Multi-operator Fairness in Transparent RAN Sharing

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Abstract*—Radio access network (RAN) sharing attracts much attention from telecom operators. However, current mechanisms applied to RAN sharing do not consider fairness among operators such that the RAN is not fairly shared, and either under- or over-utilized. Fairness cannot be guaranteed among operators because resources are distributed on a first-come-first-serve basis. "Soft-partition with Blocking and Dropping" (SBD)" is proposed to offer inter-operator fairness based on a "soft-partition" concept. Subscribers to an operator may overuse the predefined service-level-agreement (SLA) when the shared RAN is under-utilized, but become blocked or even dropped when over-utilized. According to our simulation results, SBD maintains inter-operator fairness at 0.997, even better than hard-partition at 0.98 and much better than no-partition at 0.6. Meanwhile, it retains high utilization of shared RAN at 98%. SBD reduces blocking rate from 35% of hard partition to almost 0%, while controlling dropping rate at 5%.

***Keywords*—radio access networks; RAN sharing; soft partition; fairness; utilization; blocking rate; dropping rate**

I. INTRODUCTION

RAN sharing is an inevitable trend for telecom operators for addressing upcoming data surges with minimum investment in CAPEX and OPEX [1][2][3]. Transparent RAN sharing, which means RAN sharing achieved through an intermediate mechanism with least configuration to BSs and core networks, is especially attractive to operators for the following reasons: 1). It is easier and more cost effective for operators to set up RAN sharing with existing infrastructure; 2). RAN sharing can be managed by a third-party operator to assure the independence and fairness among sharing operators [4][5]. To achieve transparent RAN sharing, RAN Proxy (RANP) was proposed in our earlier work [6] with comprehensive emulation results.

To make RAN sharing more practicable, the fairness and efficiency in allocating resource among sharing operators need further consideration. RAN resource is limited, especially the capacity of a base station (BS) in terms of number of served user equipments (UEs) and available bandwidth. For example, in LTE the RCC-connected [7] users for a macro cell is more than 1000, and the number may decrease to 50-100 for a typical 5G small cell [8][9] considering its smaller coverage. As for bandwidth, it may be limited by the bottleneck in the entire backhaul network. Although LTE provides sophisticated mechanisms for an operator to coordinate UEs and their bandwidth within its own network, the coordination among operators is still immature. On one hand, if there is no coordination, and any new UE is allowed to attach regardless of its operator until the shared BS reaches its capacity limit, very large operators with large subscriber bases may consume most resources, and the UEs of smaller operators may be of unacceptable quality of experience (QoE). On the other hand, if the resource is reserved for each operator according to predefined inter-operator agreement, the QoE of UEs from each operator is guaranteed, at the cost of reduced BS utilization if any operator doesn't fully use the resource reserved for it, which causes reduced traffic as well as revenue for the third party providing the RAN sharing service [2]. How a trade-off between the conflicting requirements becomes the key to the success of RAN sharing.

In this paper, we propose a "Soft-partition with Blocking and Dropping" (SBD) to control the fairness among different operators based on "Soft-partition" concept, which means that telecom operators can use resource more than what is agreed among operators whenever there is still available resource. However, once the network is fully loaded, the overusing operator will return the overused resource according to a predefined agreement. In this way, the utilization of RAN resources can be increased while the requirements of each operator can be satisfied. In addition, the blocking and dropping rate for each operator can be maintained in at an acceptable level.

The rest of this work is organized as follows. Section II provides background and related works. In Section III the problem is formulated, followed by the detailed design of SBD mechanism in Section IV. Numerical results of SBD mechanism, including fairness among multiple operators, utilization of a shared BS and blocked/dropping rate of resource requests, are provided in Section V, followed by conclusions and future work in Section VI.

II. INTER-OPERATOR CONTROL: RELATED WORKS

Nokia [10] provides a solution for radio resource management in a roaming scenario among multiple operators in 3G networks. A Control-Plane-based Hard Partition is used to fix the resource in CN. Qualcomm [11] uses both Control-Plane and Data-Plane in its solution. In Data-Plane, a mechanism called "Erase Packet" detects which packet remains in the queue for the longest time and deletes it to release the radio resource when a BS runs out of resource. After resource re-organization Control-Plane can decide whether to accept a new request or not.

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The attributes of the above related works, including location in the network, either based on Control or Data Plane, on Soft or Hard partition, supporting UE and/or bearer admission control, are listed in Table 1, together with the proposed SBD mechanism. As can be seen in Table 1, only SBD applies soft partition for BS resource utilization.

III. PROBLEM FORMULATION

Inter-operator policy is the agreement among operators for resource coordination, which is subject to the constraint as

$$\sum_i^n p_i^{inter\_ue} = \sum_i^n p_i^{inter\_bw} = 1,$$

(1) where $P^{inter\_ue} = \{p_i^{inter\_ue}\}$ and $P^{inter\_bw} = \{p_i^{inter\_bw}\}$ describes the percentage of UEs and bandwidth resource allocated to i-th operator, respectively. Given BS^{limit_ue}, the maximum number of served UEs for a BS, the i-th operator's quota in number of served UEs is determined by the inter-operator policy and calculated as $p^{inter\_ue}{}_i * BS^{limit\_ue}$. Similarly, given BS^{limit_bw}, the maximum bandwidth of a BS, the i-th operator's quota in bandwidth usage is calculated as $p^{inter\_bw}{}_i * BS^{limit\_bw}$.

The Fairness in terms of number of served UEs and bandwidth usage is defined as

$$F^{ue} = \prod_i^n \frac{s_i^{ue}}{p_i^{inter\_ue} * BS^{limit\_ue}}, \quad (2)$$

and

$$F^{bw} = \prod_i^n \frac{s_i^{bw}}{p_i^{inter\_bw} * BS^{limit\_bw}}, \quad (3)$$

respectively, where s_i^{ue} and s_i^{bw} are the quantities of in-use UE and bandwidth of i-th operator. According to the definition, the more F^{ue} (or F^{bw}) approaches one, the more actual resource assignment is aligned to inter-operator policy, and fairer the system is considered.

The utilization of a shared BS in terms of number of served UEs and bandwidth usage is defined and constrained as

$$U^{ue} = \frac{1}{BS^{limit\_ue}} \sum_i^n s_i^{ue} * 100\% \le 1, \quad (4)$$

and

$$U^{bw} = \frac{1}{BS^{limit\_bw}} \sum_i^n s_i^{bw} * 100\% \le 1, \quad (5)$$

respectively, and can be used to evaluate the resource utilization efficiency of different methods.

As suggested by the name SBD, portion of the new resource requests will be blocked, while portion of the in-use resource will be dropped, and QoE of UEs will inevitably be affected. The impact can be evaluated by the blocking rate of UE Attach and the bandwidth request, which are defined as

$$R_i^{block\_ue} = \frac{Blocked\ UE\ Initial\ Attach\ Requests}{Total\ Requests} \times 100\%, \quad (6)$$

and

$$R_i^{block\_bw} = \frac{Blocked\ Bandwidth}{Total\ Bandwidth\ Requests} \times 100\%. \quad (7)$$

The impact is also evaluated by dropping rate of in-use UEs and bandwidth defined as

$$R_i^{drop\_ue} = \frac{Drop\ UE}{Total\ Requests} \times 100\%, \quad (8)$$

and

$$R_i^{drop\_bw} = \frac{Bandwirdth\ Release}{Total\ Bandwidth\ Requests} \times 100\%. \quad (9)$$

IV. PROPOSED BLOCKING AND DROPPING COORDINATOR

The proposed Soft-partition with Blocking and Dropping (SBD) is integrated with RANP as shown in Fig. 1. It provides a two-stage control on two types of fundamental resource in the shared BS. The first stage is UE admission control. After being triggered by a UE Initial Attach request, SBD decides to accept or block the request, or drop some in-service UE whose operator has overused its quota, i.e., predefined number of UEs. The second stage is bandwidth grant control. By listening to E-RAB messages [8], SBD detects E-RAB Request and E-RAB Modify messages and decides to accept or block bearers, or drop some existing bearers whose operator has overused its quota, i.e., predefined guaranteed bandwidth. More details are described in next two subsections.

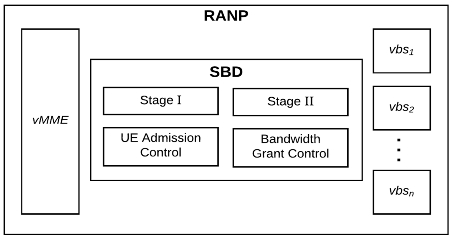


Fig. 1. Soft-partition with Blocking and Dropping Design

4.1 UE Admission control

Fig. 2 shows how UE admission control in SBD works in detail. When a packet arrives, SBD inspects and identifies its type. If it is an Initial Attach request, SBD further identifies the UE's operator, and then retrieves the current status of BS^{free_ue} (number of additional UEs that BS can serve) and $s^{ue}{}_i$ (number of in-service UEs of i-th operator). With this information, SBD decides to accept or block the Initial Attach request by checking if $s^{ue}{}_i$ is larger than the i-th operator's quota or not. If BS^{free_ue} is greater than zero, SBD accepts all the requests. However, if BS^{free_ue} equals zero, and $s^{ue}{}_i$ is larger than the i-th operator's quota, the new request will be blocked. On the other hand, if $s^{ue}{}_i$ is smaller than the i-th operator's quota, the UE dropping procedure (Fig. 3) starts so that other operators return the overused resource, and then SBD can accept the request. In the UE dropping procedure, a dropping list is maintained, and one candidate is selected each time. First, SBD looks for the operator which mostly overuses by

$$\max_i s^{ue}{}_i - (p^{inter\_ue}{}_i * BS^{limir\_ue}). \quad (10)$$

When the operator is identified, the idle UE will be selected. If there is no idle UE, the procedure continues to detect the status of UEs' bearers to find a UE without any extend dedicated bearer, i.e. with only a default bearer. If there is more than one UE,

Table 1. Comparison of related works

Papers / Patents	Location	Data / Control Plane	Hard / Soft Partition	UE Admission Control	Bearer Admission Control	Method
Roaming Based [10]	Core	CP	Hard	No	No	- CN Control
Asymmetric RAN Resource Allocation [11]	Base Station	CP/DP	Hard	No	Yes	- Blocking - Weighted Queuing - Erase Packet
SBD	RAN Proxy	CP	Soft	Yes	Yes	- Blocking and Dropping - Temporarily Over Quota

the one with longest connection time will be selected and added to the dropping list. If every UE has extended dedicated bearers, the one with least QCI priority will be selected and added to the dropping list.

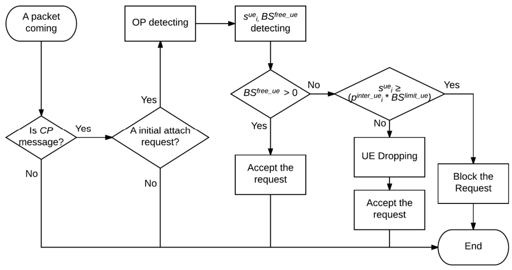


Fig. 2. UE Admission Control Procedure

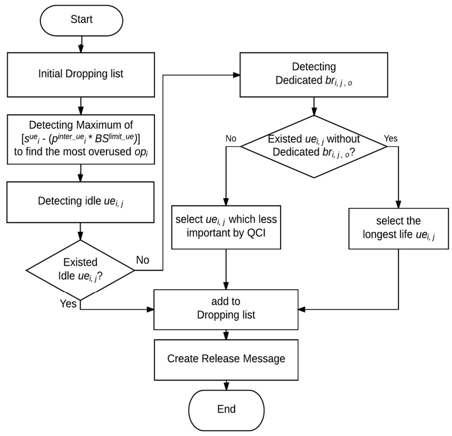


Fig. 3. UEs Dropping Procedure

4.2 Bandwidth Grant Control

The detail of bandwidth grant control in SBD is shown in Fig. 4. When a packet arrives, SBD inspects it to identify the operator it belongs and to ensure it is an E-RAB Request or an E-RAB Modify message. SBD then retrieves the current status of BS^{free_bw} (the bandwidth available to allocate) and $s^{bw}{}_i$ (bandwidth allocated to i-th operator), and decides to accept or block the E-RAB message. If BS^{free_ue} is greater than zero, SBD accepts all the requests. However, if BS^{free_ue} equals zero, and $s^{bw}{}_i$ larger than the i-th operator's quota, the new request will be blocked. On the other hand, if $s^{bw}{}_i$ is smaller than the i-th operator's quota, the bandwidth release procedure (Fig. 5) starts so that other operators return the overused resource, and then SBD can accept the request. In the Bandwidth Release procedure, another dropping list is maintained. Because of the varying size in different bandwidth requests, the procedure iterates until sufficient resource is released. First, SBD looks for the operator which mostly overuses by

$$\max_i s^{bw}{}_i - (p^{inter\_bw}{}_i * BS^{limit\_bw}). \quad (11)$$

When the operator is identified, the UEs with extend dedicated bearers will be detected. If every UE has extend dedicated bearers, the one with least QCI priority will be selected and added to the dropping list. Otherwise, if there are UEs with the same QCI, the one with the longest connection time will be selected for the dropping list. If there are no UEs with dedicated bearers, the procedure continues to detect the status of UEs' bearers to find the candidate with longest-time connection. Finally, the procedure calculates the released resource. If the released resource is not enough, the procedure resumes until sufficient resource has been returned to the corresponding operator.

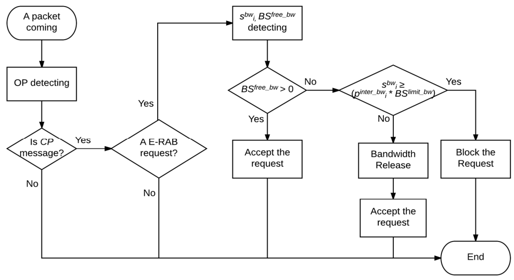


Fig. 4. Bandwidth Grant Control Procedure

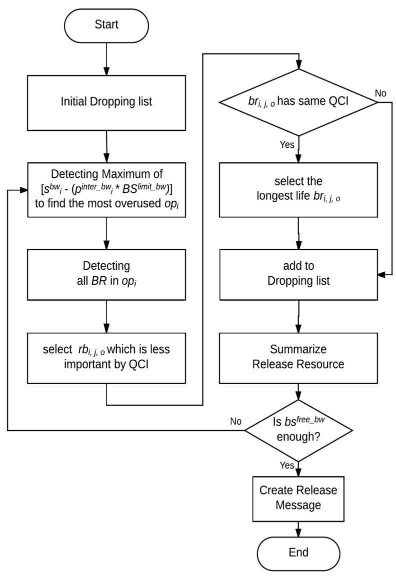


Fig. 5. Bandwidth Release Procedure

V. Numerical Results

5.1 Simulation Setup

For simplicity, there are only two operators in the simulations, and they agree to evenly share the resource as

$$p^{inter\_ue}_i = p^{inter\_bw}_i = 0.5, \text{ where i=1, 2.} \quad (12)$$

The maximum number of served UEs and quantity of allocated bandwidth for the shared BS is 100 UEs and 100 Mbps. According to (9), the quota for each operator is 50 UEs and 50 Mbps. The distribution of arriving UEs and bandwidth request from operator-*i* follow a Poisson distribution with arrival rate λ_i^{ue} and λ_i^{bw}, respectively. Full loading is assumed in the fairness evaluation experiment, while in utilization and blocking/dropping rate evaluation experiments, the system is not fully loaded. Every simulation condition simulates duration of 500 minutes, during which in-use resource is released (UE or bandwidth) whenever use time reaches 250 minutes.

5.2 Results

The performance of SBD can be evaluated in terms of 1) resource fairness among operators 2) total resource utilization of the shared BS and 3) the blocking and dropping rate of new resource requests and in-use resources, respectively. The evaluation results are described and discussed in the following subsections.

5.2.1 Fairness among Multiple Operators

Fairness is defined as in (2) and (3). When there is no control at all (i.e. no partition), UEs arriving first become attached until the shared BS reaches the maximum number of served UE, and so does bandwidth request. For hard partition mechanism, each operator can only use the resources allocated to it and overusing a resource is strictly forbidden. With SBD, on the other hand, operators are allowed to overuse a resource, as described in Section IV. In Fig. 6, we depict fairness in terms of (a) Number of UEs and (b) bandwidth usage, using the three mechanisms (without partition, hard partition, and SBD) with respect to varying UE arriving ratio which is subject to the constraint as $\sum_{i=1}^{n} \lambda_i{}^{ue} = 5$, and $\sum_{i=1}^{n} \lambda_i{}^{bw} = 5M$. Intuitively, when there is no partition, the operator with higher UE ratio takes up more resource, and the fairness decreases. As for hard partition and SBD, fairness is close to 1 (perfectly fair), and the small deviation is because the shared BS is not fully loaded. SBD is slightly better than hard partition because with SBD operators can put more UEs into the system in some occasions.

5.2.2 Utilization of Shared BS

The Utilization of a shared BS is defined as in (4) and (5). In Fig. ', we provide utilization of shared BS in terms of (a) Number of UEs and (b) bandwidth usage, using the two mechanisms (hard partition and SBD) with respect to varying UE arriving ratio which is subject to the constraint as $\sum_{i=1}^{n} \lambda_i{}^{ue} = 2$, and $\sum_{i=1}^{n} \lambda_i{}^{bw} = 1M$. In the experiment, λ_1^{ue} and λ_1^{bw} are fixed, and λ_2^{ue} and λ_2^{bw} are gradually decreased..

As shown in Fig. 7(a), the utilization of HP is closed to SBD when the arrival rate is identical, but it is only 70% when $\frac{\lambda_1^{ue}}{\lambda_2^{ue}} = 5$. Furthermore, the utilization of SBD is always around 95%. In Fig. 7(b), SBD improves from 63% to 98% in utilization of bandwidth usage when $\frac{\lambda_1^{bw}}{\lambda_2^{bw}} = 5$. The deviation of utilization from 100% is because the system is not kept in full-loading status all the time. In summary, SBD greatly improves the utilization of shared BS. If RANP is operated by a third-party operator, and the revenue is utilization-based, SBD has stronger economic benefits.

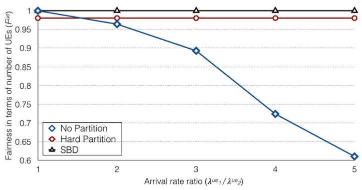
5.2.3 Blocking Rate and Dropping Rate

The Blocking rate and Dropping rate is defined as in (6)-(9). In Fig. 8, we provide blocking rate and dropping rate of *i*-th operator in terms of (a) Number of UEs and (b) bandwidth usage, using the two mechanisms (hard partition and SBD) with respect to varying UE arriving ratio subject to the constraints as $\sum_{i=1}^{n} \lambda_i{}^{ue} = 2$, and $\sum_{i=1}^{n} \lambda_i{}^{bw} = 1M$. In the experiment, λ_1^{ue} and λ_1^{bw} are fixed, and λ_2^{ue} and λ_2^{bw} are gradually decreased. This means the resources for Number of UEs and bandwidth of operator 2 can be under-utilized because of decreasing usage. Therefore, as can be seen that in Fig. 8 (a), $R_1^{block\_ue}$ is reduced from 35% of HP to almost 0% of SBD because of the UE dropping feature of SBD. For operator 2, $R_2^{block\_ue}$ under HP and SBD mechanisms have the same trend, since the operator 2 gradually decreases its requirements of Number of UEs. Thus, the available resources can always satisfy operator 2's needs. As for the dropping rate, it can be seen that HP has no dropping UEs for operators 1 and 2 (i.e., $R_1^{drop\_ue}$ and $R_2^{drop\_ue}$ of HP), since it will not overuse the resource, while SBD may have about a 5% dropping rate for operator 1 (i.e., $R_1^{drop\_ue}$ of SBD), since operator 1 overused the resource borrowed from the operator 2, and then returns the resources temporarily borrowed when operator 2 needs it. The trend of $R_1^{drop\_ue}$ resembles an inverted U-shaped curve because when $\frac{\lambda_1^{ue}}{\lambda_2^{ue}} = 1$, the overused condition does not occur frequently, but when $\frac{\lambda_1^{ue}}{\lambda_2^{ue}} = 2$, operator 1 is usually overused while operator 2 also has many requests, operator 1 should return resources frequently. When the arrival rate of operator 2 decreases, the resources operator 1 should return also decrease. Similar phenomena occur in Fig. 8 (b) for bandwidth allocation between operator 1 and operator 2. In summary, SBD can improve the blocking rate efficiently when the shared BS is under-utilized, and control the dropping rate at around 5%. On the other hand, when shared BS is over-utilized and the arrival rates of operators are close, the hard partition is preferred to avoid unnecessary dropping occurring.

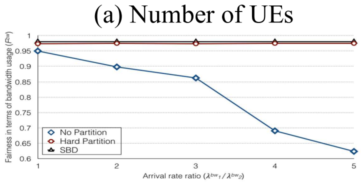
VI. Conclusions and Future Work

Soft-partition with Blocking and Dropping (SBD) is proposed in transparent RAN sharing to control the fairness among different operators based on a "Soft-partition" concept. In SBD, telecom operators can utilize resources more than what is agreed among the operators when the shared BS is under-utilized. However, SBD only allows overusing whenever there is no impact on the other operators, i.e. SBD monitors the usage of the resources for each involved operator and dynamically adjusts the available resources among the operators by blocking or even dropping. According to our simulation results, SBD not only makes sure of fairness between sharing operators but also keeps the high utilization of shared BS around 100%. Furthermore, SBD obviously reduces blocking rate from 35% of hard partition to almost 0% when the shared BS is under-utilized, and control the dropping rate at around 5%.

In the future work, an enhanced algorithm and scale down feature will be added to SBD to optimize the blocking and dropping rates, and mathematical analysis will be included to validate the extended SBD scheme. A comprehensive model will be developed to analyze the performance of SBD in terms of resource utilization, blocking rate and dropping rate to prove the validity of SBD scheme.

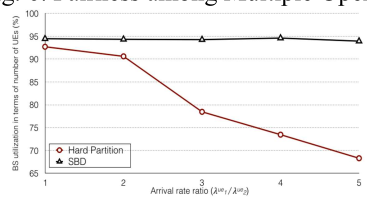


(a) Number of UEs

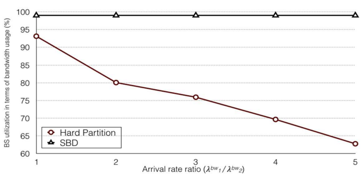


(b) Bandwidth Usage

Fig. 6. Fairness among Multiple Operators

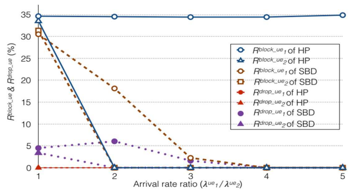


(a) Number of UEs



(b) Bandwidth Usage

Fig. 7. Utilization of Shared Base Station Comparison



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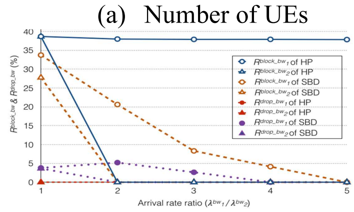

(b) Bandwidth Usage

Fig. 8. Blocking Rate and Dropping Rate

Reference

[1] T. Frisanco, P. Tafertshofer, P. Lurin and R. Ang, "Infrastructure sharing and shared operations for mobile network operators From a deployment and operations view," IEEE Network Operations and Management Symposium, April 2008.

[2] GSMA Head Office, "Mobile Infrastructure Sharing," Accedian RAN Sharing White Paper, Sep. 2012.

[3] Nokia Solutions and Networks, "Network Sharing: Delivering mobile broadband more efficiently and at lower cost," Nokia Network Sharing White Paper, 2014.

[4] Accedian Network, "RAN Sharing Solutions: Network Performance Monitoring," Accedian RAN Sharing White Paper, Q2 2015.

[5] J. Markendahl and A. Ghanbari, "Shared smallcell networks multi-operator or third party solutions - or both?," Modeling & Optimization in Mobile (WiOpt), May 2013.

[6] Y. D. Lin, H. S. Chien, H. W. Chang et al., "Transparent RAN Sharing of 5G Small and Macro Cells", IEEE Wireless Communication Magazine, to appear. Available in (https://goo.gl/pYmmid).

[7] Y. D. Lin, H. S. Chien, H. W. Chang et al., "Transparent RAN Sharing of 5G Small and Macro Cells", IEEE Wireless Communication Magazine, to appear. Available in (https://goo.gl/pYmmid).

[8] L. Frenzel, "Understanding The Small-Cell And HetNet Movement," ELECTRONIC DESIGN, Sep. 2013.

[9] X. Ge, S. Tu, G. Mao et al., "5G Ultra-Dense Cellular Networks," IEEE Wireless Communications, Volume: 23, Feb. 2016.

[10] K. Johansson, M. Kristensson and U. Schwarz, "Radio resource management in roaming based multi-operator WCDMA networks," IEEE 59th Vehicular Technology Conference, May 2004.

[11] A. Gogic and G. B. Horn, "Asymmetric Radio Access Network (RAN) Resource Allocation in RAN Sharing Arrangement," US patent, 20140029529, Jan. 2014.