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Slotted Aloha Game for Decreasing Transmission Delay and Packet Loss Ratio in Wireless Data Networks

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ABSTRACT

When attempting to access the medium, nodes in Wireless data networks based on Slotted Aloha medium access control protocol, present a fort competition to gain free time slots needed for their transmissions. Here each node searches to accomplish successfully its packets transmission in the shortest delay. However, if two nodes transmit at the same time, packets are collided and at reception, it will be very difficult to recover all the data sent. In this paper, we present a redundant packet control game, to describe the interactions between active nodes and to solve the problem of long transmission delay in Slotted Aloha networks. At the Nash equilibrium, network becomes more stable and gives lower transmission delay with smaller packet loss ratio.

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INTRODUCTION

The Slotted Aloha (Roberts, L.G., 1972) (S-ALOHA) is a random medium access control (MAC) protocol, used in Wireless data networks and more particularly for signaling bandwidth requests in Satellite-Earth station link. To prevent network from interferences, slotted version divide the time axis in periods of equal length called time slots (TS) when all nodes are synchronized and should start their transmissions only at the beginning of each TS. However, collision still exists leading the system to be saturated due to successive retransmissions process that weakens the throughput and extends transmission delay. We find in literature different proposed solutions that aimed to improve S-ALOHA network performances. However, in recent years, many searchers have treated S-ALOHA protocol as a strategic Game based on Game theory techniques to study the behavior of nodes when they try to access the medium. The advantage of Game theory is to bring the system to an equilibrium level (if exists) that makes it more stable and more effective. Among these researches, we distinguish the work (Altman, E., *et al*., 2003) in which the author studies S-ALOHA as a stochastic game with partial information to determine the equilibrium in retransmission probability. Also, in (Machenzie, A., S. Wicker, 2003) and (Machenzie, A., S. Wicker, 2001) authors present a game model to describe the selfish behavior of nodes who try to access the medium. In (Yu, Y., *et al*., Sabir, E., *et al*., 2011) new solutions are proposed to improve network performances and optimize power consumption. In (Boucenna, M.L., M. Benslama, 2012) we present a new solution based on erasure coding and game theory techniques to solve the problem of low throughput in S-ALOHA protocols. In this paper, as in (Boucenna, M.L., M. Benslama, 2012) we present a non-cooperative redundant packet control game to reduce both the transmission delay and the packet loss ratio.

The paper is organized on three main parts; the first contains definitions, suppositions and operating principal of S-ALOHA protocol. In the second part, we present our game model, when we describe its basic elements and discuss its utility function to confirm the Nash equilibrium existence. At the last part, we evaluate the advantage of Nash equilibrium in S-ALOHA network by some simulations and comparisons with conventional model (out of equilibrium).

Slotted Aloha Algorithm:

Instead of using rigid circuit boards, cotton fabric is used as substrate, conductive fabric “Nora dell” as a ground plane and silver plated nylon thread as patch antenna. The properties of selected conductive fabrics may

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optimize the characteristics of the designed textile antenna in a specific application. Some of the electro-textiles properties they are flexible for deformation when worn, low electrical resistance to minimize losses, lightweight and comfortable. Therefore, the "Nora dell" has been selected. There are three Nora dell elements which are nickel, copper and nylon silver. Nora dell proposed a highly protective from galvanic corrosion and extremely flexible to the harsh environment of 90oC temperature (Machenzie, A., S. Wicker, 2003).

In Slotted Aloha, all transmissions start at the beginning of time-slots in synchronization with the system horologe. If two or more nodes send a packet in a given time slot, then there is a collision. If just one node sends a packet in a given slot, the packet is correctly received. The node confirms the success of its transmissions by receiving feedback signal (ACK) from the receiver. Otherwise, the transmission is considered failed, and packets involved in collision must be retransmitted in some latter slots. The nodes with packets waiting for retransmission are called backlogged nodes. If each backlogged node decides simply to retransmit in the next slot after being involved in a collision, then another collision would surely occur. Instead, such node waits for some random number of slots before starting retransmission. The node continues with further retransmissions until the packet is successfully transmitted. However, despite several prevention techniques, S-ALOHA still suffer from collisions that occur when at least two backlogged nodes or one backlogged node with a new active node send together. Here, the network enter in repeated retransmission process that extend the overall transmission delay and deteriorate network performances.

The overall transmission delay D is defined as the average time from when the packet is generated until it is successfully received. Thus, it comprises the time of transmission, sufficient time for retransmissions and the recurred time for feedback. Where the acknowledgment packets are supposed handled on separate channel to avoid further packets interferences. Therefore, the feedback signal is always correctly received with probability one. So, now we can write;

$$D = D_{trans} + D_{retrans} + D_{fback} \tag{1}$$

The overall delay function is in relation with the system throughput as given in (Kleinrock, L., S. Lam, 1973);

$$D = \frac{w}{w+1}\left\{ e^{-\frac{\lambda}{w}} + \frac{\lambda}{w} e^{-\lambda} \right\}^{w} .e^{\lambda - Th} \tag{2}$$

Where we assume that each backlogged node can start retransmitting at random during one of the next slots. So, each slot would being chosen with probability. is the overall traffic load (new and backlogged packets).

Why Game Theory in Slotted Aloha Networks:

We find that in wireless networks, users wishing to transmit typically want to do as soon as possible by the lower cost and the shortest delay, and if multiple users try to transmit randomly (as in S-ALOHA protocol) without following a suitable manner for all participate users; many access fail. Moreover, unsuccessful transmission attempts may be costly. In addition, we remark that the choice of slot in which the backlogged node starts retransmission, is very critical for the success or the fail of remained packets retransmissions. Such as, if the backlogged node starts retransmission at an idle slot, then the packet is correctly received. However, if it starts retransmission at a busy time slot, the transmission is failed to gain. We conclude that, users truing to transmit have conflicting objectives in cost and delay; where the action of one node has an impact on the other nodes' actions. In such situations, the appropriate tool for examining interaction between selfish users with conflicting objectives is Game Theory. We present in the remained of this paper, our game model based on the S-ALOHA protocol, where we integrate the Erasure coding to recover collided packets.

Slotted Aloha Game Model:

First, we explain the Erasure coding mechanism; the purpose of Erasure coding is to recover lost packets if their positions are known in (N,k) erasure codes. A (N,k) code word consists of N code packets with k original packets and (N-k) redundant packets. The k original packets can be recovered successfully if we receive N' packets out of the N coded packets. If N is sufficiently large compared to the loss rate, we can achieve high reliability without retransmission. The author in (Sacham, N., P. Mckenny, 1990) explains how to generate redundant packets.

We consider M wireless nodes that are willing to transmit data (active nodes) to a designed receiver as shown in Fig. 1. Nodes use Non-persistent Slotted Aloha based protocol to resolve contention at MAC layer and to reduce the number of collisions among packets by always rescheduling a packet that upon arrival finds the channel to be busy. We assume the nodes are the players in the game. A player enters the game when ha has a packet to transmit, and leaves the game when all his packets have been successfully transmitted. The game in this paper is a repeated non-cooperative game, i.e., there is no coordination between players and they act as free agents and each player attempts to his own payoff according to his strategy. Here, the strategy is to select a suitable type of erasure coding and the utility is the player's overall transmission delay. When in the game, the player chooses the number of redundant packets that minimizes both the overall transmission delay and the packet loss ratio. After each transmission failure, the player repeats his strategy until transmission succeeds.

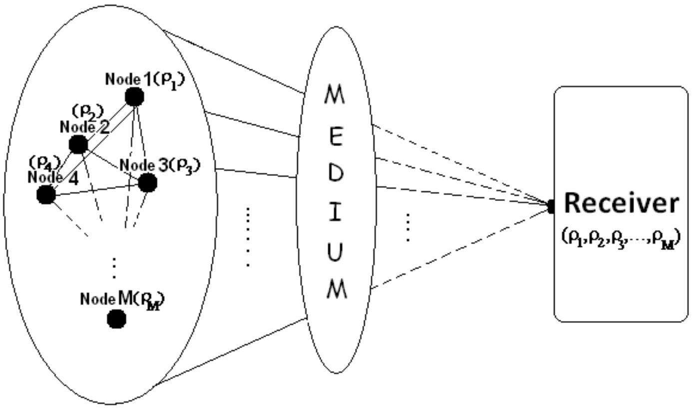

Fig. 1: Network Model for M nodes.

Fig. 2 illustrates the Game Model where each node selects in coding before transmitting via a medium in Wireless network. The strategy of each player involves setting the number of redundant packets to minimizes player 's expected utility . A Game consists of a principal and a finite set of players, each of which selects a strategy with aim of minimizing his utility function. The utility function represents each player's sensitivity to the actions of the other players. Thus, our game can be modeled as a triple, When denotes the set of players in the game, denotes the set of strategies for the players (denotes the strategies for player and denotes the strategies for all players accept the player,). denotes the payoff assigned to each player (where is the payoff utility assigned to player).

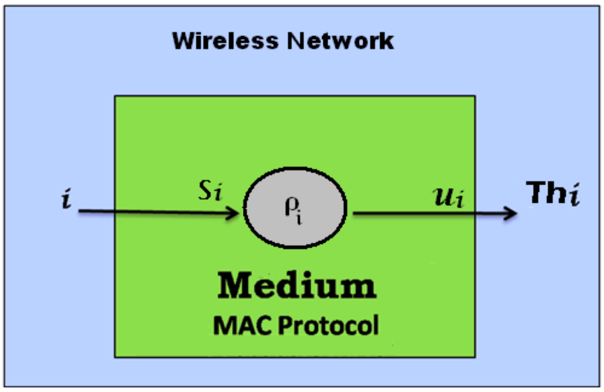

Fig. 2: Slotted Aloha Game

Utility function:

We assume that packets arrive for transmission at which of the M transmitting nodes according to independent Poisson processes. We put the overall arrival traffic load to the system, and the arrival rate at each transmitting node. Then, according to equation (2); the overall delay is expressed as;

$$u = \frac{w}{w+1}\left\{ e^{-\frac{\lambda}{w}} + \frac{\lambda}{w} e^{-\lambda} \right\}^{w} . e^{\lambda - Th} \tag{3}$$

When the throughput can be expressed as;

$$Th = \lambda . Ps \tag{4}$$

When,

$$Ps = P_k + \sum_{n=1}^{k-1} \sum_{m=1}^{n} m/k \, P_{n,m} \tag{5}$$

After encoding, the overall traffic load becomes. Then, the probability that a packet is successfully transmitted is given by;

$$P_\rho = (e^{-\lambda(1+\frac{\rho}{k})})(1-e^{-\lambda(1+\frac{\rho}{k})})^{M-1} \tag{6}$$

Where. We put.

The probability that at least k encoded packets are received successfully is;

$$P_k = \sum_{i=k}^{N} \binom{N}{i} P_\rho Q_\rho^{N-i} \tag{7}$$

is the probability that only n ( ) encoded packets are received when m out of n are original packets. So;

$$P_{n,m} = \binom{k}{m}\binom{N-k}{n-m} P_\rho^n Q_\rho^{N-n} \tag{8}$$

An original packet can be successfully received or recovered if at least k out of N encoded packets are correctly received or n ( ) out of N encoded packets are received, m out of n received packets are original and the packet under consideration is among these packets (with probability m/k). Thus, according to Equation 5;

$$Ps = \sum_{i=k}^{N} \binom{N}{i} P_\rho Q_\rho^{N-i} + \sum_{n=1}^{k-1}\sum_{m=1}^{n} \frac{m}{k} \binom{k}{m}\binom{N-k}{n-m} P_\rho^n Q_\rho^{N-n} \tag{9}$$

We replace (9) and (4) in (3); the overall transmission delay can be expressed as;

$$u(\rho) = \frac{w}{w+1}\left\{e^{-\frac{\lambda}{w}} + \frac{\lambda e^{-\lambda}}{w}\right\}^w \exp\lambda\{1-Ps\} \tag{10}$$

$$u(\rho) = \frac{w}{w+1}\left\{e^{-\frac{\lambda}{w}} + \frac{\lambda e^{-\lambda}}{w}\right\}^w .\exp(\lambda - Th(\rho)) \tag{11}$$

Discussion of Equilibrium Existence:

From equation (11), we put $A = \frac{w}{w+1}\left\{e^{-\frac{\lambda}{w}} + \frac{\lambda e^{-\lambda}}{w}\right\}^w .e^{\lambda}$. Then, (11) becomes;

$$u(\rho) = A.e^{-Th(\rho)} \tag{12}$$

Where is a positive constant. Now, we investigate whether there exists the value of such that a minimum delay is achieved. We consider the scenario where all nodes use the same value and modify this in synchronization with the other nodes in the network. First, we can remark that the variation of utility function is depending only on the variation of throughput, which is varying in bounded interval [0, 0.35] parquets/ time slot, in conventional Slotted Aloha. In this interval, our utility is an exponential decreasing function. For every , the utility is continue and bounded between $[u(0), u(0.35)]$. In (Boucenna, M.L., M. Benslama, 2012), we discussed only the network throughput in both conventional and Equilibrium system, when we proved the existence of unique Nash Equilibrium for our Game whose strategy spaces are nonempty compact convex subsets for an Euclidean space. And, we observed that operating with leads to achieve the minimum value of our utility function ($\arg\min(D)$). Therefore, it exists an optimal point of operation $\rho = 2$ packets, at which the Delay is minimized, $D(\rho = 2) = \arg\min\ (D(\rho))$ for every node in the network. We refer to this optimal point of operation as ρ^* which corresponds to the best response and the Network Equilibrium for our scheme. In other words, When $\rho \le \rho^*$ Delay decrease until achieving ρ^* , whereas when Delay increases. Thus, $D(\rho, \rho_{-i}) \le D(\rho', \rho_{-i})$ for all $\rho' \in s$ and $\rho = BR(\rho_{-i})$.

Slotted Aloha performances at Nash Equilibrium:

Now, we'll investigate the importance of obtained results. In Fig. 3 we can observe the improvement that the Nash Equilibrium can make. The transmission delay in equilibrium is lower than in the conventional model (out of equilibrium). Thus, the S-ALOHA protocol at equilibrium acquires the minimum of delay when transmitting packets. It can be seen, that the delay increases slowly at equilibrium, whereas when receiving just small load traffic it increases very quickly like in conventional model. This is due to collisions that lead to network congestion.

The Fig. 4 shows how at Nash equilibrium the network presents a lower packet loss. We remark that, for each type of erasure coding (number of redundant packets; ER(5) means five redundant packets) the network gives more success for transmission in comparison with conventional model. This is due to the role of erasure coding who makes the Slotted Aloha able to correct collided packets and recover at reception all original sent packets.

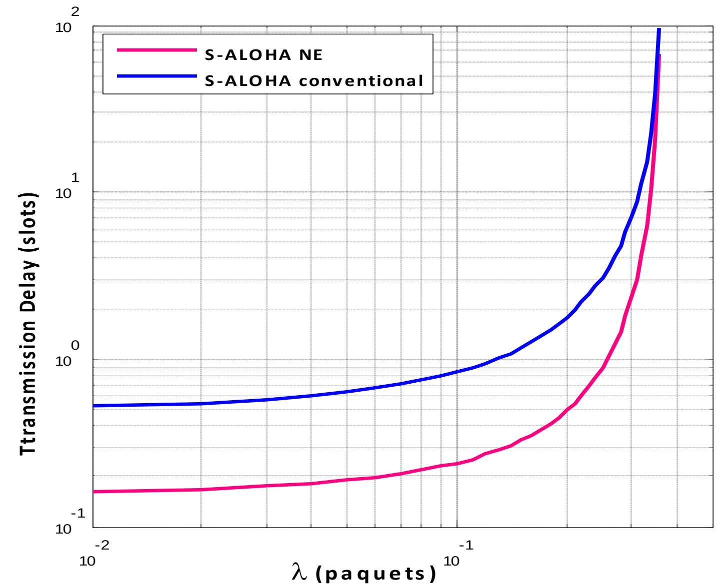

Fig. 3: Overall transmission Delay in Equilibrium and in out of Equilibrium.

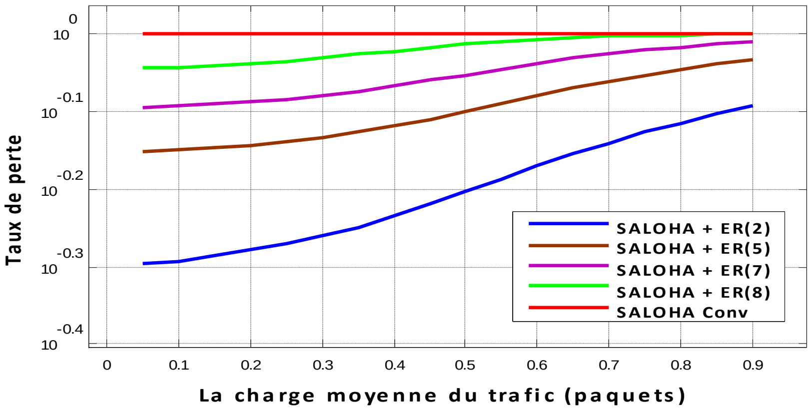

Fig. 4: Packet loss ratio in Equilibrium and in out of Equilibrium.

Conclusion:

The integration of Erasure Coding in Slotted Aloha protocol makes the network more effective to success its transmissions. When, it can correct collided packets and recover all original sent packets. However, use of random type of erasure coding could increase the average traffic load that leads to network saturation. Therefore, we use our Game model for Slotted Aloha network to study the interactions between users and guide the system to operate in its equilibrium. The simulations demonstrate that at equilibrium the network presents a considerable progress in terms of Delay and packet loss ratio.

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