channel conditions for LTE networks. Channel aware scheduling system can be divided into two main categorises, scheduling algorithm based compensation system and opportunistic scheduling [40].

A. Opportunistic Scheduling Algorithm

The opportunistic algorithms are considered a greedy decision when de-queue packets from service class that experience good channel quality. Moreover, the algorithm will defer de-queuing packets with bad channel condition. Hence, in these channel-aware algorithms, the higher bandwidth granted only for connections that experience a good channel condition. By doing so, the utilization of bandwidth is improved. However this can prioritize non real-time connection located near the base station that experience good channel condition over real-time connection.

Rath, et al. [41], proposed the Opportunistic-Deficit Round Robin (O-DRR) scheduler, which is an analytical method for getting an optimal polling interval for UL data traffic via the polling interval mechanism, the BS polls service traffic periodically to make sure that the traffic delays are achieved. The system considering several situations, for instance, the SSs must ensure that the queue should not be empty as well as the receive Signal-to-Noise Ratio (SNR) must exceed the threshold value. Nevertheless, the allocation mechanism of the O-DRR algorithm leads to an additional overhead at the BS because it requires the manipulation of quantum size and a DC for each SS, repeatedly.

Ball, et al. [42] presented a scheduling algorithm for the rtPS. It manipulates a scheduling list that contains all the SSs, which can be served at the next frame. Nevertheless, the algorithm specifies that the SSs that have low transmission quality are suspended temporarily from the transmission list for a period of time. Moreover, this mechanism is repeated periodically for all SSs. In addition, the scheduler grants another suspended period of time if the transmission quality is still low.

Gan, et al. [43] designed a cross layer scheduling algorithm to cope with the features of UL traffic in LTE system. It referred as dynamic Modulation and Coding Scheme (MCS) and Interference Aware Scheduling (DMIA). The main feature for its structure is taking into account the queue status, the status of the channel and the QoS parameters of service type queue. The main algorithm aim is to improve the total throughput, besides sustaining the QoS requirement of diverse classes. Thus, this algorithm considered as an optimization problem to the current scheduling algorithm.

Niyato, et al. [44], proposed a queue-aware algorithm in the SS side for UL direction. It defined set thresholds, which can be identified for bandwidth allocation for the connected services as follows:

$\Psi = \{\psi_1, \psi_2, ..., \psi_b, \psi_{1b,max}\}$

Where, $\psi_1 \in \{1, ..., X\}, \psi_b < \psi_{b+1}$ and $b = 1, ..., b_{max}$

The purpose of theses sets is to recognize the required bandwidth to be allocated in the UL subframe. In specific, the sum of bandwidth assigned to polling service is considered as a function of amount of PDUs in a queue. Nevertheless, they estimate the period amongst successive thresholds in the set is equal as follows:

$$b(x) = \begin{cases} 0, & \text{x=0} \\ b & \psi_b \le x < \psi_{b+1} \\ b_{max} & \psi_{bmax} \le x \end{cases} \quad (1)$$

Lin, et al. [45] proposed a latency and modulation aware bandwidth allocation algorithm called Highest Urgency First (HUF). HUF converts the incoming data rates into time slots in order to determine the influence of several MCS. Nevertheless, the MCS diversity does not fully exploit. Furthermore, HUF process force the request that approach its deadline to be discarded.

B. Scheduling Algorithms based on Compensation System

The scheduling algorithms are categorized under the channel aware scheduling algorithms that are able to amend the allocation based on the variability of LTE channel and QoS parameter provisioning. In this paper, we elaborate more descriptions with reference to related studies related to different algorithms such as fuzzy algorithm which used as an intelligent approach to deal with diverse traffic services.

The authors in [46] discussed a resource allocation and scheduling of cloud computing for five major topics, such as, locality-aware task scheduling; reliability-aware scheduling; energy-aware; Software as a Service layer; and work flow scheduling. Moreover, they classified these five topics into different parts such as performance-based and cost-based resource allocation. In addition, they presented a comparative analysis of the five identified problems with their representative algorithms. On the other hand, a modification to DRR known as Modified Deficit Round Robin (MDRR) was proposed in [47]. They implement a quantum ϕ and DC for each service type queue. The scheduler, in each round, assigns the service type queue by DC value that is in every round added by the ϕ value. Moreover, the scheduler transmits the packets traffic until the DC empties or when the queue length of the packet is greater than the DC, then the scheduler move to the next queue. Nevertheless, real-time packets will experience disruption delay due to heavy traffic in the system. Furthermore, unfairness in resource sharing among non real-time connections will arise when assigning fixed weight to the queues.

Another research as in Laias, et al. [48], they presented a Customized Deficit Round Robin (CDRR). Their algorithm concerned with real-time service through adding a new queue to schedule real-time connections imminent to the deadline. Nevertheless, an extra queue adds further delay which degrades the overall system throughput for non real-time connections such as nrtPS and BE. Moreover, it will violate the packets deadline for real-time connection such as rtPS queues due to the interception of the extra queue for the real-time signal that leads to increase system overhead, which is not desirable mainly for a high real-time traffic.

On the other hand, in this category, the fuzzy logic approaches considered as one of the important scheduling algorithms. The wireless queue scheduling scheme which uses an adaptive fuzzy logic to alleviate the effect of inaccurate state information, achieves better scheduling performance. In addition, a reinforcement learning scheme is adopted to improve the scheduling performance.

Fuzzy logic is able to achieve a near precise decision according to incomplete and inaccurate information. It can be applied to resource allocation and management in wire line and wireless networks. As mentioned in [49], fuzzy logic is used for queues scheduling in order to solve the problem of inaccurate state information in queue scheduling. This is done through using fuzzy inference to make a near optimal solution regardless of in accurateness of status information such as, traffic characteristics, channel condition, and queue status.

In Kumar, et al.[50], the researches use a dynamic fuzzy based priority scheduler intended to provide an implement of the IEEE 802.16e standard that focus on the QoS aspects such as, delay, throughput, and bandwidth utilization. They proposed a fuzzy based scheduling algorithm to overcome the conventional scheduling algorithms drawbacks that are not meeting the necessary QoS parameters.

IEEE 802.16 standard, as discussed earlier, stipulates the signalling mechanisms of QoS and the scheduling services classes to cope with the various application requirements. Table 3 shows the existing IEEE 802.16 QoS support algorithms that are implemented at MAC Layer, which includes the state-of-the-art algorithms that are executed at the BS. Moreover, for more contribution to this field this paper elaborates more details about algorithms characteristics, as well as either contribution or drawbacks of supporting multimedia traffic in order to make straightforward future research.

2.3. LTE Physical Layer QoS Scheduling Algorithms

IEEE 802.16 provisions a variation of physical layers that are frequencies diverse from 2-66 GHz. The Wireless MAN-SC (Single Carrier) is considered for 10-60 GHz band as it supports low system complexity.

Even though IEEE has standardized this PHY, there are not many platforms employing it due to the nature of this PHY characteristic that involves LOS communication. The purpose for allowing NLOS communication, IEEE 802.16 intended to implement the Orthogonal Frequency Division Multiplexing (OFDM) via frequency range of 2-11 GHz spectrum.

Moreover, this support type of PHY is referred to as IEEE 802.16d that eventually targeted for fixed SSs. Popularly this type of communication is used in TDMA. In arrangement of time division and frequency division multiple accesses in combination with OFDM is called Orthogonal Frequency Division Multiple Access (OFDMA). Further details about these techniques can be found in [3]. Figure 5 depicted OFDMA subcarriers structure. In this paper, we highlight a several of the current mechanism conducted in the area of resource allocation in LTE networks with detailed emphasis on OFDMA-based LTE networks.

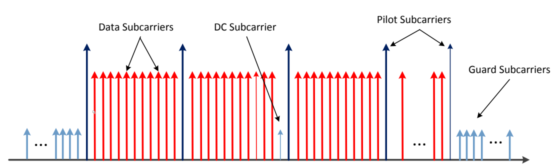


Figure 5. OFDMA Subcarrier Structure

Table 3. Summary of various LTE Scheduling Algorithms

Papers	Objective	Key Idea	Limitations
Tarchi [27]	A hybrid structure algorithm for UL direction	UGS is scheduled by PBRR, EDF for the rtPS and WFQ for nrtPS and BE	It is complex because it depend on different algorithms to handle their QoS requirements
Vinay [29]	Bandwidth allocation for UL traffic to gives better performance for rtPS	Combined EDF and WFQ to serve rtPS	It is complex because it combined two algorithms
Wongthavarawat [31, 32]	Enhance the system throughput and fairness to queues	Constant allocation for rtPS using EDF, whereas WFQ and Equal Sharing are used to schedule nrtPS.	Hybrid algorithms lead to higher complexity
Chen [35]	Ensuring fairness to different service class and to improve throughput	A two-tier hierarchical scheduling for downlink(DL) and uplink(UL) services	Unable to guarantee QoS requirements for rtPS services
Msadaa [36]	Minimise the latency of real-time connection	Guarantee QoS requirements for real-time services	Gives more bandwidth to rtPS at the expenses of BE traffic
Safa [37]	To improves the performance of real-time services by considering a deadline constraint	Modify uplink and downlink bandwidth dynamically	degraded the opportunity for non real-time services such as nrtPS and BE
Shang [38]	Allocating the available bandwidth among BE.	This algorithm is based on the so called soft-QoS and hard-QoS structure	Complex and unfairness for overall system traffic
Sun [39]	Two QoS schedulers located at BS and SS to guaranteed required bandwidth	Gives higher priority to UGS, ertPS and rtPS during the connection setup	Fixed priority assigned to nrtPs and BE starved their connection when more rtPS connections existed in the network
Meng [40]	Designed to extend the PF scheduling algorithm to real-time services and satisfies various QoS requirements	The algorithm tries to differentiate the delay performance of each queue based on GPTS principle	Applied to treat the non real-time application for nrtPS and BE
Nie [41]	Guarantees the delay requirements of UGS, ertPS and rtPS in downlink traffic	QoS priority and fairness scheduling	Not support nrtPS and BE
Rath [49]	To make sure that the traffic delays are achieved	For getting an optimal polling interval for uplink data flow via the polling interval mechanism	The allocation mechanism of the algorithm leads to an additional overhead at the BS

OFDMA. The OFDMA refers to a multiuser OFDM, is recognized as a powerful access technology that is mainly employs the OFDM technique using a modulation technique [51]. The capacity of the system is improved by employing a combination of frequency and multiuser diversities. This is done through allocating a variety of divisions of OFDM subcarriers towards numerous users giving adequate attention to interferences.

In addition, many research has been attempted to improve the optimal subcarrier allocation to the end users, however, there are remaining an open issue related to the allocation problem, with developing problems yet to be conducted [52, 53].

Adaptive Modulation and Coding (AMC) Schemes. In IEEE 802.16e, once higher layer data have been classified into their corresponding service type queues and scheduled by the MAC layer, they are mapped into OFDMA slots by a mapper. A slot is the basic resource unit in an OFDMA frame structure visualized in a rectangular two-dimensional allocation [3]. In order to ease the resource allocation process in the OFDMA downlink, the subcarriers are grouped into sub-channels by using a mode of permutation.

There are two main classes of permutation modes. The first permutation is Partial Usage of Subcarriers (PUSC) and Full Use of Subcarriers (FUSC) modes. They are diversity permutation schemes that distribute the subcarriers of a sub-channel pseudo-randomly in a wide frequency band. The second permutation mode is Adaptive Modulation and Coding (AMC). In this method a number of carriers adjacent on the frequency spectrum are grouped into a band of AMC sub-channels.

In a multipath fading channel different sub-channels experience different levels of fading. Achievable rates can be maximized by adjusting the modulation and coding rate according to the fading level for each

Table 4. IEEE 802.16 OFDMA PHY Modulation and Coding Schemes

Mode	Modulation	Coding Rate	Information bits/symbol	Receiver SNR (dB)
1	QPSK	1/2	1	5
2	QPSK	3/4	1.5	8
3	16QAM	1/2	2	10.5
4	16QAM	3/4	3	14
5	64QAM	1/2	3	16
6	64QAM	2/3	4	18
7	64QAM	3/4	4.5	20

sub-channel [3]. In each frame, user's connections are allocated a successive set of subcarriers, forming a rectangular slot. Each allocation is represented in the DL-MAP message by the slot offset and the number of slots in the allocation frame.

On the other hand, the BS combats fading on each slot by adjusting the modulation technique. Moreover, users have experience the same modulation scheme in each rectangular slot and this experience is a same bit rate which depends on the distance away from BS. The AMC objective is to maximize the data rate through adjusting transmission modes to channel variations while maintaining a prescribed BER. Table 4 presents the AMC for IEEE 802.16 OFDMA [11] .

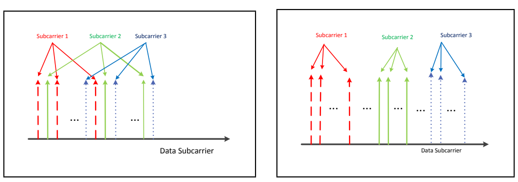
LTE OFDMA Frame Structure. IEEE 802.16 standard defines a frame sub-channelization and structure. Figure 6 shows frame sub-channelization mechanisms: Distribute sub-channelization (PUSC) and adjacent sub-channelization (AMC), respectively. Moreover, Figure 7 shows frame structure [56]. Furthermore, the frame constructs of two sub-frames, DL and UL and the burst time can be distinguished by DL-MAP and UL-MAP as referred for their usage in Frame Control Header (FCH). Thus, the users granted their required bandwidth based on these bursts.

Furthermore, in order to suggest LTE scheduler algorithm it must note that, the number of burst per frame must be distinguished, since the number of frame burst increases, the overhead is increased proportionately.

Multiuser Diversity. The multiuser diversity scheme is recognized as a wireless system with diverse users sharing a time-varying channel. Moreover, this scheme presented by [54] considered the uplink overall capacity over fading channels with full knowledge of Channel State Information. Their results show the mechanism that manages the capacity for the users that can deliver the maximum available bandwidth. Furthermore, with employments of multiuser characteristics, the overall capacity can be enhanced proportional to the increased number of connections in the network.

Other researchers as in [55] attained similar outcomes for the adjustment of downlink fading channels. Even though fading is typically observed as an impairment that has to be improved, the role of multiuser diversity alters this observation through adjusted fading features. Hence, the multiuser diversity is gradually obtained among diverse users from the presence of channel variations.

Particularly, the achieved diversity can be obtained by exploiting the characteristic of wireless channels, and transmissions scheduling towards users that achieved



(a) Distributed Sub-channelization (PUSC) (b) Adjacent Sub-channelization (AMC)

Figure 6. Comparison of Sub-channelization Mechanism – a) Distributed (PUSC) and b) Adjacent (AMC)

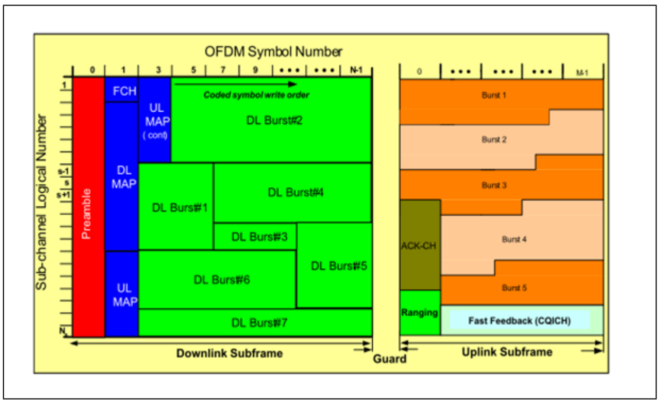


Figure 7. LTE OFDMA Frame Structure [56]

good channel conditions. Hence, the multiuser diversity can significantly increase the spectral efficiency of wireless systems [57] with conventional scheduling mechanisms and CSI feedback.

Generally, the concept of multiuser diversity has attracted a significant consideration, as well as recognised as a key principle in developing well-organized adaptive resource allocation algorithms for wireless communication systems [58].

3. Conclusion

This survey has provided the fundamental information about the design of traffic scheduling algorithms for BWA networks. An overview of BWA networks was presented, with a focus on the IEEE 802.16 standard. In particular, the MAC and PHY layers, as well as the IEEE 802.16 QoS architecture were also discussed.

In addition, a number of essential concepts for designing wireless scheduling algorithms including wireless channel modelling, AMC technique, and multiuser diversity have been described. Furthermore, a detailed about wireless channel poses both challenges and opportunities to traffic scheduling has been discussed. Therefore, a well-designed scheduler should exploit the time-varying nature of wireless channels via the AMC technique and multiuser diversity in order to improve the system performance. This is because overall system utilization starts to be challenged when degradation may happen due to bandwidth allocation disorder. This paper elaborates more detail for MAC QoS scheduling algorithms and discusses their categorizations. In addition, an overview of QoS architecture and the related supported algorithm are presented in detail with their classifications and limitations. Furthermore, this survey investigates the techniques that intend to support QoS for real-time and non real-time services in mobile LTE, especially during packet scheduling and bandwidth allocation that has attracted a significant consideration in developing well-organized adaptive resource allocation and scheduling algorithms for wireless communication systems.

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