Performance Analysis of TDMA Protocol in a Femtocell Network

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ABSTRACT

In this paper, we evaluate the performance of TDMA (Time Division Multiple Access) protocol using queuing theory in a femtocell network. The fair use of wireless channel among the users of network is carried out using TDMA protocol. The arrival of data packets from *M* communicating nodes becomes multiple Poisson process. The time slots of TDMA protocol represent *c* servers to communicate data packets coming from communicating nodes to the input of FAP (Femtocell Access Point). The service time of each server (time slot) is exponentially distributed. This complete communication scenario using TDMA protocol is modeled using M/M/c queue. The performance of the protocol is evaluated in terms of mean number in system, average system delay and utilization for varying traffic intensity.

Key Words: **Average Delay, Femtocell, Mean Number of Packets, Queuing, Time Division Multiple Access.**

1. INTRODUCTION

Nowadays, we have started witnessing a rapid growth in number of electronic devices embedded with wireless communications capabilities. These devices transmit and receive a massive amount of data. Current cellular systems were designed and deployed with limited resources such as bandwidth. These systems have almost reached their maximum capacity. To facilitate this new paradigm shift in technology, researchers from both academia and industry are putting their best efforts to enhance old systems, and propose and develop new network designs and protocols to support this ever increasing data demand [1,2]. One of the possible solutions in this regard is coexistence of macrocells and small cells called femtocells [3]. This kind of deployment brings a number of advantages such as increased user capacity, high link reliability, coverage in cellular dead zones, and energy efficiency [4,5].

Femtocells are small cells which mainly aim at providing short range communication to either stationary or slowly moving indoor users [3]. A femtocell is comprised of a FAP and few communication nodes. In an area there can be a number of femtocells simultaneously existing within a macrocell [6]. This type of network architecture enables continuous connectivity for mobile users. A femtocell based deployment requires the use of old or new communication protocols to synchronize and manage communication among a number of users. As all communication nodes in a femtocell network will be using the same wireless channel, hence a robust wireless MAC (Medium Access Control) protocol is needed to share the available bandwidth in a fair manner among the available communicating nodes. In literature, a number of MAC protocols have been proposed to establish wireless communication.

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Commonly used MAC protocols are TDMA, FDMA (Frequency Division Multiple Access) and CDMA (Code Division Multiple Access) [7].

A wide range of communication setups can be analyzed using a well-known mathematical tool called queuing theory [8]. In past, analytical modeling using queuing theory has been extensively used to evaluate the performance of communication networks in terms of a number of QoS (Quality of Service) metrics such as delay, blocking, and throughput [9,10]. The issue of buffer optimization with respect to throughput has been addressed in [11]. For a multirate ODFMA (Orthogonal Frequency-Division Multiple Access) protocol network, in [12] a scheme has been proposed for performance analysis of link level. In this work, the performance of the system is evaluated using a queuing theory model in terms of transmission delay of packets and packet dropping probability. In [4], authors have evaluated performance of a FAP with M/M/1 queue where QoS metrics considered were utilization and delay. A finite capacity femtocell network has been modeled using M/M1/K queue in [5]. In this work, the performance of the femtocell network was evaluated with regard to packet loss, utilization, and mean delay. The issue of energy efficiency in both finite and infinite capacity femtocell networks has been addressed in [3,4] respectively, where the FAP switches to low power state (takes vacation) to save energy when there are no packets in the system. In [13], a 3D Markov model was proposed for an LTE system. The queuing delay and session blocking were the two QoS parameter evaluated in this work.

In our previous work [3-5], we developed queuing models for a FAP by considering both finite and infinite buffer sizes. In this paper, we analyze the performance of TDMA protocol using M/M/c queue in a femtocell network in terms of mean number in system, average system delay and utilization.

Following the introduction, the paper is arranged as follows: Section 2 introduces the studied scenario. A queuing model for TDMA protocol is presented in Section 3. The performance analysis of TDMA protocol in a femtocell network is detailed in Section 4. The paper conclusion is provided in Section 5.

2. STUDIED SCENARIO

In this paper, we evaluate the performance of TDMA protocol in a femtocell network. The studied scenario is comprised of *M* communicating nodes and a femtocell access point as shown in Fig. 1. TDMA protocol is used here to share wireless channel (available data rate) among users in a fair mechanism. Without loss of generality, only uplink communication is taken into account (from communicating nodes to the FAP).

3. ANALYTICAL MODELING OF TDMA PROTOCOL

The arrival process of packets at each node in a femtocell network follows Poisson process [3-5]. Hence, each communication node generates packets with a mean rate of λ_n. As there are *M* communicating nodes, therefore the combined arrival process of packets becomes multiple Poisson process having a mean rate of $\lambda=M\lambda_n$ [3,14]. The packets are transmitted over the wireless channel and arrive at the input of the FAP. For fair use of wireless channel among communicating nodes, TDMA protocol is considered as medium access control protocol. Each slot of TDMA protocol represents a server serving the incoming packets. Hence *c* slots of TDMA protocol become *c* servers [14]. In this work, we have taken a real packet length from [15] into account. An exponential distribution is used for packet length. Since each slot (server) of TDMA protocol has a constant bit rate R_b, hence each server has an Exponential service time distribution. The mean service rate of each server is μ. The communication using TDMA protocol in a femtocell network is modeled as M/M/c queue. The state transition diagram of this scenario is illustrated as a birth-death process in Fig. 2 [16].

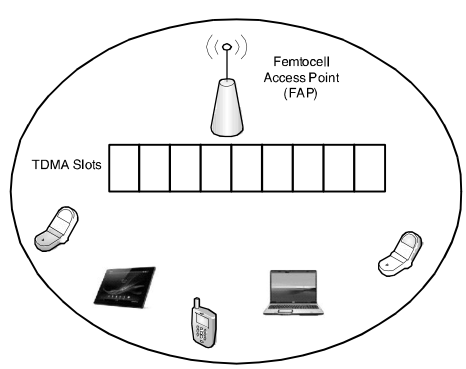

FIG. 1. FEMTOCELL NETWORK WITH TDMA AS MEDIUM ACCESS CONTROL PROTOCOL

The packet arrival rate is given as:

$$\lambda = M\lambda_n \qquad (1)$$

The service rate is defined as:

$$u_k = \begin{cases} k\mu & 1 \le k \le c \\ c\mu & k > c \end{cases} \qquad (2)$$

where k represents the number of packets in the system [16]. Since, there are total c servers; hence the mean service rate cannot exceed $c\mu$ even if the number of packets in the system becomes greater than number of available servers. The steady state distribution of packets in this M/M/c system is:

$$p_k = \begin{cases} p_0 \dfrac{(c\rho)^k}{k!} & k \le c \\ p_0 \dfrac{(c\rho)^k}{c^{k-1}c!} & k > c \end{cases} \qquad (3)$$

Where $\rho=\lambda/c\mu$ is the traffic intensity and should be less than 1 to ensure the stability of the system, and p_0 is the probability that system is empty and it is given by:

$$p_0 = \left[1 + \sum_{k=1}^{c-1} \frac{(c\rho)^k}{k!} + \frac{(c\rho)^c}{c!}\frac{1}{1-\rho}\right]^{1} \qquad (4)$$

The average number of packets in the system can be computed as:

$$N = \sum_{k=0}^{\infty} kp_k \qquad (5)$$

The mean delay experienced by a packet in the system can be calculated using Little's theorem [16] as:

$$W = \frac{B}{\lambda} \qquad (6)$$

The utilization in an M/M/c queue is the expected fraction of busy servers (slots). It also tells how well wireless channel is utilized, and is given by:

$$U = \rho = \frac{\lambda}{c\mu} \qquad (7)$$

4. PERFORMANCE EVALUATION

In this section we evaluate the performance of TDMA protocol in the femtocell network. A wireless link of 6 Mbps is taken into account. This wireless link capacity is divided into six slots representing the six slots of TDMA protocol used for uplink communication. Hence each server (slot) operates at a data rate of 1 Mbps. A measurement based realistic mean packet length from [15] is considered here. Each packet is generated from an exponential distribution with mean packet length of 867.4 bytes. Hence, the mean service rate of each server becomes 144.10 packets/second. Each communicating node generates data at a rate of 320 kbps. Therefore, the mean packet arrival rate at each node (λ_n) is 46.11 packets/second [3]. As there are total M communicating nodes, the combined arrival rate is $M\lambda_n$. In this paper, we analyze three performance parameters, i.e. mean number of packets in the system, average system delay and utilization. These parameters are evaluated with varying traffic intensity values. The traffic intensity values are determined using number of servers, mean service rate of each server, and mean arrival rate of the combined Poisson process. In this work, both service rate and number of servers are kept fixed. The traffic intensity (ρ) values vary with different values of λ.

Fig. 3 shows variation of mean number of packets in the system. The mean number of packets is low with the traffic intensity value 0.1. It is because the average arrival rate of packet is fairly low compared to service rate. It can be observed from the transition diagram of M/M/c queue that if number of packets in the system become more than the available number of servers, the service rate does not change and remains constant. Moreover, as service rate of all servers is fixed, from Fig. 3 it is obvious that a continuous increase in the arrival rate will cause more packets in the system waiting to be served by the time slots (servers) of TDMA protocol. The mean number of packets becomes more than 25 (quite high as compared to the number of available servers) as traffic intensity values reaches 1, which represents congestion in system.

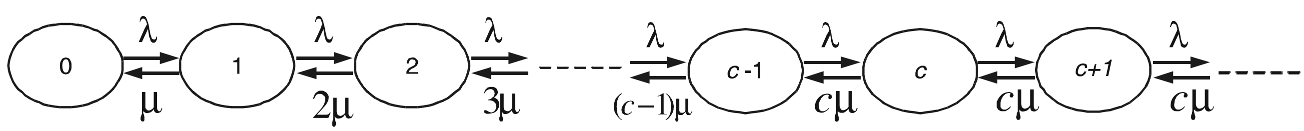

FIG. 2. TDMA STATE TRANSITION DIAGRAM USING M/M/C QUEUE

Fig. 4 illustrates the average delay experienced by each packet in the system. This QoS parameter varies with traffic intensity. Average delay is because of both waiting time in queue and service time. The value of average delay is determined using Equation (6). As can be noticed from the figure, the delay is very low for small traffic intensity values. The delay experienced by each packet in this case is because of the service time required by each packet (about 6 ms). As the traffic intensity increases the delay also rises. For traffic intensity $\rho<0.8$, the average delay is less than 10ms. As traffic intensity value becomes more than 0.8, it means more packets in the system which subsequently result in a higher delay. As traffic intensity approaches to 1, the delay continuously increases. The value of traffic intensity should not be greater than 1 to ensure the stability of the system. When traffic intensity approaches to 1, it means that system is fully occupied and all TDMA slot are busy serving incoming packets. In this case, the value of average delay in more than 30ms which is not acceptable in many communication scenarios.

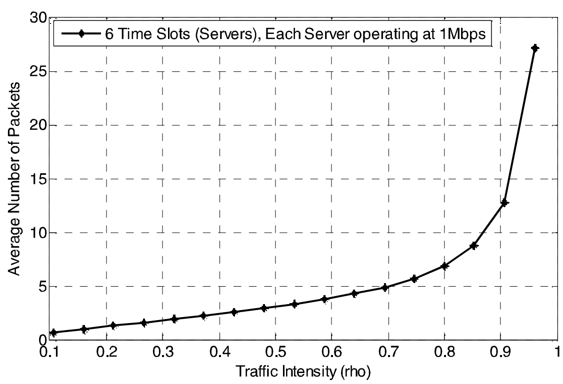

FIG. 3. MEAN NUMBER OF PACKETS

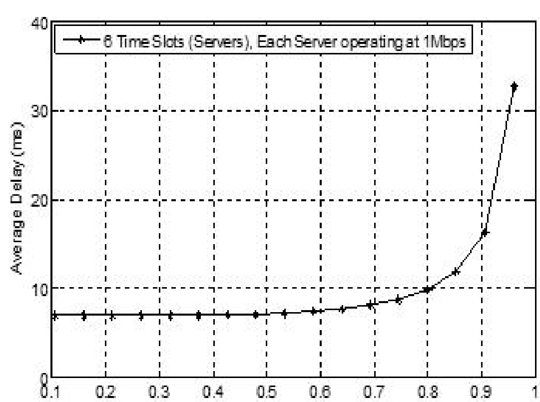

FIG. 4. AVERAGE SYSTEM DELAY

The utilization is the expected fraction of busy servers and is shown Fig. 5. From Equation (7), it can be noticed that the utilization is a function of combined arrival rate and total system service capacity, and is equal to the traffic intensity. Fig. 5 shows that the utilization varies linearly with traffic intensity. For smaller arrival rate the utilization is low. It is because the service capacity of the system is quite high compared to the traffic arrival rate. As the arrival rate grows the traffic intensity escalates which further causes utilization to increase. The maximum value of utilization can be 1; however this represents an unstable system.

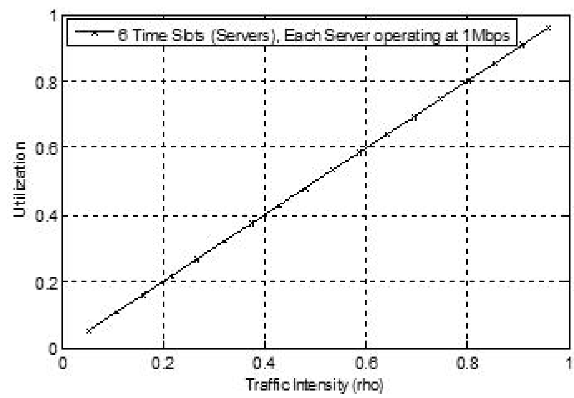

FIG. 5. UTILIZATION

5. CONCLUSION

In this paper we have evaluated the performance of TDMA protocol in a femtocell network. There are M communicating nodes and one FAP in the network. The wireless channel is divided into a number of slots for fair and synchronized use of data rate among all users. The uplink communication using TDMA protocol is modeled as M/M/c queue. We have considered measurement based packet length distribution. A wireless link of 6 Mbps is taken into account. This link capacity is divided among six TDMA slots (servers) where capacity of each slot is 1 Mbps. The performance of the system is evaluated in terms of mean number of packets in the system, average system delay and utilization. It has been observed from results that as traffic intensity increases the mean number of packets also increases. The average number of packets becomes more than 25 when the traffic intensity approaches 1. A similar trend was observed in average delay analysis. Delay is pretty low for small traffic intensity value. It increases as the arrival rate of packets increases. It becomes more than 30 ms when the arrival rate is nearly equal to the total service capacity of TDMA protocol. Results also reveal that the utilization of TDMA protocol varies linearly with traffic intensity.

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