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A Markov Model to Evaluate System Performances under Slotted Aloha Protocol

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Abstract

The Multiple access system deals with a situation where multiple nodes are required to access a commonly shared channel. These multiple accesses can be viewed as uncoordinated nodes which compete for bandwidth. Various random access mechanisms, such as ALOHA protocol and its corresponding variations, have been widely studied as efficient methods to coordinate the medium access among competing users. In such situations, one of the most important objectives is to evaluate the system performances under such protocol.

In this paper we enhanced a model already studied in a previous work by expanding the number of states in a Markov model for a system implementing slotted Aloha protocol; and we use a three state Markov process in order to represent and evaluate the performances of the system under different scenarios.

In this model we are interested in representing the time occupancy of the system, evaluating the throughput system under different fairness conditions, and evaluating the probability that the system is in a backlogged state or in an idle state.

Keywords: *Slotted ALOHA, Markov Process, Mac Protocol, Cooperative Game, Performance Metrics.*

1. Introduction

The quality of service (QoS) waited by individual user on a wireless next generation network (NGN) is heavily influenced by the manner in which wireless channel capacity is allocated.

In communication network, managing the limited resources attracted big attention in research in the past decades. Indeed, the limited resources in wireless networks lead to several problems that affect the system performance such as delay, energy, throughput and acceptance probability. To overcome this constraint networks based on multi-access medium requires mechanisms for effective access to the media.

The IEEE 802.16 (WiMAX) network [1,2,3] provides numerous advantages such as improved performance and robustness end-to-end IP-based networks, secure mobility and broadband speeds for voice, data, and video. It leads a very high utilization of radio resources and a good QoS framework. However, In WiMAX, at the entrance of this network, subscriber stations (SS) contend for resource on the initial ranging interval in order to access the network [4]. This contention based access scheme at the medium access control (MAC) layer in 802.16 WMANs is expected to be the main mode of operation for supporting the QoS requirements, especially for the best effort (BE) class of traffic generated by most Internet applications (Web surfing, FTP, etc).

In wireless networks various techniques can be used to reduce collisions in a contention situation. For example, the Ethernet uses CSMA-CD (Carrier Sense Multiple Access with Collision Detection) as a MAC protocol, while 802.11 wireless LAN uses CSMA-CA (Carrier Sense Multiple Access with Collision Avoidance). But in wireless communication settings, collision detection (CD) is expensive and collision avoidance through carrier sensing is often difficult for high-density, low-cost devices. An alternative, lightweight protocol that has been often used to ovoid such a problem is the Slotted ALOHA (S-ALOHA), used particularly in IEEE 802.16 [5].

The slotted-ALOHA protocol [6] was introduced to improve the utilization of the shared medium by synchronizing the transmission of devices within time-slots because ALOHA protocol [7] is a fully decentralized medium access control protocol that does

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not perform carrier sensing. Recently, various forms of slotted-ALOHA protocols are used in most of the current digital cellular networks such WiMAX and GSM (Global system for Mobil Communication) where the control channels of the Time Division Multiplexing (TDM) channels uses this mechanism.

For our analysis, we consider the situation where users (wireless nodes) communicate over a random access channel. That is, whenever a user (node) has a new packet to send, it will do so immediately. If packets are sent simultaneously by more than one user then they collide. After the end of the transmission of a packet, the transmitter receives the information on whether there has been a collision (and retransmission is needed) or whether it was well received. All packets involved in a collision are assumed to be corrupted and are retransmitted after some random time (a backoff algorithm) [8].

In this work we assume that the entire slot is used solely by the BE (Best Effort) traffic in a WiMAX network. Taking this assumption into consideration, BE uses choice of retransmission probabilities to obtain access to the service. Multiple transmissions simultaneously result in a collision. We model a system of M users implementing a cooperative slotted ALOHA protocol with tunable parameters via Markov process that allows us to evaluate throughput under different fairness conditions.

Cooperation is in the sense that all users retransmit with the same probability, and fairness is ensured by the fact that the time of occupation of the channel by a user once it transmits a packet with success has the same distribution for all users, and users will thus achieve the same performance on average.

The rest of the paper is organized as follows: we begin by introducing a brief overview of related work in section 2, in section 3 we will construct a Markov Model and evaluate the system throughput in a cooperative team problem where users seek to maximize the total throughput of the system. In section 4 we will evaluate numerically the throughput under different scenarios. Section 5 will be devoted to the conclusion.

2. Related work

A number of multiple access protocols have been proposed in the literature. The most popular protocols are those based on slotted-ALOHA [9]. These protocols have been adopted mainly by broadband access networks such as in satellite as well as cellular telephone networks for the sporadic radio channels [10], and most recently in the IEEE 802.16 standard. In this protocol, a user with a data session follows a slotted ALOHA contention mechanism to access the media. A user transmits the first packet of the data session by contention to access the media. Once it successfully accesses a slot, it reserves the same slot in future frames until the end of data session where that slot is released [11]. In [12,13] the slotted ALOHA exhibits an instability, namely, in this protocol, the number of backlogged users with packets awaiting to be retransmitted is steadily growing; research in [14] focused on stabilization.

Rivest proposed a pseudo-Bayesian algorithm that uses the information to estimate the number of current backlogged nodes [13]. In [15] a Markovian decision model is formulated for dynamic control of unstable slotted ALOHA protocol and optimum decision rules are found. Authors in [16] analyze the stability properties of slotted ALOHA with capture for random access over fading channels with infinitely-many users; Their analysis shows that, with regular users, the system is unstable under any kind of power and probability control mechanism that is based only on decentralized channel state information. Another approach adopted is the implementation of an admission control process that limits the number of simultaneous users in the system to avoid stabilization challenges.

In the last years, the slotted ALOHA protocol is still a current topic in scientific research. Thus, Patet et al [17] have analyzed the number of backlogged packets by using statistical approach and stabilize the expected number of backlogged packets minus mean number of packets which are successfully transmitted.

The authors in [18] proposed an adaptive Slotted ALOHA algorithm that can accelerate the adjusting speed and can acquire stable throughput on the conditions that there is large fluctuation of system load.

The authors in [19] propose a study based on the Markov chain model to define optimal binomial distribution probabilities of retransmission and arrival packets; in the case of slotted ALOHA protocol, they defined the average packet delay and the throughput, and show the effect of the increase of the number of sources on these parameters.

In [20] a repeated Bayesian slotted ALOHA game model to analyze the selfish behavior of impatient users is proposed. The authors prove the existence of Nash equilibrium mathematically and empirically. The proposed model enables any type of transmission probability sequence to achieve Nash equilibrium without degrading its optimal throughput. That Nash equilibrium can be used as a solution concept to thwart the selfish behaviors of nodes and ensure the system stability.

In [21] we have studied a cooperative slotted ALOHA using a two state Markov chain. However, in this model two states "idle" and "backlogged" were considered as a single state. But, for the operator, it would be better to distinguish between the two. Indeed, in terms of energy the "idle" state is a state where there is no packet to be transmitted in the system and the energy can be conserved. In addition, the operator would be interested in the probability that the system is in this state and also by the transition probabilities between the" idle" state and other states of the system. This is why in this paper we extend this model to a three state Markov chain and we focus on the global throughput of the system under different scenarios.

We argue why time-based fairness is desirable in some cases and we analyze the achieved throughputs of competing nodes, possibly using different data rates and packet sizes in 802.16 cellular networks. We are interested to evaluate the system performance in the case where M users shared the channel.

We provide a simple model that represents the time of occupation of the channel by a user once it transmits a packet with success.

3. Modeling uplink channel utilization

To control the medium access, MAC protocol coordinates the nodes in a network and resolves the contention among their accessing the shared medium, so that the resources are shared fairly and efficiently [7]. In this section, we construct a Markov Model from which we can analyze the throughput and we describe a cooperative slotted-ALOHA MAC protocol in which time is divided into units. At each time unit a packet may be transmitted, next in this protocol our system is in either a backlogged state or a busy state or an idle state. The transmission decision only depends on the state of the user. Therefore, the decision in slotted – ALOHA for each user is actually Markovian. We will use a three system state as the following: the first state where the medium is busy, the second state when the system is idle and the third one when the system is backlogged. We adopt the following notations for a generalized Markov model for slotted- ALOHA type MAC protocol.

The notations used in the rest of the paper are presented in the following.

M: Number of users in the system.

N: Number of backlogged packets in the system.

PT^i: Transmitting probability at free states for user i.

PR^i: Transmitting probability at backlogged states for user i.

Th_i: Throughput function, which indicates the average throughput of user i.

As the system is cooperative, we can assume that $PT^i = PT$ and $PR^i = PR$, for all user i.

The transition matrix is:

$$P = (P_{ij});\ i,j \in \{1,2,3\}$$

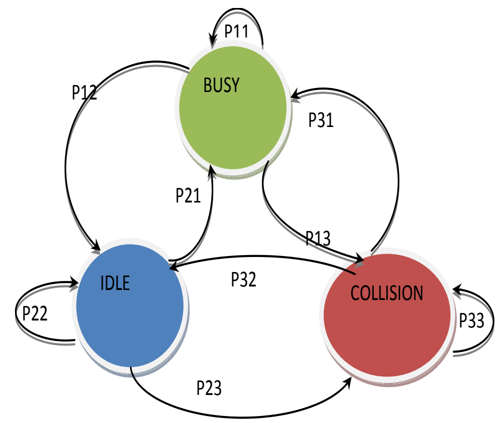

Fig.1: Transition Diagram of the Markov chain

The P_{ij} are the transitions probabilities:

$$\begin{cases} P_{11} = 1 - P_C - P_I \\ P_{12} = P_I \\ P_{13} = P_C \end{cases}$$

$$\begin{cases} P_{21} = P_B \\ P_{22} = 1 - P_B - P_C \\ P_{23} = P_C \end{cases}$$

and

$$\begin{cases} P_{31} = P_B \\ P_{32} = P_I \\ P_{33} = 1 - P_I - P_B \end{cases}$$

where:

$P_I = (1 - PR)^N (1 - PT)^{M-N}$ represents the probability that there is neither transmission nor retransmission.

$$P_C = (PT)^2 \left(\frac{1-(1-PT)^{M-N-1}}{1-PT}\right) + (PR^2)\left(\frac{1-(1-PR)^{N-1}}{1-PR}\right) + (PT)\left(\frac{1-(1-PT)^{M-N-1}}{1-PT}\right)(PR)\left(\frac{1-(1-PR)^{N-1}}{1-PR}\right)$$

represents the probability of the state where at least two users request access channel at the same time.

and

$P_B = (M - N)PT(1 - PT)^{M-N-1}(1 - PR)^N + NPR(1 - PR)^{N-1}(1 - PT)^{M-N}$ is the probability that a user gets access to the channel successfully.

The steady state probability is a solution of the following system:

$$\begin{cases} \pi = \pi P \\ \sum_{i=1}^{3} \pi_i = 1 \end{cases}$$

where: $\pi = (\pi_i);\ i \in \{1,2,3\}$

which is equivalent to:

$$(S)\begin{cases} \pi_1 * (1 - P_I - P_C) + \pi_2 * P_B + \pi_3 * P_B = \pi_1 \\ \pi_1 * P_I + \pi_2 * (1 - P_B - P_C) + \pi_3 * P_I = \pi_2 \\ \pi_1 * P_C + \pi_2 * P_C + \pi_3 * (1 - P_B - P_I) = \pi_3 \\ \pi_1 + \pi_2 + \pi_3 = 1 \end{cases}$$

We find then: $\pi_1 = \frac{P_B}{P_B+P_C+P_I}$, $\pi_2 = \frac{P_I}{P_B+P_C+P_I}$ and

$$\pi_3 = \frac{P_C}{P_B+P_C+P_I}$$

π_1 is the throughput for the system.

4. Performance evaluation

4.1. Retransmission and transmission probability

In general, after one user successfully transmits a packet, it obtains the channel. This user will continue to occupy the channel for a random amount of time T. We assume that T is an exponential random variable with parameter λ= (P_I +P_C). Let E[T] the mean for the random variable T. If we put E [T] =U.

We know that $E[T] = \frac{1}{\lambda}$ then $U = \frac{1}{P_C+P_I}$

4.2. Throughput

Using the above results, the total throughput can be computed as a function of U, it is given by:

$$\pi_1 = \frac{U * P_B}{[1 + U * P_B]}$$

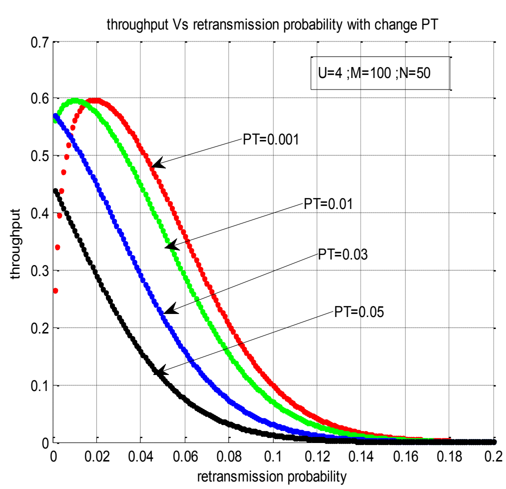

Fig.2: throughput vs retransmission probability under different values of PT.

Fig.2 plots the throughput versus the retransmission probability PR. the throughput is a decreasing function according to PR, that the system becomes backlogged, as there will be more probability that collision occurs. In this figure, we note also that for small values of PT (lower than 0.01) the throughput reaches a maximum value when PR is in the range [0.01, 0.02]. The figure also shows that more PT is less more the throughput is high and it is almost zero when PR exceeds 0.14.

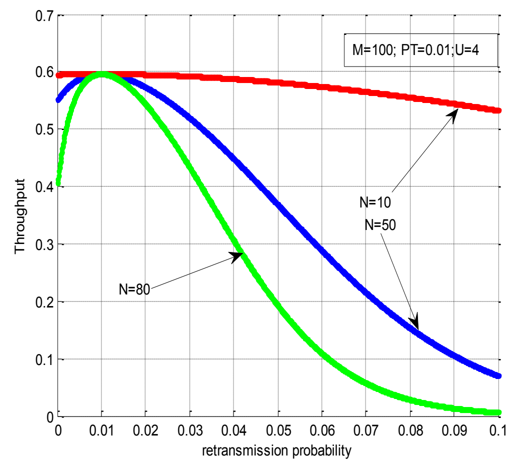

Fig.3: throughput vs retransmission probability und under different values of N and PT=0.01.

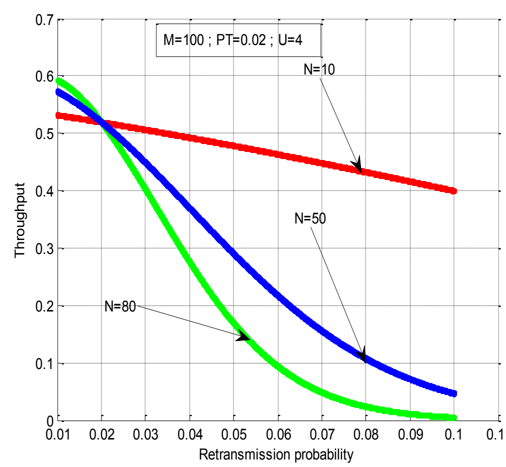

Fig.4: throughput vs retransmission proy bability and under different values of N and PT=0.02.

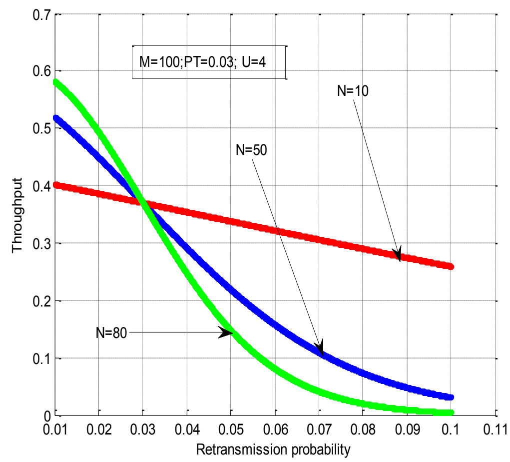

Fig.5: throughput vs retransmission probability under different values of N and PT=0.03.

An outstanding Point that appears in Fig.3, Fig.4 and Fig.5 is that in which PT = PR. At this point all the curves (regardless of the number of backlogged users) intersect. This means that when PT and PR are equal, the throughput is the same regardless of the number N.

For a value of Pt higher than 0.01(Fig.4 and Fig.5) we remark that when PR<PT, more than the number of backlogged users increases more than the throughput is better, however, if PR>PT the throughput decreases with N.

Whereas for PT = 0.01, (Fig.3) the relative behavior of the three curves (N = 10, 50 and 80) does not change on either side of the remarkable point of intersection: it always has the curves corresponding to great values of N below the curves corresponding to small values of N.

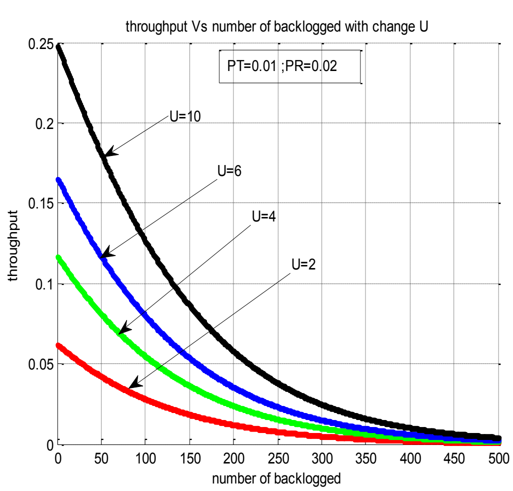

Fig.6: throughput vs N under different values of U.

Fig.6 confirms the decreasing of throughput according to the number of backlogged users. Moreover, when U decreases (the time occupancy of the system by a user who had a success), we note that the system throughput decreases.

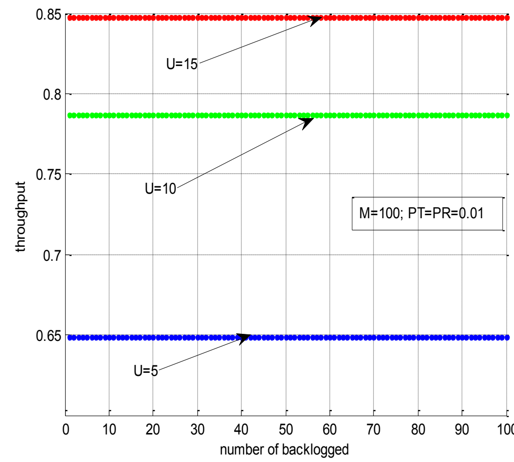

Fig.7: throughput under different fairness conditions with PT=PR.

The special and important case where PR = PT is shown in Fig.7, which confirms the stability result of throughput regardless of the number of backlogged users. But when the time occupancy (U) of the system increases, the throughput increases. Except that this leads to a selfish user behavior which harms cooperation and fairness in the system.

5. CONCLUSION

In this work, we presented and studied a Markov model with three states for the cooperative slotted-ALOHA protocol in IEEE 802.16 system. The users compete for access to the system resources. In this model we compute the global system throughput under different scenarios. We assumed that the users cooperate in order to fairly share the available bandwidth and to maximize the throughput of the system.

The analytical and numerical analysis show that, when the transmission probability has small values (less than 0.01), the equation PR = PT partitions the retransmission probability interval into two parts where the behavior of throughput is very affected by the number of backlogged users, but in different manners.

The results show that to achieve a maximum value of throughput it is more suitable to choose PR and PT in an appropriate interval, and more there is backlogged users more we have interest to take PR < PT.

In spite of the increasing relation between throughput and time occupancy (U), taking great value of U will affect negatively the fairness and the cooperation in the system.

The characteristics of the idle state in the proposed model, and the study of other performance parameters like delay and energy are some important features of this work.

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