Admission Control for Multi-tenant Radio Access Networks

J. Pérez-Romero, O. Sallent, R. Ferrús, R. Agustí
Universitat Politècnica de Catalunya (UPC)
[jorperez, sallent, ferrus, ramon]@tsc.upc.edu

***Abstract*— The sharing of Radio Access Networks is gaining momentum in small cell scenarios, due to the associated reduction in capital and operational costs. In this scenario, the split of radio resources among tenants sharing the network becomes a fundamental problem to provide each one with its required capacity. In this respect, this paper proposes a multi-tenant admission control scheme for performing this split with the target of ensuring an efficient use of the radio resources by exploiting traffic multiplexing principles at both intra-cell and multi-cell level in order to cope with heterogeneities in the spatial traffic distribution of the different tenants. A simulation-based analysis is presented to assess the flexibility of the proposed approach under different traffic mixes of the different tenants in each cell. Substantial bit rate improvements (e.g. up to 106%) and blocking probability reductions are obtained with respect to a baseline scheme.**

Keywords—Multi-tenancy; RAN sharing; Admission Control

I. INTRODUCTION

The evolution of mobile communications systems towards the Fifth Generation (5G) needs to face not only the challenging requirements of Mobile BroadBand (MBB) use cases but also of new diverse use cases associated to customers of new market segments and vertical industries (e.g., e-health, automotive, energy) [1]. Therefore, on top of supporting the evolution of the current business models, 5G will expand to new models. Partnerships will be established on multiple layers ranging from sharing the infrastructure, to exposing specific network capabilities as an end to end service, and integrating partners' services into the 5G system through a rich and software oriented capability set.

In this context, the sharing of mobile network infrastructure among multiple communication providers denoted as "tenants", is identified in [2] as one of the main objectives to be addressed by future architectures of mobile networks, since the sharing process will reduce capital and operational costs. Besides, the provisioning of small cells under multi-tenancy is particularly envisaged as a key component to fulfil the expected requirements of future 5G networks in highly densified scenarios. Specifically, in [3] a market analysis is presented to support the importance of introducing multi-operator capabilities in small cell networks, discussing the benefits from the perspective of different players, i.e. Mobile Network Operators (MNOs), non-mobile service providers, enterprises and site owners. The use of neutral host models offering Small Cell as a Service (SCaaS) is regarded as an interesting approach to stimulate multi-operator small cells, as this will create fewer conflicts of interest for MNOs than other approaches in which shared cells are owned by one of the MNOs.

3GPP specifications have already added some support for sharing the legacy network infrastructures among multiple tenants. Two main architectures are identified in [4], namely Multi-Operator Core Network (MOCN), where a shared Radio Access Network (RAN) is directly connected to each of the multiple operator's core networks, and Gateway Core Network (GWCN), where a shared core network is considered. Recently, in [5], an overview of 3GPP standardization activities on network sharing is presented, introducing the main enablers for realizing future multi-tenant networks.

Different works have addressed the virtualization of the Radio Access Network (RAN) as a solution to enable that multiple operators share the physical radio resources available at a base station. In [6][7] the Network Virtualization Substrate (NVS) is proposed, meeting the requirements of isolation in a single cell, customization within virtual networks and efficient resource utilization. In [8] the problem of radio resource sharing among multiple operators is addressed from a more fundamental, algorithmic perspective. It formulates the multi-operator scheduling as a concave generalized rate scheduling problem intending to keep a specific sharing ratio per operator. The approach of these previous works relies on the packet scheduling process to schedule the transmissions of the different tenants in accordance with a certain amount of radio resources to be assigned to each tenant in a single cell. In [9], multi-tenancy also relies on the NVS concept based on packet scheduling but applying on top of it a tenant-specific admission control. The sharing process in the abovementioned approaches is done separately for each cell in a multi-cell scenario. In [10], the NetShare framework is proposed, which extends NVS for a multi-cell scenario with the inclusion of a network-level scheduler that decides the sharing ratios for each base station. Similarly, [11] proposes the RAN Multi-tenant cell Slicing Controller (RMSC), which intends to decide the adequate UE-to-cell association in a multi-tenant scenario.

The split of radio resources among tenants can be performed at different levels, as discussed in [12]. While most of the above references consider the split at packet scheduling level, this paper proposes the split at admission control (AC) level. AC is in charge of accepting or blocking new service requests and, therefore, in a multi-tenant scenario it plays a key role for ensuring the Quality of Service (QoS) guarantees to be provided to the different tenants. The split at AC level provides a simple approach for enabling multi-tenancy because it is based on controlling the acceptance of new bearers of each tenant rather than on scheduling the physical radio resources to packet flows on a per-tenant basis, so it does not require modifications at the lower layers of the protocol stack (i.e. RLC/MAC/PHY).

The proposed multi-tenant AC scheme for a multi-cell RAN is designed with the target of ensuring an efficient use of the radio resources by exploiting traffic multiplexing principles at both intra-cell and multi-cell level in order to cope with heterogeneities in the spatial traffic distribution of the different tenants. While the AC problem in cellular LTE networks has been profusely considered in the literature (e.g., [13]-[18]), only very few studies, such as [9], have dealt with AC in multi-tenancy, and in that case the AC was devised at single cell level.

The rest of the paper is organized as follows. Section II presents the principles of operation of the proposed multi-tenant AC. Then, Section III presents the proposed algorithmic solution. Section IV presents the performance evaluation while the paper is concluded in Section V.

II. MULTI-TENANT ADMISSION CONTROL

Let us assume a multi-tenant RAN, in which an infrastructure provider deploys and operates a number of cells in a certain area that are shared by different tenants, e.g. MNOs and/or mobile virtual network operators (MVNOs), to offer services to their own customers. The technical and operational aspects for implementing the sharing model will be captured through Service Level Agreements (SLAs) between the infrastructure provider and each involved tenant.

From a service perspective, the RAN provides Radio Access Bearers (RAB), which are the data delivery services offered for information exchange between the User Equipment (UE) and the mobile core network. In the context of LTE, a RAB is denoted as Evolved-RAB (E-RAB), it is designed to transfer IP packets over the air interface and its expected behavior is parameterized with a set of QoS attributes [19].

The establishment, maintenance and release of RABs involve the configuration of radio resources associated with them. In particular, the AC function, executed at each cell, makes the decision on whether the establishment request of a new RAB is accepted or rejected in the cell. The AC should account for the overall resource utilisation in the cell, the QoS requirements of already active RABs and the requirements of the new RAB request.

In this paper, a new multi-tenant AC function is proposed, intending to control the amount of RABs that are admitted from each of the involved tenants in the different cells. The multi-tenant AC algorithm is formulated based on the following considerations:

- The admission/rejection decision has to take into consideration the amount of capacity that is committed to the tenant that requests the RAB set-up, as specified in the SLA terms. This is specified in terms of the so-called Scenario Aggregated Guaranteed Bit Rate (SAGBR), which indicates the aggregated bit rate to be provided for all the RABs of a tenant across all the cells deployed in the scenario.
- Due to the random behaviour of the radio channel and the propagation conditions experienced by the different UEs, the bit rate requirements of a RAB cannot be deterministically mapped to a number of required radio resources at the physical layer, i.e. Resource Blocks (RBs) in LTE. Indeed, the number of required RBs to provide a certain bit rate to a RAB will vary and thus it can only be statistically estimated. Therefore, the admission/rejection decision has also to take into consideration the actual RB utilisation in order to estimate whether there is sufficient capacity at the physical layer to support the bit rate requirements of the new RAB or not.
- In pursue of an efficient utilisation of the available radio resources, traffic multiplexing principles at both cell and multi-cell level will be exploited in the admission/rejection decisions. In this way, the admission control should enable that a tenant gets the agreed SAGBR across all the considered cells but should be flexible enough to cope with heterogeneities in the traffic distribution of one tenant across different cells as well as complementarities in the traffic distribution of different tenant (e.g. a tenant has most of its traffic in certain cells while the traffic of another tenant is mainly generated in other cells).

III. ALGORITHMIC SOLUTION

Let us consider a scenario with N cells numbered as n=1,...,N shared by S tenants numbered as s=1,...,S. The number of available RBs at the n-th cell is given by $\rho(n)$. This value depends on the number of carriers allocated to the cell and of the InterCell Interference Coordination (ICIC) strategy (that may prevent the usage of some RBs at the cell in order to avoid intercell interference).

The AC process at the n-th cell is executed every time that a RAB set-up request is sent from the core network to this cell. The RAB set-up request, which is associated to a specific tenant, includes the required QoS of the RAB, defined in terms of the required bit rate to be guaranteed R_{req}.

In a multi-tenant RAN, the AC should consider two different aspects. First, it must ensure that the amount of RBs required by the new RAB and by the already admitted RABs does not exceed the number of available RBs in the cell $\rho(n)$. Second, it must ensure that the available RBs are fairly shared between the tenants in accordance with their SAGBR values. Therefore, the proposed multi-tenant AC admits the new RAB if the following two conditions hold simultaneously.

A. Capacity check at cell-level

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

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

where:

- $\rho_G(s,n)$ is the average number of RBs that the Packet Scheduling (PS) of the n-th cell has assigned to the RABs of the s-th tenant. The average is measured over a certain time window T.
- $\Delta\rho$ is the estimated number of RBs required by the new

RAB. It is computed based on the required bit rate R_{req} as:

$$\Delta\rho = \frac{R_{req}}{\hat{r}(n)} \tag{2}$$

where $\hat{r}(n)$ is an estimation of the bit rate per RB that can be obtained in the n-th cell. This estimation is computed based on actual measurements of the obtained bit rate during a certain time window T_e:

$$\hat{r}(n) = \frac{\sum_{t=1}^{T_e} R_{meas}(n,t)}{\sum_{t=1}^{T_e} N_{RB}(n,t)} \tag{3}$$

$N_{RB}(n,t)$ is the number of RBs that have been allocated by the PS in the t-th Transmission Time Interval (TTI) to the different RABs of the n-th cell and $R_{meas}(n,t)$ is the aggregated bit rate obtained on these RBs.

- $\rho(n)\cdot\alpha_{th}(n)$ is the cell-level AC threshold. It considers only a fraction $\alpha_{th}(n)\in(0,1]$ of the total number of RBs in the cell, $\rho(n)$, thus leaving a margin to cope e.g., with handover UEs, statistical variations of the RB usage, etc.

B. Per-tenant capacity share check

This check establishes an upper bound in the RBs used by the RABs of a tenant in accordance with the agreed SAGBR. For this purpose, the AC makes use of the *nominal capacity share* of a tenant s, $C(s)$, defined as the ratio between the SAGBR(s) of the s-th tenant across all the cells with respect to the aggregated SAGBR of all the tenants:

$$C(s) = \frac{SAGBR(s)}{\sum_{s'=1}^{S} SAGBR(s')} \tag{4}$$

The per-tenant capacity share check is defined as:

$$\rho_G(s,n) + \Delta\rho \le \rho(n)\cdot\alpha_{th}(n)\cdot\left(C(s) + \Delta C(s,n)\right) \tag{5}$$

This condition reflects that the s-th tenant should be allowed to use a fraction of the RBs in the n-th cell given by $C(s)$ plus an additional term $\Delta C(s,n)$ that enables some flexibility on the capacity share per tenant to account for unused capacity left by other tenants and to cope with heterogeneities in the spatial traffic distribution. Specifically, the term $\Delta C(s,n)$ is defined as:

$$\Delta C(s,n) = \begin{cases} \beta\cdot\Delta C_e(s,n) & \text{if } \Delta C_e(s,n) > 0 \\ \gamma\cdot\Delta C_b(s,n) & \text{if } \Delta C_e(s,n) = 0 \end{cases} \tag{6}$$

where

- The configuration parameters β, γ are scalars in the range [0,1]
- $\Delta C_e(s,n)$ is the extra capacity share that is potentially available for the s-th tenant in the n-th cell. It measures the RB under-utilisation of the other tenants $s'\neq s$ below their nominal share, and is defined as:

$$\Delta C_e(s,n) = \max\left(\sum_{s'\neq s}\left(C(s')\cdot\theta - \frac{\rho_G(s',n)}{\rho(n)}\right), 0\right) \tag{7}$$

where the parameter $\theta\in(0,1]$ is a margin to account for the variability in the traffic generation, reflecting that RB under-utilisation of tenant s' should only be considered when the average RB utilisation $\rho_G(s',n)/\rho(n)$ is below $C(s')\cdot\theta$.

- $\Delta C_b(s,n)$ 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 RB utilisation of the s-th tenant across all the cells equals $C(s)$. It is defined as (see demonstration in the appendix):

$$\Delta C_b(s,n) = (N-1)C(s) - \sum_{\substack{n'=1 \\ n'\neq n}}^{N} \frac{\rho_G(s,n')}{\rho(n')} \tag{8}$$

Both $\Delta C_e(s,n)$ and $\Delta C_b(s,n)$ are measured as an average over a long-term time window $W>>T$.

The term $\Delta C(s,n)$ in (6) is defined based on the following considerations:

- Efficiency: When extra capacity share is available in the n-th cell (i.e., $\Delta C_e(s,n)>0$, which means that the other tenants $s'\neq s$ are not consuming all their nominal capacity), the term $\Delta C(s,n)$ 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).
- Capacity balancing across multiple cells: Under high traffic conditions (i.e., $\Delta C_e(s,n)=0$), the term $\Delta C(s,n)$ intends to modify the resource share of the s-th tenant based on the overall RB utilisation across all the cells, targeting an adequate capacity share from a multi-cell perspective. For this reason, the term $\Delta C(s,n)$ is varied in accordance with the metric $\Delta C_b(s,n)$.

IV. Performance Evaluation

The performance of the proposed approach has been evaluated in the outdoor Urban Micro scenario of [20][21]. Each cell has one LTE carrier of 10 MHz, corresponding to a total of 50 RBs. Simulations consider the downlink direction with the simulation parameters summarized in Table I. The simulations assume 2 tenants, denoted as T1 and T2. The UEs of each tenant request GBR RABs following a Poisson arrival model and exponential session duration. Different offered loads of each tenant are simulated by varying the session arrival rate in each cell.

The capacity contracted by Tenant T1 in the scenario is SAGBR(1)=25 Mb/s, while the capacity contracted by Tenant T2 is SAGBR(2)=37 Mb/s. Based on these values, the infrastructure provider has to come up with an appropriate deployment whose capacity fits the tenants' needs[1]. In the scenario considered here, and based on the parameters of Table I, the infrastructure provider decides to deploy a total of N=2 cells operating in different carriers and it estimates the total capacity per cell to be around 31 Mb/s. The nominal capacity

[1] The determination of the appropriate deployment and the available cell capacity depends on different factors like the characteristics of the traffic, the propagation and interference conditions, etc. and is out of the scope of this paper.

shares of each tenant are C(1)=40% for T1 and C(2)=60% for T2.

Given that the main characteristic of the proposed AC algorithm is to achieve an efficient usage of the available RBs (by allowing that the unused capacity left by one tenant, at cell and/or multi-cell level, can be exploited by another tenant), the performance assessment places the focus on analysing different offered traffic load mixes of each tenant in each cell in relation to their capacity share.

The efficiency in the resource usage pursued by the proposed algorithm is mainly provided by the term $\Delta C(s,n)$ of the per-tenant capacity share check in (6). Therefore, the reference benchmark for comparison will be the case in which $\Delta C(s,n)$ is set to 0, denoted in the following as "NoDelta".

In order to gain a first insight in the algorithm's behaviour, Fig. 1 and Fig. 2 depict the gain achieved by the proposed algorithm in terms of aggregated bit rate in the scenario obtained by tenants T1 and T2, respectively, with respect to the "NoDelta" case. Results are presented as a function of the total offered load of each tenant in the scenario, considering the case where the offered load of a tenant is equally distributed in the two cells. It is observed from Fig. 1 that the proposed algorithm can increase the aggregated bit rate of T1 up to 106% when the offered load of T2 is 0. A similar result is seen in Fig. 2 for T2, i.e. there is an aggregated bit rate increase of up to 43% when the offered load of T1 is 0. These improvements reflect that, thanks to the term $\Delta C(s,n)$, the algorithm allows that a tenant benefits from a higher aggregated bit rate when the other tenant is not consuming all its capacity, thus leading to a more efficient use of the radio resources.

In order to gain further insight, let consider that the average offered load of a tenant in a given cell can be as Planned (denoted as P), which means that the offered load is in accordance to the expected level associated to the SLA, well below the planned value (denoted as Low, L) or well above the planned value (denoted as High, H). As a result of the offered load levels per cell, the total offered load of a tenant over the whole scenario can also be classified as P (i.e., total load equal to the SAGBR), L or H. Based on this, Table II presents two representative traffic mixes that have been selected for the evaluations. In each case, the offered load of each tenant per cell and in total is presented, indicating the corresponding levels {L,P,H} as well. Each traffic mix intends to study the behaviour of the algorithm in specific conditions of interest.

Traffic mix A represents a situation in which the offered load of tenant T1 is H in both cells, while the offered load of tenant T2 is L. In this case, Fig. 3 depicts the performance

TABLE I. SIMULATION PARAMETERS

Parameter	Value
ISD (Inter-Site Distance)	200m
Path loss model	Urban micro-cell model with hexagonal layout [20]
Shadowing standard deviation	3 dB in LOS and 4 dB in NLOS.
Base station antenna gain	5 dB
Frequency	2.6 GHz
Transmitted power per RB	24 dBm
Number of RBs per cell $\rho(n)$	50 RBs (1 LTE carrier of 10 MHz)
UE noise figure	9 dB
Spectral efficiency model to map SINR with bit rate	Model in section A.1 of [22]. The maximum spectral efficiency is 4.4 b/s/Hz.
GBR (R_{req})	1024 kb/s
Session duration	Exponential model, average 30s.
Session arrival rate	Poisson model. Different average values considered in the simulations to simulate different loads.
$\alpha_{th}(n)$	1
Averaging windows (T, W, T_e)	(0.1, 300, 30) s
(θ, β, γ)	(0.77,1.0,1.0)

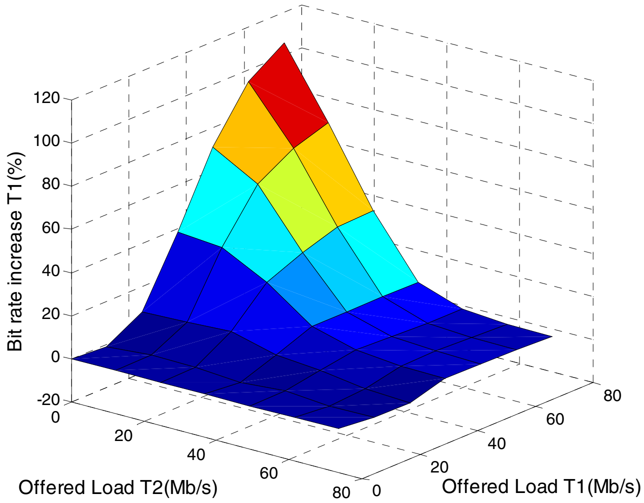

Fig. 1. Increase in the aggregated bit rate obtained by T1 with the proposed algorithm in relation to the reference benchmark "NoDelta".

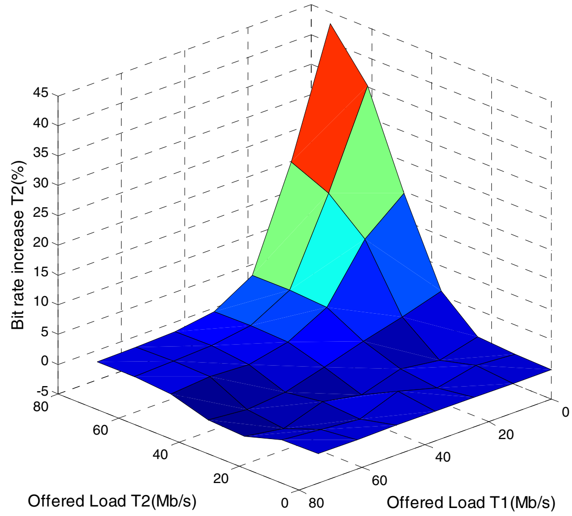

Fig. 2. Increase in the aggregated bit rate obtained by T2 with the proposed algorithm in relation to the reference benchmark "NoDelta".

TABLE II. SELECTED TRAFFIC MIXES (OFFERED LOADS IN MB/S)

Traffic Mix	Tenant T1			Tenant T2		
	Load Cell 1	Load Cell 2	Total Load	Load Cell 1	Load Cell 2	Total Load
A	24.6 (H)	24.6 (H)	49.2 (H)	12.3 (L)	12.3 (L)	24.6 (L)
B	19 (H)	6 (L)	25 (P)	12 (L)	25 (H)	37 (P)

experienced by each tenant in terms of aggregated bit rate obtained in the scenario and blocking probability. It can be observed that the proposed algorithm allows that the spare capacity of T2 is used by T1, who obtains a bit rate improvement of 33% with respect to the reference case without degrading the aggregated bit rate of T2, as well as a substantial reduction in the blocking probability. The improvements of T1 are obtained with only a slight degradation in the blocking probability of T2 which is kept below 2%.

In turn, in the traffic mix B, although the offered load of both tenants equals the planned level, this load is not evenly distributed in the two cells. In this case, Fig. 4 depicts the bit rate obtained by each tenant in each cell and in the whole scenario. The flexibility offered by the capacity share shift $\Delta C(s,n)$ in the proposed algorithm allows modifying the resource share in the two cells in order to better absorb the traffic demands. This leads to an increase in aggregated bit rate of 18% for T1 and 8% for T2 compared to the case that $\Delta C(s,n)=0$, which intends to enforce the nominal capacity share in the two cells.

Fig. 5 presents the blocking probability, which reflects a substantial reduction in terms of total blocking probability in for both tenants when $\Delta C(s,n)$ is exploited. The global gain for T1 is achieved thanks to a significant blocking probability reduction in Cell 1 (where T1's load is H and takes advantage of the spare capacity left by T2) and a very slight increase in Cell 2 (where the unused capacity by T1 is exploited by T2).

To further analyse the behaviour of the algorithm in different load conditions, Fig. 6 plots the aggregated bit rate obtained by each tenant with the proposed algorithm and with the reference scheme as a function of the total offered load of T2, which is varied in relation to the traffic mix A of Table II, as depicted in Fig. 6. The total offered load of T1 is the one corresponding to the traffic mix A (i.e. 49.2 Mb/s, corresponding to a H level). The offered load is equally distributed in the two cells. It is observed in Fig. 6 that, when the load of T2 is below the level of traffic mix A (i.e. 24.6 Mb/s), further improvements are obtained by T1, which can benefit from the unused capacity left by T2. Then, as the load of T2 increases above the Planned level (i.e. 37 Mb/s) and becomes H, the performance of both algorithms becomes approximately the same. In this case each tenant gets a bit rate in accordance with its nominal capacity share. The figure also reveals that the bit rate obtained by T2 is approximately the same with the two schemes for all the load levels, because in this case T1, whose offered load is H, is not leaving unused capacity.

V. Conclusions and Future Work

This paper has addressed the support of multi-tenancy in a multi-cell RAN through the split of resources at the admission control stage, by regulating the amount of bearers that can be admitted for each tenant in each cell in order to keep the required QoS guarantees.

The proposed admission control scheme is designed with

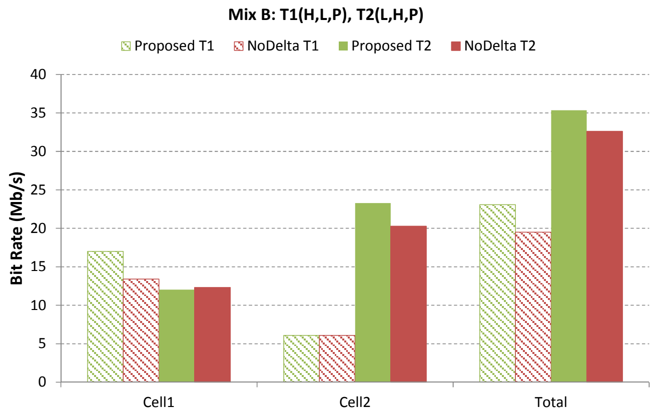

Fig. 5. Aggregated bit rate obtained by each tenant in the scenario and blocking probability with traffic mix A.

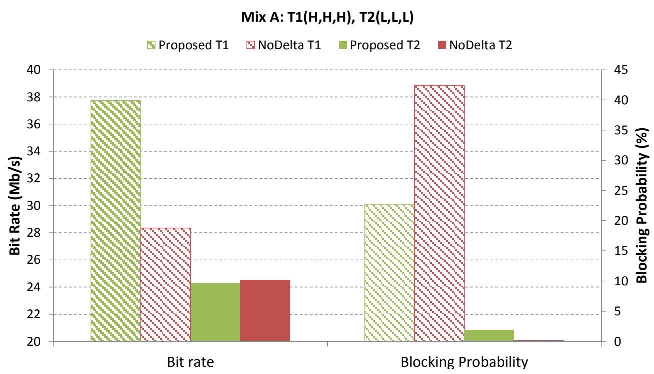

Fig. 6. Bit rate experienced by each tenant in each cell and in the total scenario with traffic mix B.

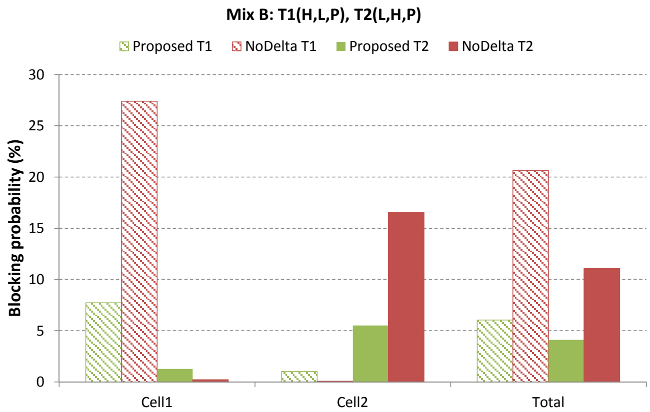

Fig. 3. Blocking probability experienced by each tenant in each cell and in the total scenario with traffic mix B.

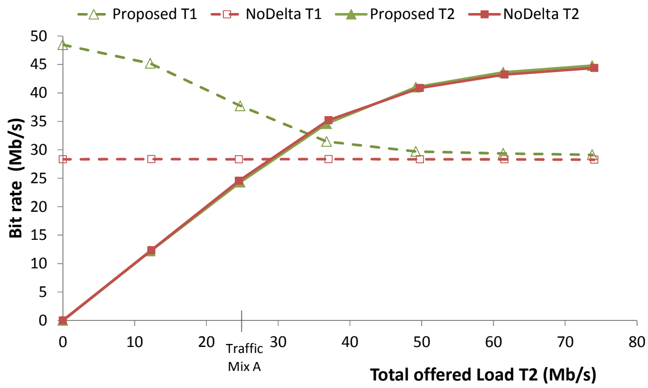

Fig. 4. Aggregated bit rate experienced by each tenant as a function of the total offered load of T2.

the target of ensuring an efficient use of the radio resources by exploiting traffic multiplexing principles at both intra-cell and multi-cell level. For this purpose, 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 radio resources for accepting the new bearer. In turn, the later check controls the amount of bearers that are admitted for each tenant in accordance with the agreed SLA terms. This check includes a capacity share shift that is dynamically modified in order to adapt to traffic heterogeneities, facilitating on the one hand that extra capacity left by one tenant in one cell can be used by other tenants and, on the other hand, that the capacity share is adequately balanced from a multi-cell perspective.

The paper has performed a simulation-based analysis to assess the behavior of the algorithm under different traffic loads of each tenant in each cell. Results have demonstrated that bit rate improvements of up to 106% can be obtained with respect to the case where the proposed capacity share shift is not used. Similarly, substantial blocking probability reductions (e.g. from 11% down to 4%) have been observed in situations where the traffic of the tenant is not homogeneous across the different cells.

Based on the promising behavior of the proposed admission control algorithm, different future research directions are envisaged. First, the possibility of combining the algorithm with other approaches that perform the split of radio resources among tenants at other levels (e.g. at packet scheduling) needs to be explored. Second, the operation of the algorithm needs to be analyzed in cases where tenants exhibit different types of requirements (e.g. one tenant requiring a high level of service availability and very low blocking probability). In such a case, a different setting of the algorithm parameters on a per-tenant basis may be required. Finally, the practical implementation of the proposed algorithm should be analyzed considering the applicability of software defined networking concepts in the light of advancing towards the abstraction and programmability of the multi-tenant admission control function in a multi-cell scenario.

APPENDIX: DEMONSTRATION OF $\Delta C_B(s,n)$

Let assume that the average RB utilisation of the *s*-th tenant in cell $n' \neq n$ at a certain point of time is $\rho_G(s,n')/\rho(n')$. In order to achieve an average RB utilisation across all the cells equal to C(s), the fraction of RBs used by the *s*-th tenant in the *n*-th cell should be $\rho_G(s,n)/\rho(n) = C(s) + \Delta C_b(s,n)$ and the following relationship should be fulfilled:

$$\frac{1}{N}\sum_{n=1}^{N}\frac{\rho_G(s,n)}{\rho(n)} = C(s)$$
$$\frac{1}{N}\left(C(s) + \Delta C_b(s,n) + \sum_{\substack{n'=1\\ n'\neq n}}^{N}\frac{\rho_G(s,n')}{\rho(n')}\right) = C(s) \tag{9}$$

Expression (8) can be obtained from (9) in a straightforward way.

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