

Design of Elastic Call Admission Control in Tidal Load Scenario for Cloud-based Cellular Networks

Ali M. Mahmood, Azad R. Kareem*, Ahmed R. Nasser

*Control and Systems Engineering Department, University of Technology - Iraq,
Al-Sina'a St., Baghdad, Iraq
azad.r.kareem@uotechnology.edu.iq*

Abstract—Cellular networks have witnessed an unprecedented expansion represented by the number of subscribers in addition to the unlimited number of applications. In the era of IoT, connections may involve machines working side by side with humans on the same network. Tidal load is one of the key challenges in mobile networks, which represents a temporary phenomenon resulting from increasing traffic volumes at certain times of the day in particular places. This leads to the problem of overutilization of some base stations, particularly in fixed resources allocation systems such as 4G LTE architecture, which contains physically separated base stations. This results in increasing the dropping and blocking probability for the incoming calls in an overloaded area, while others suffer from underutilization or might be almost idle for a particular time. In this paper, an Elastic Call Admission Control (ECAC) approach is proposed to reduce the probability of blocking and dropping to improve the network performance in the tidal load scenario. This is achieved using the concept of gain multiplexing technique and cloud-based cellular architecture for utilizing the shared available resources of the co-located virtual base stations in the cloud. A Fuzzy Type 2 (FT2) system is used to maintain the switching decision for resource sharing mode, the network load is predicted in advance using Gaussian Process Regression (GPR) model. Performance evaluation is carried out using the cloud-based Fog-Radio Access Network (F-RAN) platform. Compared to legacy LTE architecture, the results illustrate a noticeable enhancement in terms of minimizing blocking probability, enhancing overall network performance represented by network data throughput, and network utilization.

Index Terms—Cellular networks; Call admission control; Tidal load; Gain multiplexing; Fuzzy type 2; Fog-RAN; Gaussian process regression.

I. INTRODUCTION

Future 5G mobile networks and beyond are expected to support one million connections for each square kilometre [1], [2]. Call Admission Control (CAC) is a technique that manages the process of admitting, blocking, or dropping new or handoff calls in cellular networks. The bandwidth of the system is normally finite, so at certain times the network may not be able to receive further calls due to the incidental increase in the incoming calls, where the demand can exceed the available network resources in many folds [3].

This phenomenon is commonly known as the effect of the tidal load [4] when the density of people varied remarkably during the day between two places represented by work areas and home areas. Hence, the fixed bandwidth allocation is inefficient to meet the requirement of a high traffic load. Consequently, at the tidal load area, the network may not be able to meet the Quality of Service (QoS) requirements for a large number of the present and incoming calls as well. This is due to the problem of high dropping and blocking, probably resulting from the deficiency of resources. Therefore, the concept of gain multiplexing can be employed to elastically manage the incoming calls in the network. Although sharing the responsibilities of serving User Equipments (UEs) between legacy hardware-based base station networks is possible, in the cloud-based network, the task will be easier. This is due to the shafting of several base stations (distributed structure) into the cloud in the form of a pool (centralized structure). The gain increases when more areas can be cooperatively served by the pool of virtual Base Band Units (BBUs).

In this paper, an Elastic CAC (ECAC) algorithm is proposed. ECAC involves network load prediction using Gaussian Process Regression (GPR) model, gain multiplexing, and Fuzzy Type 2 (FT2). ECAC is proposed to maintain low probability of call blocking and dropping. The proposed ECAC aims to improve QoS under the condition of tidal load. The main contribution of this paper is represented by alleviating the problem of performance degradation in the cellular network throughout the tidal load period using the concepts of multiplexing gain and smart decision making for an ultra-high arrival rate of calls received in the Fog-Radio Access Networks (F-RANs). The proposed elastic CAC approach is evaluated against the traditional fixed resources CAC represented by the 4G LTE architecture. The rest of the paper is organized as follows. Section II shows related works in this field. In Section III, we discuss the theoretical background of Fog-RAN (F-RAN) and the effect of tidal load with its modelling. Section IV demonstrates the proposed elastic CAC. Section V presents the results and a discussion. Section VI illustrates the conclusions of the paper.

II. RELATED WORKS

The challenges of CAC in mobile networks have been

extensively investigated in the prior literature. Nevertheless, most related researches are discussed in this section. In general, several categories of the research routes have been followed to minimize the probability of blocking in mobile networks.

In [5]–[7], adaptive bandwidth allocation schemes have been proposed. Regarding QoS provision, several QoS-aware CAC algorithms have been designed, such as contributions in [8], [9]. The third route of research focuses on the development of an opportunistic CAC algorithm [10], which is based on an optimization problem. In [11], [12], dynamic resource reservation has been proposed. The fifth technique is based on resource scheduling schemes [13], [14]. Another approach is CAC classification based on different aspects such as the mobility speed of UEs. In [15], users are categorized according to mobility speed. In [16], users are categorized according to user speed and types of traffic along with user situations such as delay-aware users [17]. Furthermore, Bandwidth Degradation (BD) schemes are proposed [18], [19], which reduce the resources that are allocated to some of the low urgency calls for the admission of more UEs to the network. Queuing-based CAC is also proposed, which applies the concepts of queuing theory in managing the incoming calls [20]. Last but not least, the principle of fuzzy logic is used to improve QoS [21], [22] resulting from the uncertainty caused by inaccurate information in the traditional CAC schemes. It is worth stating that the authors of the former appreciated studies have tried to tackle the challenge of blocking probability and improve network performance. However, it can be noticed that the focus on minimizing the blocking probability via the condition of the tidal load has rarely been studied. In other words, there is still no standard multiplexing approach in the literature that can solve the problem of tidal load efficiently in cloud-based architectures.

III. PRELIMINARIES

In this section, the concepts of Fog-Radio Access Network (F-RAN) and tidal load effect are discussed.

A. Fog-Radio Access Network

In the 4G architecture, the base station is hardware that is physically located at the site. Hence, sharing the resources between neighbour base stations may consider a challenging task. This is due to the signal processing being achieved separately in each physical base station. On the contrary, the F-RAN is recently proposed as an extension to Cloud-RAN (C-RAN) architecture that contains a pool of virtual base stations all located in one cloud to gain the benefits of cloud computing such as resource sharing. F-RAN equips Remote Radio Heads (RRHs) with signal processing and caching functionalities, which can improve the traditional C-RAN architecture by minimizing end-to-end latency. The idea is simply represented by bringing the functionalities of cloud computing closer to the end UEs for quick response and fast decision making [23] via decentralized management. The components of the F-RAN are similar to C-RAN architecture in shifting the baseband processing from dedicated hardware on the ground to be a virtual base station in the cloud; except that the RRHs are enhanced with the local caches for storage regularly demanded contents to

reduce the latency of content delivery. The main components of the F-RAN architecture are depicted in Fig. 1 [24].

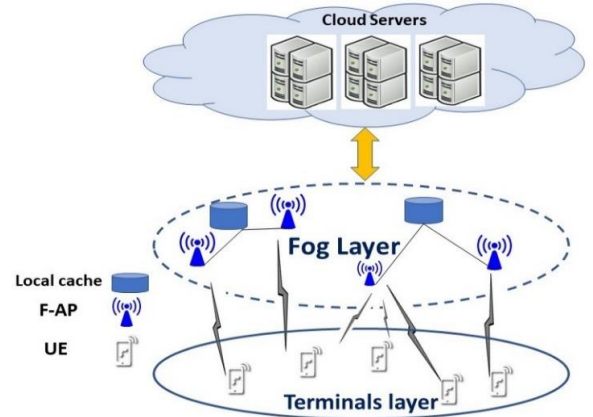


Fig. 1. The general architecture of the F-RAN network.

B. Modelling of Tidal Load

The applied load on the cell is varied on the basis of the type of area, which may fluctuate during the day. For instance, cells in an office area may suffer from ultra-high load during working hours, while in residential areas; the load starts to grow through afternoon up to midnight. Therefore, fixed bandwidth allocation approaches are ineffective to maintain the demand for such high traffic loads [4]. In this work, to generate practical data for the evaluation, a sinusoidal model [25] is used to describe the tidal load for different load areas (home and office) in cellular networks throughout the day, which is described as follows

$$TF_i(t) = \text{lognrnd}(\beta(t), \delta), \quad (1)$$

where $TF_i(t)$ is the load represented by the number of calls generated in a certain period t , i is the area of interest (home and work areas), δ is the standard deviation, and $\beta(t)$ is the mean value of the normal distribution that can be calculated in (2)

$$\beta(t) = \log \left[\frac{1}{M} \left(\varphi + \sum_{j=1}^k \sin \left(\frac{j\pi}{12} t + f_j \right) \right) \right] - \frac{1}{2} \delta^2, \quad (2)$$

where M is the number of base stations, φ is the mean traffic load over a time, f_j is the variation in traffic of the frequency components k .

IV. THE PROPOSED ELASTIC CAC ALGORITHM

This section describes the proposed ECAC, which comprises mainly three parts. The first part includes the Gaussian Process Regression (GPR) model for predicting the future probable call arrival rate in the network. The second part of the proposed ECAC is the application of the Fuzzy Type 2 (FT2) approach to check the bandwidth availability of Virtual Base Stations (VBSs). The main purpose of FT2 is to decide whether to admit the incoming calls or pass the overflow calls to other virtual pools of VBSs. The third part of the design is represented by the elastic gain multiplexing algorithm, which is responsible for

allocating and sharing the available resources. The entire design of the proposed algorithm is illustrated in Fig. 2.

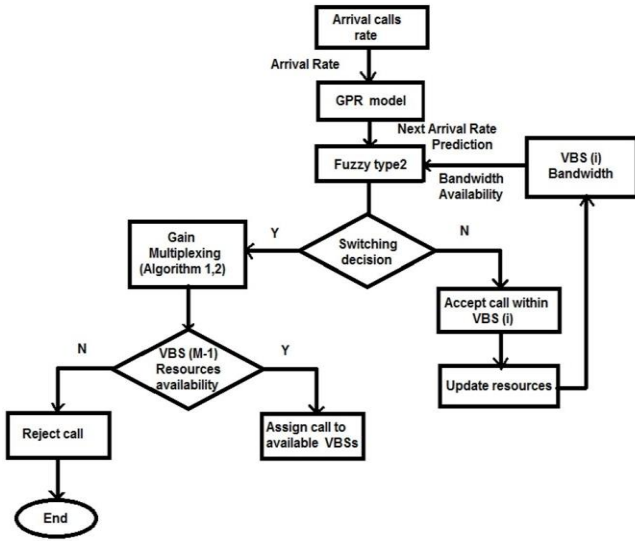


Fig. 2. Flow diagram of the proposed Elastic CAC Algorithm.

A. Call Arrival Rate Prediction Using GPR Model

Gaussian Process Regression (GPR) is a non-parametric Bayesian approach to regression that is considered a sub-field of machine learning and artificial intelligence [26]. GPR has several benefits, where it works well on small datasets and can support measures of uncertainty over predictions. Generally, the Bayesian approach determines a probability distribution over all possible values. GPR is a non-parametric model suitable for solving nonlinear regression problems of prior functions to posterior functions based on conversion. The estimation can be achieved using a continuous number of training labels of the test vectors, and the estimated values at this point can be represented in the form of systematic or random values. In GPR, $f(x)$ defines the probability distribution in the GP functions and can be expressed as in (3)

$$f(x) \sim GP(m(x), K(x, x')), \quad (3)$$

where $m(x)$ is the mean and $K(x, x')$ is the covariance function which can be determined in (4) as follows

$$K(x, x') = \theta_f^2 \exp\left(-\frac{1}{\theta_l^2} \|x - x'\|^2\right), \quad (4)$$

where θ_f^2 and θ_l^2 are specified in the covariance function, which define the x-scaling (amplitude) and y-scaling (length scale), respectively. The covariance and mean value (x) allow one to evaluate all finite combinations of the input components of the data. The covariance matrix for the n input data samples is illustrated in (5)

$$K := K((x_1, \dots, x_n), (x_1, \dots, x_n)). \quad (5)$$

In this work, the GPR model is used to predict the next value of the call arrival rate in the future. The GPR model is trained based on the tidal load data that have been obtained from the network load model (described earlier in Section

III-B) for one week with different load figures from the network data for each day. The evaluation process of the GPR model shows that it can achieve a prediction accuracy of 6.509 in terms of Root Mean Square Error (RMSE) calculated in (6) [26]

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (a_i - p_i)^2}, \quad (6)$$

where n is the number of samples, a_i is the actual value of the network load, and p_i is the predicted value of the network load.

The actual values of the network load and the predicted values using the GPR model are shown in Fig. 3 below.

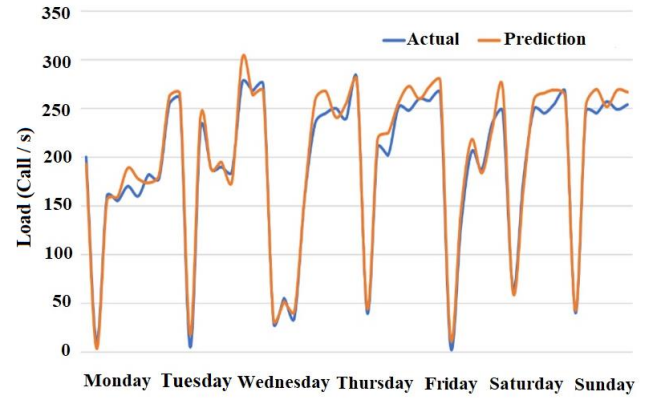


Fig. 3. The actual and predicted values of network load using the GPR model.

B. Fuzzy Type 2 Design

The Fuzzy Type 2 (FT2) application system in the ECAC is to reach decision making regarding the availability of the resources. In case sufficient resources are available, the call is accepted within the present VBS. On the other hand, the elastic gain multiplexing algorithm (Algorithm 1) will be triggered to pass the calls to the rest VBSs in the F-RAN. FT2 has superior performance in various applications. Unlike the Type 1 fuzzy logic, in the FT2 system, the fuzzy sets can be used to model and minimize uncertainties problems [27]. This is along with its ability to offer new partitions for the input domain. In this work, the FT2 interval is used as shown in Fig. 4 since it represents a simplified method and low computation compared to the general FT2 [28].

The rules designed that are used to describe the relationship between the input and output data are illustrated in Table I. The rules shown in Table I are a linguistic representation for both the arrival rate and bandwidth availability, which are the input to the FT2 system. The FT2 inputs are deployed with three Gaussian membership functions, which are (Low “L”, Medium “M”, and High “H”) as shown in Fig. 4. The FT2 output has represented the switching decision for the ECAC (Yes “Y” refers to execute Algorithm 1; No “N” denotes no switching and accepting the call).

The fuzzy set of an interval FT2 system can be expressed as follows

$$S = \{(v, z), \mu_s(v, z) \mid \forall v \in V, z \in J_v \subseteq [0,1]\}, \quad (7)$$

where v is a primary variable of domain V , z is the second variable of domain J_v for all $v \in V$, J_v is the primary membership of v . The footprint of uncertainty (FOU) of S is depicted in Fig. 5. Equations (8) and (9) illustrate the upper $\overline{\mu}_S$ and lower $\underline{\mu}_S$ membership functions:

$$\overline{\mu}_S = \overline{FOU(S)} \quad \forall v \in V, \quad (8)$$

$$\underline{\mu}_S = \underline{FOU(S)} \quad \forall v \in V. \quad (9)$$

Hence, the J_v is the interval set that can be expressed as follows

$$J_v = \left\{ (v, z) : z \in \left[\overline{\mu}_S(v), \underline{\mu}_S(v) \right] \right\}. \quad (10)$$

Algorithm 1. Elastic Gain Multiplexing for CAC.

Input: M: no. of overflow UEs, N: no. of VBS, Bth: percentage of the lower limit of available bandwidth

Output: service for the overflow UEs

```

1:   For i=1 to N-1
2:     ABW= VBS (i). ABWp // Get percentage of available
      bandwidth from Algorithm 2
3:     If (ABW> Bth)
4:       K= VBS(i). U // Get expected number of UEs to be
      served from Algorithm 2
5:       If (K>M)
6:         K=M
7:       End if
8:       For j=1 to K
9:         VBS(i) = Assign UEs(j)
10:      End for
11:      M= M-K // remind no. of overflow UEs
12:    End if
13:    If (M= =0)
14:      Go to End
15:    End if
16:  End for
17:  If (M>0)
18:    Reject rest calls (M) // no bandwidth availability to
      serve the rest calls
19:  End
    
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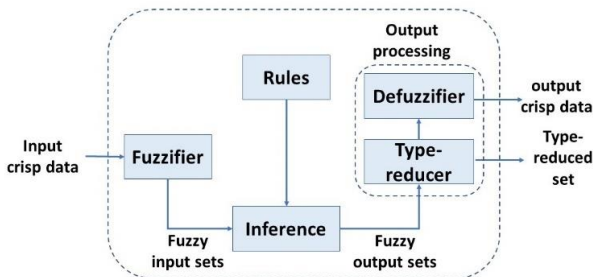


Fig. 4. Structure of interval FT2 system.

The applied rules as illustrated in Table I can be expressed in statements of if-then as shown in (11). It is worth stating that the type-reduced sets are calculated using the Karnik-Mendel (KM) method [29] to find crisp defuzzified output values

$$\text{IF } v_i \text{ is } S_i \text{ AND, ..., AND } v_l \text{ is } S_l, \text{ then } Y \text{ is } \beta, \quad (11)$$

where Y is the consequent part of rule i with its consequent

membership function β .

TABLE I. THE PROPOSED RULES OF INTERVAL FT2.

Rules	Arrival Rate	Bandwidth Availability Factor	Switching Decision
1	L	L	N
2	L	M	N
3	L	H	N
4	M	L	N
5	M	M	Y
6	M	H	N
7	H	L	Y
8	H	M	N
9	H	H	Y

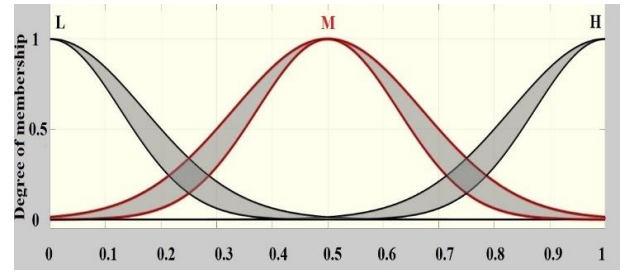


Fig. 5. Interval FT2 upper and lower memberships.

C. Elastic Gain Multiplexing Design

In this section, to implement elastic gain multiplexing, two algorithms are developed to share the available resources from the other VBS that may be underutilization in the virtual pool of VBSs in the tidal load scenario. Algorithm 1 is used to maintain elastic gain multiplexing by assigning the overflowed UEs calls from overloaded VBS to other underutilization VBSs. For example, the VBSs of the home areas can be utilized by the working areas and vice versa to minimize the impact of the tidal load. As shown in Algorithm 1, the assignment of overflowed UEs is distributed on the VBSs with the available resources, which is determined in Algorithm 2 to ensure the elasticity in providing service to the UE calls.

Algorithm 2 is used to generate and update a lookup table, which includes information regarding all cells in the virtual pool of VBSs. This information involves the current capacity and bandwidth availability per VBS.

Algorithm 2. Generation of Virtual Lookup Table of VBSs loads.

Input: N: no. of VBS, BW, VCBW: video call bandwidth

Output: ABWp: percentage of available bandwidth, U: expected number of UEs to be served

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1:   Function Virtual Lookup Table of VBSs Resources (N, VCBW)
2:     {i=1 // initialization
3:   Do {
4:     BWT= Get cell bandwidth VBS (i)
5:     CBW = Calculate current bandwidth VBS(i)
6:     ABWp = CBW/BWT
7:     U = CBW/ VCBW
8:     Lookup-Table [VBS(i), ABWp, U]
9:     i= i+1
10:  While (i<N)
11:    Go to step 1 }
12:  End function
    
```


V. PERFORMANCE EVALUATION AND DISCUSSION

The performance evaluation methodology of the proposed elastic CAC algorithm is investigated and compared with the traditional fixed resource CAC algorithm under the tidal load effect. The metrics used in the evaluation involve the the probability of dropping and blocking, the utilization of the network, and the data throughput.

To evaluate the proposed elastic CAC approach in a tidal load scenario, the simulated F-RAN network is classified into two load areas. The first area represents the work area that suffers from a high percentage of calls during working hours, and the other area is the home area that is underloaded. The load data of each area is generated using the tidal load model demonstrated in (1) and (2) for a 24 hours period as shown in Fig. 6. The tidal load of the work area is assumed between (11 AM to 8 PM), while in the home area, the load starts from 4 PM to midnight [4].

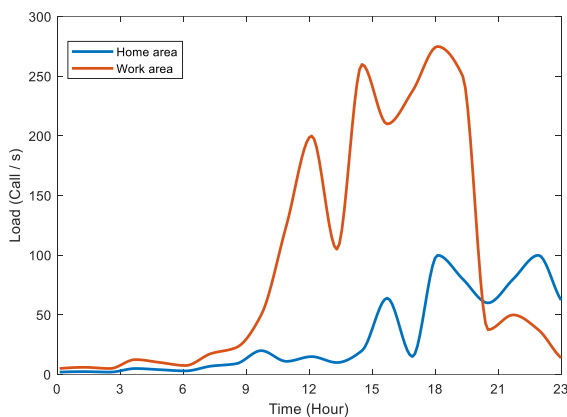


Fig. 6. The generated tidal load (home and work areas).

The simulation parameters are illustrated in Table II.

TABLE II. SIMULATION PARAMETERS.

Parameter	Value
Types of Calls	Handoff, VoIP, Video call
Bandwidth	20 MHz
No. of calls (load)	Up to 250 calls for work area Up to 100 calls for home area
No. of VBSs per pool	10 VBS
Simulation time	24 hours
Area types	Home area and work area

To investigate the effectiveness of the proposed CAC in the tidal load scenario, the evolution criteria are based on two main areas (work and home). The test of each area is conducted using three types of calls (handoff, Voice over IP (VoIP), and video). Four metrics are used in the evaluation process, which are the probability of blocking, the probability of dropping, the utilization of bandwidth, and the data throughput. The first test is illustrated in Fig. 7, which shows the Dropping Probability (DP) and Blocking Probability (BP) for three types of call (handoff, voice, and video) under the condition of tidal load in a work area for a period of 24 h, where the blocking probability (for new calls) and the dropping probability (for handoff calls)

represent the chance that a UE call will be denied as a result of deficiency of resources. The comparison is achieved between the traditional fixed bandwidth allocation CAC algorithm for the 4G LTE architecture and the proposed elastic CAC algorithm for F-RAN. The results show a noticeable reduction in both DP and BP with the proposed algorithm. While there are a high DP and BP with a fixed CAC algorithm. Likewise, in the simulation for the home area scenario, as demonstrated in Fig. 8, it can be observed that with the proposed elastic CAC algorithm both DP and BP are significantly enhanced compared to the fixed CAC algorithm.

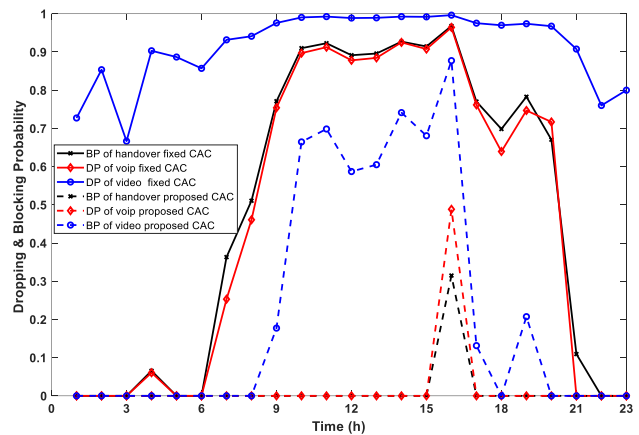


Fig. 7. The probability of dropping and blocking for the traditional and elastic CAC (work area).

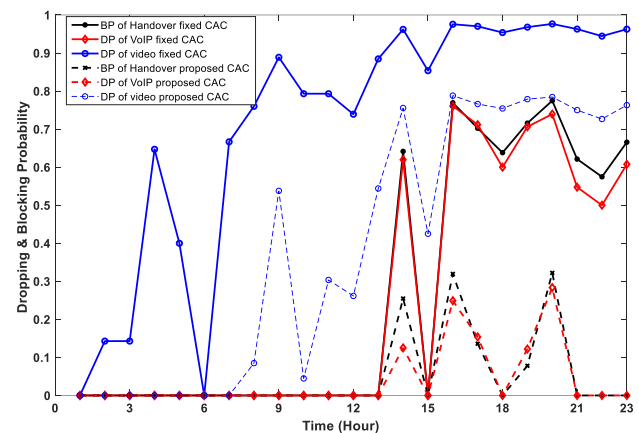


Fig. 8. The probability of dropping and blocking for the traditional and elastic CAC (home area).

Figures 9 and 10 show the percentage of improvement in both the work and home areas. It is noticed that in the work area, the percentage of average DP is improved by almost 39 % for video calls, and around 40 % of the DP is minimized for the VoIP and handoff calls. In the home area, the enhancement is 43 % for video calls, 85 % for VoIP, and 83 % for handoff calls. The improvement in the home area is greater than in the work area due to the lower load distribution. Compared with the related works, the proposed ECAC approach shows superior performance as illustrated in Table III.

The second simulation scenario focuses on the amount of improvement in network bandwidth utilization and data

throughput. The results in Fig. 11 illustrate a comparison between bandwidth utilization in the work and home areas. For both areas, there is a clear enhancement part in the utilization outside the tidal load period due to sharing resources from other VBSs (gain multiplexing). Regarding data throughput, the results in Fig. 12 demonstrate an upsurge of many folds in data throughput compared to the fixed CAC algorithm due to the elasticity of resource sharing in the proposed CAC algorithm.

TABLE III. COMPARISON WITH RELATED WORK.

Work	Method	Results (average)
[6]	Adaptive bandwidth allocation	4 % improvement in bandwidth utilization. 5 % improvement in dropping probability.
[9]	QoS aware	25 % improvement in throughput, 15.2 % improvement in dropping probability.
[10]	Opportunistic CAC	3 % improvement in dropping probability.
[22]	Hybrid CAC	35 % improvement in dropping probability.
Proposed	Elastic CAC	48.8 % improvement in bandwidth utilization. Work area 39 % improvement in dropping probability. Home area 70.6 % improvement in dropping probability. The throughput is improved by 10 folds.

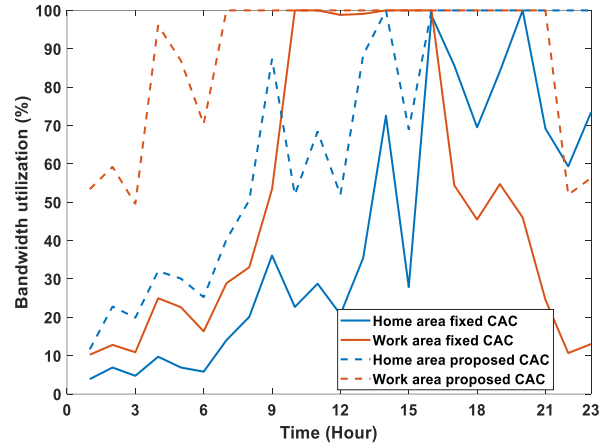


Fig. 11. Network utilization for traditional and elastic CAC (home and work areas).

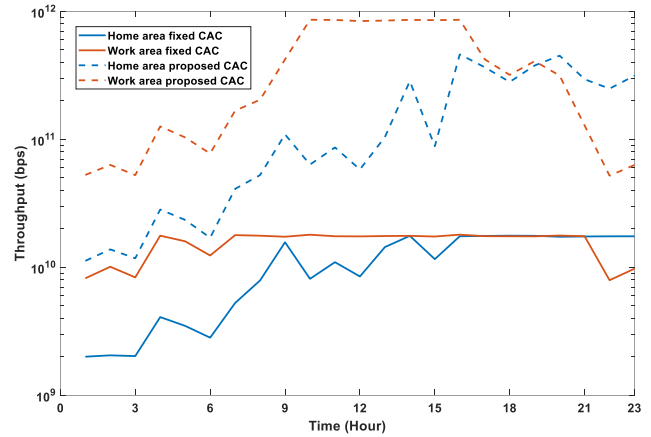


Fig. 12. Throughput for the traditional and elastic CAC (home and work areas).

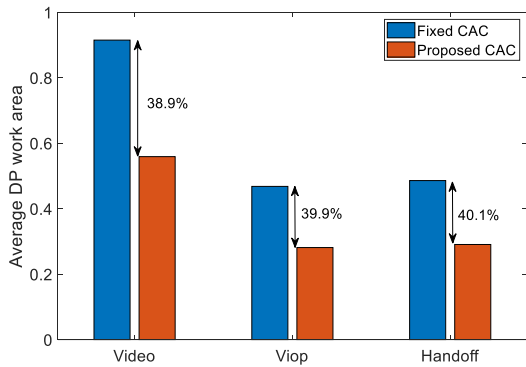


Fig. 9. Percentage of average DP minimization in elastic CAC compared to traditional CAC in the work area.

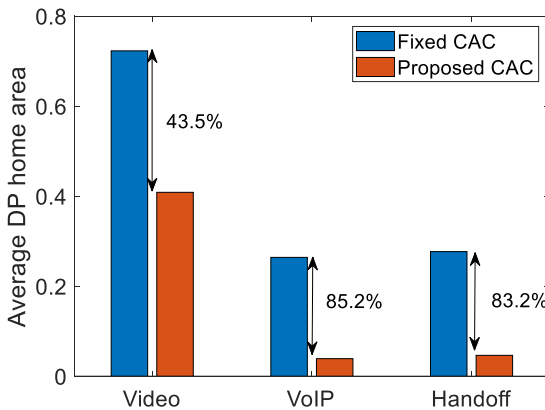


Fig. 10. Percentage of average DP minimization in elastic CAC compared to traditional CAC in the home area.

VI. CONCLUSIONS

A high level of probability of blocking and dropping under the condition of tidal load effect can lead to performance degradation when the CAC algorithm for allocation of fixed resources is used. In this paper, an elastic CAC based on FT2 and gain multiplexing technique is proposed along with the concept of the cloud-based F-RAN architecture. Before the application of the proposed ECAC, a prediction for the network load was achieved in advance using the GPR model. This is so that the network is aware of the possibility of near-future tidal load occurrence to trigger the ECAC for resource management. In the proposed approach, the underutilized VBS can share its available resources with other overloaded VBSs by using the concepts of gain multiplexing. The results with the proposed algorithm reveal a noticeable improvement in terms of low blocking and dropping probabilities, higher data throughput, and increasing network utilization. In fact, in the proposed algorithm, the resources will be shared between the pool of VBSs, and this property leads to accepting more calls. In other words, in the event that no more resources are available in the current VBS, the proposed ECAC will try to provide the required resources for accepting the incoming calls. This leads to an increase in the overall performance of the network. The comparison shows that the proposed ECAC outperforms the related methods of existing contributions.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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