Survey of Down Link Data Allocation Algorithms in IEEE 802.16 WiMAX

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ABSTRACT

IEEE 802.16 standard and its marketing technology Worldwide Interoperability for Microwave Access (WiMAX) is one of the leading technology that gain benefit of adopting orthogonal frequency division multiple access (OFDMA) as its multiple access technique. OFDMA gives flexibility in resources allocation to accommodate a large number of users supporting several services classes with quality of service (QoS). This loads big challenges on its resource allocation. One of the key performance factors of OFDMA resource allocation is its downlink data packing mechanism. In IEEE802.16 standard based OFDMA the downlink data is packed into down link frames in the form of rectangular slots called burst. The standard leaves details of packing mechanism as an open issue for researchers and manufacturer to implement. Therefore recently several algorithms have been proposed in literature. This paper endeavours to identify key factors and tradeoffs issues associated with designing of downlink data packing algorithm for WiMAX based IEEE802.16 through a competitive survey of recent proposed algorithms.

KEYWORDS

IEEE 802.16, WiMAX, OFDMA, Resource allocation.

1. INTRODUCTION

WiMAX is a wireless technology that provides broadband data access for fixed, portable, and mobile users based on OFDMA. This multiple access technique based on OFDM modulation provides significant advantages in terms of high spectrum efficiency, robustness against multipath fading channels, resistance to multiuser interference, simplified equalization, and so on [1]. IEE802.16 OFDMA divides the available resources (frequency & time) into several orthogonal sub carriers in frequency domain and into several adjacent symbols in time domain. This gives more flexibility in assigning those recourses, serving many users supporting several service classes with QoS. This leads to a significant increase in resource allocation challenges. Scheduling in a way so as to accommodate the largest number of users/services and packing data before delivery to the users are the major factors that affect efficiency of resource allocation, as a whole system capacity and system performance.

In centralized system such as WiMAX system the Base Station (BS) performs scheduling using Quality of services (QoS) scheduling algorithms and data packing using data packing algorithms. The standards specify only uplink (UL) Packing algorithm and leaves QoS scheduling algorithms and downlink (DL) Packing algorithms as open issues which open the door for researcher and manufacturer to propose new algorithms or adopt some existing algorithms to improve WiMAX system performance and capacity. In designing efficient downlink packing algorithm many factors and tradeoffs issues like mapping overhead, wastage slots, power consummation ... etc have to be considered. In This paper we identify most key

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factors and tradeoffs issues associated with downlink data packing algorithm design. A competitive survey of recent proposed algorithms and how they tackle the key factors and trade off issues is presented.

The rest of the paper is organized as follows: - section 2 gives brief overview of WIMAX systems, section 3 gives details of Downlink sub frame allocations, section 4 discuss Downlink data packing problem, while conclude in section 5.

2. WiMAX overview

WiMAX is a wireless broadband solution that offers a rich set of features with a lot of flexibility in terms of deployment options and potential service offerings [4] IEEE802.16d, IEEE802.16e and IEEE802.16m are standards for Wireless Metropolitan Area Network (WMAN) [1, 2, and 3]. In parallel the WiMAX forum releases several technical specification profiles [5]. Together they make WiMAX one of the most promising technologies for broadband wireless access solution, as well as a 4G candidate. The major distinguish futures of WiMAX are scalable OFDMA, multiple input multiple output (MIMO) antenna, beam forming and adaptive modulation and coding (AMC), support time division duplexing (TDD) and frequency division duplexing (FDD), space time coding, strong security and multiple QoS classes [6].

2.1. PHY Layer overview

One of the operating band profiles for WiMAX is 3.5GHz with subcarrier spacing of 10.94 kHz allowing 128, 512, 1024 and 2,048 FFT size with channel bandwidth of 1.25MHz, 5MHz, 10MHz, and 20MHz, respectively [1]. The transmission and reception between BS and subscriber station (SS) is based on OFDMA. WiMAX divides the channel into orthogonal sub carrier and group those sub carriers into logical sub channel using distributed permutation mode such as Partial Use of Subcarriers (PUSC), Full Use of Subcarriers (FUSC) or adjacent permutation mode Adaptive Modulation and Coding (AMC). Further modulate and code those subchannels adaptively based on SNR Quality to improve overall channel efficiency. Time division duplex (TDD) is favourable duplexing where the frame is divided asymmetrically into downlink subframe followed by an uplink subframe separated by a small gap as shown in Figure 1. On the frame the minimum resource allocation unit is a slot which consists of one subchannel over one or more symbol based on permutation modes. Slot capacity can vary with Modulation & Coding Scheme (MCS) used. Packing data into DL and UL frame is done by BS packing algorithms and it broadcasts detail of packing arrangement in DL-MAP &UL-MAP for all users at the beginning of each frame. The next section gives more detail of DL-MAP.

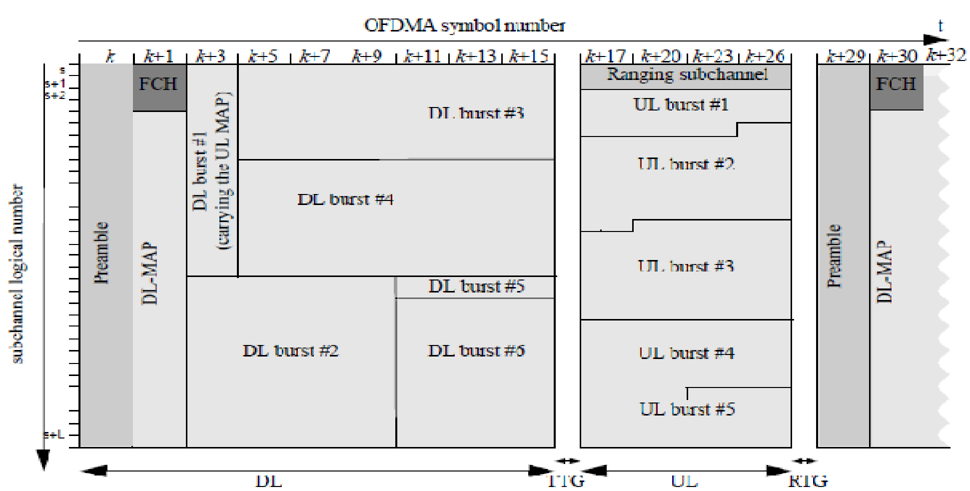

Figure 1. OFDMA TDD frame structure

2.2. MAC Layer overview

WiMAX MAC Layer consist of three sublayers namely the convergence sublayer, the common part sublayer and the security sublayer. Convergence sublayer handle interface with upper layer protocols like ATM, Ethernet and IP protocol. Security sublayer secures the air transmission and protects the data from theft of the services using encapsulation protocol and a privacy and key management protocols. MAC common part performs several essential functions like access controls, MAC PDU construction, mobility support, Automatic Repeat Request (ARQ), power saving, call admission control, QoS provisioning, connection managements and packet scheduling [7].

2.2.1. MAC PDU construction

The incoming MAC Services Data Unit (MSDUs) from the higher layer is assembled to form MAC Protocol Data Unit (MPDUs) where single MSDU fragments into two or more MPDUs. Or multiple MSDUs aggregate into single MPDU so it can be efficiently transmitted over the air. Farther multiple MPDUs that share same PHY parameter are concatenated into single burst to reduce MAP overhead. Each MPDU start with a 6 byte generic MAC header (GMH) followed by variable length payload information and optional 4byte CRC [8]. Fragments, packing, and concatenation are shown in Figure 2.

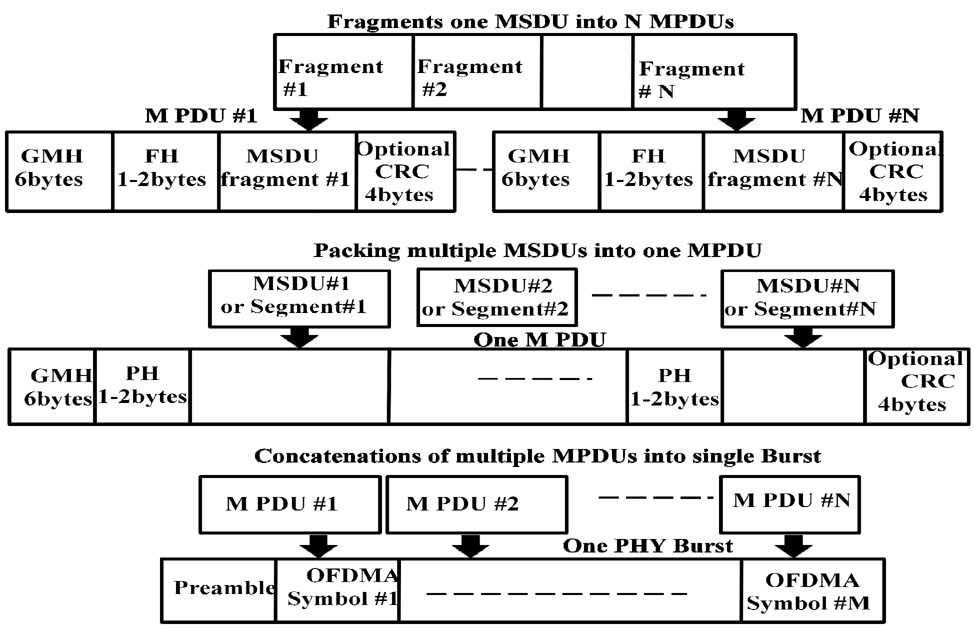

Figure 2. MPDUs Fragments, packing, and concatenation.

2.2.2. QoS scheduler

WiMAX is connection oriented, where each uplink or downlink session application is associated with a 16 bit logical ID called Connection Identifier (CID). A WiMAX service flow is a unidirectional flow of packets with a particular set of QoS parameters, and is identified by a Service Flow Identifier (SFID) [9]. Services classes supported by WiMAX consist of Unsolicited Grant Service (UGS), Real Time Polling Service (rtPS), Non Real Time Polling Service (nrtPS), Extended Real Time Polling Service (ertPS) and Best Effort (BE). WiMAX implements QoS by BS QoS scheduler which classifies the traffic into flows and maps each connection CID into associated SFID that define its QoS parameters. The QoS scheduler maintains this parameter by its scheduling police.

2.2.3. Call Admission Control (CAC) & Bandwidth allocation

Call Admission Control is a mechanism of controlling new connections that want to connect to the network where The BS decides whether to accept or reject new connections based on the available resource and QoS requirements. The BS will grant the bandwidth to SS in two modes. First mode is Grant per Connection (GPC) where each connection is treated separately and Bandwidth is allocated after BS received SS request. Second is Grant per Subscriber Station (GPSS) where all connections from a single SS are treated as single unit and bandwidth is granted accordingly by the BS on a per SS basis [10].

3. WiMAX frame allocation.

In TDD WiMAX the frame is divided into DL subframe and UL subframe. DL-MAP & UL-MAP messages are used by BS to control access to the air frame. DL-MAP & UL-MAP relevant time is shown in Figure 4. In the uplink direction, data is allocated horizontally to minimize number of subchannel. The allocation starts with lowest numbered subchannel in the lowest numbered OFDMA symbol and continues till the last subchannel is reached. It is then continued from the lowest numbered subchannel in the next OFDMA symbol [3]. In the downlink direction data are allocated in rectangular shape to minimize both number of subchannels and number of OFDMA symbols which required an efficient two dimensional packing algorithm [11]. Figure 5 shows data mapping in DL &UL frame.

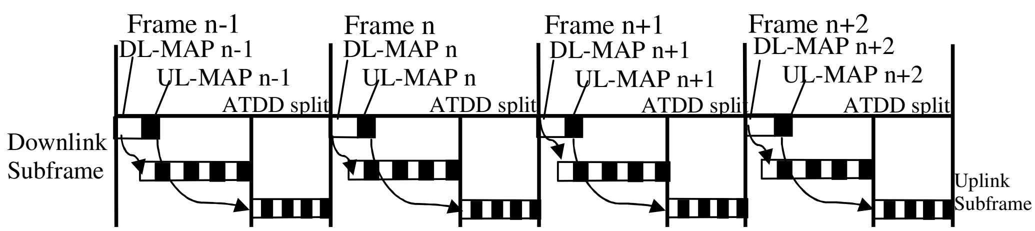

Figure 4. Minimum time relevance of DL-MAP & UL-MAP (TDD).

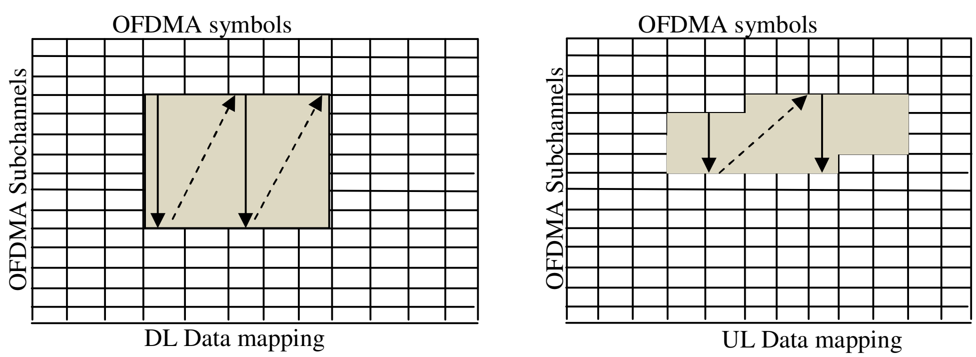

Figure 5. DL &UL data mapping.

3.1. DL-Map and it's overhead

WiMAX assigns slots to users in downlink in a rectangular form called a burst where a burst contains data for a single or multiple CID that share the same physical parameters. Each user is informed about its burst allocation by broadcasting the DL_MAP massage with the most reliable MCS at the beginning of the DL subframe. Table (1) describes the fields of DL-MAP. The fields consist of two main groups. The first group which required 104 bits once per DL Subframe consists of Message Type, PHY Synchronization, DCD Count, BS ID and No Symbols. The second group consist of No CID, CID, Symbol Offset, Subchannel Offset, Boosting, No Subchannel, No Symbols, Repetition Coding Indication and DIUC [3]. This group requires 44+16 No CID bits once per burst to define a two-dimensional allocation pattern of the burst and is called Downlink MAP Information Element (DL_ MAP_ IE). The total DL_MAP header is equal to summation of required bits as in equation (1) [12].

$$\text{DL\_MAP header} = 104 + \sum_{1}^{No\ bursts} (44 + 16\ \text{No CID}) \quad (1)$$

Table 1 DL-MAP fields.

DL-MAP fields	
DL-MAP fields per Subframe.	DL-MAP fields per burst (DL_ MAP_IE)
Message type (8bits) to specify type of the message. **PHY synchronization** (32bits) for frame duration and number. **DCD Count** (8bits) to count change in DCD, which describes the downlink burst profiles. **BS ID** (48bits) to identifying the BS. **No Symbols** (8bits) to specify number of OFDMA symbols used.	**No CID** (8bits) to specify number of connections on this burst. **CID** (8bits) to represents the assignment of the IE to a broadcast, multicast, or uncast addresses. **Symbol offset** (8bits) to specify starts of burst measured in OFDMA symbols. **Sub channel Offset** (6bits) to specify lowest index OFDMA sub channel used for carrying the burst, starting from sub channel 0. **Boosting** (3bits) to specify if Power boost is applied to the allocation's data subcarriers. **No Subchannel** (6bits) to specify number of OFDMA Sub channel used to carry the burst. **No Symbols** (7bits) to specify number of OFDMA symbols used to carry the burst. **RCI** (2bits) Repetition Coding Indication to Indicate the repetition code used inside the allocated burst. **DIUC**(4bits) to specify type of burst profile.

Now let see how it work in an example scenario where we have 10 users running VoIP application. Each user received (42 bytes in each frame [13]). The total data to be sent in each frame is (10 x 42) =420 byte. If each user has its own burst then the size of DL-MAP is ((104+ 60x10)/8) = 88 byte. To broadcast DL-MAP massage we have to use most reliable MCS so it may required 88/3 = 29.333 ≈ 30 slot. Higher MCS can be used to unicast VoIP data such as 12 byte on average per slot so it required 420/12 = 35 slot. Therefore to sending 35 slots of data we spend 30 slots wastage as overhead. Though this may not always be the case, but it does illustrate how crucial DL_MAP overheads can be. In WiMAX release 1.5 proposes periodically allocation to overcome this problem.

3.2. Wastages slots in downlink frame

The wastage in the down link frame not only because of DL-MAP overhead but also because of packing process. To illustrate this wastage a simple packing example is given hereafter. We consider (10 subchannels x 10 symbols, 50 slots) DL subframe with PUSC mode and four requests (303, 235, 90, and 55) bytes it has to be send in this DL subframe. First step is convert those request into slot as per MCS (403/24 = 16.79 ≈ 17 slot, 235/16 = 14.6 ≈ 15 slot, 90/9 = 10 slot, 47/6 = 7.33 ≈ 8). Second step shape those request into best rectangle that can fit into DL subframe as following (17+1 = 18 into 3 x 6, 15 into 3 x 5, 10 into 2 x 5 and 8 into 4 x 2). Finally fit those rectangles in DL subframe as shown in Figure 6.

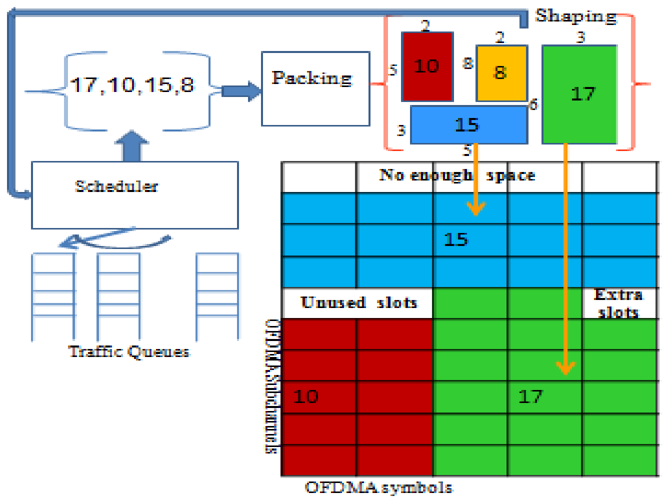

Figure 6. Arbitrary data packing example

There are several wastages in this packing example, firstly some request cannot form a rectangle so it needs to allocate extra slot like 17+1=18. Secondly bad fitting may cause unused slot and final last request will not get enough space duo to previous wastage so it return to QoS scheduler this may affect QoS requirements. DL-MAP packing algorithm and its overhead are crucial to system performance as it affect spectrum efficiency, capacity and QoS of the system.

4. Downlink data packing problem

The QoS scheduler select data packet to be sent in the current frame for each SS from the queued traffic flows. It also decides size of the selected data packets in slots based on the available slots and quality of services without any shape constrain. Then data packing algorithm maps the selected data packets (known as "burst") into downlink. Since, the standard specifies that mapping data burst has to be in rectangular form into downlink sub frame. This constrain make the mapping as two-dimensional rectangle mapping problem. Shaping the selected data bursts in rectangles may require allocation of extra slots and fit those rectangles into big rectangle may leave some unutilized slots. Thus these unutilized slots effect the efficiency of mapping algorithm and WiMAX system performance. Also there are many consideration with two-dimensional rectangle burst mapping problem like: (i) minimize the number of burst time symbols to reduce SS active time and power consummation, (ii) minimize the number of burst subchannels to efficiently utilize the subchannel and (iii) reduce number of bursts to reduce DL-MAP overhead size. The two-dimensional rectangle burst mapping problem is considered to be NP-complete problem [14]. The complexity of the solution grows exponentially with the number of objects [18]. Recently many heuristic algorithms have been proposed to solve this problem.

4.1. Survey of recent solutions for downlink data packing

This section discuses most of recent proposed solution for downlink data packing problem and it classified bases on most important factor addressed.

4.1.1 Algorithms concentrating on packing efficiency with fragments

Ben-Shimol et. al. address the problem of two-dimensional mapping for wireless OFDMA in [15], where a Raster Algorithm is proposed. The algorithm sorts the selected requests data in descending manner and packs them row by row from left to right and from top to bottom. It starts with the largest request that can be fitted without fragments. It then breaks the other requests into more bursts which lead to an increased DL_MAP overhead. Also grouping requests with same MCSs is not considered. Allocation by rows increases SS active time leading to increases the power consumption which is not suitable in mobile application and allocation from left fixed the size of DL-MAP.
Xin et. al. Propose Mapping with Appropriate Truncation and Sort (MATS) Algorithm in [16]. MAT tries to improve Raster Algorithm by limit fragments of large request into one using truncation and then mapping. But it still produces many fragmentations which result in large overhead.

4.1.2 Algorithms concentrating on packing efficiency without fragments.

The Weighted less flexibility first (WLFF) Algorithm was proposed by Wang et. al. [17] .The algorithm defines the flexibility on calculated terms and allocates the requests based on the flexibility which may require more computation. Also one of flexibility criteria is to sort the requests from large to small which may contradict with the requests QoS order. WLFF reserves the first column for DL_MAP and this may limit the number of allocated bursts.

One Column Striping with non-increasing Area first mapping (OCSA) proposed by So-In et. al. [11] which was further enhanced in [18] as (eOCSA) by reduce it complexity from O (n3) to O (n2) at the cost of assigning some extra slot also problem of unused slot still exist and the algorithm does not consider grouping allocations with same MCSs which increase the map over head. The efficiency of the algorithm highly degraded under some traffic sizes.

Zhu et. al. allocate the burst in columns of identical width then shuffle allocated bursts to combine the scattered unused space in the frame to form a large space that can accommodate more burst [19]. Orientation-Based Burst Packing (OBBP) algorithm present by Eshanta et. al. [20] was similar to [11]. The algorithm is based on burst factorization and pre-arranging them using matrices. This simplify finding optimal column or rows to minimize the unused slot and avoids padding the algorithm shows good efficiency at heavy load but the efficiency goes down at low loads. Also the algorithm efficiency is dependent on burst size ratio.

4.1.3 Algorithms concentrating on reduce DL_MAP overhead.

Sample Data Region Allocation Algorithm (SDRA) was proposed by Bacioccola et. al. [21]. The algorithm first groups the SS data with same MCS into so called date regions and then assigns data regions by columns from bottom to top and from right to left. This minimizes DL_MAP by reducing the number of IEs. But the SS has to decode the entire data region to get its own data from listed SSs in the region which increases the SS power consumption.
Ohseki et. al. [22] propose an algorithm that first prepare a bucket of one time slot with more than one sub channel to construct data from different SSs with the same MCS in combined columns. It starts as one column, and if the buckets grow it expands by filling another column which may not be fully utilized. The algorithms maintain QoS requirements as it group the requests sequentially as order by the QoS scheduler.
Shiann et. al. [23] Aim to reduce DL_MAP overhead by minimizing the number of bits required for a DL_MAP IE. Instead of sending complete IE indexing they construct the relation among bursts and send portion of IE indexing and leave it for the SSs to reconstruct complete IE indexing. Piggybacking IE on data so that it is transmitted with higher MCS was proposed by Ju-Yeop et. al [24]. Both [23, 24] need modifications in the standards.

4.1.4 Algorithms concentrating on reducing the power consumption

Desset et. al. Present algorithm to reduce the SS power consumption by using binary search tree[25]. The algorithm minimizes the average duration of a burst within a given frame, in such a way that a SS needs to be awake for receiving data during a shorter time, but the complexity limits number of users to 8. This is no practical. Papers by Abbas et. al. [26,27] model DL packing problem as a programming model where the authors formulate objectives, decision variables and constraints mathematically, and apply optimization solver or full search to get optimal solution. The algorithm aims to reduce BS energy consumption by maximizing the use of resources at the base station while reducing the energy wasted caused by sending padding bits. But the algorithm requires more computation time.

4.1.5 Algorithms concentrating on traffic QoS priority

Considering traffic QoS priority Yen-Wen et. al. propose Target Side Allocation (TSA) Algorithm in [12] .The algorithm searches for rectangular side that can accommodated the burst without fragments called target side, from left to right so that the number of traffic bursts can be minimized. Otherwise it is placed normally which may increase number of bursts. In addition they analyze tradeoffs between degrading of modulation level cost and DL-MAP cost to increase the resource utilization.

Jia-Ming et. al. combine problem of scheduling and burst allocation in cross-layer manner and propose that the scheduler arrange the size of real time and non real time data traffic as multiples of fixed size called buckets so that they can be easily packed into DL subframe. But this gives less freedom to the scheduler [28]. Greedy Scheduling Algorithm (GSA) introduced by Anatolij et. al. in [29]. This algorithm is one of few algorithms that address efficiency, flexibility, QoS, interference management and computational load in both online and offline architecture for DL packing problem. The algorithm consist of stages each stage concern with one or more performance factors to optimize the overall performance. But the complexity of packing stage is O (n4) which is quite high.

4.1.6 Other related work.

Caretti et. al. [30]. Focus on resources consumed by edge SSs. Edge SSs experience poor channel quality, due to severe path-loss and high interference from concurrent transmissions in nearby cells. The authors propose partitioning the sub-carriers of an OFDMA MAC frame into logical bands with different power levels to provide edge SSs with extra power to use more efficient modulations, thus limiting the wastage of channel capacity while improving the quality perceived by edges users. But allocating extra power may not solve the problem. In addition to previous designing factors Joo-Young et. al. Apply power boosting to improve downlink capacity and propose a heuristic burst construction algorithm [31] that constructs bursts in a manner that reduces both resource wastage and resources usage using power boosting. Yuan-Cheng et. al. propose search for best corner algorithms (BCO) in [32]. The algorithm avoids request fragments, assign some extra slot and reduce the unused slot by placing the request in the best corner in the two-dimension subframe.

4.2. Summary of some issues and considerations associated with designing of downlink data packing algorithms

- Allocation vertically minimizes number of time slot which leads to minimizes SS power consumption but it might leads to inefficient utilizing of subchannels.
- Sorting the request gives more efficient backing but it might effect the QoS priority.
- Considering the request QoS priority in allocation, convert the problem from two-dimensional packing to knapsack problem where each request has size and value. This makes the problem more complicated.

- Grouping the request of different SS with same MCS, minimizes DL-MAP overhead but it increase SS power consumption.
- Allowing fragment one request into one or more bursts simplifies the packing problem but it increases the DL-MAP overhead.
- Full search packing algorithms gives efficient packing but its complexity major problem.
- Considering power boosting or apply optimal block in allocation leads to minimizes the number of subchannel that increase number of symbols and SS power consumption
- Combining the design of scheduler with packing algorithm as cross layer design, gives efficient packing but it add more constrain on the scheduler.

5. CONCLUSION

In this survey we study the downlink data packing algorithms for OFDMA WiMAX based IEEE802.16. Process of designing efficient downlink data packing algorithm involve steps that effect, Channel efficiency, Scalability, QoS, SS Power consummation, and System Capacity. Unfortunately most of these factors are contradicted with each other and most of proposed algorithms try to improve some factors at the cost of scarifying in other factors, such as grouping requests with same MCS to minimize DL-MAP overhead at the cost of increase SS power consumptions. In addition this paper identifies most key factors and tradeoffs issues associated with designing of downlink data packing algorithm for WiMAX through a competitive survey of recent proposed algorithms. In literature many algorithms have been proposed to solve this problem but there is lack of comprehensive comparative analysis of these algorithms under different traffic classes.

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