Channel Borrowing Admission Control Scheme in LTE/LTE-A Femtocell-Macrocell Networks

Olusegun O. Omitola and Viranjay V. M. Srivastava
Department of Electronic Engineering, Durban–4041, South Africa
Email: omitolasegun@gmail.com; viranjay@ieee.org

***Abstract*—**Provisioning Quality of Service (QoS) is a challenging issue in the mobile cellular networks. Supporting different QoS requirements for different traffic is much more challenging in LTE-A femtocell-macrocell networks. Different call traffic types can be assigned to different level of priority to accommodate more calls with stringent QoS. In this study, a channel borrowing Call Admission Control (CAC) Scheme in femtocell-macrocell integrated Long Time Evolution-Advanced (LTE-A) networks is proposed. In this scheme, for a better QoS of handover calls, some of the system bandwidth is reserved for the handover calls. This reserved channel can however be borrowed by the Non Real-Time (NRT) new calls whenever it is not used by the handover calls to reduce the total number of blocked calls. The simulation results, when compared to the conventional scheme without borrowing shows the advantage of this scheme in terms of resource utilization, blocking probability of new originating calls, and dropping probability of handover calls.

Index Terms—CAC, LTE/LTE-A, femtocell, macrocell, QoS, wireless networks

I. INTRODUCTION

Femtocell has been described as an important radio access technology for improving the capacity and the coverage performance in Long Term Evolution Advanced (LTE-A). They are low cost, low power-based cellular stations which operate in the same licenced spectrum as macrocells [1]. They are sometimes called low range access points because of their low coverage. They are very easy to deploy and operate, and can be configured in three access modes as open, closed, and hybrid mode [2], [3]. They are connected to the home via Digital Subscriber Line (DSL), cable modem or fiber and make use of the internet connection (wired or wireless) to connect to the operator's core network [4], [5]. They are usually placed inside the macrocell coverage area to form a two-tiered network with the macrocell and provide cheapest way of offloading large amount of traffic from the macrocell [6]. In residential homes and enterprise environments, they provide increased data rate with improved signal quality indoor, and outdoor, high user density areas, shadowed areas, as well as macrocell edges. As a low range access point, connected user equipment (UEs) can be characterised by frequent handovers leading to fewer calls been accepted. Therefore, to effectively utilise the benefits provided by the femtocells in the two-tier networks, a Call Admission Control (CAC) scheme is needed to accommodate more handover calls to the network for successful macrocell-femtocell integration [7].

Generally, admission control schemes in cellular networks can be classified into: prioritized and non-prioritized admission control schemes as shown in Fig. 1. In the prioritized admission control, priority is given to the calls with stringent QoS by allocating a guard (fixed or dynamic) channel to them [8]. This scheme can be further broken down into reservation (i.e. guard channel), call queuing and channel borrowing scheme. Whereas in the non-prioritized admission control, no priority is given to any call i.e. new calls and handover calls are handled exactly the same way [9]. More discussion on prioritized and non-prioritized admission control has been given in [10]. This study proposes channel borrowing CAC scheme in femtocell-macrocell integrated LTE-A Networks. The proposed scheme, which is a priority scheme, is based on reservation of channel for the handover calls and borrowing of the reserved channel for NRT new originating calls in order to efficiently utilize the channel resources, decrease the blocking probability of new originating calls as well as maintaining the dropping probability of handover calls. The motivation for this work is to provide a robust CAC scheme for LTE/LTE-A femtocell-macrocell integration. The proposed scheme is aimed at accepting more high priority calls and increasing the total number of calls accepted into the system.

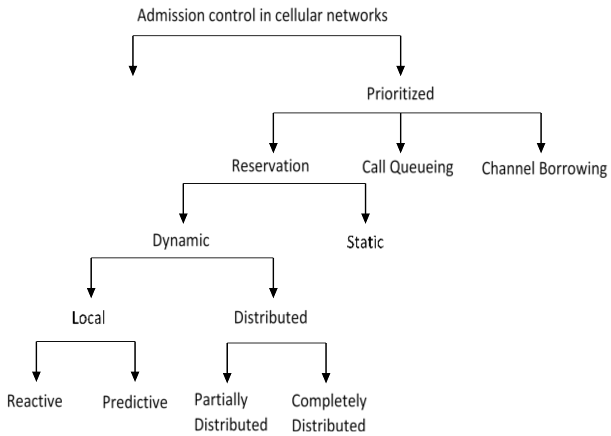

Fig. 1. Call admission control [10]

Manuscript received March 20, 2019; revised September 2, 2019.
Corresponding author email: omitolasegun@gmail.com.
doi:10.12720/jcm.14.10.900-907

Various priority CAC schemes for LTE-A have been proposed in literatures to admit more calls into the network. Majority of which focused on allocating guard channel to the calls with the highest priority such as handover calls. Guard channel schemes can be categorised into fixed (static) guard channel and dynamic guard channel. In the fixed guard channel, a static number of channel is reserved for high priority calls. The development of fixed guard channel is simple due to the fact that no exchange of control information is required between the base stations [9]. However, fixed guard channel normally results in increased Call Blocking Probability (CBP) and inefficient resource utilization because only few calls make use of the reserved channels exclusively [11]. *Jie and Yangfan* [5] introduced a CAC to LTE femtocell networks with different multimedia services. By distinguishing various traffic types with specific bandwidth requirements, dynamic guard channel has been proposed to prioritise the different services and to reduce the handover call dropping as well as new call congestion. A resource allocation CAC scheme proposed in [9] for 3GPP LTE guaranteed QoS of handover calls by giving priority to handover calls over new calls. The number of Resource Blocks (RBs) in the on-going low priority calls are degraded such that the required RBs are available for the high priority calls. In a two-stage CAC policy proposed for LTE systems in [12], a dynamic threshold Signal-to-Noise Ratio (SINR) was employed to admit new incoming calls and link capacity requirement was evaluated afterwards using resource utilization factor. Also, packet scheduler algorithm was employed to assign highest priority to guaranteed bit rate (GBR) services as explained in [21]. For better QoS of video conference, multimedia traffic were also prioritized by the CAC scheme proposed in [13]. To minimize the delay in the network, an adaptive scheduling was employed to allocate optimum rate to each traffic queue. While most of the CAC schemes in literature uses fixed guard channel for better QoS of high priority calls, it has been discussed that the use of fixed guard channel is not efficient to maximize the scarce bandwidth resources [14]. The dynamic guard channel on the other hand can guarantee QoS of high priority calls while also improving the efficiency of system utilization (i.e. bandwidth resources) [15]. In dynamic guard channel strategies proposed in [16], [17], to use the resources efficiently, some of the bandwidth used by the admitted less priority calls were reclaimed and used by the high priority calls. However, these strategies can disrupt the existing handover call, because there is no means of differentiating handover calls from the new calls. Similarly, the idea of channel borrowing introduced to the dynamic guard channel in [18], [19] to accept more originating new calls do not differentiate the classes of new calls. In the dynamic guard channel CAC proposed in [20] for two-tier LTE networks Picocell/Macrocell, to utilize the available resources efficiently, a queuing approach was used and improved system utilization recorded. The work was only applied to the originating new calls and there was no provision for the handover calls.

In this work, we propose a channel borrowing CAC Scheme in femtocell-macrocell integrated LTE-A networks. The proposed work borrows channel from the reserved guard channel for the handover calls to accept more NRT new originating calls into the system. Classes of new calls have been differentiated as real time (RT) and non-real time (NRT) originating calls. Also, we have adopted pre-emptive method to allow the handover calls (whenever available) to reclaim the channel whenever it is being used by the NRT new calls. This is done to utilize the available bandwidth resources more efficiently while also maintaining the QoS of handover calls.

The rest of this work is organized as follows: the system model showing femtocell access point deployment in LTE/LTE-A networks is presented in the section 2. Section 3 discusses the proposed CAC scheme. In section 4, we discussed the performance evaluation of the proposed CAC scheme and then proposed two system estimations for analysis. Simulation results and discussions are provided in section 5. Finally, the work is concluded in section 6.

II. System Model

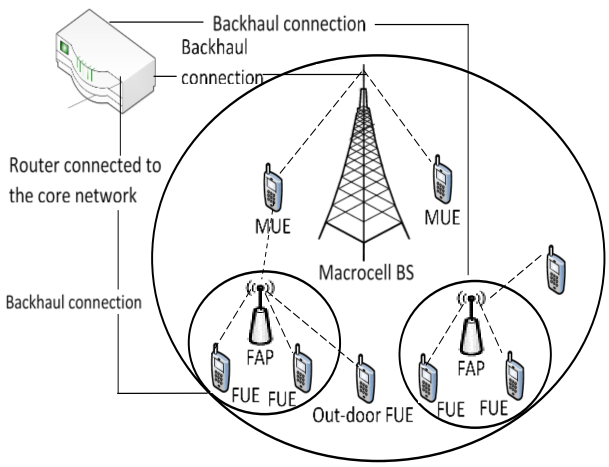

Fig. 2. System model for FAP deployment in LTE-A networks

We considered femtocell deployment within the macrocell in LTE/LTE-A network. By equipping the user equipment (UE) deployed in the LTE/LTE-A macrocell BS with dual interface feature, the UE can communicate simultaneously with the femtocell and the macrocell. The UE initially connected to Femtocell Access Point (FAP) are represented by Femtocell User Equipment (FUE) and the ones connected to the macrocell initially by Macrocell User Equipment (MUE). As shown in the Fig. 2, the femtocell coverage area is smaller compared with the macrocell coverage area. We represent the areas covered by both femtocell and macrocell as A_f and A_m. By assuming that the total bandwidth of the system has been channelized, the total number of channels in the macrocell is C_m. The femtocell and macrocell users' call arrival follows Poison Distribution with mean rates λ_f and λ_m respectively. In addition, the arrivals of new and handoff calls can be generated randomly within the coverage area of LTE-A macrocell BS. The probability of placing a new call within the femtocell's coverage can be given as, $P = A_f/A_m$ and outside the femtocell coverage as $1\text{-}P$.

The proposed system which operates at *2* GHz uses frequency-division duplex with allocated bandwidth of *10* MHz. The radio frame which is given as RBs of M set for the data transmission, where M is a function of bandwidth (W) [20]. When a request is made, a certain *RB* number is assigned to that request. The resources for each request is defined by the LTE RBs.

III. Proposed Call Admission Control with Borrowing Strategy

We assumed two types of UE calls: (i) new (originating) calls and (ii) handover calls (HO). These two calls can be classified further into real time (RT) and non-real time (NRT) calls or services. The RT services include real time gaming and video conferencing while in the NRT services, we have non-real time video and web browsing. To maintain the QoS of ongoing call, the handover call was assigned the highest priority and reserve channel allocated dynamically to it as shown in the Fig. 3. We also employed channel-borrowing strategy to the reserved channel such that whenever the reserved channel is not being used or fully used, the new originating NRT services can make use of it. However, when the handover services are available, the new originating NRT services are pre-empted by the handover services, forcing it to wait in the queue until bandwidth resource is available.

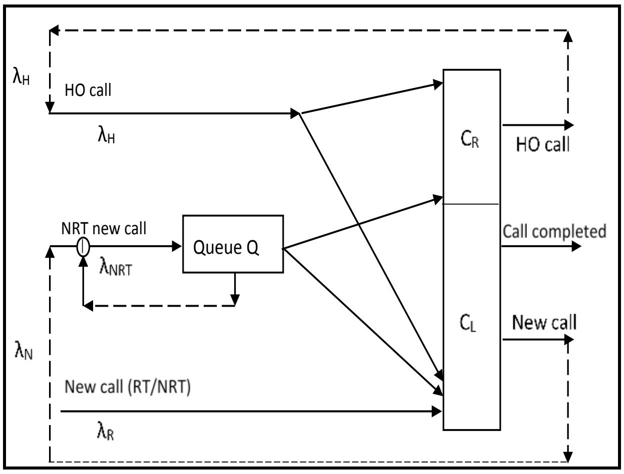

Fig. 3. Channel borrowing CAC strategy

A. Proposed CAC scheme Procedure

Whenever a new originating call (RT/NRT) arrives LTE macrocell coverage area A_f, the new call checks if the femtocell resources are available, if the resources are available, the call is accepted into the femtocell. If not, the call tries to connect to the macrocell if the bandwidth resources are available in the macrocell unreserved channel (C_L). The proposed strategy for accepting calls into the macrocell illustrated in Fig. 3 can be described further as follows. If the bandwidth resources are not available in the C_L, the traffic type is determined. If the new originating call is NRT, and the reserved channel C_R is not fully utilized, then this channel will be borrowed and used by the *NRT* new originating call; otherwise, the call is blocked. For the handover calls, we have: femtocell-to-femtocell, femtocell-to-macrocell, macrocell-to-femtocell and macrocell-to-macrocell handover calls. When the call (RT/NRT) is femtocell-to-femtocell/macrocell-to-femtocell handover call, the call is connected to the femtocell if there are available resources in the femtocell. Otherwise, the call is dropped. However, the operation differs in femtocell to macrocell or macrocell-to-macrocell handovers. Here, the handover (HO) calls from the femtocell/macrocell can be connected to the C_L or to the C_R. If the C_R is fully occupied by the NRT new originating call and the C_L is also being used, the HO call pre-empts the service of NRT call in order to make use of the C_R. The connected NRT new calls are kept in the queue and makes use of the C_R again whenever it is free. The NRT new originating call operation can be delayed for some time since it is not delay sensitive. The size of the queue at time t is denoted as $X(t)$ and the NRT new call will be blocked if $X(t) > 0$. The essence of this proposed strategy is to utilize the network resources efficiently which eventually leads to reduced total blocking probability of the new originating calls. In the same vein, the reservation of channel for handover calls is crucial for a good QoS of handover calls.

If the total channel (in terms of bandwidth) is defined as C_T, the reserved bandwidth for the HO calls to be C_R and the remaining bandwidth for both new calls and HO calls as C_L. Let the number of HO calls, RT and NRT calls be denoted as N_h, N_r and N_n respectively, then we have the following:

- A HO call will be dropped if $N_h + N_r + N_n \geqslant CT$ and $N_h \geqslant C_R$
- A HO arrival will be accepted if $N_h + N_r + N_n \geqslant C_T$ and $N_h < C_R$ by pre-empting *nRT* call.
- An RT arrival will be blocked if $N_h + N_r + N_n \geqslant C_T$ or $N_r + N_n \geqslant C_T\text{-}C_R$ (i.e. C_L)
- An NRT will be blocked if $x(t) \geqslant 0$ *and* $N_h + N_r + N_n \geqslant C_T$.

B. Performance Evaluation of the Proposed CAC Strategy

As shown in Fig. 4, of all the three types of call, only the pre-empt NRT calls are allowed to be in the queue. The proposed model is a mixed loss-queuing system which is very difficult to analyse mathematically. Consequently, we have proposed two estimation methods as follows.

System Estimation 1

In this estimation, it is assumed that the pre-empt NRT calls return to make use of the reserved channel after it has been displaced by the HO calls. If *p* (N_h, N_r, N_n) is the steady-state probability of state (N_h, N_r, N_n) in the proposed CAC strategy, then the arrival rate to the queue using [22] can be given as in equation (1):

$$\lambda_h \sum_{\substack{N_h+N_r+N_n=C_T \\ N_h<C_T}} p(N_h, N_r, N_n) \tag{1}$$

where $\sum_{N_h < C_R} N_h + N_r + N_n = C_T\, p(N_h, N_r, N_n)$ is the probability that the system is in the state that all the channels used by the HO calls is less than C_R. λ_h is the HO calls arrival rate.

If the queue in the system is removed, then arrival rate of NRT calls λ_{NRT}^{new} can be modified as in equation (2):

$$\lambda_{NRT}^{new} = \lambda_{NRT} + \lambda_h \sum_{\substack{N_h+N_r+N_n=C_T \\ N_h<C_R}} p(N_h, N_{r,} N_n) \tag{2}$$

where λ_{NRT}^{new} is determined by the arrival rate λ_h of HO calls and the state probabilities.

From the system estimation method above, a three-dimensional Markov chain can be obtained as follows:

$$S = \{(N_h, N_r, N_n) \mid N_h, N_n \geq 0, 0 \leq N_r \leq C_T - C_R, N_h + N_r, N_n \leq C_T\} \tag{3}$$

The transition rates for the Markov chain of this estimation is given below:

$$q(N_h, N_r, N_n; N_h, N_r, N_n - 1) = N_n \mu_n (0 \leq N_h < C_T, N_n > 0, 0 \leq N_r, \leq C_T - C_R, N_h + N_r + N_n \leq C_T)$$
$$q(N_h, N_r, N_n; N_h, N_r, N_n + 1) = \lambda_{NRT}^{new} (0 \leq N_h < C_T, 0 \leq N_r \leq C_T - C_R, N_h + N_r + N_n < C_T)$$
$$q(N_h, N_r, N_n; N_h, N_r - 1, N_n) = N_r \mu_{RT} (0 \leq N_h, < C_T, 0 < N_r \leq C_T - C_R, N_h + N_r + N_n \leq C_T)$$
$$q(N_h, N_r, N_n; N_h, N_r + 1, N_n) = \lambda_{RT} (0 \leq N_h, < C_T, 0 \leq N_r, + N_n, < C_T - C_R, N_h + N_r + N_n < C_T)$$
$$q(N_h, N_r, N_n; N_h - 1, N_r, N_n) = N_h \mu_h (0 < N_h, \leq C_T, 0 \leq N_r, \leq C_T - C_R, N_h + N_r + N_n \leq C_T)$$
$$q(N_h, N_{r,} N_n; N_h + 1, N_r, N_n) = \lambda_h (0 \leq N_h < C_T, 0 \leq N_r, \leq C_T - C_R, N_h + N_r + N_n < C_T)$$
$$q(N_h, N_r, N_n; N_h + 1, N_r, N_n - 1) = \lambda_h (0 \leq N_h < C_R, 0 \leq N_r, \leq C_T - C_R, N_h + N_r + N_n = C_T)$$
$$p(0, C_T)(\lambda_H + C_{T\,\mu H}) = p(0, C_T - 1)\lambda_{NRT}^{new} = \lambda_{NRT}\, p(0, C_T - 1) + \lambda_H \sum_{n_1+n_2=C_T (n_1<C_R)} p(0, C_T - 1) p(n_1, n_3) \tag{4}$$

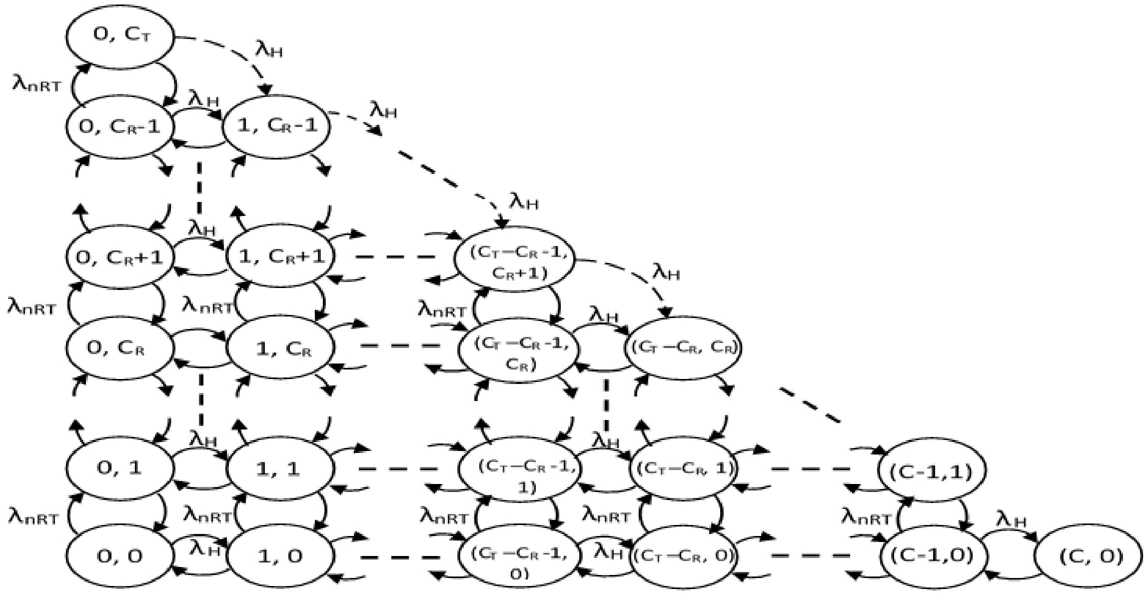

Fig. 4. Markov chain for the channel-borrowing strateg

It is computationally difficult to solve three-dimensional Markov chain. Therefore, the existence of NRT calls and HO calls is assumed for the purpose of obtaining a two-dimensional Markov chain. This however does not affect the channel borrowing idea. The state diagram of the two-dimensional Markov chain for the system estimation 1 is as indicated in Fig. 4. The arrival rate of NRT calls is represented by λ_{NRT} and the handover calls as λ_H. By using global balance equations method in [22] the two-dimensional Markov chain can be solved numerically using non-linear solvers.

We represent the new NRT arrival rate to be λ^{new}_{NRT} and, used it in the global balance equation of state (0, C_T) as shown in equation (4).

The term $p(0, C_T - 1)p(n_1, n_3)$ in equation (4) makes the equation a non-linear. For example, the size of this equation increases rapidly as C_T increases. Therefore, to resolve this equation into linear equations, system approximation 2 is used.

System Estimation 2

In this estimation, $\lambda^{new}{}_{NRT} = \lambda_{NRT.}$ Unlike the system estimation 1, it is assumed that the pre-empt NRT calls are dropped and will not return to make use of the reserved channel. The output of this estimation method yielded linear balance equations because the arrival rate of the pre-empt calls determine the accuracy of the system. Since system estimation 2 resulted in linear equations, which can be solved efficiently within a smaller time, it can therefore be used for large systems with high number of channels.

The performance evaluation of the proposed CAC with channel strategy is compared with an existing strategy without channel borrowing using the following metrics: CBP, CDP and resource utilization. Details about these metrics have been given in our previous work in [21] and also by [23].

We first show the comparison in the results of the two estimation methods using global balance equations. For the two system estimations, the global balance equations can be solved numerically to obtain CBP and CDP as in equations (5) and (6):

These global balance equations can be solved using MATLAB with C_T and C_R assumed to be *16* and *8* respectively. The parameter used for numerical analysis of the two estimations is indicated in Table I.

TABLE I: PARAMETER FOR NUMERICAL ANALYSIS

Parameter	Value
Total number of channels (C_T)	16
Reserved channels (C_R)	8
Service rate (μ_H, μ_R, μ_N)	1
λ_{RT}	0.5
λ_H	0.5 * i
λ_{NRT}	0.5 * I where i=1,2…..10

The obtained results for CBP and CDP are as shown in Fig. 5 and Fig. 6 respectively. It can be shown that the system estimation 2 performs better than system estimation 1 with respect to both CBP and CDP because the pre-empted NRT calls are dropped in system estimation 2. This lowers the NRT load as well as overall load in the system. Consequently, fewer number of calls can be blocked and dropped in the system estimation 2.

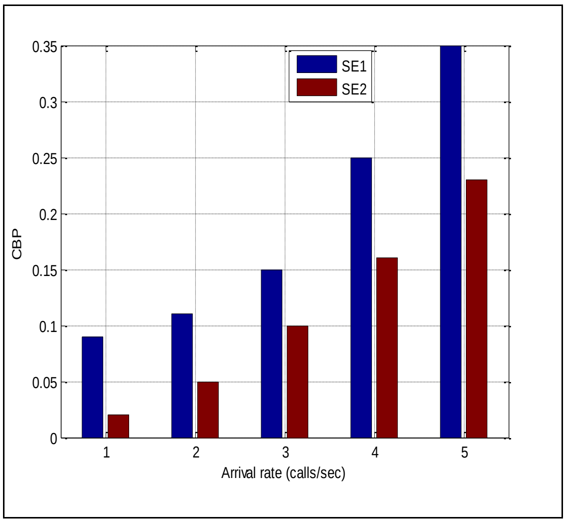

Fig. 5. Call blocking probability for system estimations

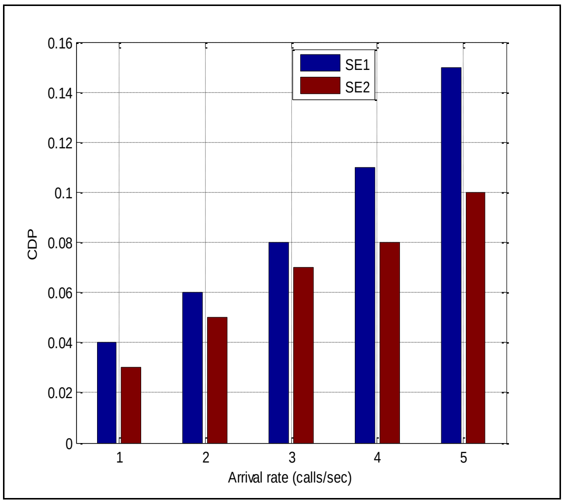

Fig. 6. Call dropping probability for system estimations

$$CBP = \Big(\sum_{(N_r,N_r,N_n):N_r+N_n \supseteq C_t - C_r} \frac{\lambda_{RT}}{\lambda_{RT} + \lambda^{new}_{NRT}} + \sum_{(N_h,N_r,N_n):N_r+N_n \supseteq C_T - C_R} \frac{\lambda^{new}_{NRT}}{\lambda^{new}_{NRT} + \lambda_{RT}} + \sum_{\substack{(N_h,N_r,N_n):N_r+N_n \subset C_T - C_R \\ N_h+N_r+N_n = C_T}} \Big) p(N_h, N_r, N_n) \quad (5)$$

$$CDP = \sum_{\substack{(N_h,N_r,N_n):N_r+N_n \subset C_T - C_R \\ N_r+N_r+N_n = C_T}} p(N_h + N_r + N_n) \quad (6)$$

The system estimations were used to obtain values for CBP and CDP in the mixed loss queueing model used in the proposed channel borrowing strategy because the CBP and CDP cannot be easily obtained through analytical means from the mixed loss queueing model. We also employed simulations to obtain CBP, CDP as well as resource utilization and then compares the results in the next section.

IV. SIMULATION RESULTS AND DISCUSSION

The proposed CAC with channel borrowing strategy can be evaluated and compared with the existing strategy without channel borrowing scheme. The simulation parameters are as shown in Table II.

TABLE II: PARAMETER FOR NUMERICAL ANALYSIS

Parameter	Value
Power of HeNB	20 mW
Power of eNB	46 mW
Radius of HeNB	15 m
Radius of eNB	500 m
MacrocellBandwidth capacity	10 Mbps
Number of UEs	Varies
Initial number of users in a femtocell	4
Access mode of femtocell	Open/closed
UE's mobility model	Random WayPoint
UE speed	Varies
Average call duration	150 seconds

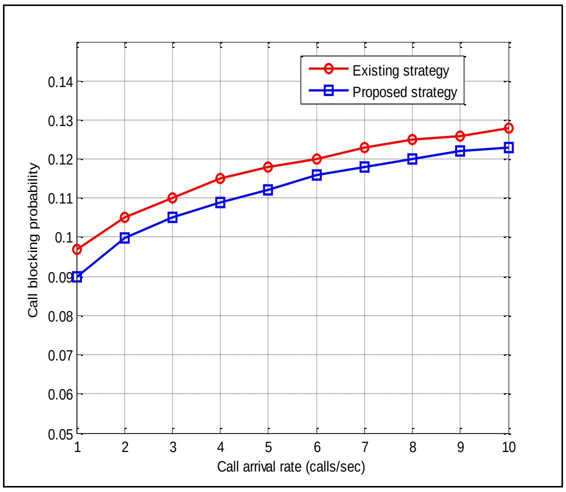

Fig. 7. Call Blocking Probability

The result of call blocking probability (CBP) for both existing strategy and proposed strategy is as shown in Fig. 7. We assume the existing strategy to be the one without channel borrowing scheme. We simulate and evaluate this strategy together with our proposed strategy. In the existing strategy where channel borrowing is not employed, to guarantee reduced CBP, some channel are reserved for the handover calls. Thereby more handover calls are admitted into the system leaving few new originating calls into the system. This is because in this strategy, the resources are not effectively utilized. The new originating calls (RT and NRT) have access only to the remaining non-reserved channel.

In the proposed strategy however, channel borrowing strategy has been employed to increase the number of accepted new originating calls in the system while also guaranteeing reserved resources for the handover calls. For instance, more NRT calls will be accepted into the unused reserved channel while keeping the pre-empted ones in a queue. The pre-empted NRT calls resume to make use of the channel as soon as the channel is available. Therefore, overall call blocking probability of the new calls is considerably reduced. In the Fig. 7, the proposed strategy reduces CBP by about 10% of the existing strategy for every traffic load. This means that with the proposed strategy more new originating calls were accepted while also allowing handover calls to use the resources anytime.

The result of Call Dropping Probability (CDP) is presented in Fig. 8 for both existing strategy and proposed strategy. The CDP though initially lower in the proposed strategy compared to the existing strategy owing to the lower traffic, however, as the traffic increases the CDP becomes higher in the proposed strategy than the existing strategy. This is because fewer handover calls can now use the unreserved channel. The increase in the CDP here is minimal in contrast to the performance gain obtained in terms of CBP with the proposed strategy. The difference in CDP, which is only noticeable as the traffic increases, is less than 1%.

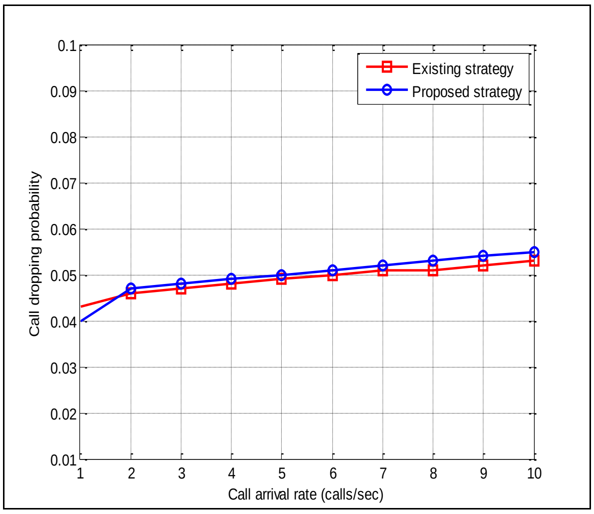

Fig. 8. Call Dropping Probability

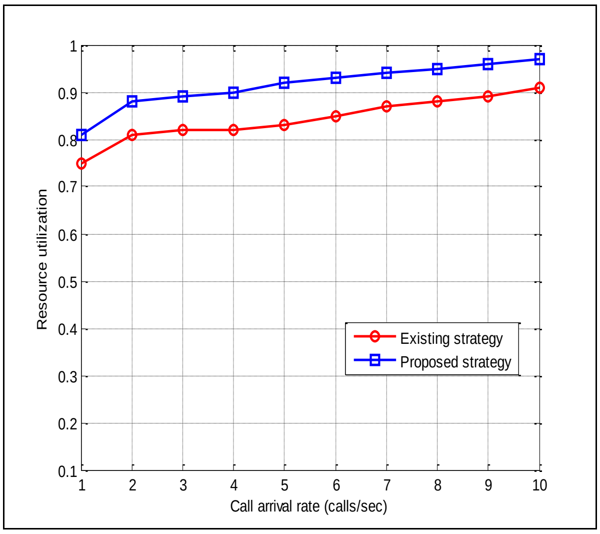

Fig. 9. Resource utilization

The result of resource utilization for both existing strategy and proposed strategy is as shown in Fig. 9. Resource utilization has been improved with the proposed strategy. In the existing strategy, the resource utilization is worse than in the proposed strategy because of the fixed channel reserved for the handover calls and in the absence of handover calls, the reserved channel is not used, thereby the entire channel resources become underutilized. However, with the proposed strategy, channels are used effectively by ensuring that whenever there are few or no handover calls, the reserved channel are used by the NRT new originating calls. This increases the resource utilization by about 10%. Summarily, the proposed strategy outperforms the existing strategy in terms of system resource utilization.

V. Conclusions

In this section, a channel borrowing call admission control strategy has been proposed to manage the UE calls in LTE-A networks efficiently and to ensure that channels are used effectively. In our strategy, the reserved channel for handover calls in the macrocell can be borrowed by the new originating NRT calls. However, when the handover calls arrive, the ongoing NRT call is pre-empted, and made to queue in order to use the channel at other times when channel is available. The channel-borrowing strategy is modeled using a mixed-loss system with two system estimations proposed. Based on the evaluation with regards to CBP and CDP, the system estimation 2 performed better than system estimation 1. Also, from the simulation results, we showed that when comparing the proposed strategy with the existing strategy, the proposed strategy performed better with respect to CBP and system utilization while there is a very little drop in CDP.

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Olusegun O. Omitola received M.Sc. in Mobile Computing and Communications from the University of Greenwich, London, UK and B.Tech degree in Computer Engineering from Ladoke Akintola University of Technology (LAUTECH), Nigeria, in 2007. He is a lecturer at the department of Electrical, Electronic and Computer Engineering, Afe Babalola University, Nigeria. He is currently pursuing his PhD in Electronic Engineering at the University of KwaZulu-Natal, South Africa. His interests include mobile and wireless communications, femtocells, LTE/LTE-A, and mobile ad-hoc networks.

Viranjay M. Srivastava is a Doctorate (2012) in the field of RF Microelectronics and VLSI Design, Master (2008) in VLSI design, and Bachelor (2002) in Electronics and Instrumentation Engineering. He has worked for the fabrication of devices and development of circuit design. Presently, he is a faculty in Department of Electronic Engineering, Howard College, University of KwaZulu-Natal, Durban, South Africa. He has more than 13 years of teaching and research experience in the area of VLSI design, RFIC design, and Analog IC design. He has supervised various Bachelors, Masters and Doctorate theses. He is a senior member of IEEE, and member of IEEE-HKN, IITPSA, ACEEE and IACSIT. He has worked as a reviewer for several Journals and Conferences both national and international. He is author/co-author of more than 110 scientific contributions including articles in international refereed Journals and Conferences and also author of following books, 1) VLSI Technology, 2) Characterization of C-V curves and Analysis, Using VEE Pro Software: After Fabrication of MOS Device, and 3) MOSFET Technologies for Double-Pole Four Throw Radio Frequency Switch, Springer International Publishing, Switzerland, October 2013.