Performance of Collaborative Codes in CSMA/CA Environment

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Abstract—**A new media access scheme is proposed for implementing collaborative codes on the carrier sense multiple access with collision detection (CC-CSMA/CA) protocol. New backoff algorithm is suggested which is simple to implement and to model. Tagged channel approach is used to model the scheme. Markov chain analysis is developed for modeling pure CSMA/CA and CC-CSMA/CA. A performance comparison is made between the two schemes in terms of throughput and packet delay.**

Keywords—**CSMA/CA, Collaborative codes, Multiple access, Markov chain analysis, Pure ALOHA,**

I. INTRODUCTION

Collaborative coding multiple access (CCMA) is technique where more users (K) per time step are allowed to access a communication channel. There are several codes available in the open literature: 2-user code [1], 3-user code [2], and 5-user code [3]. Each of the K-users is assigned a unique code which it uses to encode its data with. Codewords from different users are sent simultaneously on the channel where they add up. Each of the channel sums is unique, and the decoder (or decoders) can extract the information sent by each user and deliver it to its intended destination. As an example, a 2-user code is given in table I

TABLE I
CHANNEL SUMS FOR A 2-USER COLLABORATIVE CODING SCHEME.

User bits	Codeword K_1	Codeword K_2	channel sum
00	00	01	01
01	00	10	10
10	11	01	12
11	11	10	21

CCMA is best regarded as a way of increasing the number of users of a given transmission scheme. If a particular modulation and transmission protocol is in place, then by applying CCMA codes and modifying the detection process to be able to detect the sum values, the number of users can be increased with relatively small additional complexity.

Collaborative codes in statistically multiplexed communication systems utilizes K codes for N users (where $K < N$). Any one of the N users can access the system at the start of the next clock cycle using one of the available K codes. Therefore, the number of users present in the channel at each clock cycle varies between 0 and N. Fig. 1 shows user activity versus time for a 3-code system where where at some times more than one user is able to access the channel simultaneously while at others collisions occur.

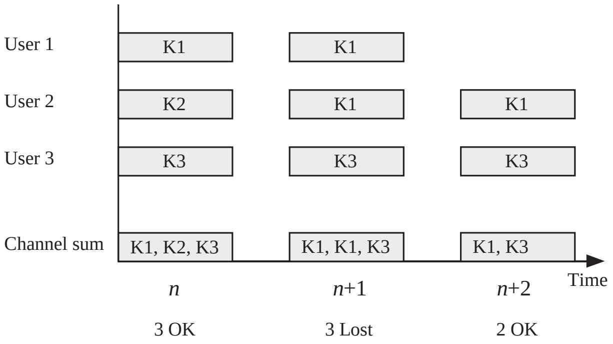

Fig. 1. Packet flow through the channel for the 3-code random access multiple access system.

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Each user accessing the channel may randomly select one of the K codes available. A maximum of K users can utilize the channel simultaneously. If they have used different codes, otherwise collision will take place and *all* messages will be lost. For the case of 3-user code, for instance, up to three users can access the channel at the same clock cycle without interfering or corrupting their data, if the three messages were encoded differently.

In this paper we propose to complement the code division multiple access-collision avoidance (CDMA-CA) protocol with CCMA, so that more users can access the channel at the same time.

In Section II we discuss the carrier sense multiple access with collision detection (CSMA/CA) or Ethernet protocol. In Section III we propose a protocol for using collaborative codes under the carrier sense multiple access with collision detection (CC-CSMA/CA). In Section IV we detail the assumptions we employ for modeling the CC-CSMA/CA protocol. In Section V we study the performance parameters of the CC-CSMA/CA protocol and we compare those results with the standard CSMA/CA protocol.

II. DISCRETE-TIME MARKOV CHAIN MODEL FOR CSMA/CA

CSMA is used for wireless LANs where the time required for **one bit** to travel between the two farthest stations (propagation time) is much smaller than the time required for **one packet** to be sent by the sender (transmission delay).

Basically when a station has a packet to sent, it first senses the channel to determine if it is free. If there are no other transmissions, the station sends a jamming signal (which is short compared to a data packet) and waits for a time sufficient for all other stations to receive this signal before transmitting its packet. If during transmission the station detects a jam signal from other stations, it refrains from transmission for a random time (which is called the backoff algorithm).

Let us define τ_p to be the propagation delay between users, and τ_t to be the transmission delay for one packet. Therefore, periods of transmission are separated by one or more *contention minislots* [4]. Similar to ALOHA, a user could determine if there is contention or not during the packet propagation delay, i.e. τ_p.

The wireless channel can be in one of three states: *idle*, *collided*, or *transmitting*. Figure 2 shows the state diagram of CSMA/CA protocol. The channel has several transmitting states because the time required for transmitting one packet (τ_t) is bigger than the propagation delay τ_p.

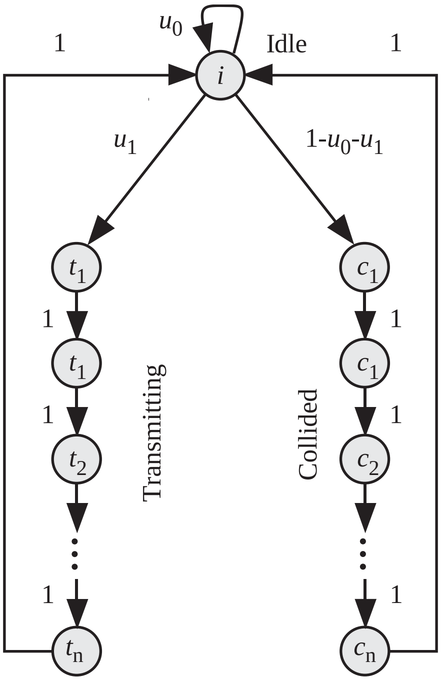

Fig. 2. State transition diagram for CSMA/CA channel.

The solution to the above this system is:

$$\mathbf{s} = \frac{\mathbf{1}}{\mathbf{n(1-u_0)+1}} \times \begin{bmatrix} 1 \\ u_1 \\ u_1 \\ \vdots \\ u_1 \\ 1-u_0-u_1 \\ 1-u_0-u_1 \\ \vdots \\ 1-u_0-u_1 \end{bmatrix} \qquad (1)$$

where u_0 and u_1 are channel state with zero and one user present respectively.

The throughput is given by the equation

$$\begin{aligned} Th &= \sum_{i=1}^{n} s_{t_i} \\ &= \frac{nu_1}{n(1-u_0)+1} \end{aligned} \tag{2}$$

III. COLLABORATIVE CODES UNDER CARRIER SENSE MULTIPLE ACCESS WITH COLLISION DETECTION (CC-CSMA/CA)

In a CC-CSMA/CA communication system users with data to send monitor the channel to ensure that it is not being used before attempting a transmission. As soon as the channel becomes idle, a user with data to send will randomly choose a code to employ for sending the data. A transmitting user can not monitor the channel to ensure that no collisions are taking place. A collision is determined only after packet transmission has been completed and a negative acknowledgment has been received.

However, idle stations can monitor the channel and decode other station transmissions. As a byproduct of this monitoring process, each station is able to determine how many code channels are being used. Thus the state of a particular code channel (termed: tagged channel) can be determined by monitoring and decoding the symbols being transmitted.

IV. MODEL ASSUMPTIONS FOR CC-CSMA/CA

We make the following assumptions for our analysis of the CC-CSMA/CA protocol.

1. A certain code out of the K codes is studied. We call this the *tagged code channel*.
2. Since the current state of the channel depends only on its immediate past history, we can model the channel using Markov chain analysis.
3. The states of the Markov chain to be modeled represent the status of a tagged user in the system.
4. The time step duration T is equal to the propagation delay (τ_p).
5. All transmitted packets have equal lengths such that the ratio of transmission delay to propagation delay is n. In that case, a packet requires n time steps to be completely transmitted.
6. The channel is shared among N stations.
7. There is a single station class (equal priority).
8. Probability that an idle station receives a packet for transmission during a packet transmission time is a.
9. There are K available codes in the collaborative code system.
10. A user with a packet to send picks one of the available codes at random with probability $1/K$.
11. A p-persistent CSMA/CA is assumed.
12. Collision occurs if more than one user select the same code for transmitting a packet.
13. The probability that a collided user requests to transmit a packet in a frame equals the packet arrival probability.

Assumption 10 implies that the effective user population seen by a given code is $N' = N/K$.

Assumption 13 implies that collided users employ an *adaptive backoff strategy* where each user keeps an estimate of its traffic intensity and adapts its backoff strategy accordingly. From an implementation point of view, the advantages of adopting this strategy are to keep minimal state information which is simple to effect in software or hardware. From a modeling point of view, the advantage of adopting this strategy is that there is no distinction between collided and uncollided users since both show the same level of activity.

V. CC-CSMA/CA PERFORMANCE

Based on the above assumptions the tagged channel can be in one of the following states: *idle* (i), *collided* (c), or *transmitting* (t).

For a tagged code channel, the state transition diagram for that channel is shown in Fig. 3 for the CSMA/CA system.

In the figure, x is the probability that all users are

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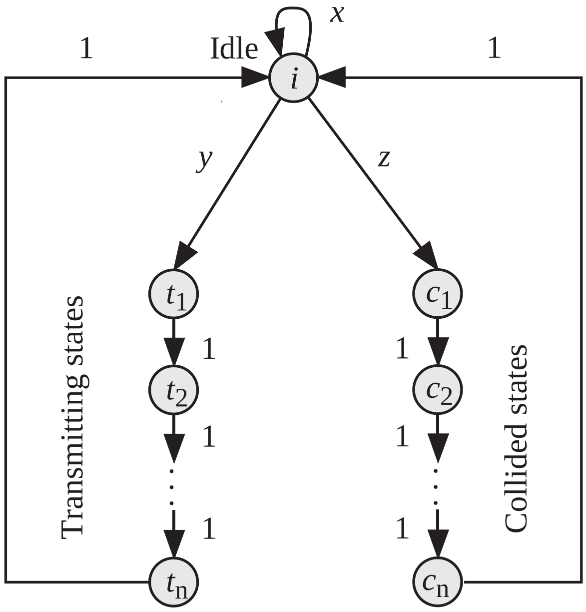

Fig. 3. State transition diagram for the CC-CSMA/CA channel.

idle:

$$x = (1-\alpha)^N \tag{3}$$

where α is the the probability that a station requests a transmission during a time step:

$$\alpha = \frac{ap}{n} \tag{4}$$

where the states are organized as follows:

$$\mathbf{s} = \left[\begin{array}{cccccccc} s_i & s_{t_1} & s_{t_2} & \cdots & s_{t_n} & s_{c_1} & s_{c_2} & \cdots & s_{c_m} \end{array} \right]^t \tag{5}$$

y is the probability that only one user in the tagged channel requests access and no collision has taken place. y is given by

$$y = v\, u_1 \tag{6}$$

where u_1 is the probability that only one user is active from among N' users and v is the probability that no collisions have taken place in any of the other $K-1$ code channels. u_1 and c can be written as

$$\begin{aligned} u_1 &= N'\alpha(1-\alpha)^{N'-1} & (7)\\ v &= (u_0+u_1)^{K-1} & (8) \end{aligned}$$

In general, the probability that i users are active and requesting the same tagged code at a given time slot is given by

$$u_i = \binom{N'}{i} \alpha^i (1-\alpha)^{N'-i} \tag{9}$$

z is the probability that a collision has taken place and we can simply write this as

$$z = 1 - x - y \tag{10}$$

We organize the distribution vector at equilibrium as follows.

$$\mathbf{s} = \left[\begin{array}{ccccccccc} s_i & s_{t_1} & s_{t_2} & \cdots & s_{t_n} & s_{c_1} & s_{c_2} & \cdots & s_{c_n} \end{array} \right]^t \tag{11}$$

The corresponding transition matrix of the channel is given by

$$\mathbf{P} = \left[\begin{array}{ccccc ccccc} x & 0 & 0 & \cdots & 1 & 0 & 0 & \cdots & 1 \\ \\ y & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & 0 & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\ \\ z & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & \cdots & 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & 0 & \vdots & \vdots & \cdots & \vdots \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \end{array} \right] \tag{12}$$

where the states are organized as follows: At equilibrium the distribution vector is given by (1). obtained by solving the following two equations [5]

$$\begin{aligned} \mathbf{P}\,\mathbf{s} &= \mathbf{s} & (13)\\ s_i + \sum_{i=1}^{n} s_{c_i} + \sum_{i=1}^{n} s_{t_i} &= 1 & (14) \end{aligned}$$

The solution to the above two equations is

$$\mathbf{s} = \frac{\mathbf{1}}{\mathbf{n(1-x)+1}} \times \left[\begin{array}{ccccccccc} 1 & y & y & \cdots & y & z & z & \cdots & z \end{array} \right]^{\mathbf{t}} \tag{15}$$

We note here that when $K = 1$ for a single code channel, we get the same theoretical expression for the steady state distribution vector of the CSMA/CA protocol given by (1).

The system throughput is given by the equation

$$Th = K\sum_{i=1}^{n} s_{t_i} = \frac{Knz}{n(1-x)+1} \qquad (16)$$

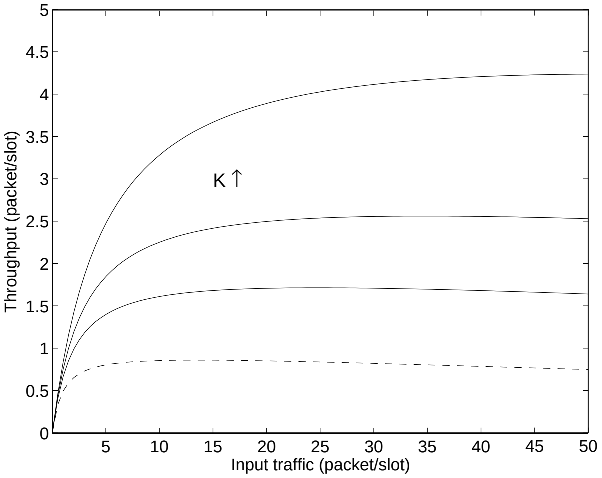

Fig. 4. The throughput for CC-CSMA/CA versus the average input traffic when $n = 100$, $N = 50$, and $K = 2, 3, and 5$. The dashed line represents the throughput of CSMA/CA.

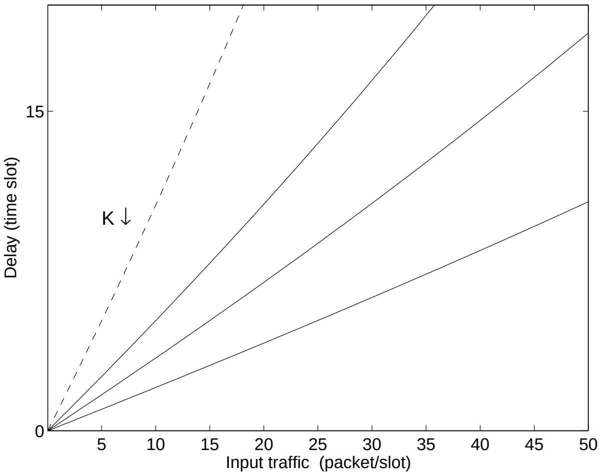

Fig. 5. Packet delay for CC-CSMA/CA versus the average input traffic per time slot when $n = 100$, $N = 50$, and $K = 2$, 3, and 5. The dashed line represents the delay of CSMA/CA.

Figure 4 shows the throughput while figure 5 shows the delay of the CC-CSMA/CA network when $n = 100$, $N = 50$, and $K = 2$, 3, and 5. The arrow indicates increasing values of K while the dashed line represents the throughput of the standard CSMA/CA. The throughput for collaborative codes is approximately higher than the standard CSMA/CA by a factor of K. More results are available in [6].

VI. CONCLUSIONS

This paper presented a new media access control protocol for collaborative codes using CSMA/CA for wireless channels (CC-CSMA/CA). Discrete-time Markov chain analysis of the standard CSMA/CA and of the proposed CC-CSMA/CA were developed and performance measures for each protocol were studied. The throughput for collaborative codes is higher than the standard CSMA/CA by a factor of K, where it is 2.2, 3.4, and 5.9 for $K = 2$, 3, and 5, respectively. A modified (new) adaptive backoff strategy was introduced where each user keeps an estimate of its traffic intensity and implements its backoff strategy accordingly. This strategy is simple to implement in hardware or software as minimal number of states is needed to be stored. It also simplifies the modeling process as there is no distinction between collided and uncollided users since both show the same level of activity. In this study, tagged channel code technique was used which simplifies the channel model.

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