A Two-stage RRH Clustering Mechanism in 5G Heterogeneous C-RAN

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Abstract

Cloud Radio Access Network (Cloud RAN) is one of the most promising mobile architectures for 5G networks. The basic concept of Cloud RAN is to separate the digital baseband processing units (BBUs) of conventional cell sites, from the Remote Radio Heads (RRHs), and virtualize their functions in the cloud for centralized signal processing and management. In conventional RAN architectures, one BBU is assigned to one RRH in order to maximize network capacity. However, Cloud RAN may establish a one to many logical mapping, so as to enhance network energy efficiency. This paper addresses RRH clustering problem in heterogeneous C-RAN. The proposed clustering mechanism aims to reduce network power consumption, without compromising user QoS (Quality of Service).

1 Introduction

The evolution toward mobile networks is characterized by an exponential growth of traffic. This growth is caused by an increased number of emerging mobile user equipment (UE), smartphones, tablets, etc. To satisfy this growing user demands, mobile network operators have to significantly increase wireless network capacity. Access network densification was proposed as a solution to achieve this objective. However, implementing this densification in the access network raises many challenges: network power consumption increase, low base station utilization efficiency, inter-cell interference increase, etc.

In order to face these challenges, cloud-based radio access network was proposed. Cloud RAN is an emerging paradigm for RAN architecture that attempts to apply cloud technologies for hosting and deploying RAN functions. The concept of C-RAN was first introduced in [1] and described in details in [2].

It consists of decoupling the Base Band Units (BBUs) from Radio Remote Heads (RRHs) and move them to the cloud enabling a centralized processing and management. Traditional expensive base stations can be simplified to cost-effective and power-efficient radio units (RRHs) by centralizing the processing, which is very important for the deployment of large-scale small-cell systems. In addition, the centralized processing power enables more advanced and efficient network coordination and management.

In conventional architectures, one BBU is logically associated to one RRH. Therefore, radio resources may be underutilized since one RRH may not consume all BBU resources. Moreover, this one-to-one assignment is very expensive for 5G networks where a massive number of cells is deployed. Cloud RAN architecture resolves this problem by allowing a one-to-many mapping between BBUs and RRHs. Thus, BBU radio resources could be more efficiently used.

This work is conducted in this context. Considering a heterogeneous Cloud RAN architecture, we propose to efficiently cluster RRHs in order to enhance network power consumption while keeping the same quality of service level as the one-to-one mapping case.

The remainder of this paper is organized as follows. In the next section, previous works are discussed. In section III, the proposed RRH clustering approach is explained. Simulation results are exhibited in section IV. Finally, conclusion and perspectives for this work are provided in section V.

2 Related work

RRH clustering has already been proposed in the literature for many purposes. In [3], authors formulated the problem of RRH clustering as a bin packing problem. Then, they proposed optimal and heuristic solutions to improve network energy consumption without compromising the QoS expressed as numbers of required resource blocks in available RRHs. In [4], the authors studied the problem of joint activation and clustering of RRH in order to improve user utility function. They introduced a coverage constraint to the problem formulation to ensure the connectivity for all users. The overall user QoS is defined as a weighted sum of SIR (signal to interference ratio) and average number of users assigned to one RRH. In another work [5], authors proposed a light-weight and load aware dynamic RRH assignment (DRA) algorithm. The proposed algorithm reduced the complexity of clustering procedure and offered quite close BBU resource savings as compared to FFD (First Fit Decreasing). In [6], authors introduced a greedy RRH clustering algorithm for C-RAN downlink with aims to maximize the sum-rate gain and reduce network piloting overhead. Authors in [7] presented a greedy dynamic RRH clustering mechanism based multi-objective optimization in order to balance the throughput maximization and RRH energy consumption minimization. In [8], authors focused on delay-tolerant best-effort traffic to derive a dynamic clustering and user scheduling approach for cooperative base stations.

In all these works, the approach was focused on homogeneous scenarios (i.e., clustering one type of cooperating RRHs). However, 5G systems are deemed to be heterogeneous networks.

In our work, we address the heterogeneous Cloud RAN architecture and propose a two stage RRH clustering mechanism. As a first step we propose to use a fuzzy logic controller to cluster Low RRHs (small cells) considering inter and intra cluster interference with cell loads. In a second step, we cluster High RRHs (macro cells) considering system interference and BBU capabilities using linear programming optimization. The aim is to study different RRHs clustering techniques in order to improve network power consumption and resource utilization while keeping a good system QoS.

3 RRH Clustering Mechanism for C-RAN Architecture

3.1 Scenario and problem statement

The considered scenario is depicted in figure 1. We consider a C-RAN heterogeneous architecture composed of H-RRHs (High RRHs) which acts as macro cells and L-RRHs (Low RRHs) which acts as small cells. In each macro cell, n L-RRHs are connected to the H-RRH. In our scenario, we introduce the Cloud-RRH which represents the edge cloud. While in a traditional C-RAN architecture, all RAN functionalities are centralized in BBU pools, in this contribution, we propose to flexibly split these functionalities between edge cloud and central cloud. We also introduce additional computation and storage resources in the Cloud-RRH for computation offloading. These resources are represented by cloud containers.

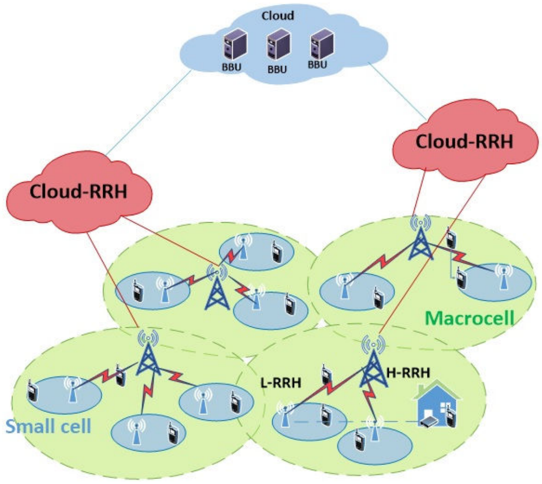


Figure 1: Proposed C-RAN Architecture

We propose a two-stage control loop for our heterogeneous C-RAN system. The first loop involves the decision of L-RRH clustering while the second loop involves the decision of H-RRH clustering. The decision making process of the first loop should be aware of intra- and inter-cluster interference and traffic load of all base stations. Furthermore, the decision making process of the second loop should be aware of system interference and BBU capacity. Therefore, the global objective is to enhance resource utilization in order to improve network power consumption and QoS.

3.2 Interference coordination model

When a user i is associated with RRH j, the received signal to noise and interference ratio is formulated by the following expression [2]:

$$SINR_{i,j} = \frac{\left|h_{i,j} w_{i,j}\right|^2 p_{i,j}}{\sum_{r \in C} \left|h_{i,r} w_{i,r}\right|^2 p_{i,r} + \sum_{r \in C_r / C} p_{i,r} + \sigma^2} \tag{1}$$

Where C is the RRH cluster containing RRH j, C_r are other RRH clusters which don't contain RRH j, $h_{i,r}$ is the channel vector of user i served by RRH r, $w_{i,r}$ is the precoding weight between user i and RRH r, $p_{i,r}$ is the received power at user i from RRH r before the Rayleigh fading effect and σ^2 is the noise. The first interference term, $\sum_{r \in C} \left|h_{i,r} w_{i,r}\right|^2 p_{i,r}$, stands for the intra-cluster interference. It depends on the coordination strategy used within this RRH cluster. The second term, $\sum_{r \in C_r / C} p_{i,r}$, stands for the inter-cluster interference, which we assume to be function of the path-loss only.

For L-RRH clustering we will consider both intra-cluster and inter-cluster interference. However, for H-RRH clustering, we will assume using zero-forcing (ZF) precoding within each cluster. Therefore, intra-cluster interference is eliminated and the SINR is formulated as follows:

$$SINR_{i,j} = \frac{p_{i,j}}{\sum_{r \in C_r / C} p_{i,r} + \sigma^2} \quad (2)$$

3.3 L-RRHs clustering

For L-RRHs clustering, and as a first stage of our clustering mechanism, we propose to use a fuzzy logic controller (FLC) in order to reduce uncertainties in clusters creation and reduce overhead while considering a multitude of parameters.

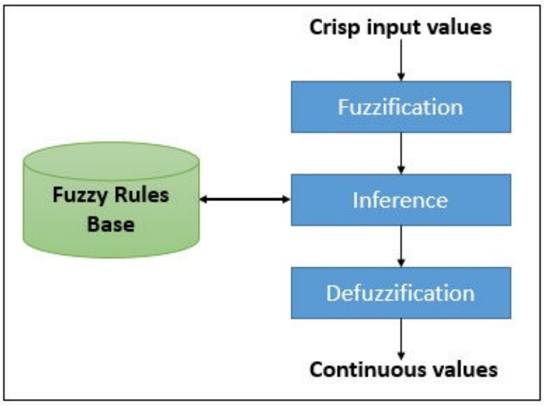


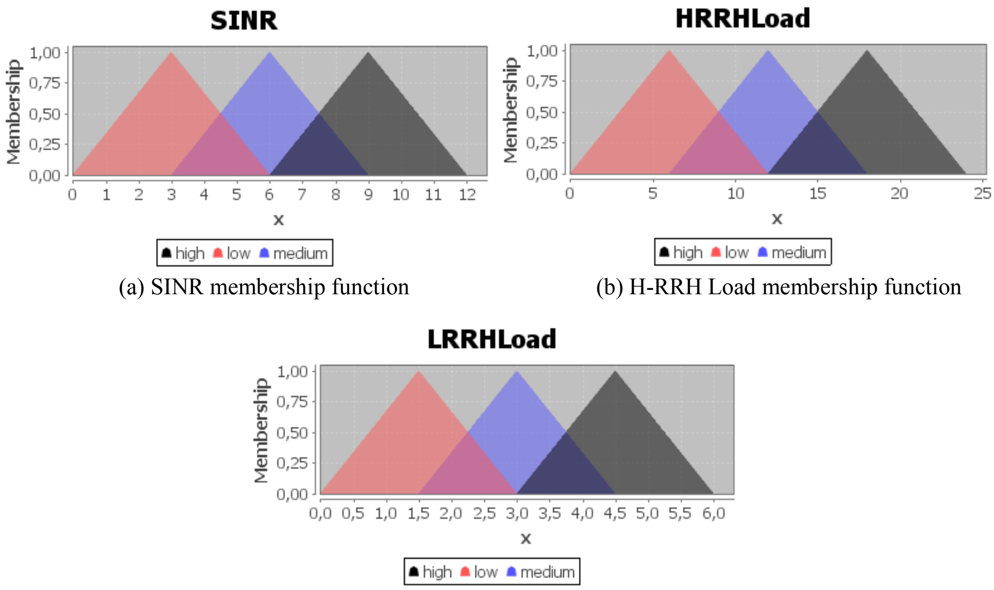
Figure 2: Fuzzy Logic Control Process

FLC is composed of three steps as illustrated in Figure 2. The first is the fuzzification. It consists of mapping each crisp input into a fuzzy variable. In our work, we will consider three variables which are SINR, load of L-RRH and load of H-RRH expressed by the number of RB (Resource Blocks). We divide each variable into three fuzzy levels: low, medium and high. Mapping is done using a membership function which defines the membership degree of the crisp input with the fuzzy variable. In our case, we will apply a triangular membership function, giving accurate and exact values. In the second step, inference is modelled as a set of fuzzy rules. We applied 27 rules here which are summarized in Table 1. In deffuzification step, the output action which is denoted here by the probability of L-RRH being added to the cluster C, is given by the gravity center of conclusions c_l in each rule weighted by the membership function using the following expression:

$$a(x_1, x_2, x_3) = \frac{\sum_{l=1}^{27} \mu_l(x_1)\mu_l(x_2)\mu_l(x_3)\, c_l}{\sum_{l=1}^{27} \mu_l(x_1)\mu_l(x_2)\mu_l(x_3)} \quad (3)$$

3.4 H-RRHs clustering

H-RRH clustering will allow obviously a better resource utilization by avoiding one-to-one mapping between BBUs and H-RRHs. The aim of clustering is to reduce the number of used BBUs in order to improve the network energy consumption while controlling the QoS by enhancing the SINR. We propose here to model the problem as an optimization problem under resources constraints.



(a) SINR membership function (b) H-RRH Load membership function

(c) L-RRH Load membership function

Figure 3: Membership Functions

We consider a system composed of a BBU with a capacity *K*, a set of n H-RRHs, each with an average RB demand $(d_1,\dots,d_n)$ and m users $(u_1,\dots,u_m)$ each with an average SINR $(s_1,\dots,s_m)$. The problem consists of finding a number of BBUs $B \le n$ and B-partition $Cl_1 \cup Cl_2 \cup \dots \cup Cl_B$ of the set of n H-RRHs such that $\sum_{i \in Cl_k} d_i \le K$ and $\sum_{i \in Cl_k} s_i \ge S$ for all k=1,…,B and where S is the SINR threshold. The solution is optimal when B is minimal.

We introduce two binary variables $x_{(i,j)}$ to indicate if a H-RRH is added to a cluster or not:

$$x_{(i,j)} = \begin{cases} 1 & if\ H-RRH\ i\ is\ added\ to\ cluster\ j \\ 0 & otherwise \end{cases}$$

and b_i to indicate if a BBU is active or not:

$$b_i = \begin{cases} 1 & if\ a\ BBU\ is\ active \\ 0 & otherwise \end{cases}$$

The linear programming formulation of the problem is as follows:

$$Minmize \quad B = \sum_{i=1}^{n} b_i$$

$$Subject\ to$$

$$\sum_{j=1}^{n} d_j x_{(i,j)} \le K\, y_i \ , \forall i \in \{1,\dots,n\} \tag{4}$$

$$\sum_{k=1}^{m} s_k x_{(i,j)} \ge m \cdot S \ , \forall i,j \in \{1,\dots,n\} \tag{5}$$

$$\sum_{i=1}^{n} x_{(i,j)} = 1 \ , \forall\, j \in \{1,\dots,n\} \qquad (6)$$

Table 1: FLC Rules for L-RRHs Clustering

Rule	SINR	L-RRH load	H-RRH load	Cluster membership
1	Low	Low	Low	$\in$
2	Low	Low	Medium	$\notin$
3	Low	Low	High	$\notin$
4	Low	Medium	Low	$\in$
5	Low	Medium	Medium	$\in$
6	Low	Medium	High	$\notin$
7	Low	High	Low	$\notin$
8	Low	High	Medium	$\notin$
9	Low	High	High	$\notin$
10	Medium	Low	Low	$\in$
11	Medium	Low	Medium	$\in$
12	Medium	Low	High	$\notin$
13	Medium	Medium	Low	$\in$
14	Medium	Medium	Medium	$\in$
15	Medium	Medium	High	$\notin$
16	Medium	High	Low	$\notin$
17	Medium	High	Medium	$\notin$
18	Medium	High	High	$\notin$
19	High	Low	Low	$\in$
20	High	Low	Medium	$\in$
21	High	Low	High	$\notin$
22	High	Medium	Low	$\in$
23	High	Medium	Medium	$\in$
24	High	Medium	High	$\notin$
25	High	High	Low	$\in$
26	High	High	Medium	$\notin$
27	High	High	High	$\notin$

The optimization is subject to constraints given by (4) through (6). Constraint (4) guarantees that BBU maximum capacity is not exceeded, i.e. the sum of loads from the cluster of H- RRHs associated to a BBU does not exceed the BBU peak capacity. Inequality (5) expresses the interference constraint, i.e. the sum of SINR of H-RRHs constituting the cluster should exceed a threshold in order to guarantee the QoS. Finally, constraint (6) ensures the fact that each H-RRH is associated with exactly one cluster.

H-RRH clustering is formulated as a modified one dimensional bin packing problem. Since the bin packing problem is NP-hard [9], it is hard to find an optimal solution in large network systems. Therefore, we propose a heuristic algorithm to cluster H-RRHs.

4 Simulation and results

This section provides simulation results for the first stage of our RRH clustering scheme: L-RRH clustering. The fuzzy logic controller is developed using jFuzzyLogic java library [10][11] and the experiments are carried out using Eclipse. We consider a small heterogeneous C-RAN composed of 7 H-RRHs each with of capacity of 24 resource blocs (RB). H-RRHs have a coverage of 500m and L-RRHs are 30m-radius [12].

Figure 4 shows the evolution of average SINR by the number of L-RRHs per H-RRH. Results show that while without using clustering the QoS degrades with the increase in density, the proposed clustering scheme is able to improve the QoS with the increasing of L-RRHs density. Results clearly show that presented scheme is effective in dense deployment scenario. Therefore, the proposed clustering mechanism can be deployed in high dense 5G C-RANs.

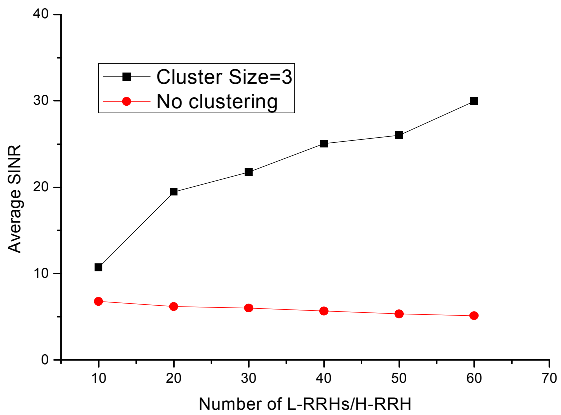


Figure 4: Average QoS variation as the number of active L-RRHs per H-RRH

5 Conclusion

In this paper, we have formulated the RRH clustering problem in heterogeneous Cloud RAN architecture as a two-stage control loop. The first loop used a fuzzy logic controller to decide about L-RRHs clustering. The second loop was dedicated to H-RRHs clustering using a linear programming optimization. Our contribution aims to ameliorate network resource utilization in order to enhance power consumption and user QoS. Simulation results of L-RRH clustering show that the proposed scheme is effective for dense deployments.

As a future work, we will develop an optimal solution for H-RRHs clustering problem. Moreover, we will simulate the proposed clustering mechanism in order to evaluate our system performances especially for energy consumption and interference avoidance and compare it to other state of art contributions.

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