Elastic Call Admission Control Using Fuzzy Logic in Virtualized Cloud Radio Base Stations

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Abstract. Conventional Call Admission Control (CAC) schemes are based on stand-alone Radio Access Networks (RAN) Base Station (BS) architectures which have their independent and fixed spectral and computing resources, which are not shared with other BSs to address their varied traffic needs, causing poor resource utilization, and high call blocking and dropping probabilities. It is envisaged that in future communication systems like 5G, Cloud RAN (C-RAN) will be adopted in order to share this spectrum and computing resources between BSs in order to further improve the Quality of Service (QoS) and network utilization. In this paper, an intelligent Elastic CAC scheme using Fuzzy Logic in C-RAN is proposed. In the proposed scheme, the BS resources are consolidated to the cloud using virtualization technology and dynamically provisioned using the elasticity concept of cloud computing in accordance to traffic demands. Simulations shows that the proposed CAC algorithm has high call acceptance rate compared to conventional CAC.

Keywords: Qos · CAC · C-RAN · Cloud computing · Fuzzy Logic · Virtualization

1 Introduction

A plethora of mobile phones and multimedia services in recent years has resulted in gigantic demands for larger system capacities, higher data rates over large coverage areas in high mobility environments. Hence, 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 and non-real time services while optimizing resource utilization is a major challenge due to poor and ineffective Radio Resource Management (RRM) schemes. Call Admission Control (CAC) is a RRM scheme that offers an effective way of avoiding network congestion and plays a key role in the provision of guaranteed QoS in the RAN. The basic function of a CAC algorithm is to accurately decide whether a new or handoff call can be accepted into a resource-constrained network without violating the service commitments made to the already admitted calls. A good CAC scheme aims to optimize Call Blocking Probability (CBP), Call Dropping Probability (CDP) and system utilization. There are many drawbacks

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facing conventional CAC schemes which make them unsuitable for future mobile communication systems. 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. However, in practice the network is dynamic and values measured keep changing.

Second, as stated in previous work [1], traditional CAC schemes are based on standalone RAN Base Station (BS) architectures. 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 BS utilization, high CBP and CDP. Intelligent CAC schemes based on intelligent decision making techniques like Fuzzy Logic are a promising solution and solve the problem of imprecision and uncertainties cellular networks. 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 cellular networks.

This paper presents an intelligent elastic CAC scheme using Fuzzy Logic in a centralized Cloud RAN (C-RAN), herein termed as eFCC. C-RAN was introduced as a way of solving the drawbacks of conventional RAN [2] by pooling BS resources to a centralized cloud as shown in Fig. 1. Virtualization concept is used on general purpose CPUs (e.g. x86 or ARM processors) to dynamically allocate BS processing resources to different Virtual BS (vBS) and air interface standards. Several air interface standards can be supported and the so called 'tide effects', where traffic of each BS changes rapidly, can also be minimized. The rest of this paper is organized as follows. Section 2 presents the C-RAN architecture that is adopted in this paper. Related work on CAC schemes will be presented and analysed in Sect. 3. The proposed eFCC scheme is described in Sect. 4. Section 5 presents the simulation model and the obtained performance results. Finally, conclusion and further works are presented in Sect. 4.

2 C-RAN Architecture

C-RAN is a paradigm shift for next-generation RANs. C-RAN is described using four C's which stand for; clean, centralized processing, collaborative radio and real-time cloud computing. 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. These digital only BSs, called Virtual BS (vBS), are linked via fiber or the Common Public Radio Interface (CPRI) to remote radio heads (RRHs). Using the concept of Virtualization which separate software from hardware, the digital functionality in the BS hotel is shifted to the cloud and the BSs are abstracted as vBSs. General purpose processors (GPPs) like X86 and ARM processors are used to house physical baseband resources and using cloud

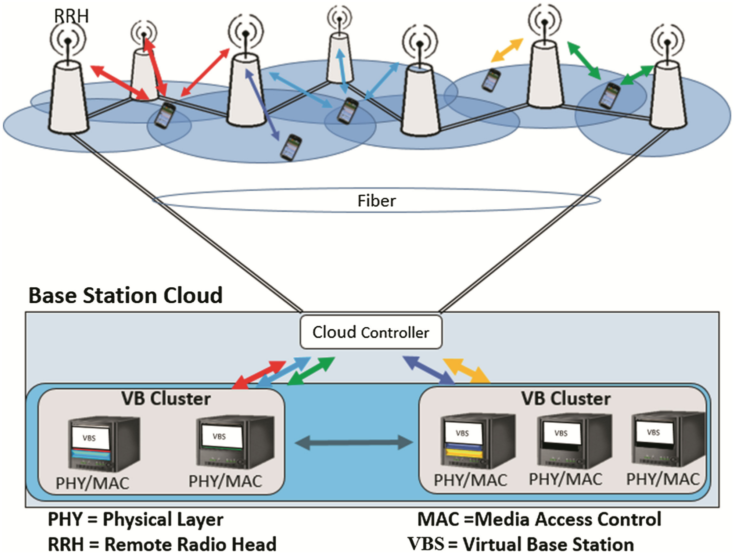

Fig. 1. C-RAN architecture.

computing virtualization concept, multiple vBS virtual machines (VMs) are dynamically provisioned in accordance to traffic demands. The aim is to dynamically scale up and down vBSs in accordance with the traffic fluctuations and the tide effect [2].

The key advantages of C-RAN based network architecture are summarised as follows:

1. Simpler and faster system roll-out and network expansion. Only RRHs need to be installed to expand coverage. Increased network load is combated with cloud hardware (HW) upgrade.
2. Support multi-cell collaborative signal processing. This reduces interference and handover latencies.
3. Improved CAPEX and OPEX.
4. Sharing processing power effectively utilizes the BS.
5. C-RAN is based on open platform, can support multiple standards, and smooth evolution and easy upgrading.
6. Maximum resource sharing and great flexibility to allocate processing resources with traffic demands.

3 Related Work

There are many ways of categorizing CAC schemes like Parameter based, measurement based, utility based, centralized/distributed, static/dynamic etc. Comprehensive surveys can be found here [3–6]. Conventional CAC approaches suffer uncertainties due to time varying nature of parameters (speed, location, direction, channel conditions, available power, etc.) Many of these CAC schemes make erroneous decisions as they tend to assume network state information is static. However, in practice the network is dynamic and values measured keep fluctuating. Intelligent CAC schemes based on intelligent decision making techniques solve the problem of error and uncertainties in conventional schemes. They are adaptive and flexible, thus making them suitable to cope with the rapidly changing network conditions and bursty traffic that can occur in cellular wireless networks to give an efficient network management scheme. Some of the commonly used intelligent decision making mechanisms used for CAC are described below:

3.1 Genetic Algorithm (GA)

GA's are based on the principles of evolution and natural genetics. The genetic algorithms are directed random search techniques used to look for parameters that provide optimal solution to the problem. The notion of a GA is the survival of the fittest in nature, which implies that the 'fitter' individuals are more likely to survive and have chance of passing their features to the next generation. In [7], a CAC scheme using 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, 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.

3.2 Neural Networks (NN)

NN's are algorithms that are patterned after the structure of the human brain. NN's have learning and adaptive capabilities that can be used to construct intelligent computational algorithms for traffic control. A neural approach for CAC with QoS guarantee in multimedia high-speed networks is proposed in [8]. 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 [9]. The near optimal CAC policy is obtained through a form of Neuro-Evolution algorithm. This method guarantees that the specified Call Dropping Rate (CDR) remain under a predefined upper bound while retaining acceptable Call Blocking Rate (CBR). This scheme is black box learning approach since the knowledge of its internal working is never known. The scheme also requires high processing time.

3.3 Fuzzy Logic (FL)

In this paper, FL scheme is used because of its simplicity and robustness [5]. FL techniques resembles the human decision making with an ability to generate precise solutions from certain or approximate information. FL avoids uncertainties and computational complexities brought by many CAC schemes. It does not require precise inputs, and can process any number of inputs. FL incorporates a simple, rule based approach based on natural language to solve control problem rather than attempting to model a system mathematically. The main point of interest in eFCC scheme is that it make use of FL to handle uncertainties in the network. A Fuzzy CAC Scheme for High-speed Networks was proposed in [10]. Even though the author used Fuzzy to better estimate equivalent capacity, he does not show how the schemes performs in terms of acceptance rate. In [11], the author propose a fuzzy 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. A method of fuzzy admission control for multimedia applications (MFAC) scheme is proposed in [12]. In this method, for multimedia applications, QoS and Congestion Control (CC) have more parameters and thus two additional fuzzy based controllers: Fuzzy QoS Controller (FQC) and Fuzzy Congestion Controller (FCC) have been introduced to the fuzzy based admission controller, allowing better estimation of QoS parameters. The drawbacks of this scheme is that it has many fuzzy controllers that can magnify CAC complexity and computation latency.

4 Proposed Scheme: Elastic Fuzzy C-RAN CAC

In our proposed scheme, baseband signals from multiple cells are no longer processed on their stand-alone Baseband Units (BBU) but processed in the cloud using the concept of cloud computing. The BS traffic from various cells are processed on a General Purpose Processor (GPP). The GPP is 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 advantages of virtualization in our scheme are:

- **Green:** With virtualization, fewer servers are used and less power and less cooling is required. Also, during low traffic, *server consolidation* and *VM migration* can help reduce power by switching off some of the less loaded servers.
- **No Vendor Lock-in:** The virtual machines do not really care what hardware they run on, hence no more tied down to a single vendor
- **Reduced Cost**: Reduced amount of hardware used coupled with less downtime, easier maintenance, less electricity used.
- **Disaster Recovery:** If disaster strike the data center itself, virtual machines can always be moved elsewhere.

Virtual Machines (VMs) are dynamically provisioned to service traffic requests from cells. The VMs are defined as vBS in this paper. The vBS performs baseband signal processing of specific cell traffic. The traffic demand from cells is mapped into baseband processing resource utilization such that every cell traffic is serviced by its own vBS. The proposed model considers a C-RAN cellular network with BS resources being pooled together to the cloud to serve two cell coverage areas as shown in Fig. 2. One of the main components is the Cloud Controller which is comprised of the CAC processor and the Resource Estimator (RE). RE continuously measures and dynamically provisions resources to the different vBSs. The eFCC scheme consists of two key elements: an elastic scheme for dynamically allocating resources to vBS and Fuzzy based CAC.

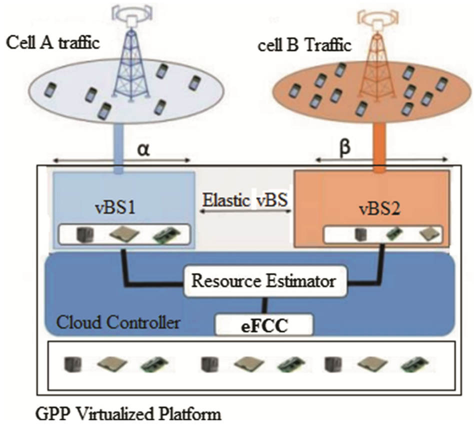

Fig. 2. Elastic C-RAN CAC architecture

The aim is to fairly service requests from cell A and cell B by dynamically provisioning resources from vBS1 and vBS2 respectively while sharing the same processing infrastructure. It is imperative that QoS in the network is not affected hence call blocking probability is used as a performance matrix. If cell A high load compared to cell B, resources are scaled up in an elastic manner. If there is high traffic load on both cells such that the GPP might overload, some of the task for incoming traffic are forwarded to other GPP which can accommodate them and there will be some communication cost inquired. Alternatively, One of the VBS have to be migrated to a less loaded GPP of a less loaded GPP to be able to accommodate the migrated vBS, but migration in real time processing might cause delays and jitters and interrupt service connection.

4.1 Elastic BS Resource Provisioning Model

The resources being shared are processing and computational resources. The processing resources are dimensioned in proportion to correspond with radio resources. Users in coverage areas generate traffic which is aggregated in the BS. This generated traffic from BS is mapped into $\alpha \leq 1$ denoting BS traffic demand as follows:

$$\alpha = \frac{cell^{A}_{traffic\_load}}{cell^{A}_{max\_traffic\_load}} \tag{1}$$

where $cell^{A}_{traffic\_load}$, $cell^{A}_{max\_traffic\_load}$ is the current load in cell A and peak traffic load for cell A respectively. As such, α also denote the utilization of a BS hence the amount of resources required to service the traffic from cell A is calculated as follows:

$$vBS1_{capacity} = \alpha * Cloud^{total}_{capacity} \tag{2}$$

where $vBS1_{capacity}$ is a virtual BS provisioned in the cloud to services total traffic from cell A and $Cloud^{total}_{capacity}$ is the total amount of processing resources in the cloud. Similarly for cell area B, $\beta \leq 1$ denote the utilization in cell area B:

$$\beta = \frac{cell^{B}_{traffic\_load}}{cell^{B}_{max\_traffic\_load}} \tag{3}$$

where $cell^{B}_{traffic\_load}$, $cell^{B}_{max\_traffic\_load}$ is the current load in cell B and peak traffic load for cell B respectively. *vBS2* which is the amount of resources required to service traffic from cell B is calculated as follows:

$$vBS2_{capacity} = \beta * Cloud^{total}_{capacity} \tag{4}$$

The proposed scheme of GPP sharing is suitable during low traffic times, but when traffic surges, some vBS are forced to be migrated to other less loaded GPP's.

Using the proposed method, two vBSs can be dynamically and elastically provisioned based on the traffic demands from the two coverage areas or RRHs. It is assumed that there are *3* classes (VoIP, video streaming and file download). The traffic classes have different QoS requirements. The arrival rates of new calls of class i, $i = 1, 2 \ldots K$, are assumed to form a Poisson process with a mean arrival rate λ_i. The service times of new calls of class i are assumed to follow an exponential distribution with mean service time $1/\mu_i$.

4.2 Structure of Fuzzy Logic Controller (FLC)

In order to make a more accurate decision for call acceptance, this paper proposes a fuzzy based CAC scheme, called eFCC scheme. The Fuzzy Logic Controller (FLC) called eFCC is the main part of the FL and its basic elements are shown in Fig. 3. It takes in four inputs and outputs the decision of call acceptance or rejection. The four inputs are: Available Capacity *Ac,* effective capacity of a new call request *Ec,* network congestion parameter *Nc* via Congestion Indicator (CI). The output of the eFCC is admittance decision *Ad*. The RE measures the total capacity on ongoing connections and dynamically scale out resources in the cloud based on the traffic demand.

4.3 Membership Functions

The term sets of *Nc, Ac, Ec* and *Ad* are defined as follows:

- *T (Nc) = {Negative, Positive} = {N, P}*
- *T (Ac) = {NotEnough, Enough} = {NE, E)*
- *T (Ec) = {small, medium, big} = {sm, me, bi}*
- *T (Ad) = {R, WR, AR, WA, A}*

For *T(Ad), R = Reject, WR = Weak Reject, AR = Average Reject, WA = Weak Accept and A = Accept*. Triangular functions as MF are chosen for simplicity. The membership functions for input and output linguistic parameters are shown in Figs. 4, 5, 6 and 7. The values of MF function have been chosen based on commonly used values of MFs in various literature.

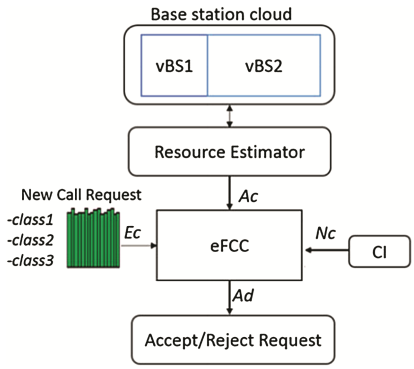

Fig. 3. eFCC CAC model

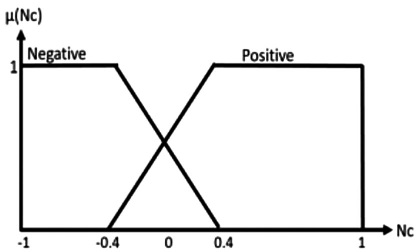

Fig. 4. Membership function for network congestion.

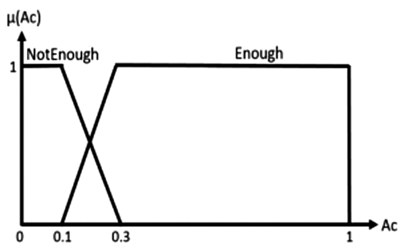

Fig. 5. Membership function for available capacity.

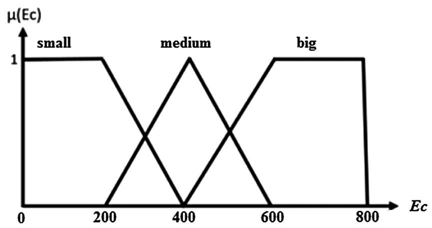

Fig. 6. Membership function for effective capacity.

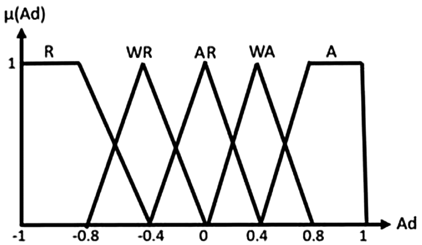

Fig. 7. Membership function for admittance decision.

4.4 Fuzzy Rule Base

The Fuzzy Rule Base consists of a series of 24 fuzzy rules, shown in Table 1. These control rules are of the following form: IF "condition", THEN "action". Example: if *Nc* is *Negative* and *Ac* is *NotEnough* and *Ec* is *Medium*, then *Weak Reject* the request.

5 Simulation and Results

5.1 Simulation Parameters

The posed scheme aims to provide elastic provisioning of capacities for the vBSs from the cloud. MATLAB Simulink was used to simulate the proposed scheme which is compared with a baseline CAC scheme in [1]. The CAC scheme in [1] is applied in C-RAN but without Fuzzy. For simulation and performance evaluation the following three traffic classes shall be considered: VoIP (class1), Video streaming (class2) and file download (class3). Call requests of the three traffic classes were generated with Poison process with parameters shown in Table 2. The value of λ was varied from 0.01 to 1 with every simulation. 100 calls were generated for each traffic class. The simulation time was kept at 500 s. It is assumed that the QoS of a traffic class is equivalent to *Ec*. Membership Functions for congestion factor and available capacity are shown in Figs. 4 and 5. The MF for *Ec* in Fig. 6 ranges from non-normalized limits of 0 to 800 Kbps to accommodate all traffic classes from Table 1. The output of the FL is the variable *Ad* which is the decision factor with five possible outcomes. Triangular and trapezoidal MF are used since they are simple and are suitable for real time traffic. The total capacity was kept constant for the baseline scheme which is based on stand-alone BS and then varied elastically for the eFCC scheme which is based on C-RAN.

Table 1. Fuzzy rule base

Rule	N_c	A_c	E_c	A_d
1	N	NE	Sm	AR
2	N	NE	Me	WR
3	N	NE	Bi	WR
4	N	E	Sm	WA
5	N	E	Me	AR
6	N	E	Bi	WR
7	P	NE	Sm	WA
8	P	NE	Me	AR
9	P	NE	Bi	WR
10	P	E	Sm	A
11	P	E	Me	A
12	P	E	Bi	A
13	N	NE	Sm	R
14	N	NE	Me	R
15	N	NE	Bi	R
16	N	E	Sm	AR
17	N	E	Me	AR
18	N	E	Bi	R
19	P	NE	Sm	WR
20	P	NE	Me	R
21	P	NE	Bi	R
22	P	E	Sm	AR
23	P	E	Me	AR
24	P	E	Bi	WR

Table 2. Simulation parameters

Traffic type	Parameters			
	λ (calls/s)	*1/μ (s)*	*Ec (kb/s)*	*Priority*
Voip	varied	300	12.2	1
Video streaming	varied	300	768	2
File download	varied	300	144	3

5.2 Simulation Results

The CBP is measured for every service class to evaluate the performance of the proposed CAC scheme. 100 calls are simulated while changing call arrival from 0.01 calls per second (36 calls/h) to 1 call per second (3600calls/h) for each scheme. The CBP for the two schemes are shown in Figs. 8, 9 and 10. In Fig. 8 it can be seen that the CBP for VoIP for eFCC is lower than for baseline scheme by 34 %. This is because the baseline resources get exhausted quickly, while for eFCC, resources are elastically pooled from the cloud to serve incoming requests. Both schemes completely flattens for $\lambda > 0.8$ since calls are rejected to maintain QoS. Figure 9 shows the CBP for video streaming application. In this scenario also the eFCC scheme outperforms the baseline scheme by a factor of approximately 75 %. Figure 10 shows the CBP for file download application. Here eFCC also outperforms the baseline scheme at a much larger average factor of 90 %. File downloads in baseline follows a constant behavior of CBP while with eFCC CBP increases constantly.

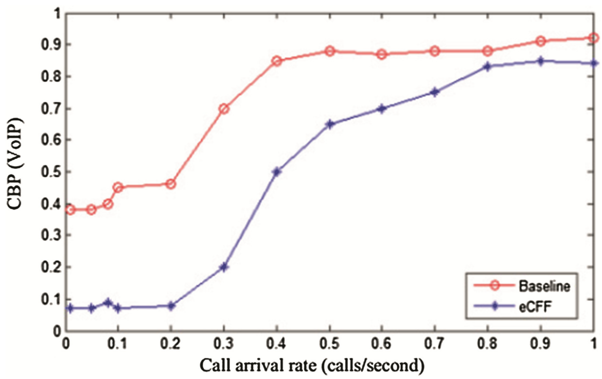

Fig. 8. Call blocking probability (VoIP).

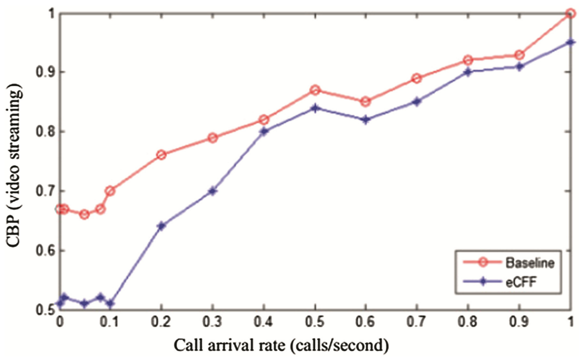

Fig. 9. Call blocking probability (video streaming).

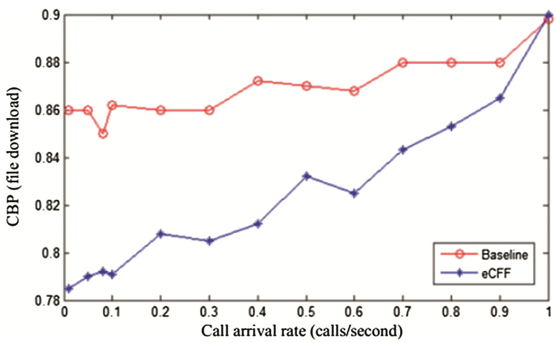

Fig. 10. Call blocking probability (file download).

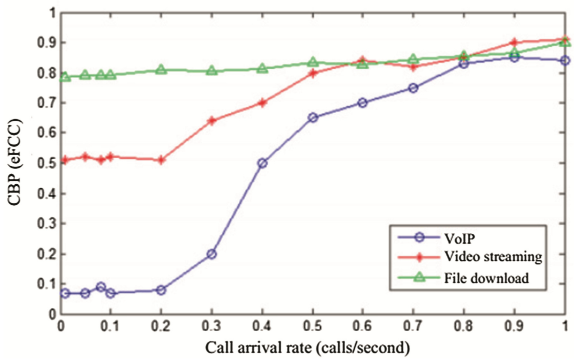

Fig. 11. Call blocking probability (eFCC).

From the results, it can be seen that in general the CBP increases as traffic load increases for both the schemes since the network resources get exhausted as more requests are serviced. It can also be seen that the CBP of the proposed eFCC scheme is lowest for all traffic classes in all the application scenarios. This is so because eFCC elastically provision resources that are pooled from the cloud hence increasing call acceptance rate. Figure 11 shows the CBP for all traffic classes simulated under eFCC scheme. It can be observed that high priority traffic have lower CBP that low priority traffic. This is necessary to maintain QoS of the overall network.

6 Conclusion

The paper presents an intelligent elastic fuzzy logic based call admission control scheme in cloud radio access networks. A combination of fuzzy and C-RAN improve uncertainties and imprecations in conventional CAC schemes and combat the problem of constrained resources by sharing BS resources in the cloud. The scheme take the advantage of cloud computing's elasticity and resource sharing to dynamically provision resources based on traffic demands. The simulation results shows that for heterogeneous traffic classes, the proposed scheme has lower CBP than conventional CAC. The scheme proposed has better robust performance and outperforms the conventional schemes. In future the system will be extended to consider handoff calls and additional performance measures like system utilization and call dropping. The energy saving gained by virtualization and vBS migration will be the main target in future.

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