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ENHANCEMENT TECHNIQUES OF IEEE 802.11 WIRELESS LOCAL AREA NETWORK DISTRIBUTED COORDINATION FUNCTION: A REVIEW

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ABSTRACT

A wireless local area network (WLAN) connects at least two devices and usually operates in unlicensed radio frequency spectrum bands. After being introduced nearly two decades ago, the demands for WLAN deployments has continuously increased due to their low cost and ease of installation. Each user must gain access to the wireless channel in a controlled manner, using the medium access control (MAC). It is based on the well-known bianary exponential backoff (BEB) algorithm, which only allow a node to transmit if the channel is unoccupied for a period of time consisting of a fixed and random component. The latter is recognized as backoff time which is uniformly chosen from the backoff window (known as contention window, (CW)) within the interval (0, CW). The window size begins with CW_{min} and will be doubled whenever there is a packet collision and automatically foreseen a retransmission. The absence of acknowledgment frame (ACK) from the receiver indicates a corrupted packet (collision). As the number of competing node increases, the backoff time lengthens resulted in throughput degradation. It has been extensively agreed in the literature that the BEB algorithm is the key factor to WLAN performance degradation. Therefore, this work presents a comprehensive review on the techniques to improve the legacy BEB algorithm.

Keywords: WLAN, BEB, CW size, throughput, backoff.

INTRODUCTION

The main entities defined in the wireless local area network (WLAN) architecture are the station (also known as wireless user (WU)) and the access point (AP). The station connects to the wireless medium via a network interface card (NIC) embedded in electronic devices (i.e. desktop, laptop or mobile phone). On the other hand, an AP is an entity that forms a bridge between the wireless medium and a wired network like the IEEE 802.3 LAN. The AP acts as a base station for the IEEE 802.11 devices and aggregates them on to the wired network such as the LAN [2].

In general, the IEEE 802.11 architecture consists of basic service set (BSS) which is a collection of stations that communicate among themselves. The architecture can be classified into three operating modes as illustrated in Figure-1. The first operating mode is the independent basic service set (IBSS), shown in Figure-1(a). In the IBSS mode, stations are communicating with each other without any connection to an external network (i.e. access point) and creates an ad hoc network. It has a short lifespan and only serves a specific purpose such as exchanging or sharing files [3]. Hence, in a real-world WLAN deployment, the second operating mode which is an infrastructure BSS (referred to as BSS throughout this thesis) is more preferable to an ad hoc type of network. BSS allows a station to communicate with any other stations irrespective of their location and distance. Figure-1(b) illustrates the architecture of a BSS that includes the presence of a single access point(AP) , which provides connectivity to a wired network and eventually to the internet [2, 3]. Practically, the AP relays the received frames from the source stations to the intended destination within its serving BSS. Therefore, all stations must communicate through the AP though the destination station is in the same BSS. Prior to initiating a transmission, a station must be associated with the AP by exchanging important information such as radio synchronization and supported data rates. Finally, the third operating mode defined in the IEEE 802.11 standard is an extended service set (ESS). Figure-1(c) demonstrates the architecture of ESS which comprises a set of two or more BSSs that form a single sub network. ESS architecture extends the network coverage by allowing inter networking among APs in the joint BSSs via a wired local area network to forward traffic and facilitate movement of stations. It is commonly deployed in large public or corporate places such as university campuses, corporations, airports or shopping malls [3].

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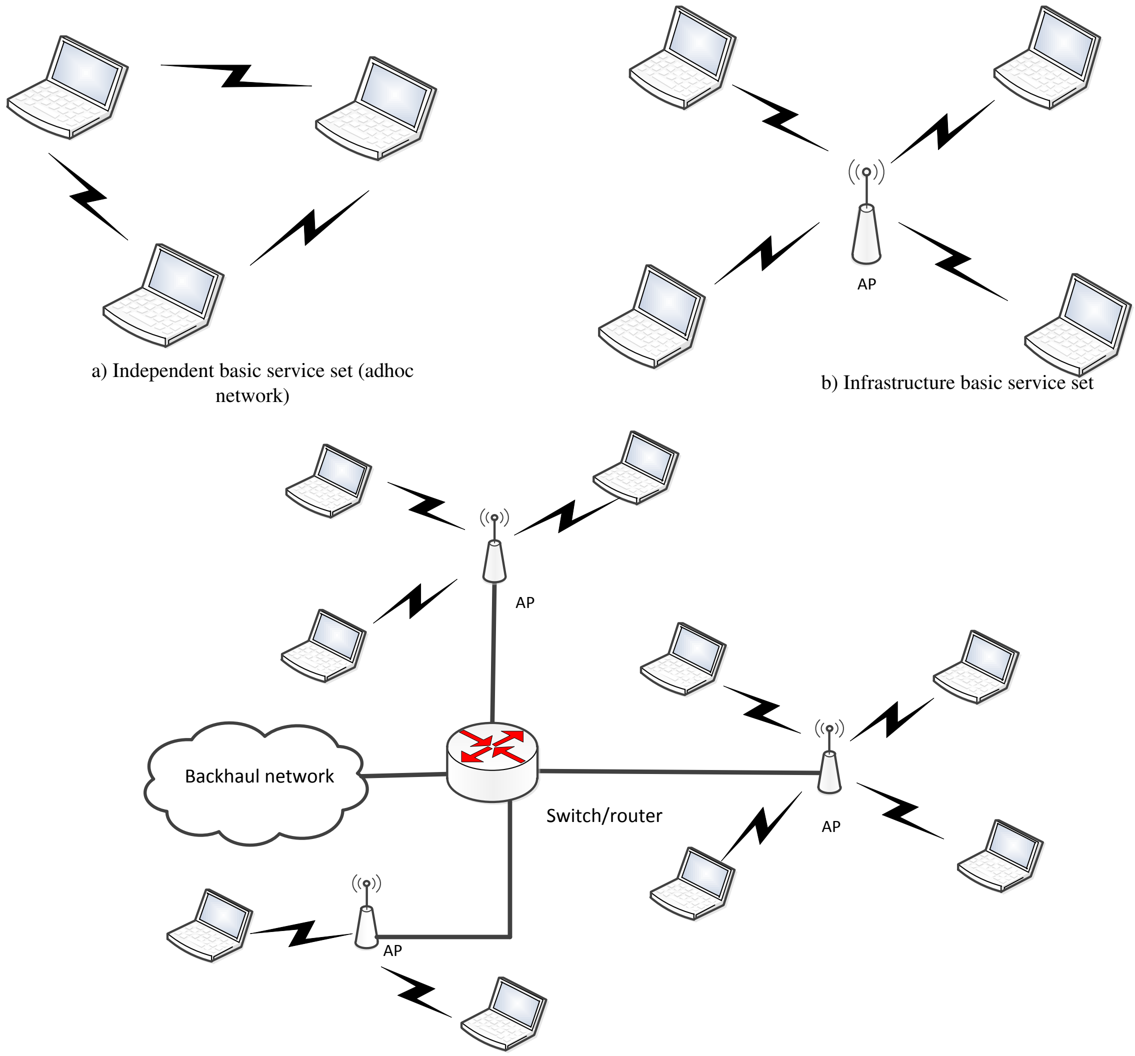

a) Independent basic service set (adhoc network)

b) Infrastructure basic service set

c) Extended basic service set

Figure-1. IEEE 802.11 LAN architecture [2, 3, 5].

WLAN adopted the IEEE 802.11 standard as described in [4]. The standard specifies two important layers in WLAN deployment namely physical (PHY) and media access control (MAC) layers. PHY specifies the modulation scheme used and signaling characteristics for the transmission through radio frequencies and its specification varies from one protocol to another (i.e. IEEE 802.11a, IEEE 802.11b and IEEE 802.11g). On the other hand, the latter is responsible for moving data packets across a shared wireless channel. The MAC protocols specify a channel access control mechanism to allow several stations to communicate without colliding with each other. These protocols are known as coordination functions and can be classified into two access methods. The fundamental method is called distributed coordination function (DCF) which uses a distributed algorithm, where all stations run the algorithm. The second method is known as point coordination function (PCF) which employs a centralized algorithm, where the AP runs the algorithm [6-8]. Despite the fact that the PCF has the priority to access the channel, in practise, the majority of vendors do not implement PCF mode in their APs because it requires additional coordinations, mainly when multiple APs are deployed within interference range [3]. Therefore, this paper only focuses on the fundamental method distributed coordination function.

The remaining sections of this paper are organized as follows: Distributed Coordination Function' section describes the fundamental medium access protocol for WLAN IEEE 802.11. 'Performance Analysis of WLAN' analysis the throughput performance of WLAN. 'Network Indicators for the enhancement in BEB Algorithm' section classifies types of network indicators used in the enhancement of BEB algorithm. 'The Uplink and Downlink Priority Schemes' section reviews the existing techniques of the uplink and downlink priority schemes. Finally, 'Conclusions' section concludes the paper.

DISTRIBUTED COORDINATION FUNCTION (DCF) PROTOCOL

The distributed coordination function (DCF) is the main medium access control protocol adopted by IEEE

802.11 standard. It is a random access scheme; based on the carrier sense multiple access with collision avoidance (CSMA/CA) DCF employs two approaches to sense the channel which are physical sensing and virtual sensing. In physical sensing, a station senses the channel to determine the condition of the channel (i.e. busy or idle). On the other hand, virtual carrier sensing is a logical abstraction which minimizes the need for physical carrier-sensing at the air interface in order to save power. The MAC layer frame headers contain a duration field that specifies the transmission time required for the frame, in which time the medium will be busy. The stations listen on the channel by reading the duration field in the MAC layer frame headers. The duration field provides information on the transmission time required for the frame. Then, each station updates their network allocation vectors (NAVs), which is an indicator for a station on how long it must defer from accessing the channel due to packet transmissions from other stations. The station can switch off to save power, for the duration of their NAV setting. It is only allowed to initiate a transmission after the channel is sensed idle for a period defined as DCF interframe space (DIFS) by means of either physical or virtual sensing mechanisms. If the channel is sensed busy either immediately or within the DIFS period, the station keeps on listening on the channel until it is sensed idle for a DIFS period. Consequently, the station generates a backoff interval which is randomly chosen from the backoff window (known as contention window (CW) size) [9]. The window size begins with a minimum CW size and it is doubled at each retransmission up to a maximum CW size. Retransmission takes place whenever there is a packet collision, indicated by the absence of acknowledgement frame (ACK) from the receiver. This backoff algorithm is known as binary exponential backoff (BEB) technique. In general, two schemes for packet transmissions are defined in DCF protocol which are basic access scheme and four handshakes scheme.

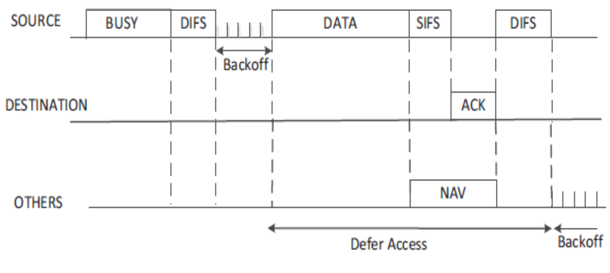

Figure-2. IEEE 802.11 basic access scheme [3, 10].

Figure-2 illustrates the default mechanism for packet transmission, known as basic access scheme. In this scheme, only DATA and ACK frames are involved. Upon DATA frame transmission from the source station, other stations update their NAV value after hearing the frame transmission. In this scheme, the NAV value is set based on the duration field in the DATA frame includes the short inter frame spacing (SIFS) period and the ACK frame transmission following the DATA frame as shown in Figure-2 [10]. When the destination station has successfully received the DATA frame, it immediately waits for SIFS duration and is followed by ACK transmission to the source station indicating a successful transmission.

The four handshakes method is considered as an optional scheme in the DCF protocol to reserve the channel before transmission and as a solution to the hidden station problem. As illustrated in Fig. 3, this method uses a four-phase RTS-CTS-DATA-ACK handshake, which is also known as request-to-send/clear-to-send (RTS/CTS) scheme [3, 10]. Initially, after sensing the channel is idle for DIFS duration, the source station broadcasts an RTS frame to notify the destination and other stations the total time required to transmit the DATA and ACK frames. Upon successful transmission of the RTS frame, the destination station replies by broadcasting a CTS frame to give the source station explicit permission to send DATA frame and inform other stations not to send for the reserved duration [5]. After receiving the CTS frame, the source station waits for SIFS duration before it proceeds to transmit the DATA frame. Meanwhile, other stations which hear the RTS and CTS frames update their NAV value according to the duration fields in those frames. In general, this four handshakes scheme is able to solve the hidden station problem because the DATA frame is transmitted only after the channel has been reserved. Moreover, it also reduces the collision duration since the collisions may only occurs for the RTS or CTS frames which are definitely shorter size than the DATA frame. Once the RTS and CTS frames are correctly transmitted, the following DATA and ACK frames should be successfully transmitted. However, this scheme

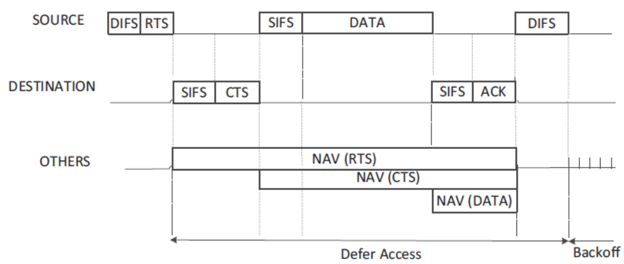

Figure-3. Four handshakes scheme [10].

also introduces delay and consumes channel resources due to the additional overheads involved. Hence, this scheme is only employed to transmit a long DATA frame. In practice, each station can set an RTS threshold such that the the scheme is only implemented if the DATA frame is longer than the threshold [5].

PERFORMANCE ANALYSIS OF WLAN

This section studies the WLAN performance by evaluating the normalized saturation throughput of IEEE 802.11 DCF. Bianchi has proposed an accurate analytical model in [9] to analyze the saturation throughput of the BEB algorithm. He defines the normalized throughput as the fraction of time the channel is used to successfully

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transmit payload bits. The saturation throughput indicates that the throughput has reached the limit despite the increase in offered load. In order to allow a comparison to the analysis in [9] (for a validation purpose), all the simulation parameters and assumptions for the IEEE 802.11 performance evaluation are following the specifications in [9]. The throughput performance of IEEE 802.11b adhoc WLAN is now verified using OPNET 1 simulation software [49]. The main OPNET simulation parameters are listed in Table 1 and the following assumptions are made: 1) all stations always have packets to transmit (greedy stations) 2) the channel is ideal 3) all stations can hear each other (no hidden stations).

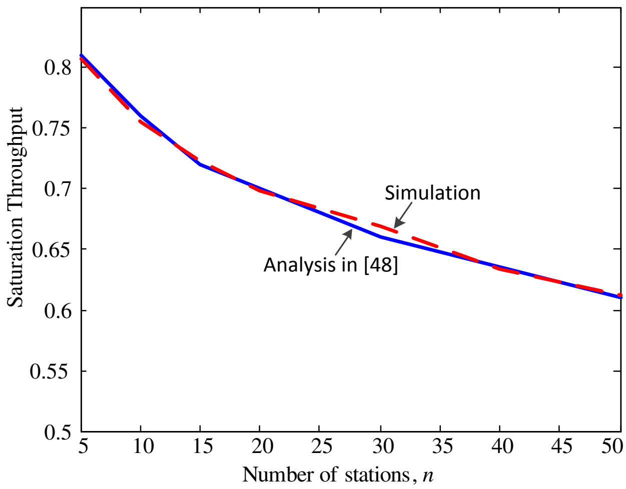

Figure-4. Effect of network size on saturation throughput in comparison to analysis in [9].

Figure-4 shows the saturation throughput gradually decreases as the number of stations increases from 5 to 50. It is shown that the obtained simulation results matched with the analysis established in [9]. As more stations contend the channel, there is an increase in collisions that deteriorates the whole system utilization. It is also observed (Figure-5) that the selection of initial CW (CWmin) size gives a significant impact to the throughput performance. The throughput for a small number of stations (5 stations) is severely deteriorated when CWmin is set to a high value, 1024. In contrast, bigger network size (50 stations) gained maximum throughput when CWmin is assigned to 1024. The best choice of CWmin strongly depends on the network size.

Table-1. IEEE 802.11b OPNET simulation parameters saturated condition.

Parameter	Value
Payload size	8184 bits
MAC header	272 bits
PHY header	128 bits
ACK	112 bits + PHY
Channel bit rate	1 Mbps
Network type	Infrastructure
Slot time	50 μs
SIFS time	28 μs
DIFS time	128 μs
ACK Timeout	300 μs

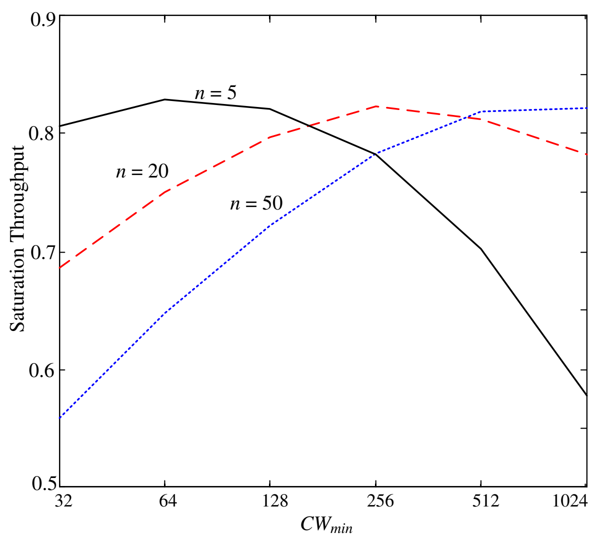

Figure-5. BEB saturation throughput versus CW_{min}.

Further, it is extensively agreed in the literature that the BEB algorithm adopted in the IEEE 802.11 standard is the key factor to WLAN performance degradation [9, 11-20]. There are two major drawbacks found in BEB that cause the network degradation [21]. First, the contention window is increased upon transmission failure regardless of the cause of failure. Second, after a successful packet transmission, the contention window is reset to the minimum size, thus forgetting its knowledge of the current congestion level in the network and increasing its collision chances. Numerous modifications have been proposed in the literature to improve the legacy BEB algorithm. In common, all modifications are made to adjust the contention window size according to the network condition. A number of approaches have been proposed in the literature to identify the network condition using different types of traffic indicators as classified in the following sections.

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NETWORK INDICATORS FOR THE ENHANCEMENT IN BEB ALGORITHM

MAC Frames Indicator

The proponents of the first category take advantage of the least overhead size information carried by MAC frames including ACK, RTS and CTS frames.

a) ACK Frame

Stations continuously monitor the traffic on the channel to identify collisions. The presence or absence of an ACK can be used to identify the success or otherwise (collision) of a transmission [11-13, 18]. In [11], the authors propose to exponentially increase the CW size when there is a collision and exponentially decrease the CW size when there is a successful transmission, known as the EIED (exponentially increases exponentially decreases) algorithm. The exponential factors are then optimized to get maximum throughput. The proponents of [12] use a more conservative approach, they linearly decrease the CW size when there is a successful transmission. Similarly, [18] proposes to halve the CW size (unlike BEB where the CW size is reset to minimum) to increase the overall throughput. Further, the work in [52] proposes a fairness based algorithm for mobile adhoc networks (MANETs) by adjusting the CW size according to the number of successful transmissions. In common, all of the above techniques steadily decrease the CW after a successful transmission to retain the overall network state information. Though this approach may have a positive correlation, it usually falls short of predicting the overall network status.

b) RTS and CTS frames

The schemes [14, 15] proposed in this category use the network allocation vector (NAV) information embedded in RTS and CTS packets as the overall network traffic indicator. The transmitting station explicitly indicates the length of time that it will be using the channel. Consequently, all stations will update their NAV by checking RTS and CTS frames from their transmitting neighbours. Initially, the authors in [22] utilized NAV information to analytically derive an interference aware metric named network allocation vector count (NAVC). A function is derived to predicate the possible delay and the available bandwidth for a dynamic interference aware routing protocol in a MANET. Later, [15] employed NAVC to adjust the contention window size in the routing protocol. Similarly, Wang and Song in [14] used NAV information to approximate the intensity of surrounding traffic and the density of stations. Though NAV information can be a good traffic indicator to tune the CW sizes, this approach is only limited to the four handshakes mode (RTS/CTS reservation mechanism) and not available in the basic access mode of IEEE 802.11 DCF access method.

Wireless channel status indicator

All contending stations can listen to each other, allowing them to identify whether the channel is idle or busy. The resultant channel status becomes a traffic indicator of the overall network [9, 16, 17, 23-27]. The CW sizes can be manipulated in various ways for throughput enhancement as below:

a) History based backoff

Authors in [25, 26] use the past channel status to control the current CW size. The work in [26] proposed history based adaptive backoff (HBAB) algorithm that checks the last two states of the channel and decides whether to increase or decrease the CW sizes based on the channel's tendency to being free or busy. Further, a dynamic, deterministic contention window control (DDCWC) scheme [25] extended the algorithm to include the last three states in a channel state vector. The backoff range is divided into several small sub-ranges which are selected based on the channel state vector.

b) Number of backoff pauses

The pause count backoff (PCB) algorithm proposed in [23] observed the number of backoff pauses (due to busy channel) until its backoff counter becomes zero and sets an appropriate CW size that matches the estimated traffic status. However, [24] claimed the PCB algorithm could not adjust to dramatically changing traffic loads because the algorithm could not estimate the number of active stations. Hence, [24] took one step forward by introducing the estimation-based backoff (EBA) algorithm which estimates the number of active stations by observing the number of idle slots during the backoff period.

Number of idle slots

The works in [28-31] dynamically control the CW sizes by monitoring the estimated mean number of idle slots between transmission attempts $\bar{I}_i$. This method is known as Idle Sense, a distributed control method where all contending stations in IS compare their $\bar{I}_i$ with the target value I_t, a common value to all stations, and adapt their CW size using the additive increase multiplicative decrease (AIMD) algorithm. The station gradually increases its CW size when $\bar{I}_i < I_t$ or multiplicatively decrease the CW if $\bar{I}_i > I_t$. The CW sizes of all stations will converge to the same value. The CW sizes of all stations will converge to the same value. However, it is recently shown in [32] that IS can go unstable if the initial CW sizes are significantly different.

Number of contending stations

The techniques in this category use an analytical approach based on Markov models to determine the optimum CW sizes for maximum throughput as a function of the number of n contending stations. For example, the adaptive window algorithm (AWA) proposed by Bianchi et al. [20], used the number of active stations in the network to control the CW size; the number of active stations were estimated by observing the activity on the channel. A similar approach is employed in [16] and [17] to control a complex p-persistent MAC protocol that selects the optimum backoff interval. More recently, [66] identified the relationship between backoff parameters, contention level, and channel bit error rate (BER) in order to propose a distributed algorithm that allows a station to dynamically adjust its contention window size based on turn-around-time measurement of channel status. These analytical approaches may result in better network performance because the algorithms allow each station to independently tune the backoff window size at run time. However, complex computations are required that lead to high power consumption, which is in many cases considered unaffordable in wireless networks context [25, 26]

In common, the above studies focused on the enhancement of the IEEE 802.11 protocol in an adhoc configuration; with all stations having an equal chance to transmit. However, in infrastructure networks, the AP requires more transmission opportunities to give fairness to the uplink/downlink performance. The following section reviews on the performance enhancements for infrastructure based WLAN.

UPLINK AND DOWNLINK PRIORITY SCHEMES

In practice, the majority of WLAN deployments operate in an infrastructure mode where an access point (AP) serves its own basic service set (BSS) of associated wireless users (WUs). The AP acts as a bridge between the wired network and the associated WUs. Therefore, AP requires more transmission opportunities than WUs. However, in the standard DCF access method, every station including the AP is given an equal chance of transmission which leads to unfairness between uplink and downlink transmissions and consequently degrades the overall performance of the WLAN. Extensive works have been carried out to mitigate the uplink and downlink unfairness. The following subsections discuss several types of techniques proposed in the literature.

Control CW size

The schemes proposed in [30, 33-36] control the contention window sizes of the contending stations (i.e. AP or WUs or both) in order to achieve the desired fairness between uplink and downlink transmissions. The work in [30] provides the AP with a higher transmission priority by scaling the CW size to a constant value while allowing the associated WUs to dynamically control their CW sizes according to the Idle Sense method [28], Abeysekera *et al* [33] introduced a simpler technique which modifies the well known BEB MAC protocol. The minimum CW size, CWmin of the AP is adaptively adjusted based on the target packet ratio between uplink and downlink flows. Nevertheless, this scheme does not consider throughput maximization and dynamics in WLAN (e.g. channel condition and traffic loads) when deriving the optimal CWmin. Therefore, [36] improves the scheme by considering the dynamics of WLAN environment. The most recent work in [34] analytically derived the optimum CWmin sizes for an AP and associated WUs in order to achieve the target downlink/uplink ratio and the optimum network throughput. The derived formulations show that CWmin sizes depend on the number of WUs. However, the scheme does not propose any algorithm to estimate this number. In common, this approach always sets the CW size of an AP lower than WU's to give the AP priority access. The limitation is that it increases the collision rate due to the smaller CW size and consequently deteriorates the overall WLAN performance.

Reduce Interframe Space (IFS) period

Priority access for an AP is obtained in [37, 38] by reducing its sensing time. In [38], the AP performs carrier sensing only for a PCF interframe space (PIFS) period instead of DIFS (in the default IEEE 802.11), where the length of PIFS is shorter than DIFS but longer than SIFS. The same approach is also proposed in guaranteed access mode mechanisms [37] to solve the unfairness problem in 802.11e. In this scheme, when the AP perceives unfairness problem, the enhanced distributed channel access (EDCA) protocol is modified by fixing the arbitration interframe space (AIFS) period equals to 1 and the backoff algorithm is ignored. Though this has immediate effect and gives the AP the greatest amount of required bandwidth, it may cause AP hogging before the desired ratio is achieved.

Adjust TXOP limit

The authors in [39-41] utilizes this approach based on a concept of transmission opportunity (TXOP) in the IEEE 802.11e [42]. It allows a station gaining the channel to transmit multiple frames without any contention within the predefined TXOP limit. The TXOP limit is typically fixed by the IEEE 802. 11e standard. Therefore, [39] introduces an adaptive priority control (APC) which dynamically adjusts the TXOP limit of an AP according to the traffic volume of uplink and downlink. It is shown that APC balances the uplink and downlink delay effectively in VoIP traffic without additional overhead. However, it should be noted that if the transmission of any frame in TXOP fails, the burst transmission is terminated (loosing a considerable amount of data) and is retransmitted after the next channel access. Therefore, the TXOP approach is not suitable for error prone environments [43]. As an alternate solution, Clifford et.al in [40] proposed to use a smaller TXOP limit with multiple transmission opportunities and a smaller value of CWmin to improve the AP's access priority.

Other schemes

Xiao [44] used an analytical approach to model the backoff-based priority schemes for IEEE 802.11 and IEEE 802.11e WLANs. Three backoff based metrics including the initial window size, the retry limit and the backoff window-increasing factor are differentiated to achieve the target throughput and priority. However, this work does not propose any specific algorithm to adaptively tune the metrics. In contrast, the work in [45] proposed a novel dynamic EDCA parameter adaptation algorithm to achieve a predetermined fairness ratio in IEEE 802.11e where the initial parameters (i.e. AIFS, CWmin and TXOP limit) are calculated from their analytical model. Other schemes are proposed in [46] to support the fairness between uplink and downlink while maintaining the maximum throughput. The schemes usually involve improving the AP's transmission probability. Techniques such as ACK-piggybacked data and replacing the DIFS waiting period with the shorter SIFS waiting period are occasionally applied as control methods. Conversely the UL priority can be reduced [47, 48], or the AP can establish a contention free period by spoofing the 'duration' field in the MAC header; effectively forcing large NAV values in the WUs [49].

In summary, it is worth noting that all the above priority schemes have been proposed for a single BSS infrastructure network; that is one AP and n associate WUs sharing the same radio resource. The demand for high data rate WLAN services has resulted in reduced transmission ranges caused by the use of high order QAM modulations. However, the carrier-sensing range remains essentially constant, set by the -82 dBm CCA specification (Fig. 6). Any co-channel BSSs located within the carrier sensing zone will need to share the same frequency resource. Unfortunately, in today's high density urban environment the spectrum is so crowded that many BSSs are forced to share the same channel. The problem of overlapping coverage areas potentially increases collisions and reduces saturated throughput as is evident in the BEB algorithm used in today's IEEE802.11 standards. There are now a number of fairness issues to consider: uplink-downlink fairness for each BSS, fairness between BSSs and fairness among WUs.

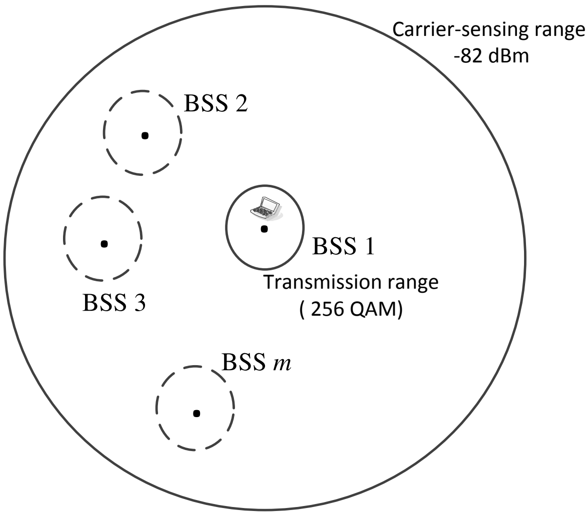

Figure-6. The dotted circle BSSs are potential interferers to the AP and WUs in BSS 1 (solid circle).

CONCLUSIONS

This paper provides a critical review of the relevant subjects in wireless local area network (WLAN). The IEEE 802.11 WLAN standards and the fundamental distributed coordination function (DCF) medium access control (MAC) protocols are introduced. The throughput performance was evaluated by means of OPNET simulations and identified that the binary exponential backoff (BEB) algorithm adopted in the DCF MAC protocol is the key factor in the throughput degradation. The two two major drawbacks found in BEB that cause the network degradation. First, the contention window is increased upon transmission failure regardless of the cause of failure. Second, after a successful packet transmission, the contention window is reset to the minimum size, thus forgetting its knowledge of the current congestion level in the network and increasing its collision chances. Existing adaptive backoff schemes are critically reviewed and the schemes are classified according to the traffic indicators used in the proposed algorithms including MAC frames, wireless channel status, number of idle slots and number of contending stations. In common, the reviewed enhancements focused an adhoc configuration; with all stations having an equal chance to transmit. However, infrastructure network is more popular in the real practice which requires the access point (AP) to have more transmission opportunities to give fairness to the uplink/downlink performance. Therefore, a literature survey of transmission priority schemes is presented to seek understanding of the techniques to improve the fairness between uplink and downlink transmissions. Finally, it is worth noting that all the reviewed priority schemes were proposed for a single BSS infrastructure network; that is one AP and n associate WUs sharing the same radio resource. The demand for high data rate WLAN services has resulted in reduced transmission ranges caused by the use of high order quadrature amplitude modulations (QAM) causing any co-channel BSSs located within the carrier sensing zone will need to share the same frequency resource. Any co-channel BSSs located within the carrier sensing zone will need to share the same frequency resource. However, in today's high density urban environment the spectrum is so crowded that many BSSs are forced to share the same channel resulted in the problem of overlapping coverage areas. This problem potentially increases collisions and reduces saturated throughput as is evident in the BEB algorithm used in the current IEEE802.11 standards. As such, there are now a number of fairness issues to consider for future review such as uplink-downlink fairness for each BSS, fairness between BSSs and fairness among WUs.

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