto the resources available for u. Also in this case, a water-filling approach is employed to obtain a solution, labeled as $\mathbf{P}_u^{\mathrm{SIC}}$ to highlight the fact that this is the minimum power needed for the SIC constraint. In case of OMA, $P_u^{\mathrm{SIC}}(f) = 0$, $\forall f \in \mathcal{F}_u$ because SIC is not employed.

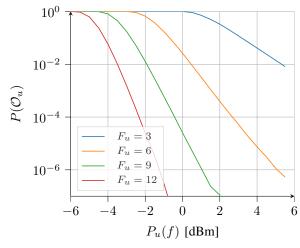
B. URLLC constraints

For the URLLC user, having solved the latency requirement with eq. (12), we only need to focus on the reliability problem. Thus, eq. (9) can be rewritten as

$$\Pr\left\{\frac{1}{F_u}\sum_{f\in\mathcal{F}_u}\log_2\left(1+\frac{\gamma_u(f)P_u(f)}{1+\gamma_u(f)P_e(f)}\right)\leq \bar{r}_u\right\}\leq \epsilon_u.$$
(17)



(a) $P_e(f) = 0$ dBm, $\forall f \in \mathcal{F}_u$



(b) $P_e(f) = 5.5 \text{ dBm}, \forall f \in \mathcal{F}_u$

Fig. 2: Experimental simulation of $P(\mathcal{O}_u)$ versus $P_u(f)$ with different number of F_u , $M_u=1$, $r_u=1$, $\rho_u=30$ dB and $P_u(f)=P_u$, $\forall f\in\mathcal{F}_u$.

In case of a single frequency resource, i.e. $F_u=1$, the resolution of (17) is known [18]. However, the use of a single frequency resource may hardly be done in practice due to the prohibitive value of power needed. On the other hand, when $F_u>1$, the exact evaluation of the probability presented in (17) is not known. Experimental results show that increasing the available frequency resources will lead to a great improvement in terms of reliability, as shown in Figures 2.

From eq. (9) we can see that the outage probability depends on r_u , ρ_u , F_u , P_e and P_u . In theory, we can tabulate the outage probability varying these parameters. However, the variation of each element of P_e and P_u cannot be done in practice due to the high number of trials to be done. Thus, we tabulate the outage assuming that the same P_u and the same P_e are used for all the considered FRs. Let us denote as $\hat{O}_u(P_u, P_e, \rho_u, F_u, r_u)$ the Monte Carlo estimation of the outage probability $P(\mathcal{O}_u)$ when $P_u(f) = P_u$ and $P_e(f) = P_e$

for every $f \in \mathcal{F}_u$, as in Figures 2.

Let us now consider to have computed the eMBB power coefficients $P_e(f)$ have been computed through solution of (15). A possible algorithm guaranteeing the reliability is the following. Given ρ_u , r_u and F_u , we consider the resource of the worst interference seen, i.e. $f^* = \max_f P_e(f)$. Then, we extract from table $\hat{\mathcal{O}}_u$ the minimum P_u that guarantees $\hat{O}_u(P_u, P_e(f^*), \rho_u, F_u, r_u) \leq \epsilon_u$. In other words, we assume that all channels have the strongest interference. Finally, we set:

$$P_u^*(f) = \max\left\{P_u, P_u^{SIC}(f)\right\}, \quad \forall f \in \mathcal{F}_u, \tag{18}$$

which guarantees both SIC and reliability requirements. This scheme is sub-optimal in terms of power spent, considering that we constraint all channels to act as the worst one. To overcome this problem, we propose a different heuristic approach. Given ρ_u , r_u and F_u , we perform the allocation per FR: we extract from table $\hat{\mathcal{O}}_u$ the minimum $P_u(f)$ that guarantees $\hat{O}_u(P_u(f), P_e(f), \rho_u, F_u, r_u) \leq \epsilon_u$. In other words, we deploy the power for channel $f \in \mathcal{F}_u$ assuming that all other channels have inference power $P_e(f)$. Finally, for each FR we set:

$$P_u^*(f) = \max \left\{ P_u(f), P_u^{\text{SIC}}(f) \right\}, \quad \forall f \in \mathcal{F}_u.$$
 (19)

Even if this scheme is still sub-optimal, it saves some power with respect to the previous algorithm. Note that there is no theoretical guarantee that this heuristic will satisfy the reliability constraint. However, experimental results will show that using this scheme the reliability constraint is always verified for the parameters of interest.

Remark that, for OMA allocation, eqs. (19) and (18) give the same results. In fact, the power coefficient of e user is zero for every resources given to u, i.e. $P_e(f) = 0$, $\forall f \in \mathcal{F}_u$. Moreover, the minimum outage probability for unknown i.i.d. parallel channels is reached when the same power coefficient is allocated for each channel [15].

V. NUMERICAL SIMULATIONS

In this section, a comparison in terms of power consumption of using NOMA and OMA for eMBB and URLLC traffics is presented.

Increasing the number of mini slots linearly reduce the average target rate on each resources, while increasing the number of frequency resources gives a not negligible diversity gain. Hence, we consider a resource grid formed by a single mini slot M=1 and F=12 FRs. Furthermore, we set $r_u=1$ and $r_e=6$ bit/s/Hz; the noise power of both user is $\sigma_i^2=-92$ dBm; the reliability requirement is set as $\epsilon_u=10^{-5}$.

Each instance of simulation is made placing the users in a small cell of 100 m of radius and computing the power consumption in case of OMA and NOMA. In case of NOMA, we show the results for both solution (18) and (19), labeled as N-alg and N-heu, respectively. In the case of OMA, we present the results for different frequencies reserved for the URLLC user. In particular, we set $F_u \in \{3,6,9\}$, labeled as O-3, O-6, O-9, respectively. The positioning of the two users is made as follows: the URLLC user u is placed at a

fixed distance d_u [m] from the BS; the eMBB user is then randomly positioned following a uniform distribution in the cell. The path loss is then computed assuming no shadowing and setting the global antenna gain to 17.5 dB and the path loss exponent to 4. Finally, the results are averaged for all the different positions of the eMBB user.

Fig. 3a shows the total power spent P^{tot} as a function of d_u , while the corresponding estimated $P(\mathcal{O}_u)$ is presented in Fig. 3b. $P(\mathcal{O}_u)$ is evaluated by Monte Carlo simulation keeping fixed the allocated power coefficients of each instance while the channel gains of u are randomly generated with the corresponding path loss given by the distance d_u . Moreover, the tabulated outage N-tab for NOMA paradigm used for the evaluation of power is also plotted in Fig. 3b, to show the difference between the tabulated and estimated outage in the NOMA case. The tabulated outage for the OMA case is not presented because identical to the estimated one. We can see that NOMA assures a lower power consumption with respect to the OMA paradigms, guaranteeing at the same time the reliability requirement. It is worth noting that the number of resources to use in case OMA depends on d_u . In particular, when $F_u = 3$ we obtain better performance if $d_u < 29$ m, while better performance are given when $F_u = 6$ for the other distances presented.

To fully understand these results, we present in Table I the average value of the total power spent for the eMBB user, which does not depends on d_u . The pre-allocation of resources lead to a considerable increasing in power. In

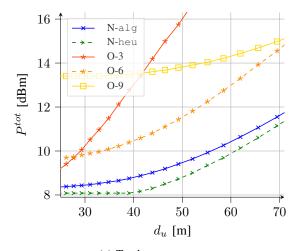
TABLE I: Average eMBB power spent in dBm.

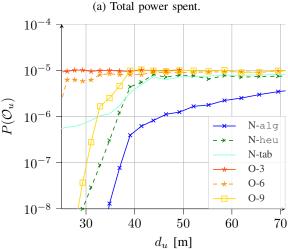
NOMA	O-3	O-6	O-9
7.02	7.90	9.50	13.28

Fig. 4 we show the power spent for the URLLC user, i.e. $P_u^{\text{tot}} = \sum_{f \in \mathcal{F}_u} P_u(f)$. In particular, we show: the results of N-alg and N-heu before the application max operator of solutions (18) and (19); the average minimum power needed to satisfy the SIC requirement, labeled as N-SIC; the power spent for the OMA allocations. Unsurprisingly, the power spent decreases with the increase of resources reserved for the URLLC. However, we can clearly see that the power consumption of N-heu is lower than the one of O-9 when $d_u \geq 45$ m. Furthermore, for $d_u \leq 40$ m. the power needed by the SIC limits the power consumption for N-heu. The floor obtained by O-9 for $d_u < 35$ m is given by the minimum power available per each resource, set as -12 dBm due to computational limits.

VI. CONCLUSIONS

In this paper, the comparison in terms of power consumption for OMA and NOMA paradigms applied on eMBB and URLLC users is studied. Our model assumes a perfect CSI knowledge for the eMBB user and a statistical CSI knowledge of the URLLC user. Furthermore, we assumed that the resources are pre-allocated for the different traffics. Under





(b) Tabulated and estimated outage.

Fig. 3: Average results obtained as a function of URLLC distance d_u .

these assumptions, the general power allocation process of both traffics can be split into several sub-problems. Using the knowledge of eMBB CSI, we provide a practical solution for the minimum power coefficients for both OMA and NOMA cases. Numerical results prove that NOMA approach assures a lower power consumption with respect to the OMA paradigm, guaranteeing at the same time the minimum requirements of both users.

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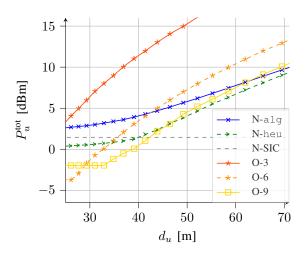


Fig. 4: Average URLLC power spent as a function of the distance d_u .

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