Sigwele *et al. EURASIP Journal on Wireless Communications and Networking* (2017) 2017:157
DOI 10.1186/s13638-017-0944-x

EURASIP Journal on Wireless Communications and Networking

RESEARCH Open Access

Fuzzy logic-based call admission control in 5G cloud radio access networks with preemption

Tshiamo Sigwele[1*†], Prashant Pillai[2†], Atm S. Alam[3] and Yim F. Hu[1]

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 preemption 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 preempted 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), Preemption, 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.

---

*Correspondence: t.sigwele@bradford.ac.uk
†Equal contributors
[1] Faculty of Engineering and Informatics, University of Bradford, BD7 1DP Bradford, UK
Full list of author information is available at the end of the article

© The Author(s). 2017 **Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

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, 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 behavior of human mind without the need for complex mathematical modeling 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 preemption in 5G C-RAN. During congestion, some delay tolerant NRT low priority connections are preempted 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 5GC-RAN using fuzzy logic without preemption. The work in this paper will add preemption and cloud bursting technique. Below are the contributions of this paper:

(i) A CAC scheme based on fuzzy logic with preemption 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 preempted 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 preemption technique have been previously studies in the past, but in this work, preemption 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 2 presents the related works on CAC schemes. The proposed fuzzy logic CAC scheme in 5G C-RAN is presented in Section 3. Section 4 presents the simulation model and the obtained performance results. Finally, Conclusions and further works are presented in Section 5.

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 [4–7]. 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 remains under a pre -defined 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

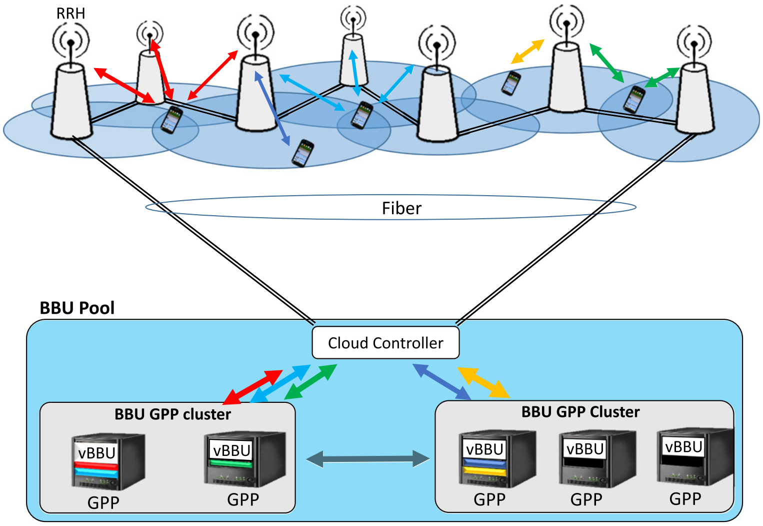
C-RAN is a paradigm shift for next-generation RANs like 5G. C-RAN is described using four C's which stand for; clean, centralized processing, collaborative radio, and real-time cloud computing [1]. The C-RAN architecture adopted in this paper is shown in Fig. 1. The C-RAN concept separates the radio 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 question to be answered is how can efficient CAC schemes be deviced and then be 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



GPP = General Purpose Processor, BBU=Baseband Unit
RRH = Remote Radio Head , vBBU= Virtual Baseband Unit

Fig. 1 C-RAN architecture. A figure showing the C-RAN architecture 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.

Figure 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 preempt 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.

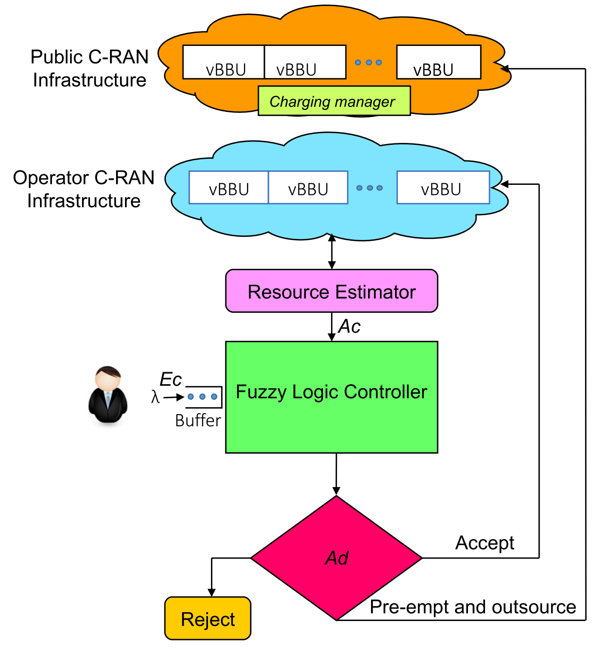


Fig. 2 Proposed system model. A figure showing the proposed system model

- 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 preempted 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 preempted 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 preempt 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

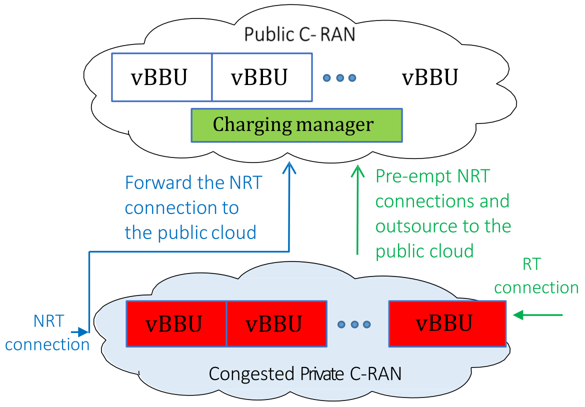


Fig. 3 Cloud bursting model. A figure showing the cloud bursting technique when RT and NRT connections arrive into the congested BBU pool

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

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]:

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

3.3.3 Queueing system for preempted 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 that 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]:

$$\rho = \frac{\lambda}{c\mu}, \rho < 1 \tag{2}$$

The variable ρ should be less than one for the queue to be stable otherwise the queue will grow without bound.

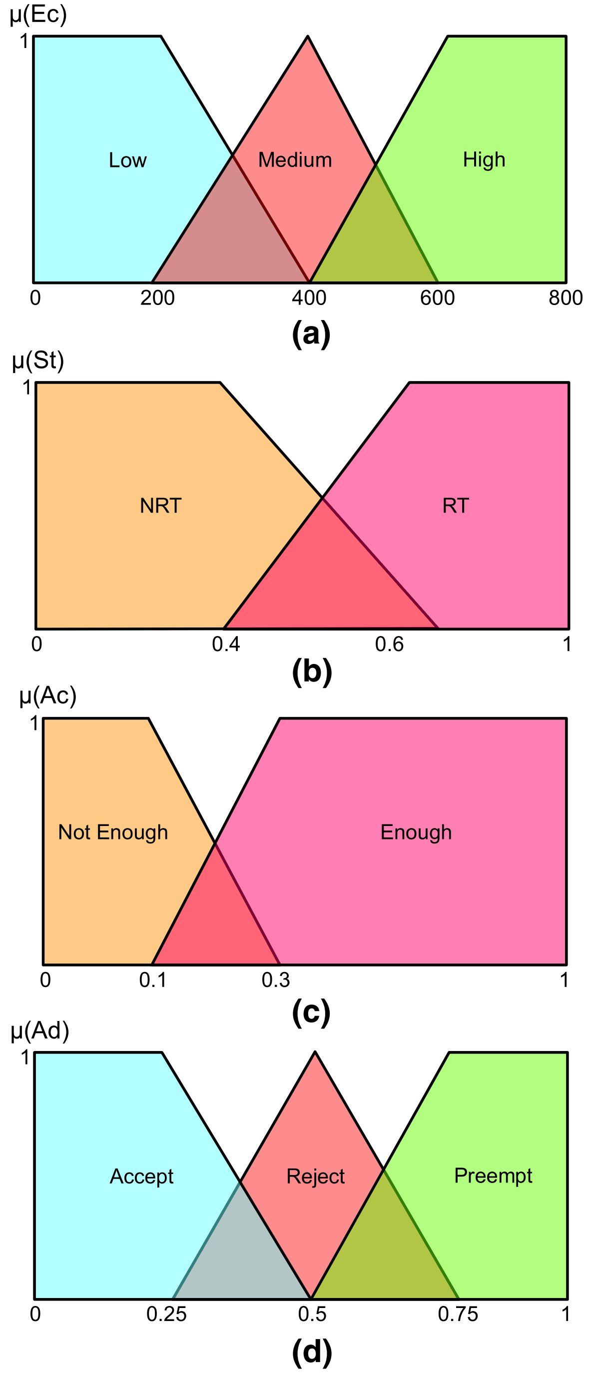


Fig. 4 Membership functions for (**a**) effective capacity, Ec (**b**) service type, St (**c**) available capacity, Ac (**d**) admittance, Ad. A figure showing the the membership functions of various fuzzy logic terms

The probability that the system contain n connections can be written as [16]:

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

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

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

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]:

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

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

$$P_b = \frac{\frac{\rho^c}{c!}}{\sum_{i=0}^{c} \frac{\rho^i}{i!}} \tag{6}$$

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 preemption from our previous work in [2], and
4) the proposed CAC with fuzzy logic on C-RAN with preemption in this paper.

The Matrix Laboratory (MATLAB) was used to simulate the proposed framework. For simulation and performance evaluation, the following four traffic classes or service types were considered as shown in Table 2 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 s. 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 enters 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 the future, but in this paper, only 10% is deducted by the public cloud.

4.2 Simulation results

Figures 5, 6, and 7 shows a comparison of the combination of the input terms Ec, Ac, St, and the output term Ad when the fuzzy rules in Table 1 are applied. The figure shows that as the value of Ec increases, the admittance (Ad) decreases meaning that when the value Ec of a particular service is Low, the admittance becomes Accept and as the value of Ec increases, the admittance becomes Preempt. Also, for available capacity (Ac), the figures show that when Ac is NotEnough, the admittance value becomes higher meaning that there is Preemption of NRT connections. As the value of Ac increases (to Enough), the admittance tend to Accept. Finally for service type (St), when the value of St increases from NRT to RT, the admittance decreases from Preemption to Accept since the NRT requests are preempted and the RT connections are accepted.

Table 2 Simulation parameters [17]

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

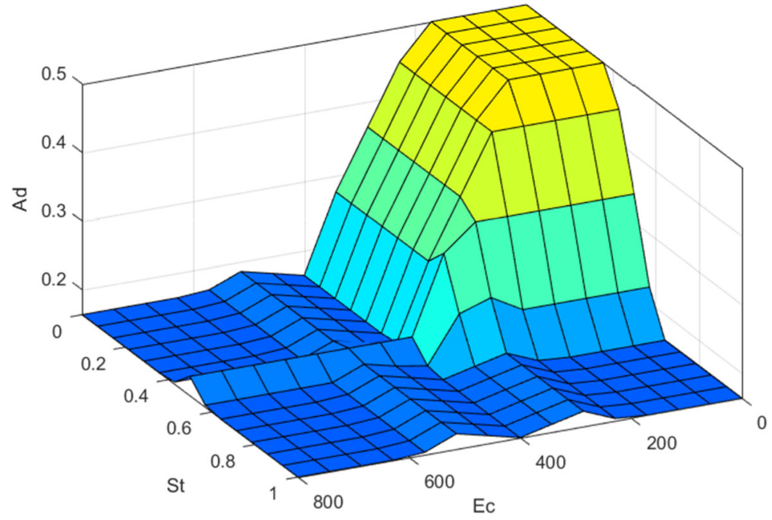


Fig. 5 Comparison for inputs St, Ec, and the output Ad. A figure showing the comparison of fuzzy inputs and output

Figure 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 preemption 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 preemption 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.

Figure 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 preemption and the fuzzy C-RAN without preemption scheme have the same but higher

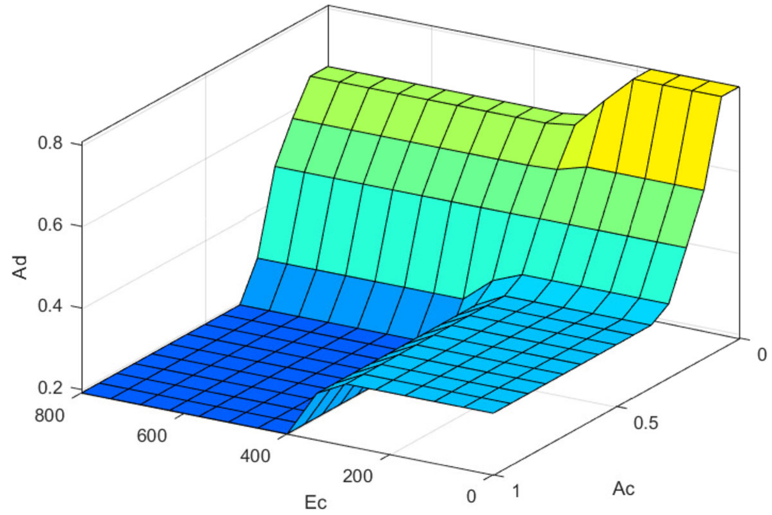


Fig. 6 Comparison for inputs Ec, Ac, and the output Ad. A figure showing the comparison of fuzzy inputs and output

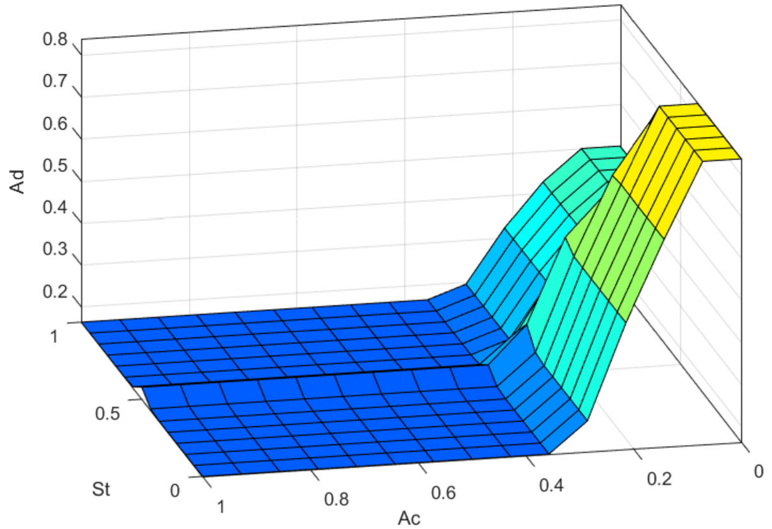


Fig. 7 Comparison for the inputs St, Ac, and the output Ad. A figure showing the comparison of fuzzy inputs and output

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 preemption 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. Figure 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 take more time to be processed. The figure shows that the preempted NRT connections take more time to be processed because they are forwarded to the public cloud which incurs more delays, but this does not affect the NRT preempted 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.

Figure 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 preemption scheme has a blocking probability of 10% at peak traffic leading to 90% revenue for the operator while the fuzzy C-RAN with preemption scheme has the

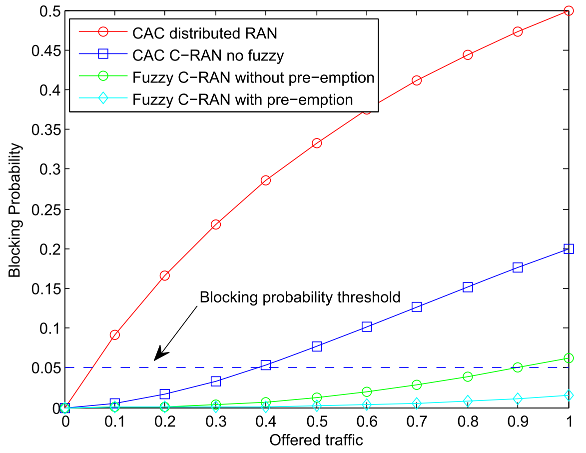


Fig. 8 Blocking probability versus offered traffic load

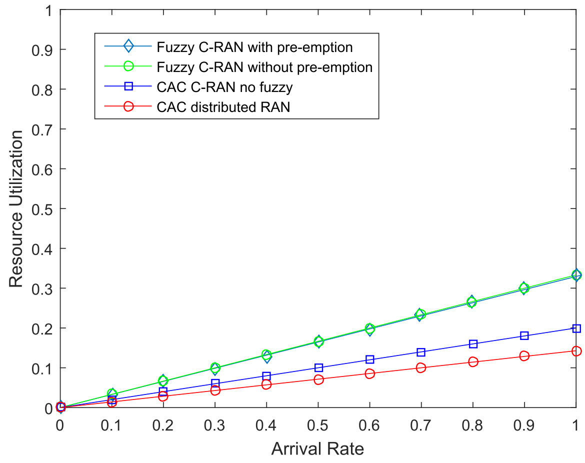


Fig. 9 System utilization versus arrival rate. A figure showing how the system utilization in the BBU pool varies with the change in arrival rate of requests

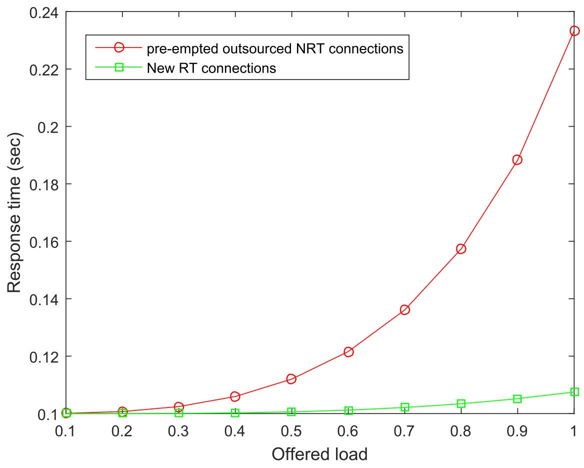


Fig. 10 Response time versus offered traffic load. A figure showing how the service response time/delay varies with the increase in the offered traffic load

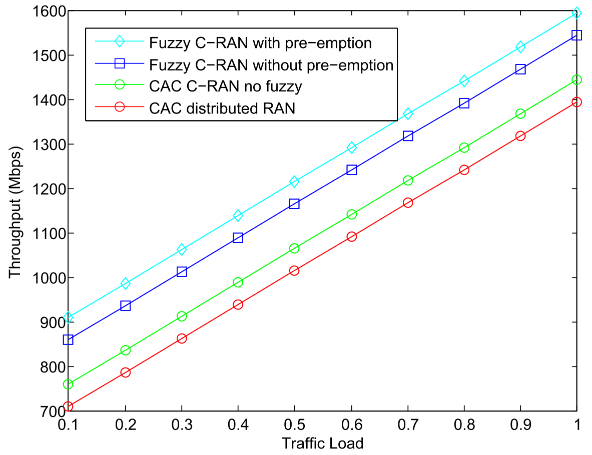


Fig. 12 System throughput. A figure showing the total throughput of the C-RAN system

highest revenue than all the schemes which is 95% since more requests are accepted in both the private and public cloud. Figure 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, is calculated at the BBU pool, and is expected to be larger. The fuzzy C-RAN with preemption scheme has a higher throughput than all the other schemes with 900 and 1600 Mbps during low and peak traffic, respectively, and the scheme is 28.6% effective compared to 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 preemption has a throughput of 880 and 1550 Mbps 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 700 and 1400 Mbps during low and peak traffic, respectively, because it has high blocking probability due to limited baseband computing resources.

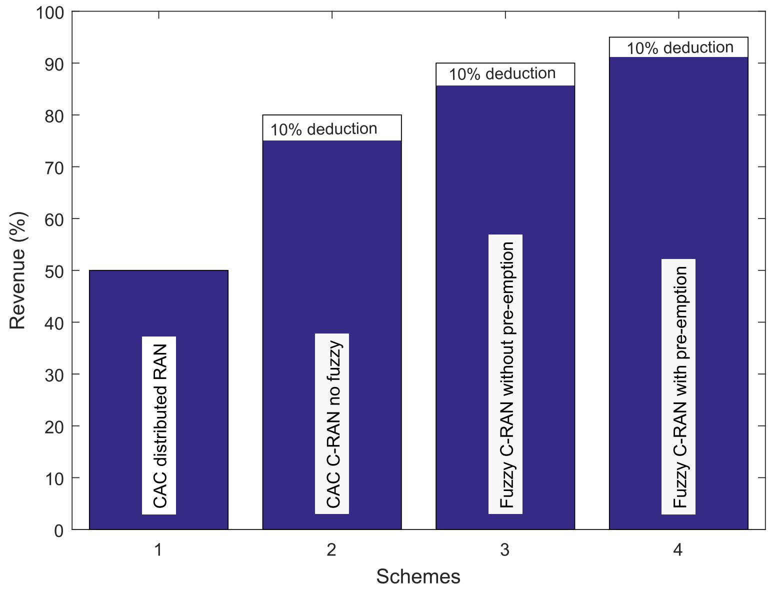


Fig. 11 Operator revenue. A figure showing the operator's income from hosting connection requests from users

5 Conclusions

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 non real-time (NRT) connections are preempted 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%.

Acknowledgements
The authors would like to thank MoESDP-DTEF (Ministry of Education Skills and Development Planning, Department of Tertiary Education and Financing, Botswana, Africa) for financing this research.

Authors' contributions
All the authors have contributed significantly to this research articles. Below are the author's contributions: Mr TS have contributed significantly to this paper on the coming up with mathematical models, running simulations, and writing up the paper. Dr PP has contributed significantly on the aspects of supervision, the organization of the paper, reviewing, and the validation of the proposed framework. Dr ASA has also contributed significantly in the related work section and also helped in drawing the diagrams in this paper. Prof YFH has also contributed significantly in this work by proof reading the work and validating the proposed framework and also restructuring the paper. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Author details
[1]Faculty of Engineering and Informatics, University of Bradford, BD7 1DP Bradford, UK. [2]Faculty of Technology, Design and Environment, Oxford Brookes University, Oxford, UK. [3]Institute of Communication Systems, 5G Innovation Centre University of Surrey, Düsternbrooker Weg 20, GU2 7XH Guildford, UK.

Received: 13 March 2017 Accepted: 31 August 2017
Published online: 21 September 2017

References

1. T Sigwele, P Pillai, Y Hu, in *IEEE Future Internet of Things and Cloud*. Call admission control in cloud radio access networks, (2014)
2. T Sigwele, P Pillai, Y Hu, in *International Conference on Wireless and Satellite Systems*. Elastic call admission control using fuzzy logic in virtualized cloud radio base stations, (2015)
3. M Farahabady, YC Lee, AY Zomaya, Pareto-optimal cloud bursting. IEEE Trans. Parallel Distrib. Syst. **25**, 2670–2682 (2014)
4. MH Ahmed, Call admission control in wireless networks: a comprehensive survey. IEEE Commun. Surv. Tutorials. **7**(1-4), 50–69 (2005)
5. D Niyato, E Hossain, Call admission control for QoS provisioning in 4G wireless networks: issues and approaches. IEEE Netw. **19**(5), 5–11 (2005)
6. Q Liang, NN Karnik, JM Mendel, Connection admission control in ATM networks using survey-based type-2 fuzzy logic systems. IEEE Trans. Syst. **30**(3), 329–39 (2000)
7. Y Liu, M Meng, in *Future Computer and Communication*. Survey of admission control algorithms in IEEE 802.11e wireless LANs, (2009)
8. V Kolici, T Inaba, A Lala, G Mino, S Sakamoto, L Barolli, in *Network-Based Information Systems*. A fuzzy-based cac scheme for cellular networks considering security, (2014)
9. L Barolli, A Koyama, T Yamada, S Yokoyama, T Suganuma, N Shiratori, in *12th International Workshop on Database and Expert Systems Applications*. A fuzzy admission control scheme for high-speed networks, (2001)
10. CT Ovengalt, K Djouani, A Kurien, A fuzzy approach for call admission control in lte networks. Procedia Comput. Sci. **32**, 237–244 (2014)
11. L Barolli, M Durresi, K Sugita, A Durresi, A Koyama, in *19th International Conference on Advanced Information Networking and Applications*. A cac scheme for multimedia applications based on fuzzy logic, (2005)
12. D Karabudak, C Hung, B Bing, in *Proceedings of the 2004 ACM Symposium on Applied Computing*. A call admission control scheme using genetic algorithms, (2004)
13. RG Cheng, CJ Chang, LF Lin, A QoS-provisioning neural fuzzy connection admission controller for multimedia high-speed networks. IEEE/ACM Trans. Networking. **7**(1), 111–121 (1999)
14. X Yang, J Bigham, in *International Joint Conference on Artificial Intelligence*. A call admission control scheme using neuroevolution algorithm in cellular networks, (2007)
15. S Acs, M Kozlovszky, P Kacsuk, in *Applied Computational Intelligence and Informatics*. A novel cloud bursting technique, (2014)
16. AO Allen, *Probability statistics and queueing theory, 1edn*. (Academic Press, London, 2014)
17. K Leonhard, How to dimension user traffic in 4G networks. (Slideshare, 2014). https://www.slideshare.net/mobile/althafhussain1023/how-to-dimension-user-traffic-in-lte. Accessed 1 June 2017

Submit your manuscript to a SpringerOpen journal and benefit from:

- ► Convenient online submission
- ► Rigorous peer review
- ► Open access: articles freely available online
- ► High visibility within the field
- ► Retaining the copyright to your article

Submit your next manuscript at ► springeropen.com