
Finite Capacity Energy Efficient Femtocell Network

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ABSTRACT

This paper presents the performance analysis of a finite capacity energy efficient femtocell network. A FAP (Femtocell Access Point) provides continuous connectivity for M communicating nodes in this network. The data transmission from M communicating nodes to the central entity (FAP) is represented using $M/M/1/K$ queue. To save energy, the server, in this case, takes exponentially distributed vacations during idle periods. Due to finite buffer size of FAP, this network represents a finite capacity system. The network model where sever takes vacation to save energy is solved with help of MGM (Matrix Geometric Method). For different system capacities, the network performance is analyzed in terms of power savings and QoS (Quality of Service) parameters such as utilization, average packet delay, and packet blocking probability. Results show that with small traffic intensity the energy savings is high, whereas utilization, delay and blocking are low. Moreover, the maximum energy can be saved when system in quite under-utilized.

Key Words: Capacity, Energy, Femtocell Access Point, Matrix Geometric Method, Quality of Service.

1. INTRODUCTION

The rapid growth in the number of subscribers leads to an increased bandwidth demand which results into higher energy expenditure in current cellular networks [1-3]. This in turn increases the CO_2 emission which is a critical issue nowadays. Furthermore, the increased number of users also leads to the problem of spectrum scarcity. A possible and more economical solution to wireless spectrum scarcity is the deployment of small cells (called femtocells) with already available or new macrocells. This hybrid architecture escalates the problem of bad signal quality for indoor users, achieves energy savings, and increases the spatial reuse [2-4]. Moreover, users can communicate at higher data rates.

The issue of energy efficiency in ICT (Information Communication Technology) sector has motivated many researchers from academia and industry to propose and develop new communication architectures and protocols. Many countries have committed to reduce the carbon footprint of ICT sector [2,5]. In this regard, the United Kingdom is aiming to achieve energy efficiency of 80% by year 2050. The research statistics show that current cellular communication causes only 1-2% of the total emission. However, the ever increasing number of subscribers and rapidly growing demand of data services will cause exponential increase in carbon emission. A hybrid cellular architecture consisting Macrocell and few femtocells is a

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practicable solution to address the issue of energy efficiency and to improve reliability in present cellular systems [2].

Previously, we evaluated the performance of energy efficient femtocell network by considering M/M/1 queue [2]. However, the finite capacity queue such as M/M/1/K represents practical system where an incoming packet can see system full and hence is blocked [3,6]. Therefore, in this paper we analyze the performance of a femtocell network using M/M/1/K queue where server goes on vacation (sleep mode) to save energy during idle period (when system is empty). Moreover, we also evaluate the QoS parameters along with energy efficiency. This paper is an extension of our previous work [2,3].

Following the introduction, rest of the paper is structured as follows: Section 2 describes the related work. The studied scenario is briefed in Section 3. A queuing theory based analytical model is presented in Section 4. Section 5 explains the performance analysis of the network in terms of QoS parameters and energy savings. Finally paper conclusion is described in Section 6.

2. RELATED WORK

A number of problems and setups in communication networks can efficiently be solved using analytical modelling developed with help of queuing theory [7]. QoS parameters for performance evaluation of communication network have been successfully calculated using queuing models [8]. The authors in [9] 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.

Previous studies have suggested the optimization of RF output power to save energy in wireless networks [10,11]. In [10], it has been shown that the node mobility characteristics can be utilized to save energy in a store-carry and forward fashion in a mobile network. A clustering based energy efficient protocol has been proposed for micro sensors in [11]. The research work in both of these studies shows that energy efficiency can be achieved by controlling the transmission power. However, a different view is presented in [12] where circuitry was shown to consume very high power compared to the transmitter output power and author argues that there is little point in saving energy using RF power optimization technique. Other studies show that by considering a sleep strategy at a node during its inactivity, a certain amount of energy can be saved [2,13]. In [13], authors have compared the performance of synchronous and asynchronous protocols in terms of energy savings. Results show that their proposed semi-asynchronous protocol is more energy efficient compared to other protocol.

Femtocell refers to a network consist of a femtocell access point and few slow moving users. These small cells intend to provide short range continuous connectivity to the indoor users. This kind of small cells deployment in present cellular system is a cost effective way of accommodating more users while saving a substantial amount of energy [3]. In [14] authors have considered an LTE system with femtocells and have proposed an optimal solution using queuing theory for handover. The results in this work show that queuing delay and session blocking achieved using their suggested scheme are improved while comparing with other available schemes. In [2], the performance analysis of a femtocell network has been evaluated in terms of QoS parameters and energy savings. Results show that the higher energy savings can be attained with longer sleep cycles and with small offered load. In [15], authors have studied the performance of a

3G femtocell base station in terms of energy expenditure for both data and voice traffic. A cluster based energy efficient algorithm based on sleep strategy has been proposed in [16] for densely deployed femtocell network.

3. STUDIED SCENARIO

In this paper we consider a communication network similar to the one presented in our previous papers [2,3]. Fig. 1 shows a communication setup where a macrocell and few femtocells exist. However, in this setup a femtocell with finite buffer size is considered. In this paper, we analyze the performance of a femtocell network comprised of a femtocell access point and M communicating nodes. Without loss of generality, only uplink communication is taken into account.

4. ANALYTICAL MODELLING

In femtocell network, packets are generated with a mean rate λ_n by each node. The combined arrival process of packets from M communicating nodes follows Poisson distribution, where $\lambda = M\lambda_n$ is the mean arrival rate of combined Poisson process [2,3]. The packets are gathered in the buffer (of size K-1) of FAP. These packets are further transmitted to their destinations through main basestation using backhaul connection (between FAP and base station). The gathered packets are served with a mean service rate of μ by FAP using communication link in FIFO (First in First Out) mechanism. The exponential distribution is used for the service time as packet length follows an exponential distribution and server (backhaul) serves with a rate R_b [2]. To save energy, the FAP switches to sleep

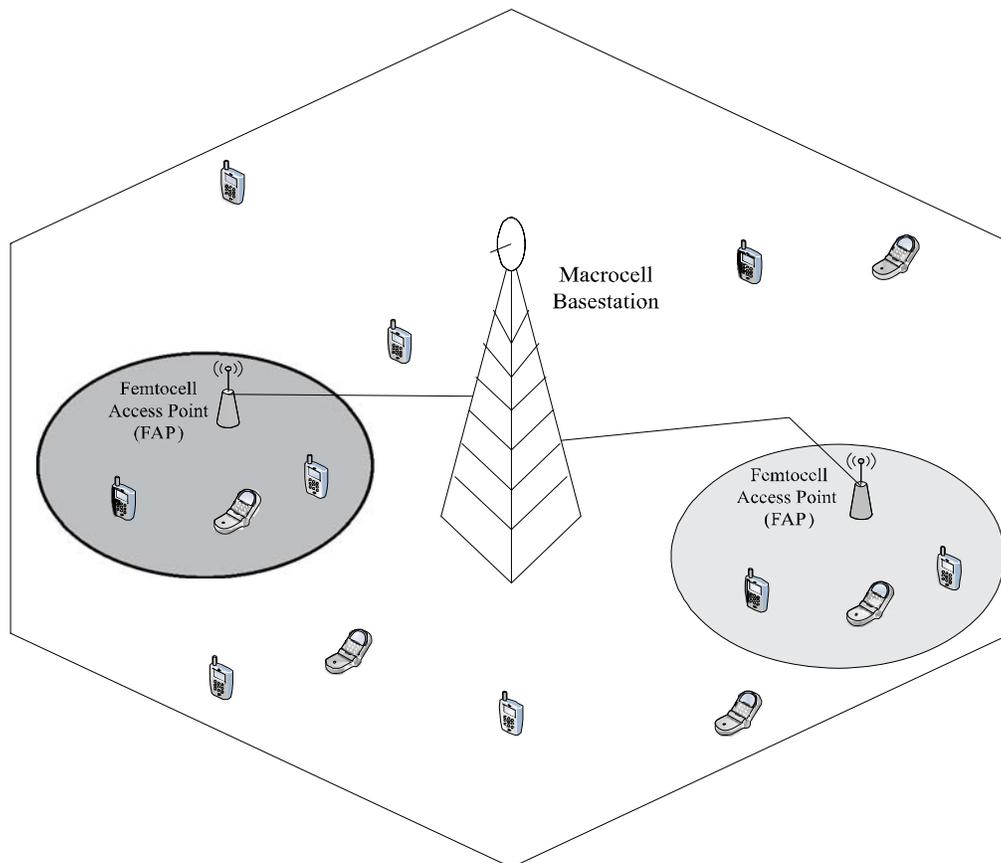


FIG. 1. HYBRID COMMUNICATION NETWORK [2]

where \mathbf{u} is unit vector. The number of packets in the system can be computed as:

$$N = \sum_{k=0}^K k p_k \quad (6)$$

The packet blocking probability is:

$$P_B = P_{(0,K-1)} + P_{(1,K)} \quad (7)$$

The average packet delay can be computed using Little's theorem [3,19] as:

$$W = \frac{N}{\lambda'} = \frac{L}{\lambda(1 - P_B)} \quad (8)$$

where λ' is effective arrival rate of packets [3]. It is the rate at which packets actually enter the system. It does not consider the blocked packets. The utilization is given as:

$$U = \frac{\lambda}{\mu} (1 - P_B) = \rho (1 - P_B) \quad (9)$$

where ρ is the offered load to the system [19]. The power saving (energy efficiency) of network at FAP can be computed as:

$$P_s = ((1 - U) \times P_t) - (P_{OH}) \quad (10)$$

where P_t represents the transmit power of FAP and P_{OH} denotes the overhead power needed for changing from a transmit state to a low power state [2,18].

5. PERFORMANCE EVALUATION

The performance of femtocell network has been evaluated in terms of QoS parameters and energy efficiency (% power savings). These performance parameters are analyzed for different values of traffic intensities. In our previous paper [2], we analyzed that mean sleep duration of 5 ms can save significant amount of energy with lower P_{OH} . In this paper, an Exponential distributed sleep cycle (with

mean 5 ms) has been taken into account. Packet length has an Exponential distribution with mean of 867.4 bytes [20]. The data is generated with a rate of 320 kbps per node. Hence, each communication node has a mean arrival rate of 46.11 packets per second [3]. These data packets are transmitted to the main base station using a 6Mbps link (between FAP and base station). Therefore, the service time follows an Exponential distribution (i.e. departure rate is Poisson distributed). As FAP can hold a maximum of K packets, therefore system becomes a finite capacity system. In this paper, we have considered three system capacities (i.e. 10, 30, and 50) [3].

Fig. 3 shows the variation of packet blocking probability with respect to traffic intensity. It is evident from the figure that with smaller traffic intensity ($\rho \leq 0.2$) the blocking is negligible. However, as traffic intensity increases the blocking in the system with capacity 10 increases sharply. Whereas the blocking, with system capacities 30 and 50, remains very low with $\rho \leq 0.8$. At $\rho=1$, the packet blocking probability is about 0.04 and 0.02 with system capacities of 30 and 50 respectively. In case of system capacity of 10, the blocking is 0.12 with $\rho=1$. The results reveal that systems with larger buffer size can hold more packets and thus result in small blocking.

Fig. 4 shows the average packet delay for all three cases (i.e., buffer sizes 9, 29 and 49). This system delay is because of both service time and waiting time. When traffic intensity is very low, the delay is dominated by sleep duration as there is very small number of packets in the system. In case of system capacity of 10, the delay remains within 10 ms for all values of traffic intensity. However, this small delay (because of small system capacity) results in higher blocking (Fig. 3). The average delay in the other two cases is almost the same as the first case for traffic intensity values up to 0.5. At $\rho=1$, delay is about 20ms for a system with a buffer size of 29. It becomes more than 32ms for a system capacity 50 packets. Higher delays are unacceptable for many communication scenarios.

Fig. 5 illustrates the system utilization for all three cases. Low utilization refers to a system with small number of packets arriving as compared to service rate of the server. For all three cases utilization is approximately equal for

$\rho \leq 0.5$. It starts deviating in case of system capacity 10 when $\rho > 0.5$. Maximum value of utilization attained is 1. In all three cases, it never reaches to 1 because of finite capacity as some of the packets are blocked (Fig. 3).

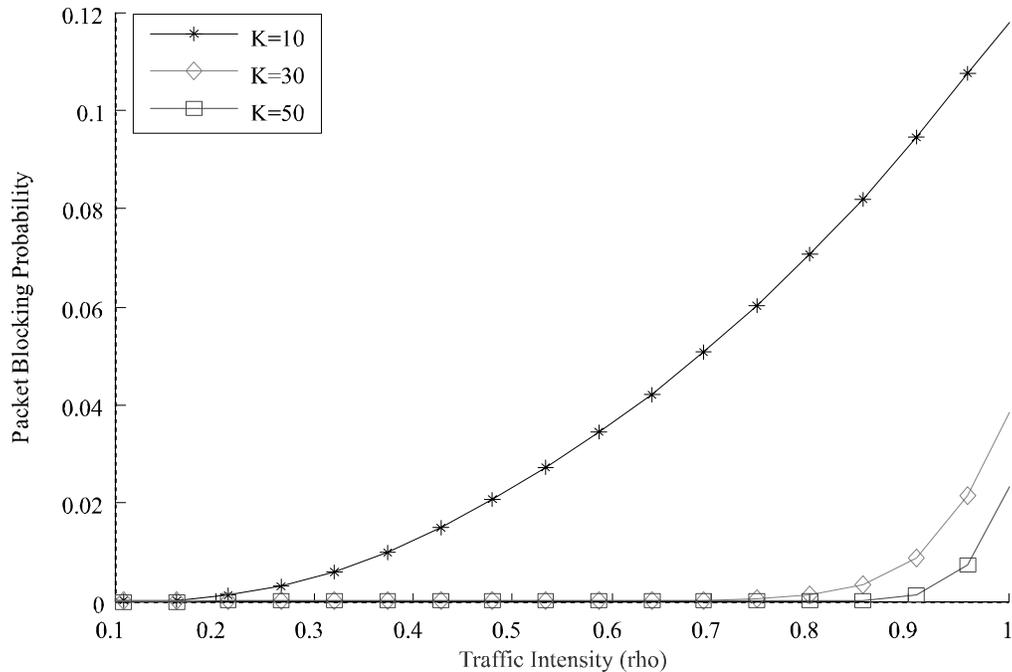


FIG. 3. PACKET BLOCKING PROBABILITY WITH DIFFERENT SYSTEM CAPACITIES

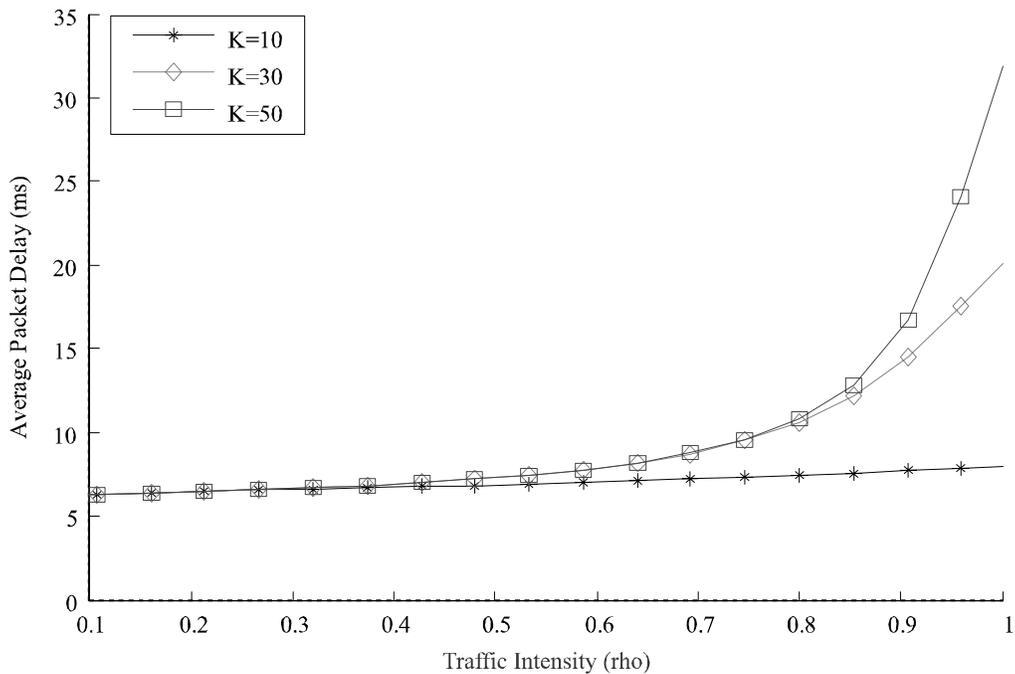


FIG. 4. AVERAGE PACKET DELAY WITH DIFFERENT SYSTEM CAPACITIES

Table 1 shows the power savings with varying traffic intensity values for three system capacities. FAP consumes 30W power [2,18]. Mean sleep duration of 5ms is considered. An over-head power of 1.5W (5% of P_t) is taken into account. As can be noticed from the calculations in Table 1, the maximum energy is saved when the system utilization is very low. This scenario refers to the condition when arrival of the data traffic is small. Results further reveal that as traffic intensity increases, the power saving starts decreasing. For low traffic intensity, the energy savings are approximately same with all three system capacities. When traffic intensity becomes quite high, the energy savings with small buffer size are more compared to large buffer size. This can be attributed to the fact that small buffer size holds a small number of packets and as soon as server gets free it takes vacation. Whereas, in case of large buffer size, the system can hold more packets and it does not go to vacation as quicker as system with small buffer size with high traffic intensity values. Energy savings almost vanish with the utilization attaining the value 1.

TABLE 1. POWER SAVINGS WITH DIFFERENT SYSTEM CAPACITIES

Traffic Intensity (ρ)	Power Savings (%)		
	K=10	K=30	K=50
0.05	89.67	89.67	89.67
0.11	84.33	84.33	84.33
0.16	79.15	79.14	79.14
0.21	73.69	73.67	73.67
0.27	68.41	68.33	68.33
0.32	63.18	63.05	63.05
0.37	58.03	57.67	57.67
0.43	52.97	52.33	52.33
0.48	47.99	47.01	47.01
0.53	43.11	41.67	41.67
0.59	38.34	36.33	36.33
0.64	33.69	31.01	31.00
0.69	29.18	25.68	25.67
0.75	24.82	20.37	20.33
0.8	20.64	15.10	15.00
0.85	16.67	9.95	9.68
0.91	12.89	5.14	4.44

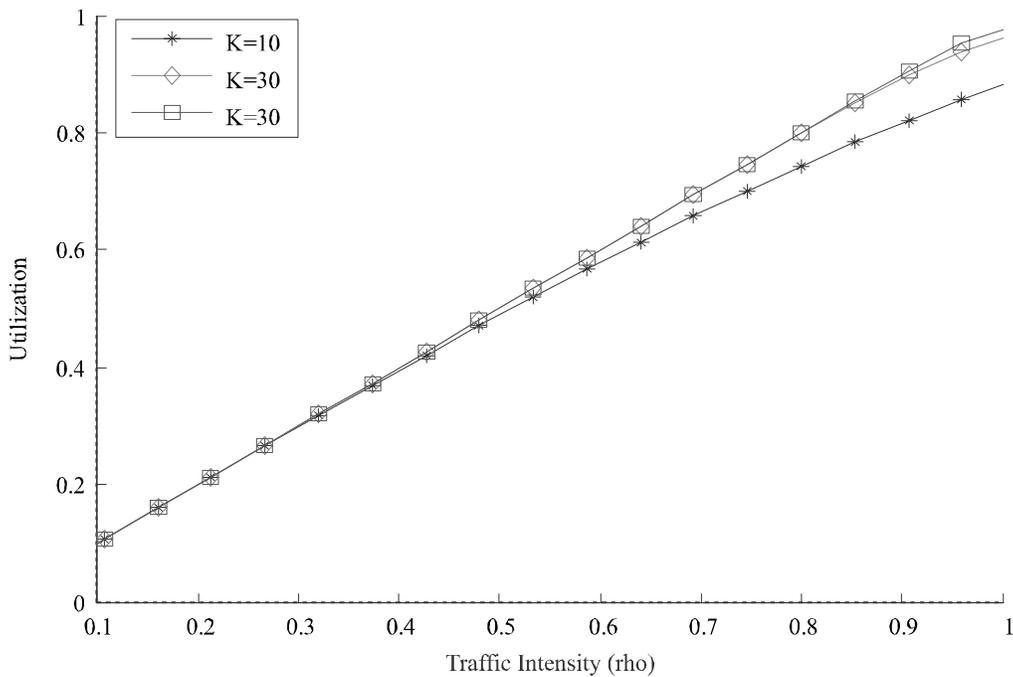


FIG. 5. UTILIZATION WITH DIFFERENT SYSTEM CAPACITIES

6. CONCLUSION

In this paper, we have evaluated the performance of a femtocell network. An M/M/1/K model with vacation has been used to represent the finite capacity energy efficient femtocell network. The FAP goes to sleep mode (takes vacation) to save energy during inactivity duration. Three system capacities (10, 30, and 50) and mean sleep duration of 5ms were considered to analyze system performance in terms of QoS parameters and energy efficiency. Results reveal that with small traffic intensity the energy savings is high, whereas utilization, delay and blocking are low. As packet arrival rate increases, the delay and blocking also increase, however the energy savings decreases because of the increased utilization. Energy savings become almost negligible when traffic intensity approaches 1. This is because the server is pretty busy and seldom goes on vacation. In this situation, the delay and blocking also rise. Results show that maximum energy can be saved when system is quite under-utilized.

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