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An Enhanced Mac Scheme for 802.11 with Constant Time Contention using Sequencing Technique

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Abstract

Wireless networks offer a vast variety of uses by both business and home users. Now, the industry accepts a handful of different wireless technologies. Each wireless technology is defined by a standard that describes unique functions at both the Physical and the Data Link layers of the OSI Model. These standards differ in their specified signaling methods, geographic ranges, and frequency usages, among other things. Stations using the IEEE 802.11 Standard contend for the channel using the Distributed Coordination Function (DCF) because it's performance degrades especially with the large number of stations. IEEE 802.11 standard specifies a MAC scheme called CONTI that resolve the contention (collision) in constant number of time slots. The main aim is to have only one station remaining in contention that will transmit the data. CONTI shows better performance when compared to other scheme like DCF based on the parameters like throughput, collision rate, delay etc. The performance can be further improved by introducing a sequencing technique via VBA algorithm. Simulation is done using NS2 (version 2.34).

Keywords: Protocols, Networks, Algorithms.

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1. Introduction

Wireless network refers to any type of computer network that is not connected by cables of any kind. It is a method by which homes, telecommunications networks and enterprise (business) installations avoid the costly process of introducing cables into a building, or as a connection between various equipment locations. Wireless telecommunications networks are generally implemented and administered using a transmission system called radio waves. This implementation takes place at the physical level (layer) of the network structure.

The need for mobile computing has launched a successful wireless LAN market, with ELANs promising to replace most wired LAN infrastructure. Wireless Local Area Network (WLAN) is a rapidly emerging field of activity in computer networks. WLAN can be used in many places. A common one is the wireless office. The currently emerging WLAN standards are: the European Telecommunications Standards Institute (ETSI), High performance European Radio LAN (HIPERLAN) and the IEEE 802.11 WLAN.

In cellular networks, bandwidth is deterministic in terms of the number of channels by frequency division, time division, or code division. On the contrary, bandwidth allocation in distributed wireless LANs is extremely challenging due to its contention-based nature, packet-based network and the most important aspect: only one channel is available, competed for by an unknown number of stations under different traffic patterns. Therefore, guaranteeing bandwidth and allocating bandwidth are both extremely difficult. These open up a new research avenue and call for novel ways to support QoS in contention based distributed WLANS. The medium access control (MAC) of the IEEE 802.11 WLAN employs a mandatory contention-based channel access function, called the Distributed Coordination Function (DCF), and an optional centrally controlled channel access function, called the Point Coordination Function (PCF). The DCF adopts a carrier sense multiple access with collision avoidance (CSMA/CA) with binary exponential backoff. DCF does not support QoS and even cannot support any priority scheme. PCF can support very limited QoS. The IEEE 802.11e MAC will support multimedia applications such as voice and video over the IEEE 802.11 WLANs. The IEEE 802.11 DCF enables fast installation with minimal management and maintenance costs and is very robust protocol for the best-effort service [2],[4].

The popularity of the IEEE 802.11 WLAN is mainly due to the DCF whereas the PCF is barely implemented in today's products due to its complexity and inefficiency for normal data transmissions, even though it has some limited QoS support. To support the MAC-level QoS, the IEEE 802.11 Working Group has recently developed IEEE 802.11e providing QoS features and multimedia support to the existing 802.11a/b/g WLANs while maintaining a full backward compatibility with these legacy standards. The IEEE 802.11e MAC employs a channel access function, called the Hybrid Coordination Function (HCF) which includes both contention-based channel access and centrally-controlled channel access mechanisms.

CONTI, the MAC scheme for wireless LANs attempts to resolve the contention in a constant number of time slots (or constant time). The contention resolution happens over a predefined number of slots. Over several slots, the aim is to have only one station remaining in the contention, which will then transmit its data. The optimal parameters of CONTI were found and performance analysis was done. More evaluation is presented in the simulation results where comparison between CONTI and DCF was done [1].

2. 802.11 Medium Access Control

The MAC data communication protocol sub-layer, also known as the Medium Access Control, is a sub layer of the Data Link Layer specified in the seven-layer OSI model (layer 2). It provides addressing and channel access control mechanisms that make it possible for several terminals or network nodes to communicate within a multi-point network, typically a Local Area Network (LAN) or Metropolitan Area Network (MAN). The hardware that implements the MAC is referred to as a Medium Access Controller. MAC sub-layer acts as an interface between the Logical Link Control (LLC) sub layer and the network's physical layer. The MAC layer emulates a full-duplex logical communication channel in a multi-point network.

The 802.11 family uses a MAC layer known as CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance). Classic Ethernet uses CSMA/CD - collision detection). CSMA/CA is, like all Ethernet protocols, peer-to-peer; there is no requirement for a master station [3].

In CSMA/CA a Wireless node that wants to transmit performs the following sequence:

- Listen on the desired channel.
- If channel is idle (no active transmitters) it sends a packet.
- If channel is busy (an active transmitter) node waits until transmission stops then a further CONTENTION period.
- If the channel is still idle at the end of the CONTENTION period the node transmits its packet otherwise it repeats the process defined in 3 above until it gets a free channel

2.1 DCF Interframe Space

In the DCF protocol, a station before transmitting has to sense the status of the wireless medium. If the medium is continuously idle for DCF Interframe Space (DIFS) duration, only then it is supposed to transmit a frame. If the channel is found busy during the DIFS interval, the station should defer its transmission.

2.2 Short Interframe Space

Short Interframe Space (SIFS), is the small time interval between the data frame and its acknowledgment. SIFS are found in IEEE 802.11 networks. They are used for the highest priority transmissions enabling stations with this type of information to access the radio link first. This value is fixed per PHY and is calculated in such a way that transmitting station will be able to switch back to receive mode and be capable of decoding the incoming packets.

Examples of information which will be transmitted after the SIFS has expired include ACK (acknowledgement) and CTS (Clear to Send) messages. SIFS duration is a constant value and it depends on the amendments.

2.3 Spatial Reuse

The network capacity depends on the achievable channel capacity at each individual wireless link and the level of spatial reuse - the total number of concurrent transmissions that can be accommodated in the network. In IEEE 802.11 based ad hoc networks, concurrent transmissions and channel contentions are managed by the distributed coordination function (DCF).

To improve efficiency additional features are employed:

- Positive Acknowledgement (ACK)
- MAC level retransmission
- Fragmentation

2.4 Backoff Algorithms

In a single channel contention based medium access control (MAC) protocols, whenever more than one station or node tries to access the medium at the same instant of time, it leads to packet collisions. If the collided stations try to access the channel again, the packets will collide as the nodes are synchronized in time. So the nodes need to be displaced in time. To displace them temporally, a backoff algorithm is used. For example, in BEB algorithm, whenever a node's transmission is involved in a collision with another node's transmission, both nodes will choose a random waiting time and wait for this amount of time before attempting again. If they are not successful in this attempt, they double their contention window and choose a random waiting time before transmitting again. This process will be repeated for certain number of attempts. If the nodes are not successful in their transmission after this limit, the packets will be dropped from their queue.

3. Constant Time Contention Resolution

The stations using the wireless LAN Standard contend for the channel while using the Distributed Coordination Function (DCF) in today’s wireless networks [5]. The 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 [6]. A Medium Access Control (MAC) scheme for wireless LANs is presented and compared its performance to DCF and to other efficient schemes. This scheme that attempts to resolve the contention in a constant number of slots (or constant time), is called CONTI [1].

The aim is to have only one station remaining in the contention which will then transmit its data. The optimal parameters of CONTI are found and performance analysis is done. It aims at bounding the collision rate. The smallest number of slots and the corresponding probability vector are found so that the collision rate is bounded by a given value. It uses an algorithmic approach and finds the parameters with a low computation time. The second method uses an optimization approach to find the parameters that maximize the throughput. But this method requires a larger computation time. To find the parameters offline and make them known to the station during the data transmission, this method doesn't need to operate; instead the parameters that it has produced are readily used.

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 CONTI and present an analysis on its performance. More comprehensive evaluation is presented in the simulation results where we compare CONTI, DCF, and other efficient schemes from the literature. We consider the number of slots used, the collision rate, the throughput, the delay, and the fairness. The highest throughput was achieved by CONTI. Moreover, our results provide measurements from each of the schemes that we consider and provide the insight on each scheme's operation.

The Medium Access Control (MAC) scheme that is most widely used is the Distributed Coordination Function (DCF). But 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 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. A MAC scheme that provides access by resolving the contention between stations is presented here. The main feature of this scheme is that it attempts to resolve the contention in the same number of slots every time. This 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 is defined, choose an event of sending a jam on the channel for the slot duration. The 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. The aim is to have one remaining station at the end of contention to provide it with access to the medium.

There are two methods for finding the parameters. The parameters are the number of slots in a contention and the probability corresponding to every slot. The first method aims at bounding the collision rate. The smallest number of slots and the corresponding probability vector are found so that the collision rate is bounded by a given value. It uses an algorithmic approach and finds the parameters with a low computation time. The second method uses an optimization approach to find the parameters that maximize the throughput. While this method requires a larger computation time, we only need to find the parameters offline and make them known to the stations. Thus, during the data transmission, this method doesn't need to operate; instead the parameters that it has produced are readily used.

An analysis that characterizes the throughputs of CONTI and DCF are made and compared. Analytically the effect of the slot duration on the performance achieved by CONTI is also done. In the simulation results, comparison of CONTI and DCF is done. Results on the number of slots used in the contention resolution, the collision rate, and the throughput are obtained. From the results it is shown that CONTI achieves the highest throughput among the schemes.

3.1 Methodology

CONTI resolves the contention of n stations 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 si, a station chooses signal 1 with probability pi or signal 0 with probability 1 - pi. During a contention slot, the station will transmit a pulse on the channel if it has signal 1. The station will listen to the channel. The pulse that is transmitted doesn't need to contain information. 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 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.

It is better to eliminate the largest number of stations possible during a contention slot. This means that the contention resolution is occurring quickly and the amount of time spent on contention resolution is minimized. Before slot si, there are ri-1 stations. At the end of slot si, there are ri stations that are remaining in the contention. Thus, slot si has eliminated stations from the contention, which we seek to maximize [1].A retire state variable is used in the algorithm to indicate whether the station transmits or not. If retire is 1 it indicates that the station has been preempted and if retire is 0 it indicates that the station is in contention. The function defer(t) indicates that the station is idle for t time. The function pulse(t) indicates that the station transmits a pulse in the time duration t and the function pulseDetect(t) indicates that the stations detect if there is any pulse on the channel [1].

4. Results and Discussions

In this section, we will present simulation environment used to evaluate our scheme and then present our experimental results. Here we compare the performances of CONTI and DCF. Simulation is carried out in NS2 under LINUX (FEDORA) platform for analyzing the average number of claims, packet lost, and end to end delays. The following table shows that the important parameters chosen for the NS2 simulation. We used 200 nodes placed in a square area of 1000m×1000m.AODV was used as the routing protocol. Simulation was performed for 100s. Each node moves with a minimum speed of 20m/s.

4.1 Parameters

In this scheme, evaluation is done in terms of several parameters. Parameters like collision rate, throughput and delay are considered. The performance comparison of CONTI and DCF are done based on these parameters.

i. Collision Rate

An analysis is done to find the optimal parameters of CONTI based on a bounded collision rate. This section has the following contents. First, the definition of optimal solution is presented and then the algorithmic concepts used to get the parameters are shown. Then, the collision rate is found analytically, which will be used to find the parameters. Then, k(number of slots) and p(probability vector) are found for a given number of stations, n. The optimal solution with CONTI can be defined in more than one way. To minimize the collision rate, say to make it equal to zero, the number of slots must be too large. On the other hand, if small number of slots is used to avoid wasting time in the contention, it ends up with a large collision rate that adversely affects the throughput. Thus, a trade-off is needed between these two factors. Optimal solution is based on the idea that it can tolerate a small collision rate. Then, minimum number of slots and the corresponding probabilities are found such that the collision rate is bounded. The minimum value of k and a probability vector p should be found such that the collision rate p coll is bounded by a value given in p*coll.

Let the term $\sigma(n,k,p)$ be the probability that the instance of CONTI, *S(k,p)*, resolves the contention successfully for n stations. The probability that scheme *S(k,p)* resolves the contention successfully for n stations is given by:[1]

$$\sigma(n,k,p) = \sum_{i=0}^{n-1} \quad [\tau_{n,n-i}(p_1).\sigma(n-i,k-1,\pi_2)]$$

ii. Throughput

The optimal parameters for CONTI, k and p that maximize the throughput are found. The time utilization of CONTI, designated by ρ, is found as the following

$$\frac{p_s.t_{data}}{p_s T_{successful} + p_c T_{collision}}$$

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

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

$$T_{collision} = T_{difs} + \text{k}.\,T_{slot} + t_{data}$$

iii. Delay

In this part evaluation of the delay of the schemes is done. The delay is defined as the time spent from when the frame arrives at the station’s head of the queue to the time where it’s transmitted successfully. The number of stations and the frame size are varied and the results are shown. When there are more stations, DCF’s delay rises significantly. CONTI has a small advantage in the delay values over the other schemes.

Simulation Time	100s
Topology Size	1000m x 1000m
Number Of Nodes	200
MAC Type	MAC 802.11
Radio Propagation Model	Free space Model
PLCP data rate	1Mbps
CW min	13
CW max	1023
Frequency	914MHz
Initial Energy	100J
Antenna type	Omni directional
Max no. of packets in queue	250
Traffic Type	CBR
Routing protocol	AODV
Slot time	20μs
SIFS	10μs
DIFS	50μs

Table 1: Parameter Values used in simulation Experiment

5. Simulation Results

The simulation results are presented in this section. We compare CONTI and DCF based on the parameters like collision rate, delay and Throughput.

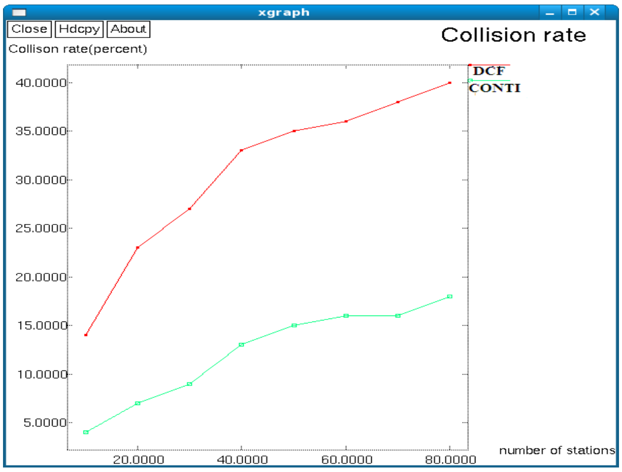

Figure 1: Plot of Collision Rate versus Number of Stations

Here the number of stations are varied from 20 to 80 and the collision rate of CONTI and DCF are plotted. It can be seen that CONTI has low collision rate than DCF.

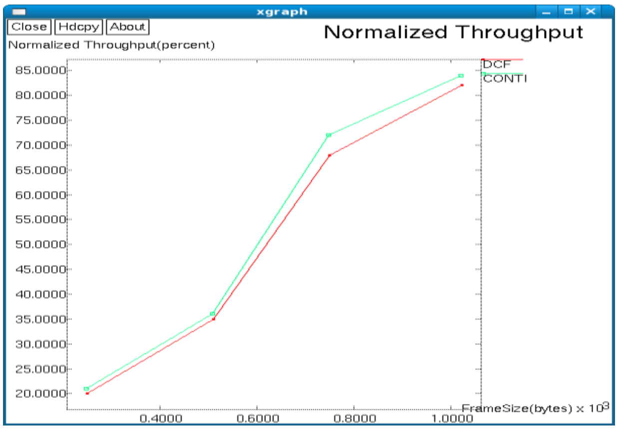

Figure 2: Plot of Normalized Throughput versus Frame Size

The plot shows normalized throughput on y axis and frame size in bytes on x axis. For the given frame size CONTI has higher throughput than DCF.

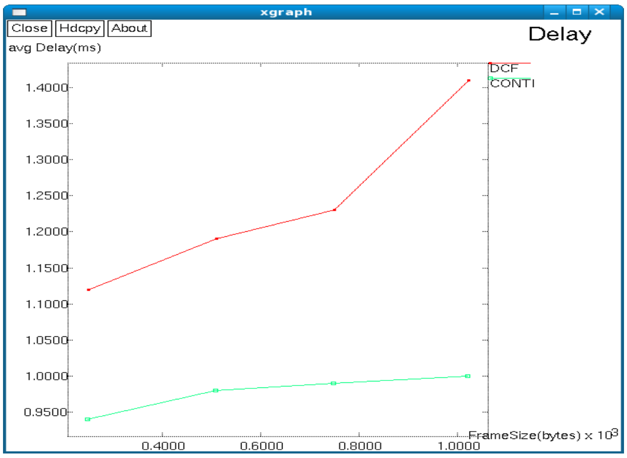

Figure 3: Plot of Average Delay versus Frame Size

Here the average delay is plotted for both CONTI and DCF. From the graph it is clear that CONTI has less delay than DCF and hence it has better performance.

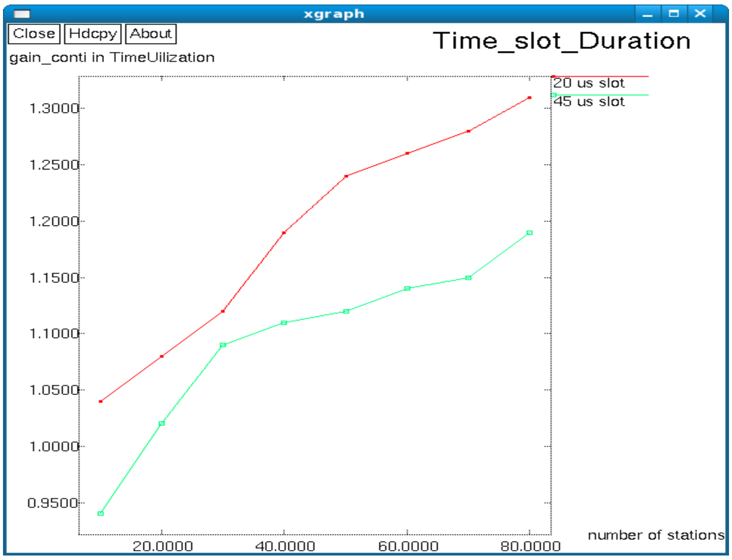

Figure 4: Plot of Gain in Time Utilization and Number of Stations

Time slot durations of 20 and 45 μs are considered. It can be seen that gain is higher for less number of time slots. Less number of time slots are preferred for better performance.

6. Related Works

Numerous MAC schemes are discussed here in this related works. Mainly two types of schemes are discussed: The contention window-based scheme (ex: idle sense) and the jamming-based scheme (PREMA and k-EC). The scheme Prioritized Repeated Eliminations Multiple Access (PREMA) was proposed by G.Wikstrand, T.Nilson and M.Dougherty [9]. PREMA is a jamming-based scheme. The scheme k-Round Elimination Contention (k-EC) was proposed in the paper by B. Zhou, A. Marshall, and T.-H. Lee [10] which, like PREMA, is a jamming-based scheme. It also has several rounds of eliminations in a contention. There are k rounds of elimination, where k is a parameter. The scheme Idle Sense was originally proposed by M. Heusse, F. Rousseau, R. Guillier, and A. Duda [12], and then it was revised by Y. Grunenberger, M. Heusse, F. Rousseau, and A. Duda [13]. Unlike PREMA and k-EC, Idle Sense is based on the contention window (CW) mechanism, like the standard's DCF scheme. The main idea of Idle Sense is observing that there is an optimal number of slots between two consecutive transmissions. In the paper proposed by N.H. Vaidya, P. Bahl [6], the objective is to develop a fully distributed algorithm for scheduling packet transmissions such that different flows are allocated bandwidth in proportion of their weights. It proposes a Distributed Fair Scheduling (DFS) approach obtained by modifying the Distributed Coordination Function (DCF) in IEEE 802.11 standard. The similarities between DFS and DCF would make it easier to incorporate DFS in a modified version of 802.11. In the paper by J.L.Sobrinho and A.S.Krishnakumar [8]. the scheme can be overlaid on current CSMA implementations, notably those that comply with the IEEE 802.11 standard, without requiring changes to the access procedures of data nodes. Real-time nodes contend for access to the channel by sending pulses of energy, the durations of which are a direct function of the delay they experienced until the channel became idle. In the paper by H.Wu, A.Utgikar and N.Tzeng [14] discussed one of the most important functions in 802.11e is the contention-based channel access medium called enhanced distribution Coordination Function (EDCF). It provides a priority scheme by differentiating the interframe space and the initial window size. They provided an analytical model to evaluate the EDCF priority scheme. They showed that differentiating the initial window size is better than differentiating the interframe space in terms of total throughput and delay. The Contention-Based channel access mechanism called enhanced distributed coordination function (EDCF) is evaluated in comparison with the 802.11 legacy MAC.

7. Conclusion

In this paper, CONTI is compared with DCF based on the parameters like collision rate, throughput and delay. CONTI attempts to resolve contention in constant number of time slots. The details of CONTI were studied and obtained its parameters in two ways, algorithmic and optimization approach. Finally in the simulation results, performance of CONTI and DCF were compared and shown that CONTI has low collision rate, low delay and high throughput. Thus from the graphical results its shown that CONTI has better performance.

8. Future Work

This paper proposes further research into more techniques to minimize the collision rate and delay. Sequencing technique by using VBA algorithm can enhance the performance further.

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