QoS based Radio Resource Management Techniques for Next Generation MU-MIMO WLANs: A Survey

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***Abstract*—IEEE 802.11 based Wireless Local Area Networks (WLANs) have emerged as a popular candidate that offers Internet services for wireless users. The demand of data traffic is increasing every day due to the increase in the use of multimedia applications, such as digital audio, video, and online gaming. With the inclusion of Physical Layer (PHY) technologies, such as the OFDM and MIMO, the current 802.11ac WLANs are claiming Gigabit speeds. Hence, the existing Medium Access Control (MAC) must be in a suitable position to convert the offered PHY data rates for efficient throughput. Further, the integration of cellular networks with WLANs requires unique changes at MAC layer. It is highly required to preserve the Quality of Service (QoS) in these scenarios. Fundamentally, many QoS issues arise from the problem of effective Radio Resource Management (RRM). Although IEEE 802.11 has lifted PHY layer aspects, there is a necessity to investigate MAC layer issues, such as resource utilization, scheduling, admission control and congestion control. In this survey, a literature overview of these techniques, namely the resource allocation and scheduling algorithms are briefly discussed in connection with the QoS at MAC layer. Further, some anticipated enhancements proposed for Multi-User Multiple-Input and Multiple-Output (MU-MIMO) WLANs are discussed.**

***Index Terms*—OFDM, MIMO, QoS, RRM, Scheduling.**

I. INTRODUCTION

Conventionally, IEEE 802.11 is a means for users to stay connected via the Internet, check mails or browse the web at home or in the enterprise. It offers higher data rates with limited mobility. Today, the trend is rapidly changing, whereby IEEE 802.11 is being used for content consumption, such as streaming music and videos. The recent IEEE 802.11ac [1] [2] WLAN offers gigabit speeds by incorporating some enhancements to the current technology. However, with the increasing demand for data rates, the provision to support QoS [3] also increases in the future WLAN standards. The performance of WLANs degrades mainly due to time-varying channels, user mobility, interfering nodes and collisions due to hidden stations [4]. In future, to cover a number of users and to provide higher transmission rates, the WLAN access points will be densely deployed along with Cellular networks [5]. Hence, achieving the required QoS in these scenarios is a difficult and challenging task. These extensions to WLANs brought some additional challenges to existing MAC, with limited mobility.

In order to guarantee QoS, there is a need to develop efficient Radio Resource Management techniques for the next generation WLANs [6]. The growing demand for advanced multimedia services combined with the resource constraints of the wireless networks shows that there is a need for efficient resource allocation schemes to attain a competent resource management that combines with acceptable QoS levels for end users. QoS in Wireless networks [7] is highly related to a number of network resources and it maximizes the number of users accordingly. Effective resource management with adequate QoS makes WLANs suitable for increasing the demands of multimedia. A huge amount of research has been conducted on the topic of QoS provision in WLANs. The survey of QoS enhancement techniques for WLANs can be found in [8] [9] [10]. Some useful QoS architectures for 802.11 WLANs can be found in [11] [12] [13]. Most of the research have been focused on conventional Orthogonal Frequency Division Multiplexing (OFDM) based WLANs. These networks are primarily mentioned for single user communications. Later, to communicate with many users at the same time and to improve the overall system capacity [14] [15], Multiple Input Multiple Output (MIMO) is introduced in the PHY layer of WLANs. This brought a shift from single user to multiuser communications [17]. The system capacity has been greatly improved [18]. The combination of MIMO and OFDM [19] has a number of advantages. Though the technology enhancement in the PHY layer has improved the data rates, it poses a question of how far MAC is efficient to offer sufficient QoS to users. Only, a few papers have addressed the QoS issue in the forthcoming WLANs. In this survey, a focused overview of resource management schemes to ensure QoS in 802.11 WLANs has been addressed. Further, some proposals to enhance MAC efficiency based on traffic demands and QoS are discussed.

This paper discusses a brief survey of QoS based Radio resource management techniques in Wireless local area networks. It is organized as follows: In section II, a brief review of IEEE 802.11 WLAN standards is provided. Section III discusses various aspects of Radio resource management that can be used to facilitate the provision of QoS in the upcoming WLANs. With the increased data rates and the integration of future heterogeneous networks, the algorithms need to be adaptive. Hence, in Section IV, issues in resource utilization and scheduling related to the current trend are addressed. Finally, Section V concludes the paper.

II. OVERVIEW OF IEEE 802.11 WLANS

In this section, a brief overview of IEEE 802.11 wireless standards/amendments with the emphasis on the PHY and MAC layer specifications is provided. There have been different variants of IEEE standards or amendments, generally specified by the name of standards or amendments interchangeably. These standards are designated with IEEE 802.11 followed by the year when they are published (e.g., IEEE 802.11-2012) and the amendments are represented as documents in the existing standards (e.g., IEEE 802.11n or IEEE 802.11ac). Standards are updated continuously by amendments. In June 1997, the IEEE Std. 802.11-1997 was published, and it was the first WLAN standard. Later, IEEE has released four standards: 802.11-1997, 802.11-1999 [20], 802.11-2007 and 802.11-2012. The IEEE 802.11-2012 [21] is the most recent version that is currently in publication.

A. IEEE 802.11 Physical (PHY) Layers

The fundamental 802.11 standard defines many physical specifications, and it has undergone revisions since its ratification. The most current 802.11 physical has been the result of the 802.11ac amendment, and several physical layers based on other amendments to the standard, including 802.11n and the legacy versions (for example, the 802.11a, 802.11b, 802.11g are still in use). This section covers the legacy 802.11 physical layers along with the revised amendments, such as the 802.11n [22] and the 802.11ac. The initial 802.11-1997 standard is operated within the frequency band of 2.4 GHz. It uses two wideband spread spectrum techniques, namely the Frequency Hopping Spread Spectrum (FHSS) and the Direct Sequence Spread Spectrum (DSSS). The binary data is transmitted at a maximum rate of 2 Mbps. It also supports Infra Red (IR) transmission. However, the IR technique is not in used due to its inherent drawbacks. The remaining two techniques are still in used in some WLANs. Later, two amendments [20] were ratified in 1999, namely the 802.11a and the 802.11b. The IEEE 802.11a Physical layer operates in 5 GHz frequency band and uses OFDM as its modulation technique. The OFDM Physical layer delivers data rates between 6-Mbps and 54-Mbps in the 2.4GHz band. The 802.11a is considered as the basis for high-speed WLANs.

The 802.11 High-Rate Direct Sequence Spread Spectrum (HR-DSSS) supports enhanced data rates. It is an extension of the initial 802.11 DSSS standard HR-DSSS, commonly stated as the 802.11b (ratified in 1999 along with the 802.11a) and operates in the same 2.4 GHz and achieves extended data rates of 5.5 Mbps and 11Mbps. The HR-DSSS is backward compatible to the implementation of the 802.11 DSSS. The 802.11g amendment ratified in 2003 extends the data rates in the 2.4GHz band to 54Mbps through the use of OFDM and, it is backward compatible with the initial DSSS and HR-DSSS (802.11b) physical layers. It is most commonly referred as the Extended Rate Physical (ERP) layer. The 802.11n [22] amendment, which specifies MIMO technology to enhance data rates into hundreds of megabits per second in the 2.4 GHz and 5 GHz band was ratified in 2009. The 802.11n is backward compatible with the 802.11a/b/g. Because of the much higher data rate and flexibility of 802.11n, the newest deployments today is in 2.4 GHz band based on the 802.11n.

IEEE 802.11ac is the latest amendment ratified in the year 2013. Aiming to provide throughput rates ranging 1Gbps, it operates entirely in 5 GHz frequency band. The 802.11ac has undergone some primary changes in its physical layer compared to 802.11n. It supports wider bandwidths (80 and 160 MHz) and higher order modulation schemes (256-QAM: Quadrature Amplitude Modulation) and most importantly downlink MU-MIMO transmissions (supports up to 4 stations using 8 parallel spatial streams). The 802.11ac is termed as Very High Throughput (VHT) WLAN.

B. IEEE 802.11 Medium Access Control (MAC) Layers

In the IEEE 802.11, the basic media access mechanisms are the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF), where DCF is a distributed access scheme and PCF is the centralized access scheme. The DCF is a default Medium access scheme of the IEEE 802.11 based WLANs. It is based on a contention protocol called the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) used to detect and share the wireless channel among stations (STAs). It is not capable of providing the required performance for voice and video applications because it is developed for services that do not guarantee reliability.

The basic MAC mechanism of the 802.11 [20] does not differentiate the services of users. For that reason, the IEEE 802.11e [23] amendment was ratified in order to provide QoS support [24] to WLANs. It differentiates the services into four Access Categories (ACs) with different priorities: voice, video, best effort and background. The IEEE 802.11e [23] proposes an extension to DCF called the Enhanced Distributed Coordination Access (EDCA) in support to the QoS [25] of voice and video services. Although this amendment brings in service differentiation, it is not able to guarantee QoS for applications that have firm QoS requirements [26]. However, the EDCA is unable to solve the performance degradation problem when the channel becomes saturated. Hence, the IEEE 802.11n next generation standard seems to be a reasonable technology to support the demand of multimedia applications. It has three main MAC enhancements to reduce the protocol overheads in the frame transmission: Aggregation MAC Service data unit (A-MSDU), Aggregation MAC protocol data unit (A-MPDU) and Block Acknowledgement (BA). In this scheme, the frames are combined and transmitted together in aggregated packets. Hence, the aggregation scheme reduces the overhead transmission time and decreases the waiting time resulting from the random backoff period during consecutive frame transmissions. Although the 802.11n delivers high throughput, only one user benefits at one time. To overcome this, the IEEE 802.11ac is approved in 2013 with PHY and MAC enhancements over the 802.11n. The MAC layer mechanism is a Transmission Opportunity (TXOP) sharing scheme used to perform multiple downlink streams to multiple receiving stations simultaneously. TXOP sharing allows the Access Point (AP) to perform simultaneous transmissions to multiple receiving stations with different access categories.

The performance of these 802.11n and 802.11ac packet aggregation schemes is studied in [27]. With the advances in the 802.11 PHY layer and changes undergone by MAC, considerable research has to be done on the design of MAC protocols [28] to further improve the efficiency of the MAC layer. At present, the trend is moving towards the design of efficient MAC for Multiuser MIMO Wireless LANs. In the literature, there exists some useful works on the design of MAC protocols for MIMO system, which can be found from [29-34].

III. Radio Resource Management

The main functions of the Radio resource management are Resource allocation, Scheduling, Admission control and Routing as shown in Figure 1. In this section, these aspects are briefly discussed with respect to QoS in WLANs. The fundamental MAC mechanisms limit efficiency [35], hence MAC throughput is low compared to the offered PHY raw rates [28]. There have been many research efforts to adapt the IEEE 802.11 MAC to technological changes, such as the Multi-antenna technique; however, there is a lot of scope to investigate the efficiency of MAC [28]. QoS is considered as the desired metric for high throughput WLANs. QoS relies mostly on the network resource utilization, scheduled access flow in a non-interfering manner to avoid packet loss, accepting or rejecting requests based on congestion and dropping of requests made during handover. These are the essential components in enhancing the required QoS. They play a significant role in the development of the next generation high throughput WLANs.

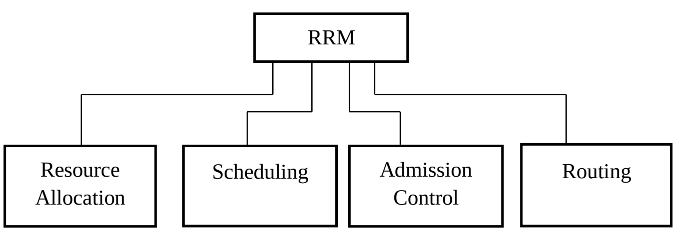

Figure 1: RRM Functions

A. *QoS-aware Resource Allocation*

Due to the rapid growth of wireless devices and the increasing demand for multimedia applications, the current WLANs are not only crowded, but they also emphasize high throughput. Multiuser MIMO [36] has gained popularity due to its high capacity and is adapted as an additional PHY technique for the next generation high throughput wireless LANs. In the forthcoming scenarios, such as dense WLANs, a relative number of users contend for resources at the same time. This will lead to the degradation of network performance and service quality due to dropped packets congestion. Hence, efficient bandwidth allocation to users plays a major role to improve the throughput and system performance. The primary resource in any wireless communication network (Cellular, WiMaX, WLAN) is bandwidth. It is one of the essential components of QoS. Efficient resource allocation enhances the spectral efficiency, which in turn improves the throughput. With the increasing demand for high-performance services, implementing low complexity and efficient resource algorithm in the IEEE 802.11 is a major challenging issue. The conventional multiple access techniques, such as the Time Division, Frequency Division and Code Division Multiple Access (TDMA, FDMA, and CDMA) give a static performance to the end users. However, when the OFDM is used in combination with any of these techniques, it gives a dynamic high speed performance to active users that share a channel.

The integration of multiuser dynamic Orthogonal Frequency Division Multiple Access (OFDMA) with WLANs and system performance is briefly studied in [37]. In the literature, many resource allocation algorithms for OFDM based networks have been studied extensively. Some of the algorithms are utilized either based on throughput or delay [38] [39]. All these algorithms achieved required QoS for all users by minimizing transmit power and maximizing transmission rates. In [40], the author considered the problem of multiuser subcarrier, bit and power allocation. The main objective is to reduce the overall transmitted power for the individual user. In [41], a fair queuing algorithm is used to determine the target bit rates by taking into consideration the user channel conditions and the QoS requirements. The main problem with queuing of packets is their random arrival rates. For example, if more than one source misbehaves and increases their arrival rates in such a way that the set of arrival rates lies above the capacity region, it leads to system instability. Hence, in [44] the author considered a dual algorithm with a combination of queue length stability and fair scheduling of resources. This not only brings throughput to its optimal level, but it also gives fairness among the queues. In [45], the author used the gradient scheduling and the resource allocation algorithm based on users QoS requirements and channel conditions.

As the wireless channel has many effects caused by fading, there is a need to provide optimal resource allocation to several fading distributions. Hence, in [46] an optimized multiuser scheduling and resource allocation algorithm based on utility functions is developed to provide fairness and efficiency. Another utility based on fair QoS resource allocation scheme is documented in [48]. Here, the fair allocation is done for different context based on their QoS demands. In this paper, the concept of dominant resource fairness is proposed to achieve fairness in QoS and strategic multi-resource allocation. As the demand for high data rate applications increases, the need for efficient and low complexity resource allocation algorithms increases. Hence, in [49], the author presented a scheduled sub-channel allocation framework for the 802.11 based wireless OFDM networks. Here, the whole bandwidth is divided into sub-channels and allocated to different active users. However, it does not guarantee any delay and fairness to the users. As per the futuristic real-time demands and the dazzling speeds offered, the next generation WLANs must be in a position to handle multiple requests at a time of varying environment. The various algorithms discussed in this section are summarized in Table 1. In most of the algorithms discussed above, the channel allocation is purely based on channel conditions and SNR measurements. However, in the MU-MIMO based WLANs, the number of Channel State Information (CSI) requests may be sufficiently large. Therefore, careful resource allocation should be made for users with bad channel conditions. Hence, there is a need for efficient and adaptive resource allocation [50] techniques in such conditions.

Table 1
QoS-aware Resource Allocation Schemes for OFDM based Wireless Networks

Scheme/Algorithm	Main Features	Remarks	References
Combined subcarrier, bit, and power allocation scheme for multiuser OFDM systems	The objective is to decrease the overall power transmitted, for given QoS requirements	Concentrated only on power efficiency, neglected link layer issues.	[40]
Cross-layer adaptive resource allocation algorithm for packet-based OFDM systems	Improves the spectral efficiency and enhanced queuing performance	Traffic classification is not done. No clarity on fairness issue.	[41]
Fair Resource allocation using queue length based scheduling	Primarily focused on queue length stability for throughput optimization	Admission control is required. Complexity is not addressed.	[44]
Gradient scheduling and resource allocation algorithm	Low complexity heuristic algorithm with throughput utility optimization.	Queue size (or) delay is not considered	[45]
Multiuser scheduling and resource allocation algorithm	The throughput based utility function provides fairness and efficiency	Queue size (or) packets in the buffer are not considered.	[46]
Fair QoS resource allocation scheme	Provides fairness and QoS utility for delay sensitive applications	Channel behavior is not considered	[48]
Sub-channel allocation and scheduled access	Improves throughput and reduces delay	Not guaranteed fairness Starvation problem for Low rates	[49]

B. *QoS oriented Scheduling*

Scheduling is performed to control the allocation of the resources to every user in a shared manner at each instant of time. The scheduler first decides the order of requests to be served, and then it manages the queues of these awaiting requests. The scheduling process of information in wireless networks is much more difficult when compared to wired networks because the wireless channel can be easily affected by fading. The process of queuing and scheduling the packets during the congestion is shown in the Figure 2 below.

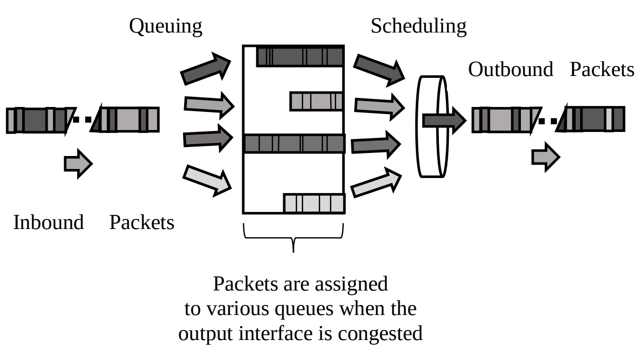

Figure 2: Queuing and Scheduling of Packets

The scheduling of packets can be broadly classified as Uplink and Downlink Scheduling. The AP plays a major role in downlink compared to uplink. However, the downlink scheduling techniques can be applied for the uplink access. The downlink scheduling can be either packet-based scheduling or STA-based scheduling. In packet-based scheduling, the AP makes the scheduling of packets using certain standard algorithms, such as the First-In-First-Out (FIFO), Weighted Fair Queuing (WFQ), Weighted Round Robin (WRR), Earliest Deadline First (EDF) and others. The STA-based scheduling follows certain criteria to group the stations like the channel variations, spatial compatibility, fairness etc. for simultaneous downlink transmissions. As the demand for multimedia applications increases, the multiple requests from multiple user causes the AP scheduler to become stress in wireless LANs. One can refer to [51] for a detailed explanation of the scheduling algorithms in multimedia networks. The QoS support in the 802.11 WLANs started with the differentiation of services in four access categories as stipulated in the 802.11e amendment. It also does not guarantee QoS when the channel becomes saturated. In dominant wireless networks like 802.11 WLANs, the scheduling of the packet arrivals in queue plays a crucial role in maintaining the required QoS. Fair queue-based scheduling algorithms like Idealized Wireless Fair Queuing algorithm (IWFQ) can be found in [52]. These algorithms offer throughput and delay guarantees for cellular networks with the base station as the central controller. However, they usually suffer from bandwidth rate and fairness problem. An Extended Earliest Due Date algorithm (EEDD) based on location dependent error can be found in [53].

A scheduling algorithm based on link adaptation and transmission time of data packets is discussed in [54]. It gives a better delay performance compared to the optional PCF in the fundamental IEEE 802.11. The QoS requirements in the IEEE 802.11e are achieved by using the Hybrid coordination function (HCF). A fair HCF scheduler that provides fairness in bandwidth and delays to support in the 802.11e is proposed in [55]. The transmission times in [55] are allocated with the mean sending rates instead of the maximum sending rate. The enhancements to the QoS scheduling techniques mentioned above can be found in [56] [57] [58]. Another recent enhancement in MAC scheduler for the 802.11n standard is proposed in [59] which dynamically chooses the aggregated frame size and the combat tradeoff between the throughput and the delay. In [60], the author used an adaptive-queue scheduling mechanism for the IEEE 802.11 based on adhoc networks that perform scheduled distinction among nodes that have traffic in the same access category.

The author in [61] focused on the collision avoidance mechanism for the standard 802.11 MAC. A CSMAC protocol is proposed to enhance the network performance in terms of the throughput and the delay. The QoS Oriented Scheduling provides guaranteed services by taking into consideration the bit rate, delay, jitter, throughput, etc. The scheduling can be broadly classified as the channel-independent scheduling and the channel-dependent scheduling. The general algorithms that ensure QoS in scheduling are broadly classified into two types, namely the channel independent and the channel dependent algorithms [62]. A brief review of these algorithms is presented below.

C. Channel Independent Scheduling Schemes

Channel independent strategies were first presented in wired networks with the assumption of time-invariance and zero error transmission media. The simplest examples of those scheduling algorithms are discussed here.

a) Strict priority using FIFO

This strategy works basically on the principle of First-Come, First-Serve basis. The arrived packets are kept in queues for processing according to their own priority. The flows in the same queue are then sent using the FIFO scheme. In this case, the arrival order of packets determines the output order. This mechanism is very simple to understand, but unfortunately, lower priority packets are in starvation when there is a steady flow of high priority packets. In [63], a slight modification to the FIFO algorithm is proposed where various flows are assigned with different parameters.

b) Round Robin

Round Robin (RR) is one of the modest scheduling algorithms designed particularly for a time-sharing system, where the scheduler allocates time slots to each queue in equal share without precedence. The Round Robin algorithm contains serving the queues one after the other. If the current queue contains a packet, it will be assisted; otherwise, the algorithm chooses the next queue for service.

c) Weighted Round Robin

Weighted Round Robin (WRR) scheduling performs the sharing of the network bandwidth in a controlled manner. Each queue is assigned a weight and that value is then used to determine the amount of bandwidth allocated to the queue. However, this algorithm only supports the Variable bit rate (VBR) traffic stream. Hence, in [64] a dynamic WRR algorithm is proposed in order to support both the Constant bit rate (CBR) and the VBR flows. The queues of traffic are assigned with dynamic weight. It helps the network in providing multimedia services even in the presence of bursty traffic. To support multiple classes of traffic with varying delays and loss requirements, a scheduling scheme that guarantees diverse QoS requirements is needed. Hence in [65], a modified dynamic WRR scheme is proposed. This scheme guarantees the delays in real-time traffic and provides efficient transmission for other kinds of traffic.

D. Channel Dependent Scheduling Schemes

Channel-dependent scheduling takes the benefit of promising channel conditions to increase the throughput and system spectral efficiency. Some of these scheduling algorithms are discussed below.

a) Weighted Fair Queuing

Here, the packets are grouped into different queues. A weight, which defines the fraction of the total bandwidth available to the queue, is given to each queue. An upper bound on the buffer size is kept to share the bandwidth among the users. The weight may depend on both channel quality and the number of packets in the queue of distinct users. It offers a balanced utilization of resources between fairness and efficiency. In [66] an extension to DCF of the 802.11 MAC protocol, the Distributed Weighted Fair Queuing (DWFQ) algorithm is proposed to allocate the bandwidth of the wireless network among the different flows proportional to their weights. A Class-Based Queuing (CBQ) algorithm is implemented in [67] during bursty traffic or heavy load on the network. This technique enhances HCF (eHCF) for the 802.11 MAC protocol and it shows fairness in allocating bandwidth to different priority classes. In CBQ, the maximum bandwidth allocated to a class is fixed and it is not possible for any class to obtain bandwidth more than the maximum allocated bandwidth even if there is unused bandwidth in other classes. To overcome this problem, in [68] a Dynamic Weighted Fair Scheduling Scheme (DWFSS) is proposed to allocate the bandwidth dynamically among different classes.

b) Earliest Deadline First

The Earliest Deadline First algorithm (EDF) maintains a list of waiting packets to be executed. This list is sorted by the deadline of packets in the queue preferably the earliest deadline first. Each packet priority is decided based on its deadline value. The highest priority is given to the task with the nearest deadline. In [53], an Extended Due Date Algorithm (EEDD) is proposed to provide bounded delay and fair queuing for wireless networks. In [69], the channel that is aware of the earliest due date algorithm for the 802.11e WLANs is proposed to provide delay guarantee for real-time traffic in wireless multimedia applications. In this scheme, the packets are queued by the scheduler on the basis of the earliest expiry time and the channel variations. The prioritized flow consequently gets the highest transmission rate among all the flows.

In principle, channel dependent scheduling has the ability to increase the throughput by taking the benefit of frequency selective fading channels. On the other hand, channel dependent scheduling consumes system bandwidth because it requires stations to transmit channel sounding signals that span the entire frequency band of the system.

The summary of the scheduling algorithms discussed above and the QoS metrics addressed in those algorithms is provided in Table 2.

Table 2
QoS oriented Scheduling Schemes for 802.11 WLANs

Reference item	MAC	Features	Remarks	QoS metrics
[54]	802.11e HCF	Compatible with link adaptation mechanism Reduces delay and Packet loss rate for Video and VoIP traffic	No admission control Not suitable for bursty traffic	Throughput Delay Packet loss rate
[55]	802.11e HCF	Simple and efficient scheduling algorithm Higher degree of fairness among different multimedia flows	Not considered reliability issues	Throughput Delay
[57]	802.11e EDCA	Provides very good service differentiation Group acknowledgement	Complex since it includes call admission control Not addressed delay	Throughput
[58]	802.11e HCF	Uses queue length information to allocate TXOP Provides QoS guarantee for real-time flows	Complex system model	Delay
[59]	802.11n	Eliminates the tradeoff between throughput and delay during frame aggregation	Not considered service differentiation	Throughput Delay
[60]	802.11e EDCA	Provides differentiation in the nodes having same access category. Requires minimal overhead and ease of implementation.	Suitable for 802.11ad adhoc networks Only VoIP traffic considered	Network capacity Delay
[61]	802.11 DCF	Focused on backoff scheme to avoid collisions in basic 802.11 WLAN Can be used for future WLANs	No service differentiation Centralized scheme	Throughput Delay

E. QoS based Smart Resource Scheduling

The MU-MIMO enables simultaneous multiuser transmission to different stations from the AP in the downlink and from multiple stations to the AP in the uplink. Although this PHY enhancement improves the throughput, it needs the design of efficient MAC resource scheduling to support the high data rates. Generally, the scheduler in WLANs performs scheduling of active users by considering the QoS requirements, traffic demands, and channel conditions. Finally, the resources are allocated to the scheduled users. A brief literature on these essential components can be found in Section A and Section B. It can be seen that several parameters from various layers can be jointly considered to obtain optimum results. The combined operation of these layers gives better performance by sharing and configuring information. This cross layered approach seems to be a suitable way in the design of efficient resource scheduler to satisfy the future user specific QoS demands and to cope up with the information-theoretic rates offered at lower layers. In [70] and [71], the author provided guaranteed QoS for the users in the wireless fading channels with adaptive modulation and coding at the physical layer and service classification at the link layer. Each connection is given a priority, in which it is updated dynamically based on its channel and service status and the highest priority user, scheduled each time. The author in [72] discusses packet scheduling in single and multiple antenna wireless systems with QoS support. In [73] a dynamic queue length scheduling strategy based on a cross-layered approach is proposed to maximize the throughput of real-time delay sensitive applications. This method uses channel information at the physical layer to schedule the users in the queue. In all the Cross-layer and QoS scheduling schemes discussed above, the acquisition of channel state information at the physical layer is assumed. In the wireless scenarios, the instantaneous channel information is needed due to the time varying behavior of the channel. The CSI can be obtained in two ways: The implicit feedback, where the AP computes the CSI by estimating training sequences sent from stations, and the explicit feedback, where the STAs calculate the estimated CSI and send feedback to the AP. A detailed study of the implicit and explicit CSI feedback mechanisms is found in [75]. The performance analysis and the impact of CSI feedback on throughput in the 802.11ac are studied in [76], [77]. In the upcoming MU-MIMO WLANs [78], there is a huge overhead due to the sounding information from the users in the high dense deployments [79]. Hence, adaptive algorithms are required to dynamically alter the frequency of the CSI feedback. In future scenarios [80] like crowded stadiums, public places, airports and business environments, the APs will be heavily deployed to provide internet access to users. In such cases, when several users contend for resources at the same time, it is important to know the number of active users scheduled concurrently.

Another major issue is the formation of clusters or groups among the stations that need to be co-scheduled. Hence, an efficient grouping algorithm is essential to maximize the overall throughput. In most of the papers surveyed on the QoS-aware MAC scheduling, differentiation is made based on service category only. Currently, a wide variety of terminals exist on networks like the legacy 802.11 a/b/g/n. These terminals have performance differences. Low rate terminals take more time to transmit the same packet compared to high rate terminals. This degrades the performance of high rate terminals. Hence, solutions to reduce huge CSI overhead, grouping the active users and to provide rate differentiation will require the use of Smart Resource Schedulers that considers current traffic demands and QoS requirements from the users. Cross-layer design seems to be the only approach, which fulfills the future user specific QoS requirements in wireless environments.

Cross-layer scheduling for MIMO based WLANs fills the gap between the high performance physical layer and the user centric higher layers. Channel aware and queue aware scheduling promises a maximum throughput and a minimum delay with considerable fairness.

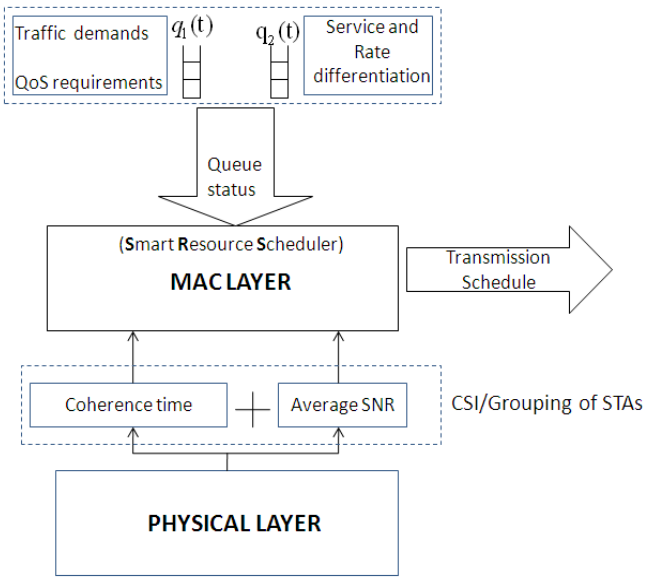

Figure 3: Schematic of the proposed Scheduler

In the literature of resource allocation schemes discussed above, the author in [49] proposed dynamic sub-channel allocation scheme for the 802.11 WLANs to improve throughput and to reduce delay. Since the scheduler works on the SNR measurements received from the physical layer, most of the time is spent on the identification of the best user with the largest SNR. The size of the sub-channel allocation table increases with the number of users and adds complexity to the scheduler. Further, no schemes have discussed the rate differentiation among the users. Due to this low rate, the user takes more time to process the same packet compared to the high rate users. This introduces a fairness problem in the bandwidth allocation. Hence, to provide high resolution to the scheduler and to satisfy the QoS requirements of the users, a Smart Resource Scheduler based on Cross-layer approach is proposed, as shown in Figure 3. Here, instead of acquiring SNR values from all users, the average SNR is requested from the correlated subcarriers of the users. The frequency of CSI requests depends on the coherent time of the channel. This substantially reduces the frequent CSI requests and provides the best channel to users. This feedback scheme is adapted to active users only. In this scheme, the Queue stability will be considered to maintain optimum system performance. The combination of any of the schedulers discussed above with QoS requirements, CSI information constitutes the smart resource scheduler for the future WLANs.

F. Resource Allocation and Scheduling process

OFDM is the radio access technology primarily employed at the physical layer. In particular, OFDMA is used in the downlink direction since it allows multiple accesses by assigning a set of subcarriers to individual users. In multiuser scenarios, bandwidth sharing becomes crucial when many users contend for resources at the same time. Fading is usually considered as the dominant factor in such situations. One important means to deal with such effects is dynamic resource allocation by optimizing available bandwidth using CSI estimates. The fundamental task of the physical layer is to provide reliable information to the scheduler in order to improve its efficiency. In the proposed scheme, the AP acquires information about the channel static time and SNR values from the physical layer. Using this information, the scheduler has now eliminated the need for frequent knowledge of the channel status; hence, the complexity may be reduced. In current wireless environments like stadiums, airports, and public places, most of the users are active in transmitting and sharing information. Some of them are inactive or in idle states. If the user stations are grouped according to their operating states, the scheduler load will be reduced further. Grouping of stations is made to identify users that can be co-scheduled.

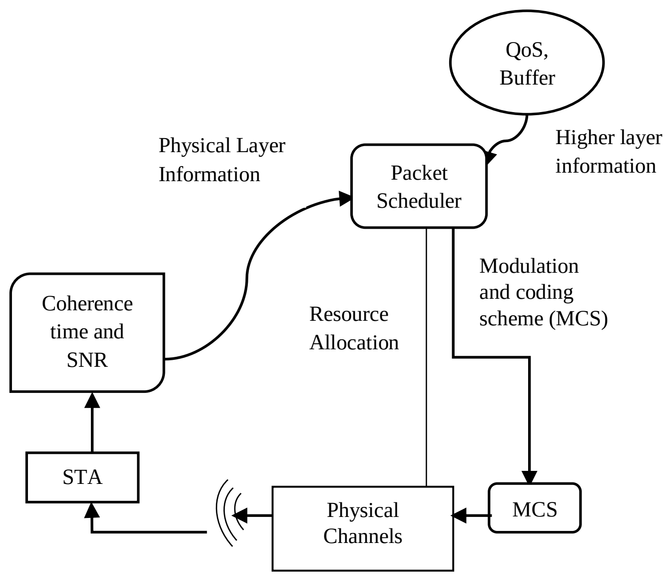

Figure 4: Simplified Packet Scheduler

The detailed functional diagram of the proposed smart scheduler is shown in Figure 4. The RRM modules perform several functions in the MU-MIMO WLANs. Each user decodes the transmitted training sequences and sends the STA signal strength values back to the AP scheduler. The AP obtains the CSI estimates based on the static conditions on the physical channel. This eliminates frequent sounding from the user stations. The physical layer performance is improved by adapting the modulation and the coding schemes. The AP scheduler situated at the MAC layer schedules the user stations based on the QoS requirements, traffic demands from higher layers, and finally releases the transmission schedule. The service and rate differentiation situated above the MAC provides backward compatibility among users; hence, providing fairness to the users. Therefore, by providing enough sufficient information to the MAC scheduler, the efficiency can be improved and the complexity will be reduced.

IV. FUTURE ISSUES IN RRM

The next generation Wireless LAN standard IEEE 802.11ac has already been standardized and widely adopted across the industry. The new IEEE 802.11ac incorporates some very good enhancements such as support for MU-MIMO and Enhanced frame aggregation. But, in reality, there are some serious limitations that drastically affect the 802.11ac standard's ability to deliver on its promises. All the existing RRM schemes are not able to provide strict QoS requirements for real time applications. 802.11ac affects radio resource allocation [78] since overlapped devices can now transmit over 80MHz or even 160MHz. The system has to work harder since the APs operate in these overlapped bands [79] are affected due to interference. Multi-user MIMO enables multiple simultaneous transmissions to different STAs from the AP in the downlink, and from multiple STAs to the AP in the uplink. In the downlink, the overhead caused by the explicit channel sounding feedback mechanism depends on the channel sounding interval and the number of sounded STAs, which can result in an unacceptable overhead in situations with several STAs. Solutions to reduce such a large overhead, apart from replacing the current channel feedback mechanism with a more efficient solution, will require the use of smart schedulers that consider the instantaneous traffic conditions and the QoS demand from the users [80] to decide when the CSI has to be requested, and from which STAs. Thus, it is necessary to propose solutions that minimize delay, maximize throughput, with guaranteeing fairness in bandwidth sharing.

V. CONCLUSION

In this paper, a survey of crucial elements that provides and enhances QoS on radio resource management has been presented. The relevant proposals such as resource allocation and scheduling are discussed in detail. The advances in IEEE 802.11 PHY layer have left some open challenges to the MAC and higher layers. Hence, there is a need to develop efficient resource utilization techniques in order to handle the QoS with varying traffic demands.

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