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Generalized Model of Hybrid ALOHA*

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***Abstract*-- Since the genesis of layered network, designing a popper MAC control protocol was a major concern. Among many protocols which introduced earlier, there is always a trade-off between utilization and load overhead. ALOHA is one of the first MAC protocols with virtually possess no overhead, but its maximum throughput is limited. Hence a new MAC protocol introduced on basis of multi-packet reception model named Hybrid ALOHA. In the original paper stability and throughput of this algorithm for 2 or 3 users case system had been analyzed. Although stability region for above two users' circumstances had been studied, there was no general form for throughput nor any practical examination of stability. In this paper, beside expanding formula for throughput for any arbitrary number of users, the throughput of system is checked with simple simulation of probability of successes and failures. Achieved results shows that regardless of additional overhead for more users, throughput remains proper, and the system is not lost stability in larger number of users.**

***Index Terms*-- Hybrid ALOHA, MPR model, throughput analysis, stability and performance evaluation.**

INTRODUCTION

In early 1970's Norman Abramson and his colleagues introduced a new method for channel allocation problem and named it ALOHA, which is used in one of the earliest computer networking system known as ALOHAnet. The main idea in this approach is based on any system with race of users on using a channel [1]. In simple ALOHA all users immediately send their at-hand packet to the receiver without considering conditions and status of other users in system. Slotted ALOHA is a simple upgrade over its predecessor and restrict transmission only at the beginning of a synchronized time slot.

In any centralized communication management system such as phone network it is near impossible to achieve %100 utilization all the times. In other words, there is always deliberate empty capacity to prevent failure on the peak of traffic load in network. Although requests may forestall system capacity and lead to failure. Same behavior exists in random access system, while in the phone you have busy tone, in random access system transmissions will be blocked to prevent devastating collisions [2].

Since the introduction of ALOHA medium access control (MAC), studies were based on modelling of collision status. It means that a successful transmission is one which committed lonely, or no simultaneous transmission does not exist in any time [3-5].

Related work

There are many ways to improve overall throughput and nearly prevent collision such as network coding [6]. In this method collisions are handles by combining and coding of massage in relay phase.

In a network with spatially distributed nodes, reusing backoff mechanisms is inefficient [7]. This is a simplistic and optimistic model that does not evaluate facts such as fading and noise on channel [8]. The fact is physical layer can provide more information about channel and there is even possibility to successfully receive a message while there are more transmissions in the same time [9]. With this hypothesis Ghez et al. by-passing collision model analyzed multi packet reception (MPR). In this model failure or success of a transmissions are no longer determined by deterministic processes, but by stochastic conditions [10, 11]. In addition, for the previous model Nawere investigated this method by asymmetric approach [12]. There is also an adaptive MAC proposed by Zhao for heterogeneous networks with finite population that exploits several queues to address different quality of service requirements of users [13]. There is also possibility to combine network coding with MPR model to cover defects such as wasted time to gather all segments [14]. While these approaches are promising they demand more calculations.

In [17] for improve Aloha protocols and reduce the number of collisions or to avoid them, proposed a new approach named ZigZag decoding to enhance slotted Aloha mechanism by reducing the loss rate of packets colliding. They had modeled the system by a Markov chain witch the number of backlogged packets is taken as the system state and used a stochastic game to achieve their objective. Then they evaluated and compared the performances parameters of the proposed approach with those of slotted Aloha mechanism and in according to results they concluded that their approach was more efficient than the slotted Aloha mechanism.

ZigZag decodable coded slotted ALOHA (ZDCSA) was proposed in [18], they applied ZigZag decoding (ZD) into ALOHA scheme with successive interference cancellation (SIC), namely coded ALOHA, then they presented an optimization method to maximize the throughput performance

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of ZDCSA.

In [19], for confront with the collision problems, they combined the useful features of both CE and the ZD techniques and consequently the Slotted ALOHA performance enhanced.

In [20], they have presented a new MAC (Medium Access Control) protocol, called Hybrid ALOHA (H-ALOHA), which is a combination of two existing protocols: Pure ALOHA (P-ALOHA) protocol and Slotted ALOHA (S-ALOHA) protocol. The idea behind it is to design a MAC protocol that could meet some specific requirements in wireless networks, such as reducing energy consumption, delay minimization, and increasing the throughput.

In [21], they leveraged mathematical models and analysis techniques from game theory and Markov chain modeling to investigate the performance of the hybrid ALOHA protocol under cooperative and non-cooperative scenarios. Additionally, they provided insights into the retransmission probabilities that optimize the performance metrics of interest for both scenarios.

In [11], a new protocol “Hybrid ALOHA” introduced in basis of MPR model [11]. In this approach chance of data collision is virtually eliminated and simultaneous transmission is possible. Despite stability criteria and throughput of this approach is calculated for up to 3 users, the actual throughput for higher number of users is unclear, ergo we expand equation of throughput by stochastic rules and express the results. Outcome of this equation indicates that even with increasing in the number of users with satisfaction of physical load constraints do not have negative effect on protocol. Besides that, the maximum throughput and area under the curve of throughput per arrival rate will improve [11]. The main contribution of this paper is as follows.

- Proposal of generalized form of hybrid Aloha throughput.

-The investigation of Hybrid Aloha throughput and stability.

In this paper, Section II presents the system model. Section III introduces the hybrid aloha model concept. Section IV formulates a generalized form of hybrid ALOHA. In section V this generalized form is examined and some test conducted in it in order to discuss throughput and stability and section V brings concluding remarks.

SYSTEM MODEL

Consider an N users wireless network with M out of its N users (M= {1, 2, 3, …, N}) which are willing to communicate with target access point and also consider infinitive buffer size for storing incoming packets. When the i-th user’s buffer is nonempty, the user with help of sensing or weighing up different conditions and criteria commit transmission to prevent collision as much as possible, let probability of the successful transmission for i-th be given by user p_i. Let the process of generation of new packets independent and also consider the length of packets all the same. Each packet splits in two distinguishable parts: training sequence space and data, where the length of first part is usually considerably shorter than the later part. The arrival rate for i-th user’s packets is independent from others, different in every slot and is distributed by Bernoulli distribution. The average number of packets in each slot is λ_i and with considering general form of MPR which supposes possibility of multiple users in physical layer simultaneously feasible, the probability model with condition tuning is formed [8].

The Media Access Control is designed such that the performance is improved by use of status of data transmission in the physical layer. In fact, in this approach (Hybrid ALOHA), the MAC will exploit some pilot sub-slots to investigate situation of communication channel and the length of these pilot sub-slot is set to τ.

As mentioned earlier, in slotted ALOHA each user can transfer data at the beginning of a slot while in Hybrid ALOHA whenever a user decides to perform a transmission, selects a pilot sub-slot and sends its training sequence. Hence the availability of channel is being evaluated. One of the main criteria which affects physical channel quality is channel status. It has a fundamental rule in inspecting media and evaluation of channel. In this approach by using feedbacks from physical layer transmissions, performance of MAC is improved. On the other hand, MAC and PHY layers entangled and form a tight relation and by the mean affect performance of entire system [8].

In the hybrid Aloha, the λ_i is Arrival rate of user i in each slot, and Λ_i stands for arrival rate of user i in time unit. While Λ is the whole system arrival rate.

$$\boldsymbol{\Lambda = \sum_{i=1}^{N} \Lambda_i} \qquad (1)$$

The P_i demonstrates chance of transmission of user i. The multiple users PHY layer determined by series of conditional probabilities.

S is set of all transmissions and U is set of successful transmissions.

$$\boldsymbol{q_{u,s} = P_r\{only \quad U recieved | S sends\}} \qquad (2)$$

Probability of successful receive is a set R and $R \subseteq S$,

$$\boldsymbol{q_{R|S} = \sum_{U:R\subseteq U\subseteq S} q_{u,s}} \qquad (3)$$

N_i^t: Length of i-th queue in the beginning of slot t.

β_i^t: Number of received packets by user i while $E(\beta_i^t) = \lambda_i$

Y_i^t: A Bernoulli random variable which counts number of leaves from queue i in slot t [11].

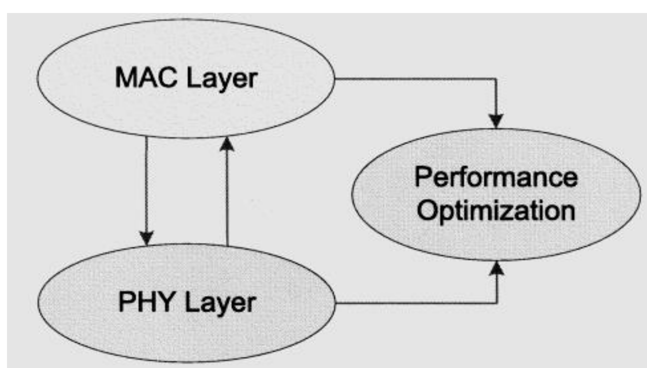

Fig.1. Interaction of MAC and PHY layer in Hybrid ALOHA [8].

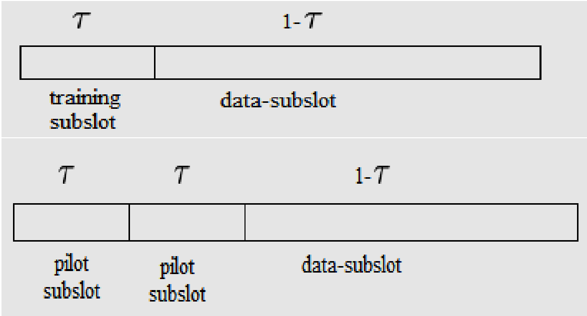

Fig. 2. Slot structure of Hybrid ALOHA protocol for M=1,2($\tau << 1$) and when M=2 or channel can send 2 packets.

Suppose $[x]^+ = max(x, 0)$ then,

$$\boldsymbol{N_i^{t+1}} = [\boldsymbol{N_i^t} - \boldsymbol{Y_i^t}]^+ + \boldsymbol{\beta_i^t} \quad (4)$$

HYBRID ALOHA

The prime goal of Hybrid ALOHA is to promote MPR capability with symmetric channel and collision free channel evaluation. Structure of a slot in Hybrid ALOHA is depicted in Fig 2.

In this method users which want to send packet randomly select one of the M sub-slots and send its training sequence, thus the probability of collision is evaluated and also Hybrid ALOHA possess M-1 more sub-slots in each slot compare to traditional Slotted ALOHA [15].

Analysis of Hybrid Aloha is based on MPR and parameters such as throughput and stability region are examined.

T_t : The number of packets which successfully received from channel in slot t.

A_S: Event that transmitted set is S

A_S^R: Event that only set R is successfully received with condition that transmitters belong to S.

Throughput is mean value of number of successfully received packets.

$$q_{r,s} = P_r\{A_S^R\} \quad (5)$$

And average traffic per slot is:

$$R(\tau) = \Lambda(M\tau + 1 - \tau) \quad (6)$$

Hence throughput can be calculated as:

$$\begin{aligned} \nu(\tau) &= \sum_{S\subseteq N} E(T_t|A_S)P_r\{A_S\} \\ &= \sum_{S\subseteq N}\sum_{R\subseteq S} E(T_t|A_S^R)P_r\{A_S^R\}P_r\{A_S\} \\ &= \sum_{S\subseteq N}\sum_{R\subseteq S} R(\tau)\frac{|R|}{|S|}q_{R,S}P_r\{A_S\}. \end{aligned} \quad (7)$$

In symmetric MPR model users are indistinguishable, ergo a simpler formula can be obtained for throughput. If A_K is an event which K users transmit per slot and A_K^i is an event that there is i successful receive:

$$\begin{aligned} \nu(\tau) &= \sum_{K=1}^{M} E(T_t|A_K)P_r\{A_K\} \\ &= R(\tau)\sum_{K=1}^{M}\sum_{i=1}^{K}\frac{i}{k}P_r\{A_K^i|A_K\}P_r\{A_K\} \end{aligned} \quad (8)$$

Number of sub-slots is M and value of $P_r\{A_K\}$ depends on packet reception model, so $P_r\{A_K^i|A_K\}$ can be calculated by MPR capabilities [16].

Suppose that arrival of packets models with Bernoulli process and Λ is arrival rate. If number of users is large enough, we can approximate binomial distribution by Poisson distribution. With Poisson distribution and $R(\tau)$ in Hybrid ALOHA throughput will be obtained from:

$$\begin{aligned} &\nu(\tau) \\ &= R(\tau)\sum_{K=1}^{M}\sum_{i=1}^{K}\frac{i}{k}P_r\{A_K^i|A_K\}\frac{R(\tau)^{k-1}e^{-R(\tau)}}{(k-1)!} \end{aligned} \quad (9)$$

GENERAL FORM OF HYBRID ALOHA

In Lee et al. there is no closed form for calculation of $P_r\{A_K^i|A_K\}$ for any arbitrary number of users, in fact this proposition is probability of the event “from K transmission in system there is only i successful receive”. In this work we explain how to reach a closed form of this equation based on probability rules [16].

Value of $P_r\{A_K^i|A_K\}$ depends on value of M or number of pilot sub-slots besides the value of i and K. If K users want to select M sub-slots so that a sub-slot may be taken by more than one user then the total number of possibilities is equal to MK. The number of states that i out of K transmissions be successful is equal to number of exact i successful transmission multiply by number of states that K-i users fail. In other words, each of i successful transmissions stand in one sub-slot alone while other K-i users place in remaining M-i sup-slots so none of the sub-slots do not host one user (two and more or nothing), in this scenario there is K-i failures.

Number of possibilities of choosing out of K is equal to$C(K,i) = \frac{K!}{(K-i)!i!}$, so from K users selecting i users (C(K,i)) and from M sub-slots i sub-slots select for placing users (C(M,i)) and these i users can sit beside each other in $i!$ ways. Therefore, number of successful states are equal to$C(K,i) \times C(M,i) \times i!$. When i users find their place K-i users remains that should be placed in remaining M-i sub-slots. For having exact i successful users, all K-i users must be unsuccessful. For fulfilling this criterion each remaining sub-slot must place 2 or more users on none at all. For sake of simplicity, we can subtract the sum of number of states that exactly 1,2, …, K-i are successful from number of states that K-i users can place in (M-i) sub-slots ($[M-i]^{K-i}$). Culminating from told states, we can express a recursive equation for solving problem:

$$P_r\{A_K^i|A_K(M)\} = \begin{cases} \frac{i!\binom{M}{i}}{M^K} & i = K \\ \frac{(\binom{K}{i}\binom{M}{i} i!)((M-i)^{K-i}(1-\sum_{j=1}^{K-i} P_r\{A_{K-i}^j|A_{K-i}(M-i)\}))}{M^K} & i \neq K \end{cases} \quad (10)$$

By adding this recursive formula in Eq.8, throughput can be estimated for any arbitrary number of users and network capacity and load. A secondary problem in calculation hindrance may incur due to nature of three variable recursive equation, but it can be easily addressed via bottom-up dynamic programing. With help of dynamic programing with memory, the calculation speed will dramatically improve while total memory order is$M \times K \times i$.

RESULTS AND DISCUSSION

Throughput analysis and experiments

In this section, the results of throughput of hybrid Aloha are presented. It is obvious that throughput is a function of τ; it means that higher values of τ lead to better performance and MPR capability via longer training sequence [8]. But as always things are not going well altogether without any tradeoffs. Larger τ means more unused space and reduce spatial effectiveness of each slot, on the other side larger M needs larger number of sub-slots which lead to longer slots with same size data sub-slot.

Other than τ throughput is also depends on $P_r\{A_K^i \mid A_K(M)\}$. This value is improved when amount of M is increased, needless to say that there is a tradeoff between τ and M and their assigned value must be met field situations. For additional satisfaction we simulate a simple condition of value of $P_r\{A_K^i \mid A_K(M)\}$ by randomly manipulate sub-slot selection scheme. Number of iterations for each value of N is its value, fivefold. Fig 3 depicts a comparison of random experiments and probability evaluation of throughput. If number of experiments are high enough, the values of experiment and analytical approach are alike.

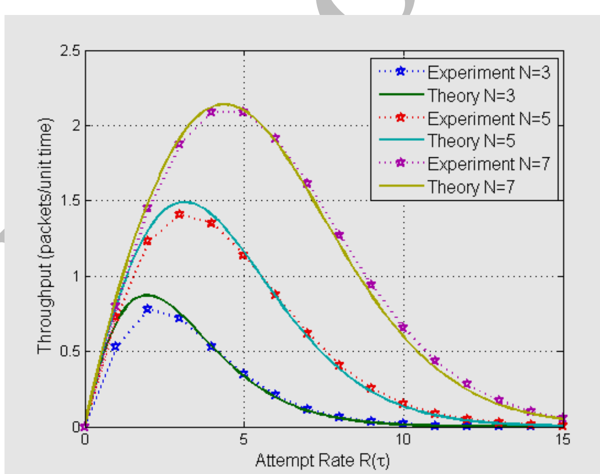

Fig. 3. Throughput values for different number of users in stochastic/simulated manner

Stability investigation

There is also some stability condition for N>2 in [8]. Now with closed form we are able to test stability with any conditions with various number of users and situations. In a simplistic assumption of this protocol a total failure is an event, when all user's training sequences collide each other, in this scenario the data sub-slot remained unoccupied till next slot thus it will be wasted. We measure probability of absolute failure in two scenarios. Constant number of maximum concurrent users and the chance of total failure based on how many users tried. This scenario is shown in Fig 4. It is obvious that chance of total failure rise while number of senders is even. This phenomenon is due to more chance of coupling with even number. Fig 4 also depicts that chance of total failure converge to a constant amount which is lower than its predecessors.

Gradually increase of maximum concurrent users while all of them have tried to transmit is the second scenario. In other words, investigate total failure probability per number of channels while all of them are busy. This scenario is demonstrated in Fig 5. While this figure shares same general features with previous figure, it shows convergence to zero with increase of M.

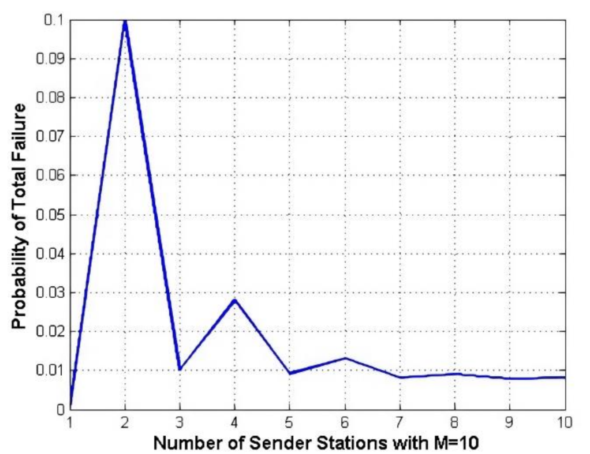

Fig. 4. Scenario 1: probability of total failure per number of sender stations. Note that this number is less or equal to M. M is constant in this approach

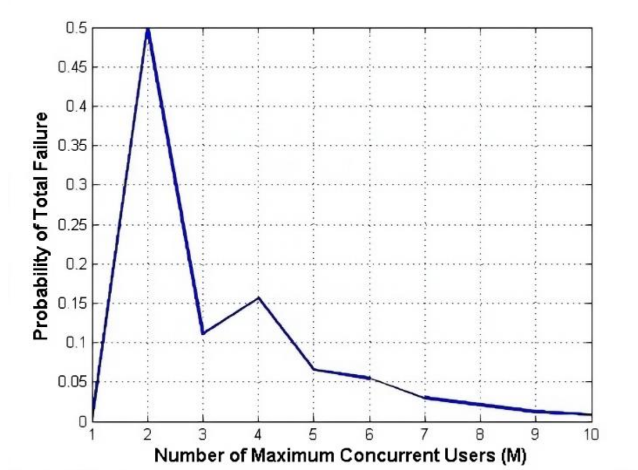

Fig. 5. Scenario 2: Probability of total failure in full load occasion per M. Horizontal axis is value of M which stands

for maximum concurrent users.

CONCLUSION

Hybrid ALOHA is a vastly improved MAC protocol over slotted ALOHA, it increases throughput via providing means to transmit multiple packets simultaneously. In original paper of Hybrid ALOHA, the results for 2 and 3 users were discussed. In this paper we achieved a closed form of throughput which can be used to calculate throughput with any combination and number of users. For evaluating this closed form, we designed an experiment based on model throughput to test the validity of formula. It must be considered that there is limitation in increasing of M due to additional imposed overheads. Nevertheless, we can see significant improvement when number of maximum potential users arise despite of increased overhead. There is also shown that while maximum potential user capacity (M) is larger, the chance of total failure begets close to zero and with constant M, total failure rate is stable and manageable.

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