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A Review of Resource Allocation Techniques for Throughput Maximization in Downlink LTE

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Abstract: Long Term Evolution (LTE) by 3rd Generation Project Partnership (3GPP) is one of the radio access technologies used for delivering broadband mobile services. It is mainly influenced by high data rates, minimum delay and the capacity due to scalable bandwidth and its flexibility. The downlink LTE employs Orthogonal Frequency Division Multiple Access (OFDMA) as a multiple access technique. The conventional resource allocation method in OFDMA employed different Modulation and Coding Scheme (MCS) on allocated subcarriers to achieve good throughput. But in the downlink LTE, all scheduling blocks at a given Transmission Time Interval (TTI) to user must adopt same MCS and these brings about constraints in the system and as a result degrade system performance. This study reviewed several resource allocation schemes for throughput maximization in LTE downlink. In each of the schemes considered, the sub-optimal solution shows a significant performance improvement compared to the optimal solution. A Quality of Service (QoS) guaranteed RB allocation achieves high throughput compared to other schemes considered in this study.

Key words: Downlink, throughput, subcarrier, coding, modulation

INTRODUCTION

The mobile communications' development has passed through a sequence of successive generations, starting from 1st Generation (1G) analog, 2nd Generation (2G) digital and to the present 3rd Generation (3G) broadband technologies. The 3G enable audio, video and data transmission simultaneously within the same channel (Astely *et al*., 2009).

Long Term Evolution (LTE) by 3rd Generation Project Partnership (3GPP) is one of the radio access technology used for delivering the broadband mobile services. LTE offers many features with flexibilities in terms of deployment options and potential service offerings. The downlink of LTE employed Orthogonal Frequency Division Multiple Access (OFDMA) technique in order to obtain robustness against multiple interference, frequency domain channel-dependent scheduling and multi-input-multi-output (Anonymous, 2008; Lee *et al*., 2009).

In OFDMA, users are assigned separate sub-channels that effectively divides up the broadband into multiple narrow bands and transmit information on these narrow bands in parallel. OFDMA is based on the modulation technique called Orthogonal Frequency Division Multiplexing (OFDM) which similarly uses a multitude narrow bands subcarriers that are orthogonal with each other and carry lower data streams which sum up to a high data rate transmission (He *et al*., 2012).

The need for intelligent resource allocation cannot be over emphasized not only because of the limited nature of the spectrum but also because of how it affects the quality of service of users at low cost. A considerable amount of literature has been published on the problems of resource allocation in an OFDMA system in recent years. Previous research findings in OFDMA resource allocation focused on scheduling decisions based on the current time instant subject to the current resource constraints. They were not able to utilize the dynamic nature of the wireless spectrum to improve the performance of the communication system. Furthermore, the conventional method of resource allocation in OFDM system is that a user can employ different Modulation and Coding Scheme (MCS) at a given Transmission Time Interval (TTI) on the allocated subcarriers to improve the throughput. In the downlink LTE systems, however all Scheduling Blocks (SB) allocated to a user must adopt the same MCS at any given TTI. Therefore, the application of conventional resource allocation in LTE results in degraded performance, since MCS must be chosen according to the worst SB (Chadchan and Akki, 2010).Therefore due to the constraints discussed above and the complexity of the problem, several researchers focused in developing sub-optimal solutions to the resource allocation problems to improve the overall system performance. This study will review the research conducted on several resource allocation schemes to improve the system's throughput in LTE downlink.

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Table 1: Summary of LTE major parameters

Parameters	Values
Access scheme UL	SC-OFDMA
Access scheme DL	OFDMA
Bandwidth	1.4, 3, 5, 10, 15, 20 MHz
Minimum TTI	1 m sec
Subcarrier spacing	15 kHz
Cyclic prefix short	4.7 μ sec
Cyclic prefix long	16 μ sec
Modulation	QPSK, 16, 64 QAM
Spatial multiplexing	Single layer for UL per UE, up to 4 layers for DL per UE, MU-MIMO supported for UL and DL

OVERVIEW OF LTE

The LTE is a mobile technology by 3rd Generation partnership project (3GPP) group that is divided into generations from 1st-4th with 3rd Generation (3G) as the first mobile handling broadband data and later, voice and other services were integrated. The specifications of LTE are formally known as Evolved UMTS terrestrial radio access (E-UTRA) and Evolved UMTS terrestrial radio access network (E-UTRAN), although they are all referred to as LTE (Ali-Yahiya, 2011). Table 1 summarizes some of the important features of LTE and some of them will be highlighted in this research.

LTE can achieve theoretical high data rate of 100 Mbps with 20 MHz bandwidth in the downlink and 50 Mbps with 20 MHz in the uplink. It has scalable bandwidth of between 1.4-20 MHz for flexible radio planning. LTE has reduced packet latency, reduced radio access network cost and a cost effective migration from earlier 3GP releases. Other important features of LTE are the usage of multiple access schemes, Adaptive Modulation and Coding (AMC) Hybrid Automatic repeat Request (HARQ) technology (He and Fei, 2010) and the radio resource allocation technique (Ramli *et al*., 2011). The main drivers of are, therefore data rates, delay and capacity.

FRAME STRUCTURE IN LTE

The LTE frame structure is shown in Fig. 1. The frame duration is 10 m sec and each frame is divided into subframes of 1 m sec each. The subframes are further divided into 2 slots of 0.5 m sec durations. Depending on the cyclic prefix configuration, each slot has seven and 6 OFDM symbols in the normal and extended cyclic prefix, respectively. In the frequency domain, resources are grouped in units of 12 subcarriers from each OFDM symbol, separated by 15 kHz and therefore occupying a total of 180 kHz. One resource block is defined as one of the subcarriers for duration of 1 slot. The resource block is the main unit to schedule transmissions over the air interface.

Table 2: Bandwidth and corresponding PRBs in LTE

Channel bandwidth (MHz)	No. of resource blocks
1.4	6
3	15
5	25
10	50
15	75
20	100

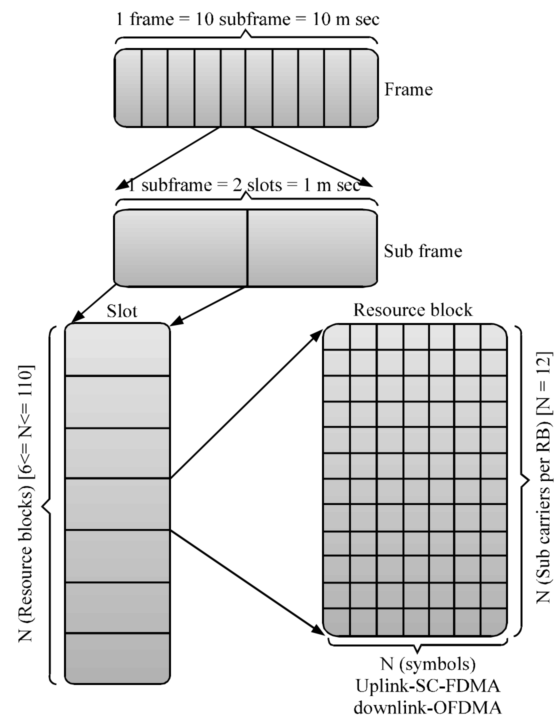

Fig. 1: The LTE frame structure

Based on the frame structure in the downlink of LTE, its operation depends on the concept of Physical Resource Block (PRB). A PRB is defined as consisting of 12 consecutive subcarriers for 1 slot (0.5 m sec) in duration. The PRB is the smallest element of resource allocation assigned by the base station scheduler. The relationship between the bandwidth and the PRBs for downlink LTE is shown in Table 2.

METHODS OF RESOURCE ALLOCATION IN LONG TERM EVOLUTION (LTE)

The resource allocation schemes in downlink LTE attract attention from various scholars due to time varying nature and fading associated with the wireless channel. The downlink LTE employs Orthogonal Frequency Division Multiple Access (OFDMA) as a multiple access technique. The conventional resource allocation method in OFDMA employed different Modulation and Coding Scheme (MCS) on allocated subcarriers to achieve good throughput. But, in the downlink LTE all scheduling blocks at a given Transmission Time Interval (TTI) to user must adopt same MCS and these brings about constraints in the system and as a result degrade system performance. Therefore, optimum allocation of resources and MCS selection will improve the overall throughput of the system and mitigate against the effects of fading and the time varying nature of the wireless channel.

Adaptive Block-Level Resource Allocation technique (ABLRA): Fan *et al*. (2011b) proposed a resource allocation scheme in LTE that allocates Resource Blocks (RB) power and rate jointly to maximize the network throughput. In this study, exponential effective Signal to Interference-plus Noise Ratio (SINR) mapping (EESM) and Mutual Information Effective SINR Mapping (MIESM) methods are used to convert the for post-processing SINR to determine an appropriate MCS for RBs with different channel gains. This method uses the Modulation and Coding Scheme (MCS) information in the uplink as a feedback to the Base Station (BS). Based on the feedback, the BS optimises RB assignment, power allocation and MCS selection to achieve the highest sum throughput with the limited resources. In order to reduce the complexity of the process, the joint optimization was separated into RB assignment and power allocation. The RB assignment to the users is based on the highest Signal to Interference to Noise Ratio (SINR) or largest MCS index to achieve the highest throughput after relaxing the MCS constraint in LTE. Modulation and Coding Scheme (MCS) was selected based on power allocation not only to ensure the Block Level Error Rate (BLER) performance of RBs with worst channel condition but also to exploit the RBs with better channel conditions more efficiently. The relative power was allocated among the RBs' belonging to the same user which is termed as Power Allocation among RBs' of the same user (PAaRB). The power is then adjusted among users to achieve further improvement and the corresponding MCS is also determined which is called Power Allocation among Users (PAaUE). Therefore after completing PAaRB and PAaUE, the power allocation at the RBs of a user can be found then accordingly new SINR of each user obtained. Based on the new SINR of a user, MCS corresponding to a user is also found.

The MCS indices were used by the Base Station (BS) to approximate the SINR and it was based on that the resource allocation scheme was developed to improve the system throughput. The throughput increased monotonically with SINR, as shown in Fig. 2 for the LTE systems.

Figure 3 depicted the average throughput versus average SINR for various resource allocation schemes with 4 users. The average throughput of the proposed method significantly outperforms others when

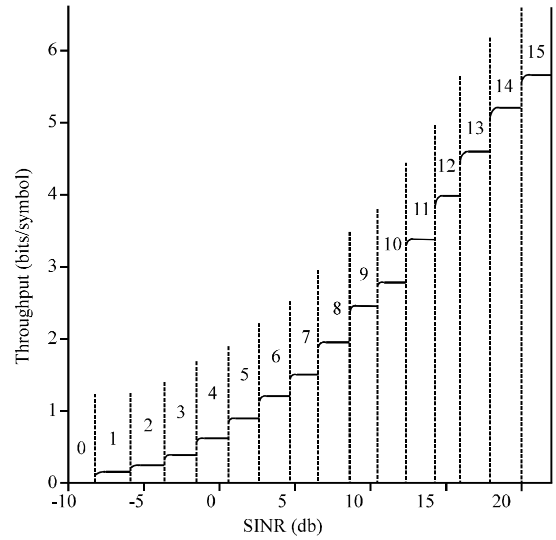

Fig. 2: Relationship of MCS, SINR and throughput in AWGN channel

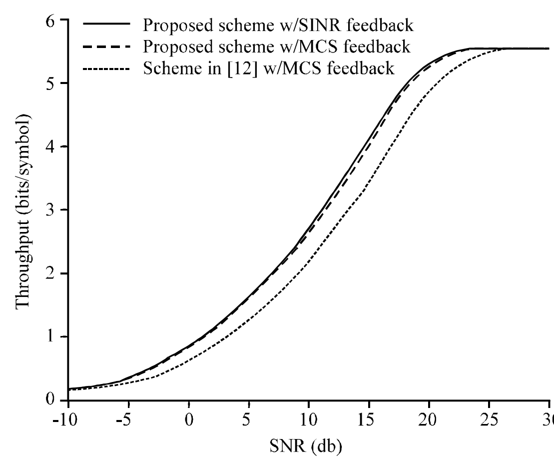

Fig. 3: Throughput versus SINR for Fan's scheme and the scheme in [4] with 4 numbers of users

-5 dB<SINR<25 dB. However, when the SINR was too low or too high, the RBs had the same minimum or maximum MCS index and therefore there was no significant difference recorded in the throughput. Also, there was slight performance difference from the proposed scheme with SINR feedback and MCS feedback.

The average throughput versus number of users for various resource allocation scheme is depicted by the simulation result shown in Fig. 4 when SINR = 10 dB. Figure 4 shows that the Fan's scheme is improved by 20% compared to other schemes when number of user is 4 and SINR = 10 dB and the proposed scheme based on MCS feedback has the same performance as that based on the

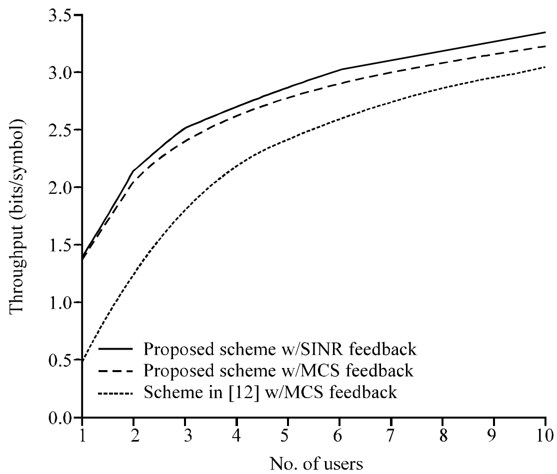

Fig. 4: Throughput versus number of user for Fan's scheme and the scheme in [4] when SINR = 10 dB

accurate SINR. Therefore, it can be concluded that the overall throughput of MCS selected through power allocation of the Fan's scheme is larger than that of the scheme based on minimum MCS selection.

MCS selection for throughput improvement in downlink LTE systems (MCSHM): Jiancun investigated MCS selection to maximize system throughput and developed effective MCS selection scheme that ensure the BLER performance of the RB with both poor and good channel conditions (Fan *et al.*, 2011a).

The joint optimization problem was simplified in the Jiancun's by separating into RB assignment and MCS selection. Appropriate RBs were assigned to users and then MCS was selected based on the effective packet-level SINR estimated by different ways.

Multiple subcarriers in an RB have different channel gains, therefore EESM and other methods are used to find the effective SINR of each resource block and then relate the values to MCS index which is feedback to the base station as channel quality indicator.

Also, Arithmetic Mean (AM), Geometric Mean (GM) and Harmonic Mean (HM) of the approximate block-level SINRs on the RBs for each user was exploited which was used to obtained the estimated packet-level SINRs with results into different impacts from these methods. For AM based scheme, the estimated effective packet-level SINR is mainly dominated by the Rbs with maximum SINR. For GM based scheme, RBs belonging to the same user are considered. While for the HM based scheme, RBs with minimum SINR are considered. It was shown that the scheme based on HM was more appropriate MCS and obtained higher throughput compared to the other schemes.

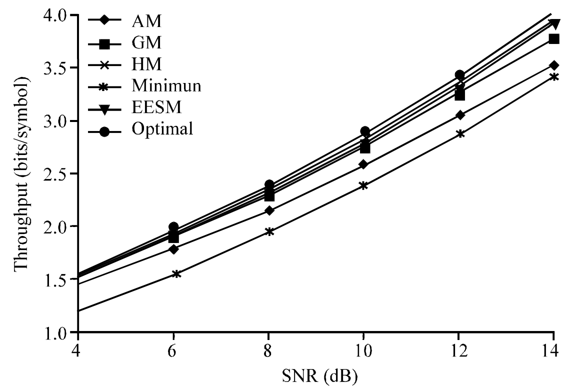

Fig. 5: Average throughput versus SINR for different MCS methods in Jiancun's scheme

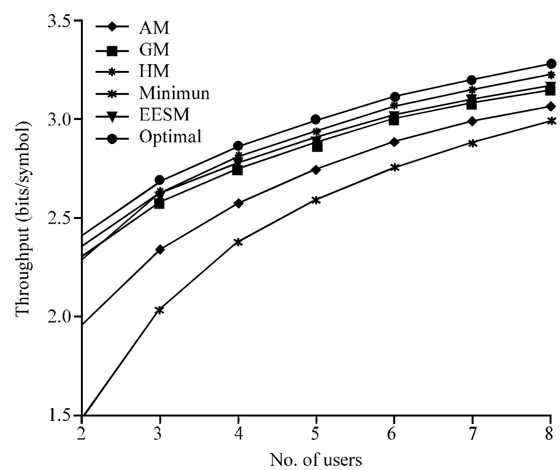

Fig. 6: Average throughput versus number of users for the Jiancun's scheme with different packet-level SINR estimation methods

From Fig. 5, the Jiancun's scheme based MCS selection obtained almost the same throughput as the optimal which was considered best among the other methods. From Fig. 6, it was shown that the throughput from Jiancun's based MCS selection is improved by 18% compared to that in [13] when number of users are 4 and SINR = 10 dB.

Quality of Service (QOS) guaranteed RB allocation algorithm for LTE systems (QSRBA): Na proposed an efficient resource block allocation algorithm which takes into account both the MCS constraints and QoS requirement for the downlink transmission in LTE (Guan *et al.*, 2011). The 3 classical practical resource allocation algorithms namely: Max Carrier-Interference (C/I), Round Robin (RR) and Proportional Fair (PF) do not take QoS into account. The OFDM system employs the

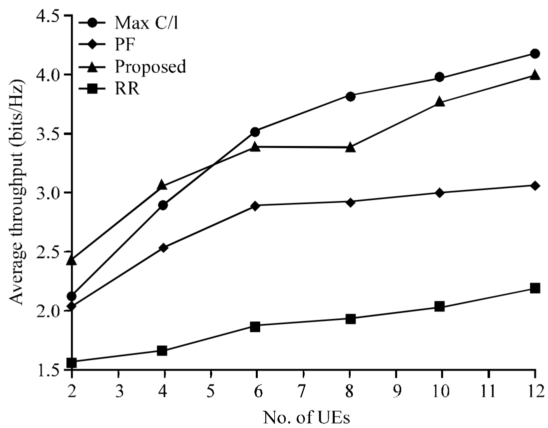

Fig. 7: Throughput of Max C/I, PF, Na's scheme and RR algorithm versus number of users

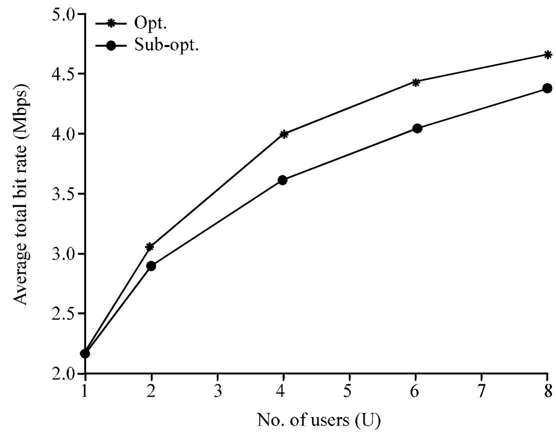

Fig. 8: A graph of average bit rate versus number of users

conventional method of allocating different MCS to subcarriers to achieve good throughput. In LTE downlink, the requirement is to assign same MCS to all the scheduling blocks allocated at a given TTI. Therefore, applying conventional resource allocation in LTE results into degraded performance since, MCS must be chosen according to worst Scheduling Block (SB). Average channel condition in form of Channel Quality Index (CQI) is the feedback to the BS from the user and it enable the scheduler to know which MCS to be adopted and be assigned to all the SBs of the same user.

The optimization problem in the scheme is complex which increases exponentially with the number of constraints and variables but the complexity was reduced by a novel suboptimal algorithm. It mainly comprises of two steps:

- Estimate the number of SBs required by each user based on the ratio of users' minimum rate requirements to its average gain
- With constrain of users' minimum rate requirement, allocate SBs to users according to users' priority

Figure 7 shows that the throughput of Na's scheme is higher than the max C/I algorithm when the number of UEs is small. It may be concluded that max C/I gives the highest performance but under the assumption that each SB employs different MCs according to their channel conditions. In LTE, max C/I cannot always provide the best throughput performance because the MCS adopted by each user should be decided by the worst SB allocated to it.

Resource allocation in an LTE cellular communication system (RALDL): Kwan *et al*. (2009) in their research investigates, the effect of multi-user diversity in resource allocation to increase throughput of the system. SBs with different channel qualities are assigned to users to achieve overall system throughput maximization. SBs with highest CQI are from a group of SBs are fedback and the signal requires smaller bandwidth but at the cost of degraded performance as in LTE Adaptive Modulation and Coding (AMC) is employed to reduce this effect on throughput. The quality of feedback defends on the method adopted. It is assumed that MCS rate increases with CQI index and SBs whose CQI values are not fedback are assigned MCS 1. If MCS are to be assigned to a user, only those blocks with good enough channel qualities or higher can be allocated. SBs with lower MCS index will result in high error rates if selected. The sub-optimal scheduler is implemented in 2 stages to reduce the complexity of the algorithm:

- Selection of best user for each SB and collection of information regarding the set of SBs associated with user
- Selection of the best MCS given the selected SBs for each user

In the case of the optimal scheduler, there are 2 types of models employed; multi-user optimization and linearized model. In both models, MCS, SBs and users are jointly assigned and therefore creating computational complexity. Therefore, suboptimal scheduler is better than the optimal scheduler due to the decouple selection between SBs and MCS.

Figure 8 is the graph of throughput against number of users to illustrate the performance of the optimal and sub-optimal algorithms. The average SINRs for all users are set to 10 dB. It can be deduced from the graph that as the number of users increases throughput also increase and sub-optimal scheduler, performs better than optimal scheduler.

COMPARISON OF THE RESOURCE ALLOCATION SCHEMES

The researchers (Fan *et al*., 2011a, b; Guan *et al*., 2011; Kwan *et al*., 2009) presented different RB allocation schemes that maximize the overall system's throughput. In comparing their research, the following points were considered:

- Channel estimation method employed
- How the resources are assigned
- The optimization method used and the channel parameters considered

Figure 9 depicts the graph for the comparison of the resource allocation schemes considered in this research while Table 3 shows the of summary of the comparison.

The researchers used EESM and MIESM to estimate the packet-level MCS index for RBs with different channels gains (Fan *et al*., 2011b). The effect of channel

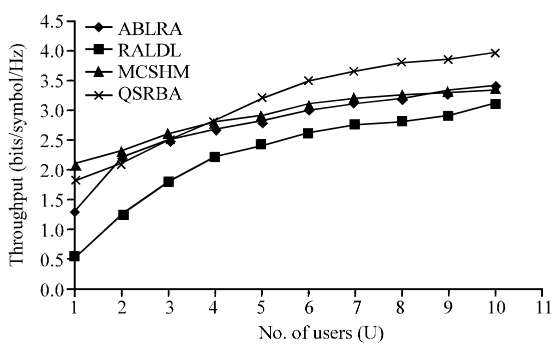

Fig. 9: Graphs of throughput versus number of users comparing the methods of resource allocation

estimation on the average throughput was investigated by Fan *et al*. (2011a) where they developed EESM, AM, GM and HM effective selection schemes. Guan *et al*. (2011) in their research expressed the average channel condition in form of CQI and used it as feedback to estimate the MCS to be used in the scheme. The researchers Kwan *et al*. (2009) unlike Fan *et al*. (2011a, b) and Guan *et al*. (2011) estimated the channel values of those whose feedback messages were not received at the scheduler by assigning MCS 1 to them.

The RBs assignment in Fan *et al*. (2011a, b) were based on the users with best channel condition, i.e., highest SINR or largest MCS index to achieve highest throughput. RBs assignment considers channel average condition and rate requirement base on priority (Guan *et al*., 2011). RBs with good channel qualities or higher are considered for assignment (Kwan *et al*., 2009).

The resource allocation methods considered in this research used sub-optimal methods of optimization to maximize their systems' throughput. The schemes in Fan *et al*. (2011a, b) and Jiancun were divided into RB assignment and power allocation. The RB assignment was based on the highest SINR or largest MCS. The allocation is divided into 2 stages: Power allocation among RBs of the same user PAaRB and power allocation among users PAaUE to achieve further improvement. The scheme was divided into estimation and allocation (Guan *et al*., 2011). Channel gain was considered in the estimation. The SBs allocation is divided into 2 stages; user priority was calculated and sorted in descending order then SBs are allocated base on priority on user-by-user basis. The assignment considered in the research of Kwan *et al*. (2009) is on stages. In the 1st stage, SBs are only assigned to the user who can support the highest bit rate

Table 3: Comparison of the Resource Block (RB) allocation schemes

Resources schemes	Fan	Jiancun	Guan	Kwan
Resource allocation methods	Optimization of RB and power allocation	RB assignment with MCS using EESM	QoS guaranteed RB allocation	SBs allocation based on high channel quality to high MCS index
Packet-level MCS index estimation	EESM and MIESM	EESM, AM, GM and HM	Average channel condition used as CQI index (AM)	CQI index defends on the method used
RB assignment method to users	Based on high SINR or MCS index	Based on high SINR or MCS index	CQI and rate requirement base on channel priority	Based on RBs with good channel qualities or higher
Optimization technique	Sub-optimal, RB assignment and power allocation	Sub-optimal, RB assignment and power allocation	Sub-optimal, SBs estimation per user and allocation based on priority	Sub-optimal; selection of best user for each SB and MCS assignment the MCS
Objective	Maximization of network's overall throughput	Maximization of throughput by resource allocation and MCS selection methods	Throughput maximization and QoS guaranteed	To allocate SBs having different channel qualities to users to maximize throughput
Throughput improved	Increased by 20% when No. of users is 4 and SINR is 10 dB	Increased by 18% with HM based MCS estimation to [4] when users number is 4 and SINR 10 dB	Max C/I has the better throughput as the number of user increases	Increased as the number of users increases and SINR set 10 dB

and best MCS for each user are determined. In the 2nd stage, best MCS to be selected given the selected SBs for each user.

CONCLUSION

One of the more significant findings that emerged from this review is that resource allocation scheme with QoS consideration has the highest throughput compared to other schemes as depicted in the graph of Fig. 9. Also from the resource allocation schemes investigated, the sub-optimal solutions show significant performance improvement with less complexity when compared to the optimal solutions in the downlink LTE.

RECOMMENDATIONS

It is recommended that further research be undertaken on the effects of delay in the feedback (uplink) and error due to channel estimation on resource allocation for throughput maximization.

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