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Fuzzy-Logic Based Call Admission Control in 5G Cloud Radio Access Networks with Pre-emption

Tshiamo Sigwele^{1*}†, Prashant Pillai², Atm S Alam³ and Yim F Hu¹

Abstract

Fifth generation (5G) cellular networks will be comprised of millions of connected devices like wearable devices, Androids, iPhones, tablets and the Internet of Things (IoT) with a plethora of applications generating requests to the network. The 5G cellular networks need to cope with such sky-rocketing traffic requests from these devices to avoid network congestion. As such, cloud radio access networks (C-RAN) has been considered as a paradigm shift for 5G in which requests from mobile devices are processed in the cloud with shared baseband processing. Despite call admission control (CAC) being one of radio resource management techniques to avoid the network congestion, it has recently been overlooked by the community. The CAC technique in 5G C-RAN has a direct impact on the quality of service (QoS) for individual connections and overall system efficiency. In this paper, a novel Fuzzy-Logic based CAC scheme with pre-emption in C-RAN is proposed. In this scheme, cloud bursting technique is proposed to be used during congestion, where some delay tolerant low-priority connections are pre-empted and outsourced to a public cloud with a penalty charge. Simulation results show that the proposed scheme has low blocking probability below 5%, high throughput, low energy consumption and up to 95% of return on revenue.

Keywords: Call Admission Control (CAC); Cloud Radio Access Network (C-RAN); Pre-emption; Fuzzy-Logic; 5G

1 Introduction

In recent years, a large number of mobile devices and multimedia services in recent years has resulted in gigantic demands for larger system capacities and higher data rates over large coverage areas in high mobility environments. As a result, radio access networks (RAN) have tremendously grown so complex and are becoming so difficult to manage and control. Maintaining quality of service (QoS) for real-time (RT) and non-real time (NRT) services while optimizing resource utilization is a major challenge for next generation systems like fifth generation (5G). The 5G cellular networks will be comprised of millions of devices like wearable devices, Androids, iPhones, tablets and Internet of Things (IoT) connected to the network with a plethora of applications. The 5G cellular networks will need to cope with the explosive increase of traffic requests from these devices to avoid network overload and traffic congestion in the core network. The 5G will comprise of cloud based architecture called cloud RAN (C-RAN) which was introduced as a way of solving the drawbacks of conventional RAN by pooling BS resources to a centralized cloud. Virtualization concept is used on general purpose processors (GPPs) to dynamically allocate BS processing resources to different virtual baseband units (vBBU) in the BBU pool.

Call admission control (CAC) is a scheme that offers an effective way of avoiding network congestion and can play a key role in the provision of guaranteed QoS and avoid traffic congestion in 5G. The basic function of a CAC algorithm is to accurately decide whether a connection can be accepted into a resource constrained network without violating the service commitments made to the already admitted connections. On the other hand, However, traditional CAC schemes are not suitable for 5G C-RAN while an efficient CAC scheme aims to optimize call blocking probability (CBP), call dropping probability (CDP) and system utilization.

There are many reasons as to why conventional CAC schemes are not suitable for 5G. First, conventional CAC approaches in cellular networks suffer uncertainties due to real-time processing of radio signals and the time varying nature of parameters such as speed,

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location, direction, channel conditions, available power, etc. Many of these traditional CAC schemes are ineffective leading to incorrect request admission when the network is actually incapable of servicing the request or incorrect rejection when there are actually enough resources to service the request. Some of these CAC schemes tend to assume network state information is static [1]. However, in practice the network is dynamic and values measured keep changing. Second, as stated in our previous work [1], traditional CAC schemes are based on stand-alone RAN base station (BS) architectures while 5G will be based on centralized cloud BSs. These BSs are preconfigured for peak loads and have unshared processing and computation resources located in the BS cell areas. These BS resources cannot be shared to address varied traffic needs on other cell areas, causing poor resource utilization, high CBP and CDP. As such there is a need for efficient CAC schemes suitable for 5G. Intelligent CAC schemes based on intelligent decision making techniques like fuzzy-logic are a promising solution and solve the problem of imprecision and uncertainties in cellular networks [2]. The schemes mimic the cognitive behaviour of human mind without the need for complex mathematical modelling making them adaptive, less complex, flexible and suitable to cope with the rapidly changing network conditions of cellular networks in 5G.

This paper presents a fuzzy-logic based CAC scheme using pre-emption in 5G C-RAN. During congestion, some delay tolerant NRT low priority connections are pre-empted and outsourced to a public cloud with a pricing penalty to accommodate the RT connections, a technique called cloud bursting [3]. This work is the continuation of our published works in [1] and [2] where the former proposed CAC in 5G C-RAN without fuzzy-logic while the latter proposed CAC in 5G C-RAN using fuzzy-logic without pre-emption. The work in this paper will add pre-emption and cloud bursting technique. Below are the contributions of this paper:

- i) A CAC scheme based on fuzzy-logic with pre-emption in 5G C-RAN is proposed. The fuzzy-logic avoids uncertainties caused by traditional CAC schemes in distributed RAN systems.
- ii) A cloud bursting technique is proposed where during congestion, low priority delay tolerant NRT connections are pre-empted and outsourced to a public cloud at a certain price penalty to accommodate the RT connections. It is assumed that the public cloud is of infinite processing capacity as such it cannot get congested, as such it will not be captured in the simulation.

- iii) A rigorous simulation study is conducted for validating the proposed scheme, which shows a significant performance improvement.

CAC with pre-emption technique have been previously studies in the past, but in this work, pre-emption in CAC have been implemented using fuzzy logic technique which significantly improves blocking probability, also, CAC on its own have not been studied in C-RAN and this is the first work to study CAC in C-RAN. Also, cloud bursting have not been implemented in CAC before and is introduced in our work.

The rest of this paper is organized as follows. Section II presents the related works on CAC schemes. The proposed fuzzy-logic CAC scheme in 5G C-RAN is presented in Section III. Section IV presents the simulation model and the obtained performance results. Finally, conclusion and further works are presented in Section V.

2 Related Work

There are many ways of categorizing CAC schemes such as parameter based, measurement based, utility based, centralized/distributed, static/dynamic etc. Comprehensive surveys can be found here [4, 5, 6, 7]. This paper concentrate on intelligent CAC schemes which are based on intelligent decision making techniques for solving the problem of error and uncertainties in conventional CAC schemes [8]. They are adaptive and flexible, thus making them suitable to cope with the rapidly changing network conditions and bursty traffic that can occur in 5G networks to give an efficient network management scheme. A fuzzy-logic CAC scheme for stand alone BSs for high-speed networks was proposed in [9]. Even though the author used fuzzy-logic to better estimate equivalent capacity, he does not show how the schemes performs in terms of CBP. In [10], the author proposed a fuzzy-logic CAC approach scheme for long term evolution (LTE). Even though the proposed scheme shows better call rejection than the quality index based approach, the CAC scheme is based on standalone BS architecture with low BS utilisation not suitable for 5G. A method of fuzzy admission control for multimedia applications scheme is proposed in [11]. In this method, for multimedia applications, two fuzzy controllers have been introduced allowing better estimation of QoS. The drawbacks of this scheme is that it has many fuzzy controllers that can magnify CAC complexity and computation latency. In [12], a CAC scheme using genetic algorithm (GA) has been proposed for roaming mobile users with low handoff latency in next generation wireless systems. The scheme provides high network utilization, minimum cost but it is not suitable for real time applications since

GA is very slow and cannot be used for real time decision making. A neural network approach for CAC with QoS guarantee in multimedia high-speed networks is proposed in [13]. It is an integrated method that combines linguistic control capabilities and the learning abilities of a neural network. Even though the scheme provides higher system utilization, it requires large computational resources working in parallel. A novel learning approach to solve the CAC in multimedia cellular networks with multiple classes of traffic is presented in [14]. The near optimal CAC policy is obtained through a form of Neuro-Evolution algorithm. This method guarantees that the specified CDP remain under a predefined upper bound while retaining acceptable CBP. This scheme is black box learning approach since the knowledge of its internal working of the scheme is never known.

3 Proposed CAC Scheme

3.1 C-RAN Architecture

C-RAN is a paradigm shift for next-generation RANs like 5G. C-RAN is described using four C's which stand for; clean, centralized processing, collaborative radio and real-time cloud computing [1]. The C-RAN architecture adopted in this paper is shown in Fig. 1. The C-RAN concept separates the radio and antenna parts from the digital baseband parts and pools multiple baseband units (BBUs) in a central office called the BBU pool. These digital only BSs, called vBBUs, are linked via high bandwidth, low latency fiber to remote radio heads (RRHs). GPPs like X86 and ARM processors are used to house the BBUs and using cloud computing virtualization concept, multiple vBBU virtual machines (VMs) are dynamically provisioned in accordance to traffic demands.

3.2 Problem Formulation

The main problem is that next-generation cellular networks like 5G C-RAN will have to process many requests from billions of devices, as such there will be traffic congestion in this 5G network. The questions to be answered is; *How can efficient CAC schemes be devised and then incorporated in 5G C-RAN to improve CBP and resource utilization while maintaining the required QoS.*

3.3 Fuzzy-Logic based CAC Scheme

In this paper, fuzzy-logic scheme is used for performing CAC in 5G C-RAN because of its simplicity and robustness [6]. Fuzzy-logic techniques resembles the human decision making with an ability to generate precise solutions from certain or approximate information. Fuzzy-logic avoids uncertainties and computational

complexities brought by many CAC schemes and does not require precise inputs, and can process any number of inputs. Fuzzy-logic incorporates a simple, rule based approach based on natural language to solve control problem rather than attempting to model a system mathematically. In the proposed scheme, baseband signals from multiple cells are no longer processed on their stand-alone BBUs but processed on GPPs in the cloud using the concept of cloud computing. The GPPs are software defined enabling multiple radio signal from different cells to be processed in one computer platform. This is made possible through virtualization technology where hardware components are abstracted from software components. The vBBUs are dynamically provisioned to service traffic requests from cells. The vBBU performs baseband signal processing of specific cell traffic. The traffic demand from cells is mapped into baseband processing resource such that every RRH traffic is serviced by its own vBBU.

Fig. 2 shows the proposed fuzzy CAC system model diagram for 5G C-RAN which is located in the BBU pool inside the cloud controller. The model consists of various modules comprising of the operator's C-RAN infrastructure for normal processing of requests when the congestion is low and a third party public C-RAN infrastructure for handling requests for the operator's C-RAN during congestion. Connection requests that are processed in the public infrastructure are charged a certain price by the charging manager depending on the type of service and the size of the connection request. The resource estimator estimates the available capacity in the operator's C-RAN infrastructure and indicate whether the cloud is congested or not. The model also comprise of the fuzzy controller which performs the CAC decisions for incoming requests from users. The fuzzy controller takes as inputs three variables which are effective capacity, Ec , in Kbps, service type St and normalized available capacity, Ac and the output is the admittance decision, Ad . The admittance decision is either, accept a request, reject a request or pre-empt some low priority requests and outsource them to a public cloud. The traffic requests are divided into two groups, namely RT and NRT traffic as shown below.

- RT classes - These are called guaranteed bit rate (GBR) which include VoIP, live streaming, video call and real time gaming. This type of services are delay sensitive.
- NRT classes - This are called non-GBR which include buffered streaming, and transmission control protocol (TCP) based services like web browsing, email, file transfer protocol (ftp), and point to point (p2p). These types of services are delay tolerant.

3.3.1 Cloud Bursting Technique for Pre-empted Connections

The cloud bursting technique allows the operators to dynamically extend their infrastructure by renting third-party resources [15]. During congestion of the operator's C-RAN infrastructure, when a high priority RT connections arrives as illustrated in Fig. 3, and the cloud is congested, two things happen, either the low priority NRT connections are pre-empted from the operator's C-RAN and then bursted into the public C-RAN infrastructure to accommodate the high priority RT connections or the RT connection is dropped if there are no NRT connections to pre-empt in the operator's C-RAN. RT connections are never outsourced to the public cloud because they are delay sensitive. Only NRT connections are outsourced to the public cloud. An agreement is made between the operator and the public cloud operator and a certain price is charged for outsourcing some NRT connections. When a NRT connection arrives and the operator's cloud is congested, the NRT connection is forwarded to the public cloud as shown in Fig. 3 with a certain price penalty where the request will be charged by the charging manager.

3.3.2 Structure of Fuzzy-Logic Controller

The fuzzy controller of the proposed scheme takes three inputs: (i) effective capacity, Ec ; (ii) available capacity, Ac ; and (iii) network congestion factor, Nc and output the admittance decision, Ad . Below is the description of the structure of the proposed fuzzy-logic controller.

Membership Functions: Trapezoidal and triangular membership functions are chosen for simplicity. The membership functions for input and output linguistic parameters are shown in Fig. 4. The values of the membership functions have been chosen based on commonly used values of membership functions in various literature. For the fuzzy controller, the term sets for Ec , St , Ac , Nc and Ad are defined as follows:

- i) $T(Ec) = \{Low, Medium, High\}$
- ii) $T(St) = \{NRT, RT\}$
- iii) $T(Ac) = \{NotEnough, Enough\}$
- iv) $T(Ad) = \{Accept, Reject, Preempt\}$

Fuzzy Rule Base: The fuzzy rule base consists of a series of fuzzy rules, shown in Table 1. These control rules are of the following form: IF 'condition', THEN 'action'. Example: if St is 'RT' and 'St' is 'Not Enough' and 'Ec' is 'High' then 'Reject'.

Defuzzification Method: The Center of Gravity (COG) [1] method is used for defuzzification to convert the degrees of membership of output linguistic variables into crisp/numerical values. The COG method is adopted since the membership functions used are simple triangular and trapezoidal shapes with low computational complexity and can be expressed as [1]:

$$Z_{COG} = \frac{\int_z \mu(z)z dz}{\int_z \mu(z) dz} \quad (1)$$

3.3.3 Queueing System for pre-empted connections

The connections in the cloud follows the $M/M/c/K$ queueing model or Erlang-B model [16]. In the $M/M/c/K$ model, the request arrival is governed by a Poisson process at arrival rate λ and the service times are exponentially distributed with parameter μ and there are c servers in the cloud processing the requests from the front of the queue. The variable K denotes the capacity of the system. The buffer is considered to be of a finite size and connection requests greater than the queue length are dropped. The model can be described as a continuous time Markov chain which is a type of a birth death process. The server utilization, ρ , is written as [16]:

$$\rho = \frac{\lambda}{c\mu}, \rho < 1 \quad (2)$$

The variable ρ should be less than one for the queue to be stable otherwise the queue will grow without bound. The probability that the system contain n connections can be written as [16]:

$$\pi_0 = \left[\sum_{n=0}^c \frac{\lambda^n}{\mu^n n!} + \frac{\lambda^c}{\mu^c c!} \sum_{n=c+1}^K \frac{\lambda^{n-c}}{\mu^{n-c} c^{n-c}} \right]^{-1} \quad (3)$$

$$\pi_n = \begin{cases} \frac{(\lambda/\mu)^n}{n!} \pi_0, & \text{for } n = 1, 2, \dots, c \\ \frac{(\lambda/\mu)^n}{c^{n-c} c!} \pi_0, & \text{for } n = c+1, \dots, K. \end{cases} \quad (4)$$

where π_n is the probability that the cloud system contains n connections. The amount of time a connection spends in both the queue and in service is called the response time. The average response time is given as [16]:

$$T = \pi_0 \frac{\rho(c\rho)^c}{(1-\rho)^2 c!} + \frac{1}{\mu} \quad (5)$$

Then the probability that an arriving connection is blocked can be written using Erlang B formula as [16]:

$$P_b = \frac{\rho^c}{c!} \sum_{i=0}^c \frac{\rho^i}{i!} \quad (6)$$

4 Results and Analysis

4.1 Simulation Parameters

Four schemes are compared for performance evaluation;

- 1) CAC scheme on distributed RAN systems with stand alone BBUs serving individual BSs from our previous work in [1],
- 2) CAC on C-RAN without fuzzy-logic applied from our previous work in [1],
- 3) CAC with fuzzy-logic on C-RAN without pre-emption from our previous work in [2] and
- 4) the proposed CAC with fuzzy-logic on C-RAN with pre-emption in this paper.

The Matrix Laboratory (MATLAB) was used to simulate the proposed framework. For simulation and performance evaluation the following 4 traffic classes or service types were considered as shown in Table II from [17]:

- VoIP as RT service
- Conversational video (live streaming) as RT service
- ftp as NRT service
- web browsing or www as NRT service

The MBR values are taken as the values for E_c . Four traffic classes are evaluated for simplicity but the proposed framework applies to multiple traffic classes. The value of λ was varied with every simulation and 100 calls were generated for each traffic class. The simulation time was kept at 500 seconds. The membership function for the inputs and output of the fuzzy controller are shown in Fig. 4. It is assumed that the network operator operating the private cloud enter into an agreement with the public cloud operator which involves the Service Level Agreement (SLA) which involves the cost. The cost of accepting a connection request in the public cloud is assumed to be 10% of what the private C-RAN operator will make when processing the request. It should be noted that the request size, duration and QoS can form the basis of how much the request can be charged but this will be considered in future, but in this paper, only 10% is deducted by the public cloud.

4.2 Simulation Results

Fig. 5, Fig. 6 and Fig. 7 shows a comparison of the combination of the input terms E_c, A_c, S_t and the output term A_d when the fuzzy rules in table 1 are applied. The figure shows that as the value of E_c increases, the admittance (A_d) decreases meaning that when the value E_c of a particular service is *Low*,

the admittance becomes *Accept* and as the value of E_c increases, the admittance becomes *Preempt*. Also, for available capacity (A_c), the figures shows that when A_c is *NotEnough*, the admittance value becomes higher meaning that there is *Preemption* of NRT connections. As the value of A_c increases (to *Enough*), the admittance tend to *Accept*. Finally for service type (S_t), when the value of S_t increases from *NRT* to *RT*, the admittance decreases from *Preemption* to *Accept* since the NRT requests are pre-empted and the RT connections are accepted.

Fig. 8 shows the blocking probability versus offered traffic load. The figure shows that for all the schemes, as the offered traffic increases, the blocking probability also increases. The CBP of the CAC distributed RAN is higher than all the other schemes because the baseband computing power is limited as each cell is covered by a single BBU with limited capacity. The blocking probability of CAC C-RAN with no fuzzy scheme also performs poorly with blocking probability greater than threshold at 40% offered traffic load due to improper and uncertain decision making of the admission control scheme without fuzzy-logic. The fuzzy C-RAN without pre-emption performs well up to 90% traffic load compared to the previous two schemes because fuzzy-logic avoids imprecisions and uncertainties when performing admission control. The fuzzy C-RAN with pre-emption scheme performs better than all the rest with 100% traffic below blocking probability threshold of 5% because, instead of connection requests being blocked, they are forwarded to a public cloud as such more connections are accepted in the system.

Fig. 9 shows the resource utilization in the private C-RAN cloud for different traffic arrival rates. The figure shows that as the arrival rate increases, the resource utilization in the cloud also increases because more requests are being processed and occupies the available capacity. The fuzzy C-RAN with pre-emption and the fuzzy C-RAN without pre-emption scheme have the same but higher resource utilization than all the other schemes because the BBUs in the cloud are shared and a single BBU can process requests from multiple cells. It can be noticed that pre-emption have no impact on resource utilization. The CAC C-RAN with no fuzzy scheme has high utilization than the CAC distributed RAN scheme because in the latter, BBUs are stand alone and BBU processing resources are not shared to address varied traffic needs in the cell area. Fig. 10 shows the response time versus offered traffic load for C-RAN system. The figure shows that as the offered traffic increases, the response time increases because more requests takes more time to be processed. The figure shows that the

pre-empted NRT connections takes more time to be processed because they are forwarded to the public cloud which incurs more delays, but this does not affect the NRT pre-empted connections because they are delay tolerant. The new RT connections are delay sensitive and they have small response time because they are processed in the private cloud and not in the public cloud.

Fig. 11 shows the operators revenue for peak traffic periods. At peak traffic periods, the CAC distributed RAN scheme has a blocking probability of 0.5 which means the revenue is 50%, where the lower revenue is due to higher blocking probability. The CAC C-RAN with no fuzzy scheme has a blocking probability of 20% at peak traffic leading to a revenue of 80%. The fuzzy C-RAN without pre-emption scheme has a blocking probability of 10% at peak traffic leading to 90% revenue for the operator while the fuzzy C-RAN with pre-emption scheme has the highest revenue than all the schemes which is 95% since more requests are accepted in both the private and public cloud. Fig. 12 shows the the total network throughput for different traffic loads and it can be shown that for both schemes, as the traffic load increases, the network throughput also increases. The throughput is for the entire network and it is calculated at the BBU pool and it is expected to be larger. The fuzzy C-RAN with pre-emption scheme has a higher throughput than all the other schemes with 900Mbps and 1600Mbps during low and peak traffic respectively and the scheme is 28.6% effective compared CAC distributed RAN scheme. This is because more connections are being accepted as more computing resources are being provided by the public cloud using the cloud bursting technique. The fuzzy C-RAN without pre-emption has a throughput of 880Mbps and 1550Mbps during low and peak traffic respectively and outperforms the CAC distributed RAN scheme by 25.7%. The CAC C-RAN with no fuzzy performs better than the CAC distributed scheme by 8.6%. The CAC distributed RAN performs poorly that the rest of the schemes with 700Mbps and 1400Mbps during low and peak traffic respectively because it has high blocking probability due to limited baseband computing resources.

5 Conclusion

In this paper, a fuzzy-logic based call admission control (CAC) scheme is proposed in fifth generation (5G) cloud radio access networks (C-RAN). The fuzzy-logic avoids uncertainties caused by traditional CAC schemes in distributed RAN systems. A cloud bursting technique used proposed where during congestion, low priority delay tolerant none realtime (NRT) connections are pre-empted and outsourced to a public

cloud at a certain price penalty. The simulation results shows that the proposed scheme has low blocking probability which is within blocking probability threshold limit of 5%. The proposed scheme has a return revenue of 95%.

Competing interests

The authors declare that they have no competing interests.

Author's contributions

All the authors have contributed significantly to this research articles.

Below are the author's contributions:

- i) Mr Tshiamo Sigwele have contributed significantly to this paper both on coming up with mathematical models, running simulations and writing up the paper.
- ii) Dr Prashant Pillai has contributed significantly on the aspects of supervision, the organization of the paper, reviewing and the validation of the proposed framework.
- iii) Dr Atm Shafiul Alam has also contributed significantly in the related work section and also helped in drawing the diagrams in this paper.
- iv) Prof Yim Fun Hu has also contributed significantly in this work by proof reading the work and validating the proposed framework and also restructuring the paper.

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Tables

Table 1 Fuzzy Rule Base for Fuzzy Controller.

Rule	St	Ac	Ec	Ad
1	RT	Not Enough	Low	Outsource
2	RT	Not Enough	Medium	Reject
3	RT	Not Enough	High	reject
4	RT	Enough	Low	Accept
5	RT	Enough	Medium	Accept
6	RT	Enough	High	Accept
7	NRT	Not Enough	Low	Outsource
8	NRT	Not Enough	Medium	Outsource
9	NRT	Not Enough	High	Outsource
10	NRT	Enough	Low	Accept
11	NRT	Enough	Medium	Accept
12	NRT	Enough	High	Accept

Figures

Figure 1 C-RAN Architecture. A figure showing the C-RAN architecture.

Figure 2 Proposed System Model. A figure showing the proposed system model.

Table 2 Simulation Parameters [17].

QCI	Service	Type	Priority	Delay	PER	MBR/ E_c
1	VoIP	GBR	2	100ms	10^{-2}	12Kbps
3	Conversational video	GBR	4	150ms	10^{-3}	240Kbps
8	ftp	non-GBR	8	300ms	10^{-6}	512Kbps
9	www	non-GBR	9	300ms	10^{-6}	512Kbps

Figure 3 Cloud bursting model. A figure showing the cloud bursting technique when RT and NRT connections arrive into the congested BBU pool.

Figure 4 Membership functions for (a) Effective capacity, E_c (b) Service type, St (c) Available capacity, Ac (d) Admittance, Ad . A figure showing the the membership functions of various fuzzy-logic terms.

Figure 5 Comparison for inputs St , Ec and the output Ad . A figure showing the comparison of fuzzy inputs and output.

Figure 6 Comparison for inputs Ec , Ac and the output Ad . A figure showing the comparison of fuzzy inputs and output.

Figure 7 Comparison for the inputs St , Ac and the output Ad . A figure showing the comparison of fuzzy inputs and output.

Figure 8 Blocking probability versus offered traffic load.

Figure 9 System utilization versus arrival rate. A figure showing how the system utilization in the BBU pool varies with the change in arrival rate of requests.

Figure 10 Response time versus offered traffic load. A figure showing how the service response time/delay varies with the increase in the offered traffic load.

Figure 11 Operator revenue. A figure showing the operator's income from hosting connection requests from users.

Figure 12 System throughput. A figure showing the total throughput of the C-RAN system