Small Cell Enhancement for LTE-Advanced Release 12 and Application of Higher Order Modulation

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Abstract. The mobile data traffic is expected to grow beyond 1000 times by 2020 compared with it in 2010. In order to support 1000 times of capacity increase, improving spectrum efficiency is one of the important approaches. Meanwhile, in Long Term Evolution (LTE)-Advanced, small cell and hotspot are important scenarios for future network deployment to increase the capacity from the network density domain. Under such environment, the probability of high Signal to Interference plus Noise Ratio (SINR) region becomes larger which brings the possibility of introducing higher order modulation, i.e., 256 Quadrature Amplitude Modulation (QAM) to improve the spectrum efficiency. In this paper, we will firstly introduce the ongoing small cell enhancement discussion in the 3rd Generation Partnership Project (3GPP). And then focus on the application of higher order modulation in small cell environment. Important design issues and possible solutions will be analyzed particularly in the higher order modulation discussion.

Keywords: Higher order modulation · Small cell · LTE-advanced release 12

1 Introduction

Long-term evolution (LTE) provides full IP packet-based radio access with low latency and adopts orthogonal frequency division multiple access (OFDMA) and single-carrier frequency division multiple access (SC-FDMA) in the downlink and uplink, respectively. The 3rd generation partnership project (3GPP) finalized the radio interface specifications for the next generation mobile system as LTE release 8 in 2008 [1,2]. In Japan, the commercial service of LTE was launched in December, 2010 under the new service brand of "Xi" (crossy) [3]. Meanwhile, in the 3GPP, there have been efforts targeting at establishing an enhanced LTE radio interface called LTE-Advanced (release 10 and beyond) [4,5] and the specification for LTE-Advanced release 11 is now freezed and the standardization for release 12 is started.

Mobile traffic data forecasts predict a tremendous growth in data traffic in the next several years and by some projections the traffic growth is expected to be

I. Stojmenovic et al. (Eds.): MOBIQUITOUS 2013, LNICST 131, pp. 794–805, 2014.
DOI: 10.1007/978-3-319-11569-6_69

1000 times of the data from the previous decade [6]. The primary drivers of this growth are the increased penetration of smartphone type handsets and various assorted mobile devices running a vast array of mobile applications, especially video applications. Furthermore, end-user expectations on achievable data rates are also continuously raised. Currently commercially available mobile networks typically offer end-user data rates up to in the order of a few Mbps. In the future, there will be demands for typical end-user data rates of several tens of Mbps, with hundreds of Mbps or even several Gbps of data rates demanded in specific scenarios.

Explosive overall mobile data traffic and rising expectations on achievable data rates on end-user side challenge the mobile network operators. To satisfy these future traffic-volume and end-user demands existing mobile networks need to evolve and be enhanced. Since obtaining new spectrum is quite cost-prohibitive as well as difficult due to various government regulations in different parts of the world, other ways are being looked into to achieve this demand. Most operators are increasingly drawn to the idea of network densification with small cells deployment to achieve the increasing traffic capacity [7]. Currently, there is a study item (SI) called "Small Cell enhancements for E-UTRA and EUTRAN" in progress to explore the potential of small cells in the 3GPP standards body [8].

The basic deployment of small cells that is being studied involves using an LTE base station that has much lower transmission power than a macro base station. Several different types of deployments are being considered such as small cells using the same or different carrier frequency as the macro base station, small cells deployed indoors or outdoors, small cells deployed in areas with or without overlapping macro cell coverage and so on. There are also some new techniques involved in the small cell enhancement discussion. For example, efficient small cell discovery for power saving and traffic offloading, small cell power on/off for the interference coordination and higher order modulation in small cell for improved spectral efficiency etc. In this paper, we focus on higher order modulation involved in the scenario where macro cell and small cell are deployed with separate carrier.

The rest of the paper are organized as follow. Firstly, more detailed descriptions about small cell enhancement are provided in Sect. 2. Secondly, we elaborates the higher order modulation in small cell including the motivation, design issues and comparison of possible solutions in Sect. 3. Finally, we conclude this paper in Sect. 4.

2 Small Cell Enhancement

2.1 Deployment Scenario Identified in 3GPP

3GPP decided in September 2012 to start a study on the scenarios and requirements of small cell enhancements. This study was completed successfully in December 2012 and the agreed deployment scenarios and relevant technical requirements are captured in a technical report [9]; these are briefly introduced hereinafter.

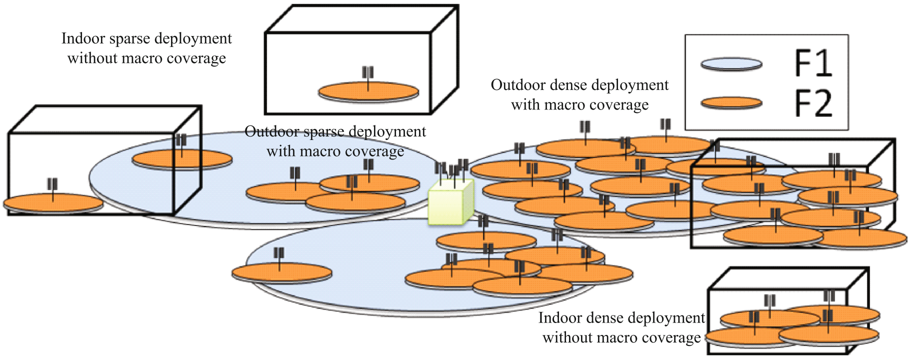

Fig. 1. Small cell deployment

Enhanced small cells can be deployed both with macro coverage and stand alone, both indoor and outdoor, and support both ideal and non-ideal back hauls. Enhanced small cells can also be deployed sparsely or densely. An illustration of possible deployment scenarios is shown in Fig. 1 [9].

2.1.1 With and Without Macro Coverage

Small cell enhancement should target the deployment scenario in which small cell nodes are deployed under the coverage of one or more than one overlaid macro-cell layer(s) in order to boost the capacity of already deployed cellular network. And it should also work without macro coverage, for example, in deep indoor situations.

2.1.2 Outdoor and Indoor

Small cell enhancement should target both outdoor and indoor small cell deployments. A key differentiator between indoor and outdoor scenarios is mobility support. In indoor scenarios, users normally stay stationary or move at very low speeds. In outdoor scenarios, operators may deploy small cell nodes to cover certain busy streets where relatively higher terminal speeds can be expected. 3GPP has decided to focus on low terminal speeds (up to 3 km/h) for indoor and medium terminal speeds (up to 30 km/h and potentially higher) for outdoor scenarios.

2.1.3 Backhaul

The backhaul, which generally means the link connecting the radio access network and core network, is another important aspect for small cell enhancement, especially when considering the potentially large number of small cell nodes to be deployed. 3GPP has decided both the ideal backhaul (i.e., very high throughput and very low latency backhaul such as dedicated point-to-point connection using optical fiber) and non-ideal backhaul (i.e., typical backhaul widely used in the market such as xDSL) should be studied.

2.1.4 Sparse and Dense

Small cell enhancement should consider sparse and dense small cell deployments. In some scenarios (e.g., hotspot indoor/outdoor places, etc.), single or a few small cell node(s) are sparsely deployed, e.g. to cover the hotspot(s). Meanwhile, in some scenarios (e.g., dense urban, large shopping mall, etc.), a lot of small cell nodes are densely deployed to support huge traffic over a relatively wide area covered by the small cell nodes. The coverage of the small cell layer is generally discontinuous between different hotspot areas. Each hotspot area can be covered by a group of small cells, i.e. a small cell cluster. For mobility/connectivity performance, both sparse and dense deployments should be considered with equal priority.

2.1.5 Synchronization

Both synchronized and un-synchronized scenarios should be considered between small cells as well as between small cells and macro cell(s). For specific operations e.g. interference coordination, carrier aggregation and inter-eNodeB coordinated multiple point transmission, small cell enhancement can benefit from synchronized deployments with respect to small cell search/measurements and interference/resource management. Therefore time synchronized deployments of small cell clusters are prioritized in the study and new means to achieve such synchronization shall be considered.

2.1.6 Spectrum

Small cell enhancement should address the deployment scenario in which different frequency bands are separately assigned to macro layer and small cell layer, respectively, where F1 and F2 in Fig. 1 correspond to different carriers in different frequency bands.

Small cell enhancement should be applicable to all existing and as well as future cellular bands, with special focus on higher frequency bands, e.g., the 3.5 GHz band, to enjoy the more available spectrum and wider bandwidth. Co-channel deployment scenarios between macro layer and small cell layer should be considered as well.

2.1.7 Traffic

In a small cell deployment, it is likely that the traffic will fluctuate greatly since the number of users per small cell node is typically not large due to the small coverage area. It is also likely that the user distribution is very non-uniform and fluctuates between the small cell nodes. It is also expected that the traffic could be highly asymmetrical, either downlink- or uplink-centric. Traffic load distribution in the time domain and spatial domain could be uniform or non-uniform.

2.1.8 Backward Compatibility

Backward compatibility, that is, the possibility for legacy user equipment (UE) to access a small-cell node/carrier, shall be guaranteed and the ability for legacy UE to benefit from small-cell enhancements can be considered.

2.2 New Techniques to Improve the Spectral Efficiency and Capacity in Small Cell

2.2.1 Small Cell Discovery

Different from in the homogeneous deployment, the UEs in small cell should always perform inter-frequency measurement in order to detect the surrounding small cells timely and make maximum use of them. Thus a well designed discovery signal and discovery mechanism will not only improve the power efficiency but also facilitate neighboring cell identification and synchronization.

2.2.2 Small Cell On/Off

The traffic in small cell fluctuates greatly in time domain and spatial domain. When there is no traffic, small cell should go “off” state quickly for more power saving. On the other hand, small cell should be activated timely when traffic arrives. In addition, when one cell experiences severe interference from neighboring cells, turning off some neighboring cells could mitigate interference and improve the overall performance. Hence manners to support prompt and flexible switch between small cell “on” state and small cell “off” state is quite beneficial for both power saving and interference reduction.

2.2.3 Higher Order Modulation

Sperate frequency for macro cell and small cell is the prioritized scenario. Due to the absence of strong interference from Macro cell high SINR performance is easily achieved which provides another chance to solve the explosive data problem from spectral efficiency dimension by introducing higher order modulation schemes. In 3GPP meeting discussion, many operators and vendors show their great interests [10–12]. In the following section, we will introduce this technique in details.

3 Higher Order Modulation in Small Cell

3.1 Motivation

The basic premise of 256 QAM introduction is that there should be some scenarios satisfy the usage SINR requirement. Figure 2 shows the spectral efficiency performance for various modulation schemes. The spectral efficiency is defined as $(1 - block\ error\ rate\ ) \times modulation\ order \times coding\, rate$. The results are obtained by using piratical channel coding (Turbo coding) in AWGN scenario. From Fig. 2, it is observed that the switch point between 256 QAM and 64 QAM is around

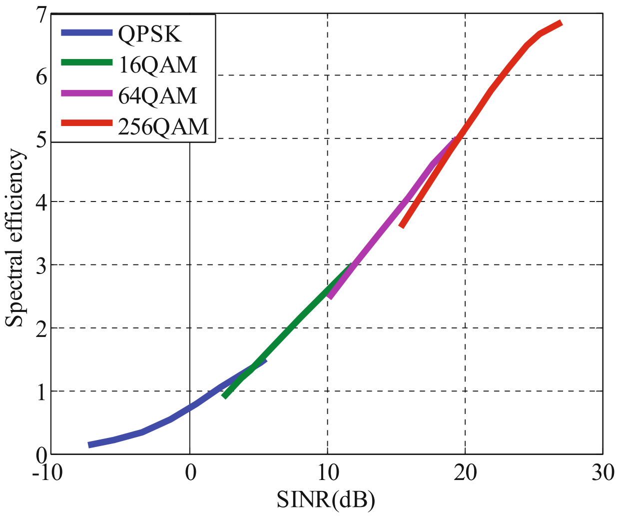

Fig. 2. Spectral efficiency

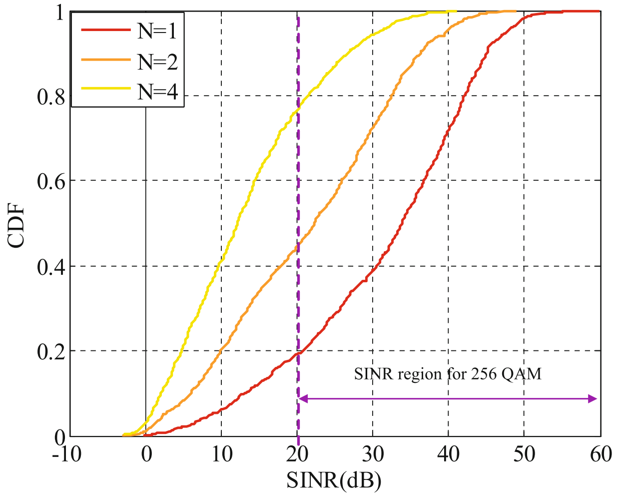

Fig. 3. SINR distribution

20 dB. Therefore, the precondition for 256 QAM introduction is there should be some small cell scenarios where some UEs could experience SINR larger than 20 dB.

In small cell deployment, the prioritized scenario is separate frequency for macro cell and small cell. As mentioned above, good SINR performance could be achieved due to the absence of strong interference from macro. Figure 3 shows the SINR geometry for different small cell density. In the figure, N denotes the

Table 1. CQI table in LTE Rel8-Rel11

CQI index	Modulation	Code rateX1024	Efficiency
0	Out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16 QAM	378	1.4766
8	16 QAM	490	1.9141
9	16 QAM	616	2.4063
10	64 QAM	466	2.7305
11	64 QAM	567	3.3223
12	64 QAM	666	3.9023
13	64 QAM	772	4.5234
14	64 QAM	873	5.1152
15	64 QAM	948	5.5547

number of small cells per macro sector. It is observed that more than 20 % UEs could reach the SINR larger than 20 dB in sparse small cell deployment. Thus more than 20 % UEs could benefit from 256 QAM in the sparse small cell deployment. High cell throughput gain is expected from introducing 256 QAM in small cell.

3.2 Design Issues in Implement 256 QAM

In LTE release 8, quadrature phase shift keying (QPSK), 16 QAM and 64 QAM have been specified for data transmission. These modulation schemes are implemented in the channel quality indicator (CQI) table and modulation and coding scheme (MCS) table [13]. The CQI table is mainly used to assist the channel quality feedback from UEs to eNodeBs. The original CQI table includes 16 levels of different modulation and coding schemes, as shown in Table 1. UEs feed back the effective SINR by conveying the CQI index with 4 bits in uplink control indicator(UCI). The mapping from effective SINR to a corresponding CQI value is carried out such that a BLER lower than 0.1 is achieved by using corresponding modulation and coding rate. The MCS table is mainly used to inform the detailed modulation and coding schemes for physical downlink shared channel (PDSCH) or physical uplink shared channel (PUSCH) transmission. The original MCS table which is an extension of CQI table includes 32 levels of different modulation and coding schemes and 3 of them are reserved for future use. eNodeBs inform UEs of the detailed modulation and coding scheme in the table by conveying the corresponding MCS index with 5 bits in downlink control indicator (DCI).

In order to support 256 QAM in current LTE-Advanced system, the new entries of 256 QAM should be merged in the CQI table and MCS table. However, how to implement the new entries in these tables needs careful investigation by taking the performance gain, impact on the control signaling, specification effort etc. into consideration.

3.3 Possible Solutions

Based on whether to change the sizes of the tables and corresponding indicators, there are 2 potential alternatives to implement the 256 QAM in current network.

3.3.1 Alt.1 Extend the Tables and Corresponding Indicators

This alternative is a simple extension of the existing MCS/CQI tables. Contents based on 256 QAM can be attached at the end of the tables. This method guarantees the performance of UEs supporting 256 QAM since all the existing modulation levels can be reused. However, the changed table size will lead to the changed payload size of relevant indicator, e.g., DCI formats with larger MCS indication field and channel state reporting with larger CQI feedback bits should be defined. The increased payload sizes in general result in reduced robustness of the DCI and UCI. From the standardization aspect, additional specification effort is needed to specify the new DCI format and channel status reporting.

3.3.2 Alt.2 Keep the Same Table Size and Refine the Content

Keeping the same sizes of the tables has the advantage that the sizes of the relevant indicators are not affected. Hence, less specification effort is required due to no need to define new DCI format and channel status reporting. To keep less change on the interpretation of the new content in CQI/MCS table, a possible method is to remove some entries from the extended table in Alt.1 (extended table is formed by attaching new entries at the end of the existing tables). The entries contribute less cell throughput improvement will be removed. The removed entries could be the original content or the newly added content. It is noted that some MCS used in severe channel condition should be kept to maintain the basic service requirement. The detailed criteria for the remove is related to the spectral efficiency improvement brought by one entry and the possibility of the entry to be used. Both factors contribute to the cell throughput. For one entry other than entries used in severe channel condition, if it brings little improvement in the spectral efficiency or has little possibility to be used, it could be removed because of less improvement on the cell throughput. By this way, the cell throughput performance could be guaranteed to the largest extent.

Table 2. Simulation parameters

Deployment scenarios	Heterogeneous network with 3 small cells within one macro cell sector
Carrier configuration	Macro@ 2 GHz Small cell @3.5 GHz
System bandwidth	10 MHz
Channel model	ITU-UMa for Macro ITU-UMi for small cell
Number of UEs	10,20,30 UE (per macro sector)
DL transmission scheme	SU-MIMO with rank adaptation
UE speed	3 km/h
Tx power (Ptotal)	Macro:46 dBm Small cell: 30 dBm
Traffic model	Full buffer
Number of TX and RX antennas	For macro: 2 × 2 For small cell: 2 × 2
Antenna configuration	CPA
UE receiver	MMSE
Feedback scheme	Rel-8 RI/CQI/PMI based on Rel-8 2Tx codebook
EVM	28 dB (4 %)

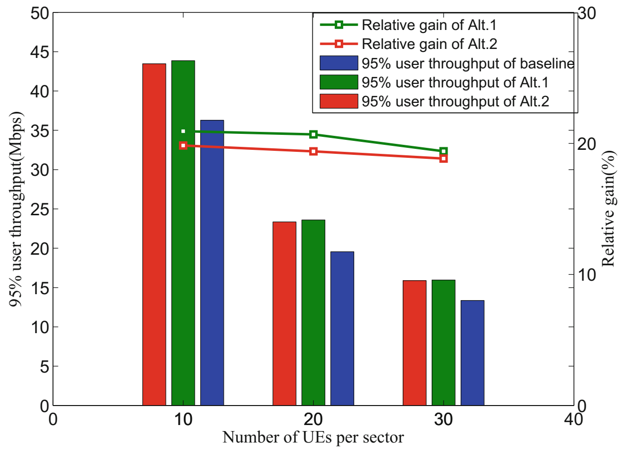

Fig. 4. 95 % user throughput performance

3.4 Performance Evaluation and Discussion

To compare the performance of these 2 alternatives. System level simulation is performed. The baseline for comparison is current LTE-Advanced performance

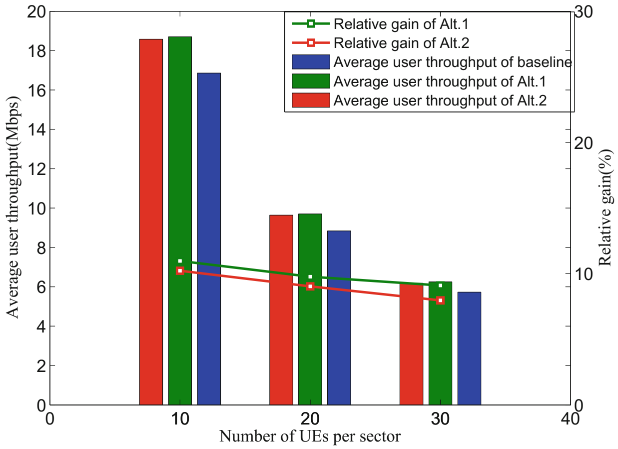

Fig. 5. Average user throughput performance

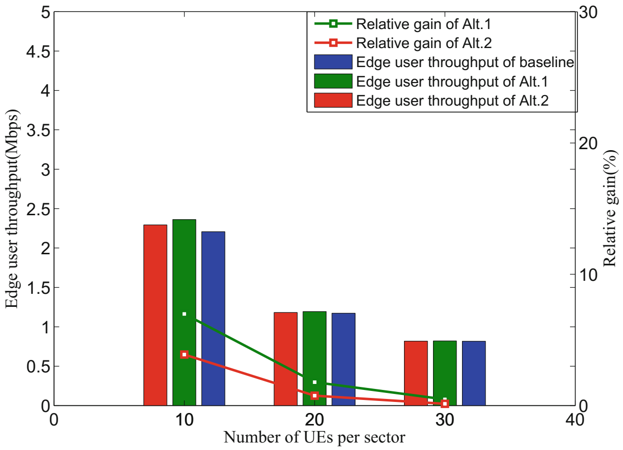

Fig. 6. Cell edge user throughput performance

with rank adaption. 95 % user throughput, average user throughput and 5 % user throughput will be evaluated. Furthermore, to model the RF impairment in realistic network, 4 % error vector magnitude (EVM) effect are assumed on the eNodeB side. Other detailed parameters are listed in Table 2.

According to the simulation results in Figs. 4, 5 and 6, we observe that both alternatives could achieve significant gain in 95 % UE throughput and average UE throughput. Small gain is obtained in 5 % user throughput. 5 % user throughput represents the cell edge user performance. For cell edge users, they have less chance of reaching high SINR to support 256 QAM. This is why the small gain is caused. Due to less entries supported in tables of Alt.2, it provides relative coarse channel condition information compared with Alt.1 as the same range of SINR is covered by less amount of indicators. Thus Alt.2 suffers slightly performance loss compared with Alt.1.

More supported indicators in Alt.1 yields slightly throughput gain. But on the other hand, it also pays more signaling overhead and specification effort for this little gain. Considering the tradeoff between the throughput gain and signaling overhead, specification effort pain. It is better to use Alt.2 to implement 256 QAM in small cell.

4 Conclusion

Small cell deployments are key tools to satisfy future traffic-volume and end-user service-level demands. Higher order modulation scheme based on small cell deployment further improves the ability. In this article, we first introduce the typical small cell deployment and the related features. Then focus on higher order modulation which is one of important technique for small cell enhancement. In the discussion, we elaborate the motivation and analyze the main design issues for 3GPP. Based on the analysis, we show our consideration on the possible solutions. Performance evaluation and further discussion are performed to analyze the merits and demerits of the solutions. Based on the analysis, we observe that Alt.2 achieves similar performance gain to Alt.1 with less overhead and standardization effort. Thus Alt.2 is preferred.

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