Efficient RRH Assignments for Mobile Network Operators in Shared Cellular Network Architecture

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***Abstract*—Radio Access Network (RAN) sharing that ensures efficient usage of network equipments among multiple mobile network operators (MNOs) and Cloud-RAN (C-RAN) benefiting installation, evolution, management and performance improvements are two major candidates towards the next generation mobile networks. In addition to them, Software-Defined Networking (SDN) paradigm 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 dynamic virtualization of RAN in order to ensure network sharing among multiple MNOs and efficient usage of the RAN equipments such as remote radio heads (RRHs). In this work, we provide a use case study of SDN-based shared RAN infrastructures for channel-aware remote radio head (RRH) assignment to multiple MNOs benefiting from global view of the network in order to provide better received signal strength levels. We propose two assignment mechanisms and compare the performance of them with traditional RRH distribution. The Monte-Carlo simulation results reveal the proposed methods' performance advantages.**

Keywords*—*RAN Sharing; C-RAN; RRH Assignment, Mobile Network Operators.

I. INTRODUCTION

The fundamental requirements to counteract the data explosion in 5G networks have been stated as a new infrastructure providing $1,000$X data volume, $1,000$X connected devices, $1/5$X latency, $1/10$X energy consumption with respect to the current network infrastructure [1]. In recent years, the deployment of Heterogeneous Networks (HetNets) has been introduced with Long Term Evolution (LTE)-Advanced and increasingly gaining momentum in order to meet the requirements of the foreseen data explosion. However, HetNet developments brings both capital expenditure (CapEx) and operating expenditure (OpEx) increments due to their construction, planning of locations and management etc. for Mobile Network Operators (MNOs).

Radio Access Network (RAN) sharing paradigm that ensures efficient usage of network equipments among multiple MNOs have already been explored and deployed among multiple MNOs in several countries in order to avoid from increment on both CapEx and OpEx. In addition to expenditure aspects, Cloud RAN (C-RAN), where baseband units (BBUs) are separated from remote radio heads (RRHs), and shifted to cloud, benefits installation, evolution, management and performance aspects by introducing centralized coordination and inter-site operation. Network virtualization with Software-Defined Networking (SDN) framework providing many features such as hardware abstraction, programmable networking and centralized policy control can be an effective solution to reduce CapEx and OpEx through ensuring using network resources efficiently under the consideration of the long investment cycles of MNOs. One of the main benefit of shared C-RAN architecture exploiting the advantages of SDN and network virtualization for multiple MNOs is centralized processing and collaborative decision mechanism for all RAN equipments based on global view of the network. More specifically, this structure provides an opportunity for sharing of RRHs related to multiple MNOs and assignment of them to different MNOs in different time slots based on pre-defined metrics.

Several RAN sharing mechanisms, C-RAN based architectures, SDN and virtualization concepts have been investigated in the literature [2-8]. Overview of 3GPP standard evolution from network sharing principles, mechanism and architectures to future mobile networks is provided in [2]. In [3], operation of C-RAN architecture coordinated with cloud computing services are analyzed in order to enhance end-to-end system performance. In [4], 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 [5], 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, [6] proposes a energy-efficient deployment with the selection of RRH subset. The authors in [7] provide an overview of the integration of SDN, network virtualization and Network Functions Virtualization (NFV) with mobile network architectures and discuss the issues toward the future mobile networks. The benefits of network virtualization in mobile cellular networks are investigated in our previous work [8]. However, none of the above works, consider RRH assignment mechanism to different MNOs in different time slots with the aim of maximizing some pre-defined metrics, as a consequence of shared C-RAN architecture exploiting the advantages of SDN and network virtualization for multiple MNOs. We provide a case study ensuring efficient usage of RRH among multiple MNOs that increases received signal strength (RSS) levels in user equipment (UE) side. We propose two channel-aware assignment mechanism and compare their performances through Monte-Carlo simulations while considering traditional RRH distribution as benchmark. The results reveal that our proposed methods outperform traditional approach in terms of obtained RSS levels.

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The rest of this paper is organized as follows. In Section II, we introduce system model of shared networks and propose two RRH assignment mechanisms in Section III. Section IV demonstrates the performance results of those mechanisms and we conclude the paper in Section IV.

II. CHANNEL-AWARE RRH ASSIGNMENT MECHANISMS IN SHARED NETWORK ARCHITECTURE

Fig. 1 depicts SDN-based shared mobile architecture where RAN slicing can be performed using C-RAN controller. Given K RRHs and M MNOs in this architecture, let $\mathcal{M} = \{1, 2, \dots, M\}$ denote the MNO set and $\mathcal{K} = \{1, 2, \dots, K\}$ denote the RRH set. UEs associated with m-th MNO can be chosen from the set $\mathcal{N}_m = \{1, 2, \dots, N_m\}$, thereby, total number of UEs in the given network architecture can be defined as $N = \sum_{m=1}^{M} \mathcal{N}_m$. A binary variable $q_{m,k}$ can be introduced to indicate whether RRH $k \in \mathcal{K}$ is assigned to MNO $m \in \mathcal{M}$ or not (i.e., if k-th RRH is assigned to m-th MNO then, $q_{m,k} = 1$ else $q_{m,k} = 0$). One of the main constraints is the fact that each RRH $k \in \mathcal{K}$ can be assigned to only one MNO during a certain time interval,

$$\sum_{m\in\mathcal{M}} q_{m,k} = 1. \tag{1}$$

Let $\boldsymbol{\Delta}_{K\times M} := [\boldsymbol{\Delta}_1 \;\; \boldsymbol{\Delta}_2 \;\; \dots \;\; \boldsymbol{\Delta}_M] = (\boldsymbol{\Delta}_m, \boldsymbol{\Delta}_{-m})$ or alternatively $\boldsymbol{\Delta}_{K\times M} = [\boldsymbol{\Psi}_1 \;\; \boldsymbol{\Psi}_2 \;\; \dots \;\; \boldsymbol{\Psi}_K]^T = (\boldsymbol{\Psi}_k, \boldsymbol{\Psi}_{-k})$ as the $K \times M$ RRH assignment matrix of all MNO. Here, $\boldsymbol{\Delta}_m = [q_{m,1} \;\; q_{m,2} \;\; \dots \;\; q_{m,K}]^T$ is a $K \times 1$ is RRH assignment vector of m-th MNO and Δ_{-m} is the assignment vector of all MNOs other than the m-th MNO. Moreover, $\boldsymbol{\Psi}_k = [q_{1,k} \;\; q_{2,k} \;\; \dots \;\; q_{M,k}]^T$ denotes k-th RRH's $M \times 1$ MNO assignment vector and $\boldsymbol{\Psi}_{-k}$ as the assignment vector of all RRHs other than the k-th RRH where $\boldsymbol{\Psi}_k \in \mathcal{I}_k$ and $\mathcal{I}_k$ denotes the set of all possible MNO assignments for k-th RRH and assume that $\mathcal{I} = \mathcal{I}_k = \{\boldsymbol{\Psi}^1_k, \boldsymbol{\Psi}^2_k, \dots, \boldsymbol{\Psi}^M_k\}$ where each $\boldsymbol{\Psi}^m_k$ is $M \times 1$ orthogonal identity vector $\mathbf{I}_{M\times 1}$. For an RRH assignment profile $(\boldsymbol{\Psi}_k, \boldsymbol{\Psi}_{-k})$, denote the set of users of m-th MNO as $u \in \mathcal{N}_m$ choosing RRH $k \in \mathcal{K}$ as $\mathcal{C}_{k,m}$, i.e. $\mathcal{C}_{k,m} = \{u \in \mathcal{N}_m : q_{m,k} = 1,\}$ $\forall k \in \mathcal{K}$, then the total number of users connected to k-th RRH can be expressed as $\Upsilon_{m,k} = |\mathcal{C}_{k,m}|$.

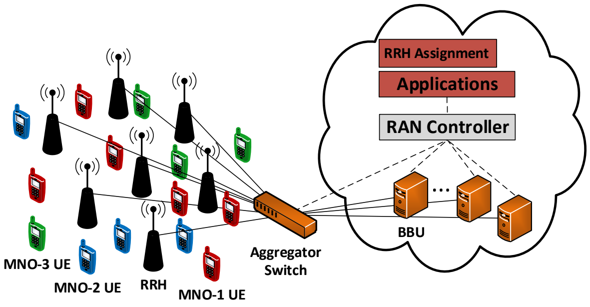


Fig. 1: SDN-based shared network architecture with three MNOs.

Other binary variable, $\vartheta^m_{k,i}$, can be introduced to indicate whether RRH $k \in \mathcal{K}$ is in the range of the user $i \in \mathcal{N}_m$ or not. It should be noted that UEs receive signals from multiple RRHs in a particular region, however, a finite number channel measurements can be reported due to capabilities of UEs, which is the second constraint. In respect to this, the maximum number of measured and estimated channels that are related to different RRHs are identified by an integer value of α. For this reason, each user can be connected to at most α different number of RRHs, i.e.,

$$\sum_{k\in\mathcal{K}} \vartheta^m_{k,i} \leq \alpha. \tag{2}$$

We define $\boldsymbol{\Theta}_{m_i} = [\vartheta^m_{1,i}, \vartheta^m_{2,i}, \dots, \vartheta^m_{K,i}]^T$ as a $K \times 1$ vector associated with i-th user of m-th MNO and $\boldsymbol{\Omega}_{m_i} = [w^m_{1,i}, w^m_{2,i}, \dots, w^m_{K,i}]^T$ as $K \times 1$ vector of the measured channel quality indicator (CQI) values from K different RRHs which is called as *channel measurement report* from i-th user of m-th MNO. Note that the values inside $\boldsymbol{\Omega}_{m_i}$ vector can have at most α non-zero values due to (2). The set of users of m-th MNO $u \in \mathcal{N}_m$ having highest CQI values from RRH $k \in \mathcal{K}$ is denoted by

$$\mathcal{C}^{CQI}_{k,m} = \{u \in \mathcal{N}_m : \arg\max\nolimits_{i\in\mathcal{N}_m} \{\omega^m_{k,i}\}, \; \forall k \in \mathcal{K}\}, \tag{3}$$

then, the total number of users connected to k-th RRH and has highest CQI values can be expressed as $\Upsilon^{CQI}_{m,k} = |\mathcal{C}^{CQI}_{k,m}|$.

After introducing above parameters, the problem definition can be described as follows: Given a network state $\mathbf{S} = (\boldsymbol{\Psi}_k, \boldsymbol{\Psi}_{-k})$ where $(\boldsymbol{\Psi}_k, \boldsymbol{\Psi}_{-k})$ is a combination of each MNO assignments in the set of MNOs $\mathcal{M}$ to each RRH in the set $\mathcal{K}$, we look for the optimal values of assignments to minimize a cost function,

$$f(\boldsymbol{\Psi}_k, \boldsymbol{\Psi}_{-k}) = -\sum_{k\in\mathcal{K}} U_k, \tag{4}$$

where U_k is the utility of the k-th RRH. In order to accomplish this, each RRH's utility needs to be maximized by choosing appropriate MNO assignments. Using CQI as the maximization parameter, the utility function of k-th RRH is expressed as

$$U_k = \sum_{m\in\mathcal{M}} \sum_{i=1}^{N_m} \left(q_{m,k} \times \omega^m_{k,i}\right), \tag{5}$$

where the term $q_{m,k} \times \omega^m_{k,i}$ is the obtained CQI value of the UE $i \in \mathcal{N}_m$ that is attached to k-th RRH. Then, the optimization problem can be described as follows: Our goal is to maximize the sum of observed total CQI utility of all UEs (which also maximizes RSS level) with the decision variables: (i) *Assignment problem:* the assignment of RRHs to each MNOs is represented by the variables $q_{m,k}$. (ii) *Connected users problem:* the successful assignment of all UEs of each MNOs to various RRHs is specified by the multiplication of variables $\boldsymbol{\Theta}^T_{m_i}\boldsymbol{\Delta}_m$. For the shared mobile architecture, we use the following formulation for our optimization problem:

$$\begin{array}{lll}
\underset{\boldsymbol{\Delta}}{\text{minimize}} & f(\boldsymbol{\Psi}_k, \boldsymbol{\Psi}_{-k}) & (6) \\
\text{subject to} & \boldsymbol{\Theta}^T_{m_i}\boldsymbol{\Delta}_m > 0, \quad \forall i \in \mathcal{N}_m, \forall m \in \mathcal{M}, & (6a) \\
 & 0 < \Upsilon_{m,k} \leq N_m, \quad \forall k \in \mathcal{K}, \forall m \in \mathcal{M}, & (6b) \\
 & \sum_{k\in\mathcal{K}} q_{m,k} = 1, \quad \forall m \in \mathcal{M}, & (6c) \\
 & 0 < \sum_{k\in\mathcal{K}} \vartheta^m_{k,i} \leq \alpha, \quad \forall m \in \mathcal{M}, \forall i \in \mathcal{N}_m, & (6d) \\
\{q_{m,k}, \vartheta^m_{k,i}\} & \in \{0,1\}, \quad \forall m \in \mathcal{M}, \forall k \in \mathcal{K}, \forall i \in \mathcal{N}_m. & (6e)
\end{array}$$

In particular, the constraint (6a) tackles the case when there should not be any unconnected UEs in RRH assignments. The constraint in (6b) represents the fact that there should be nonzero number of UE connections to each RRHs for all users of each MNOs. The constraint in (6c) enforces each RRH be assigned to only one MNO, (6d) ensures each user be in the range of RRHs and (6e) denotes the binary decision variables of assignment and channel measurement reports.

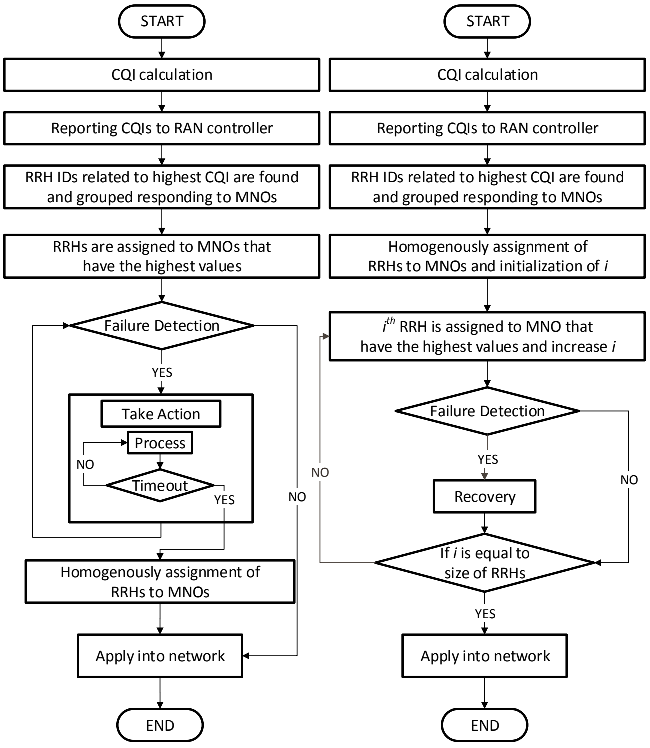
In order to tackle the above problem, the RRH assignment matrix $\boldsymbol{\Delta}$ needs to be optimized considering the constraints of (6a)-(6e). However, solving (6) problem is challenging due to coupling behaviour between the RRHs assignments and connected users problem. In the following sections, we will discuss the scenarios and algorithms (both fully centralized and C-RAN controller aided distributed) where the RRHs are searching for the best MNO assignment strategies that can also provide convergence guarantees.

A naive approach for solving the problem (6) is to all RRH assignment vector profiles of each MNO exhaustively and pick the assignment profile with the maximum utility that gives successful assignments of all UEs of MNOs to RRHs as well. In order to compute (6), the centralized agent calculates the total CQI values for M^K possible RRH assignment vector combinations. For example, for a network topology with 160 RRHs, where infrastructure provider need to assign 3 MNO, the search space is 3^{160} assignment profiles. Therefore, finding the centralized MNO selections for all RRHs is cumbersome in large-scale wireless network. To alleviate the complexity problem, while maintaining good performance results, we propose two algorithms, including capability of global and local view of the network, using centralized techniques aided with C-RAN controller.

III. CHANNEL-AWARE RRH ASSIGNMENT MECHANISMS

A. *R**AN** **C**ontroll**e**r Ba**s**ed Cen**t**ralized Alg**or**ithm (ANCESTOR)*

We first propose a generic framework performing a joint channel-aware RRH assignment mechanism in a centralized manner called *ANCESTOR*. The method is *fully centralized* and can run as an application on top of C-RAN controller. The assumptions in our model are that UE's CQI is perfect, updated and collected by C-RAN controller which uses this information to perform the RRH assignments to multiple MNOs. More specifically, the C-RAN controller aims to maximize $f(\boldsymbol{\Psi}_k, \boldsymbol{\Psi}_{-k})$ by properly issuing the MNO assignments to each RRH. A summary flowchart representation of the proposed algorithm is shown in Fig. 2(a). First, UEs measure the reference signals transmitted from different RRHs and estimate the relative channel coefficients. Let each UE $i \in \mathcal{N}_m$ measure channel measurements. BBUs collect and form $\boldsymbol{\Omega}_{m_i}$, also called as *channel measurement report* through high bandwidth, low latency fronthaul network. An example of *channel measurement reports* associated with three UEs and ten RRHs is given in Table I. Note that some elements are not available due to UE's incapability of measuring values from all RRHs. When a relevant application running on top of C-RAN controller starts, C-RAN controller first requests $\boldsymbol{\Omega}_{m_i}$ values from the corresponding BBUs. Then, C-RAN controller populates a $M \times K$ matrix, $\boldsymbol{\Phi} = [\varphi_{m,k}]$, called as *attempt report*, whose columns include RRHs with respect to their IDs and rows include MNOs. Each element $\varphi_{m,k}$, denotes the obtained utility/benefit of the MNO $m \in \mathcal{M}$ for selecting the RRH $k \in \mathcal{K}$, thereby, we set it to total count of RRHs whose related CQI value is the highest among them. A sample of *attempt report* is depicted in Table II.



(a) (b)

Fig. 2: Flow charts of (a) *ANCESTOR* and (b) *ROSEN*.

TABLE I: An example of $K \times 1$ *Channel measurement reports* vector $\boldsymbol{\Omega}_{m_i}$ associated with three UEs collected from BBUs.

RRH-1	15	1	N/A
RRH-2	11	3	11
RRH-3	14	N/A	15
RRH-4	2	N/A	N/A
RRH-5	4	15	12
RRH-6	N/A	N/A	7
RRH-7	5	8	N/A
RRH-8	N/A	N/A	2
RRH-9	N/A	2	2
RRH-10	N/A	4	4

TABLE II: An example of *Attempt report* $\boldsymbol{\Phi}_{M \times K}$ and its elements of $\varphi_{m,k}$ under the consideration of $M = 3$ and $K = 10$.

	RRH -1	RRH -2	RRH -3	RRH -4	RRH -5	RRH -6	RRH -7	RRH -8	RRH -9	RRH -10
MNO-1	18	15	6	3	5	5	20	10	9	10
MNO-2	16	2	11	19	1	5	18	12	2	9
MNO-3	3	14	19	17	2	16	19	13	15	1

In order to perform assignment of k^{th} RRH to m^{th} MNO, the C-RAN controller sets $q_{m,k} = 1$ if

$$m = \arg\max_{i \in \mathcal{M}} \{\varphi_{i,k}\}. \tag{7}$$

A sample *assignment report* is given in Table III under the consideration of $M = 3$ MNOs and $K = 20$ RRHs.

Depending on the input parameters of the decision of RRH assignment into multiple MNOs is done can be adjusted accordingly. For example, when the RRH assignment is available to obtain core/backhaul network parameters in addition to RAN related parameters (i.e., CQI), the backhaul parameters of each MNO can be incorporated into the above benefit function. For example, one possible selection of $\varphi_{m,k}$ would be $\varphi_{m,k} = \Upsilon^{CQI}_{m,k} \times C^{rem}_{m,k}$ where $C^{rem}_{m,k}$ is the remaining capacity of k^{th} RRH when assigned to m^{th} MNO. Without loss of generality, in our simulation analysis, we assume bottleneck is fronthaul rather than backhaul network and we have selected $\varphi_{m,k} = \Upsilon^{CQI}_{m,k}$.

TABLE III: An example of *Assignment report* $\mathbf{\Delta}_{K \times M}$ under the consideration of $M = 3$ and $K = 10$ RRHs.

	MNO-1	MNO-2	MNO-3
RRH-1	1	0	0
RRH-2	1	0	0
RRH-3	0	0	1
RRH-4	0	1	0
RRH-5	1	0	0
RRH-6	0	0	1
RRH-7	1	0	0
RRH-8	0	0	1
RRH-9	0	0	1
RRH-10	1	0	0

In order to indicate association between RRHs and MNOs, $K \times 1$ assignment vector of $\mathbf{\Delta}_m$ is utilized for MNO $m \in \mathcal{M}$. Note that if any of RRH IDs in i-th UE's $\mathbf{\Omega}_{m_i}$ does not match with associated MNO's $\mathbf{\Delta}_m$, i.e. when $\mathbf{\Theta}^T_{m_i}\mathbf{\Delta}_m = 0$, then i-th UE is not able to connect to any RRH. Therefore, after all RRH assignments are done, the next step is to check whether there are any UEs left that cannot be connected with any RRH. This process is called as *Failure Detection* and described in following paragraph (see Algorithm 1).

After assignment of RRHs to MNOs, C-RAN controller checks each UE's $\mathbf{\Omega_{m_i}}$ collected in the previous step. If any RRH ID within i-th UE's report ($\mathbf{\Omega}_{m_i}$) does not match with RRHs assigned to i-th UE's m-th MNO then, i-th UE is added to *failure report*, which is represented by the set $\mathcal{U}$. This process is repeated for each UE $i \in \mathcal{N}_m$ associated with each MNO $m \in \mathcal{M}$. We denote the final size of the set $\mathcal{U}$ as $L = |\mathcal{U}|$ after failure detection.

Algorithm 1 Failure Detection

```
procedure FAILUREDETECTION($\mathbf{\Omega}$, $\mathbf{\Delta}$)
    set $\mathcal{U} = \{\}$
    for each MNO $m \in \mathcal{M}$ do
        for each UE $i \in \mathcal{N}_m$ do
            if $\mathbf{\Theta}^T_{m_i}\mathbf{\Delta}_m$=0 then
                $\mathcal{U} = \mathcal{U} + \{i\}$
            end if
        end for
    end for
    Return $\mathcal{U}$
end procedure
```

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 Action* (see Algorithm 2).

Inside *Take Action*, first, UEs within the set of $\mathcal{U}$ are categorized with respect to their associated MNOs. For each MNO, a $M \times L$ matrix, $\mathbf{\Sigma} = [\sigma_{m,l}]$, called as *failure information report*, is generated with respect to Algorithm 3. *Failure information report* associated with m-th MNO is denoted by $\mathbf{\Sigma}_m = [\sigma_{1,m}\sigma_{2,m} \dots \sigma_{L,m}]$. At this step, the maximum value of each $\mathbf{\Sigma}_m$ is found and the RRH associated with the maximum value is assigned to related MNO. Hence, several failures can be resolved.

Algorithm 2 Take Action

```
procedure TAKEACTION($\mathbf{\Sigma}$, $\mathbf{\Theta}$, $\mathbf{\Delta}$, $\mathcal{B}$)
    for each MNO $m \in \mathcal{M}$ do
        set counter to 0
        define $T_O$
        while $\mathbf{\Sigma} \neq 0_{MxK}$ and counter $\leq T_O$ do
            set $i$-th column of $\mathbf{\Sigma}$ if $i$-th RRH $\in \mathcal{B}$ to 0
            assign $\arg\max_{i \in \mathcal{K}} \{\mathbf{\Sigma}_{m,i}\}$-RRH to $m$-MNO
            update $\mathbf{\Delta}_m$ and $\mathcal{B}$
            if $\mathbf{\Theta}_{m_i}(\arg\max_{i \in \mathcal{K}} \{\mathbf{\Sigma}_{m,i}\}) = 1$ then
                $\mathbf{\Sigma}_m = \mathbf{\Sigma}_m - \mathbf{\Theta}^T_{m_i}$
            end if
            counter++
        end while
    end for
    Return $\mathbf{\Delta}$, $\mathcal{B}$
end procedure
```

Algorithm 3 Generation of Failure Information Report

```
procedure FAILUREINFORMATIONREPORT($\mathbf{\Omega}$, $\mathbf{\Delta}$)
    set $\mathbf{\Sigma} = 0_{MxL}$
    for each MNO $m \in \mathcal{M}$ do
        for each UE $i \in \mathcal{N}_m$ do
            if $\mathbf{\Theta}^T_{m_i}\mathbf{\Delta}_m$=0 then
                $\mathbf{\Sigma}_m = \mathbf{\Sigma}_m + \mathbf{\Theta}^T_{m_i}$
            end if
        end for
    end for
    Return $\mathbf{\Sigma}$
end procedure
```

In order to avoid from ping-pong, the newly assigned RRHs are added to a set $\mathcal{B}$, 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 connection of each UE to an RRH is tried. Additionally, *Take Action* has a *timeout* parameter (T_O). In order to avoid from non-convergence issue, when *timeout* parameter is exceeded, all RRHs are homogeneously (traditionally) assigned to MNOs.

B. **R**AN C**o**ntroller-Aided Di**s**tributed M**e**cha**n**ism (ROSEN)

For selection of the appropriate MNO assignments for each RRH $k \in \mathcal{K}$, the utility function defined in (4) is utilized. The flowchart of the distributed version named as *ROSEN* is given in Fig. 2(b). The algorithm runs as a centralized manner in C-RAN, however, it investigates the network equipments as local view. Therefore, it is simpler than *ANCESTOR*. *ROSEN* starts with CQI calculation where each UE transmits to BBUs and C-RAN controller. The controller generates *Attempt report* $\mathbf{\Phi}_{M \times K}$ as in Table II. On the other, unlike *ANCESTOR* where homogeneous allocation of RRHs to MNOs is performed at the last step when the algorithm cannot resolve any failure, this algorithm initially performs this assignment. Instead of bulk allocation of RRHs which is followed by *failure detection* and *take action* procedures, *ROSEN* allocates RRHs sequentially and executes *failure detection* at each step. The utilized allocation mechanism is given by (7). After allocation of one RRH to MNO that satisfies this equation, if any failure occurs then, rollback to initial decision is performed for this RRH (recover step at flow chart). Since it uses rollback action against occurring failures, *take action* procedure is not required. It should be noted that *ROSEN* has lower complexity and requires less number of computational calculations with respect to *ANCESTOR* approach.

IV. PERFORMANCE EVALUATION

In this section, we present the benefits of proposed channel-aware RRH assignment mechanisms on generated shared network region including 180 RRHs associated with 3 MNOs that is depicted in Fig. 3. The RRHs have omni-directional antennas and each MNO has 60 RRHs which are homogeneously distributed in the given region and very close to each other in order to serve the same coverage region. The distance between adjacent RRHs of each MNO is set to $5\ \mathrm{km}$ and the distance between adjacent MNOs associated with different MNOs is set to $0.4\ \mathrm{km}$. In this case, UEs of each MNO are connected to associated MNO's RRH that provides the highest CQI. The performance improvements by our proposed model are shown through Monte-Carlo simulations with the use of defined parameters in Table IV under the consideration of $10\ \mathrm{MHz}$ 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 $62\ \mathrm{dBm}$. Additionally, based on UE noise figure, thermal noise (calculated by (Boltzmann constant × Temperature (290K) × Bandwidth)) and signal-to-interference-plus-noise ratio (SINR) [9], receiver sensitivity becomes $-107\ \mathrm{dBm}$. When the size of *channel measurement report* is set to $\alpha = 9$, each UE terminal forwards its report including the highest 9 channel measurement associated with RRHs whose associated received signal is higher than $-107\ \mathrm{dBm}$.

We consider urban environment $\mathrm{Okumura-Hata}$ path loss model [9] which can be written as

$$\begin{aligned} \text{Path Loss} =& 69.55 + 26.16\log(f) - 13.82\log(h_B) \\ & - C_H + (44.9 - 6.55\log(h_B))\log(d)\ \text{dB}, \end{aligned} \tag{8}$$

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

$$C_H = 0.8 + (1.1\log(f) - 0.7)h_M - 1.56\log(f), \tag{9}$$

where f is operating frequency of MNOs' RRHs and it is set to $900\ \mathrm{MHz}$ for red-colored RRH, $1800\ \mathrm{MHz}$ for green-colored RRHs and $2100\ \mathrm{MHz}$ for blue-colored RRHs in Fig. 3. However, this situation leads to 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. In order to have same path loss values for different operating frequencies at the same locations, bias values of $7.8479\ \mathrm{dB}$ for RRHs operating at $1800\ \mathrm{MHz}$ and $9.5932\ \mathrm{dB}$ for RRHs operating at $2100\ \mathrm{MHz}$ are used compared to RRHs operating at $900\ \mathrm{MHz}$. We further assume that perfect channel state information (CSI) is available in receiver sides and used instead of quantized CQIs values.

We compare the performance of *ANCESTOR* and *ROSEN* with respect to the homogeneously assignment of RRHs as in Fig. 3. The used evaluation metric is RSS level which can be calculated by $\mathrm{HS-DSCH\ Power + Antenna\ Gain - Cable\ Loss - Path\ Loss}$ as a consequence of connection with those RRHs under the consideration of the two different scenarios. In the first scenario, the average number of UEs associated with MNO-1, MNO-2 and MNO-3 is set to 100 and in the second scenario, more skewed and heavier loaded distribution, where the average number of UEs associated with MNO-1,

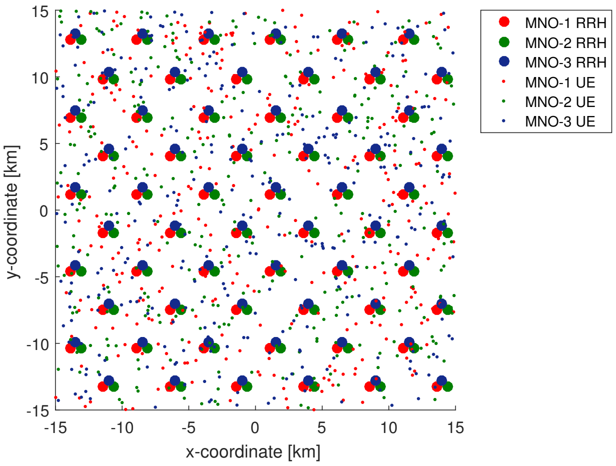
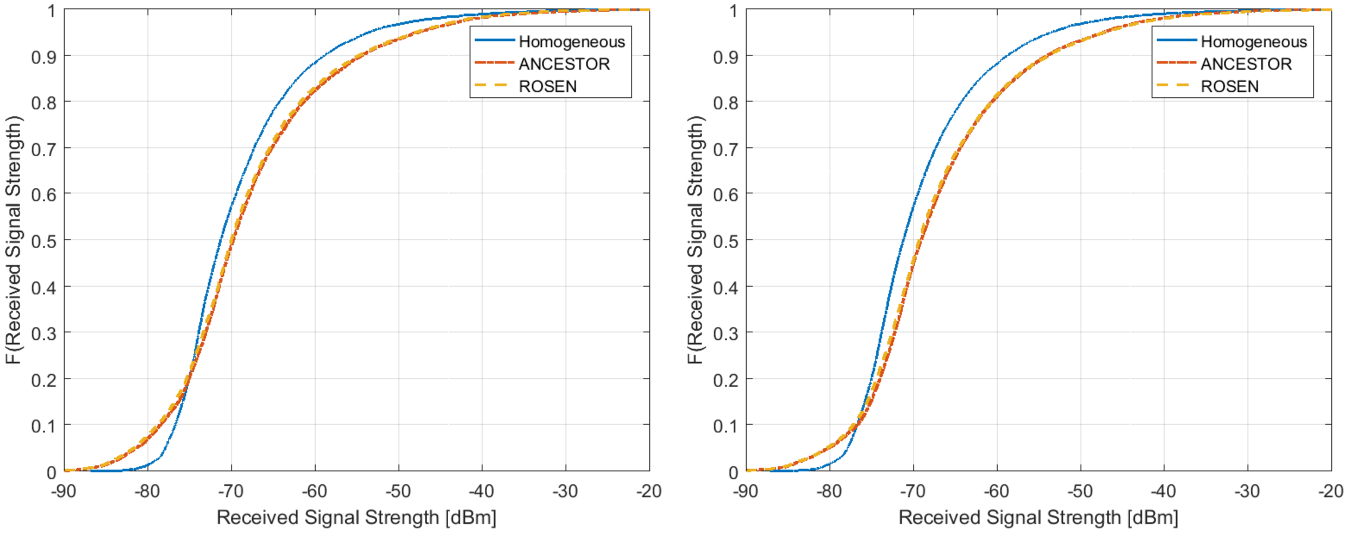


Fig. 3: Homogeneously distributed RRHs associated with different MNOs.

TABLE IV: Downlink channel simulation parameters [9].

$\mathrm{HS-DSCH\ power}$	$46\ \mathrm{dBm}$
$\mathrm{RRH\ transmitter\ antenna\ gain}$	$18\ \mathrm{dBi}$
$\mathrm{Cable\ loss}$	$2\ \mathrm{dB}$
$\mathrm{UE\ noise\ figure}$	$7\ \mathrm{dB}$
$\mathrm{Thermal\ noise}$	$-104\ \mathrm{dBm}$
SINR	$-10\ \mathrm{dB}$
$\mathrm{Height\ of\ RRH\ antenna}$	$80\ \mathrm{m}$
$\mathrm{Height\ of\ UE\ antenna}$	$1.5\ \mathrm{m}$



(a) (b)

Fig. 4: RSS of UEs with respect to homogeneous distribution and proposed methods in (a) first and (b) second scenarios.

MNO−2 and MNO−3 is set to 10, 100 and 300, respectively, is considered. In both scenarios, UEs are randomly distributed.

In the first scenario (see Figs. 4a where $\mathrm{F}(.)$ denotes cumulative density function (CDF) of given variable), mean value of RSS level with homogeneous RRH assignment becomes -69.1272 dBm. It can observed that it is increased to -67.7647 dBm and -68.0866 dBm with the use of *ANCESTOR* and *ROSEN*, respectively. It should be noted that RRHs locating at border, totally 20 RRHs per MNO, are not considered during calculation of this metric since the number of UEs connected to those RRHs is not fair with respect to the other RRHs. On the other hand, when more skewed and heavier loaded scenario is considered (see Figs. 4b), the benefits of *ANCESTOR* can be clearly observed. *ANCESTOR* aims to share UEs among all RRHs under the consideration of their channel gains related to each RRH. In this scenario, RSS in the benchmark is -69.1125 dBm and this value is increased to -66.9843 dBm and -67.1490 dBm with the use of *ANCESTOR* and *ROSEN*, respectively. The significant increment on RSS levels with the use of both *ANCESTOR* (1.3625 dB and 2.1281 dB for first and second scenarios, respectively) and *ROSEN* (1.1357 dB and 1.9574 dB for first and second scenarios, respectively) guarantees the efficient usage of RRHs according to homogeneously distribution of those RRHs. Moreover, the trade-off between *ANCESTOR* and *ROSEN* approaches are observed such as *ANCESTOR* achieves higher RSS level in contrast to *ROSEN*'s less complexity.

V. CONCLUSION

In this paper, we propose two different channel-aware RRH assignment mechanism in SDN-based shared network architecture after describing analytical model of RRH sharing and assignment. We consider two different scenarios with respect to distribution and total number of UEs associated with those MNOs. The performance of the tow proposed mechanisms is evaluated in terms of RSS level while considering traditional homogeneous RRH assignment as a benchmark. The results reveal the advantages of two mechanisms over traditional approach.

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