Self-Optimized Admission Control for Multi-tenant Radio Access Networks

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***Abstract*— Multi-tenant Radio Access Networks (RANs) are envisaged to play a key role in highly dense scenarios for fulfilling the challenging capacity requirements of future enhanced Mobile BroadBand services while reducing the capital and operational costs per tenant. In this context, this paper proposes a self-optimized Admission Control (AC) strategy for automatically adjusting the share of resources per tenant in each cell of the shared RAN in order to account for uneven time/space distributions of tenants' traffic demand across cells. The proposed approach is evaluated by means of simulations to analyze the operation of the self-optimization process under different traffic distributions. Results reveal that the proposed self-optimized AC can provide substantial throughput gains of up to 65% with respect to the case without self-optimization.**

***Index Terms*— Multi-tenancy, RAN sharing, Admission Control, Self-Organizing Networks (SON).**

I. INTRODUCTION

On top of supporting the evolution of the current business models for the provision of Mobile BroadBand (MBB) services, future Fifth Generation (5G) systems are expected to expand to new models regarding the network deployment and operation. In this respect, neutral host models such as Small Cell as a Service (SCaaS) in which a company deploys and operates a number of cells to be shared among multiple communication providers, are envisaged to be particularly beneficial to fulfil the challenging capacity requirements in highly dense scenarios, since the sharing process will reduce capital and operational costs [1].

An overview of 3rd Generation Partnership Project (3GPP) standardization activities on network sharing is presented in [2], introducing the main enablers for realizing future multi-tenant networks. Besides, the virtualization of the Radio Access Network (RAN) is considered in different works as a solution to enable that multiple operators (tenants) share the physical radio resources available at a base station [3]-[6].

An important challenge in RAN sharing is the optimization of the network configuration to ensure that the deployed radio resources are used efficiently and that each tenant gets the desired service. For that purpose, given the high variability of the MBB traffic and the random behavior of the radio channel, an extensive use of Self-Organizing Network (SON) functionalities, able to reduce or remove the need for manual planning, deployment, optimization and maintenance activities of the network is envisaged [7].

Under the above context, this paper presents a new multi-tenant RAN Admission Control (AC) algorithm that makes use of a SON function to automatically adjust the AC parameters and regulate the share of resources used by each tenant in each cell. The novelties of this work in relation to prior works are in terms of (1) the use of AC for realizing multi-tenancy, in contrast to e.g. [3]-[6], which have focused on the scheduling process to split the radio resources of a RAN among tenants and (2) the use of SON in a multi-tenant scenario, in contrast to e.g. [8]-[12], which have addressed SON for AC optimization for traditional RAN owned and operated by a single Mobile Network Operator (MNO). The consideration of multi-tenancy introduces a fundamental difference in the way how these techniques have to be designed, because they need to incorporate additional dimensions to capture the specificities of each tenant (e.g. the different service expected in accordance with the Service Level Agreements [SLA]) and the possible complementarities between tenants (e.g. the spatial and time distribution of each tenant may not be the same across the whole RAN). In this respect, one of the key novelties of the proposed AC solution is the ability to exploit, by means of SON techniques, the statistical multiplexing gain resulting from an uneven time/space distribution of tenants' traffic demand across cells.

In a prior work of the authors [13] a multi-tenant admission control scheme was proposed for performing the split of radio resources between different tenants in a cellular network. This paper extends this prior work by including the SON functionality to autonomously adjust the AC thresholds. The SON functionality is developed through two different architectural components, namely

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the decentralized SON (dSON) and the centralized SON (cSON).

The rest of the paper is organized as follows. Section II presents the algorithmic process of the proposed self-optimized multi-tenant AC. Then, Section III presents a simulation-based performance evaluation and Section IV concludes the paper.

II. SELF-OPTIMIZED MULTI-TENANT ADMISSION CONTROL

Let us consider a multi-tenant RAN scenario where the infrastructure provider has deployed N cells numbered as $n=1,...,N$. These cells are shared among S tenants numbered as $s=1,...,S$, which offer services to their own customers.

From a service perspective, and following the terminology of Long Term Evolution (LTE), the RAN provides Evolved Radio Access Bearers (E-RAB), which are the data delivery services offered across the RAN for information exchange between the User Equipment (UE) and the mobile Core Network (CN). Accordingly, the SLA between a tenant and the infrastructure provider is specified in terms of an aggregated bit rate to be provided for the set of the tenant's E-RABs activated across all of the deployed cells.

The radio resources of each cell are organized in Physical Resource Blocks (PRB) that are dynamically assigned to the UEs depending on their required bit rate. The AC function, executed at each cell, makes the decision on whether the establishment request of a new E-RAB is accepted or rejected. The AC should account for the overall PRB utilization in the cell, the bit rate requirements of already active E-RABs and of the new E-RAB request, and the SLA terms.

The functional architecture of the proposed framework for self-optimized AC is shown in Fig. 1. The AC function at the n-th cell is triggered from each tenant's CN, i.e. from the Mobility Management Entity (MME) in the case of LTE, indicating the bit rate R_{req} to be guaranteed to the E-RAB.

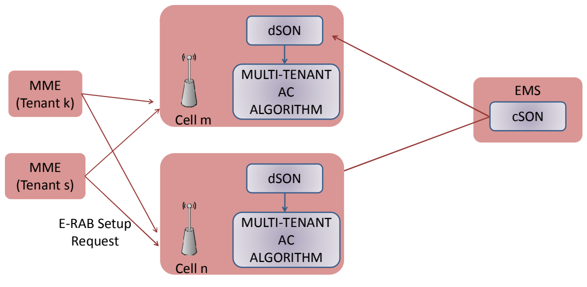

Fig. 1. Functional architecture of the AC Self-Optimization

In order to adapt to different network conditions and to further optimize the performance of the AC, a SON function is used to dynamically modify some of the AC parameters. As shown in Fig. 1, a hybrid SON approach is considered in which a distributed SON function (dSON) running at each cell optimizes some parameters with the support of a centralized SON (cSON) function running at the Element Management System (EMS). The cSON function can make decisions based on an overall view encompassing multiple cells relying on Performance Measurement (PM) reports.

A. Multi-tenant Admission Control algorithm

The AC must ensure that the amount of PRBs required by the new E-RAB and by the already admitted E-RABs does not exceed the number of available PRBs in the cell $\rho(n)$. Moreover, given that a multi-tenant RAN is considered, the AC must ensure that the available PRBs are both fairly and efficiently shared among the tenants. Therefore, the proposed multi-tenant AC admits the new E-RAB if the following two conditions hold simultaneously.

1) Capacity check at cell-level

This capacity check evaluates the aggregated number of PRBs used by all the tenants in the n-th cell after accepting the E-RAB request and ensures that the cell has sufficient physical resources for serving the new E-RAB. The capacity check is passed if the following condition holds:

$$\sum_{s'=1}^{S} \rho_G(s',n) + \Delta\rho \le \rho(n)\alpha_{th}(n) \qquad (1)$$

$\rho_G(s,n)$ is the average number of PRBs that the Packet Scheduling (PS) of the n-th cell has assigned to the E-RABs of the s-th tenant during a window T. This can be obtained by particularizing on a per-tenant level the "PRB usage per traffic class" measurement of [14]. $\rho(n)\cdot\alpha_{th}(n)$ is the cell-level AC threshold. It considers only a fraction $\alpha_{th}(n)\in(0,1]$ of the total number of PRBs in the cell, $\rho(n)$, thus leaving a margin to cope with e.g. handovers, statistical variations of the PRB usage, etc. $\Delta\rho$ is the estimated number of PRBs required by the new E-RAB and is computed based on the required bit rate R_{req} as $\Delta\rho = R_{req}/\hat{r}(n)$ where $\hat{r}(n)$ is an estimation of the bit rate per PRB that can be obtained in the n-th cell. It is based on actual measurements of the obtained bit rate during a certain time window T_e.

2) Per-tenant capacity share check

This check establishes an upper bound in the PRBs used by the E-RABs of a tenant in accordance with the capacity contracted through the SLA, which for the purpose of this paper is defined by the so-called Scenario Aggregated Guaranteed Bit Rate (*SAGBR*) that establishes the total bit rate to be guaranteed for all the E-RABs of a tenant across all the deployed cells. Based on this, the *nominal capacity share* of the s-th tenant, $C(s)$, is defined as the ratio between the $SAGBR(s)$ of this tenant with respect to the aggregated *SAGBR* of all the tenants:

$$C(s)=\frac{SAGBR(s)}{\sum_{s'=1}^{S} SAGBR(s')} \tag{2}$$

Then, the per-tenant capacity share check is defined as:

$$\rho_G(s,n)+\Delta\rho \le \rho(n)\cdot\alpha_{th}(n)\cdot\left(C(s)+\Delta C(s,n)\right) \tag{3}$$

This condition reflects that the *s*-th tenant should be allowed to use a fraction of the PRBs in the *n*-th cell given by *C*(*s*) plus an additional term Δ*C*(*s*,*n*) that enables some flexibility in the capacity share per tenant to account for unused capacity left by other tenants and to cope with heterogeneities in the spatial traffic distribution. This term is dynamically configured by the dSON function with the support of the cSON, as explained in the following.

B. SON function

The dSON function at the *n*-th cell is in charge of adjusting the term Δ*C*(*s*,*n*) of the per-tenant capacity share check. Specifically, the term Δ*C*(*s*,*n*) is defined as:

$$\Delta C(s,n)=\begin{cases}\Delta C_e(s,n) & \text{if } \Delta C_e(s,n)>0\\ \Delta C_b(s,n) & \text{if } \Delta C_e(s,n)=0\end{cases} \tag{4}$$

The term $\Delta C_e(s,n)$ is the extra capacity share that is potentially available for the *s*-th tenant in the *n*-th cell when the other tenants *s*'≠*s* are leaving unused capacity (i.e., their PRB utilization is below the nominal share). Therefore, $\Delta C_e(s,n)$ pursues higher efficiency: when extra capacity share is available in the *n*-th cell (i.e., $\Delta C_e(s,n)>0$), the term Δ*C*(*s*,*n*) facilitates that the *s*-th tenant can get part of this extra capacity and occasionally be able to serve a traffic load above the agreed *SAGBR*(*s*).

The term $\Delta C_b(s,n)$ is the capacity share shift for the *s*-th tenant in the *n*-th cell to ensure capacity share balance across all the cells. It measures the increase or decrease in the capacity share that should be applied in the *n*-th cell to ensure that the average PRB utilization of the *s*-th tenant across all the cells equals *C*(*s*). Therefore, $\Delta C_b(s,n)$ pursues fairness from a multi-cell perspective: under high traffic conditions (i.e., $\Delta C_e(s,n)=0$), the term Δ*C*(*s*,*n*) intends to modify the resource share of the *s*-th tenant based on the overall PRB utilization across all the cells, targeting an adequate capacity share from a multi-cell perspective.

Given that $\Delta C_e(s,n)$ only involves local information (i.e., cell level) while $\Delta C_b(s,n)$ involves global information (i.e., multi-cell level), the algorithms to compute $\Delta C_e(s,n)$ and $\Delta C_b(s,n)$ are executed in dSON and cSON entities, respectively.

The dSON component computes the term $\Delta C_e(s,n)$ as:

$$\Delta C_e(s,n)=\max\left(\sum_{s'\neq s}\left(C(s')\cdot\theta-\frac{\rho_G(s',n)}{\rho(n)}\right),0\right) \tag{5}$$

where $\theta\in(0,1]$ is a margin to account for the variability in the traffic generation, reflecting that PRB underutilization of tenant *s'* should only be considered when the average PRB utilization $\rho_G(s',n)/\rho(n)$ is below $C(s')\cdot\theta$. $\Delta C_e(s,n)$ is measured as an average over a long-term time window W_{dSON}.

The cSON component computes the value of $\Delta C_b(s,n)$ and provides it to dSON. The computation is based on the target of achieving an average PRB utilization across all the cells for the *s*-th tenant equal to the nominal value *C*(*s*). For that purpose, if the average utilization of the *s*-th tenant in cell *n*'≠*n* at a certain point of time is $\rho_G(s,n')/\rho(n')$, the *n*-th cell should target a PRB utilization equal to $C(s)+\Delta C_b(s,n)$, so the following relationship should be fulfilled:

$$\frac{1}{N}\left(C(s)+\Delta C_b(s,n)+\sum_{\substack{n'=1\\ n'\neq n}}^{N}\frac{\rho_G(s,n')}{\rho(n')}\right)=C(s) \tag{6}$$

Straightforward manipulation of (6) yields:

$$\Delta C_b(s,n)=(N-1)C(s)-\sum_{\substack{n'=1\\ n'\neq n}}^{N}\frac{\rho_G(s,n')}{\rho(n')} \tag{7}$$

$\Delta C_b(s,n)$ is measured as an average over a long-term time window W_{cSON}.

III. PERFORMANCE EVALUATION

The performance of the proposed approach has been evaluated by means of system-level simulations in the outdoor Urban Micro scenario of [15] with hexagonal layout and considering a total of 19 cells, numbered as shown in Fig. 2. All the cells operate in the same LTE carrier, so there exists inter-cell interference. The detailed simulation parameters are listed in Table I. Simulations consider the downlink direction with *S*=4 tenants, denoted as *s*=1,2,3,4. The capacity contracted by each tenant in the scenario is given by the *SAGBR* values in Table I, where also the nominal capacity shares *C*(*s*) are presented. The values of the parameters θ, $\alpha_{th}(n)$ and the averaging windows have been set based on prior simulations not shown here for the sake of brevity. Simulations assume that the average value of $\Delta C_b(s,n)$ is sent by the cSON to the dSON every 0.1 s.

The UEs of each tenant request Guaranteed Bit Rate (GBR) E-RABs following a Poisson arrival model and exponential session duration. The session generation rate of the s-th tenant is set so that its total offered load in the scenario equals $SAGBR(s)$. However, to analyze the effect of the different spatial distributions, it is assumed that this total offered load is spatially distributed for each tenant following a Gaussian distribution centered at the color points shown in Fig. 2, which are located at distance R(m) from the center of the scenario. The Gaussian distribution is characterized by a standard deviation of D(m) that determines how concentrated the traffic is around the central point.

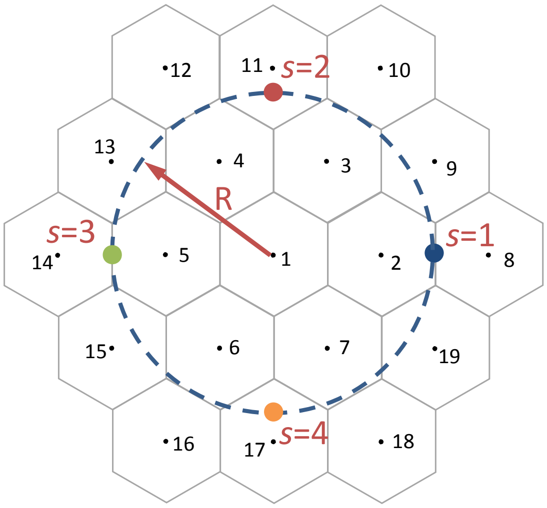

Fig. 2. Considered scenario

The performance of the proposed hybrid SON approach is compared against a reference case where no SON technique is used, so $\Delta C(s,n)$ is set to a fixed value $\Delta C(s,n)=0$. Fig. 3 depicts the total throughput improvement in % obtained by the proposed approach with respect to the reference case. In order to capture different spatial traffic distributions, results are presented as a function of the distance R(m) (see Fig. 2) and for different values of the standard deviation D(m). For comparison purposes, also the homogeneous spatial distribution is presented, in which the total offered load of a tenant is equally distributed in all the cells. Results reveal that the proposed approach is able to achieve substantial improvements with respect to the reference case thanks to the dynamic adaptation of the parameter $\Delta C(s,n)$ for each cell. It is also observed that the achieved gains increase when the spatial traffic distributions of the different tenants exhibit a higher degree of complementarity, i.e. for high values of R and low values of D, which correspond to situations in which the traffic of each tenant is concentrated in a different region of the scenario. In such cases, the observed gains are up to 65%.

TABLE I. SIMULATION PARAMETERS

Parameter	**Value**
ISD (Inter-Site Distance)	200m
Path loss and shadowing model	Urban micro-cell model with hexagonal layout (see details in [15])
Shadowing standard deviation	3 dB in Line Of Sight (LOS) and 4 dB in Non Line Of Sight (NLOS) [15]
Base station antenna gain	5 dB
Frequency	2.6 GHz
Transmitted power per PRB	24 dBm
Number of RBs per cell $\rho(n)$	50 RBs (1 LTE carrier of 10 MHz)
UE noise figure	9 dB
Link-level model to map Signal to Interference and Noise Ratio and bit rate	Model in section A.1 of [16] with maximum spectral efficiency 4.4 b/s/Hz.
SAGBR	$SAGBR(1)$=56Mb/s; $SAGBR(2)$=42 Mb/s; $SAGBR(3)$=21Mb/s; $SAGBR(4)$=21 Mb/s.
Nominal capacity shares $C(s)$	$C(1)$=40%; $C(2)$=30%; $C(3)$=15%; $C(4)$=15%.
GBR (R_{req})	1024 kb/s
Average session duration	30 s
$\alpha_{th}(n)$	0.75
Averaging windows	T=10s, T_e=30s, $W_{cSON}=W_{dSON}$=300 s
θ	0.77
Simulation duration	10000 s

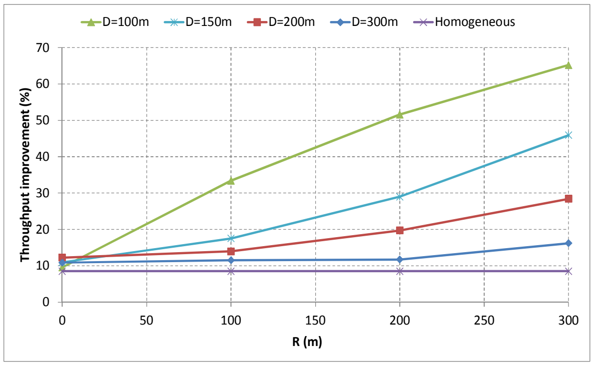

Fig. 3. Throughput improvement with respect to the reference case as a function of the distance R(m) and for different values of D(m).

To gain a further insight in the behavior of the algorithm, Fig. 4 presents the throughput of tenant s=1 in the different cells of the scenario when the spatial traffic distribution is given by R=300m, D=200m. It is observed that the highest benefits from the proposed SON approach are obtained in cells 2, 8, 9 and 19, which correspond to the cells surrounding the central point of the traffic distribution for this tenant (see Fig. 2) and therefore they are the cells that need to serve more load from this tenant. In turn, the differences between the two approaches in the rest of the cells are smaller.

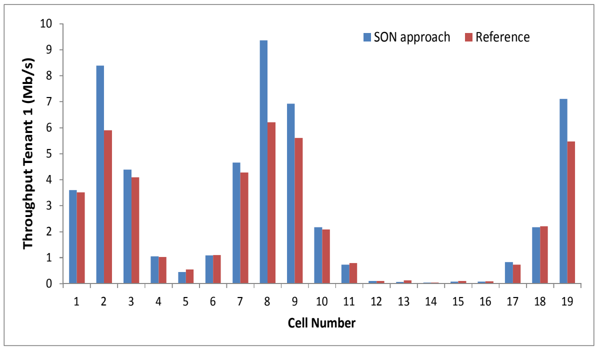

Fig. 4. Throughput of tenant s=1 in each cell for the case R=300m, D=200m.

IV. CONCLUSIONS AND FUTURE WORK

This paper has proposed a self-optimized AC for controlling the share of radio resources between different operators in a multi-tenant scenario. The AC algorithm relies on a cell-level capacity check and a per-tenant capacity share check. The former check ensures that the cell has sufficient resources to accept a new E-RAB, while the second check controls the amount of bearers admitted for each tenant. The tenant-specific threshold of this second check is adjusted by means of a hybrid SON technique that accounts for unused capacity left by the tenants and copes with heterogeneities in the spatial traffic distribution.

A simulation-based analysis has been presented to assess the behavior of the SON algorithm under different traffic spatial distributions. Results have demonstrated that the use of the SON technique allows substantially increasing the throughput obtained by the different tenants. Overall throughput improvements of up to 65% have been obtained.

Future research that derives from this work includes the extension of the cSON and dSON components to dynamically adjust other components of the AC such as the values of the margins $\alpha_{th}(n)$ and θ depending on specific performance indicators like the blocking probability or the packet dropping due to congestion.

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