New Era in Shared C-RAN and Core Network: A Case Study for Efficient RRH Usage

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***Abstract*—Radio Access Network (RAN) sharing and Cloud-RAN (C-RAN) are two major candidates for next generation mobile networks. RAN sharing ensures efficient usage of network equipments among multiple mobile network operators (MNOs) and C-RAN benefits installation, evolution, management and performance improvements. Similarly, Software-Defined Networking (SDN) concept provides many features including hardware abstraction, programmable networking and centralized policy control. One of the main benefits that can be used along with these features is virtualization of RAN and core/backhaul networks to ensure network sharing among MNOs and efficient usage of the network equipments. In this work, we propose SDN-based C-RAN architecture including RAN controller integrated to virtualization controller that is crucial for core/backhaul network sharing towards next generation cellular network. In proposed architecture, eNodeB functions are shifted to the top of C-RAN controller as a consequence of separating baseband units from remote radio heads (RRHs). We further provide RRH assignment based load balancing algorithm that is executed at the top of the controller and allows sharing of RRHs among multiple MNOs. We evaluate its performance using traditional RRH distribution as benchmark and simulation results reveal that our proposed algorithm outperforms traditional distribution in terms of average number of connected user equipments to RRHs.**

***Index Terms*—Software-Defined Networking, Network Sharing, RAN Controller, Virtualization Controller, C-RAN.**

I. INTRODUCTION

Currently deployed cellular network infrastructures will not be able to meet the demands of subscribers in the following years as a consequence of increasing number of Internet-enabled electronic devices and content rich multimedia applications. These factors are leading to mobile network data explosion and its growth over time. In order to handle these growing demands, Mobile Network Operators (MNOs) are looking for innovative and disruptive solutions that can increase their revenue and user's quality of experience by providing better services to their subscribers [1]. The fundamental requirements to counteract the data explosion have been stated as a new infrastructure that can provide hundred times higher throughput, more than ten times latency reduction, higher bandwidth allocations per unit area etc. with respect to the current network infrastructure [2].

Advanced physical and link layer solutions that improve the link efficiency under the considerations of new specifications over 2G, 3G and Long Term Evolution (LTE) networks, have reached their theoretical limits [3]. Therefore, increasing node deployment density is the only possible solution to improve the network performance [4] instead of changing radio link parameters. In respect to this, the deployment of ultra-dense networks, also titled as heterogeneous networks (HetNets), including picocells, femtocells, relay nodes etc. has been introduced with LTE-Advanced and increasingly gaining momentum in order to meet the requirements of the data explosion. The basic idea of HetNets is to increase node deployment density via bringing the Base Stations (BSs) closer to user equipments (UEs), thereby, the signal quality can be improved. In addition to macrocells that are deployed for urban, suburban or rural area coverage, small cells aim to enhance network throughput and provide better service quality to UEs that are far from macrocell evolved Node-Bs (eNodeBs). However, HetNet developments have been bringing with both capital expenditure (CapEx) and operating expenditure (OpEx) increments due to the deployment of large number of the nodes, planning of their locations, their construction and management etc. for MNOs. Radio Access Network (RAN) sharing paradigm that ensures efficient usage of network equipments among multiple MNOs with lower CapEx and OpEx have already been explored and deployed among MNOs for not only LTE-Advanced, but also 2G, 3G and LTE cellular networks in several countries. In addition to expenditure aspects, Cloud RAN (C-RAN), where BSs' digital function units, known as baseband units (BBUs) are separated from the radio function units, known as remote radio heads (RRHs), and shifted to cloud, benefits installation, evolution, management and performance aspects by introducing centralized coordination and inter-site operation.

In the literature, several RAN sharing mechanisms and C-RAN based architectures have been proposed and investigated [5-11]. Overview of 3GPP standard evolution from network sharing principles, mechanism and architectures to future mobile networks is provided in [5]. In [6], operation of C-RAN architecture coordinated with cloud computing services are analyzed in order to enhance end-to-end system performance. [7] provides an energy-efficient C-RAN architecture with the use of information theoretic concepts. In [8] performances of Coordinated Multipoint (CoMP) and handover (HO) mechanism are investigated in cloud based small cell architecture. In [9], the authors design a load-aware dynamic mapping between RRHs and BBUs with the aim of minimizing the number of active BBUs in C-RAN architecture. In [10], a RRH selection mechanism with the purpose of power saving issue under the consideration of link gain, traffic density, bandwidth allocation and spectral efficiency issues in C-RAN. Similarly, [11] proposes a energy-efficient deployment with the selection of RRH subset. Beside both network sharing and C-RAN technologies, Software Defined Networking (SDN) and virtualization concepts are also considered as candidates to be further adopted into the next generation networks. In respect to this, the authors provide an overview of the integration of SDN, network virtualization and Network Function Virtualization (NFV) with mobile network architectures and discuss the issues toward the future mobile networks in [12]. Moreover, the benefits of network virtualization in mobile cellular networks are investigated in our previous work [13]. None of the above works, however, consider shared both C-RAN and core/backhaul network architecture exploiting the advantages of SDN and network virtualization. In this work, we propose an SDN-based C-RAN including RAN Controller which is integrated to a virtualization controller that is crucial for backhaul/core network sharing over currently deployed LTE network architecture. Each eNodeB functions such as radio resource management (RRM), load balancing, CoMP, enhanced inter-cell interference cancellation (eICIC), carrier aggregation (CA) are shifted to the top of the controller that benefits from global view of the network and enables centralized processing and collaborative decision mechanism, as a consequence of locating BBUs in cloud. We further provide a RRH assignment based load balancing algorithm that is executed at the top of RAN Controller, allows sharing of RRHs among multiple MNOs under the consideration of UEs' channel state informations (CSIs) to RRHs and guarantees the efficient usage of them.

The rest of this paper is organized as follows. In Section II, we introduce our system model and architecture based on the proposed SDN-based shared Evolved Packet System (EPS) architecture integrated with controller and C-RAN. In Section III, we give our proposed channel-aware RRH assignment-based load balancer. In Section IV, the performance evaluation is available. Finally, we conclude the paper in Section V.

II. SYSTEM MODEL AND ARCHITECTURE

An overview of the proposed SDN-based shared EPS architecture integrated with RAN Controller in C-RAN and virtualization controller in the core network is shown in Fig. 1. There are two main virtualized and sliced components for the SDN-based shared EPS architecture: Virtualization of Evolved Packet Core (EPC) and virtualization of Evolved Universal Terrestrial Radio Access Network (E-UTRAN) which have been detailed in the following subsections.

A. Virtualized and Sliced EPC Architecture

SDN-based slicing of the core, backhaul and RAN elements will be a key architectural evolution for enabling the next generation cellular networks. Fig. 1 illustrates an example scenario where three MNOs are sharing the same backhaul, core and RANs via virtualization controller and RAN Controller. In this architecture, a network virtualization controller (e.g. a controller similar to OpenVirteX [14] that achieves virtualization through providing addresses for keeping address spacing separate and topology virtualization for enabling tenants to specify their topology with resiliency for underlay networks), which is owned by infrastructure provider, is directly connected to the SDN controllers of each MNO. Virtualization controller is used to adaptively perform core/backhaul sharing and slicing between different MNOs. In addition to connection with SDN controllers of each MNO, virtualization controller is also connected with RANs controllers which are distributed in a geographic area for large coverage. In the upper layer hierarchy of RAN Controller, virtualization controller has higher order of priority in terms of decision making compared to RAN Controller over RAN. Virtualization controller receives relevant RAN related information from RAN Controller and performs mid-to-long term RAN related decisions in addition to performing core/backhaul network managements.

Integration of virtualization controller with RAN Controller allows the feedback of RAN Controller information (e.g. load balancing application utilizing RRH assignment to multiple MNOs based on UEs' CSIs) sent back to the virtualization controller. This has many benefits: First of of all, since virtualization controller controls RAN Controller as a higher layer controller, virtualization controller can poll the RAN state information and control RAN Controller as the higher entity in the control plane. Second, it can enable synchronization between RAN and backhaul/core segments for efficient end-to-end control of network resources and entities as well quality-of-service (QoS) support for UEs. Third, for resilience and fault-tolerance virtualization controller can utilize different RAN Controllers in order to execute effective load distribution for failure case scenarios.

B. Virtualized E-UTRAN architecture utilizing C-RAN and RAN Controller

The overview of the proposed SDN-based E-UTRAN architecture that utilizes C-RAN and RAN Controller is also available in Fig. 1 which identifies key architectural components as well as additional elements for SDN extension for mobile RAN design. The key architectural components are identified over five main layers: UE, RRH, BBU, Control and Application Layers which are detailed as follows:

1) UE Layer: The equipments in the UE layer are connected to packet data network services such as Internet, IP Multimedia Subsystem (IMS), MNO services through fronthaul, backhaul and core network of the sliced MNO. They are supposed to have full capabilities for random access channel (RACH) procedures for each MNO's carrier so that they can listen and connect to any RRH in the particular network region.

2) RRH Layer: Radio frequency front-end equipments exist in this layer and they are connected to BBUs through high bandwidth, low latency fronthaul network. All RAN related

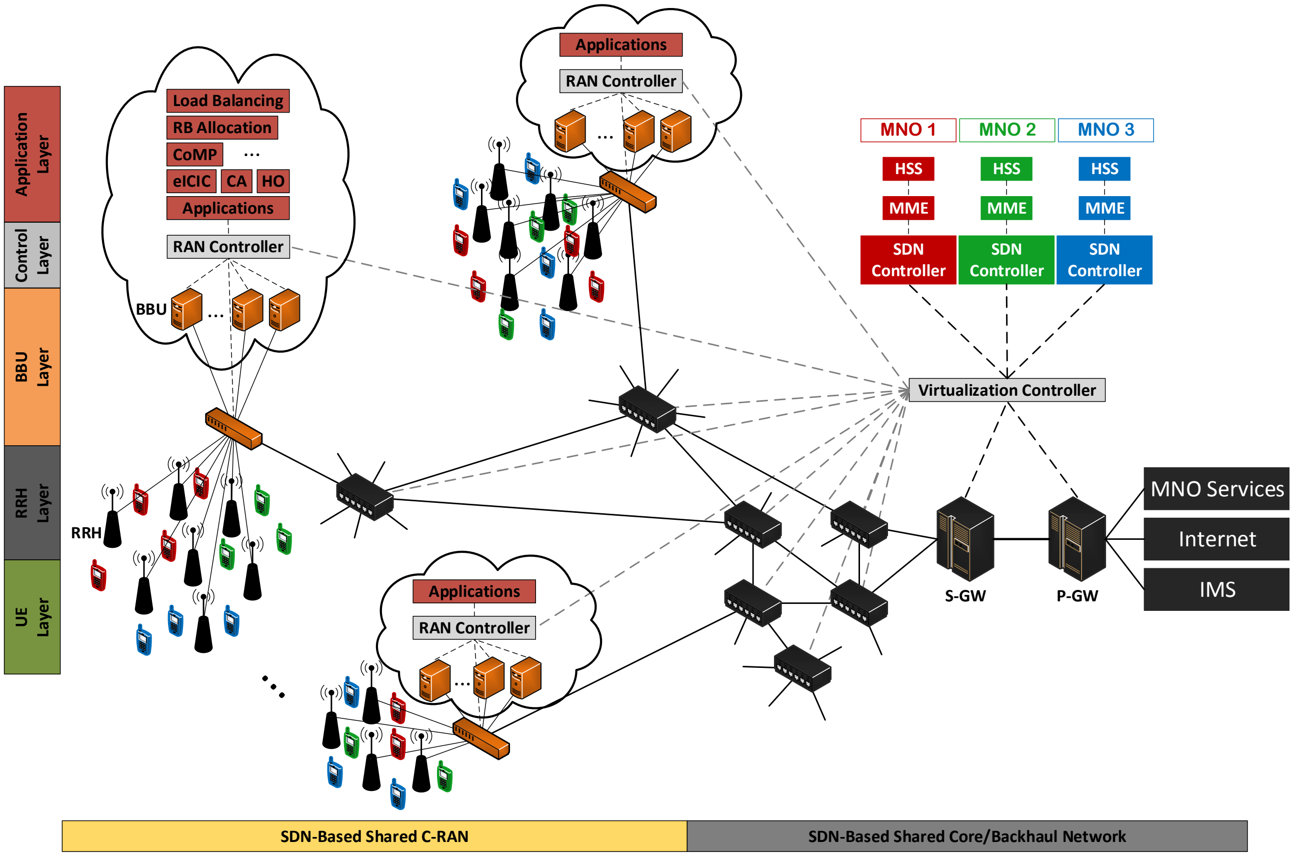

Fig. 1: SDN-based shared C-RAN and core/backhaul network architecture with integrated RAN and virtualization controllers.

functions such as not only RRM, CA, CoMP, eICIC but also Physical Cell Identity (PCI), RACH Root Sequence Index (RSI) etc. are optimized and managed by higher layers.

3) BBU Layer: Inside BBU layer, BBUs pools exist which are specialized hardware platforms utilizing digital signal processors. This layer has capability of each function available in E-UTRAN protocol stack [15], such as link adaptation, error correction, power control, cell search mechanism, mapping between logical and transport channels, priority between UEs, management, establishment, maintenance and release of radio access bearers, Packet Data Convergence Control, Non Access Stratum protocols. For RAN resource monitoring, channel quality indicator (CQI) (or CSI) feedback from each active user is received by an RRH every transmission time interval (TTI) period and stored in BBUs. This feedback is then forwarded to the RAN Controller for further processing.

4) Control Layer: The control layer contains RAN Controller which monitors and manages the RAN in coordination with C-RAN based components, i.e. BBUs and RRHs. It periodically collects data from RAN elements about the radio CSI, congestion, traffic, interference etc. at the time scales around milliseconds. In the control layer, RAN Controller is used to control the BBU layer elements (including BBU pool and switches) by pushing appropriate rules through its southbound Application Programming Interface (API) for execution of the actions that comes out of application's decision logic. The RAN Controller can communicate with applications such as inter-cell interference cancellation (ICIC), CoMP transmission, joint scheduling, QoS through its northbound API to control the operation of C-RAN segment of the network and also handle the necessary coordination between multiple RRHs for executing RAN functionalities. RAN Controller can communicate with virtualization controller in the upper hierarchy to send relevant RAN related information mid-to-long term RAN related decisions to be done by virtualization controller. Such a layered architectural framework for control layer can enable effective interference management, scheduling, bandwidth allocation and QoS management as well as provide reliable QoS guarantees for the RAN part of a mobile cellular infrastructure provider.

Note that one RAN Controller would serve several of BBUs and RRHs (on the order of tens). For the management of applications running on top of RAN Controller, resources of individual RRHs (and sometimes a group of RRHs) are allocated amongst UEs to maximize user throughput and QoS while minimizing interference of a flow to other flows nearby by the RAN Controller. RAN Controller creates and dynamically utilizes the application elements in application layers by efficiently and fairly allocating resources according to the requirements MNO and QoS of each UEs. It also has the capability of establishing or modifying the usage of each radio access element based on the demands of network. For a mobile RAN covering a large geographical area, RAN Controllers need to be deployed in a distributed fashion. However, the delay and scalability aspects are important for such a distributed deployment. A distributed deployment is favorable for minimizing delay and micro-scale visibility of RAN while it may incur scalability issues due to communication and cooperation overheads.

5) Application Layer: In the application layer, applications with functionalities such as eICIC, CoMP, CA, RRM, proposed customized algorithms (including applications for channel-aware RRH assignment based load balancer described in the next section), etc. are running for capabilities of controlling the service continuity of relevant mobile UEs at RRHs, increasing the relative rates, fair scheduling and load balancing for efficient RRH assignment among multiple MNOs. All those applications are managed by RAN Controller via Northbound API.

In summary, there are several benefits of deploying the architecture of Fig. 1 compared to a traditionally distributed one where all the functionalities are deployed in each BS. First of all, the hierarchical architecture can allow better optimization of network parameters as well as management of applications due to awareness of global (due to central controller at each segment of network) as well as local view of the network infrastructure, centralized processing and collaborative decision mechanism. Second, the processing power of BSs are limited, hence a computation bottleneck can be created with the existence of each additional functionality into the access network element. Third, scaling issues can occur if the coordination between the RRHs need to be performed in frequency time intervals. The main drawback of the proposed approach is the possibility of increase in signalling updates required for collecting the CSI values at each time for all participating users. In next section, we illustrate an application scenario for the proposed architecture.

III. CHANNEL-AWARE RRH ASSIGNMENT BASED LOAD BALANCER

We propose a channel-aware RRH assignment based load balancer executing at the top of RAN Controller in our proposed architecture. The flowchart of the proposed algorithm is shown in Fig. 2. In the first step, UEs measure the reference signals transmitted from different RRHs and estimate the relative channel coefficients. Let each UE has a two-column matrix of , also called as *channel measurement report*, where first column represents RRH IDs and second column represents estimated CSIs (or CQIs) associated with those RRHs. Note that UEs receive signals from multiple RRH in a particular region, however, a finite number channel measurements can be reported. In respect to this, the number of measured and estimated channels that are related to different RRHs are identified by an integer value of . This value also determines the row length of and limits the number of RRHs that UEs can connected to. After estimation of relative channels, UEs forward to BBUs through high bandwidth, low latency fronthaul network. When application starts, RAN Controller requests values from BBUs. Then, RAN Controller generates a matrix, (Φ), called as *attempt report*, whose columns includes RRHs with respect to their IDs and rows includes MNOs. Each element of , i.e. $_{i;j}$, denotes the total number of i^{th} MNO's UEs that have the highest CQI (or CSI) value related to j^{th} RRH. Then, the controller assigns j^{th} RRH to i^{th} MNO if the following equation is satisfied,

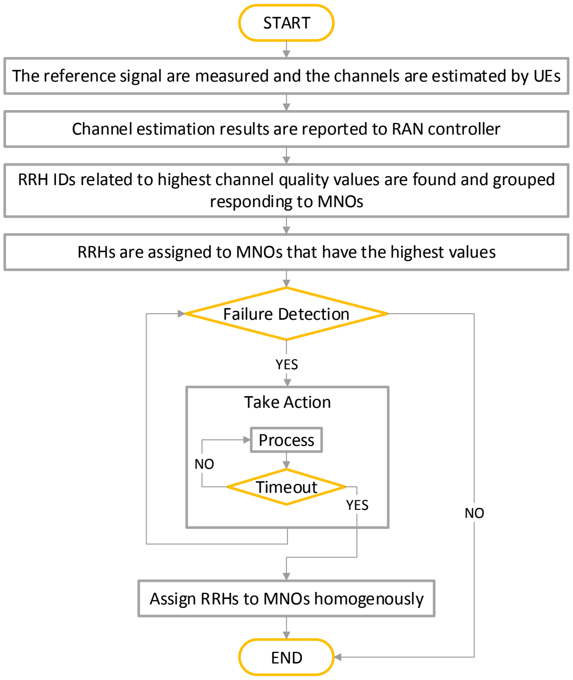

Fig. 2: Flow chart of channel-aware RRH assignment based load balancing algorithm.

$$ {}_{i;j} = \arg\max_{k} f \quad {}_{k;j} g : \tag{1} $$

In order to indicate associated RRHs and MNOs, let each MNO have a vector of , also called as *assignment report*, which includes RRH IDs that are assigned to itself.

Note that if any of RRH IDs in a UE's does not match with associated MNO's then, this UE is not able to connect to any RRH. Therefore, the next step is to check whether there is any UE that cannot be connected with any RRH. This process is called as *Failure Detection* (see Algorithm 1). After assignment of different RRHs to different MNOs, RAN Controller checks each UE's collected in the previous step. If any RRH ID within UE's report ( ) does not match with RRHs assigned to relative UE's MNO then, this UE is added to *failure report*, which is denoted by . This process is repeated for each UE associated with each MNO.

After detecting UEs whose reports do not contain any of RRHs assigned to its relative MNO, the controller rearranges the assignment decisions and this process is called as *Take*

Algorithm 1 Failure Detection

```
procedure FAILUREDETECTION( , )
    set to null
    for each UE do
        if does not contain any element of then
            insert UE into
        end if
    end for
    Return
end procedure
```

Action (see Algorithm 2). First, UEs within the vector of are categorized with respect to associated MNOs. For each MNO, a matrix, , called as *failure information report*, is generated. contains this type UE's . The *mode* (the most frequent value) of each is found and the RRH whose ID is equal to this value is assigned to related MNO. Hence, several failures can be resolved. In order to avoid from ping-pong, the newly assigned RRHs is added to a vector, called as *buffer list*, , which indicates the RRHs within the list are newly assigned to an MNO and cannot be reassigned to another MNOs. The same processes sequentially continue until all of the UE reports contain at least one of the RRHs assigned to associated MNOs. However, even though all failures of the MNO that is firstly processed are resolved, new failures related to this MNO may occur after processing to solve following MNO's failure. Therefore, *Take Action* is followed by *Failure Detection*. Until all failures are resolved, these two processes are sequentially repeated and try to connect each UE to an RRH. Additionally, *Take Action* has a *timeout* parameter. When this parameter is exceeded, all RRHs are homogeneously (traditionally) assigned to MNOs.

Algorithm 2 Take Action

```
procedure TAKEACTION( , , , )
    Generate based on
    for each MNO do
        while $\neq$ null do
            exclude from
            calculate mode( )
            update
            update
            insert mode( ) into
        end while
    end for
    Return ,
end procedure
```

Note that in existing cellular networks including 4G and previous generations, the operating frequency spectrum as well as the locations of BSs have been pre-determined under the consideration of several parameters (e.g., UE distributions and interference issues). In our proposed architecture, RRHs of BSs will continue to be used at the same spectrum and locations. Additionally, MNOs' RRHs operate at the different operating frequencies and our proposed algorithm ensures sharing of those RRHs. Hence, in our proposed architecture dynamic spectrum sharing among MNOs is exploited thanks to capability of dynamic RRHs assignments to different MNO. However, this situation leads different path loss values at the same distance which causes unfair RRH assignments in favor of RRHs with lower operating frequency. In order to avoid from this inconsistency, bias values under the consideration of operating frequencies need to be added into channel measurement reports of UEs associated with MNOs operating at higher frequencies.

IV. PERFORMANCE EVALUATIONS

In this section, we present our simulation environment and results that showcase the benefits of our proposed channel-aware RRH assignment based load balancing algorithm. We first generate a network region including several RRHs associated with multiple MNOs that is depicted in Fig. 3. The RRHs have omni-directional antennas and each MNO has 23 RRHs which are homogeneously distributed in given network region and very close to each other in order to serve the same coverage region. Then, we consider two different scenarios which vary with respect to different distribution of UE number associated with those MNOs. In the first scenario, the numbers of UEs associated with MNO 1, MNO 2 and MNO 3 are between 0 and 200, 0 and 400 and, 0 and 600, respectively. This scenario can be considered as balanced and light-loaded distribution. On the other hand, the second scenario, where the numbers of UEs associated with MNO 1, MNO 2 and MNO 3 are between 0 and 100, 0 and 400 and, 0 and 1200, respectively, is more skewed and includes heavier load user distribution with respect to the first scenario. Additionally, in both scenarios, location of UEs is uniformly distributed in considered particular region and the performance improvements by our proposed model are shown by Monte-Carlo simulations.

TABLE I: Downlink channel simulation parameters [16].

HS-DSCH power	46 dBm
RRH transmitter antenna gain	18 dBi
Cable loss	2 dB
UE noise figure	7 dB
Thermal noise	-104 dBm
SINR	-10 dB
Height of RRH antenna (h_B)	80 m
Height of UE antenna (h_M)	1.5 m

Our simulation parameters are available in Table I under the consideration of 10 MHz system bandwidth and antenna diversity. Based on High Speed Downlink Shared Channel (HS-DSCH) power, RRH transmitter antenna gain and cable loss, the output power of RRH becomes 62 dBm. Additionally, based on UE noise figure, thermal noise (calculated by (Boltzmann constant Temperature (290K) Bandwidth)) and signal-to-interference-plus-noise ratio (SINR) [16], receiver sensitivity becomes 107 dBm. With the selection of $= 9$,

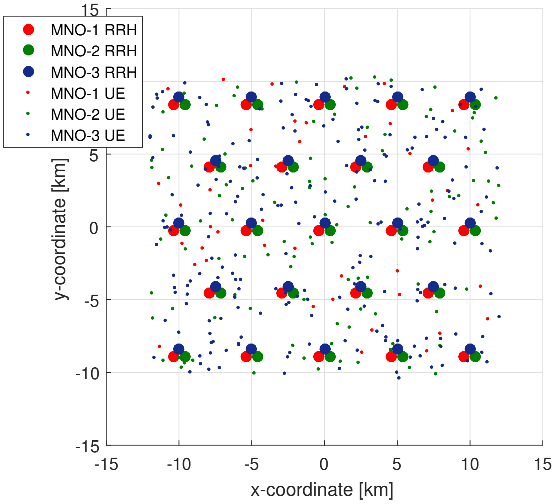

Fig. 3: Homogeneously distributed RRHs associated with different MNOs.

each UE terminal forwards its including the highest 9 channel measurement associated with RRHs whose associated received signal is higher than 107 dBm. Moreover, the timeout parameter of proposed algorithm is set to 100 iteration.

We assume that proper frequency spectrum sharing and advanced modulation techniques that ensure the interferences from neighbor RRHs to be insignificant, and urban environment Okumura Hata path loss model is considered between UE and RRH and can be calculated by

$$\text{Path Loss} = 69{:}55 + 26{:}16\log(f) \quad 13{:}82\log(h_B) \quad C_H + (44{:}9 \quad 6{:}55\log(h_B))\log(d)\ \text{dB}; \qquad (2)$$

where d is the UE distance to RRH in km and C_H is antenna height correction factor and for small and medium-sized cities, it is calculated by

$$C_H = 0{:}8 + (1{:}1\log(f) \quad 0{:}7)h_M \quad 1{:}56\log(f); \qquad (3)$$

where f is operating frequency of MNOs' RRHs and it is set to 900 MHz for red-colored RRH, 1800 MHz for green-colored RRHs and 2100 MHz for blue-colored RRHs in Fig. 3. In order to have same path loss values of (2) for different operating frequencies at the same locations, bias values of $7{:}8479$ dB for RRHs operating at 1800 MHz and $9{:}5932$ dB for RRHs operating at 2100 MHz are used compared to RRHs operating at 900 MHz.

We further assume that perfect CSI is available in receiver sides. Based on those parameter, we first present fundamental steps of our proposed algorithm in Fig. 4 before performance evaluation results. Under the consideration of first scenario, the snapshot of first assignment including *Failure Detection* is depicted in Fig. 4a. Since the total number of UEs associated with MNO 1 is the lowest, MNO 1 does not achieve the highest index in the columns of so that none of RRHs are assigned to this operator. After that, *Failure Detection* is executed and the UEs that are not able to connect to any RRH are detected (which are also shown in the same figure with square marker). Then, *Take Action* is executed in order to connect those UEs to an RRHs. The output of this execution including *Failure Detection* is depicted in Fig. 4b. All failures in the previous step are resolved. However, new failures related to MNO 2 occur due to recent assignment of some RRHs (which were previously assigned to MNO 2) to MNO 1. After the second *Take Action* execution, all failures are resolved and final RRH assignment is shown in Fig. 4c.

In Figs. 5 and 6, we evaluate the performance of our proposed algorithm under the consideration of the first and second scenarios, respectively. Homogeneous RRH distribution which is available in Fig. 3 is considered as benchmark. We present average number of connected UEs to each RRH as key performance indicator. RRHs whose IDs between 1 23 are associated with MNO 1, the following 23 RRHs are associated with MNO 2 and the rest of them is associated with MNO 3 in the homogeneous assignment. In Fig. 5, as the standard deviation of homogeneous RRH assignment is $3{:}7339$, this value is decreased to $1{:}864$ with the use of our load balancer under the consideration first scenario. On the other hand, when more skewed and heavier loaded scenario is considered (see Fig. 6), the benefits of RRH assignment based load balancer can be clearly observed. Our algorithm aims to share UEs among all RRHs under the consideration of their channel gains related to each RRH and standard deviation of this distribution becomes $3{:}9173$ whereas homogeneous RRH assignment takes the value of $10{:}3615$. The decrements on standard deviation values of connected UEs numbers reveal our proposed architecture that allows sharing of RRHs among multiple MNOs and channel-aware RRH assignment guarantee the efficient usage of RRHs with respect to traditionally distribution of those RRHs.

V. CONCLUSIONS

In this paper, we introduce a new SDN based hierarchical architecture with both RAN Controller for controlling shared C-RAN architecture and virtualization controller for core/backhaul management, slicing and sharing among multiple MNOs. The proposed architecture is modular and flexible to accommodate multiple RAN applications/functionalities running on top RAN Controllers as a consequence of separation and centralization of BBUs. A load balancing algorithm that is executed at the top of the controller and benefits from channel aware RRH assignment for multiple MNOs are further provided and its performance is evaluated through Monte-Carlo simulation results using traditional RRH assignment as benchmark.

REFERENCES

[1] S. Sezer, S. Scott-Hayward, P. K. Chouhan, B. Fraser, D. Lake, J. Finnegan, N. Viljoen, M. Miller, and N. Rao, "Are we ready for SDN? Implementation challenges for software-defined networks," *IEEE Communications Magazine*, vol. 51, pp. 36–43, July 2013.

[2] J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. K. Soong, and J. C. Zhang, "What Will 5G Be?," *IEEE Journal on Selected Areas in Communications*, vol. 32, pp. 1065–1082, June 2014.