Improvement in Medium Access Control Protocol based on new contention scheme for Wireless Ad hoc Network

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Abstract

In todays wireless networks, stations using the IEEE 802.11 standard contend for the channel using the Distributed Coordination Function (DCF). Research has shown that DCF's performance degrades especially with the large number of stations. This becomes more concerning due to the increasing proliferation of wireless devices. In this paper, we present a Medium Access Control (MAC) scheme for wireless LANs and compare its performance to DCF . Our scheme, which attempts to resolve the contention in a constant number of slots (or constant time), is called CONSTI. The contention resolution happens over a predefined number of slots. In a slot, the stations probabilistically send a jam signal on the channel. The stations listening retire if they hear a jam signal. The others continue to the next slot. Over several slots, we aim to have one station remaining in the contention, which will then transmit its data. We find the optimal parameters of CONSTI and present an analysis on its performance.

Keywords: *Access Protocol, Ad hoc network, Throughput, Medium access control.*

1. Introduction

Nowadays, wireless networks are a necessary part of the computing world. This was made possible by the IEEE 802.11 standard which provides technical specifications for the wireless interfaces. The Medium Access Control scheme (MAC) in the standard that is most widely used is the Distributed Coordination Function (DCF). Its function is to arbitrate the use of the medium to multiple stations that are connected to one Access Point (AP) in the infrastructure mode. In addition, DCF can be used in the infrastructure-less or ad hoc mode in which there It is commonly believed that there is a spectrum scarcity at frequencies that can be economically used for wireless communications.

The contention with DCF works as the following. The stations use Contention Windows(CW) to randomize their access and try to avoid collisions. Initially a station waits for DIFS(DCF Inter Frame Space) and transmits if the channel is idle. However, if the channel is busy, the CW is used. The CW is initially assigned to a preset value, CW_{min}, which depends on the physical layer. Then, a statio sets a backoff (BO) counter to a random value chosen from a uniform distribution from [0,CW]. The station decreases the BO counter by one for every time slot the channel is idle. If a busy channel is detected, the BO counter is freezed and the countdown resumes from the freeze value after the channel is idle for a duration of DIFS. The station transmits when its BO counter reaches zero. If two or more stations reach zero at the same time, there will be a collision and the transmitted frames won't be received correctly. The colliding stations will not receive an ACK frame and they will double their CW (until it reaches the maximum value equal to CW_{max}). On the other hand, when a station transmits a data frame successfully, its CW is reset to the initial value CW_{min}.

The DCF's performance degrades significantly with an increase in the number of stations. While this wasn't an issue at the inception of DCF, now more and more people use wireless connections and this becomes a limitation practically. The decrease of performance in this case is attributed to the large number of collisions with the increase in the number of stations. Other evaluations of DCF show that its delay might be very large with busy traffic conditions. Finally, the fairness of DCF has been considered and it was shown that DCF doesn't have a high fairness in the short-term, although its fairness increases as the stations contend for longer periods.

In this paper, we present a MAC scheme that provides access by resolving the contention between stations. The main feature of our scheme is that it attempts to resolve the contention in the same number of slots every time. Our scheme, which attempts to resolve the contention in a Constant Time, is called CONTI. The contention resolution has several slots. At the first slot, all the stations with frames to transmit contend. The stations, with a probability that we define, choose an event of sending a jam on the channel for the slot duration. This jam is simply a burst of energy and doesn't need to contain any specific information. With the complementary probability, the stations choose an event of listening to the medium. During a slot, stations retire from the contention if they were listening and hear a jam, which we call preemption.

The remaining stations move on to the next slot and repeat the contention. We aim to have one remaining station at the end of contention to provide access to the medium.

In the results, we compare CONSTI and DCF and we show that CONSTI achieves the highest throughput among schemes.

The rest of the paper is organized as follows: Section 2 presents the related work that we compare against, in addition to other schemes in the MAC area. The proposed MAC scheme is detailed in Section 3. Section 4 presents analysis on the parameters in order to maximize the throughput followed by the discussions on the numerical results in Section 5. Finally, Section 6 concludes the paper with a discussion on the future work.

2. Related Work

There have been numerous MAC schemes proposed in the literarture. We highlight here two types of schemes: 1) the contention window (CW) based schemes and 2) the jamming based schemes.

The scheme Prioritized Repeated limitations Multiple Access (PREMA) was proposed in [1]. PREMA is a jamming based scheme. It works as the following. Contending stations transmit a jam, whose length in slots is drawn from a geometric distribution with parameter. After the last jam slot, the stations do one slot of carrier sense. If they hear another ongoing slot, they are out of this contention. If not, it means they passed this elimination. The stations with the longest burst will survive the elimination. Following, they do elimination by choosing another random number from the same distribution and jamming and then one slot of carrier sense.

The scheme k-Round Elimination Contention (K-EC) was proposed in [2] which is also a jamming based scheme. It also has several rounds of eliminations in a contention. There are k rounds of elimination, where k is parameter. A round of k-EC consists of at most m slots. The contending stations choose a random number uniformly from [0, m-1] and transmit only one jam in the slot number. If a station chooses 0, then it's the first slot, etc. If the station is not jamming, then it should be listening by carrier sense. When a station hears a jam while it is listening, it drops out of the contention and the round is finished for it.

The scheme Idle Sense was proposed in [3] and it was revised in [4]. Unlike PREMA and k-EC, Idle Sense is based on the contention window (CW) mechanism, like the standard DCF scheme. The main idea of Idle Sense is observing that there is an optimal number of slots between two consecutive transmissions. Hence, in Idle Sense all the stations observe the number of slots and adjust the CW up or down to match the number of observed idle slots to the target value.

Other proposed approaches based on jams are in [5],[6],[7],[8],[9]. Other proposed approaches to optimize the CW schemes are in [10],[11],[12],[13],[14]. In this paper, we compare our scheme to the standard DCF.

3. The Proposed CONSTI Scheme

This section presents the proposed MAC scheme, CONSTI, which attempts to resolve contention using a constant number of slots. We start by defining the terms that are used in our work.

3.1 Notations

The number of stations in the WLAN cell is given by n.

- The contention is resolved over a number of slots given by k, and the contention slots are labeled $\{s_1,s_2,\ldots..s_k\}$.
- During the contention slot, a station either transmits a pulse, called signal 1 or listens to the channel, called signal 0.
- The probability vector used by the stations to decide whether to transmit a pulse or listen is given by p: $\{p_1,p_2,\ldots..p_k\}$. A station will choose signal 1 during slot s_i with probability p_i . Otherwise, a signal 0 is chosen with a probability $1\text{-}p_i$.
- The number of remaining stations in the contention at the end of the slots is designated by the vector r: $\{r_0,r_1,\ldots..r_k\}$. So, r_0=n stations start the contention, and r_i stations remain in the contention at the end of slot s_i.
- An instance of CONSTI is characterized by its parameters, the number of slots k and the probability vector p. Thus, an instance of the scheme, S, is designated by S(k,p).

3.2 Contention

The contention of n stations is resolved using CONSTI over k contention slots. Each of the stations uses the same probability vector p. All of the stations go through the following procedure. Before a contention slot s_i, a station chooses signal 1 with probability pi or signal 0 with probability $1\text{-}p_i$.

During a contention slot, the station will transmit a pulse on the channel if it has signal 1. Otherwise, the station will listen to the channel. The pulse that is transmitted doesn't need to contain information. Rather, its presence on the channel indicates to other stations that some stations have chosen a signal 1. A station that is listening and hears the presence of a signal on the channel is said to be preempted, and this station doesn't contend anymore in this contention. But if a station with signal 0 doesn't hear a signal, it stays in the contention. If the station has signal 1, it transmits the pulse and moves to the next contention slot. At the end of the last slot, a station transmits its data frame if it has not been preempted.

During a contention slot, it is better to eliminate the largest number of stations possible. This means that the contention resolution is occurring quickly and the amount of time spent on contention resolution is minimized. At the end of slot s_i , there are r_{i-1} stations. At the end of slot r_i, stations that are remaining in the contention. Thus, slot s_i has eliminated (r_{i-1} - $r_{i)}$ stations from the contention, which we seek to minimize.

With CONSTI, it is possible that no stations are eliminated during a contention slot. This happens if all the stations choose signal 1.Then, no station is preempted. It also happens if all the stations choose a signal 0. If this event happens, then the following slots will continue the contention. But if it happens in the last slot and there are more than one station remaining, there will be a collision.

For an efficient contention resolution, the probability choices should be optimized to minimize the collision rate. The number of slots should also be minimized so that the time spent in the contention is reduced.

Finally, we add a stipulation that ensure compatibility with the Inter-Frame Spacing used in wireless networks, such as DIFS in the standard. In CONSTI, there might be a few consecutive slots where all of the stations choose signal 0. Thus, a station that had already retired from contention should not count this silent time in its IFS timer.Thus, we require a station that has retired to stop its IFS timer until the contention is finished. Since the station knows the number of slots, k, a priori, it can do that.

3.3 Example Scenario

An example on the contention resolution using CONSTI is presented in Fig. 1. There are six stations. In the first slot, stations 2, 4, and 5 choose signal 1 and preempt stations 1, 3, and 6. Thus, stations 1, 3, and 6 don't contend anymore in this round. The graph on the left side of Fig. 1 shows the signals, while the graph on the right side depicts the jams. In the second slot, stations 2, 4, and 5 choose signal 0 and no station is preempted. All the stations move to the third slot. In the third slot, stations 2 and 4 preempt station 5. Finally, in the last slot, station 2 preempts station 4. Then, station 2 is able to transmit a data frame. In this example, n=6, k=4 and the vector r is {6, 3, 3, 2, 1}.

3.4 Proposed Algorithm

The contention resolution using CONSTI is specified in the pseudo code in Algorithm 1. The pseudo code describes the operation of a CONSTI instance S(k,p). In Algorithm 1, the state variable retire indicates if the station has been preempted, when retire=1, or if the station is still in the contention, when retire = 0.

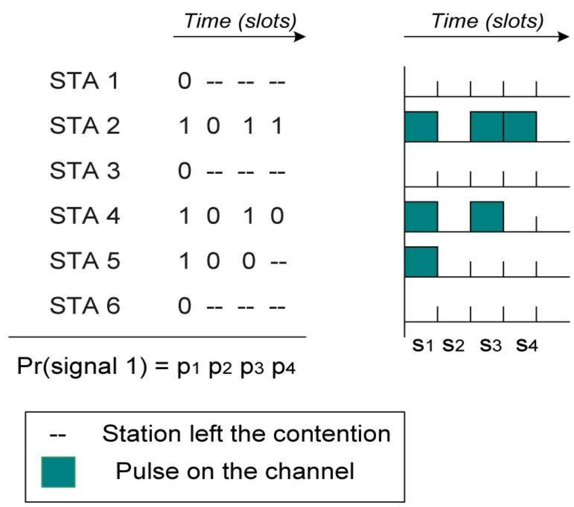

Fig. 1 Contention Resolution using CONSTI

Algorithm 1. Contention Resolution with CONSTI

```
retire:=0
i := 1
while (i≤k) do
   if retire=1                    /* Station has been preempted */
      defer(t_slot)
   else if retire=0               /* Station in contention */
      proba :=Uniform(0,1)        /* Choose signal 1 or 0 */
      if proba < p_i
         signal := 1
      else signal :=0
      if signal=1                 /* Station with signal 1 */
          pulse(t_slot)
      else if signal=0            /* Station with signal 0 */
          listen(t_slot)
          ifpulseDetected(t_slot)=true
             retire :=1
   i := i+1
```

4. Analytical Model

4.1 Time Utilization

The time utilization of CONSTI, designated by ρ_{consti}, is found as following

$$\rho_{consti} = \frac{p_s.t_{data}}{p_s.T_{successful} + p_c.T_{collision}} \quad (1)$$

where t_{data} is the time to transmit the data frame. The probability of success and collision are given by p_s and p_c, respectively. $T_{successful}$ is the time for a successful transmission symbol, and $T_{collision}$ is the time consumed by a collision cycle, which are given as follows

$$T_{successful}=t_{difs}+k.t_{slot}+t_{data}+t_{sifs}+t_{ack}$$

$$T_{collision} = t_{difs}+k.t_{slot}+t_{data} \quad (2)$$

The time utilization of DCF, designated by ρ_{dcf}, is found as following

$$\rho_{dcf} = \frac{p_s.t_{data}}{p_s.T_{successful} + p_c.T_{collision}} \quad (3)$$

where t_{data} is the time to transmit the data frame. The probability of success and collision are given by p_s and p_c, respectively. $T_{successful}$ is the time for a successful transmission symbol, and $T_{collision}$ is the time consumed by a collision cycle, which are given as follows

$$T_{successful}=t_{difs}+t_{contention}+t_{data}+t_{sifs}+t_{ack} \quad (5)$$

$$T_{collision} = t_{difs}+t_{contention}+t_{data} \quad (4)$$

Where $t_{contention}$ designates the average number of slots spent in a DCF contention.

Since CONSTI and DCF employ two different mechanisms for the contention resolution, it is obvious that they have different expressions for the probability of a successful transmission.

4.2 Probability of Successful Transmission of DCF

The characterization of the collision event in DCF was presented in [15]. Consider a fixed number n of contending stations. In saturation condition, each station has immediately a packet available for transmission, after the completion of each successful transmission. Let b(t) be the stochastic process representing size of the back off window for a given station at slot time t. Define $W_i=2^iW$ where i: (0,m) is called backoff stage and let s(t) be the stochastic process representing the back off stage (0…..m) of the station at time t.

The bidimensional process {s(t),b(t)} is a discrete-time Markov chain with the only non null one-step transition probabilities being

$$P\ \{i,k|i,k+1\} = 1$$

$$P\ \{0,k|i,0\} = 1-p/W_o$$

$$P\ \{i,k|i-1,0\} = p/W_i$$

$$P\ \{m,k|m,0\}=p/W_m \quad (6)$$

These transition probabilities account respectively for 1)the decrement of the backoff counter 2) the fact that a new packet following a successful transmissions with a backoff stage 0 and 3),4) the fact that after an unsuccessful transmission at back off stage I, the backoff interval is uniformly chosen in the range $(0,W_{min})$.

Accordingly, the probability that a station transmits in a slot, p_{tr}, and the probability that a station has a successful transmission given a transmission attempt, p_s, are given as follows:

$$p_{tr}=1-(1-\tau)^{n-1} \quad (7)$$

$$p_s= n\tau\,(1-\tau)^{n-1}/P_{tr} \quad (8)$$

where n is the number of contending stations and τ and p are given as follows:

$$\tau = \frac{2(1-2p)}{(1-2p)(CWmin+1)+pCWmin(1-(2p))^{m})} \quad (9)$$

$$p=1-(1-\tau)^{n-1} \quad (10)$$

4.3 Probability of Successful Transmission of CONSTI

Let the term $\sigma(n,k,p)$ be the probability that the instance of CONSTI, S(k,p), resolves the contention successfully for n stations. Next, the probability of preempting stations over one slot is defined. Consider a contention slot s_i, where $r_{i-1}=u$ stations start the contention and $r_i=v$ stations remain at the end of the slot. Let the probability of this event be designated by $\tau_{u,v}(p_i)$. Its expression is the following:

$$\tau_{u,v}(p_i) = (pi)^v\,(1-pi)^{u-v}\ ,\quad 1 \le v \le u-1$$

$$(pi)^u + (1-pi)^u\ ,\quad v = u \quad (11)$$

In the first case, v out of u stations remains at the end of the slot. In the second case, all of the u stations remain at the end of the slot. This happens if all the stations choose the same signal, whether it is signal 1 or signal 0.

For a vector p:{p_1,p_2,…..p_k} with k elements, the term π_i(1≤i≤k) defines the sub vector of p with k-i+1 elements given by π_i :{p_i, p_{i+1},…..p_k}, so it is a suffix sub vector.The probability that scheme S(k,p) resolves the contention successfully for n stations is given by:

$$\sigma(n,k,p)=\sum_{i=o}^{n-1}\left[\tau_{n,n-i}(p1).\,\sigma(n-i,k-1,\pi_2)\right] \qquad (12)$$

The value of σ for the case where there is one station left and there are one or more slots is given by

$$\sigma(1,i,\pi_{(k-i+1)}) = 1, \qquad 1\le i\le k \qquad (13)$$

The value of σ for the case in the scenario when there is one slot left and there are one or more stations contending is given by

$$\sigma(v,1,\pi_{(k)}) = \tau_{v,1}(p_k), \qquad v\ge 1 \qquad (14)$$

In this case, the contention is resolved correctly if all the stations are preempted except one.First, notice that π_1 designates the same vector as p.Then, σ(n,k,p) can be rewritten as σ(n,k, π_1). After the elapse of one slot, the number of stations is reduced from r_o=n to r_1, where $r_o \ge r_1$. The remaining problem is the contention resolution of r_1 stations in k-1 slots using the vector π_2. This subproblem is solved successfully with a probability given by σ(r1,k-1,π_2). During the first slot, the number of stations that are preempted is between 0 and n-1. Each of thess events occur with a probability of $\tau_{n,n}(p_1)$,…. $T_{n,1}(p_1)$, respectively. Thus, σ(n,k,p) is equal to the following expression:

$$\sigma(n,k,\pi_1)=\tau_{n,n}(p_1)\sigma(n,k-1,\pi_2)+\tau_{n,n-1}(p_1)\sigma(n-1,k-1,\pi_2)+\ldots\ldots+\tau_{n,1}(p_1)\sigma(1,k-1,\pi_2). \qquad (15)$$

4.4 Gain

The characterization of the time utilization between CONSTI and DCF can be written as the following:

$$Gain_{conti} = \rho_{conti} / \rho_{dcf} \qquad (16)$$

$$Gain_{conti} = (p_s^{conti} \times p_s^{dcf} T_{sucessful}^{dcf} + p_c^{dcf} T_{collision}^{dcf}) / (p_s^{dcf} \times p_s^{conti} T_{sucessful}^{conti} + p_c^{conti} T_{collision}^{conti})$$

5. Numerical Results

For the analytical expressions in section 4, numerical evaluations are presented in this section. The physical layer we consider is 802.11b. The data rate is 11Mbps and the control rate is 1Mbps. Each of the schemes that we compare requires a certain number of contention slots. While the number of slots spent in contention isn't the only performance indicator, having a small number of slots is generally considered as preferable. The proposed scheme CONSTI takes a constant number of seven slots where as DCF spend a varying number of slots for each contention. With DCF, the number of slots is reduced with more stations even though the CW size is becoming larger. This happens since the number of slots that are spent is the minimum among all the backoff counters of stations. The parameters used are presented in Table 1.

Table 1: Parameters Used

Parameter	*Value*	*Comments*
tSlotTime	20 µs	Slot time
tSIFSTime	10 µs	SIFS time
tDIFSTime	50 µs	DIFS time
CW_{min}	15	Min contention window size
CW_{max}	1023	Max contention window size
tOverhead	192 µs	Control overhead
Nslots	7	No of slots
Nstations	5,10,15	Variable

Table 2: Comparision of throughput for DCF and CONSTI

No of nodes	*DCF*	*CONSTI*	*Gain*
5	0.0725	0.292	4.023
10	1.42×10^{-3}	0.035	24.6
15	2.27×10^{-5}	0.0614	267

At any moment of time, the number of contending transmissions in the system has an impact on the throughput of the network, because there will be more potential transmissions if there are more contending transmissions. The results of the performance evaluation are illustrated in Fig.1, where the results of throughput are shown for different values of n, the number of nodes. The

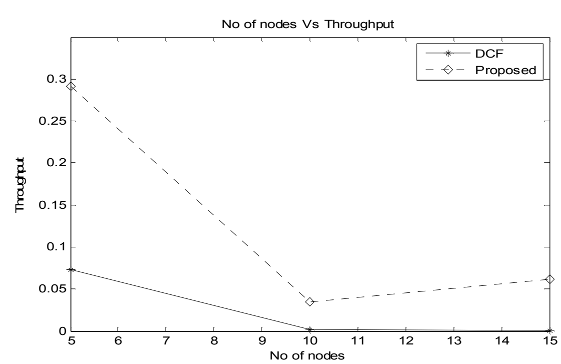

Fig. 1 Throughput Vs Number of stations

performance of the proposed scheme is better than that of basic DCF scheme. With the increase of number of contending stations, the throughput falls slightly as shown in Fig 1 because of increase in control overhead. The enhancement of throughput is more than the cost of control overhead. Throughput Comparison for CONSTI and DCF is shown in Table 2.

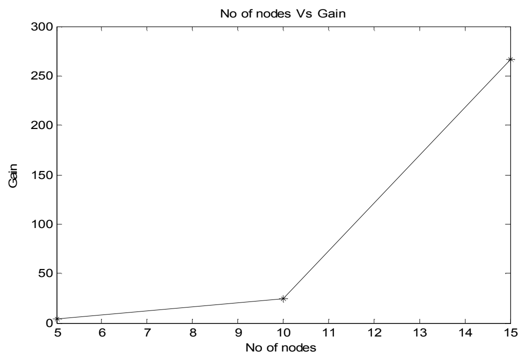

Fig.2 Gain Vs Number of nodes

As shown in Fig.2 gain which is the ratio of time utilization of CONSTI to DCF increases with the number of stations. This happens due to the fact that time utilization of CONSTI with increase in number of stations is more than that of DCF.

6. Conclusion

This paper presented a comparison of MAC schemes for wireless LANs. Our scheme, which attempts to increase throughput by resolving contention in a constant-time (CONSTI), was compared to basic DCF. First, we reviewed the related work and described the operations of a few schemes. Then, we presented the details of CONSTI and obtained its optimal parameters. Following, we presented an analysis that shows the effect of the contention slot on the throughput of CONSTI. Finally, in the results, we compared the performance of CONSTI to other scheme(DCF).

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