Sharing RANs for energy efficiency

Daniela Renga*, Maoquan Ni*, Marco Ajmone Marsan*§, Michela Meo*
*Politecnico di Torino, Italy; §IMDEA Networks Institute, Spain

***Abstract*—The transition towards 5G scenarios is coping with increasingly demanding communication services featuring strict Quality of Service constraints, hence leading to extreme densification of Radio Access Networks (RANs), especially in urban environment. This process, in turn, raises relevant sustainability concerns, due to the growing energy demand of network infrastructures that typically result overprovisioned and underutilized. In this context, this paper aims at exploring the potential benefits derived from sharing network resources among Mobile Operators (MOs) to make the RAN operation more sustainable and resilient. Considering real mobile traffic profiles, various types of traffic areas, and different MOs, we implement Network Sharing (NS) strategies aiming at sharing the bandwidth capacity among BSs owned by different MOs. These strategies are proved effective to deactivate unneeded network resources for long periods of time under proper configuration settings, hence saving energy and reducing operational cost for MOs. Furthermore, we investigate the impact of traffic features and location dependent network characteristics on the NS performance. Finally, we show that a proper tuning of the NS parameters based on traffic demand characterization is crucial to effectively trade off sustainability goals and the need to preserve network nodes from fast degradation.**

***Index Terms*—Network Sharing, 5G, Sustainability, Resilience**

I. Introduction

The deployment of 5G networks heralds a new era of connectivity, promising to revolutionize communication capabilities and support a myriad of emerging applications and services. However, the large-scale adoption of 5G technology brings with it a number of challenges, ranging from the efficient management of network resources to the sustainability and resilience of network infrastructure. Indeed, we are witnessing the widespread penetration of extremely demanding communication services, featuring tight Quality of Service constraints and leading to a staggering increase of the exchanged traffic volumes [1]. Furthermore, 5G is forecast to support one million devices per square kilometer for applications based on massive Machine Type Communication (mMTC) [2], with the connection density expected to further increase by a factor 10 in the 6G era [3]. A similar challenging scenario clearly entails the need for extensive densification of Radio Access Networks (RANs) [3]. Nevertheless, this process poses relevant sustainability concerns, in relation to the huge energy demand to operate overdimensioned communication infrastructures, that mostly result underutilized during off peak periods, and to the relevant expenses faced by Mobile Operators (MOs), due to the growing energy bill and the capital expenditures incurred to integrate their current infrastructure with new expensive network components based on 5G technology. In this context, network sharing (NS) emerges as a compelling strategy to cope with this challenging scenarios and unlock the full potential of 5G networks. Sharing network resources among different MOs results a promising solution to jointly achieve manifold objectives, i.e., making the RAN operation more energy efficient, reducing both operational and capital expenditures faced by MOs, and enhancing the network resilience to new emerging vulnerabilities that may impair the provisioning of communication, due to potentially more frequent power outages determined by electric grid overload, emergency situations, and cyber attacks [1], [4], [5].

By shedding light on the role of network sharing in future communication networks, this paper aims at exploring the potential of NS to make the RAN operation more sustainable and resilient, and demonstrating the effectiveness of properly designed data-driven NS strategies to enable the extensive deactivation of unneeded network resources for long periods of time, hence allowing huge energy savings for MOs. Indeed, based on predefined agreements among MOs, NS approaches allow to dynamically offload traffic between BSs that are installed on the same site and belong to different MOs, in order to consolidate traffic on few network nodes and deactivate those BSs that do not carry any traffic. Our previous paper [6] offers a preliminary investigation of the NS potential to reduce the RAN energy demand in 5G ecosystems, focusing on the application of NS on few sample pairs of co-located BSs owned by two different MOs that agree to share the bandwidth capacity of their BSs. The examined sample BS pairs are extracted from various types of traffic areas, from a urban densely populated environment to a rural region. With respect to [6], we expand our analysis exploring the performance of NS strategies over a wider set of BS pairs and considering two distinct areas for each of the three investigated traffic area types (city center, suburban, and rural), in order to derive performance analysis results that are more representative of realistic scenarios. Furthermore, instead of considering only a pair of MOs, our analysis is conducted considering all the MOs active in the studied region, and investigating the NS potential for all the possible combinations of MOs.

The main novel contributions of our paper can be summarized as follows. First, considering all the pairs of co-located BSs owned by two different MOs in various area types and including all the possible combinations of MOs, we implement a data-driven NS strategy to investigate via simulation the effectiveness of the NS approach to enable the deactivation of unneeded base stations (BSs) for long periods of their operational time. Second, we extensively analyse the impact of the traffic characteristics and the effect of different configuration settings of the proposed NS strategy on the system performance. In addition, we explore the potential to further extend the NS application from pairs of co-located BSs to sets of three or more co-located BS owned by multiple MOs. Finally, we extensively study the impact of NS on the frequency of BS switching on/off operations under different configuration settings, to provide useful insights about how the BS lifetime may be negatively affected by the application of NS. In particular, our results show that a proper tuning of the NS parameters is fundamental to achieve the desired trade off between sustainability goals and the need to preserve network

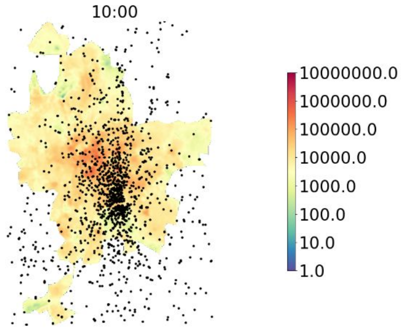


Fig. 1: Sites of *Orange* BSs and traffic load intensity in Lyon during a sample time slot (at 10:00 a.m.).

nodes from fast degradation.

II. Methodology

We consider the case in which two MOs provide mobile access service to their customers within the same coverage area, in which a number of LTE BSs are installed. Based on a predefined agreement, pairs of colocated BSs owned by two different MOs can share their capacity, according to a NS strategy that is detailed in Section II-B. This strategy aims at consolidating the traffic load on one of the two BSs in each pair whenever possible, in order to deactivate the offloaded BS and save energy. To estimate the BS energy consumption we adopt the power models detailed in [7] for LTE technology, considering a Radio Remote Head (RRH) BS. Real traces of normalized mobile traffic from the NetMob dataset, provided by a French mobile operator, are used to model the BS traffic demand [8]. The traffic patterns cover a period of 77 days, with samples collected every 15 minutes with a spatial resolution of 100×100 m^2, and represent more than 60 different mobile services. Real data about the geographical distribution of sites hosting mobile BSs, with information about the adopted mobile technology and the owner network operator (Bouygues, Free Mobile, Orange, SFR) for each BS are retrieved from public datasets made available by the Agence Nationale des Fréquences (ANFR) [9].

A. Mobile network modeling

The mobile access network is modeled as in our previous work [6]. For our analysis we consider the city of Lyon, France. Fig. 1 depicts the traffic volume distribution over the entire city during a sample time slot extracted from the traffic time series (at 10:00 a.m.), with warm shades closer to red indicating higher normalized traffic volumes and cold nuances corresponding to low loaded areas. The black dots represent the actual locations of the BSs installed in the city of Lyon and its surrounding, and owned by Orange, that is the MO for which NetMob traffic traces are provided. BSs clearly appear more densely deployed in the city center, whereas a lower BS density characterizes the peripheral and suburb areas. Within this region, we identify various restricted areas on which our analysis is focused, corresponding to two urban areas in the city center, two suburban areas, and two rural areas. Each area is square in shape, and it is derived from the aggregation of $n \times n$ contiguous tiles, each sized 100×100 m^2, for which traffic traces are available based on NetMob dataset. We then consider the location of actual BSs installed within the defined area that are owned by Orange.

In the NetMob dataset, mobile traffic data is in the form of time series representing the traffic volume generated within each tile with 15-minute time steps. In order not to disclose the sensitive information of the actual volume of traffic served by the mobile network operator, the traffic volume is normalized by a same random value, still resulting fully comparable across space and time [8]. We now need to derive realistic traces of the traffic volumes handled by the Orange BSs located in the considered areas, hence mapping the traces of traffic volumes distributed over the $n \times n$ tiles to each of the BSs from Orange included in the considered area. To this aim, we exploit an Euclidean distance based strategy. Let us denote $L = \{L_1, L_2, \ldots, L_{n\times n}\}$ the set of $n \times n$ traffic time series available for a given area, and $B = \{B_1, B_2, \ldots, B_m\}$ the set of m BSs owned by Orange. Each traffic volume corresponding to the time series L_i from tile i is mapped to the nearest BS B_j such that the Euclidean distance d_{ij} is minimized. Finally, the traffic trace representing the actual traffic volumes handled by each BS B_i is derived from the aggregation of the traffic data series associated to that BS according to the presented method. Notice that the aggregated traffic trace is further scaled up by a factor f_C that is proportional to the actual BS bandwidth capacity, making the conservative assumption that the peak of the aggregated normalized traffic volume should correspond to 90% of the overall estimated BS capacity. In a real scenario, BSs may typically result more underloaded, thus entailing even larger benefits from the NS application with respect to those demonstrated in this paper. In addition, based on the ANFR data [9], we consider the locations of BSs owned by the other MOs active in the considered area. The assignment procedure is hence repeated for all the four MOs, so that within each MO the BSs are assigned an aggregated traffic volume profile that is derived from the raw Orange traffic traces, based on the same processing method presented above.

B. Traffic offloading strategy

To enable the sharing of the network infrastructures among two MOs, that we denote Op_1 and Op_2, the traffic offloading strategy described in [6] is applied to every pair of co-located BSs owned by different operators. Two BSs from different operators are assumed to be co-located if they are placed sufficiently close to each other to provide a nearly overlapping coverage over the same area, hence assuming their distance results smaller than 50 m. A preliminary agreement is assumed among MOs envisioning that the traffic offloading in a given BS pair i is performed from the BS featuring the lowest capacity between the two BSs towards the other BS. Let us assume that for the pair i this BS, that we denote b_1, is owned by Op_1. At every time slot, if the current residual capacity of the BS b_2, owned by Op_2, is sufficient to host the traffic volume handled by the other BS b_1, the traffic volume from b_1 is shifted to b_2, provided that its capacity is not saturated above a threshold that we denote C_{th}. The Op_1 BS, b_1, can hence be deactivated to save energy.

C. Key performance indicators

The following key performance indicators are defined to evaluate the potential of applying Network Sharing in the considered scenario.

Network Sharing Duty Cycle - D: it is the daily average fraction of time slots during which the NS is successfully applied to a pair of colocated BSs (i.e., one of the two BSs in a pair can be deactivated). Large values of NS Duty Cycle reflect a higher capability to provide huge energy savings and significant reduction of operational costs.

Residual Capacity to Traffic per BS ratio - C2T: let us denote C_r the average residual capacity of a BS pair per time slot, defined as follows:

$$C_r = C_i - t_p \tag{1}$$

where C_i represents the average overall capacity per time slot of the considered BS pair i, whereas t_p is the average total traffic volume per time slot handled by the BSs of pair i. Notice that, during NS application, the BS that is deactivated in a pair is the one characterized by the smallest capacity among the two, hence the value of C_i is derived as:

$$C_i = max(C_1^i, C_2^i) + min(C_1^i, C_2^i) \cdot (1 - D^i) \tag{2}$$

where C_1^i and C_2^i corresponds to the capacity of b_1 and b_2 in the BS pair i in the baseline case in which no NS is applied. For each BS pair i, the value of $C2T$ is computed as follows:

$$C2T = \frac{C_r}{t_b} \tag{3}$$

where t_b, derived as $0.5t_p$, represents the average traffic volume per BS per time slot for the pair i. The value of $C2T$ hence reflects the average residual capacity that is available in a BS pair to potentially host additional traffic offloaded from up to $C2T$ close by BSs, assuming that any additional colocated BSs likely handle traffic volumes similar to the BSs belonging to the considered pair i.

BS switching operation frequency - f_s: this metric represents the average number of BS switching on and switching off operations (i.e., any time a BS is either activated or deactivated, respectively) occurring in a BS pair per time slot.

III. Investigating the Network Sharing Potential

Our performance analysis is conducted via simulation over a period of one month, with time step duration of 15 minutes. We consider two different city center areas, two suburban areas, and two rural areas. The size of each identified area is 20×20 tiles (4 km^2), in order to include in our investigation a reasonable number of BSs, that are operated by four different Mobile Operators (Bouygues, Free Mobile, Orange, SFR). The BS density results 26.25 BSs per km^2 in the urban areas, 7.88 BSs per km^2 in the suburban areas, and 3.63 BSs per km^2 in the rural areas. Within each area, we consider all the possible pairs of colocated BS from all possible combinations of Mobile Operator pairs (for a total of 6 different MO pairs).

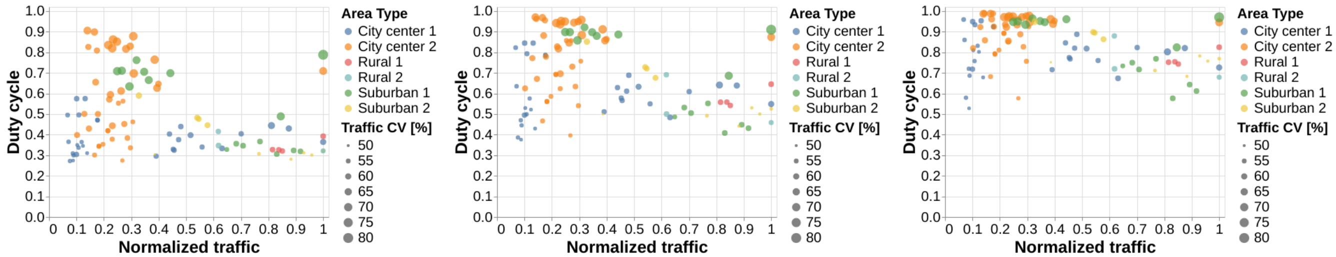
A. Impact of area and traffic on Network Sharing potential

We first investigate the NS potential in different area types considering the NS Duty Cycle, D, that is reported in Fig. 2 versus the average traffic volume per time slot carried by each considered pair of BSs. The traffic is normalized with respect to the value of the largest traffic volume handled by a BS pair over all area types. Each circle in the plots represents a different pair of BSs owned by two different MOs, with the size of each circle resulting larger as the coefficient of variation of the BS pair traffic volume per time slot, that we denote CV, grows larger. Finally, each color corresponds to a different area type. The performance in terms of NS Duty Cycle is reported for various values of the saturation threshold C_{th}. Fig. 2a considers the case of C_{th}=0.5. The highest values of duty cycle are mostly achieved for BS pairs carrying relatively low traffic volumes characterized by high variance, especially in the city center and suburban areas. However, for most BS pairs, the Duty Cycle results higher than 30% under any traffic level and in any area type. The enhanced NS performance under higher traffic variance likely reflects the higher level of traffic decoupling between two BSs in a pair, i.e., there are more frequent occurrences of time slots in which one of the two BSs is relatively highly loaded whereas the other BS features a low traffic load, hence making more likely the consolidation of the traffic on a single BSs with the deactivation of the unused BS. Notice that areas of the same type, like the city center areas, may feature a very different distribution of BS pairs: the City center 1 (blue circles) includes BS pairs featuring very low to high traffic load, whereas rather limited traffic variability is observed; conversely, in City center 2 (orange circles), most BS pairs are low loaded, whereas the traffic variability ranges from intermediate to high values. This affects the potential benefits provided by NS, that results more effective in the City center 1. In both rural areas (red and azure circles) few BS pairs are identified, all featuring an intermediate NS potential. Indeed, in this type of regions BS installations are typically sparse and BSs provide coverage over wide areas, hence resulting highly loaded and characterized by low traffic variability. Suburban areas (green and yellow circles) appear having intermediate features, with some low loaded BS pairs characterized by high CV, like in the city center, and some highly loaded BS pairs, usually having limited traffic variance, like in the rural regions. Further investigation may be required to assess whether the data processing to derive the aggregated traffic profiles for each BS may affect to any extent the NS performance in different areas.

B. Effects of NS parameter settings

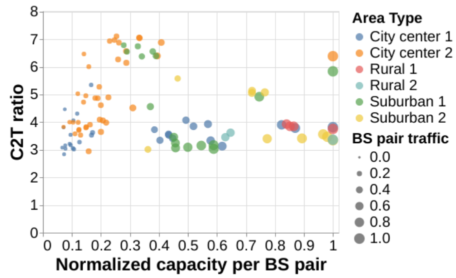
Fig. 2a-*c* shows the NS duty cycle for increasing values of the saturation threshold C_{th}. As the value of C_{th} becomes larger, BS pairs featuring relatively low traffic variability tend to achieve higher values of D, which can be almost doubled for C_{th}=0.9 with respect to C_{th}=0.5. Conversely, the additional benefit derived from higher settings of C_{th} is limited for BS pairs characterized by higher CV, especially when C_{th} is raised from 0.7 to 0.9. Furthermore, for BS pairs featuring low CV, the NS duty cycle may show an erratic behavior given similar variability levels, especially under higher settings of C_{th}. This trend entails the need to further investigate the role of possible additional features that may affect the NS performance under different settings of C_{th}. To this aim, a more extensive characterization of the traffic profiles is required, focusing on metrics that allow to more accurately explore the potential of NS in different areas and designing offloading strategies that dynamically adapt their configuration settings to the varying traffic conditions.

Our results highlight how the traffic variance rather than the traffic volume results more decisive to achieve high NS benefits even under low values of C_{th}, with high levels of CV yielding a considerably superior NS performance given the same traffic volume. Moreover, whereas high settings of C_{th} are advisable in case of traffic demand featuring low variability to remarkably improve the network sharing potential, like in rural areas, more conservative settings should be preferred for those BS pairs featuring high CV, like those observed in part of

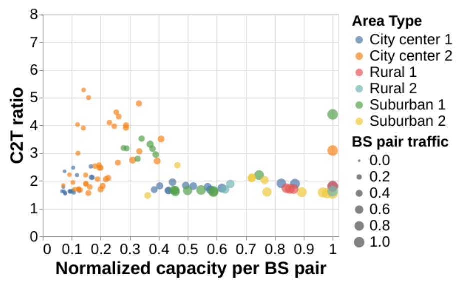


(a) $C_{th} = 0.5$ (b) $C_{th} = 0.7$ (c) $C_{th} = 0.9$

Fig. 2: Network Sharing Duty Cycle, D, for all the BS pairs considering all possible combinations of Mobile Operators in different area types, under different values of the saturation threshold C_{th}.



(a) Without NS



(b) $C_{th} = 0.9$

Fig. 3: Residual capacity to traffic per BS ratio, C2T, for all the BS pairs considering all possible combinations of Mobile Operators in different area types, without NS and under different values of the saturation threshold C_{th}.

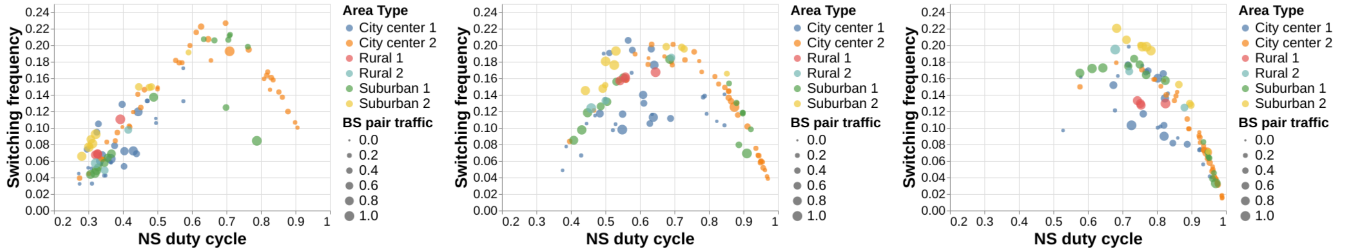
the city center and of urban areas. Indeed, in this latter case the improvement of the NS performance would not be sufficiently relevant to justify the reduced capability of the BS pair to face sudden and unexpected traffic peaks (due to the higher setting of the saturation threshold C_{th}) that may result more likely in case of high values of CV, hence impairing the Quality of Service. Finally, notice that a NS duty cycle higher than 0.9 actually means that one of the two BSs in the corresponding pair is unneeded for more than 90% of the operation time, entailing not only huge energy savings under the application of NS but also implying useful insights in relation to future network planning decisions for MOs.

C. Exploring the potential for multi-operator NS

Considering all the BS pairs in the various area types, Fig. 3 shows the Residual Capacity to Traffic per BS ratio, $C2T$, versus the overall capacity per BS pair available when both BSs in the pair are always active. The BS pair capacity is normalized with respect to the highest capacity among all the BS pairs observed in all considered areas. Different colors represent different areas, whereas the size of the circles is proportional to the normalized average BS pair traffic volume. The baseline case in which NS is not applied (Fig. 3a) is compared against the case in which the NS strategy is run under C_{th}=0.9 (Fig. 3b). In the baseline scenario depicted in Fig. 3a, C2T never falls below 3 for most BS pairs, and remarkably high C2T values of up to more than 7 can be observed in several BS pairs. This trend reflects the fact that in general BSs result extremely underloaded, with huge amounts of spare capacity that is not utilized. Conversely, as highlighted in Fig. 3b, the application of NS allows to significantly improve the efficiency of bandwidth capacity utilization, since C2T can be reduced in all BS pairs. The largest benefits are obtained for those BS pairs in the city center and suburban areas carrying small traffic volumes and characterized by a relatively overdimensioned capacity, for which the value of C2T under NS can be even halved with respect to the baseline case. At the same time, even when NS is applied under high settings of the saturation threshold C_{th}, the C2T ratio is never decreased below 1.5, meaning that there is still huge potential to extend the current NS approach, that is based on pairs of BSs owned by two different MOs, to possible scenarios in which NS can be applied on sets of three or more co-located BSs belonging to three or more different MOs. For example, Fig. 3b shows that some BS pairs in the city center (orange and blue circles) feature C2T around 2 under NS. A value of $C2T$=2 implies that, on average, the residual capacity of the BS pair is suitable to host the traffic offloaded from up to 2 additional co-located BSs (assuming that co-located BSs carry similar volumes of traffic), that can hence be deactivated. Therefore, instead of considering BS pairs, a NS strategy could be effectively applied considering triplets of quadruplets of co-located BSs owned by four different MOs, further enhancing the capacity utilization and yielding even larger energy savings.

D. NS parameter tuning to prevent BS degradation

The BS lifetime may be affected by frequent activation and deactivation operations, due to various entailed degradation phenomena [10]. To evaluate the impact of NS on the frequency of BS switching on/off operations, Fig. 4 depicts the frequency of BS switching operations, f_s, for each BS pair versus the NS duty cycle, D. Different colors correspond to various area types, whereas the size of the circles is proportional to the normalized average BS pair traffic volume. The saturation threshold is set to increasing values, from C_{th}=0.5 (Fig. 4a) to C_{th}=0.9 (Fig. 4c). In general, smaller values of BS switching frequency are granted by either relatively low or very high values of NS duty cycle, whereas the highest values



(a) $C_{th} = 0.5$ (b) $C_{th} = 0.7$ (c) $C_{th} = 0.9$

Fig. 4: BS switching frequency for all the BS pairs considering all possible combinations of Mobile Operators in different area types, under different values of the saturation threshold C_{th}.

of f_s are determined by duty cycles around 0.6-0.7. The setting of C_{th} should hence be properly tuned depending on the area type and on the traffic features, in order to achieve the desired trade off between the target NS duty cycle and the constraint on the maximum BS switching frequency. For example, let us assume a predefined limit on the maximum BS switching frequency of f_s <0.15 BS switching on/off operations per time slot (corresponding to a maximum of about 7 BS deactivations per day in a pair). Considering the Rural area 1 (red circles), this constraint can be respected by all BS pairs even under a low setting of C_{th}=0.5, yielding D of up to 0.4. Raising C_{th} to 0.7, the constraint on f_s cannot be satisfied by any BS pair in the area, but further increasing C_{th} to 0.9 can reduce the BS switching frequency below the predefined level, with the additional advantage of remarkably increasing the NS duty cycle, that results more than doubled for all BS pairs. Furthermore, the higher duty cycle granted by higher setting of the saturation threshold provides longer periods of BS deactivation, that further contribute to prevent BS hardware failure and preserve the BS lifetime [10].

However, Fig. 4 also highlights the complex relationships that link the saturation threshold settings and the traffic characteristics with the NS duty cycle and the BS switching frequency. Indeed, given the same setting of C_{th}, this complexity leads to rather different behaviors in terms of BS switching frequency. These behaviors may depend on several factors, including the area type, the average traffic volume and traffic variance of the BS pair, and possibly additional traffic properties and system characteristics that are not captured by the considered performance metrics, hence requiring to be more extensively explored in future work, to provide further insights for a more effective design of NS strategies tailored on specific features of the BS pairs in the considered area. Clearly, the design of NS strategies and the definition of parameter configuration should encompass the need for fairness among MOs, to enable a balanced contribution in terms of resources shared by each MO, achieved energy savings and operational cost reduction, and to avoid that some MO may result unevenly burdened by higher maintenance cost incurred for replacing networks nodes, due to more frequent BS hardware failures that are determined by more frequent BS switching operations. Finally, notice that new generation BS technologies tend to be less sensitive to the degradation phenomena entailed by high frequency of BS switching on/off operations [10]. Hence, in some cases, the strict constraints on the BS switching frequency may be conveniently relaxed depending on the variable penetration of 5G and beyond technology observed in the considered scenarios, in order to more effectively achieve the desired target of NS duty cycle.

IV. Conclusion

Our study explores the potential of sharing network resources among different MOs to enable a more sustainable and resilient RAN operation in future 5G and beyond scenarios. Our results highlights how NS approaches allow to deactivate unneeded BSs for long periods of time in any type of traffic area under proper configuration settings, hence saving energy and reducing operational cost for MOs. Furthermore, a fine tuning of the NS parameters based on traffic demand characterization is crucial to effectively trade off sustainability goals and the need to preserve network nodes from fast degradation. Nevertheless, further research is required to enhance the design of NS strategies with dynamic parameter configuration, tailored to specific traffic features and location dependent network characteristics that may variably affect the RAN operation, in order to more effectively exploit the full potential of NS.

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