Performance Analysis of a Finite Capacity Femtocell Network

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ABSTRACT

A feasible solution to wireless spectrum scarcity is the deployment of femtocells along with already existing or new macrocells. This hybrid architecture not only helps to increase the system capacity but also improves the wireless signal quality for indoor users. Moreover, these femtocells can offer higher data rates to indoor users. In this paper, we analyze the performance of a finite capacity femtocell network. The transmission of data from *M* communicating nodes to a FAP (Femtocell Access Point) is modelled as M/M/1/K queue. The access point in this case can hold a maximum of *K-1* packets in its buffer, hence the system represents a finite capacity network. The performance of the system is evaluated in term of QoS (Quality of Service) parameters such as packet blocking probability, average packet delay and utilization for different buffer sizes. The results reveal that with an increase in buffer size, the packet blocking probability decreases however at the cost of increased average delay.

Key Words: **Buffer, Femtocell, Queuing, Quality of Service.**

1. INTRODUCTION

Recent advance in the field of wireless communication has resulted in an increased capacity demand [1]. Nowadays, a large number of users prefer to have data services on move and thus like to have seamless wireless connectivity on their devices. Research statistics show that approximately 50% of calls and 70% of data services are carried out by indoor users in current cellular networks [2-3]. However, these indoor users face severe problem of bad signal quality while making phone calls or accessing internet. The signal quality for indoor users can be improved by deploying femtocells along with macrocell. This kind of hybrid architecture increases reliability, enables continuous connectivity, and also results in energy efficiency of the system [4].

In our previous paper [4], we evaluated the performance of a femtocell network using an M/M/1 queue. To simplify the analysis, we considered an infinite capacity system which in turn provided an approximate result. But practical systems such as FAPs can hold a finite number of data packets and thus can cause blocking [5]. Hence an M/M/1/K queue is more suitable model for this system. For this purpose, in this paper we evaluate the performance of a finite capacity femtocell network using M/M/1/K queue in terms of packet blocking probability, average packet delay and utilization.

Following the introduction paper is organized as follows. Related work is discussed in Section 2. Section 3 describes

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the studied scenario. Analytical model of the femtocell network is presented in Section 4. The performance evaluation is carried out in Section 5. Finally paper concludes in Section 6.

2. RELATED WORK

Queuing theory is a useful analytical tool to model a wide range of problems and scenarios in communication networks [6]. Traditionally, queuing theory based models have extensively been used in predicting the QoS of access networks [7]. In previous studies, queuing models were used to evaluate QoS parameters such as packet blocking probability, average packet delay and throughput [8]. In [9], a generic model based on [8] was proposed to optimize the buffer size with respect to the throughput. The authors in [10] have proposed a methodology for radio link level performance analysis in a multirate OFDMA (Orthogonal Frequency Division Multiple Access) network with adaptive fair rate allocation, where a queuing theory based model was developed to analyze the system performance in terms of packet dropping probability and packet transmission delay.

The provisioning of higher data rates to the end users in a seamless fashion has encouraged service providers to explore new networking paradigms including femtocell [11]. A femtocell is comprised of an FAP and a small number of stationary and low mobility users. Femtocells are low cost and low power small cells deployed to provide short range communication in indoor environments [12]. In [13], a multi-objective and optimal handover solution for LTE systems, consisting of femtocells, has been proposed. In this work, a queuing model with 3-D Markov chain was developed to represent the efficiency of the system. The results reveal that the proposed scheme performs better than existing schemes in terms of session blocking and queuing delay. In [4], the performance of a femtocell network was evaluated in terms of energy efficiency, utilization and delay. In this work an infinite buffer size was taken into account.

3. STUDIED SCENARIO

A cellular network comprised of a macrocell and femtocells is shown in Fig. 1 [4]. Here, we analyze the performance of a femtocell network with M communicating nodes. All communicating nodes transmit their packets to a FAP. Hence this scenario represents a packet switched network. Further, to enable a seamless communication, this FAP is connected to a macrocell base station using backhaul connection. In this paper, we evaluate the performance for uplink transmission (from communicating nodes to the access point) only.

4. ANALYTICAL MODELLING

In scenario considered, each communicating node in femtocell network generates packets with a mean rate λ_n. The complete packet arrival process of M communicating nodes becomes a multiple Poisson process with mean arrival rate $\lambda = M\lambda_n$. The packets are received at the input of access point and stored in its buffer (which can hold a maximum of $K-1$ packets). If the buffer is full then packet is blocked [14]. To enable an end to end continuous communication, received packets are transmitted to the main base station using backhaul channel. This backhaul channel represents a server which serves arrived packets with a mean service rate of μ in a FIFO (First-In-First-Out) pattern. A real packet length from [15] is considered in this paper. Further the packet length follows an Exponential distribution. Hence, the service time of the server (the backhaul with a constant data rate R_b) has an Exponential distribution. This complete scenario of femtocell network becomes an $M/M/1/K$ queue. Fig. 2 shows the state transition diagram of this network using a birth-death model [5-14]. There are a total of K states as system can handle a maximum of K packets. Each state describes the number of packet in the system.

For $0 < n < K$, the equilibrium probability for this system is:

$$p_n = \begin{cases} \dfrac{(1-\rho)\rho^n}{1-\rho^{K-1}}, & \rho \neq 1 \\ \dfrac{1}{K+1}, & \rho = 1 \end{cases} \tag{1}$$

where n represents the number of packets in the system and $\rho=\lambda/\mu$ is the traffic intensity. For this system the steady state solution always exists and system is stable even for $\rho>1$. Further, if the arrival rate is greater than the service rate, the number of packets in the system will increase however the total number will be limited due to finite capacity (buffer size).

The arriving packet is blocked (lost) if the system is full. Hence, the packet blocking (loss) probability is:

$$p_B = p_K = \begin{cases} \dfrac{(1-\rho)\rho^K}{1-\rho^{K-1}}, & \rho \neq 1 \\ \dfrac{1}{K+1}, & \rho = 1 \end{cases} \quad (2)$$

The mean number of packets in the system is:

$$L = \sum_{n=0}^{K} np_n \quad (3)$$

The effective arrival rate (λ') of the packets actually entering the system is:

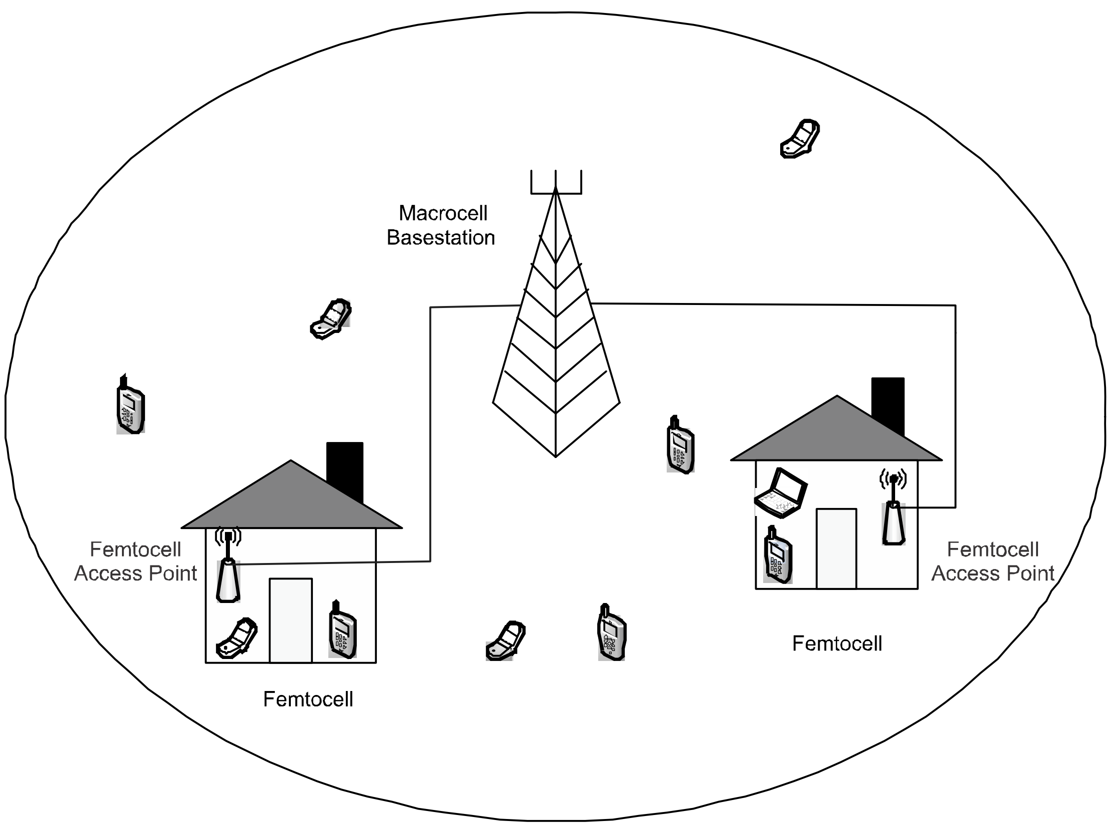

FIG. 1. A CELLULAR NETWORK COMPRISED OF A MACROCELL AND FEMTOCELLS [4]

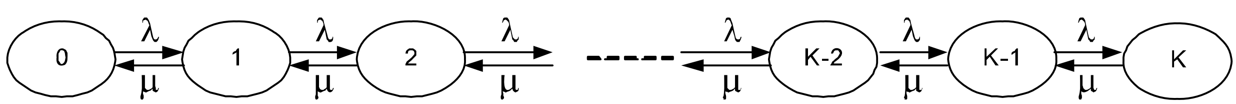

FIG. 2. STATE TRANSITION DIAGRAM OF M/M/1/K SYSTEM [5]

$$\lambda' = \lambda(1-p_K) = \lambda(1-p_B) \quad (4)$$

Effective arrival rate (λ') is smaller than total arrival rate (λ) as it does not account for blocked packets. Moreover, the state transition diagram is with respect to the total arrival rate.

The average packet delay is the delay which a packet experiences in the system and is given by:

$$W = \frac{L}{\lambda'} = \frac{L}{\lambda(1-p_B)} \quad (5)$$

The system utilization is defined as the probability that the server is busy and is given as:

$$U = 1- p_0 = \rho(1- p_B) \quad (6)$$

where p_0 is the probability that the system is empty.

5. PERFORMANCE EVALUATION

In this section, performance analysis of this femtocell network is carried out in terms of QoS parameters such as packet blocking probability, average packet delay, and system utilization. The packet length distribution follows an Exponential distribution with an average packet length of 867.4 bytes. This mean value of packet length is taken from real measurements [15]. A communication node in a femtocell generates data with a data rate of 320 kbps. Thus the mean arrival rate of data packets from a source node is 46.11 packets per second [16]. The M communicating nodes transfer their data to the FAP which eventually forwards this combined data to a central coordinating entity at a rate of 6 Mbps. Thus the mean service rate of the server is 864.65 packets per second. In this paper, we keep mean service rate of AP constant where as the combined arrival rate of data depends on the number of communicating nodes. Hence the value ρ depends on the mean arrival rate. As this system is a finite capacity system (system can hold a maximum of K packets) the value of ρ can be greater than 1 without making system unstable. Here we consider three different buffer sizes (i.e. 9, 29, and 49) and see their impact on performance analysis.

Fig. 3 illustrates the packet blocking probability of the system with varying buffer sizes as function of traffic intensity. From figure it can be noticed that the blocking increases with increase in the arrival rate (i.e. traffic intensity) as system can hold K packets at maximum. In case of buffer size of 9 (including server system capacity is 10 packets), the packet blocking probability is very low with traffic intensity values less than 0.6. However, it starts increasing with increase in traffic intensity. At ρ=1, the blocking becomes approximately equal to 0.1 which means that the 10% of the arrived packets are blocked because system is full. The number of blocked packets becomes more than 35% with traffic intensity equal to 1.6. With buffer sizes of 29 and 49 (or system capacities of 30 and 50 packets) the average packet blocking is very low for traffic intensity values less than 0.8. At this point the blocking with system capacity of 10 packets was high compared to other two cases. The difference in blocking values for all three cases starts decreasing with higher values of traffic intensity. This is because the incoming packets see system full irrespective of buffer size for higher traffic intensity.

Fig. 4 shows the system performance in terms of average packet delay in milliseconds (ms). This QoS parameter is also evaluated for three cases (i.e. system capacities of 10, 30, 50 packets). This average delay of a packet is superposition of two delays. First delay is the waiting time of a packet in queue where as second delay is the service time required for that packet. With data rate considered, a packet can be served with an average service time of 1.1 ms. Hence the major contributor of the delay in this case is the system capacity which causes waiting delay. Results in Fig. 4 reveal that the average packet delay in all three cases is very low with traffic intensity values less than 0.2. It starts increasing with increase in the arrival rate of data packets from M communicating nodes. In case of buffer size of 9 the average packet delay becomes 10 ms for traffic intensity value of 1.6. In this case the delay is small compared to the other two cases, however, it is achieved at a cost of higher blocking (Fig. 3). The delay in case of system capacity of 50 is higher as compared to other two cases. This is because the system can hold more packets compared to other two cases which in turn causes more average packet delay for higher values of traffic intensity. The average packet delay with buffer sizes 29 and 49 becomes unacceptable in some communication scenarios.

It can be noticed from Equation (6) that the utilization of the server is directly propotional to the traffic intensity, however it is effected by the system capicity. It increases with an increase in traffic intensity. The utilization of the system is shown in Fig. 5. The utilization of the system is low when small amount of data is generated by communicating nodes. At these instances, the blocking is almost zero as service rate is significantly greater than packet arrival rates. The utilization in all three cases remains aproximately same for traffic intensity values smaller than 0.7. A high utilization means that server is busy in serving incoming data. High utilization is achieved with higher arrival rate, however with greater delay and blocking. The difference between utlizations of three cases becomes evident after ρ=0.8. If the service rate is significantely higher compared to the arrival rate of packets then system becomes empty soon which results in under-utilized system. The utilization value saturates to 1 with increase in traffic intensity.

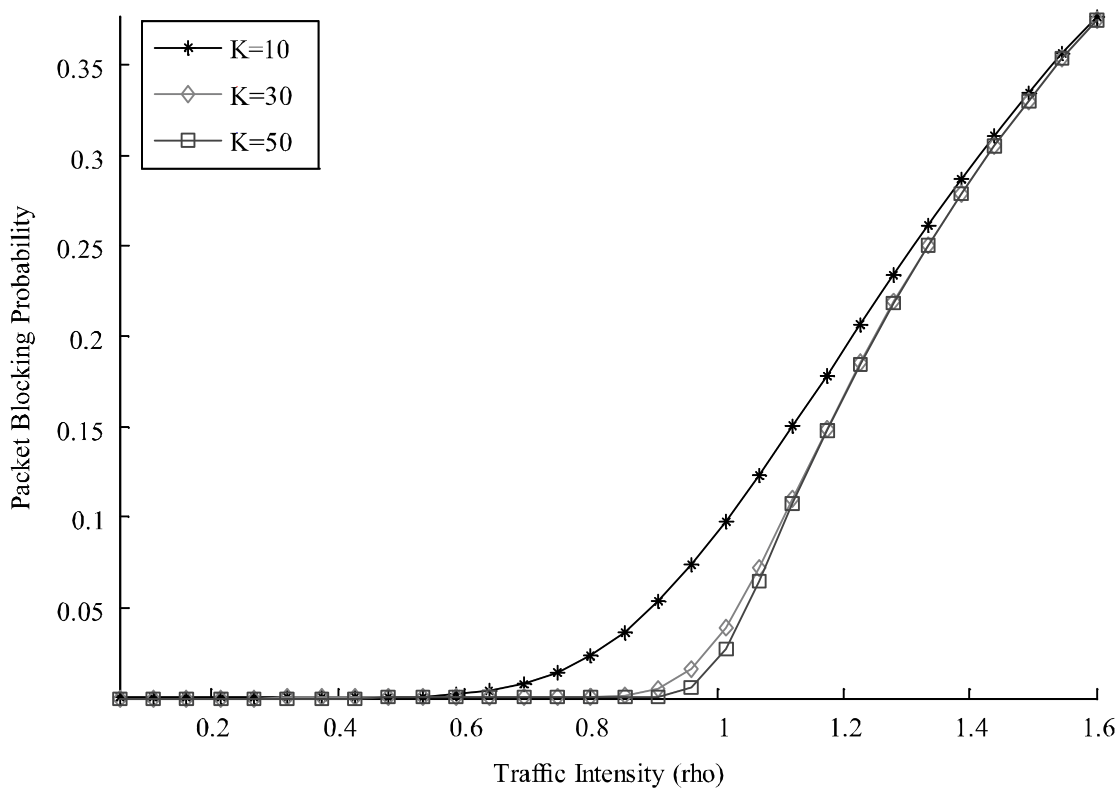

FIG. 3. PACKET BLOCKING PROBABILITY

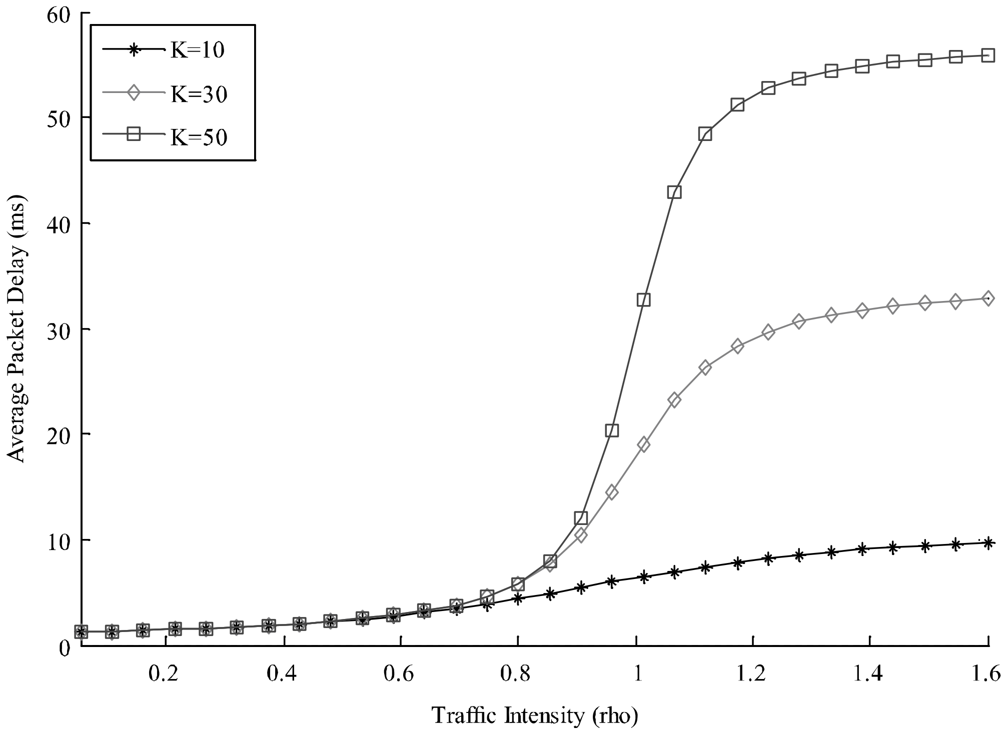

FIG. 4. AVERAGE PACKET DELAY

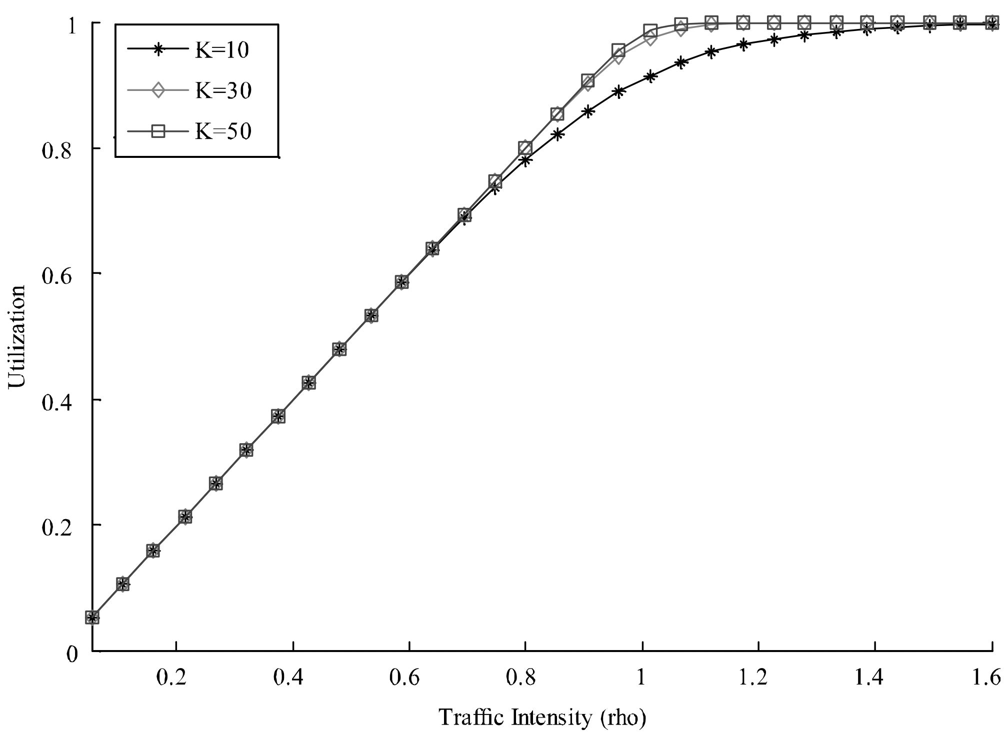

FIG. 5. UTILIZATION

6. CONCLUSION

In this paper, we have considered a finite capacity femtocell network consisting of *M* communicating nodes. The network has been modelled using *M/M/1/K* queuing model. By considering realistic packet length, the performance of the system has been evaluated in terms of average packet delay, packet blocking probability and utilization. Different system capacities (buffer sizes) have been considered while evaluating the performance. The results show that these QoS parameters are function of both traffic intensity and buffer sizes. The packet blocking probability increases with increase in traffic intensity. Further the system with higher buffer size has less packet blocking probability. However, an increase in buffer size causes more average system delay. The results also reveal that the utilization is low for small arrival rate. It reaches to 1 with higher traffic intensity which indicates that system is full and server is busy.

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