Multi-tenant Mobility Control in Small Cells as a Service

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

***Abstract*—Small Cell as a Service (SCaaS) is envisaged as a solution to facilitate the provisioning of shared radio access capacity to mobile operators in areas where dedicated per-operator deployments may be impractical, typically highly densified scenarios such as stadiums, malls, office buildings, etc. In this context, this paper firstly establishes a reference framework for SCaaS provisioning from the Radio Access Network (RAN) perspective, including management architecture and functionalities as well as Service Level Agreement aspects impacting on the way that the shared RAN is deployed and operated. Then, the implications of multi-tenancy on mobility control are analysed in order to delineate the impact on Radio Resource Management (RRM) and Self-Organizing Network (SON) functionalities as a result of the emergence of this novel business model.**

Keywords—Small cell; SCaaS; multi-tenancy; RAN sharing; Mobility control; SON

I. INTRODUCTION

With the exponential growth of the data demand and the fact that data traffic is usually presented in hotspots, new cellular deployments are necessary to fulfil the needs in coverage, capacity and high data rates. The deployment of small cells (SCs) has been considered as a means to effectively increase the available capacity in high traffic areas as well as locations with poor coverage conditions from outdoor macrocells. In this context, the so-called Small Cells as a Service (SCaaS) model is identified as an adequate solution [1] to facilitate a third-party provisioning of radio access capacity to Mobile Network Operators (MNOs) in localised areas with capacity or coverage issues.

The SCaaS model is regarded as a neutral host or wholesale model in which a company (i.e. a SCaaS provider) deploys and operates a number of small cells that can be utilised by MNOs and/or Mobile Virtual Network Operators (MVNOs) to offer services to their own customers. In this way, the SCaaS delivered capacity can supplement existing MNO's networks and increase capacity in traffic hot spots that experience peaky demand such as stadiums, etc. [2][3] as well as improve in-building coverage in e.g. office buildings, big box stores, malls, etc.[4]. The resulting densified network could serve multiple operators in scenarios when dedicated operator deployments are impractical. In that case, the multi-tenancy concept allows that the provisioned small cells are shared between multiple operators, denoted as "tenants", according to specific agreements between the SCaaS provider and each involved tenant. In [5] a market analysis is presented to support the importance of introducing multi-operator capabilities in SC networks, discussing the benefits from the perspective of different players (i.e. MNOs, non-mobile service providers, enterprises and site owners). The neutral host model inherent to SCaaS is regarded as an interesting approach to stimulate multi-operator SCs, as this will create fewer conflicts of interest for MNOs than other approaches in which shared cells are owned by one of the MNOs. The study emphasizes the importance that an MNO keeps control on their portion of the shared resources, as this will facilitate differentiation between MNOs.

3GPP specifications have already added some support for Radio Access Network (RAN) sharing [6] that can be used for implementing SCaaS. Two main architectures are identified, namely Multi-Operator Core Network (MOCN), where the shared RAN is directly connected to each of the multiple operator's core networks, and Gateway Core Network (GWCN), where a shared core network is deployed so that the interconnection of the multiple operator's core networks is done at core network level, without direct interfaces with the shared RAN. The focus of this paper is on the MOCN case, in which the shared RAN is constituted by the SCs of the SCaaS provider.

The SCaaS provisioning under multi-tenancy is envisaged as a relevant component to fulfil the expected requirements of future 5G networks in highly densified scenarios. Besides, an increase in the degree of automation to carry out the different network planning, management and operation procedures - through Self-Organizing Network (SON) functions [7]- is expected to constitute a key tool in future multi-tenant SCaaS deployments.

Different works in the wider area of RAN sharing have dealt with the virtualization of radio resources as a means to enable the multi-tenancy concept by isolating the resources assigned to each operator [8][9][10][11]. In [12] the problem of radio resource sharing among multiple operators is addressed from a more fundamental, algorithmic perspective. In [13] the coordination of several cells to create an abstraction of radio resources so that multiple tenants can be served is proposed.

Regarding the application of SON functionalities in a multi-tenant scenario, very few works can be found in the literature to the authors' best knowledge. Only [14] has addressed the problem of making multi-operator SON decisions by applying two-tier voting mechanisms, considering that a change in a network parameter may be positive for one operator but influence negatively on another operator's performance.

This paper intends to contribute to fill this gap by analysing the implications of multi-tenancy on the Radio Resource Management (RRM) and SON functions that are related with mobility control in the shared RAN. The main motivation behind is that, despite mobility control is a fundamental functionality to ensure a seamless experience to the User Equipments (UEs) of the different operators when moving across the cells of the shared RAN and when entering and leaving the shared infrastructure, no previous works in the literature have addressed this issue yet. In this context, this paper firstly establishes in Section II a reference framework for SCaaS provisioning from the RAN perspective, including management architecture and functionalities as well as Service Level Agreement (SLA) aspects between the SCaaS provider and the tenant. Then, the paper analyses in Section III the implications of multi-tenancy on mobility control in order to delineate the impact on RRM and SON functionalities as a result of the emergence of this novel business model. Finally, Section IV summarises conclusions and identifies future work.

II. Reference Architecture for SCaaS Provisioning

The SCaaS provider is in charge to acquire, deploy and operate the needed infrastructure to provide a wholesale RAN service to the tenants. Basically, this infrastructure will consist of a number of SCs and the corresponding SC network functions such as gateways and management systems [15].

A. Interconnection and network management aspects

Fig. 1 reflects the reference architecture considered for SCaaS provision. The architecture is based on the current 3GPP framework for network management in RAN sharing scenarios [16][17][18]. Assuming Long-Term Evolution (LTE) technology as the contextual framework, the interconnection of the SCs of the SCaaS provider to the Evolved Packet Core (EPC) of the tenant is done through the S1 interface, delivering both data (e.g., transfer of end-users traffic) and control (e.g., activation of radio bearers) plane functions. Using current 3GPP principles [16], the support of MOCN at the small cell can be provided using the S1-flex mechanism that allows connecting one small cell to multiple EPC nodes (e.g. belonging to different tenants).

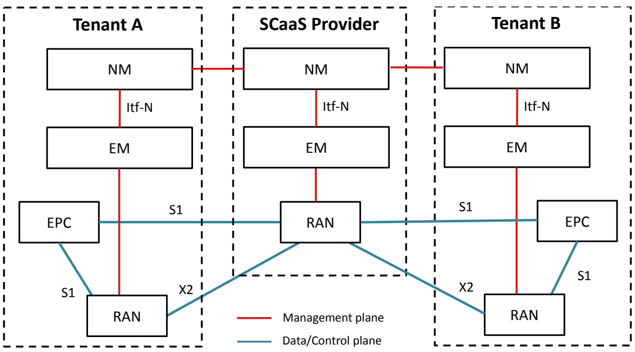

Fig. 1 Reference architecture for SCaaS provision

The tenant can have its own RAN infrastructure (e.g. in case of an MNO that uses SCaaS to complement the coverage/capacity of its own macrocells in certain areas) or not (e.g. in case of a MVNO or a service provider). In the former case, in addition to S1, the SCaaS provider's SCs can be connected with the RAN of the tenant through the X2 interfaces. The X2 interface contains a data plane for optimised handovers. Moreover, the X2 interface contains a control plane that allows neighbour cells to exchange different types of information (e.g. load, interference, handover information, trace information, information to support self-optimisation, etc.) for coordination purposes and supports procedures/messages for parameter negotiation (e.g. to request handover parameter changes, etc.) [19].

From the network management perspective, Fig. 1 depicts the central components on both the tenant and SCaaS provider sides that could be impacted to different extent depending on the SCaaS provisioning model. Based on the 3GPP network management model [17], the involved network management components would be:

- Element Managers (EMs): EM provides a package of end-user functions for management of a set of closely related types of Network Elements (NE). In the case of the SCaaS provider, the NEs are the SCs. Interfaces between EM and NE are typically proprietary, even if they might follow the structure and basic functionality of widely adopted standards such as the TR-069 protocol by the Broadband Forum. Usually, the vendor of a given NE is the one that provides the EM for that NE.
- Network Manager (NM): NM provides a package of end-user functions with the responsibility for the management of a network, mainly as supported by underlying EM(s) but it may also involve direct access to the NEs. A standardised interface between NM and EM has been defined by 3GPP (i.e. itf-N) to facilitate an ecosystem of multi-vendor NM/EM systems.

As illustrated in Fig. 1, the connectivity between the management systems of the tenants and the SCaaS provider is done at the level of the NM, in line with the current 3GPP network management architecture [18].

B. SON functions and architecture

SON refers to a set of features and capabilities for automating the operation of a network so that operating costs can be reduced and human errors minimised [7]. With the introduction of SON features, classical manual planning, deployment, optimization and maintenance activities of the network can be replaced and/or supported by more autonomous and automated processes, making network operations simpler and faster. SON functions can be organized around the following main categories:

- Self-planning: Automatization of the process of deciding the need to roll out new network nodes in specific areas, identifying the adequate configurations and settings of these nodes, as well as proposing capacity extensions for already deployed nodes (e.g. by increasing channel bandwidths and/or adding new component carriers).
- Self-optimization: Once the network is in operational state, the self-optimization includes the set of processes intended to improve or maintain the network performance in terms of coverage, capacity and service quality by tuning the different network settings. Examples of functions include Mobility Load Balancing (MLB), Mobility Robustness Optimisation (MRO), Automated Neighbour Relation (ANR), Coverage and Capacity Optimization, optimization of admission control, optimization of packet scheduling, intercell interference coordination and energy saving [7].
- Self-healing: Automation of the processes related to fault management (i.e., fault detection, diagnosis, compensation and correction), usually associated to hardware and/or

software problems, in order to keep the network operational while awaiting a more permanent solution to fix it and/or prevent disruptive problems from arising. Examples of self-healing functions include Cell Outage Detection and Cell Outage Compensation [7].

SON functions might automatically tune global operational settings of the SC (e.g., maximum transmit power, channel bandwidth, electrical antenna tilt) as well as specific parameters corresponding to RRM functions (e.g., admission control threshold, handover offsets, etc.).

Regarding the architectural models for implementing the SON functions, the following possibilities are distinguished (see [20][21]):

- Centralized SON (cSON): Solution where the SON algorithms are executed at the Network Management level (NM-Centralized SON) or at the Element Management level (EM-Centralized SON).
- Distributed SON (dSON): Solution where the SON algorithms are executed at the NE level (i.e. autonomously within a single SC or in a distributed manner among several SCs).
- Hybrid SON: It combines cSON and dSON, in such a way that part of the SON functionalities are distributed and reside at the SC while others are centralized and reside at the EM and/or the NM. This is illustrated in Fig. 2. In this case, the cSON functions can be used to provide guidelines and parameters to the distributed SON functions based on information retrieved from them in terms of e.g. performance measurements.

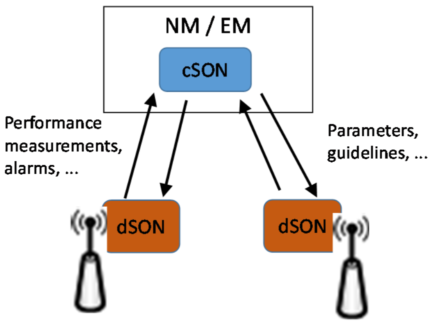

Fig. 2 Hybrid SON model.

In the above context, while aspects such as SON functionalities, architectures, algorithmic solutions, etc. are quite well established for 3G/4G through publications (e.g.[22]-[27]) research projects (e.g., FP7-SOCRATES [28], FP7-SEMAFOUR [29]) etc., the diverse fora where SON is being discussed, developed and standardised (e.g., 3GPP, NGNM, Small Cell Forum) have not covered to date in any public document the implications of multi-tenancy.

C. *Service Level Agreement between the SCaaS provider and the tenant*

Legal, financial, technical and operational aspects for the implementation of a SCaaS model between a SCaaS provider and a tenant will be captured through a specific Service Level Agreement (SLA), as commonly done to formalise contractual agreements between service providers and customers. A SLA is a negotiated agreement that records a common understanding about the service and/or service behaviour offered by the SCaaS provider, together with the measurable target values characterizing the level of the offered service.

Essentially, the SCaaS provider delivers a RAN service to the tenant so that tenant's customers (e.g. mobile subscribers) can get connected through the SCaaS provider's SCs to the tenant's core network.

The service scope includes the specification of the geographical scope (i.e., the area where the service is provided - e.g. an enterprise, a stadium, a mall, etc. with some associated coverage metrics) and the temporal scope (i.e., the time when the service has to be provided - starting time, end time, periodicities, etc.).

Regarding the way how the RAN service provides a certain capacity to the tenant's subscribers, the specification of the capacity could be done in terms of aggregated global values (e.g. total aggregated bit rate in Mb/s for all the customers of a tenant), but also more specific conditions can be established on the number and characteristics of the E-UTRAN Radio Access Bearers (E-RABs) that can be simultaneously activated. The capacity specification can be further detailed including:

- Capacity conformance: It further specifies the provisioned capacity in time and space. Constraints can be established at spatial level (i.e., maximum Mb/s over a certain area), temporal level (i.e., maximum Mb/s that can be offered within a certain time window) as well as user level (i.e., per UE Aggregate Maximum Bit Rate).
- Excess capacity treatment: It specifies how the tenant's excess capacity demand not meeting the capacity conformance will be treated.
- Guarantees: The provisioned capacity may have associated guarantees, non-guarantees or partial guarantees (i.e., part of the capacity is guaranteed and part is non-guaranteed). Guarantees are formalised in terms of E-RAB attributes (e.g., QoS parameters such as QoS Class Identifier [QCI] and Allocation and Retention Priority [ARP]) and Key Performance Indicators (KPIs) targets (e.g., E-RAB accessibility, E-RAB retainability, E-RAB Quality of Service parameters).
- Dynamic capacity negotiation. The SCaaS provider can offer by automatic means spare capacity as on-demand capacity to its tenants. Specific mechanisms for querying, requesting and granting capacity based on certain policies should be in place between the SCaaS provider and tenants.

Besides, service level management aspects can be specified, such as monitoring capabilities (KPIs and alarms that the SCaaS provider delivers to the tenant), service availability (percentage of the time that the service should be available to the tenant), response time to service related incidents (usually, incidents will be classified according to a certain priority level and different time frames will be associated to each priority), changes in the SLA (specifying the procedure to request changes in the SLA and the conditions related to these changes such as e.g. time to response) and accounting information (the SCaaS provider needs to collect events supporting the accounting of resource usage by the UEs of a tenant and possibly deliver these events to the tenant).

From the SCaaS provider perspective, the service specification has to be materialised in a way that results profitable (i.e., there are sufficient economic incentives to undertake the challenge to deploy and operate the SCaaS infrastructure) and implementable (i.e., the network incorporates mechanisms that translate the SLA in a specific network configuration). From the tenant's perspective, the service specification has to be materialised in a way that results profitable (i.e., there are sufficient economic incentives to contract the SCaaS instead of deploying and operating its own infrastructure) and traceable (i.e., the network incorporates mechanisms that enable the verification of the SLA).

Clearly, pricing establishes where supply (the SCaaS provider) and demand (the tenant) can meet for certain SLA terms acceptable from both sides. In this respect, for example it can be considered that higher prices can be expected for:

- Specific geographical scopes (i.e., venues where only one or few tenants can be expected)
- Narrow temporal scopes (i.e., tenant that intends to contract capacity only at very specific moments).
- Low volume of contracted capacity.
- High guarantees levels into the provisioned capacity.
- High dynamicity in capacity negotiation.

III. Analysis of Multi-Tenancy Support in SON/RRM Functions for Mobility Control

For the analysis of the implication of multi-tenancy in mobility control, let's consider the scenario depicted in Fig. 3. A SCaaS' RAN (e.g. small cells SA, SB, SC) provides service to a Tenant e.g., within a stadium. The Tenant is an MNO, with its own RAN around the stadium (e.g. cells TA, TB, TC). There is partial overlapping between the coverage of the SCaaS' RAN and Tenant's RAN. Mobility of UEs between cells of both RANs is supported in both ways (i.e. referred to as incoming traffic when going from the Tenant's RAN to the SCaaS's RAN and outgoing traffic in the opposite direction).

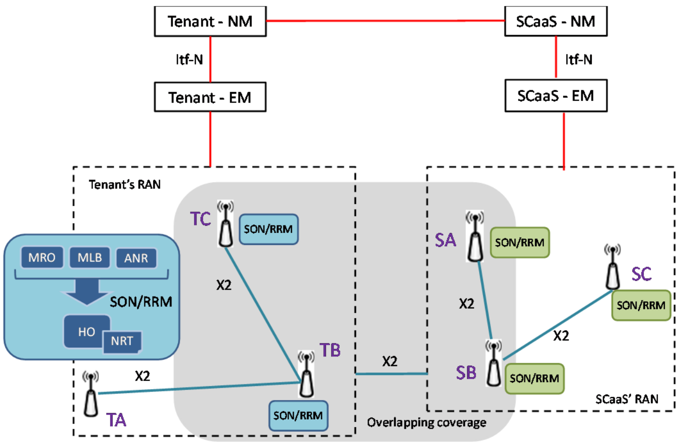

Fig. 3. Considered scenario for the analysis of multi-tenancy.

Mobility control of connected terminals is realised through the handover (HO) function, which is one of the central RRM functionalities. The RRM-HO function, executed at each SC, is used to determine the cell to which a given UE is connected to. Decisions made by the RRM-HO function are based on measurements that are compared through a set of parameters (e.g., thresholds, offsets). The RRM-HO function at a specific SC only considers as candidate cells those that are listed in the so-called Neighbour Relation Table (NRT) associated to that SC. Some parameters could be statically configured from NM/EM or dynamically adjusted at runtime by SON functions such as ANR, MRO and MLB. In a general case, the RRM-HO and SON functions implemented in the Tenant's RAN and in the SCaaS' RAN are likely to differ (e.g., different vendor's equipment in each RAN with vendor-specific implementations of RRM/SON functions) or be differently parameterised.

A. RRM-HO function

The HO function commonly considers the measurement reports provided by the UE including e.g., Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ) values for the serving and neighbour cells. Furthermore, the HO algorithm can also consider as an input the load level at neighbour cells. In this case, load information is provided by neighbour cells via X2 interface. A detailed list of HO parameters is found in [30]. They are associated to the detection of certain events used by the HO algorithm to trigger the execution of an HO (e.g. detecting that a neighbour cell becomes offset better than the serving cell, detecting that a neighbour cell becomes better than a threshold, etc.). For each event, tuneable parameters include offset values, hysteresis values, time to trigger, thresholds, etc.

Typically, within a RAN, all cells (from the same vendor) will implement the same HO function. However, by setting the HO parameters on a cell-by-cell basis, the behaviour of the HO function (e.g. the precise time that a HO decision is made) can be different in each cell.

In order to properly steer the connected UEs across the Tenant's RAN and the SCaaS' RAN, neighbourhood relationships shall be properly captured in the corresponding cells. For the example of Fig. 3, the NRT at TB should include SA and SB to enable an incoming handover to the SCaaS' RAN. Similarly, the NRT at SB should include TB and TC to enable handovers to the tenant's RAN.

As long as coverage overlapping and traffic steering strategies between the SCaaS' RAN and each of the tenants are likely to differ, the RRM-HO function shall be tenant-aware (i.e. the RRM-HO shall be able to associate E-RABs with tenants and enforce the tenant-specific policies). Furthermore, some of the parameters used by the RRM-HO function (e.g. offset values, hysteresis values) shall also be parametrised per tenant when pursing an optimised operation of the HO function. This latter aspect is analysed in the following from the perspective of the SON functions that impact on the adjustment and optimisation of the different parameters used by the RRM-HO function.

B. SON- Automated Neighbour Relation

The configuration of the NRT in each of the cells can be realised through the ANR SON function, avoiding the burden of human interactions between the Tenant and SCaaS provider to exchange information about the cells in close vicinity.

From the SCaaS perspective, each SC will maintain a single NRT list that includes neighbour SCs from the SCaaS provider and, in overlapping coverage areas, the cells of the different tenants.

The ANR function relies on different procedures to find new NRs, such as UE-assisted neighbour discovery that uses UE measurements to identify new NRs, network listen measurements done by the eNodeB (eNB), and X2 assisted network discovery (e.g., when a neighbour eNB attempts an X2 connection setup with another cell, it is automatically added in the NRT of this cell) [31].

Regarding UE measurements, a UE receives instructions about how to configure the measurement process. The UE will be indicated what frequencies to measure, possibly specifying as well the list of cells to measure in a given frequency (i.e., the cells that are defined in the NRT). This is indicated through dedicated RRC signalling for UEs in connected mode.

Similarly, the UE will be instructed about the reporting criterion (i.e. the event that triggers the UE to send a report). Example events can be detecting that a neighbour cell becomes offset better than the serving cell, detecting that a neighbour cell becomes better than a threshold, etc.

Given that the SCaaS provider and a Tenant will usually operate at different frequencies, the automated detection of neighbour cells from different RANs requires inter-frequency measurements, for which the UEs must be properly instructed while staying in the overlapping coverage area between the Tenant and the SCaaS' RAN. Then, on the one hand, UEs perform measurements at the frequency of the Tenant while they are connected to the SCaaS' RAN. On the other hand, UEs perform measurements at the frequency of the SCaaS while they are connected to the Tenant's RAN. For the example of Fig. 3, TB should configure the UEs to measure on the frequency that the SCaaS is operating. In this way, UEs will be able to detect SA and SB, report measurements from these cells and the ANR at TB will update the NRT at TB accordingly. Once this is accomplished, HO from TB to SA or SB will be possible. Equivalently, SB should configure the UEs depending on the Tenant that they belong to, so that each UE will measure on the frequency of its Tenant. In this way, the UEs of the Tenant illustrated in Fig. 3 will be able to detect TB and TC, so that the NRT at SB is updated accordingly. Therefore, measurement configuration of the UEs will be different depending on the tenant that they belong to.

C. *SON-Mobility Robustness Optimisation*

MRO function will automatically set HO parameters, aiming at avoiding different HO problems, such as connection failures due to mobility (too late handover, too early handover, handover to wrong cell), unnecessary HOs and ping pongs.

In general, optimised HO parameters will be different at each SC because each SC exhibits a particular situation with respect to its neighbours. This will be particularly relevant to be considered for SCs deployed in the overlapping coverage areas between the SCaaS and Tenant's RAN. In this case, different coverage footprints from different tenants will lead to different types of HO problems experienced by the UEs of each tenant. Therefore, the MRO function at the SCaaS' RAN shall exploit HO-related performance measurements per tenant which can be useful in detecting the likely different HO-related issues arisen between the SCaaS's cells and the cells of different tenants. Consequently, tenant-specific HO parameter settings shall be supported to achieve optimised HO operation for all tenants.

For example, let consider the situation illustrated in Fig. 4, for a UE heading from the SC to a tenant's cell. The overlapping area between the cell of Tenant B and the SC is very small, while there exists a large overlapping between the cell of Tenant A and the SC. In such situation, one could expect high call dropping rate (CDR) for UEs from Tenant B due to too late handovers. The degradation of the CDR for Tenant B in that specific cell should lead the MRO at the SC to conclude that the HO offsets should be reduced (so that, as soon as the Tenant B's cell is detected, the HO is quickly executed). Regarding Tenant A, if a low HO offset were defined for its UEs, these UEs would be handed-over to the Tenant A's RAN at a very early stage. Then, depending on the HO algorithm and its parametrisation at the Tenant A's RAN, a ping-pong effect might arise and UEs could be handed-over again to the SCaaS. In such case, the observation of a relevant ping-pong effect should lead the MRO to conclude that the HO offset should be increased, so that UEs from Tenant A wouldn't be handed-over until a much stronger signal from Tenant A's cell was received.

Regarding intra-SCaaS handovers (i.e., HO between two SCs of the SCaaS' RAN), if the HO parameters were not sufficiently optimised and HO problems occurred, this would affect in the same way to all UEs, regardless of the tenant they are associated to. Therefore, the MRO function would be in charge of tuning the setting of HO parameters in the SC, without making distinctions among tenants.

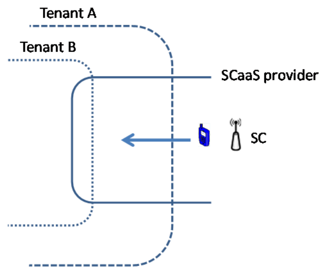

Fig. 4 Impact of different overlapping between the tenants' cells and the small cells on the MRO function.

D. *SON- Mobility Load Balancing*

The objective of MLB is to distribute cell load evenly among cells or to transfer part of the traffic from congested cells to less loaded cells. MLB relies on exchanging cell specific load information between neighbour cells over the X2 interface (e.g. resource block usage separately for Guaranteed Bit Rate and non-Guaranteed Bit Rate E-RABs, available capacity that a cell can accept, etc.).

MLB function is a hybrid SON function in which the MLB decisions are made at each SC according to policies controlled by the EM and/or NM [30]. MLB is supported by different procedures for transferring load between cells. For UEs in connected mode, MLB relies on the handover process, either by forcing HOs of specific UEs to a neighbour cell or by adjusting the HO parameters of a neighbour cell to facilitate that more UEs make HOs towards this cell. In this respect, the X2 interface includes a procedure to negotiate the changes in HO parameters between two neighbour cells, in order to facilitate a coordinated operation between them.

For UEs in idle mode, MLB relies on the modification of the cell reselection parameters (i.e. cell reselection offsets and cell reselection priorities) of each neighbour cell that are broadcast in the System Information Block (SIB) messages (e.g. SIB Type 4 for intra-frequency neighbours and SIB Type 5 for inter-frequency neighbours). When an idle mode UE detects a neighbour cell, it will use these parameters together with the received power to decide if it camps on this cell. Therefore, by adjusting these parameters, the MLB function can favour that more or less idle UEs camp in the different cells. However, in this case it is not possible to broadcast multiple parameters on a per tenant basis for a neighbour cell.

In a typical SCaaS use case, such as a stadium, high correlation among the traffic profiles (in time and space) associated to each tenant can be expected. Clearly, high load levels will be observed during e.g., a football match all over the stadium and for all the different tenants simultaneously. However, some cases and situations (e.g., supporters from the visitor team are grouped in a certain area of the stadium, youth local supporters are usually grouped right behind the goalkeeper) as well as different market segments associated to the different competing operators acting as tenants in the stadium (e.g., a low cost MNO will usually have youth customers, who in turn may stay in the areas of the stadium where attendees are standing) may lead to differences in the load levels associated to the different tenants in the different cells. Therefore, the analysis of MLB strategies in multi-tenant SCaaS scenarios requires further attention, since the load levels from the different tenants in the different cells needs to be considered. At this point, it is worth remarking that X2 interfaces should be able to exchange load information on a per tenant basis.

To illustrate how the MLB actions can vary depending on the tenants' load in different SCs, let consider the example shown in Fig. 5 with Tenant A and B. Assuming the planned load level for each tenant, as shown in the left side of the figure, let consider three different cases for the actual load distribution in small cell SC1, denoted as I, II, III.

Case I corresponds to an overload situation in which the aggregate load of both tenants in SC1 exceeds the maximum acceptable level in the cell (i.e., the overload situation is causing performance degradation). This overload situation is due to Tenant A, whose load substantially exceeds its planned level. In order to handle this situation, RRM Congestion Control techniques can reduce the load by e.g. reducing the bit rate of best-effort traffic. Additionally, assuming that a neighbour small cell SC2 has some capacity available, the MLB can transfer part of the load of SC1 to SC2 through the adjustment of HO parameters. In this case, only the load of UEs located in the overlapping coverage area between the two cells can be transferred to SC2.

Given that the transfer of a UE from SC1 to SC2 may cause some performance degradation (e.g., the UE is transferred to SC2 even if the received signal from SC2 is worse than the signal from SC1), the adjusted parameters favouring the HO should initially be applied to UEs from Tenant A, since it is the tenant originating congestion.

The fraction of the load that can potentially be transferred to a neighbour cell depends on the UEs spatial distribution within the cell. In principle, UEs in SC1 that are in close vicinity to SC2 will be handed-over. By increasing the offset, UEs that are further away from SC2 can also be transferred, at the expense of a certain degradation in performance (e.g., lower peak bit rate), as Fig. 6 illustrates.

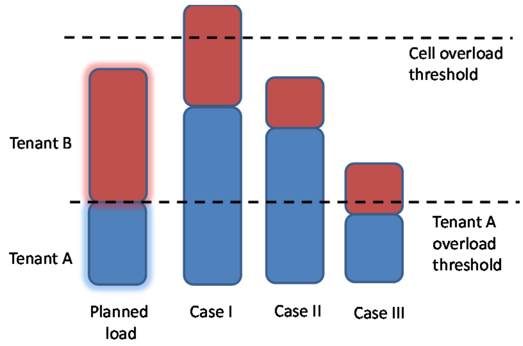

Fig. 5 Illustration of MLB with different loads per tenant.

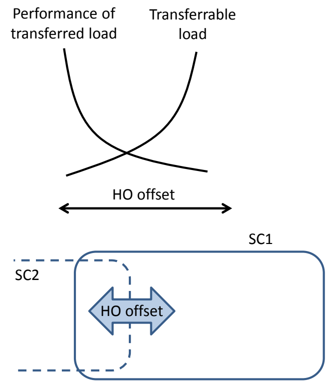

Fig. 6 Illustration of trade-off between transferrable load and performance.

In Case II of Fig. 5, the load of Tenant A in SC1 exceeds its planned level, but this does not generate overload in the cell. In this case, MLB actions to transfer some of the excess load of Tenant A to SC2 would be required if the excess of load of Tenant A causes some degradation in the performance of Tenant B.

Finally, in Case III, neither the load of Tenant A nor the load of Tenant B exceeds the planned level in SC1. Therefore, MLB actions are not strictly needed in this situation. Still, in case that the load in SC2 were very low, transferring part of the load to this cell could be of interest if, by doing so, the performance observed by the UEs in SC1 could be improved.

In the case that load balancing involves two neighbour cells from different RANs (e.g., SB and TB in Fig. 3) the availability of X2 interface between the SCs of the SCaaS provider and the cells of the tenant facilitates the coordination for MLB purposes. The X2 enables that an SC receives information about the available capacity that each neighbour cell can accept. Computation of the load per tenant should be supported and exchanged accordingly. Then, the MLB function at the SC can make decisions accordingly, thus minimising the risk that a HO is not accepted at a neighbour cell, or that a ping pong occurs if the target cell of the tenant decides to make a HO back to the SC. Otherwise, in the absence of such load information, the SC can only initiate blind MLB actions to arbitrary neighbour cells. Like in the previous example of Fig.

6, MLB decisions will depend on how the UEs of each tenant are spatially distributed and on the overlapping coverage areas between the SC and cells of the different tenants.

IV. Conclusions and Future Work

Small Cells as a Service is a solution that facilitates third-party provisioning of shared RAN capacity in scenarios where per-operator deployments become impractical. In this context, this paper has raised the relevance and analysed the implications of multi-tenancy on the RRM and SON functions that support mobility control.

In particular, the key role of ANR function has been analysed and the requirement to configure the measurements of each UE depending on the tenant that they belong to has been addressed so that the neighbourhood relations are properly capture at both the Tenant's RAN and SCaaS provider's RAN.

Regarding the MRO function, a distinction has to be made depending on the involved neighbour cells. For HOs involving the Tenant's RAN and SCaaS provider's RAN, the different coverage footprints of different tenants will lead to different HO problems experienced by each tenant and, consequently, HO parameters have to be set differently for each tenant. For intra-SCaaS HOs, the MRO function should not make distinctions among tenants.

Regarding the MLB function, the paper has shown that MLB actions in a cell should be different for each tenant, taking into consideration the different load distribution of each tenant in each cell and the spatial distribution of the UEs within the cell. Besides, it has been highlighted that different criteria for MLB could be considered in a multi-tenant context.

Moving forward from SON functional analysis to SON realisation, the multi-tenant SCaaS scenario opens various possibilities in the way that SON/RRM functions are implemented, which require further and detailed analysis that belongs to our future work. For example, for tenant-specific functions, the SCaaS provider may expose to the tenant some level of control over the SON/RRM functions. Besides, given that there are SON/RRM functions running on both the tenant's and SCaaS' RAN, establishing some level of interworking can enhance a harmonised operation. On the other side, the exploitation of Software Defined Network (SDN) and Network Function Virtualization (NFV) technologies can substantially influence the way that SON/RRM solutions are brought to the market and, therefore, deserves attention.

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