CHAPTER-5: CONCLUSION AND PROPOSAL OF A SCHEDULER FRAMEWORK

5.1 **Introduction**

Scheduler has not been defined for WLANs in IEEE standard unlike in Cellular networks. WLANs evolved from wired Ethernet meant for data networks. Cellular networks, on the other hand, had to assure QoS guarantees for voice traffic. For this reason, scheduler design was a key component in WiMAX and LTE.

Later, with the highly successful IEEE 802.11 standard and with packet applications like VOIP, voice and video have been used as much as data in WLANs. However, the media access mechanism adopted in WLANs (CSMA/CA) extended from Ethernet, is not predictable compared to time division multiplexing in mobile networks. Time bound guarantees are not possible for multimedia applications. Also, as WLANs operate in the unlicensed bands, interference is a major issue. The protocol 802.11emeant for QoS has also not been extensively used for the same reason. All these factors have been causes for performance issues in WLANs. Although schedulers have been recommended for 802.11n WLANS in the literature, these solutions have not been very satisfactory and issues persist. This chapter reviews the results derived from earlier chapter in the thesis on 802.11ac WLANs and decide if the schedulers are more suitable for this standard as compared to legacy WLANs.

This chapter is divided into two sections - section 5.2 Conclusion; Recommendation for a scheduler - section 5.3.

5.2 Conclusions of the Research

1. 802.11ac has been **verified to be superior** in performance compared to the **existing** WLANs. The following features are verified and **compared to 802.11n**

    a. MCS, CBW, SS

    b. TxBF

    c. MU-MIMO

2. It is found that individual benefits from independent features are good and can aid in working towards QoS improvement.
3. The performance of cellular networks with respect to QoS has been looked into to identify areas differing from WLANs.
4. Also, approaches used in literature for applying scheduling techniques to WLANs are analyzed.

Based on the investigations (1), (2) and (3) above, it is **recommended to employ a scheduler** for 802.11ac and next generation WLANs to provide QoS guarantees.

A paper titled "**Review of Scheduling Approaches used in WLANs**" is presented in the International Conference on Contemporary Engineering and Technology 2017 (ICCET 2017).

5.3 Need for a scheduler

The need for identifying if QoS guarantees are possible in 802.11ac has been taken up in the conference on "The Future of Wi-Fi Technology: Looking Ahead to the Future" (Osama Aboul-Magd the Chair of IEEE 802.11 ac, IEEE 802.11 HEW SG) as early as 2012. The agenda for the discussion is expressed as follows:

"Improve real world performance in indoor deployments

- *with interference*
- *In moderate to heavy user loaded Access Points*

–Can WLAN really offer any QoS/QoE guarantees?

–WLAN operates in unlicensed bands where it is difficult to predict sources of interference."

5.3.1 Current State of Advanced Applications

With 802.11ac, applications that were used earlier only over wired networks/ laptops are now possible to be used on mobile devices.

1) Wireless displays. Tablets are as capable as laptops, but have smaller screens. As they become increasingly used for business, it should be possible to link wirelessly to LCD displays which are wireless-capable.

2) Real-time updates. Time-critical applications such as ERP, CRM, business analytics and stock trading will be made possible because of the availability of 802.11ac at 5GHz.

3) Video conferencing. 802.11ac will be standardized for reliable and distortion free video conference. Special equipment or facility reservations will no more be required.

Considering the requirements of these applications, it is advisable to design a scheduler which works with a cross layer approach (say, application layer and PHY layer) to meet the QoS guarantees.

5.3.2 Vendor Features

While there is no standard defined for a scheduler, most product vendors have added advanced functionality over and above the specifications defined. We shall take the sample case of Cisco and look at features which would have been, otherwise, handled by a scheduler. Tools (e.g., Clean Air technology, Video Stream technology, etc.,) have been designed to address issues.

For Enterprise networks, WLAN Controllers are responsible for QOS, RF Management and mobility functionalities among others by working in conjunction with APs.

Radio Resource Management: RRM software present in the Cisco Wireless LAN Controller plays the role of a manager to constantly monitor over-the-air metrics and control the RF transmitted. It measures Signal, Interference, Noise, Coverage and instantaneous user load on the network, RSSI and SNR - with which RRM can periodically reconfigure the 802.11 RF network for best efficiency. This is achieved with the following functionality:

- Radio resource monitoring—collecting the metrics
- Transmit power control—adjusting for optimal power levels
- Dynamic channel assignment (DCA)—Ensuring that channel assignments do not overlap

Cisco tool (Clean Air technology) provides IT Managers information on the wireless spectrum in order to handle RF interference and avoid unexpected downtime.

Cisco Video Stream technology enhances robustness of voice with CAC.

Another tool includes Next-generation deep packet inspection (DPI) technology called Next Generation Network-Based Application Recognition (NBAR2), which permits identification and classification of stateful L4-L7 applications. After the NBAR engine recognizes applications by their discrete protocol signatures, it registers this information in a Common Flow Table so that other features (such as QoS, NetFlow, and firewall) can take advantage of it.

DBS(Dynamic Bandwidth Selection) has the ability to use multiple channels together as a single assignment on a given AP. Bonding channels—using multiple single channels to create a single super channel—has the advantage of providing more usable throughput to a client with the capability to use the channel. DBS assigns appropriate channel widths to APs to dynamically balance the bandwidth selection for the types of clients and traffic that each AP uses. DBS allows appropriately sized bandwidth to be used for the clients being served, avoids wasting multiple channels for devices that likely could not use the added capacity, and avoids the associated interference created by those devices.

Therefore, considering that that all the above features can be handled better by designing a framework which holistically addresses the issues, we find a need for a scheduler.

5.3.3 Issues Noticed in Deployment of 802.11ac

Although newer features have been added to the standard, the following are practical issues involving their usage, noticed during deployment.

(i) 256 QAM

256 QAM (MCS9) requires considerably higher SNR (at least 37 dB) for an 80 MHz channel and without much channel reuse, the co-channel contention would be very high. Hence, most client /AP connections operate at 64QAM after only 40-50 feet.

(ii) Increased Spatial Streams

With 4 SS capability we can have 4 concurrently transmitting and receiving radio chains and this provides speed enhancements, but the power drawn is raised considerably. Also, since now the capability is present to transmit larger data with 4 SS, a faster CPU and increased memory are again required to reach the Access Point 's potential throughput.

(iii) CBW

The easiest method to increase throughput is to double the CBW. However, this results in the allowable output being reduced by 50 percent, across the entire channel. It also raises the noise floor by 3 dB and enhances the chance of collision.

In enterprise WLANs where multiple APs are closely located, the issues which develop when channel bandwidths are employed is as follows. Just because one can use 80 and 160 MHz CBW need not necessitate that it should be mandatorily applied. It is proposed to use 20 MHz channels in high-density environments such as auditoriums, ballrooms, trade shows and airports as they enhance channel use efficiency. Low-density / HT environments, e.g., open office areas, may profit from 40 MHz channels in 5 GHz, under the condition that there are enough channels for a channel reuse plan. When only 1-2 Access Points will be deployed in a branch office and the interference is low then using 80 MHz channels may be useful. At present, there is no suitable application for 160 MHz channels other than highly directional p2p links.

5.4 Conclusions Derived in the Thesis Leading to Recommendation of a Scheduler

Performance in 802.11ac: Regarding performance in WLANs, QoS and Interference have been the bottlenecks, as mentioned above. We shall discuss how 802.11ac improves on these in the next two sections.

5.4.1 QoS

With 802.11ac, we have noticed improved performance as a result of verifying the new features in the above chapters.

From the results in chapter-4, it is seen that in comparison with 802.11n, even at 40 MHz, marginal improvement is present for QoS parameters at higher values of MCS. With higher bandwidths (80 and 160 MHz), 11ac cannot be compared with 11n, but the real benefits of 11ac are visible now (again with 256 QAM also available) in the case of all parameters - throughput, delay and jitter.

Higher BWs and enhanced MCS permit a scheduler to be designed to better regulate QoS. The real controlling power for the scheduler is brought about by having more spatial streams which was one of the reasons why schedulers were not successful with earlier WLANs.

Rate Adaptation mechanisms are not defined in IEEE802.11ac. Moreover, unlike in cellular networks, where link adaptation and power control is clearly defined, RA schemes are loosely coupled to the main system flow in WLANs. Hence, there is a need to integrate RA with the scheduler for performance improvement. The Ideal and Minstrel RA algorithms have been studied in chapter-4. Likewise, other algorithms need to be analyzed for 802.11ac and suitable RA algorithm needs to be identified depending on the scenario and usage.

In chapter-4, it is demonstrated that if a receiver can be a beamformee, the SNR can be enhanced with transmit beamforming as weighed against transmission with spatial expansion. The increase in received power with beamforming can result in more reliable demodulation or even a higher order MCS can be utilized for the transmission.

While Transmit Beamforming has an advantage of increasing the range, this is more pronounced when communication is between devices separated by a distance in the mid to long range. In scenarios where the STA drifts away from the AP, the scheduler can decide on which solution is best suited for the current situation - increasing the transmit power, changing MCS or using beamforming.

It is seen that from chapter-4, that MU MIMO helps in distributing data to 4 users simultaneously (acting like a 802.11 "switch") using the space streams obtained through smart antennas. This is a major improvement over the limitation imposed by the MAC algorithm used in earlier WLANs where stations can only gain access one following the other. Having a network with a better means of handling bandwidth, leads to faster buffering, more consistent and stable download speeds. These benefits are extremely useful for gaming, full-time HDTV streaming and heavy internet usage. MU-MIMO can reduce network load by enabling concurrent transmissions and thereby decreasing latency.

Hence, latency and also throughput can be increased for multimedia applications. The scheduler can, consequently, be better designed to assure QoS (Throughput and delay) for advanced applications and also regulate the spatial streams better – all of which benefits were not available to an 802.11n scheduler.

In the Appendix-4 on schedulers for cellular networks, the following can be inferred.

The BW Request and BW grant mechanism helps in negotiating QoS demands before actual transmission. The decisions are taken to grant BW or admit the connection (CAC) after the scheduler analyzes the resource availability and current status of requests. Again, in the PHY layer, the resource blocks are of fine granularity and hence resources (spectrum, powers, MCS, etc.,) are very optimally utilized. These approaches if taken forward and integrated into the WLANs, will go a long way in assuring QOS guarantees.

Thus, we can conclude that we can recommend a scheduler framework which maximizes the gain added by the new features.

5.4.2 Interference issues in WLANs

1) Sources of interference: Potential interference in WLANs can be classified into two broad categories.

Interference from other WLANs: This is experienced by residential users, especially in high-density housing.

Interference from non-WLAN traffic in the bands used by WLANs at 2.4 and 5 GHz. This includes a wide variety of cordless phones (both Wi-Fi and non-WiFi), Bluetooth devices, wireless video cameras (again, both Wi-Fi and non-WiFi), cordless headsets and other point-to-point and point-to-multipoint links, cordless video-game controllers, and, microwave ovens

They can be grouped into interference from narrow band sources, (e.g. Bluetooth, stereo, microwave oven, FHSS cordless phones) and wideband interference sources (wireless LAN and DSSS cordless phones). RADAR and CW interference (from a video bridge) are other examples.

Noise floor has information on CW interference. Spectral RSSI (from PHY) includes information from current and adjacent channel Wi-Fi interference, microwave ovens and Bluetooth devices.

Interference is detected during boot up (for automatic channel selection) and dynamically (while in operation) and the channel is switched to a cleaner channel. Detection is done by directly sensing the channel or in the form of performance degradation. Both adjacent and co channel interference are detected and triggers are dependent on channel utilization (PHY) and throughput reduction (MAC) thresholds.

Scanning algorithms are used to scan all the channels and choose a channel that has minimum interference. The channels are scanned for beacon RSSI, noise floor and spectral RSSI. Also, channel free statistics are obtained from PHY counters (load utilization, OFDM errors and CCK errors).Weighted factors of these parameters are summed for each channel. The channel which has a minimum sum is the best channel and is chosen for operation.

Noise through spur, other non-WLAN transmitters in same channel or continuous wave interferers can cause interference. The WLAN receiver may detect this as a frame if the interference has periodicity in its signal and result in false detection. This impacts the WLAN performance. One technique to make the receiver immune to such sources of interference is to reduce receiver sensitivity. This, however, reduces range of operation.

Interference mitigation is therefore a key area of research and a variety of algorithms can be utilized to resolve the issue. Interference management is quite critical in WLANs as they operate in the unlicensed spectrum. This needs improvements in both the MAC and PHY areas.

2) Interference Mitigation in 802.11ac: 802.11ac, operating exclusively in the 5GHz range, avoids the congested 2.4GHz range that can experience interference from microwave ovens and other devices. Also, Beamforming, using feedback and precoding, optimizes the communications between Access Points and clients to counteract interference.

5 GHz band: More channels translate to larger bandwidth and permits the RF link to be flexible to switch channels in event of interference. Globally about 37 channels are defined in the 5-GHz frequency ranges which were not used for wireless either because they are used for applications or they are not permitted for wireless. Now with the advent of 802.11ac Wave-2 these channels have added to the WiFi bandwidth supporting speed and more clients/applications

TBF can thus be thought of as directing a beam using phase shifts towards a particular receive antenna. As the TBF technique can converge or cancel a beam by introducing appropriate phases, it can apply the same concept to cancel interfering signals in the direction of the receiver.

5.5 Proposed Framework

5.5.1 Block diagram

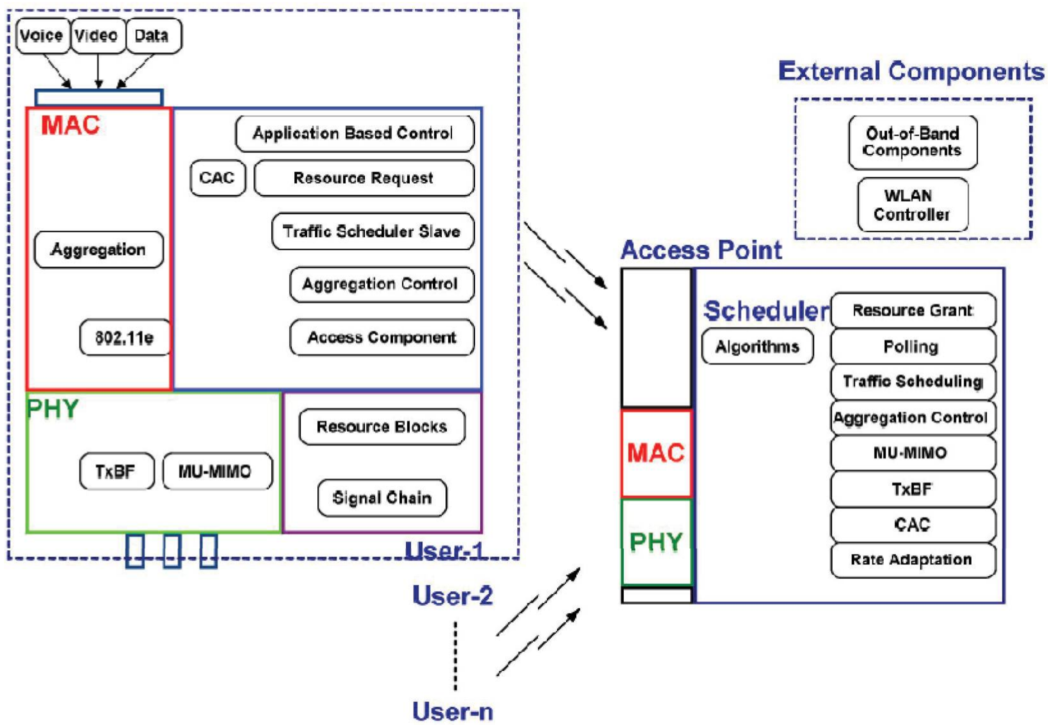

Fig 5.1 Block Diagram of the Proposed Scheduler

Figure 5.1 shows the block diagram of the proposed scheduler.

5.5.2 Components of the Scheduler

The Scheduler can be a standalone block functioning in tandem with the MAC and PHY subsystems and consisting of the following components:

1. Aggregation control: This can be used for applying vendor specific aggregation algorithms and more specifically, in combination with other approaches (discussed below).

2. CAC is responsible for admitting a connection based on the QoS parameters specified at the setup time, and the current estimate of the bandwidth available for the MS. The connection is admitted only under the following conditions:

a) There is bandwidth available to accommodate the new connection, without adversely affecting the connections already admitted.

b) Both bandwidth and delay characteristics of the connection can be met.

The methodology followed to achieve CAC in WiMAX has been discussed in Appendix 4.2.

3. Application based control: Examples are the approaches used in sections 3.6.10, 3.7.1 and 3.5.2.

4. (Medium) Access control component:

TXOP: Variety of algorithms has been recommended for schedulers which vary TXOP parameters for improving performance. For example, in [22], based on Queue length, the TXOP limit can be varied for achieving better QoS performance for multimedia services.

TXOP sharing: Algorithms can be designed to enhance this component so that fairness can be assured to multimedia applications for multiple users in a MU MIMO scenario in 802.11ac WLANs [70], [49], [50], and [51]. In [49], it is proposed to enhance the TXOP Sharing mechanism, to obtain improved DL-MU-MIMO transmission and to gain advantages with respect to throughput and channel utilization.

Backoff Mechanisms, NAV: These parameters can also be controlled by the scheduler depending on the scenario. The approaches mentioned in the papers below give an idea of how the standard can be improved and the newer algorithm could be applied to meet the desired requirement of a scenario.

In [70], a revised backoff procedure for secondary ACs is discussed. It is seen that the proposed backoff mechanism in [71] performs better, with respect to fairness, as compared to the conventional backoff mechanisms. In [48], a two-level NAV mechanism is proposed with only minor changes to the standard and it is demonstrated that the proposed mechanism achieves better throughput when evaluated against the usual NAV method. In [49], a modified backoff procedure is designed for the primary AC.

5. Traffic scheduling approaches are discussed in section 3.6.1.

6. Polling and 802.11e: 802.11e should be tightly integrated into the scheduler framework and this is a subject matter in itself. An example of how a novel polling technique called Channel Access Throttling (CAT) enhances QoS is described in [21] by enabling scheduled fine-granularity based QoS policy.

7. Rate /Link adaptation: The Base Station should monitor the SNR and determine the appropriate burst profile for each Mobile station i.e., increase or decrease the coding and modulation to optimize the throughput while maintaining a specified BER. These concepts are discussed in chapter 6.

8. Resource Request and Resource grant is one of the principal reasons why cellular networks achieve satisfactory QoS. Concepts involved in Resource blocks, Resource request and Resource grant are discussed in Appendix-4 section A4.1.

Scheduling in LTE: During scheduling in LTE [72], the eNodeB decides which UEs should be given bandwidth resources to send or receive data and how UL and DL channels are used by both eNodeB and UEs. In LTE standard, scheduling is performed at sub-frame level and on cell basis.

Data is allocated by the eNodeB to the UEs in terms of Resource Blocks. Further details are available in Appendix-4 section A4.3.

WiMAX scheduler: The packet scheduler prepares proposals indicating those connections that need to be scheduled in the current frame to meet their QoS requirements, while optimally utilizing the resources of the air link. Air link scheduler is run on the BS to schedule the air link to the various MS. For scheduling the data for specific MS, the scheduler determines the contents of the DL and UL sub frames. Further details are available in Appendix-4 section A4.2.

PHY layer scheduling in WLANS: In [5], to maximize system performance, a new solution with 802.11 PHY and MAC layers is designed with multiuser channel access and a dynamic sub-channel assignment based on traffic priority. The sub-channel scheduling access can be viewed as choosing the best set of users to allocate subcarriers according to their CSI. Two ways to merge these concepts in WLANs are discussed in Approach-1 and Approach-2 in section 3.6.7.

Sections 9, 10 and 11 are explained using figure 5.2.

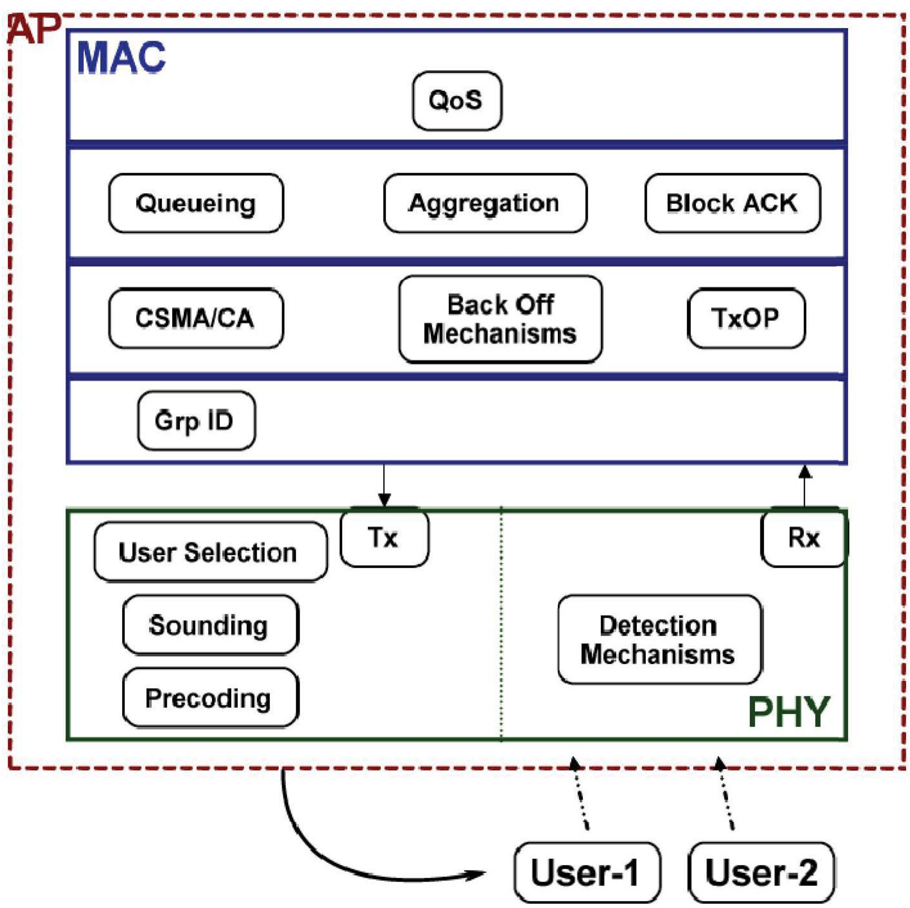

Fig 5.2 TXBF/MU-MIMO Subcomponent

9. Transmit Beamforming: Feedback and quantization algorithms are factors which delay the Transmit Beamforming mechanism. Algorithms can be integrated to the framework and used based on the scenario. Two such examples are mentioned below.

In [38], a technique "time domain quantization" is introduced wherein there is a feedback of time domain parameters which are required to form the beamforming matrix at the transmitting end. It is proved that TD-Q reaches the same sum rate capacity of the conventional Givens rotation quantization GR-Q and requires less amount of feedback.

Reference [39] proposes a method of transmitting precise channel estimation to the transmitter which requires this to enable the calculation of precoding vectors. Since there is a huge amount of channel coefficients that is required for feedback, limited CSI feedback works out to be an advantage. This scheme permits both the feedback accuracy to be better and the amount of feedback to be decreased as well.

10. MU MIMO - Precoding, Detection and user selection mechanisms: The different mechanisms are BD, RBD, SVD, CI and ZF. The choice of which algorithm to incorporate, needs to be selected by the scheduler based on the situation. The pros and cons of different mechanisms have been verified in the papers below, followed by detection mechanisms.

Precoding: Interference cancellation is the main goal of precoding algorithm.
Due to its good performance and low complexity, Block Diagonalization (BD) precoding algorithm is widely used in MU-MIMO schemes. However, it also has obvious defects: the ignoring of addictive Gaussian noise and the restrictions of antenna dimensions (i.e. number of receiving antennas < number of transmitting antennas). In [58], an algorithm called Regularized Block Diagonalization (RBD) with signal space diversity (SSD) is proposed using constellation rotation and Q-component interleavers to optimize the MIMO-OFDM, channel coding and modulation together.

In [59], the performance of CI and BD are analyzed. This has been discussed in section 3.9.3 1(b).

[60] Discusses the maximum capacity that can be obtained with BD and zero forcing (ZF) in MU-MIMO and singular value decomposition (SVD) based precoding in SU-MIMO.

Detection Mechanisms: [64] proposes to detect the SS in 802.11ac using (2×2), (4×4), (8×8) MU-MIMO systems using some of the MIMO detection algorithms. This has been discussed in section 3.9.3 1(g).

11. MU MIMO-Sounding: The algorithms (and similar others) described below which overcome inherent limitations in Sounding mechanism can be implemented and controlled by the scheduler, when required.

In practice, the beamformer has to compromise between the frequency of sounding and CSI accuracy. In [65], the evaluation of a downlink MU_MIMO sounding protocol coined Multi-User Transmission enhancer (MUTE) is presented which decouples the sounding set selection (utilized in collecting CSI) from the transmission set selection, thereby helping in reducing the sounding overhead and simultaneously selecting the best users. At the same time, adequately accurate data regarding users' channel statistics is given to the Access Point.

The sounding overhead may severely degrade the performance of a WLAN. In [72], a comprehensive sounding control scheme for IEEE 802.11ac MU-MIMO is proposed which considers broadly the sounding control needs of the network environment, including channel coherence times, nodes' DL traffic loads, DL SNRs, etc.,. The sounding node set and sounding interval to maximize the MU-MIMO throughput are jointly determined.

In MU-MIMO, the AP selects both the user set and the mode and after completing sounding and before commencing transmission. Thus, optimal user groups are selected given full CSI of a set of potential receivers (which is a major overhead) or through intermittent probing. In [73], Pre-sounding User and Mode selection Algorithm (PUMA), an algorithm for selecting user and mode earlier to sounding is designed, implemented and evaluated. After PUMA chooses the suitable mode and user group, the selected protocol's sounding mechanism is applied on the intended user subset for actual data transmission.

12. Combination approaches: It is seen that MU MIMO and TX BF have finer levels of control (discussed in the corresponding chapters) which the scheduler makes use of before a feature or combination is derived. For example, when applying TXBF, algorithm using Precoding variants, an improved Sounding and Aggregation scheme may be decided so that the solution will provide optimum QoS for the present flow as also other existing flows.

The real need for a scheduler is seen in the cross layer /combination between components approach. A) Aggregation Related: MU_MIMO in combination with aggregation improves performance considerably. The following has been observed. [52] Compares the performance of two DL user multiplexing schemes: MU-MIMO and frame aggregation in IEEE 802.11ac. If each user's encoded data stream has a similar length, the MU_MIMO achieves better throughput compared to aggregation. Conversely, if different lengths are present, the reverse is true. In a fast-varying channel, because of the overhead of channel feedback, throughput of MU-MIMO is lesser than frame aggregation.

Problem: The MU-MIMO combined with aggregation can improve performance considerably. If the frames in different SS have differing transmission times, the space channel time occurs .This is a period wherein data is carried by certain SS whereas the others do not have data. Due to space channel time, DL MU-MIMO channels transmission efficiency degrades.

Reference [55] proposes a combination of packet aggregation and MU-MIMO to augment the system performance. The technique is discussed in section 3.9.2.3.

VOIP/AMC and Aggregation balance: Section 3.9.2.3a discusses this approach.

Aggregation for VoIP: Section 3.9.2.3b discusses this approach.

A frame aggregation scheduler is proposed [24] which manages QoS for RT multimedia applications (for instance - video streaming) by combining 802.11e differentiation and frame aggregation.

Joint urgency delay scheduler and adaptive aggregation technique [25], implemented in the AP realizes a compromise between maximizing throughput and minimizing delay. Frames from voice, video, and streaming sources will be mapped into Access Categories based on Enhanced Distributed Controlled Function scheme defined by IEEE 802.11e. New scheduling metrics defined are urgency delay (UD) and waiting delay (WD). Packets with the least UD are included first in the aggregated frame following which the aggregated frame's payload size will be adjusted.

b) **Transmit Beamforming**: As with other 802.11ac features, [7] beamforming also shows modest performance improvement, and it should be combined with other techniques to realize spectacular performance enhancements.

c) **Precoding with Detection Techniques**: Selecting the correct combination of precoding and detection mechanism by the scheduler will provide the ideal solution for the appropriate situation.

In [61], the performance improvements under realistic channel conditions are measured when BD and CI are paired with various MIMO detection techniques. It is observed that high performance MIMO decoders such as LRA MMSE decoder improve the uncoded BER performance of the BD precoding. On the other hand, it does not better the uncoded BER performance of the CI precoding. The effective channel matrix of the BD precoding is a block diagonal matrix. Hence MIMO decoders can benefit from the diversity present in the inter stream interference within a single user.

The PER performance of each MU-MIMO transmission methods is considered when MIMO decoder is changed. Thus, it is seen that (1) the PER performance of the BD precoding can be improved by the MIMO decoder and (2) the BD precoding is more effective compared to CI precoding.

In [63], a unified performance evaluation of five transceiver configurations implementing MU-MIMO in 802.11ac is done: BD+ZF, BD+MMSE, CI+ZF, CI+MMSE and RI+MMSE. It is seen that while RI-MMSE schemes is optimum for low SNR region, impact on achieved performance parameters when SNR is good, is negligible.

D) While STBC feature is built to operate in open-loop mode, TBF operates in closed-loop mode with AP supporting one STA in the SU-BF mode and many STAs simultaneously in MU-BF mode.

If a station cannot perform closed-loop beamforming, data transmission from AP should be by STBC. With SU / MU-BF, variation of channel parameters with time leads to degradation. Sometimes, STBC can yield higher throughput compared to BF even in the absence of feedback in the channel. When the amount of data to be transmitted is not huge, feedback turns out to be an overhead. In such cases, open-loop BF is a better choice compared to the close-loop BF.

13. Cross layer Approach: Some examples are provided below:

A) In [29], A multi-traffic scheduler with genetic algorithm (GA) is proposed, which seeks to improve QoS, taking into account both traffic and status of the channel. The APP layer of AP generates different traffic types which is categorized in MAC and buffered in memory queues in FIFO manner. When the packet wait time in the queue gets larger than the delay limit of the packet, it will be dropped. When scheduling commences, AP initially detects queue length for every type of traffic. It then offers an opportunity for scheduling the queues that are not empty. Next the AP obtains from STA, feedback of CSI and CQI i.e. channel state and quality information. Prior to scheduling a frame, the scheduler estimates traffic QoS using queue and channel information, traffic QoS requirements and priority. The problem is of selecting the optimal traffic slot in the frame (MAC layer) where delay satisfaction, packet loss and data rate are considered. GA, a widely used random search technique learnt from the principles of evolution (i.e. survival of fittest), is used to reduce the search time for obtaining the optimal solution.

B) **Scheduler for 802.11ac**

By far, the most complete Scheduler for 802.11ac is explained in [31]. Here, a framework which considers link adaptation in networks supporting MU MIMO-OFDM, with restricted feedback and combines precoding, sounding and mode selection. This is discussed in detail in section 3.6.11.

5.5.3 Description

The procedure described below should be integrated with WLAN Management frames such as Association, Authentication, Probing, etc., During capability exchange, additional information such as Precoding and detection algorithms used, etc., in the STAs should also be conveyed which the scheduler will make use of before arriving at a decision.

1) Multimedia application requests for granting a flow.

2) Resource request for granting bandwidth is routed through 802.11e and Media Access component (CSMA/CA).

3) Scheduler algorithm will verify the availability of resources (bandwidths-20, 40, 80 and 160 MHz, MCS, spatial streams) and collaborate with polling mechanisms in 802.11e, CAC, Request grant and traffic Scheduling. The output of the activity will be to grant the access, reject the request or queue it.

2) Based on the application (for e.g. Video,), Cross-platform control with application layer (Application based control component), MAC layer (aggregation) and PHY layer (resource blocks fine tuning) the flows are provisional and regulated.

3) When interference occurs, TxBF is applied while deciding on the impact on other SS.

4) In the DL, DL-MU MIMO will be applied for delay based QoS applications when the resources are available for concurrent transmission of multiple users.

The appropriate Sounding algorithms, combination of Precoding and detection schemes, user selection mechanisms are used with Aggregation and VOIP management techniques to meet QoS requirements for all users.

5) When the signal is corrupted due to noise, rate adaptation mechanism is invoked which is now designed to be tightly coupled with the scheduler and integrated with MU_MIMO and TX BF mechanisms.

The decision of whether STBC, MU_MIMO or SU_MIMO is appropriate for the current situation is also taken.

5.6 Scenarios

The Scheduler will function during the scenarios:

- Provisioning when stations request connections - based on QoS demand.
- Rescheduling
- When stations move to a greater range from AP.
- SNR changes due to noise fading, etc.
- Interferences from external sources.

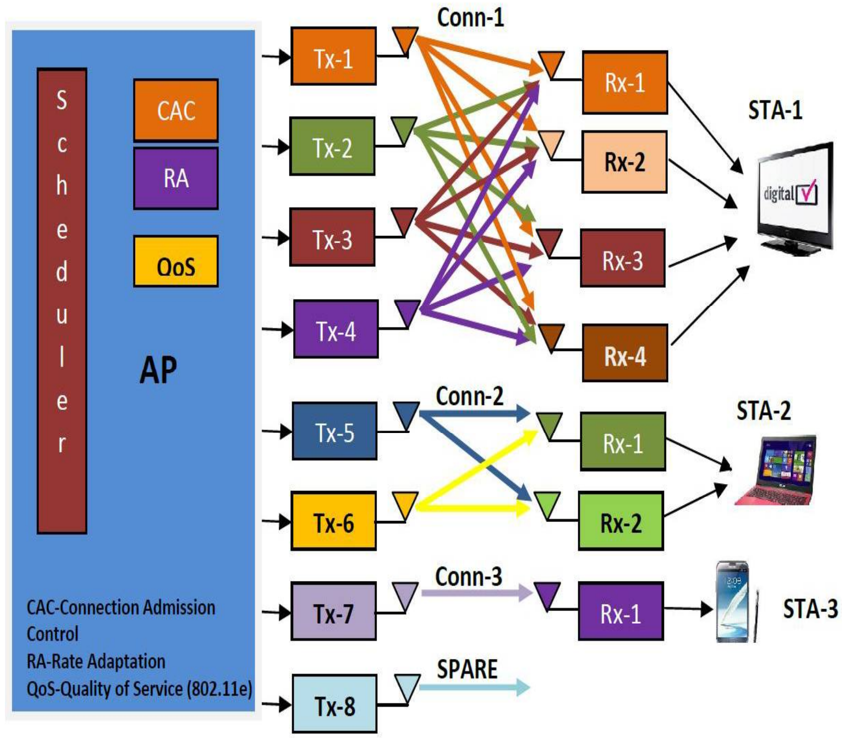

Fig 5.3 Scheduler Control in a Multi-user Scenario

5.6.1 Factors Impacting the Scheduler

<u>Inputs to the Scheduler</u>

- Deployment scenario.
- Enterprise / Home / Ideal condition WLANs
- Arrangement of APs and STAs
- Country (For transmit powers, Frequency band regulation)
- Bandwidth available, Frequency of operation
- Applications (multimedia, browsing,) cost, QoS desired
- Features which need to be jointly optimized
- Resources available - SS, BW, MCS, TxBF, MU-MIMO, Rate adaptation, Transmit power
- Scenarios in which Scheduler is operational
- Fading, interference, noise, range

Design Mechanisms: Scheduler policy, CAC, Queueing, BW Request and grant, Integration with QoS policies and other components shown in Fig 5.1.

Output from Scheduler

- Connections accepted, rejected or queued
- QoS
- End user satisfaction

5.6.2 Use-case scenarios

QoS requirement and Interference were bottlenecks in earlier WLANS inhibiting their performance. 802.11ac scheduler could better handle these issues with its enhanced features. The proposed scheduler is applied in the use cases below:

5.6.2.1 Proposed Scheduler Case-1: Provisioning

QoS requirement for new connection-*Laptop*

Connection	Type	CBW	Throughput	Jitter	Priority
Connection-1 Existing	Digital Video				
Connection-3 Existing	Mobile				
Connection-2 New	Laptop				

Scheduler maintains and periodically updates the following databases:

1. Resource table

Connection	Freq of operation	MCS reqd	Tx Power	RSSI	Spatial Streams	GI	CBW
Connection-1 Existing		9			1,2,3,4		
Connection-3 Existing		5			1		

2. MU-MIMO table

Connection	SS used	No. of Tx antennas	Other MU-MIMO parameters	
Connection-1 Existing	1,2,3,4	4		
Connection-3 Existing	1	1		

Scheduler on receiving request for a new connection, verifies the database tables, and consults QoS as per 802.11e standard. Then it uses the algorithm in CAC module to allow or block the new connection.

5.6.2.2 Proposed Scheduler Case-2: Interference

5 GHz is less prone to interference (not dependent on scheduler). Scheduler maintains channel/medium conditions, i.e. periodically TxBF is calibrated under control of scheduler. With scheduler decision is taken regarding using spare channels or existing channels (TxBF)

Connection	Signal strength	Spatial Multiplexing	TxBF
Connection-1 Existing			
Connection-3 Existing			

5.6.2.3 Proposed Scheduler Case-2: Rescheduling

RA algorithms in WLANS more adhoc as they are not monitored and controlled end-to-end. With noise and changes in SINR, scheduler with RA integrated with other schemes is in better control.