ISSN : 0256-4602

The Institution of Electronics and Telecommunication Engineers

सह वीर्यं करवावहै

IETE Technical Review

Volume 29 • No. 3 • May-Jun 2012

www.ietejournals.org

A Novel Contention Window Control Scheme for IEEE 802.11 WLANs

Ali Balador, Ali Movaghar[1], Sam Jabbehdari[2] and Dimitris Kanellopoulos[3]

Department of Information and Communication Technologies, Universitat Pompeu Fabra, Barcelona, Spain, [1]Department of Electrical and Computer Engineering, Sharif University of Technology, Tehran, Iran, [2]Department of Computer Engineering, North Tehran Branch, Islamic Azad University, Tehran, Iran, [3]Department of Mathematics, University of Patras, Greece

Abstract

In the IEEE 802.11 standard, network nodes experiencing collisions on the shared medium need a mechanism that can prevent collisions and improve the throughput. Furthermore, a backoff mechanism is used that uniformly selects a random period of time from the *contention window* (*cw*) that is dynamically controlled by the *Binary Exponential Backoff* (BEB) algorithm. Prior research has proved that the BEB scheme suffers from a fairness problem and low throughput, especially under high traffic load. In this paper, we present a new backoff control mechanism that is used with the IEEE 802.11 distributed coordination function (DCF). In particular, we propose a dynamic, deterministic contention window control (DDCWC) scheme, in which the backoff range is divided into several small backoff sub-ranges. In the proposed scheme, several network levels are introduced, based on an introduced channel state vector that keeps network history. After successful transmissions and collisions, network nodes change their *cw* based on their network levels. Our extensive simulation studies show that the DDCWC scheme outperforms four other well-known schemes: Multiplicative Increase and Linear Decrease, Double Increment Double Decrement, Exponential Increase Exponential Decrease, and Linear/Multiplicative Increase and Linear Decrease. Moreover, the proposed scheme, compared with the IEEE 802.11 DCF, gives 30.77% improvement in packet delivery ratio, 31.76% in delay, and 30.81% in throughput.

Keywords

Backoff algorithm, Contention window, IEEE 802.11, MAC layer, Wireless ad-hoc network.

1. Introduction

Nowadays, people and businesses use wireless networks to send and share data quickly whether it be in a small office building, campus, hospital, or airport. The use of wireless LANs (WLANs) is a low-cost way to be connected to the Internet in regions where the telecom infrastructure is poor, as in most developing countries. From another perspective, the decentralized nature of wireless ad-hoc Networks[#] makes them suitable for a variety of applications where central nodes cannot be relied on. It is noteworthy that wireless nodes can cooperate in order to share their antennas and other resources. As a result, they can create a virtual array through distributed transmission and signal processing. This increases coverage and reduces transmitted power, thereby bringing down co-channel interference, which results in increased system capacity. Katiyar *et al.* [1] present the state of art of various cooperation schemes and issues related to their implementation.

From another perspective, mobility management techniques between heterogeneous networks are necessary to reduce latency time and efficiently treat the insufficient radio access resources to indemnity-specific quality of service. Hamza *et al.* [2] investigated various handover management technologies that minimize a vertical handover in heterogeneous wireless networks. Such technologies provide pure mobility between different access techniques such as GPRS, UMTS, and WI-FI. More of these solutions used mobile IP, transmission control protocol, stream control transmission protocol, and session initiation protocol to support integration between WLAN and UMTS.

The efficiency of wireless channel access is a critical issue because the bandwidth of a wireless network is limited and the channel is shared among network's nodes (i.e., each node competes with other nodes having packets to transmit). Besides, a wireless channel is error prone,

---

[#] Wireless ad-hoc networks are decentralized networks that do not rely on a preexisting infrastructure, such as access points in managed wireless networks. Instead, each node participates in routing by forwarding data for other nodes, and so the determination of which nodes forward data is made dynamically based on the network connectivity thus packets may be corrupted in the channel because of transmission errors such as channel poise, path loss, fading, and interference. Among the others, the following two important problems must be tackled in wireless networks:

(1) The "hidden node" problem: As illustrated in Figure 1, the node B is within the range of nodes A and C, but nodes A and C are not in each other's range. When node A is not aware that node B is currently busy receiving from node C, and therefore may start its own transmission, causing a collision. This is referred to as the "hidden node" problem.

(2) The "exposed node" problem: This problem occurs when a node is prevented from sending packets to other nodes due to a neighboring transmitter [Figure 2]. For example, node C wants to transmit to node D but mistakenly thinks that this will interfere with B's transmission to A, so C refrains from transmitting. The "exposed node" problem leads to loss of efficiency.

To overcome these problems, medium access control (MAC) schemes are designed. IEEE 802.11 [3] is the dominant technology used in WLANs that provides a detailed MAC and physical layer (PHY) specification for WLANs**.** The main responsibility of MAC layer protocols is providing fairness among the nodes. In the IEEE 802.11 MAC layer, the essential access scheme works as a distributed coordination function (DCF). The IEEE 802.11 DCF is used for wireless ad-hoc networks and is based on the carrier sense multiple access with collision avoidance (CSMA/CA) technique. CSMA/CA is a popular MAC scheme that uses a combination of the CSMA and medium access with collision avoidance schemes. However, CSMA/CA has been developed for wired networks and has weaknesses in wireless networks [4]. In CSMA schemes, the transmitting nodes first sense the medium to check whether it is idle or busy. The node transmits its own packets, while continuing to check the medium. In contrast, the node defers its own transmission, when the medium is busy. CSMA schemes use these routines to prevent a collision with other competing nodes. However, collisions occur at receiving nodes. When this happens, the nodes involved must re-enter the competition cycle with an exponentially increasing backoff parameter value decided by the Binary Exponential Backoff (BEB) algorithm.

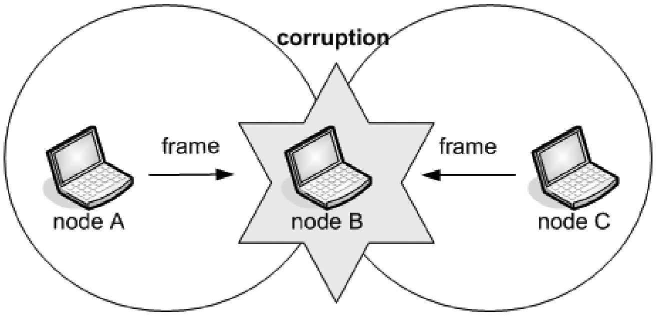

Figure 1: The hidden node problem.

BEB algorithm is used to space out repeated retransmissions of the same block of data, often as part of network congestion avoidance. It is clear that the BEB algorithm determines the performance of the WLAN system. CSMA/CA provides a mechanism that increases the backoff parameter value after collision in order to make the access control adaptive to channel conditions. In the BEB algorithm, the size of the contention window (*cw*) is reset to the initial value (CW_{min}) when transmission is successful and is doubled when transmission fails. The node selects a backoff counter from [0, $cw - 1$] and transmits its packets, if the backoff number has counted down to zero. Many analytical models have been proposed in the literature for WLAN performance evaluation.

In earlier research [5-14], more than a few controlling schemes for the BEB algorithm have been proposed to improve the performance of wireless networks, focusing on issues such as efficiency, fairness, delay, and so on. These schemes aim to adapt the *cw* to an estimation of the system load based on the transmission status.

In this paper, we propose a dynamic, deterministic contention window control (DDCWC) scheme, which can achieve high-throughput performances while keeping the implementation simplicity required in ad-hoc networks. In the proposed scheme, each node changes the

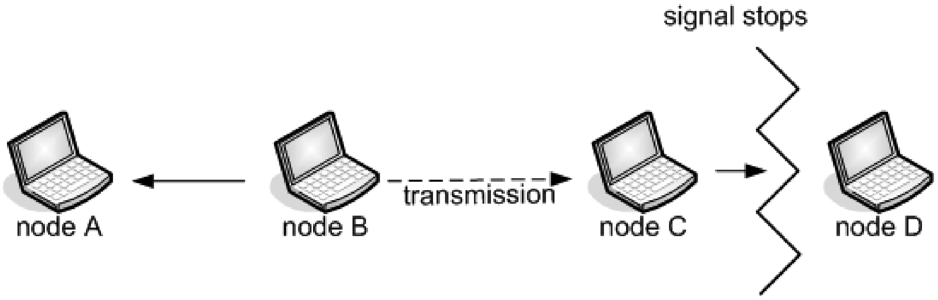

Figure 2: The "exposed node" problem.

cw size upon successful packet transmission and collision with detecting a start of busy period for all active nodes based on network condition. Extensive simulation studies for throughput, end-to-end delay, and packet delivery ratio (PDR) demonstrate that the new mechanism reaches significant results compared with that for the IEEE 802.11 DCF. Moreover, extra simulations show that the proposed scheme gives the best results such as throughput, delay, and PDR in comparison with four similar schemes: Multiplicative Increase and Linear Decrease (MILD), Double Increment Double Decrement (DIDD), Exponential Increase Exponential Decrease (EIED), and Linear/Multiplicative Increase and Linear Decrease (LMILD).

The remainder of the paper is organized as follows. Section 2 describes the DCF function and categorizes as well as analyzes related work. Section 3 describes the proposed scheme for controlling the value of *cw*. Section 4 presents and analyzes the simulation results in comparison with four similar schemes: MILD, DIDD, EIED, and LMILD. Finally, Section 5 concludes the paper and discusses directions for further work.

2. Preliminaries

This paper proposes a new algorithm/scheme and related background work is necessary.

2.1 IEEE 802.11 DCF Access Method

The IEEE 802.11 standard supports the DCF as a default, while the point coordination function‡ (PCF) is used optionally [3]. IEEE 802.11 DCF is the most widely used CSMA/CA access control mechanism. The IEEE 802.11 uses the Request-to-Send (RTS)/Clear-to-Send (CTS) mechanism in order to reserve the medium before transmitting the packet. The IEEE 802.11 protocol uses the RTS/CTS-DATA-ACK sequence for data transmission. In addition to physical carrier sensing, it also supports the virtual one. This is implemented in the form of a Network Allocation Vector (NAV), which is maintained by every node. The NAV indicates the amount of time that must elapse until the current transmission is complete and the medium can be checked again for idle status.

The IEEE 802.11 DCF controls priority access to the wireless channel through the use of Inter Frame Space (IFS) time intervals between the transmissions of frames. The IEEE 802.11 DCF specifies four IFS intervals, which are used to provide different priorities:

- Short IFS (SIFS) time intervals that have the highest priority access to the channel and are used for control packets
- Distributed coordination function IFS (DIFS) time intervals, which are used in the basic access method in IEEE 802.11 DCF
- Point coordination function IFS time intervals which are used in the IEEE 802.11 PCF mode
- Extended IFS (EIFS) time intervals. EIFS is a longer IFS used by a station that has received a packet that could not understand. This is needed to prevent the station from colliding with a figure packet belonging to the current dialog.

Figure 3 shows the different inter frame space (IFS) time intervals.

According to IEEE 802.11 DCF, each node that has a data packet for transmission sends a RTS packet and waits in order to receive a CTS packet. Receiving a CTS packet means that the receiver is ready to receive a data packet. Transmitter must wait a SIFS time interval after receiving the CTS packet and then begins to send its own data packets. Before each node is allowed to transmit a RTS packet to start communication, the nodes should listen to the channel. If the channel is found as being idle for a time interval longer than DIFS, then the BEB algorithm is started. The BEB algorithm uniformly selects the backoff time in the interval (0, CW). First of all, DCF sets *cw* with the predefined value CW_{min}. In other times, *cw* is doubled with transmission failure up to another predefined value CW_{max}. When it reaches to CW_{max}, it keeps its value with subsequent failures.

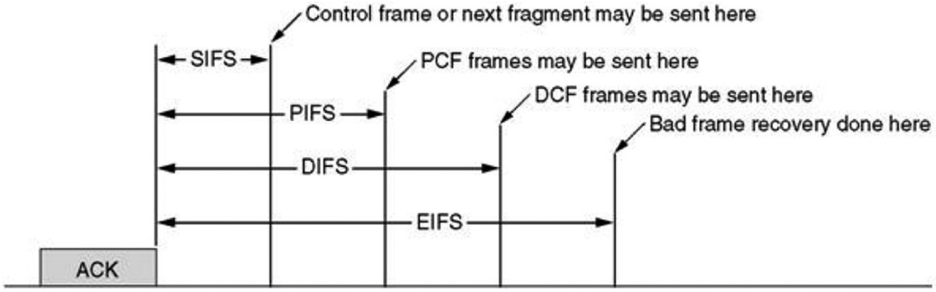

Figure 3: Inter Frame Space (IFS) time intervals [15].

---

‡PCF is used for managed (infrastructure) wireless networks and is located directly above the DCF in the IEEE 802.11 MAC architecture.

The BEB algorithm rapidly decreases the *cw* value to CW_{min} as a result of one successful transmission. In particular, it is important to not reset the *cw* at its initial value after each successful transmission in order to prevent collision. When the backoff timer is decreased by 1, the node senses the channel. When the channel is sensed busy, the backoff controller pauses the timer. At this time, another two nodes timer becomes zero and initiates the data transmission. The backoff timer is resumed when the channel is sensed idle again for more than DIFS. Figure 4 shows the IEEE 802.11 DCF mechanism. DCF also provides the RTS/CTS reservation scheme for transmitting data packets. This scheme uses small RTS/CTS packets to reserve the medium before large packets are transmitted in order to reduce the duration of a collision. Moreover, the RTS/CTS reservation scheme improves the hidden station problem.

Each node has one antenna and when it sends data packets, it cannot listen to the channel. After sending a data packet, the transmitter listens to the channel in order to receive a positive acknowledgement (ACK) from the receiver. After receiving correct data packet by the receiver, the receiver waits for SIFS time. Then, it transmits an ACK packet to the transmitter. If the transmitter receives the ACK packet correctly, then it resets the *cw* value to its initiate value and drops the data packet. Otherwise, the sender finds it as a collision and increases the *cw* value and attempts to retransmit up to a predefined value (transmission attempt limit).

The IEEE 802.11 DCF resolves collision through different *cw*s and backoff values. In the initial backoff level, the value of *cw* has the minimal value CW_{min}. After each collision, the *cw* will be doubled until reaching the maximum CW_{min} [Figure 5].

After each successful transmission, the backoff and *cw* will reset to the initial level regardless the history of network condition or number of active nodes. It is emphasized that fast reduction of *cw* entails high collision rate in a large number of nodes, which leads to significant reduction of the network performance.

2.2 Related Work

A lot of research has been conducted on improving the performance of the IEEE 802.11 DCF by modifying the value of the *cw*. Actually, many researchers focus on introducing new mechanisms/methods for decreasing the value of the *cw* better than the BEB algorithm. These methods can be categorized into four groups.

- The methods of the first group decrease the *cw* value with static scale, when a successful transmission occurs. An important factor of these methods is the lowest overhead. Such methods decrease the *cw* value with a static scale and do not pay attention to the network load. MILD [5], DIDD [16-18], EIED [19,20], and LMILD [21,22] belong to this group. As we have pointed out, the BEB scheme suffers from fairness issues under high traffic load and low-throughput problems when the network size becomes large. The MILD algorithm was introduced to eliminate this problem in the BEB scheme. The MILD scheme increases the *cw* value by multiplying by 1.5 and decreases the *cw* by one unit. The MILD algorithm is conservative, and as a result, it has low throughput when the network load is small. However, MILD works better than BEB algorithm when the network load becomes large
- The second group contains methods which introduce Markov models to evaluate the performance of IEEE 802.11 DCF. Such methods propose mechanisms to tune the *cw* size based on the estimated number of nodes by observing the channel status. The methods proposed in [7,23-28] are involved in this group. In such cases, estimation of the number of nodes (or active nodes) requires the channel status information. It is obvious that these methods need complex computations that lead to high power consumption. Unfortunately, high power consumption is undesirable in wireless ad-hoc networks
- The third group contains methods that modify both upper and lower bounds of the backoff range unlike DCF that increases only the upper bound with each collision. In addition, in these algorithms, the

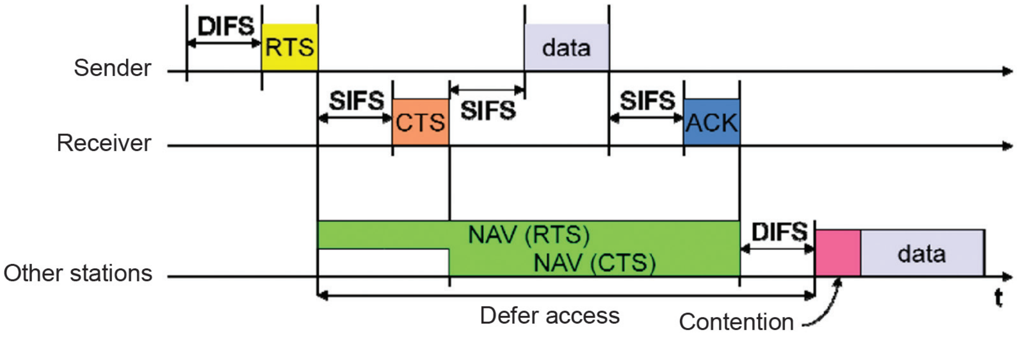

Figure 4: The IEEE 802.11 DCF mechanism.

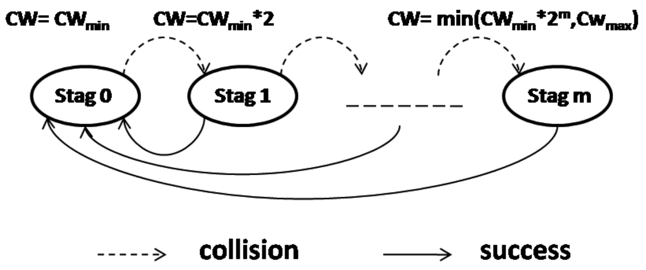

Figure 5: The IEEE 802.11 DCF scheme diagram.

backoff range is divided into several small ranges. Methods presented in [29,30] are involved in this group

- The methods of the fourth group contain algorithms that increase the *cw* value in any node overhearing a collision. Such algorithms are FCR [31] and LMILD [32].

Lin *et al.* [33] proposed a backoff mechanism called *Exponential Linear Backoff Algorithm* (ELBA) to improve system performance over contention-based wireless networks. In the ELBA, the variation of *cw* size is combined both exponentially and linearly, depending on the network load, as indicated by the number of consecutive collisions. In the ELBA scheme, a threshold is set to determine the network load. If the *cw* size is smaller than the threshold, a light network load, the *cw* is tuned exponentially. Conversely, if the *cw* size is larger than the threshold, a heavy network load, the *cw* size is tuned linearly. The numerical results show that the ELBA provides a better system throughput and collision rate in both light and heavy network loads than the related backoff schemes, including BEB, EIED, and linear increase linear decrease.

From another perspective, Ekici and Yongacoglu [34] investigated the fairness behavior and throughput performance of IEEE 802.11 DCF in the presence of hidden nodes. In particular, they developed a mathematical model, which accurately predicts a user's throughput performance and packet collision probability in non-saturated traffic and asymmetric hidden node environments. Their model allows us to see many interesting results in networks with hidden nodes.

The protocol proposed by Wang and Song [35] uses the NAV information carried in the RTS and CTS packets, in which the sender explicitly indicates the length of time that it will be using the channel for transmission. Therefore, all nodes are capable of updating the NAV based on the RTS and CTS packets from their neighbors and determining the minimum amount of time for which they should defer their access to the channel. Wang and Song [35] believe that NAV is a good indicator of the surrounding traffic, and therefore they use NAV count to approximate the surrounding traffic and the impact of interference suffered by a node. In addition, Li *et al.* [36] introduced the NAV count in routing protocol to approximate the intensity of surrounding traffic of nodes. The algorithm is improved, as the *cw*s of backoff mechanism are adjusted reasonably according to the traffic of WLAN.

Zhang *et a*l. [37] propose a dynamic priority backoff algorithm (DPBA) for IEEE 802.11 DCF. In the DPBA framework, each node collects statistical data of other node's transmission while sensing the channel, and maintaining a sending data table for all nodes in network. When the node has data to transmit, it calculates the dynamic priority and connection window according to the number of successful sending, the number of successful sending, and the statistical data in sending table.

Cui and Wei [38] present the adaptive efficiency-fairness tradeoff (AEFT) backoff algorithm, which provides not only a higher throughput and a larger fairness index, but also a tradeoff between efficiency and fairness, a simple framework for ad-hoc networks with heterogeneous stations. AEFT increases the *cw* when the channel is busy, and uses an adaptive window to fast decrease the backoff time when the channel is idle by fair scheduling. The fair scheduling mainly adopts maximum successive transmission and collision limit to finish the fairness. This scheme can achieve improved total throughput compared with 802.11 and other proposed MAC protocols such as FS-FCR (this algorithm is similar to FS-FCR) and also obtains almost the same chance to access the shared channel.

Finally, the algorithm proposed in [39] (known as pause count backoff [PCB] algorithm) observes the number of backoff counter pauses during the channel access contention and sets the appropriate *cw*, based on the estimated results.

3. The Proposed Contention Window Control Scheme

As we already mentioned, in the IEEE 802.11 DCF, fast reduction of *cw* entails high collision rate in a large number of stations, which leads to significant reduction of the network performance. To tackle these issues, we propose the following three mechanisms:

- First, we divide the overall backoff range [0, CW_{max}] into several small ranges. Each backoff sub-range is then related to a particular collision resolution level
- Second, in contrast to IEEE 802.11 DCF, we increase upper and lower bounds of the backoff range. The IEEE 802.11 DCF increases only the upper bound ranges with each collision
- Third, we propose a novel backoff mechanism in

which the history of network condition is taken into account for optimization of the *cw* size.

It is noteworthy that the proposed *cw* control scheme does not take into account collisions occurred during the transmission of control packets like RST and CTS.

3.1 The Channel State Vector

In the proposed *cw* control scheme, the channel condition is checked regularly and the result is stored to a Channel State (CS) vector. The CS vector plays an important role in our scheme as it shows the network condition in three-element array that is updated upon each transmission trial. The channel state is monitored by invoking the function: is_idle(). If the function is_idle() returns zero, it means that the channel is busy, and when it returns one, it means that the channel is free. When the new channel state is stored, the oldest one in the CS array is removed and the remaining stored states are shifted to the left.

The selection of the length of the channel state vector is a challenging design decision. For example, if we choose a longer vector (array), it will have a large overhead. On the contrary, if we choose a smaller vector (array), it will not be able to show the network condition. Based on our simulation experiences, we chose a three-element CS array.

3.2 Dynamic Backoff Range

We split the global range [CW_{min}, CW_{max}] into different ranges where each range relates to a contention level. In addition, the size of the backoff range changes based on the CS vector/array. The range size is basically selected through each channel state. For instance, assuming that a busy state occurs at the stage 110, it is obvious that the range size of the level does not perfectly suit the current competing nodes. As a result, we change the size of its range. Figure 6 illustrates the new method, where the backoff timer is randomly selected from the range that is limited by CW_{lb} and CW_{ub} (rather than 0, *CW*). But, we do not choose a determinist backoff range. In DDCWC, the backoff range changes based on the channel status**.**

As it is depicted in Figure 6, we have a transition from the stage 000 to the stage 001, if we have a successful transmission (no collisions). At the same time, the DDCDW estimates for the new stage 001 the new *cw* size by calculating the upper and lower *cw* (i.e., CWu=CWu*0.57 and CWl=CWu-32) according to the Table 1. Now, if collisions occur, then we have a transition from the stage 001 to the stage 010. In this case, the DDCDW estimates the new *cw* size (i.e., CWu=CWu*1.72 and CWl=CWu-64) for the new stage 010 according to the Table 1. Otherwise, if no collisions occur, we have a transition from the stage 001 to the stage 011. The above-described logic is applied at all transitions shown in the DDCWC scheme diagram.

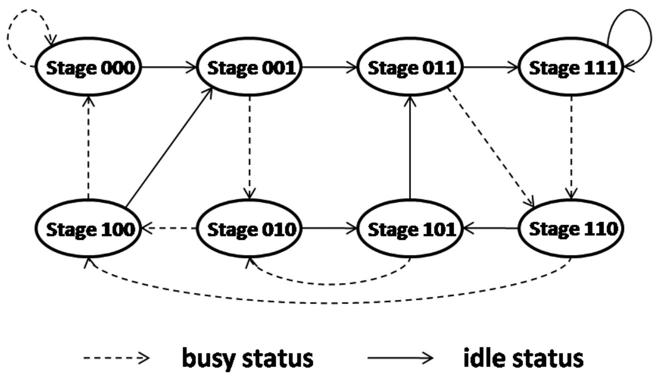

Figure 6: The DDCWC scheme diagram.

Table 1: The algorithm that estimates contention window in DDCWC

Status	CW range
000	CWu=CWu*2.09 CWl=CWu-96
001	CWu=CWu*0.57 CWl=CWu-32
010	CWu=CWu*1.72 CWl=CWu-64
011	CWu=CWu*1.72 CWl=0
100	CWu=CWu*2.09 CWl=CWu-64
101	CWu=CWu*0.57 CWl=CWu-32
110	CWu=CWu*1.72 CWl=CWu-32
111	CWu=CWu*1.72 CWl=0

DDCWC – Deterministic contention window control; CW – Contention window

3.3 Changing the Backoff Range

The CS array is initialized with the value 111. We choose CW_l, CW_u at the starting level 0 and CW_{min}, respectively. After each transmission trial, the boundaries and the size of the range are updated by following the Table 1, respectively. These window sizes [Table 1] were chosen by performing eight repetitive simulations and modifications of the DDCWC scheme.

We obtain a different range that may overlap the precedent range.

The node checks the function is_idle() when it has a new packet for transmission. If the channel is sensed idle, the CS array will be set to one, change the backoff range, and starts its defer timer with DIFS. Otherwise, we put zero in the CS array, change the backoff range, and wait for the channel to become idle.

After DIFS time, the channel is sensed again. The same procedure is followed similar to the one we have already mentioned. If the channel is found idle again, the node transmits.

In each level, CW_{lb} and CW_{ub} are reached based on Equations (1) and (2).

$$CW_{ub}(i) = CW_{ub}(i-1)*Z \quad (1)$$

$$CW_{lb}(i) = CW_{ub}(i)–size \quad (2)$$

In Equations (1) and (2), 'i' indicates the contention levels of network that can be 1 to 8 because the CS array has three elements in our scheme. 'Z' is a specific number in our scheme. Setting value for z is very challenging and needs more attention. Finally, 'size' is the size of range that was mentioned before. The difference between DDCWC and IEEE 802.11 DCF can be seen in Figures 5 and 6. Figure 7 shows the operation of the proposed algorithm.

4. Performance Evaluation

4.1 Simulation Setup

In this section, we study the performance of the DDCWC in comparison with IEEE 802.11 DCF by using the NS-2 (version 2.28) network simulator [40]. NS is a discrete event simulator targeted at networking research. NS-2 provides substantial support for simulation of IEEE 802.11 standard, routing, and multicast protocols over wireless (local and satellite) networks.

Our simulations are based on a 1000 by 1000 m flat space and 50 wireless nodes. The simulation time was set up to 600 seconds. Each node generates constant bit rate traffic. The size of data payload is 512 bytes and each node generates data packet at the rate of 4 packets per second. The propagation range for each node is 250 m and channel capacity is 2 Mb/s. We utilized random waypoint model as the mobility model. The minimum speed for the simulation is 0 m/s while the maximum speed is 20 m/s. Pause time is selected at 50 seconds. Table 2 summarizes the simulation parameters. The simulation parameters for the other compared schemes (MILD, DIDD, EIED, and LMILD) have the same values.

The metrics used for evaluating the performance of the proposed scheme are the following ones:

- Packet Delivery Ratio (PDR): It represents the ratio between the number of packets, originated by the application layer source and the packets received by the final destination
- Average end-to-end delay: It calculates the average time required to receive the packet
- Average throughput: It is the amount of data successfully received in a given time period that it is measured in Kilo bits per sec (Kbps).

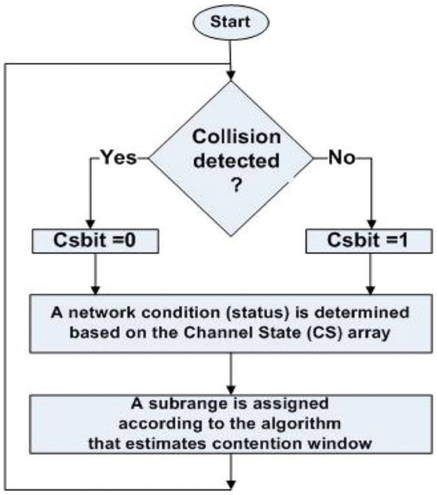

Figure 7: The operation of the proposed contention window scheme.

Table 2: The simulation parameters

Simulation parameter	Value
Propagation model	Two ray ground
Antenna	Omni antenna
Medium access control protocol	IEEE 802.11
Routing protocol	DSR
Number of nodes	50
Simulation time	600 sec
Simulation environment	1000*1000
Transmission range	250 m
Channel capacity	2 Mb/s
CBR packet size	512 byte
CBR data rate	4 packet/s
Cw_{min}	31
Cw_{max}	1023
Error rate	0.1 packet/s
Min speed for waypoint model	0 m/s
Max speed for waypoint model	20 m/s
Pause time for waypoint model	50 sec

CBR – Constant bit rate; CW – Contention window

4.2 Simulation Results

Figures 8-10 represent the PDR, average delay in seconds, and throughput, respectively, for the original and our new modified 802.11 MAC protocol with different number of connections. In these figures, we observe clearly that the PDR is improved. Totally, we obtain 30.77% improvement in PDR and 31.76% improvement in delay and 30.81% in throughput compared with IEEE 802.11. As it is depicted in Figure 8, the PDR is the same for the DDCWC and DCF schemes when we have 12 connections (a small number of connections).

For larger number of connections, the PDR for DDCWC scheme is larger than DCF. As we can see in Figure 9, the end-to-end delay (sec) is the same for the DDCWC and DCF schemes, when we have 12 connections. For larger number of connections, the end-to-end delay for DDCWC scheme is decreasing. As it is depicted in Figure 10, the throughput is the same for the DDCWC and DCF schemes when we have 12 connections. For larger number of connections, the throughput for DDCWC scheme is larger. It must be mentioned that for 25 connections, the throughput for DDCWC scheme is 140 Kbps (almost double of the DCF throughput: 85 Kbps).

Previously, we compared the new backoff control mechanism and IEEE 802.11 DCF. The proposed algorithm (DDCWC scheme) is very simple and similar (i.e., similar overhead or simplicity) to the algorithms MILD, DIDD, and EIED that belong to the group 1 (referred in Section 2.2). In addition, the LMILD algorithm (of the group 4) also increases the *cw* value in any node overhearing a collision. For these reasons, we selected these four algorithms (MILD, DIDD, EIED, and LMILD) and compared the proposed algorithm with them. It is noteworthy that various algorithms belonging to other groups (than groups 1 and 4) have more overheads such as battery overhead. Figure 11 compares the average end-to-end delay for the under comparison mechanisms. In Figure 11, we can find the effect of CW_{min} in average end-to-end delay. It is clear that when we increase the CW_{min}, it causes decrease in average end-to-end delay. Figure 11 shows that MILD scheme has the highest average end-to-end delay and DDCWC has the lowest result. First, we can find that MILD has the highest result because it decreases the backoff range by one unit. It means that it needs long time to adopt itself with network condition. Second, DIDD has better results than other methods except for DDCWC. This improvement in DIDD is related to gently and gradually *cw* decrease after a successful packet transmission. Finally, DDCWC has the best average end-to-end delay. Possibly, this is due to several interesting factors such as taking into account network condition and decreasing the *cw* value gradually.

In our method, we first pay attention to the network condition with storing it in CS array. Second, we do not reset *cw* value suddenly similar to IEEE 802.11 DCF. Unlike IEEE 802.11 DCF, the DDCWC changes the *cw* value based on the values of the CS array.

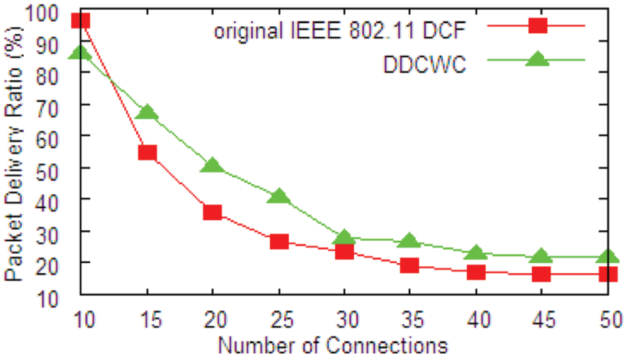

Figure 8: The packet delivery ratio (PDR).

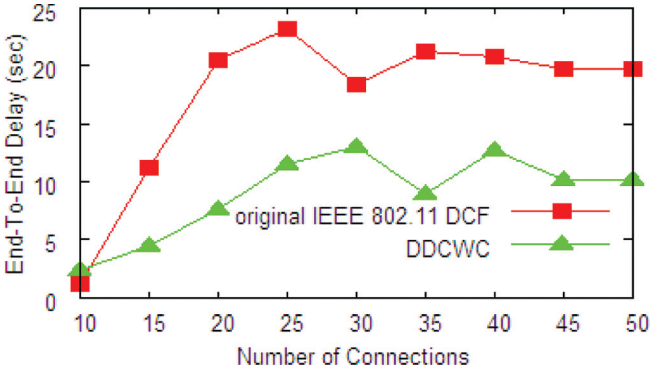

Figure 9: The average delay.

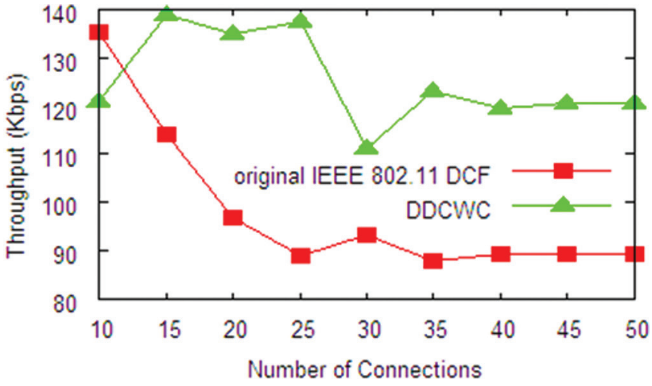

Figure 10: The throughput.

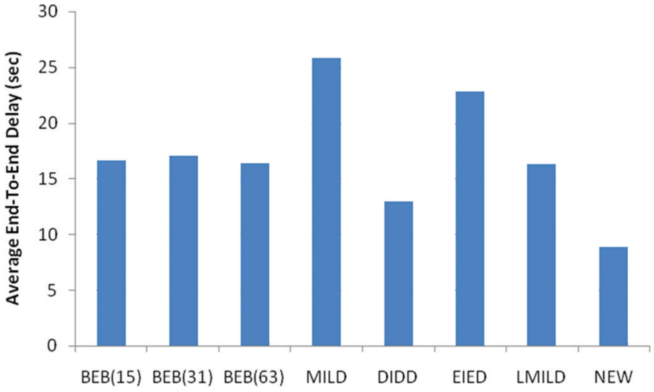

Figure 11: The average end-to-end delay.

In Figure 12, we give average PDR for different methods respectively. In Figure 12, we can find that if we increase the CW_{min} in BEB mechanism, it shows increase in average PDR. Other methods except for LMILD have better PDR than BEB mechanism. One possible explanation for better grades in the final simulation is to adopt our backoff range with network condition and divide the backoff range. As a result, the collision rate decreases in

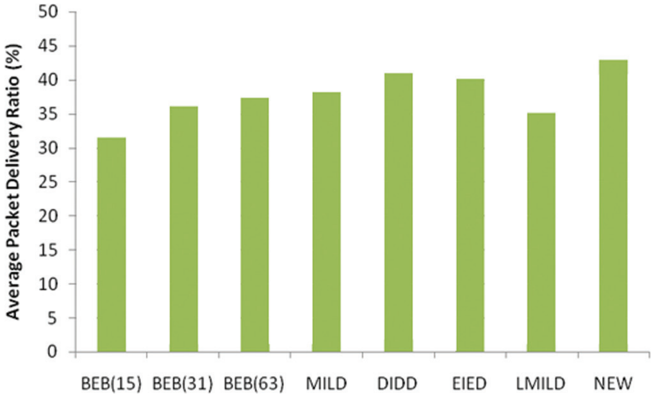

Figure 12: The average packet delivery ratio

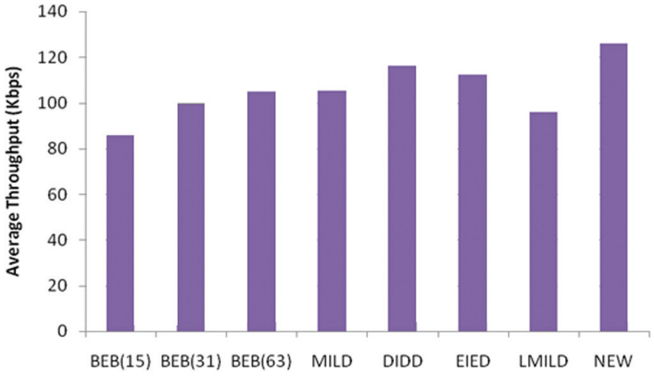

Figure 13: The average throughput.

DDCWC. As depicted in Figure 13, our method has the best average throughput. According to the result of the study that mentioned before, our new backoff control mechanism was significantly better than other known methods in the area.

The present study may be criticized in that we have not introduced Markov model in this scheme and the ‘z’ parameter needs to be designed carefully. DDCWC for adopting *cw* value with network condition was very interesting. We think it could be used in further studies but we should work on ‘z’ parameter.

5. Conclusions

In this paper, we presented a novel backoff control mechanism called “Dynamic Deterministic Contention Window Control” (DDCWC). The DDCWC scheme can achieve high-throughput performances while keeping the implementation simplicity required in wireless ad-hoc networks. In the new scheme, each node changes the *cw* size upon successful packet transmission and collision while detecting a start of busy period for all active nodes based on network condition. Other ideas we have introduced in our mechanism are dividing the backoff range into several small ranges and modifying the backoff range based on predefined network levels. These changes reduce the network collision, which contributes to the throughput improvement. Extensive simulation studies for throughput, end-to-end delay, and PDR that are conducted with the NS-2 network simulator have demonstrated that the proposed mechanism reaches significant results compared with those for the IEEE 802.11 DCF. In addition, extra simulations show that the proposed scheme gives the best results such as throughput, delay, and PDR in comparison with some other well-known methods mentioned before.

In the near future, we aim to develop an analytical model for the proposed *cw* control scheme under different conditions (status). It is noteworthy that the proposed scheme can be extended in order to choose optimum CW ranges, based on situations. In addition, the proposed scheme can be extended in order to take into account the length of packets. We can also differentiate between real-time and non real-time data flows (data or packet) and assign different Backoff value to any of them. Finally, the proposed scheme can be modified in order to overcome the effects of “misbehavior” nodes that do not obey determined policies.

References

1. H. Katiyar, B.S. Paul, and R. Bhattacharjee, “User Cooperation in TDMA Wireless System”, IETE Technical Review, vol. 25 no. 5, pp. 270-6, 2008.
2. B.J. Hamza, C.K. Ng, N.K. Noordin, M.F. Rasid, and A. Ismail, “Review of Minimizing a Vertical Handover in a Heterogeneous Wireless Network”, IETE Technical Review, vol. 27 no. 2, pp. 97-106, 2010.
3. ANSI/IEEE Standard 802.11, 1999 Edition, Information Technology, Telecommunications and Information Exchange Between Systems- Local and Metropolitan Area Networks, Specific Requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, 1999.
4. S. Kumar, V.S. Raghavan, and J. Deng, “Medium access control protocols for ad-hoc wireless networks: A survey,” Elsevier Ad-Hoc Networks, vol. 4 no 3, pp. 326-58, 2006.
5. V. Bharghavan, A. Demers, S. Shenker and L. Zhang, “MACAW: A media access protocol for wireless LAN’s”. In Proceedings of ACM SIGCOMM 1994, United Kingdom, pp. 212-25, 1994.
6. N. Song, B. Kwak, J. Song and L.E Miller, “Enhancement of IEEE 802.11 distributed coordination function with exponential increase exponential decrease backoff algorithm”. In Proceedings of IEEE VTC 2003, Jeju Island, Korea, pp. 2775-8, 2003,.
7. G. Bianchi, and I. Tinnirello, “Kalman filter estimation of the number of competing terminals in an IEEE 802.11 Network”. In Proceedings of INFOCOM 2003, vol. 2, San Francisco, CA, USA, pp. 844-52, 2003.
8. V. Vitsas, “Throughput analysis of linear backoff scheme in wireless LANs”. IEEE Electron. Lett. Vol. 39, pp.99-100, 2003.
9. P.M. Soni and A. Chockalingam, “Analysis of link-layer backoff schemes on point-to-point Markov fading links”, IEEE Trans. Commun. vol. 51, pp. 29-32, 2003.
10. C. Wang, B. Li, and L. Li, “A new collision resolution mechanism to enhance the performance of IEEE 802.11 DCF”, IEEE Trans. Veh. Technol. vol. 53, pp.1235-46, 2004.
11. Q. Pang, S.C. Law, J.Y. Lee, and V.C. Leuang, “Performance evaluation of an adaptive backoff scheme for WLAN”, Wirel. Commun. Mobile Comput. vol. 4, pp. 867-79, 2004.
12. A.L. Toledo, T. Vercauteren, and X. Wang, “Adaptive optimization

of IEEE 802.11 DCF based on Bayesian estimation of the number of competing terminals", IEEE Trans. Mobile Comput. vol. 5, pp. 1283-96, 2006.

13. J.S. Kim, E. Serpedin, and D.R Shin, "Improved particle filtering-based estimation of the number of competing stations in IEEE 802.11 network", IEEE Signal Process. Lett. vol.15, pp. 87-90, 2008.
14. H. Martin, R. Franck, G. Romaric, and D. Andrzej, "Idle sense: An optimal access method for high throughput and fairness in rate diverse wireless LANs". In Proceedings. SIGCOMM 2005, Philadelphia, PA, USA, pp. 121-32, 2005.
15. J. Schiller, Mobile Communications (2nd ed.) United States: Addison Wesley; ISBN 0-321-12381-6, 2003.
16. M. Natkaniec and A.R. Pach, "An analysis of the backoff mechanism used in IEEE 802.11 networks". In Proceedings of Fifth IEEE Symposium on Computers and Communications, Antibes-Juan les Pins, France, pp. 444-8, 2000.
17. H. Wu, S. Cheng, Y. Peng, K. Long, and J. Ma, "IEEE 802.11 distributed coordination function (DCF): analysis and enhancement. In Proceedings of IEEE Int. Conference on Communications (ICC), New York, USA, vol. 1, pp. 605-9, 2002.
18. P. Chatzimisios, A.C. Boucouvalas, V. Vitas, A. Vafiadis, A. Economides, and P. Huang, "A simple and effective backoff scheme for the IEEE 802.11 MAC protocol". In Proceedings of the 2nd International Conference on Cybernetics and Information Technologies, Systems and Applications (CITSA 2005), Orlando, Florida, USA, Vol. 1, pp. 48-53, 2005.
19. N. Song, B. Kwak, J. Song, and L.E. Miller, "Enhancement of IEEE 802.11 distributed coordination function with exponential increase exponential decrease backoff algorithm". In Proceedings IEEE VTC 2003. 2003.
20. N Song, B Kwak, L.E. Miller, "Analysis of EIED backoff algorithm for the IEEE 802.11 DCF," In Proceedings of IEEE 62nd VTC-2005 Fall (Sept. 25-28, 2005), vol. 4, pp. 2182-6, 2005.
21. Q. Ni, I. Aad, C. Barakat, and T. Turletti, "Modeling and analysis of slow CW decrease for IEEE 802.11 WLAN". In Proceedings of the 14th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2003), Beijing, China. vol. 2, pp. 1717-21, 2003
22. I. Aad, Q. Ni, C. Castelluccia, and T. Turletti, "Enhancing IEEE 802.11 performance with slow CW decrease". IEEE 802.11e working group document 802.11-02/674r0, 2002.
23. F. Calì, M. Conti, and E. Gregori E., "Dynamic tuning of the IEEE 802.11 protocol to achieve a theoretical throughput limit", IEEE/ACM Transaction on Networking, vol. 8 no. 6, pp.785-99, 2000.
24. F. Calì, M. Conti, and E. Gregori, "IEEE 802.11 protocol: Design and performance evaluation of an adaptive backoff mechanism", IEEE Journal on Selected Areas in Communications, vol. 18 no. 9, pp.1774-86, 2000.
25. G. Bianchi, L. Fratta, and M. Oliveri, "Performance evaluation and enhancement of the CSMA/CA MAC protocol for IEEE 802.11 wireless LANs", In Proceedings of the Seventh IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 1996), Taipei, Taiwan, vol. 2, pp. 407-11, 1996.
26. G. Bianchi, "Performance analysis of the IEEE 802.11 distributed coordination function", IEEE Journal on Selected Areas in Communications, vol. 18 no. 3, pp.535-47, 2000.
27. D.J. Deng, C.H. Ke, H.H. Chen, and Y.M. Huang, "Contention window optimization for IEEE 802.11 DCF access control", IEEE Transactions on Wireless Communications, vol. 7 no. 12, pp. 5129-35, 2008.
28. L. Bononi, M. Conti, and E. Gregori, "Runtime optimization of IEEE 802.11 wireless LANs performance", IEEE Transactions on Parallel and Distributed Systems, vol. 15 no. 1, pp. 66-80, 2004.
29. A. Ksentini, A. Nafaa, A. Gueroui, and M. Naimi, "Determinist contention window algorithm for IEEE 802.11", In Proceedings of IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC, Vol. 4, pp. 2712-6, 2005.
30. S. Romaszko and C. Blondia, "Dynamic distributed contention window control in wireless ad hoc LANs". In Proceedings of the Australian Telecommunication Networks and Applications Conference (ATNAC 06), Melbourne, Australia, 2006.
31. J. Deng, P.K. Varshney, and Z.J. Haas, "A new backoff algorithm for the IEEE 802.11 distributed coordination function". In Proceedings of CNDS 2004, Sandiego, CA, Jan. 2004.
32. Y. Kwon, Y. Fang, and H. Latchman, "A novel MAC protocol with fast collision resolution for wireless LANs". In Proceedings of IEEE The 22th IEEE International Conference on Computer Communications (INFOCOM 2003), San Francisco, California, USA, Vol. 2, pp. 853-62, 2003.
33. C.H. Lin, C.K. Shieh, W.S. Hwang, and C.H. Ke, "An exponential-linear backoff algorithm for contention-based wireless networks". In Proceedings of the International Conference on Mobile Technology, Applications, and Systems (Mobility '08). 2008
34. O. Ekici and A. Yongacoglu, "Fairness and throughput performance of infrastructure IEEE 802.11 networks with hidden-nodes", Physical Communication, vol. 1 no. 4, pp.255-65, 2008.
35. J. Wang and M. Song, "An efficient traffic adaptive backoff protocol for wireless MAC layer", International Conference on Wireless Algorithms, Systems and Applications, 2007 (WASA 2007). Chicago, IL, pp. 169-73, 2007.
36. T. Li, T. Tang, and C. Chang, "A new backoff algorithm for IEEE 802.11 Distributed Coordination Function", 2009 Sixth International Conference on Fuzzy Systems and Knowledge Discovery, 2009 (FSKD) vol. 3, pp.455-9, 2009.
37. M. Zhang, C. Gong, and Y. Lu, "Dynamic priority backoff algorithm for IEEE 802.11 DCF", In Proceedings of the International Conference on Computer Science and Software Engineering. Wuhan, Hubei, pp. 956-58, 2008.
38. H.X. Cui and G. Wei, "A novel backoff algorithm based on the tradeoff of efficiency and fairness for ad hoc networks", In Proceedings of the International Conference on Communications and Mobile Computing (CMC '09), Yunnan, pp. 81-6, 2009.
39. H.M. Liang, S. Zeadally, N.K. Chilamkurti, and S. Ce-Kuen, "A novel pause count backoff algorithm for channel access in IEEE 802.11 based wireless LANs", International Symposium on Computer Science and its Applications (CSA'08). Hobart, ACT, pp. 163-8, 2008.
40. NS-2: The Network Simulator - NS-2. (available from: http://www.isi.edu/nsnam/ns [Last cited on 2011 July 12]).

AUTHORS

Ali Balador born in Iran in 8th of August 1985. He received his B.Sc. and M.Sc. degrees in computer engineering from Islamic Azad University in 2007 and 2010 respectively. His current research interests include: wireless networks, ad-hoc networks and MAC layer protocol with emphasis on IEEE 802.11 standard. Balador has published a number of scientific papers in the field of mobile ad-hoc Networks. He is also a member of the IEEE.

E-mail: balador@ieee.org

Ali Movaghar is currently a professor at the department of Computer Engineering in Sharif University of Technology in Tehran, Iran where he joined first as an assistant professor in 1993. He received his B.S. in Electrical Engineering from the University of Tehran in 1977 and both M.S. and Ph.D. in Computer, Information and Control Engineering from the University of Michigan at Ann Arbor in 1979 and 1985, respectively. He visited INRIA in France in 1984, worked at AT&T Bell Laboratories during 1985-1986, and taught at the University of Michigan during 1987-1989. His main areas of interest are performance and dependability modeling, verification and validation, computer networks, and distributed real-time systems. He is also a Senior Member of both the Institute of Electrical and Electronics Engineers (IEEE) and the Association for Computing Machinery (ACM).

E-mail: Movaghar@sharif.edu

Sam Jabbehdari is currently working as an assistant professor at the department of Computer Engineering in IAU (Islamic Azad University), North Tehran Branch, in Tehran, since 1993. He received his both B.Sc. and M.S. degrees in Electrical Engineering Telecommunication from K.N.T (Khajeh Nasir Toosi) University of Technology, and IAU, South Tehran branch in Tehran, Iran, in 1988, through 1991 respectively. He was honored a Ph.D. Degree in Computer Engineering from IAU, Science and Research Branch, Tehran, Iran in 2005. He was the Head of Postgraduate Computer Engineering Department IAU-North Tehran Branch during 2008-2010. He has also written "Advanced Topics in Computer Networks" book in Persian Language (Tehran, Classic, 2009). His current research interests are Scheduling, QoS, MANETs, Wireless Sensor Networks and Grid Computing Systems.

E-mail: s_jabbehdari@iau-tnb.ac.ir

Dimitris Kanellopoulos is a member of the Educational Software Development Laboratory in the department of Mathematics at the University of Patras, Greece. He holds a Ph.D. in multimedia communication from the department of Electrical and Computer Engineering of the University of Patras. His research interests include multimedia communications, intelligent systems and web engineering. He is a member of the IEEE Multimedia Communications Technical Committee. He is on the editorial board of ten international journals and guest editor to journals including: Journal of Computational Methods in Science and Engineering (IOS Press), Informatica, Electronic Commerce Research Journal (Springer), Journal of Internet Technology. He is in the organization committee or the TPC member of refereed conferences, including IEEE ICSC2006, MINES 2009, ICAISC 2011, EISWT 2011, DCNET 2011, and eCommerce (IADIS).

E-mail: d_kan2006@yahoo.gr

DOI: 10.4103/0256-4602.98862; Paper No. TR 216_11; Copyright © 2012 by the IETE