A review on 802.11 MAC protocols industrial standards, architecture elements for providing QoS guarantee, supporting emergency traffic, and security: Future directions

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Abstract

The IEEE 802.11 -based Wireless Local Area Network (WLAN) has become a ubiquitous networking technol-ogy deployed around the world. IEEE 802.11 WLAN are now widely used for real-time multimedia applica-tions (e.g. voice and video streaming) and distributed emergency services such as telemedicine, health-care, and disaster recovery. Both time -sensitive applications and emergency traffic are not only character-ized by their high band width requirements, but also impose severe restrictions on end-to-end packet delays (i.e. response time), jitter (i.e. delay variance) and packet losses. In other words, time -sensitive applications and emergency services require a strict Quality of Service (QoS) guarantee. Medium Access Control (MAC) protocol is one of the key factors that influence the performance of WLANs. The IEEE 802.11 e working group enhanced the 802.11 MAC to provide QoS support in WLANs. However, recent studies have shown that 802.11 e Enhanced Distributed Channel Access (EDCA) standard has limitations and it neither supports strict QoS guarantee nor emergency traffic. Providing a strict QoS guarantee as well as supporting emergency traffic under high traffic loads is really a challenging task in WLANs. A thorough review of litera-ture on QoS MAC protocols reveals that most QoS schemes have focused on either network throughp-ut enhancement or service differentiation by adjusting Contention Window (CW) or Inter-Frame Spaces (IFS). Therefore, a research on developing techniques to provide a strict QoS guarantee as well as support for emergency traffic is required in such systems. To achieve this objective, a general understanding of WLANs is required. This paper aims to provide an introduction to various key concepts of WLANs that are necessary for design, model and develop such framework. Our main contribution in this paper is the QoS for IEEE 802.11 WLAN and MAC protocols for supporting industrial emergency traffic over network and future di-rections.

1. Introduction

In recent years there has been a developing interest in the use of Wireless Local Area Networks (WLANs) based on IEEE 802.11 due to the fact of its low cost and simple deployment. The IEEE 802.11-based WLAN has ended up a ubiquitous networking technology deployed around the world. A primary goal of this survey paper is to develop a framework for WLAN, which help emergency traffic and provide strict Quality of Service (QoS) assurance for lifesaving emergency traffic in a dense emergency state of affairs the place an excessive quantity of nodes report the emergency [1, 2]. To attain this objective, an ordinary perception of WLANs is required. This paper targets to provide an introduction to a number key concepts of WLANs that are crucial for design, model and develop such framework. WLAN is based on Link Layer (LL). LL is divided into Logical Link Control (LLC) and Medium Access Control (MAC) sub-layer categorizes with two functions, Distributed Coordination Function (DCF) and Point Coordination Function (PCF) [100,101].

Quality of Service (QoS) is perceived and interpreted by different communities in different ways. The Internet Engineering Task Force (IETF) defined two models relevant to QoS in IP packet-based networks. QoS behaviours tell the device how to treat the traffic as it travels from the ingress interface all the way until it is sent out the egress interface of the network device. The first model, Integrated Services (IntServ), and the second model, Differentiated Services (DiffServ) [3]. The technical or network communities refer to QoS as the measure of service quality provided by the network to the users. IETF defines QoS as "a set of service requirements to be met by the network while transporting a flow" [4]. The main goal was to provide QoS while maximising network resource utilisation. The network user community refers to QoS as the quality perceived by applications/users. The International Telecommunication Union (ITU) defines QoS as "the ability of a network or network portion to provide the functions related to communications between users" [5]. De-facto the concept of QoS is very broad. Over IP networks, QoS is a more technical one, focusing on monitoring and improving network performance metrics such as packet delay, jitter, packet loss, and throughput see in Table 1.

These traffic characteristics must be controlled and managed on a hop-by-hop basis in order to achieve the per-hop QoS behaviours needed to provide a complete end-to-end QoS solution [3]. Traditionally, there are two main approaches to achieve QoS in packet switched networks. These strategies are IntServ and DiffServ which are temporarily described under such as utility structure the QoS perspective.

Table 1
Commonly used network performance metrics [6].

Metric	Description
End-to-end packet delay (Latency)	The time required to transfer packet across a network
Jitter (delay variance)	Variability of packets delay within the same packet stream. e.g.: delay of packet 1 is 8 ms and delay of packet 2 is 5 ms then jitter is 3 ms.
Packet Loss	Router or end devices will drop packets when buffer capacity is full.
Throughput	The amount of data successfully delivered over the communication channel. Usually measured in bits per second or packets per second.

2. Applications from the QoS perspective

In current years, there is signification growth in the use of different applications over the WLANs. From the QoS perspective, these applications can be classified into three different groups [7]. Fig. 1 [31] illustrates various application from the QoS perspective. These applications from the QoS perspective are described below.

- Applications with quantitative specifications of QoS: these applications require strict QoS guarantee. These applications have a specific requirement and impose strict restrictions on packet delay, jitter, packet loss and throughput. For example, required one-way end-to-end delay for voice packet is 150 ms [8].
- Applications with qualitative specifications: these applications require QoS. These applications do not have any specific requirements to describe the desired treatment. For example, web browsing which needs QoS but does not have any specific QoS requirement.
- Applications without qualitative specification: these applications do not require any QoS. For example, an application that runs in the background.

2.1. Emergency services

An emergency may be defined as a situation or an event which involves an immediate risk to human life, health, property or environment [9]. The emergency which involves risk to life are prioritized as general thinking nothing is important than human life. In the recent year, there is significant growth in the use of emergency services (e.g. health monitoring, disaster surveillance) over WLANs [10, 11]. These applications require emergency traffic support from the medium (i.e. on-arrival channel access priority over normal traffic) together with strict QoS guarantee especially in terms of delay under saturated network conditions.

Most of the organisations which deal with emergency services categorise the emergency traffic into four different types: emergency to 1) life, 2) health [102–105], 3) property and 4) environment [12–14]. All emergencies do not require the same priority. These services can be linked to various service priorities as emergencies do not require the same level of priority. For example, emergency to life has the highest priority because nothing is more important than human lives. This is followed by prioritization to health, property and environment (see

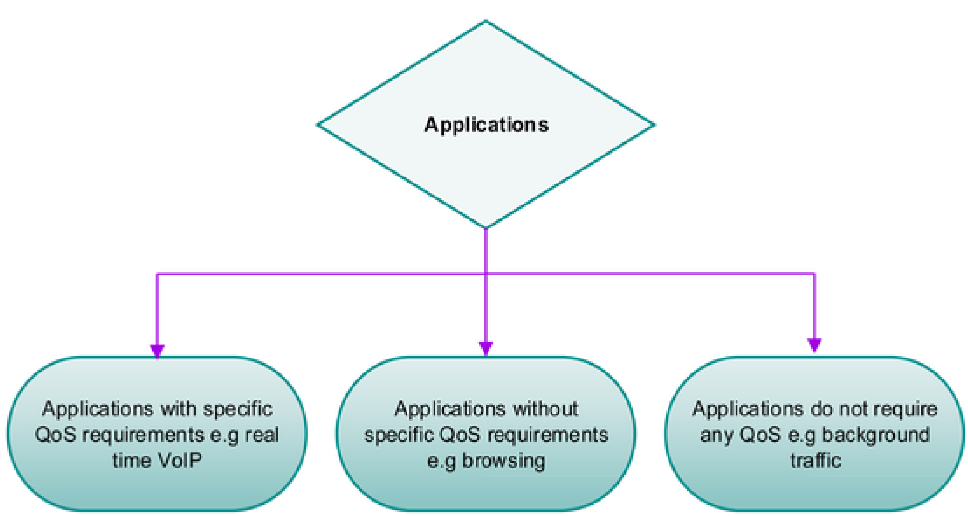

Fig. 1. Applications from QoS perspective.

Fig. 2: Type of emergencies [34–40]). The IEEE 802.11 WLAN network is a wireless Ethernet, play an important function in the future-generation networks. Now, It will discuss IEEE 802.11 standards.

3. IEEE 802.11 standards, architecture and medium access control

WLAN is based on Link Layer (LL). LL is divided into Logical Link Control (LLC) and Medium Access Control (MAC) sub-layer categorizes with two functions, Distributed Coordination Function (DCF) and Point Coordination Function (PCF) [15–17]. The IEEE 802.11 WLAN networks help each contention-based DCF and contention-free PCF functions. DCF makes use of Carrier Sensing Multiple Access/Collision Avoidance (CSMA/CA) as the get right of entry to method [18–21].

The MAC and PHY characteristics of 802.11 are specified in legacy 802.11-1997 [22]. And latter 802.11a [23], 802.11b [24] and 802.11 g [25] PHY 802.11n [26], 802.11ac [27]. Physical (PHY) and MAC specifications refer to amendments to achieve higher throughput by advancing the modulation and the channel coding. They all use the same Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) as medium access control protocol. There are several MAC amendments to support QoS (802.11e) Security (802.11i), and emergency and internetworking (802.11 u). Table 2 summarises the main characteristics of 802.11 standards. Although the PCF mode is designed for real-time traffic, it is not widely deployed due to its inefficient polling schemes, limited Quality of Service (QoS) provisioning, and implementation complexity.

3.1. IEEE 802.11 WLAN architecture

WLANs are set up in infrastructure mode, where mobile stations access the Internet through an AP, which coordinates all traffic to and from the WLAN [106]. In an infrastructure-based WLAN, the AP has a much higher traffic load and is the bottleneck. The unbalanced traffic load affects network performance and voice capacity, which needs further investigation. IEEE 802.11 WLAN can provide the highest transmission rate up to a specific distance limit and this rate is stepped down as the access distance increases beyond this limit, and so on until there is no coverage. The fundamental building block of the 802.11 architecture is the Basic Service Set (BSS). A BSS contains one or more wireless stations (STA) and a central base station knows as an Access Point (AP) in 802.11 parlances. WLANs that deploy APs are often referred to as infrastructure WLANs, with the infrastructure being the APs along with the wired Ethernet infrastructure that interconnects the APs and a router as Fig. 3 is an illustration.

IEEE 802.11 STAs can also group themselves together to form an ad-hoc network for the purpose of internetworked communications without the aid of an infrastructure network. An ad-hoc network is suitable for man-made or natural disasters such as U.S 9/11, Boston Bombing, earthquakes where infrastructure networks are either not available or highly affected by the disaster. An ad hoc network with no central control and with no connections to the outside world form an Independent BSS (IBSS). Fig. 4 is an illustration of an IBSS. An ad hoc network may be categorised into two types i.e. (1) single hop and (2) multi-hop. In single-hop network, a Station (STA) -communicates directly with another neighbouring STA within the transmission range. Another side, in multi-hop network, an STA communicates with another STA which may not be in the direct transmission range through intermediate STAs.

Another side in multi-hop network, an STA communicate with designation STA through multiple intermediate STAs. A multi-hop network may consist of hundreds of STA and there is no impact on the network if intermediate STA leaves the network. However, there are still many challenges in the design of multi-hop ad-hoc networks such providing strict QoS guarantee especially in term of end to end delay required by time-critical real-time applications, security or route failure due to mobility of intermediate devices, unreliable wireless channel and lack of centralized control [31, 32]. The 802.11 MAC layer is one of the most important components of a typical WLAN.

3.2. IEEE 802.11 medium access control

The basic access method in the IEEE 802.11 Medium Access Control (MAC) is the Distributed Coordination Function (DCF), which is based on Carrier Sense Multiple Accesses with Collision Avoidance (CSMA/CA). A good QoS MAC protocol should provide QoS guarantee to time-sensitive applications and support emergency traffic together with the simplicity of operations and high bandwidth utilisation. Ideally, a good protocol should provide high throughput, and low end-to-end packet delay, jitter, and packet losses, as well as priority to time-sensitive applications.

The 802.11 MAC provides two access methods: (1) distributed coordination function (DCF) as the core; and (2) point coordination func-

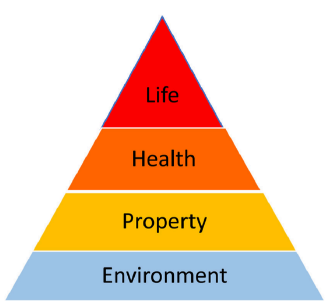

Fig. 2. Type of emergencies.

Table 2
IEEE 802.11 standards and their technical specifications [22-30].

802.11 standards	Release	Freq. (GHz)	Data Rate Mbps	MIMO Stream	Modulation	Bandwidth MHz	Indoor Range (m)	Outdoor Range (m)
802.11	June 1997	2.4	1, 2	No	DSSS, FSSS	20	20	100
802.11a	Sep. 1999	5	6, 9, 12, 18, 24, 36, 48, 54	No	OFDM	20	30	120
802.11b	Sep. 1999	2.4	5.5, 11	No	DSSS	20	38	140
802.11g	June 2003	2.4	6, 9, 12, 18, 24, 36, 48, 54	No	OFDM, DSS	20	38	140
802.11n	Oct. 2009	2.4, 5	7.2 – 150 (per stream)	4	OFDM	20, 40	70	250
802.11ac	December 2013	5	7.2 – 6933 (per stream)	8	MIMO —OFDM	20, 40, 80, 160	35	–
802.11ax	2019	2.4, 5	7.2 – 10.53	–	MIMO — OFDMA	–	–	–
802.11i	Nov. 2004	Based on IEEE 802.11 PHY Characteristics						
802.11e	Nov. 2005	Based on IEEE 802.11 PHY Characteristics						
802.11u	Feb. 2011	Based on IEEE 802.11 PHY Characteristics						

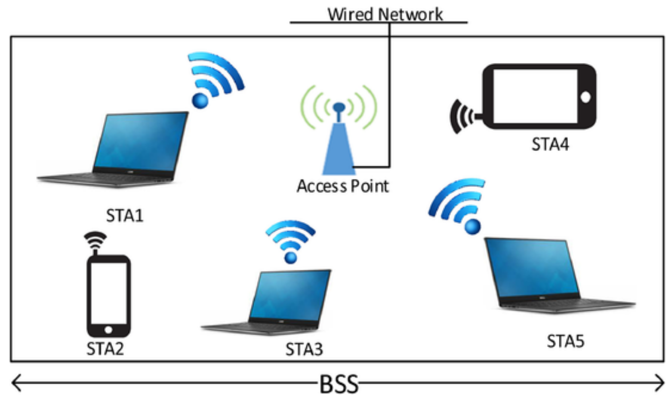

Fig. 3. A typical 802.11 wireless infrastructure network with five STAs.

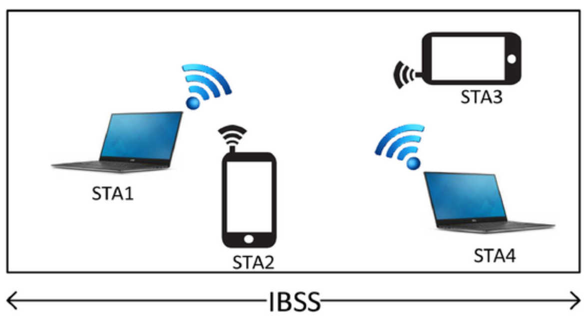

Fig. 4. A typical 802.11 wireless ad-hoc network with four STAs.

tion (PCF) as optional. DCF is a contention-based protocol that can provide the best-effort service. The DCF is built on the CSMA/CA medium and optional Request to Send / Clear to Send (RTS/CTS) mechanism to share the medium between multiple STAs. In CSMA/CA, STA must sense the medium before initiating a packet transmission. Three Interframe Space (IFS) intervals are specified in the standard: short IFS (SIFS), point coordination function IFS (PIFS), and DCF-IFS (DIFS). The SIFS interval is the smallest IFS, followed by PIFS and DIFS, respectively. SIFS has highest priority use for Acknowledgement, RTS and CTS frames. PCF has medium priority use for time-sensitive applications. DIFS has the lowest priority used for data. Many network researchers proposed IFS based schemes to support QoS for time-sensitive applications in 802.11 MAC layer [33, 34].

In DCF mode all STAs waits until the channel becomes idle for a DIFS period (see Equation 1). The DIFS time period is calculated from DCF parameters. Table 4 lists the DCF parameters of various IEEE 802.11 standards. STAs start backoff process to avoid collisions. In this process, each STA chooses a random interval, called backoff timer computed from CW: random [0, CW] × SlotTime, where CW = CW minimum (CWmin) ≤ CW ≤ CW maximum (CWmax); values of CWmin, CW, CWmax and SlotTime are based on PHY layer. Table 3 shows DCF parameters of various IEEE standards. All STAs decrement their backoff timer until the medium becomes busy. If the time has not reached zero

Table 3
DCF parameters of various IEEE 802.11 standards [23-25, 27, 36].

Standard	Slot Time	SIFS	DIFS	CWmin	CWmax
802.11a	9µs	16µs	34µs	15	1023
802.11b	20µs	10µs	50µs	31	1023
802.11g	Short = 9 µs Long = 20µs	10µs	Short = 28µs Long = 50µs	Short = 15 Long = 31	1023
802.11n (2.4 (GHz)	Short = 9µs Long =20µs	10µs	Short = 28µs Long = 50µs	Short = 15 Long = 31	1023
802.11n (5 GHz)	9µs	16µs	34µs	15	1023
802.11ac	9µs	16µs	34µs	15	1023

and the medium becomes busy, the STA freezes its timer. The STA transmits when its timer decremented to zero.

If two or more STAs' timer decrement to zero at the same time, a collision will occur. On successful transmission, the receiving STA sends an ACK after SIFS. If an ACK packet is not received within timeout then the transmitting STA retransmits the frame (assuming that the frame has collided). To reduce the probability of collision, CW is doubled until it reaches CWmax.

The PCF provides Contention-Free (CF) frame transfer. This is available in infrastructure mode, where STAs are connected to the network through an Access Point. PCF uses a centralised polling method based on the round robin algorithm. PCF would be suitable for time-sensitive traffic for QoS; however, PCF's algorithm is complex and it is expensive to implement and explained in Table 3 [35].

4. IEEE 802.11e for quality of service

The IEEE 802.11e [29] working group has developed a new standard called IEEE 802.11e to support time-sensitive applications such as Voice over IP (VoIP) and video streaming. IEEE 802.11e introduced a new coordination function called Hybrid Coordination Function (HCF) which provides the combined advantages of DCF and PCF.

HCF uses mandatory Enhanced Distributed Channel Access (EDCA) mechanism for contention based transfer and optional HCF Controlled Channel Access (HCCA) mechanism for contention-free services. Both EDCA and HCCA work on the top of DCF as shown in Fig. 5: IEEE 802.11e MAC architecture.

4.1. Enhanced distributed channel access

EDCA formally was known as enhanced distributed coordination function (EDCF) [29] is HCF's contention based channel access; provides service differentiation by using prioritised QoS approach. EDCA defines the Access Category (AC) mechanism that provides support for the priorities at the STA. Each STA may have up to four access categories i.e. Voice (AC_VO), video (AC_VI), Best Efforts (AC_BE), and background (AC_BK) to support eight User Priorities (UPs) as defined in IEEE 802.1d [37]. The mapping from priorities to ACs is defined in Table 4.

An AC with higher priority is assigned a shorter CW in order to ensure that higher priority AC will be able to transmit before lower priority ones. This is done by setting the CW limits for each AC: CWmin[AC] and CWmax[AC], from which CW[AC] is computed, as shown in (1–1).

For further differentiation, different Interframe Space (IFS) is introduced according to ACs. Instead of DIFS, an arbitration IFS (AIFS) is used. The AIFS is at least DIFS and can be enlarged individually for each AC, as shown in (1–2).

$$\mathrm{CW}[AC] = \mathrm{CWmin}\ [AC] \le \mathrm{CWmax}\,[AC] \tag{1.1}$$

$$\mathrm{AIFS}\ [AC] = \mathrm{AIFSN}\ [AC] \times \mathrm{SlotTime} + \mathrm{SIFS} \tag{1.2}$$

$$\mathrm{BackoffTimer} = \mathrm{Random}\ [0,\ \mathrm{CW}] \times \mathrm{SlotTime} \tag{1.3}$$

Similar to DCF, if the medium is sensed to be idle in the EDCA mechanism, a transmission can begin immediately. Otherwise, the STA defers until the end of current transmission on the Wireless Medium (WM). After deferral, the STA waits for a period of AIFS [AC] to start a backoff procedure. The backoff interval is now a random number drawn from the interval (1, CW [AC] + 1) as shown in (1–3). Each AC within STA contends for access to the WM and independently starts its backoff time after sensing the medium is idle for at least AIFS. A collision between ACs within a single STA is resolved by granting the medium to highest priority AC and lower priority AC will backoff. Table 5 lists the default DCF and EDCA parameters.

To give priority to voice or video applications IEEE 802.11e introduced Transmission Opportunity (TXOP). TXOP is an interval of time when a particular QoS station (QSTA) has the right to initiate frame

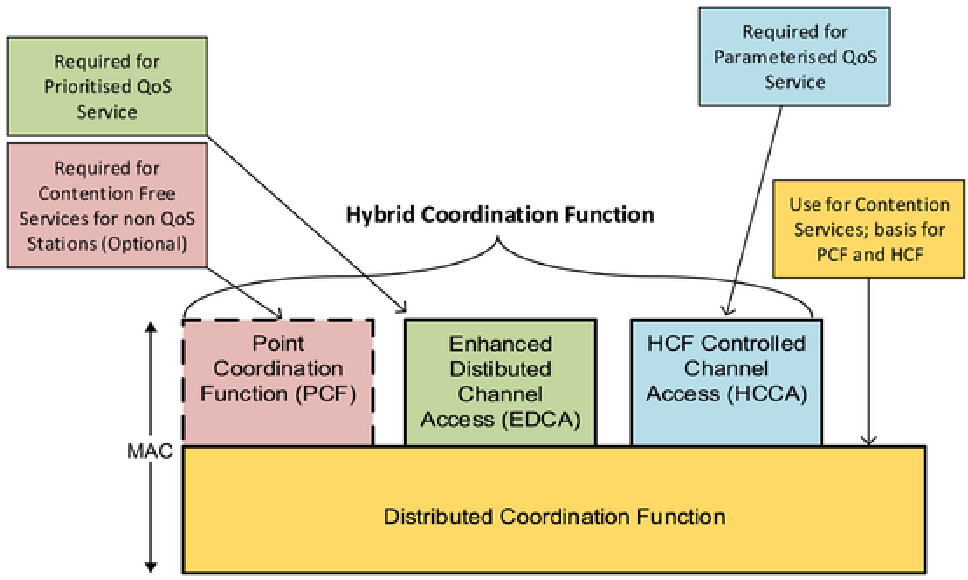

Fig. 5. IEEE 802.11e MAC architecture.

Table 4
User priority to access category mappings [29].

Priority	User Priority (Same as 802.1d Priority)	802.1d designation	Access Category (AC)	Designation (Information)
Lowest ↓ Highest	1	Background	AC_BK	Background
	2	Not defined	AC_BK	Background
	0	Best effort	AC_BE	Best Effort
	3	Excellent effort	AC_BE	Best Effort
	4	Control load	AC_VI	Video
	5	Voice	AC_VI	Video
	6	Video	AC_VO	Voice
	7	Network Control	AC_VO	Voice

exchange sequences onto the Wireless Medium (WM). A TXOP is defined by a starting time and a maximum duration. TXOP is either obtained by the QSTA by successfully contending for the channel or assigned by the Hybrid Coordinator (HC). A TXOP limit value of 0 indicates that QSTA can only send single Mac Service Data Unit (MSDU).

4.2. HCF-Controlled Channel Access

The HCF-Controlled Channel Access (HCCA) provides QoS by using parameterised QoS approach. HCCA uses a QoS-aware centralised controller, called a hybrid coordinator (HC), and operated under rules that are different from the Point Coordinator (PC) of the PCF. The HC is collocated with the QoS Access Point (QAP) of the QoS Basic Service Set (QBSS). HCCA uses the HC's higher priority of access to the WM to initiate frame exchange sequences. HCCA allocate TXOPs to itself and other QSTAs to provide limited-duration Controlled Access Phase (CAP) for contention-free transfer of QoS data. The HC traffic delivery and TXOP allocation may be scheduled during the Contention Period (CP) and any locally generated Contention Free Period (CFP) to meet the QoS requirements of a particular Traffic Category (TC) or Traffic Stream (TS).

Centralised control MAC protocols manage QoS more easily but are hardly implemented in today's products due to their higher complexity, inefficiency for normal data transmission and lack robustness [38]. This research will be conducted based on the distributed wireless MAC protocol i.e. EDCA. The main advantage of the distributed function is that no centralized control mechanism (i.e. PCF or HCCA) is required and no infrastructure (i.e. access point) is necessary [39]. HCCA is beyond the scope of this research. However, further reading about HCCA can be found in [29].

5. Transmit opportunity, frame aggregation, and block acknowledgement

The legacy 802.11 [26] uses the Stop and Wait Automatic Repeating reQuest (SW-ARQ) scheme. In this scheme, sender transmits a single packet (frame) and then waits for the acknowledgement. This involves a lot of overhead due to time spend on sensing the channel before send-ing the packet and immediate transmission of ACKs after each receiving packet [40]. Fig. 6 illustrates IEEE 802.11 MAC overhead and actual payload.

To eliminate the overhead and enhance the throughput performance, IEEE 802.11e introduced new mechanisms called Transmit Opportunity (TXOP), frame aggregation and block acknowledgement

Table 5
DCF and EDCF parameters for IEEE 802.11e [26].

Parameters	AC	CWmin	CWmax	AIFSN	TXOP Limit	
					FHSS	DSSS
DCF	–	aCW	aCWmax	2	0	0
EDCA	AC_BK	aCWmin	aCWmax	7	0	0
	AC_BE	aCWmin	aCWmax	3	0	0
	AC_VI	(aCWmin + 1)/2 - 1	aCWmin	2	6.016ms	3.008ms
	AC_VO	(aCWmin + 1)/4 - 1	(aCWmin + 1)/2 –1	2	3.264	1.504ms

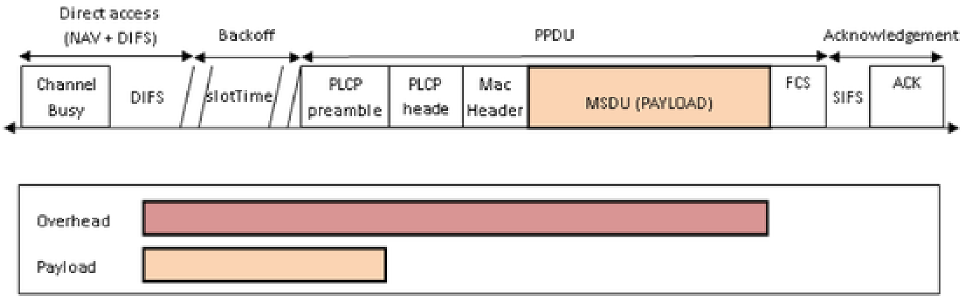

Fig. 6. IEEE 802.11 MAC overhead and actual payload.

(BlockAck). These mechanisms are briefly described in the next sections.

5.1. *Frame aggregation*

During the TXOP period, an STA may combine multiple data packets received from the upper (transport) layer to make a large aggregated frame. Frame aggregation may be categorized into two types or levels i.e. (1) aggregate MAC Service Data Units (AMSDU) and (2) aggregated MAC Protocol Data Units (AMPDU). Two level frame aggregation is illustrated in Fig. 7.

In AMSDU, multiple MAC Service Data Units (MSDUs) also called logical link control (LLC) packets are combined together. Each AMSDU has one MAC address followed by multiple MSDU. It is required for AMSDU that each MSDU should have same Traffic Identification (TID) i.e. each MSDU in AMSDU belongs to same traffic flow, comes from one source and need to be transmitted to one destination. Multiple AMSDU aggregated to form a Protocol Data Unit (PDU). Another side, in AMPDU, multiple PDUs are combined together. In contrast to MSDU, each PDU has its own TID.

5.2. *Block acknowledgement*

To eliminate protocol overhead IEEE 802.11e [29] introduced an optional Selective Repeat ARQ (SQ-ARQ) scheme which is known as block acknowledgement (BlockAck or BA). The BlockAck (illustrated in Fig. 8) is now a compulsory part of IEEE 802.11n High Throughput (HT) devices [36]. This BlockAck mechanism (i.e. sending single Ack instead of several Acks) reduce protocol overhead, improve the efficiency of the channel and enhance the throughput performance [41].

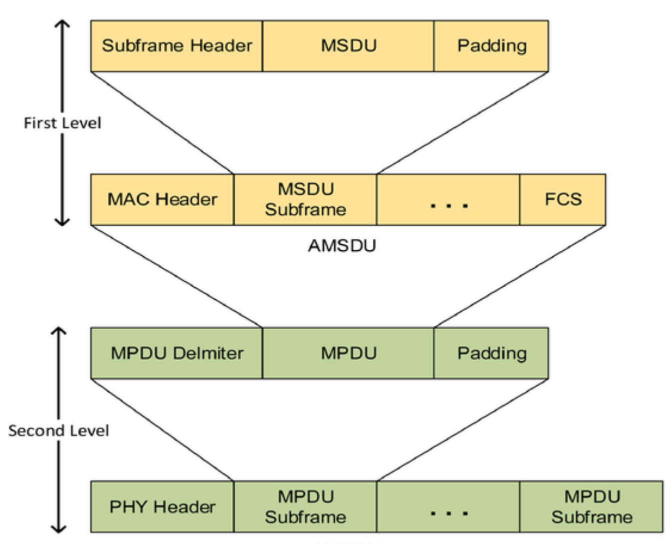

Fig. 7. Two level of frame aggregation.

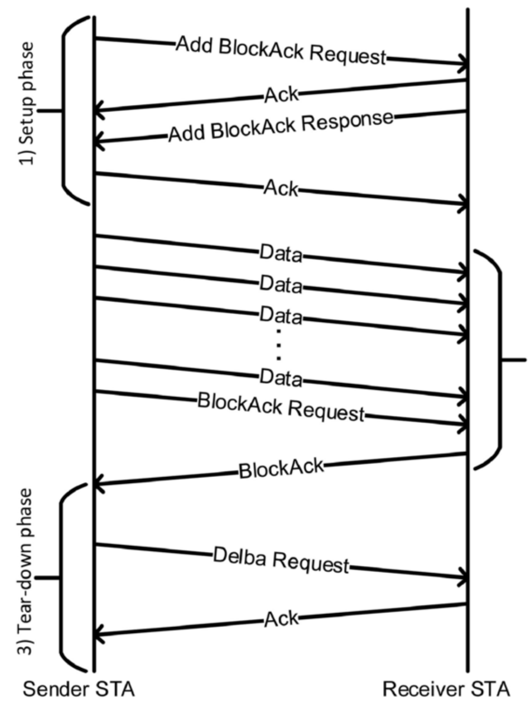

Fig. 8. IEEE 8902.11 (EDCA) BlockAck Mechanism.

The whole process of BlockAck is be divided into three phases i.e. (1) setup phase, (2) transmitting phase, and (3) tear-down phases. In the setup phase, both sender and receiver STAs negotiate the agreement on the successful transmission. The agreement may include the buffer size, and BlockAck policy. After agreeing on the buffer size, and BlockAck policy, sender STA transmit a group of data frames (during TXOP pe-riod) one by one without waiting for Ack in transmitting phase. All data frames are separated by SIFS interval. Once all frames are trans-mitted, a single BlockAck frame sent back to the sender to inform it how many packets have been received correctly. Finally, the agreement between both (sender and receiver) STAs is terminated by sending debla frame [29].

There are two BlockAck schemes used in IEEE 802.11e: delayed and immediate. Delayed BlockAck is useful for applications that can tolerate moderate latency. In this scheme, the sender sends a normal ACK frame first for acknowledging then the receiver sends back the Block Ack at any other time before BlockAck Timeout. The immediate BlockAck method is useful for the applications requiring high bandwidth and low latency. In this scheme, receiver generate the BlockAck within the SIFS time interval.

5.3. *Admission control*

The admission control is a useful technique to provide a QoS guarantee and handle network congestion [42]. An 802.11e [29] network may use admission control to administer policy, regulate the available bandwidth, or ensure that time-sensitive applications will receive required QoS guarantee. Admission control ensures that admittance of new traffic stream into a resource-constrained network does not affect the QoS required by existing traffic streams. There are two distinct admission control mechanisms: one for contention-based access EDCA and another for controlled access HCCA as illustrated in Fig. 9. Admission control, in general, depends on vendors' implementation of the scheduler, available channel capacity, link conditions, retransmission limits, and the scheduling requirements of a given stream [26].

Admission control for EDCA is limited to AC_VO and ACVI. In EDCA based admission control, AP advertise ACM bit via a beacon if admission control is required for any particular AC. An STA with the particular AC sends ADDTS request frame to AP with Traffic Specification (TSPEC). TSPEC allow an EDCA STA to send traffic requirements to the AP for admittance. After receiving ADDTS request frame, AP executes admission control algorithm and response back to the STA using ADDTS response frame. The response frame contains the admission decision.

EDCA based admission control mechanisms can be classified in different ways. For example, Gao, et al. [43] have classified admission control into two types i.e. 1) measurement based admission control and 2) model based admission control. The measurement-based admission control make the decisions by continuously measuring the network conditions such as delay or throughput. There are various examples of measurement based admission controls such as Distributed Admission Control (DAC), Two Level Protection and Guarantee, Virtual MAC and Virtual Source Algorithms, Threshold-Based Admission Control. Another side, model-based admission control use certain models or performance metrics to estimate the network status. Markov chain or contention based admission controls are the examples of model-based admission control. Fig. 9 illustrates the classification of EDCA based admission control mechanisms.

Khoukhi, et al. [44] further categorised EDCA based admission control for ad-hoc networks as 1) single hop or 2) multi-hop (illustrated in Fig. 10). The multi-hop admission controls may be further categories into two types i.e. 1) decouple and 2) couple.

In couple admission controlled schemes, intermediate STAs have capabilities to make the routing decision to achieve admission decisions. Another side, in decouple admission controls schemes, traffic route is already discovered and admission control know the route of traffic from source to destination [45].

6. Emergency traffic and QoS guarantee

The fundamentals of IEEE 802.11 WLANs, a basic understanding of QoS and emergency services were discussed. A primary objective of this paper to develop a framework that supports emergency traffic and provides a QoS guarantee in WLANs. To achieve this objective, a clear understanding of the challenges in providing QoS guarantee and supporting emergency traffic is required. This section provides a review of related literature. The rest of the section is organized as follow: Section 3.2 highlights QoS wireless MAC protocols. Many schemes have been proposed to improve the QoS but they provide service differentiation. Which are presented in Section 3.2.1. Finally, the section is summarized in Section 3.5

6.1. QoS wireless mac protocols

The increasing popularity of real-time traffic (e.g. VoIP over WLAN [106–118]) and emergency services require reliable underlying network technologies. WLANs are expected to support real-time multimedia and emergency traffic. One of the key requirement of both type of traffic (i.e. real-time multimedia and emergency traffic) is certain QoS support (in terms of packet delay, throughput, and jitter). In addition to QoS (delay, throughput, jitter), emergency traffic requires on arrival channel access priority. The challenge is to design a MAC protocol that can satisfy these requirements. A good QoS MAC protocol should provide QoS guarantee to time-sensitive applications and support emergency traffic (on-arrival channel preference and priority over normal traffic) together with the simplicity of operations and high bandwidth utilization. Ideally, a good protocol should provide high throughput, and low end-to-end packet delay, jitter, and packet losses, as well as channel access priority on arrival to emergency traffic. In the literature, many network researchers have taken efforts to investigate MAC protocols to enhance the performance of traditional IEEE 802.11 MAC protocols. These MAC protocols may be categorized into four different classes i.e. 1) MAC protocols provide service differentiation by adjusting MAC parameters i.e. IEEE 802.11e (EDCA) [29], 2) MAC protocols provide QoS guarantee in terms of delay by optimizing admission control i.e. Xio's two-level protection and guarantee mechanism [46], 3) MAC protocols

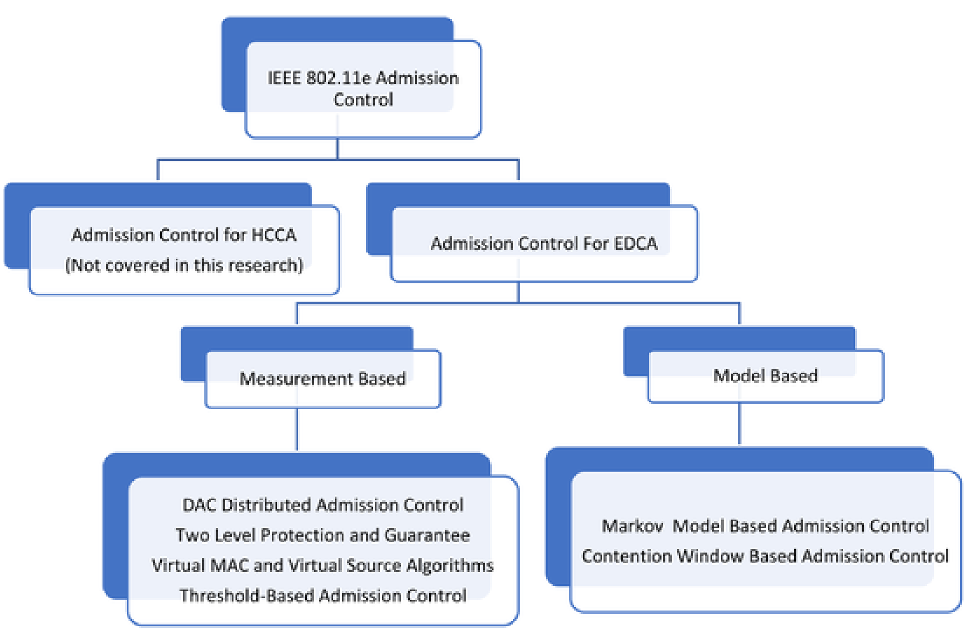

Fig. 9. Classification of IEEE 802.11e based Admission Control.

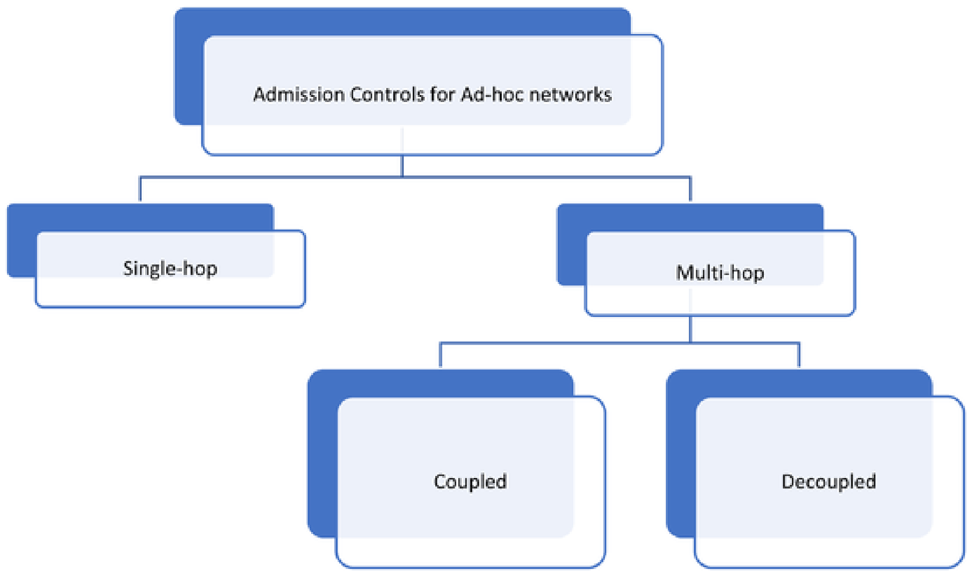

Fig. 10. IEEE 802.11e wireless ad-hoc network based admission control.

support emergency traffic by tuning physical parameters i.e. Balakrishnan's CP-EEDCA [47], and 4) MAC protocols enhance the throughput performance by reducing protocol overhead i.e. Sarkar's BUMA [48]. Fig. 11 illustrates the classification of these MAC protocols.

The next section (i.e. Section 3.2.1, Section 3.2.2, Section 3.2.3 and Section 3.2.4) provide the brief review of the literature on these classifications of IEEE 802.11 MAC protocols for QoS.

7. Service differentiation

The IEEE 802.11e working group introduced a new MAC protocol called IEEE 802.11e [29] to support time-sensitive application and provide QoS guarantee. However, many network researchers [49–54] reported that IEEE 802.11e (EDCA) does not perform well due to its high collision rate, or numbers of slots are going free (idle slots) and MAC/PHY overhead. Over the last 20 years, many MAC schemes have been proposed to improve the throughput performance or provide the service differentiation by giving priority to time-sensitive applications. Most of the schemes are based on backoff mechanism, CW, IFS or Hybrid schemes to improve the performance of EDCA in medium-to-high traffic load. Table 6 lists the key network researchers and their main contributions in the design of wireless MAC protocols for enhancing the throughput performance or providing service differentiation. Column 3 of the table shows the year when these wireless MAC protocols were developed or published. The main approaches used to design or improve the performance MAC protocol is highlighted in column 4.

These DCF/EDCA schemes were grouped into three main categories (Fig. 12). A brief description of each of the main contribution to the design of the wireless MAC protocols listed.

Younggoo et al. [55] developed an efficient MAC scheme called Fast Collision Resolution (FCR) to resolve the collision quickly by increasing contention window size for all STAs to reduce back-off in contention resolution period. FCR scheme assigns smallest window size and idle backoff timer to the STA having successfully transmitted the packet to save the idle time slots. Furthermore, it decreases the backoff timer exponentially as compared to linearly as specified in EDCA when an STA detects a number of idle slots. Younggoo, et al. [55] further proposed enhancement in FCR into real-time-FCR scheme to improve the fairness and QoS support for time-sensitive applications.

While many network researchers have worked on either MAC enhancement or service differentiation independently, very little work has been carried out by considering the combined effect of MAC enhancement and service differentiation of EDCA. Li. et al. [61] proposed dynamic priority reallocation mechanism which distributes a number of active nodes over traffic streams and dynamically alters CW and persistence factor to address the problem of high throughput with better service differentiation. Similarly, Shagdar et al. [63] also investigated the network throughput performance with service differentiation by altering CW of each AC and taking channel busyness ration and number of nodes into account. Chen et al. [49] have proposed a high performance distributed coordination function with QoS support (QHDC) scheme to enhance the performance of EDCA. QHDC works in two

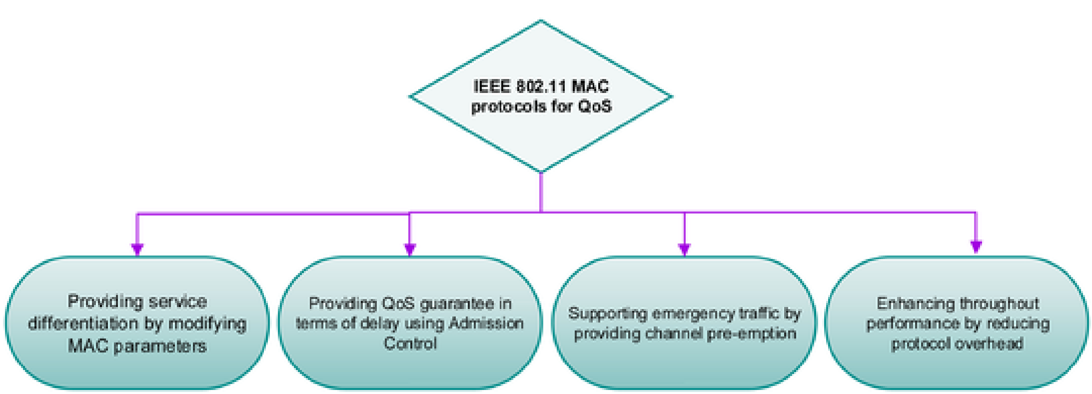

Fig. 11. Classification of IEEE 802.11 MAC protocols for QoS.

Table 6
Key researchers and their contributions in QoS-aware MAC protocols.

Researcher	Contribution	Key concept/description	Limitation
Younggoo, K. Y. et al. [55]	FCR	Adjusted contention window to achieve fast collision resolution.	FCR algorithm is only compared with that of the IEEE 802.11 MAC algorithm.
Romdhani, L. et al.[56]	Adaptive EDCF	Dynamically adjusted the contention of each traffic class.	Reduces more than 50% the collision rate but good-put obtained is up to 25%.
Lin, W. et al. [57]	M-EDCF	Avoided collisions by adjusting contention window and backoff timer.	M-EDCF limited for the inter-frame space.
Lai, Y. et al. [58]	EDCA-LA	Improved the performance by adjusting backoff timer for each access category based on channel conditions.	It's for cross-layer solution only that works in conjunction with a QoS-based MAC layer.
Jian-Xin, W. et al.[59]	RAMP	Reduced collision by using adaptive random CW and AIFS values and assign different values to same priority traffic at a time.	Limited error feedback in a complementary modular manner to achieve the output tracking and system robustness.
Moraes, R. et al. [60]	I-EDCA Improving EDCA	Achieved better performance by tuning CW based on channel condition.	Limited for default parameters of the EDCA mechanism, the number of packet losses and the average packet delays.
Li, M. et al. [61]	QoS for LPT Improving QoS for low priority traffic with high throughput.	Achieved better performance with better QoS for low priority traffic by adjusting CW and Persistence Factor (PF).	Optimal only for small problem instances and greatly outperforms some existing algorithms for large problem instances.
Liang, C. C et al. [62]	EDCA-CA Contention Adaptation	Improved EDCA performance by dynamically adjusting the CW of traffic classes based on applications requirements.	It's limited for the numerical model and analysis to verify the adaptive CW scheme.
Shagdar, O. et al.[63]	TM-EDCA Providing service differentiation with high throughput.	Maximized channel capacity with better QoS (service differentiation) by adjusting CW of each AC based on a number of nodes and channel busyness ratio.	ACs applied only without depending on the number of nodes and channel condition.
Chen, Y. et al. [49]	QHDCF	Getting better performance for high priority traffic without affecting low priority traffic with high throughput.	QHDCF does not starve the low-priority traffic.
Kosek-Szott, K. et al. [64]	IPSD-EDCA	Introduced a new backoff mechanism to improve the performance of EDCA and provide service differentiation based on AIFS and CW.	Support only traffic differentiation with the use of traffic priority-dependant access parameters such as AIFSN, and CW.
Sanada, et al. [65]	IT-EDCA Improve the throughput	Optimise the backoff to enhance the throughput performance. The proposed investigates the channel condition and optimise the CW and backoff mechanism.	IT-EDCA indexes will not increase any added load to networks.
Syed, et al. [66]	PI-EDCA Enhance throughput performance	Enhance throughput performance and reduced collision rate by optimising CW and adjust backoff time based on active STAs of each AC.	PI-EDCA increases the collision amongst STAs.

modes: active mode and contention mode. The active mode used for data; transmitting STA will select the next transmitting STA from active STAs based on probability class having high priority. The content mode follows the EDCA mechanism. Kosek-Szott et al. [64] reported a MAC scheme to improve the performance and provide service differentiation in EDCA (IPSD-EDCA). The Scheme introduced a new backoff mechanism to achieve high throughput. Moreover, CWmin, CWmax and AIFS were also used to provide better service differentiation.

Sanada, et al. [65] investigated the wireless MAC protocol to enhance the throughput performance. The concept is to optimize the backoff mechanic. Authors investigated the channel condition and optimise the CW and backoff mechanism based on the traffic load. Syed et al. [66] developed a MAC protocol for WLANs to enhance the throughput performance of EDCA. The proposed scheme estimates the active STAs for each AC based on that, optimize the contention window and adjust the backoff time.

All these QoS Wireless Mac protocols provide service differentiation and enhance the performance of 802.11e (EDCA) using certain key parameters such as contention window, block acknowledgement, transmit opportunity. None of them provides any QoS guarantee.

8. Service guarantee

Despite providing service differentiation, the EDCA cannot support strict QoS guarantee for time-sensitive applications [67]. Many efforts have been taken to provide QoS guarantee in EDCA. Table 7 lists the key network researchers and their main contributions in providing QoS guarantee to time critical applications. Column 3 of the table shows the year when these wireless MAC protocols were developed or published. The main mechanism approaches used to design or improve the performance of MAC protocols is highlighted in column 4.

Many network researchers consider that QoS guarantee cannot be provided without defining the proper network control mechanism and regulating new input traffic streams into the network. Xiao, Y. et al. [68] adapted a two-level protection mechanism to guarantee time-sensitive applications. Authors proposed distributed admission control and tried-and-known mechanism; Distributed admission control measure the channel utilization on each beacon interval, and available capacity/budget is calculated. Traffic streams are not getting transmission time if their class capacity is zero. Furthermore, STAs are not allowed to increase their transmission time. In addition to this tried-and-know approach; a new STA flow is first temporarily accepted and then measure throughput and delay performance for some beacon interval. If it affects the performance and not coming on the specific requirements then flow is rejected. Similarly, Chen et al. [69] also proposed two schemes: call admission mechanism and rate control mechanism; call admission control is for real-time traffic and rate control for best effort traffic. Rate control utilizes remaining channel capacity without affecting the time-sensitive traffic; each STA monitors the channel busyness ratio and estimates the rate of the ongoing real-time traffic before adding the traffic. Hamidian, A. et al. [51] developed EDCA

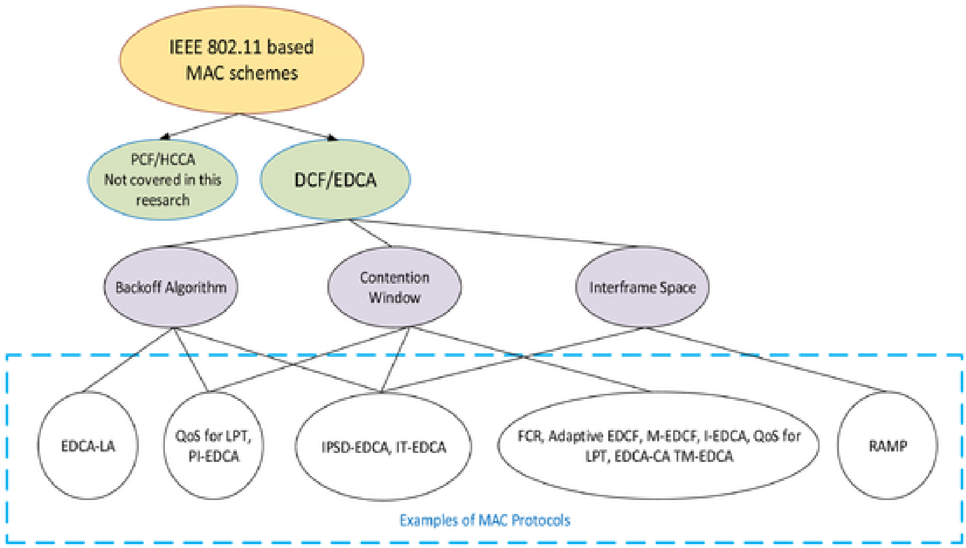

Fig. 12. Approaches used in the design of wireless MAC protocols for providing service differentiation.

with Resource Reservation (EDCA-RR). Authors proposed a traffic scheduler and admission control mechanism. Before admitting the time-sensitive traffic stream; calculate the schedule service interval and resource reservation otherwise works like EDCA. In [70] Hamidian, A. et enhanced EDCA-RR [51] and proposed EDCA-Distributed Resource Reservation (EDCA-DRR) scheme that uses a distributed approach for same admission control, traffic scheduling and resource reservation.

Yang et al. [71] investigated Priority Random Early Detection (PRED) mechanism by enhancing Random Early Detection (RED) [77]; PRED Alters Queue[AC] based on traffic load used scheduling mechanism to give priority to each packet within the STA. Sarma et al. [72] proposed a Strict Priority Based QoS Aware MAC Protocol (SPQAMP) that gives first priority to time-sensitive STA to send the packet by assigning non-overlapping values to CW for time sensitive and best effort traffic and reset the back-off counter instead of freezing for best effort traffic.

Centikaya [73] developed admission control, flow-based and class-based queuing schemes to provide QoS to different time-sensitive applications. Furthermore, each STA alters the backoff counter based on STA's own packet's priority and previously transmitted packet's priority to protect time-sensitive traffic. In Tadayon, N. et al. [74] addressed the inefficiency of uniform Probability Density Function (PDF) used by EDCA while dealing with new time-sensitive applications. Authors replace Uniform PDF with Gamma PDF to prioritize the time-sensitive applications. Most of the above proposed schemes only provide QoS guarantee under low traffic load, when the traffic load is increased they provide service differentiation rather than QoS guarantee. Here the question may arise about supporting a strict QoS guarantee rather than service differentiation to time-sensitive applications operating under medium to high traffic load conditions.

Mansoor, et al. [76] proposed a Feedback based Admission Control Unit (FACU) scheme and optimise the TXOP to improve the QoS of video transmission in WLANs. However, authors did not consider other real-time traffic such as voice or emergency. Moreover, the proposed scheme does not provide any QoS guarantee.

9. Emergency traffic support in QoS MAC protocols

The 802.11e (EDCA) does not provide any mechanism to prioritise emergency traffic [26]. Recently 802.11u-2011 [30] working group introduced a new standard called 802.11 u for interworking with external networks that also support emergency traffic over infrastructure-based WLANs but may not provide emergency traffic support over ad-hoc WLANs. General Packet Radio Service (GPRS) and Global System for Mobile Communications (GSM), or any other infrastructure networks are highly affected by disasters. An ad-hoc networking approach will allow the relief groups to enter the disaster area and communicate with each other quickly [78].

Previously, schemes to support emergency traffic over WLANs have been proposed. Table 8 summarises the Key network researchers and their main contributions in the support of emergency traffic over WLANs. Conte et al. [79] investigated centrally controlled admission control of 802.11e to enable emergency call. While using admission control mechanism, additional information is provided to identify and differentiate the requests related to the emergency call. Furthermore, two approaches are proposed to provide additional information: use Emergency flag as a field in the Traffic Specification (TSPEC) element for the source message and second approach is create high priority emergency traffic class and such class information is provided by using Traffic Stream (TS) Information field of TSPEC with the source message. Lu-min et al. [80] evaluated the performance of EDCA while considering emergency traffic during congestion situation; the authors proposed a new AC for emergency or any other time-critical traffic. Emergency traffic should be able to access the channel on a highest priority basis, should be capable to access the channel by breaking ongoing low priority transmission. To address this issue, many network researchers proposed channel preemption schemes [47, 81, 82, 84, 85].

Sheu, T.L. et al. scheduling scheme [81] proposed Centralized Channel preemption techniques which can be only coordinated by a central controller but not suitable for ad-hoc networks. Eiager et al. [82] invented latency aware service opportunity (LASO) preemption channel scheme that curtails the on-going transmission duration of the lower traffic class, but if the channel is assigned for pre-allocated time duration cannot be interrupted. Balakrishnan et al. [83] proposed a channel preemptive EDCA (CP-EDCA) scheme to support emergency traffic in ad-hoc networks. Emergency traffic stream can break an ongoing session and get the channel access by adjusting SIFS and SlotTime. This scheme is not suitable for a dense emergency situation where a high number of emergency users want to access the channel.

Son, et al. [84] investigated three types of medical traffic i.e. (1) medical alarm, (2) Electro Cardio-Gram (ECG), and (3) non-real-time traffic. Medical alarm traffic was given highest priority followed by ECG and non-real-time traffic. Authors developed a MAC protocol for WLANs to provide priority to medical traffic. An adaptive AIFS scheme with admission control is proposed for 802.11e (EDCA). The key concept is to adjust AIFS values based on the required QoS required by

Table 7
Key researchers and their contributions in providing QoS guarantee in WLANs.

Researcher	Contribution	Key concept/description	Limitation
Xiao, Y. et al. [68]	Providing QoS guarantee to voice and video	Introduced two-level approach; distributed admission control and tried-and-know mechanism to provide QoS guarantee to voice and video.	Change the connection window size for the deferring stations.
Chen, X. et al. [69]	Improving QoS guarantee to real-time traffic	Proposed two schemes; call admission control for real-time traffic and rate control for best effort traffic.	Not improving QoS for other traffics.
Hamidian, A. et al. 2006 [51] and 2008 [70]	EDCA-RR EDCA-DRR	Improved QoS guarantee by investigating admission control and traffic scheduler. Real-time traffic reserved the channel. The problem of hidden STAs during reserved TXOP is also addressed.	It cannot provide any service differentiation since all stations have the same priority.
Yang, C. et al. [71]	PRED	Enhanced in the previously proposed mechanism by Floyd, S. et al. to provide better QoS guarantee.	Scheduling mechanism to give priority.
Sarma, N. et al. [72]	SPQAMP	Improved QoS guarantee by providing non-overlapping CW to time-sensitive traffic.	A strict non-overlapping range of contention windows are assigned to real-time and best-effort traffic.
Cetinkaya, C. [73]	Providing different QoS to different real-time traffic	Proposed admission control, flow based and class based queuing schemes to provide different priorities to different applications.	Provide limited QoS for IP networks.
Tadayon, N. et al.[74]	Improving QoS guarantee	Achieved better QoS guarantee by tuning CW on the basis of channel's load.	Limitation of Replacement for Uniform PDF with Gamma PDF.
Ferng, H. et al. [75]	FRRBC	Investigated QoS guarantee with fairness.	Using multiple mapping only functions from allowances to fixed-bit binary numbers to indicate different priorities.
Mansoor, et al. [76]	FACU	Proposed admission control and optimise TXOP	FACU exploits piggybacked information containing.

medical traffic. The AIFS values are increased for low priority traffic if high priority medical traffic is not receiving the required QoS. Moreover, an admission control is introduced for low priority to provide QoS guarantee to the highest priority medical alarm traffic. However, the highest priority traffic (medical alarm) is not protected by the same class of traffic. The strict QoS guarantee may not be achieved in saturated network conditions where a high number of nodes with medical alarm traffic wants to access the medium.

Preemption schemes are also proposed in other wireless networks. Balakrishnan, M. et al. [86] investigated EDCA based channel preemption scheme for wireless sensor networks, which claims 50% decrease in a delay while accessing the WM for emergency traffic. In [85] Zhou et al. defined control emergency channel preemption scheme for cellular networks. They proposed two queues: one for emergency and one for the public; emergency traffic has limited preemption capability.

Table 8
Key researchers and their main contributions to support emergency traffic in WLANs.

Researcher	Contribution	Key concept/description	Limitation
Conte, A. et al. [79]	Enabling Emergency Support to 802.11e	Proposed admission control (Central Controller) with additional information for 802.11e to enable emergency support.	It handles only a resource request for an emergency call in a well-adapted way.
Lu-ming, C. et al. [80]	Investigating emergency traffic performance	Investigated performance of emergency traffic under high traffic load. Proposed new access category for an emergency.	Support only neural networks and synthetic model.
Sheu, T. L. et al. [81]	Centralized channel preemption	Defined centralized channel preemption mechanism that can only be coordinated through a central device.	Limited for the bandwidth resource of a web channel.
Eiger, M. et al. [82]	LASO	Proposed latency aware service opportunity channel preemption mechanism for emergency traffic.	The goal of the scheduling method is limited to meet delay requirements of HCCA traffic flows.
Balakrishnan, M. et al.[83]	CP-EDCA	Investigated in-channel preemption mechanism for emergency traffic.	It's a channel pre-emptive enhancement to the IEEE 802.11e EDCA standard. It's only for distributed wireless environments.
Selingnan, A. et al.	Terminal with Emergency Access	Proposed a terminal with an emergency access over WLAN to LAN and other communication system.	Limited for few terminals with emergency access.
[84]	Adaptive AIFS and admission control	Introducing a new Adapting AIFS and admission control to provide priority to medical application	The proposed mechanism strictly assures the medical-grade QoS.

10. Frame aggregation and blockack

The foundation background on TXOP, frame aggregation and block acknowledgement was provided. It was highlighted that IEEE 802.11 MAC does not perform well due to protocol overhead [26, 87]. To enhance the performance of 802.11 MAC and reduce the overhead, the IEEE 802.11e MAC introduced several mechanisms and parameters called TXOP, block size and BlockAck. For the performance optimization, 802.11e enhancement left these parameters open in the standard, for example, block size or BlockAck policies [88]. The use of a smaller block size increases the overhead as each time STA needs to negotiation before transmitting the frame. Another side, the larger block size may increase the error rate and results delay for real-time applications [89, 90].

Over the last 10 years, many schemes have been proposed to enhance the throughput performance by reducing protocol overhead. Most of the schemes are based on optimizing TXOP, frame concatenation and BlockAck. Table lists the key network researchers and their main contributions in the design of wireless MAC protocols for enhancing the throughput performance in WLANs. Column 3 of the table shows the year when these wireless MAC protocols were developed or published. The main approaches researchers used to design or improve the performance MAC protocol is highlighted in column 4.

These 802.11 (DCF) or 802.11e (EDCA) based schemes were grouped into three main categories (Fig. 13). A brief description of each of the main contribution to the design of the wireless MAC protocols listed in Table 9 is given.

Recent studies [90] have shown that 802.11e BlockAck scheme can enhance network throughput performance at the cost of re-sequencing delay at the receiving buffer.

Many MAC schemes have been proposed to reduce the transmission overhead, enhance the throughput performance and increase channel efficiency. These MAC schemes may be categorized as frames aggregation [36,61,97], optimising TXOP [96], BlockAck [91] or hybrid [92,94,95,98]. Sarkar and Sowerby [48] proposed a new protocol called Buffer Unit Multiple Access (BUMA) that combines short packets in a flow to form large frames (with single header and trailer) for reducing control and transmission overhead. However, BUMA is only suitable for UDP applications and may not provide assurance of delivery.

Azevêdo Filho, et al. [94] proposed Holding Time Aggregation (HTA) packet aggregation scheme for reducing the MAC transmission overload. In HTA, each station STA calculates the amount of time a packet takes for its journey and the time an application may tolerate the delay. Moreover, STA also considers the application requirement and dynamic wireless environment i.e. variable bandwidth for packet aggregation. However, the proposed HTA scheme is only suitable for UDP Applications.

IEEE 802.11n [36] standard defined two frame aggregation schemes for achieving higher throughput at the MAC layer, Aggregate MAC Service Data Unit (A-MSDU) and aggregate MAC protocol data unit (A-MPDU). In the result of aggregation, standard 802.11 introduced new frame headers. Although, these headers are smaller in the size as compare to legacy 802.11 but still have negative performance specially when added with the small payload. Moreover, network performance is highly affected while transmitting the A-MSDUs due to lack of control subsequence frames and retransmission. To address this issue, Saif, et al. [93] develop a MAC scheme called minimized header MSDU aggregation scheme (mA-MSDU) for reducing the transmission overhead by aggregating MSDUs. The proposed scheme minimized headers overhead by optimizing the subframe aggregation headers. Moreover, authors also introduced implicit sequence control (ISC) as error controller for subframes. The advantage of using ISC is to retransmit only the corrupted subframes. On the other hand, Kowsar and Biswas [96] proposed a two-level aggregation scheme by combining A-MSDU and A-MPDU schemes. This scheme enhances the throughput performance and decrease the MAC delay.

Implementation of IEEE 802.11n do not aggregate MPDU for voice traffic due to its specific end-to-end delay requirements. Seytnazarov and Kim [97] identified that the performance of the network is highly degraded in saturated traffic condition when multiple nodes access the medium for transmitting voice traffic. Authors proposed QoS aware adaptive A-MPDU aggregation scheme (QAA-MPDU). The QAA-MPDU scheme optimizes throughput performance by aggregating MPDU for voice traffic and reducing protocol overhead.

Liu, et al. [98] first reported adaptive MAC protocol data unit (A-MPDU) MAC scheme does not provide transmission efficiency under error-prone environment. To overcome from this problem, authors proposed Adaptive A-MPDU (AA-MPDU) frame aggregation scheme. The AA-MPDU uses three modules; 1) the Bit Error Rate (BER), estimator to calculate average error rate, 2) retransmission A-MPDU Level (RAL) module to identify the position of lost sub-frame, and 3) theoretical throughput decision module which uses BET estimate and RALK modules for making decision for using frame-aggregation scheme.

Hazra and De [92] proposed a frame concatenation with block acknowledgement schemes based on TXOP to enhance the throughput performance of EDCA and provide QoS guarantee to time-sensitive applications. However, the proposed schemes are only suitable for client-server application e.g. transferring a file or rich multimedia applications with sending multiple picture frames. Cabral, et al. [91] optimized the block acknowledgement (O-BlockAck) scheme to reduce the delay and increase the number of users within the network. Authors investigated the performance of O-BlockAck scheme using a single service and a mixture of services used by the node. The empirical results show that fragment size 12 is more appropriate for a mixture of services and supported users may be increased from 30 to 35within a network.

Azevêdo Filho, et al. [94] proposed Holding Time Aggregation (HTA) packet aggregation scheme for reducing the MAC transmission overload. In HTA, each station STA calculates the amount of time a packet takes for its journey and the time an application may tolerate the delay. Moreover, STA also considers the application requirement and dynamic wireless environment i.e. variable bandwidth for packet

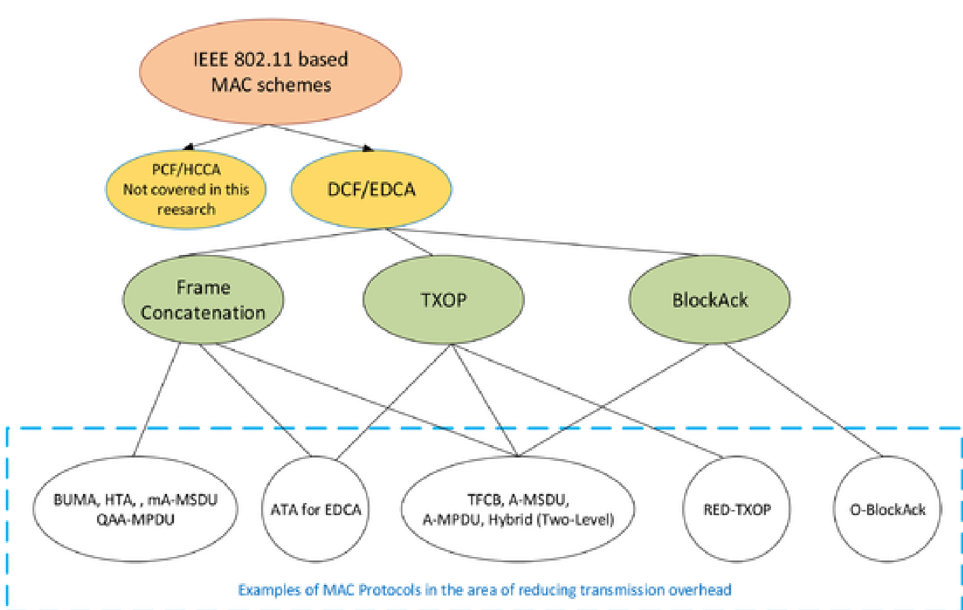

Fig. 13. Approaches used in the design of wireless MAC protocols to reduce transmission overhead.

Table 9
Key researchers and their main contributions in the design of wireless MAC protocols.

Researcher	Contribution	Key concept/description	Limitation
Sarkar and Sowerby [48]	BUMA	Enhanced throughput performance by reducing transmission overhead.	Does not consider TCP applications. It is only limited to UDP applications.
Cabral, et al. [91]	O-BlockAck	Optimised BlockAck to reduce delay and increase the number of users in the network.	Only a boundary layer separation in the hub-suction side corner grows.
IEEE 802.11n 36]	A-MSDU A-MPDU Hybrid (two-level)	Enhanced throughput performance and achieved channel efficiency by using various frame-aggregation schemes	Aggregated only into a single MPDU
Hazra and De [92]	TXOP based Frame Concatenation and BlockAck (TFCB)	Investigated frame concatenation and BlockAck based on TXOP to enhance the performance and provide QoS	It based only frame-concatenation with block-acknowledgement scheme.
Saif, et al. [93]	mA-MSDU	Proposed aggregation scheme that aggregate frame header and implemented retransmission control over individual sub-frames	Headers are small compared to the legacy headers.
Azevêdo Filho, et al. [94]	HTA	Investigated packet aggregation scheme based on packet's journey (source node to destination) time and application's delay tolerance.	Compared to another prominent packet aggregation scheme.
Kim and Cho [95]	ATA for EDCA	Achieved performance enhancement and fairness by tuning TXOP and BlockAck.	It's only for fairness amongst stations with different multimedia applications.
Kowsar and Biswas [96]	Two-level aggregation	Optimised throughput performance by aggregating A-MSDU and A-MPDU.	Analysed its performance by using only simulation in multi-client mode.
Seytnazarov and Kim [97]	QAA-MPDU	Enhanced throughput performance by aggregation MPDU for voice traffic	Less nodes transmitting. It's only for A-MPDU aggregation.
Liu, et al. [98]	Adaptive A-MPDU	Investigated retransmission scheme with two-level frame aggregation	A-MPDU retransmission scheme can achieve only higher throughput and medium access control (MAC) layer efficiency.

aggregation. However, the proposed HTA scheme is only suitable for UDP Applications.

Many researchers investigated TXOP for enhancing the throughput performance and reducing protocol overhead. Feng, et al. [99] proposed random early detection transmit opportunity (RED-TXOP). Authors tune the TXOP dynamically for optimizing the throughput performance of multimedia traffic.

Kim and Cho [95] investigated an adaptive TXOP allocation (ATA) scheme for EDCA to enhance the performance and provide fairness. In the proposed scheme, each station decides (increase or decrease) TXOP interval based on traffic load and delay bound required by the application. An STA increases TXOP interval in two conditions. First, STA increases its TXOP to satisfy the QoS guarantee required by its packet queue. Second, when the traffic load is low.

11. Wireless MAC performance issues

Previous research demonstrated that most of the proposed MAC schemes target for throughput enhancement or service differentiation by adjusting IFS and CW. In addition to service differentiation, many MAC schemes have been proposed to provide the QoS guarantee. However, none of them provides strict QoS guarantee. Furthermore, little research has been conducted in the area of emergency traffic support over WLAN.

Moreover, A lack of a suitable framework to support emergency traffic in the dense emergency situation, such as a disaster where a high number of nodes reporting an emergency. The proposed research aims to develop a robust framework to provide a strict QoS guarantee for time-sensitive applications and to support emergency traffic by enhancing 802.11e.

12. Design challenges for distributed wireless MAC protocols

Designing a distribute wireless MAC protocol is really a challenging task due to: shared medium at the Local Area Network (LAN) level, providing QoS guarantee under high traffic load; supporting emergency traffic; node mobility, probabilistic nature of wireless medium. Shared medium: At the LAN level, all the stations shared the common channel. Without proper channel access mechanism, multiple STAs may access the channel simultaneously for transmitting the packet and in the result lead to packet collision and delay.

Providing QoS guarantee: STAs with real-time multimedia or emergency traffic require QoS guarantee. The increasing number of STAs on a particular channel (high traffic load) increase the chances of simultaneous packet transmission from multiple STAs and lead the collision. In such scenario, QoS guarantee may not be provided to any time-sensitive application without proper admittance control mechanism. Node mobility: A wireless STA in the network may move independently and randomly which may increase the distance between sender and receiver STAs. Variations in the distance may affect the QoS and overall network performance.

Due to the probabilistic nature of the wireless medium, designing a MAC protocol as various problems to solve. The main challenge is to control the share wireless medium. A key LAN issue is controlling station access to a common channel. Without proper access control, two or more stations may transmit simultaneously resulting in packet collisions and delay. The characteristics of the shared wireless medium do not provide a unified view of the medium to all nodes due to the physical differences between wired and wireless communication.

13. Future research direction industrial integration and industrial standards

The IEEE 802.11 WLAN network is a wireless Ethernet, play an important function in the Industrial Integration and Industrial Standards. WLAN is based on Link Layer (LL). LL is divided into Logical Link Control (LLC) and Medium Access Control (MAC) sub-layer categorizes with two functions, Distributed Coordination Function (DCF) and Point Coordination Function (PCF) [9]. IEEE 802.11 [114] standards 802.11a support 5 GHz frequency band and 54 Mbps data rate, 802.11b support 2.4 GHz frequency and 11Mpbs data rate, 802.11 g support 2.4 GHz frequency band and data rate 54 Mbps. Details are as in Table 10 [119–122].

VoIP WLAN Industrial Integration networks have observed a fastest growth in the world of industrial communication. WLAN is most assuring technologies amongst wireless networks, which have been facili-

Table 10
WLAN Industrial Integration and Industrial Standards [119].

	IEEE 802.11a	IEEE 802.11b	IEEE 802.11g
Data Rates	54Mbps	11Mbps	54Mbps
Frequency	5GHz	2.4GHz	2.4GHz

tated high-rate voice services at very less cost and flexibility over IP-based networks [126].

Fig. 14 shows a VoIP over WLAN industrial integration architecture system with two voice sources from VoIP traffic server. WLAN networks support both wired and wireless applications for industrial Integrations. Voice sources are given two traffic paths; One is Access Point-A (AP-A) and another is Access Point-B (AP-B) with Basic Service Set (BSS) and Extended Service Set (ESS). VoIP gives a number of real-time VoIP sessions in the WLAN networks. An AP for industrial integration can support (10) to (16) Mobile Nodes (MN) over 802.11b on G.711 codec technique over infrastructure architecture network. Normally, an AP is positioned as a central direction with communication MN over WLAN networks. The bidirectional communication describes the uplink voice flow transmitted by the VoIP client and the downlink voice flow transmitted by the AP. The AP is usually present as the gateway between the wired node and the wireless node VoIP clients.

A **WIA-FA** is a recently released Internationalelectro Technical Commission (IEC) standards (IEC 62948 [123]) in 2017 for factory automation and is expected to see a wide range of applications in industrial sensing and control, such as digital workshop, Automated Guided Vehicles (AGVs), and industrial robot cooperation.

B **FlexWARE** This protocol is the result of the efforts carried out within an EU-funded international project [124], whose goal was to define an original system architecture for the industrial automation scenarios, where the communication infrastructure is based over the IEEE 802.11 wireless networks [125].

14. Conclusion

This survey paper for providing Quality of Sevice (QoS) guarantee and supporting emergency traffic in wireless QoS Medium Access Control (MAC) protocols was presented. The paper reveals that IEEE 802.11e Enhanced Distributed Channel Access (EDCA) does not have inherent emergency traffic support. Moreover, it neither provides QoS guarantee nor works well under medium to high traffic load. Therefore, many QoS MAC schemes proposed by network researchers to enhance the performance of 802.11e EDCA. However, most of the QoS schemes have focused on either network throughput enhancement or service differentiation by adjusting the Contention Window (CW) or Inter-Frame Spaces (IFS). While many efforts have been put in to provide QoS guarantee in EDCA, but they do not provide strict QoS guarantee especially under medium to high traffic loads. Additionally, there is not enough research published in the area of emergency traffic over Wireless LANs (WLANs). Therefore, a research on developing techniques to provide a strict QoS guarantee as well as support for emergency traffic is required in such systems. As for as future work is concern, it will modify WLAN MAC and it will propose schemes to reduce the protocol transmission overhead, accommodate the enlarge variety of emergency nodes over the network.

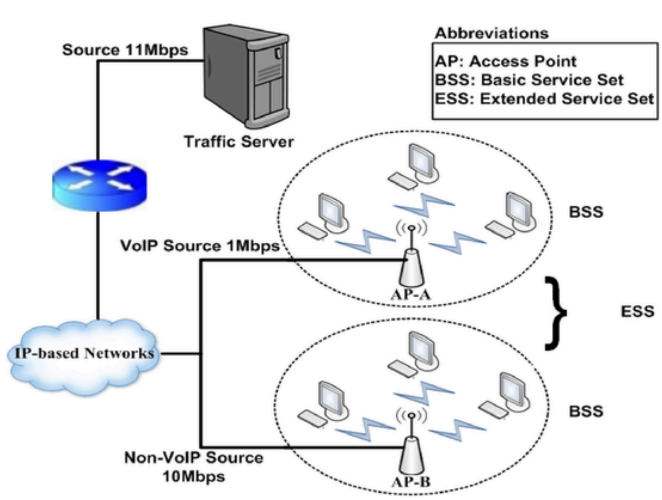

Fig. 14. VoIP over WLAN Industrial Integration Architecture System.

Declaration of Competing Interest

The authors declare no conflict of interest.

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