Optimizing Subgroups Formation for E-MBMS Transmissions in LTE Networks

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Optimizing Subgroups Formation for E-MBMS Transmissions in LTE Networks

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Abstract. Long Term Evolution (LTE) network provides a high throughput with low latency which make it suitable for multicast and broadcast services. In Conventional Multicast Scheme (CMS), data is transmitted according to the user with worst channel condition which results in wasting network resources. To overcome the drawback of CMS, a new subgrouping mechanism is proposed to split the multicast group into several subgroups based on users channel quality. The performance of the proposed mechanism has been evaluated using LTE simulator. The simulation results show that the proposed mechanism increase the multicast performance compared to CMS in term of goodput and spectrum efficiency, while maintain fairness index of users in an acceptable level.

Keywords: E-MBMS, Modulation and Coding Schema, multirate, multicast

1. Introduction

Long Term Evolution (LTE) network was introduced by the Third-Generation Partnership Project (3GPP) and was considered as the latest step towards the 4th generation of radio technologies. LTE offers a high throughput with low latency which make it the best choice for Multimedia Service. LTE network exploits the benefits of Orthogonal Frequency Division Multiple Access (OFDMA), in which various users data is multiplexed in frequency and time domains [1]. In OFDMA, the full frequency bandwidth is divided into orthogonal subcarriers, where each subcarrier is allocated 15 kHz. The LTE frame consists of 12 consecutive subcarriers and 10ms duration. Each frame consists of 10 subframes; each subframe is 1ms, which is equal to the Transmission Time Interval (TTI); and then each subframe is equal to two time slots, where each slot is 0.5ms in the time domain and 12 subcarriers in the frequency domain. However, each slot is composed of a resource block (RB), which is the minimal radio resource allocation unit in the LTE. Each RB consists of seven symbols when the normal Cycle Prefix (CP) is used or six symbols when the extended CP is used, as used in E-MBMS subframe [1].

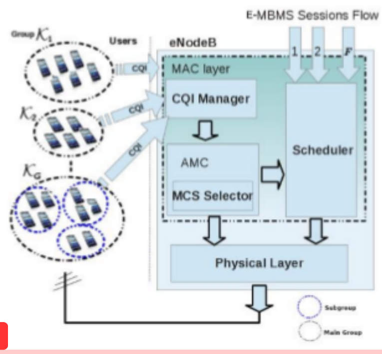
Recently, mobile devices are equipped with large screen with high resolution which requires high data rate for video and has the ability to transmit and received data with higher bit rate. In addition, the using of these devices is no longer limited only on making voice calls but they are also used to browse the Internet, watch video, watching news, play online game, and watching TV. Thus, beside the bandwidth scarcity, will increase the demand on network resources and then force the network operators to efficiently utilize the network resources. A group-oriented services, such as multicast and broadcast, are an efficient way for utilizing the network resources. The increasing demand of the group-oriented services has resulted in defined and standardized a new service called Multimedia Broadcast Multicast service (MBMS), which was introduced by the 3GPP [2,3] in 2005 over the UMTS Release 6 [4]. Since 2005, many enhancements have been made to the MBMS standard which evolved into enhanced MBMS (E-MBMS) that developed over the 3GPP LTE standard network Release 9 [5].

In E-MBMS, the same data is sent to Users Equipment (UEs), whose belong to the same Multicast Group (MG), using the same channel result in efficient sharing and usage of radio network resources. On other side, it is a challenge to select the Modulation and Coding Schema (MCS) which can satisfy all UEs belong to the same group. The cell center of UEs can receive the data with high bit rate, whereas, the cell edge UEs suffer a poor channels condition. Therefore, they can receive the data only with low MCS level which result in wasting the network resources. In CMS, a single data rate is selected to transmit the data to all UEs in each MG. The data rate is selected according to the user with worst channel gain (WCG) [6,7,8]. The CMS is a reliable multicast transmission schema to deliver the data with high fairness. In contrast, the CMS reduces the system performance by forcing the users with high channel gain (HCG) to receive the data with low MCS corresponding to the users with WCG.
Several studies have been carried out to improve the multicast performance by overcome the limitations of the CMS. For example, in [9], the authors proposed a resources allocation approach called Opportunistic Multicast Scheduling (OMS), which exploits the multiuser diversity by only selects the users with HCG to be served in a time slot. In [10], the MG is split into two subgroups (cell center and cell edge subgroups), and split the data stream into two layers (base and enhanced layer). The based stream is received by both subgroups while the enhanced stream is only received by cell center subgroup. Another interesting study was proposed by [5, 11], in which the UEs in each MG are split into several subgroups depending on users channel gain. Then each subgroup are served with MCS level corresponding to the user with WCG. Tan et al. in [i12], proposed a schema in which the multicast groups are divided into a set of subgroups dynamically using a coalition game theory. However, most previous works consider a single group which not always happens in the real system. Moreover, in a multi-groups system, splitting each group to several subgroups will results in high number of subgroups which required more radio resources and reduce the spectrum efficiency (SE). Consequently, determining the number of subgroups and the amount of radio resources that should be allocated to each subgroup are still an open issue and need to be properly selected.
In this paper, an innovative Radio Resource Management (RRM) mechanism is proposed to increase the E-MBMS performance. The proposed RRM efficiently splits each group to three subgroups and allocated the resource to each subgroup. It uses two thresholds to split the MG to three subgroups (upper, lower, and medium subgroups). These thresholds are selected according to the Standard Deviation (StD) and the average of users channel quality.

2. System Modeling and Problem Formulation

In LTE network, there are 15 levels of CQI, each level associated with an MCS level. Let $L=15$ is the CQI levels, then $CQI_l=l$, where $l=\{1,2,\dots,L\}$. Thus, MCS_i is the MCS associated with the CQI_l. Any user sent a CQI_l feedback to its eNodeB, can successfully receive and decode the transmitted data which is transmitted with the MCS_i level where $i \leq l$.

Let consider K users belong to G groups that receiving the data using N subcarriers over a single eNodeB as illustrated in Figure 1. The set of users, groups, and subcarriers are represents by $\mathcal{K}, \mathcal{G}, \mathcal{N}$ respectively. The system bandwidth W is equally shared between all subcarriers, so the bandwidth of subcarrier n is $B_n = \frac{W}{N}$. For simplicity, we assume each subcarrier n have equal power P_n. Assume a perfect orthogonality preserved, and perfect synchronization, so there is no inter symbol interference and no inter-carrier interference. All users receive transmitted data over one or more subcarriers without any interference. It is also assumed that the eNodeB uses reliable feedback channels to receive CQI report from each user without any delay. Let $\mathcal{K}_g$ denotes the g users group set, and the cardinality $\| \mathcal{K}_g \|$ denotes the number of users in group g, where $g = \{1,2,\ldots,G\}$. Thus, for multicast $\| \mathcal{K}_g \| \geq 2$, and $\| \mathcal{K}_g \| = 1$ in unicast. Moreover, $\sum_{i=1}^{G} \| \mathcal{K}_g \| = K$, $\mathcal{K} = \cup_{g=1}^{G} \mathcal{K}_g = \mathcal{K}_1 \cup \mathcal{K}_2 \cup \cdots \cup \mathcal{K}_G$. Let MCS_g^v represents the MCS vector of users in group g, where $MCS_g^v = \{MCS_1, MCS_2, \cdots, MCS_M\}$, $M = \| \mathcal{K}_g \|$.



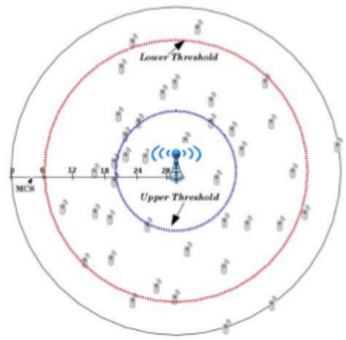


Figure 1. Subgrouping formation schema. **Figure 2**. Upper/ lower thresholds in group g.

Let consider $r_{k,n}$ is the data rate of user k on subcarrier n. Then the data rate of user k can be expressed by equation (1).

$$R_k = \sum_{n=1}^{N} r_{k,n} \omega_{k,n} \tag{1}$$

where $\omega_{k,n}$ is a subcarrier indicator to show whether the subcarrier n is used by user k or not. is formulated as equation (2).

$$\omega_{k,n} = \begin{cases} 1, & if\ subcarrier\ allocated\ user\ k; \\ 0, & otherwise. \end{cases} \tag{2}$$

In CMS, the transmission data rate of a group is selected according to the user with WCG. Let consider $r_{g,n}$ is the worst channel gain for group g on subcarrier n. The aggregate data rate (ADR) of group g can be calculated as in equation (3).

$$R_g = \| \mathcal{K}_g \| \sum_{n=1}^{N} r_{g,n} \omega_{g,n} \tag{3}$$

where $\omega_{k,n}$ indicates either the subcarrier was utilized by group g or not. The total ADR of all groups in $\mathcal{K}$ can be obtained as equation (4).

$$R_T = \sum_{g=1}^{G} R_g = \sum_{g=1}^{G} \sum_{n=1}^{N} \| \mathcal{K}_g \| r_{g,n} \omega_{g,n} \tag{4}$$

The RRM allocates the system subcarriers to all groups in a way that can maximize the system throughput while keep the fairness between UEs in acceptable level. According to [13], CMS throughput is bounded by the users with WCG, and will saturate when the UEs number increases in Rayleigh and Ricean fading environments. As aforementioned, the MMS techniques were emerged to overcome the limitations of the CMS. The MSF maximize the multicast throughput by split the G groups into S subgroups with set $\mathcal{S}$, where $\mathcal{S} = \{1,2,\ldots,S\}$ and $G \leq S \leq K$. In details, each group g can be splitted into $\mathcal{S}_g$ subgroups, where $\mathcal{S}_g = \mathcal{S}_g^1 \cup \mathcal{S}_g^2 \cup \ldots \cup \mathcal{S}_g^l$, and $1 \leq l \leq 15$. Indeed, each group g can be splitted to 15 subgroup as maximum which equal to the number of MCS level in LTE network. Then transmit the data to each subgroup using a WCG rate. To efficiently utilize the multiuser diversity, the MG users are splitted according to their channel gains. Thus, each subgroup S_g^l contains a set of users with same or close channel gains.

$$max \sum_{s=1}^{S} \sum_{n=1}^{N} \sum_{k=1}^{K} r_{s,n}\omega_{s,n}\alpha_{s,k} \quad (5)$$

$$\omega_{s,n}, \alpha_{s,k} \in \{o, 1\}, \forall s \in \mathcal{S}, \forall k \in \mathcal{K}, \forall n \in \mathcal{N} \quad (6)$$

$$\sum_{s=1}^{S} \omega_{s,n} = 1, \sum_{s=1}^{S}, \alpha_{s,k} = 1, \forall s \in \mathcal{S}, \forall n \in \mathcal{N}, \forall g \in \mathcal{G} \quad (7)$$

where $\omega_{s,n}, \alpha_{g,s,k}$ are binary indicators, which indicate either subcarrier n and user k belong to subgroup s or not.

The RRC has to assign subcarriers and users to proper subgroups in order to maximize the total throughput. Thus, the problem described in equations (5)-(7) is considered as NP-Hard problem (non-deterministic polynomial-time) which does not have an optimal solution. Indeed, there is a solution for this problem by using exhaustive search algorithm, but it is usually a high complex and time-consuming computations [14]. Moreover, the complexity of NP-Hard increases exponentially with the number of subcarriers, subgroups, and groups which make it unrealistic to practical used. Furthermore, there are S^N solutions for scheduling radio resources between all subgroups S [9, 15]. Thus, it is necessary to find a suboptimal solution which can be used in real system. This paper introduces the use of StD of users' SINR to split each group to three subgroups; worst, best, and medium subgroups. The worst subgroup will contain all cell edge UEs whose MCSs are extremely low. The best subgroup will contain the cell center UEs whose MCSs are extremely high, whereas the medium subgroup will contain the remain UEs.

3. System Modeling and Problem Formulation

The proposed subgrouping mechanism uses the StD to show how the users MCS levels are distribute and deviated from the average value of all users' MCS level values. The StD with small value means that MCSs of all users are closed to each other, whereas, the big StD value means that all users are far from each other. However, in case of the users' MCSs standard deviation value is small enough, the MCS level of worst user case will be suitable for all users. The StD and average of users' MCSs will be used to divide the multicast users into several categories or subgroups by using upper and lower thresholds, as shown in Figure 2. These thresholds will be used to split each group g into three subgroups. Nevertheless, several steps should initially be performed in order to calculate the upper and lower MCS thresholds for each group g. The following steps are repeated for each group g in the $\mathcal{K}$ groups set:

• **Step 1:** Users have to measure the SINR for received signal. The SINR for each subcarrier can be calculated using equations (8) and (9) [5,16].

$$SINR(m) = \frac{\sum_{i=1}^{A} \sum_{j=1}^{B} \frac{w(\tau_i(m)+\delta_i)P_j}{q_{i(m)}}}{\sum_{i=1}^{A} \sum_{j=1}^{B} \frac{(1+w(\tau_i(m)+\delta_i))P_j}{q_{i(m)}} + N_0} \quad (8)$$

with

$$w(\tau) = \begin{cases} 1 & 0 \le \tau \le T_{CP} \\ 1 - \frac{\tau - T_{CP}}{T_u} & T_{CP} \le \tau \le T_{CP} + T_u \\ 0 & otherwise \end{cases} \quad (9)$$

where P_j is the average power associated with the j path, $\tau_i(m)$ the propagation delay from eNodeB i, δ_j the additional delay added by path j, $q_i(m)$ the path loss from eNodeB i, T_{cp} the length of the CP and T_u the length of the useful signal frame, N_0 the noise power.

• **Step 2:** mapping the SINRs of a user subcarriers into one effective SINR, (so-called Exponential Effective SINR Mapping (EESM)), using the following equation (10) as stated in [6, 17].

$$SINR_{eff} = -\beta . \ln\left(\frac{1}{RB} \sum_{m=1}^{N} e^{-\frac{SINR_m}{\beta}}\right) \quad (10)$$

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where $SINR_m$ is the $SINR$ of the mth resource block assigned to the user; β is a factor which can be amended to match the $SINR_{eff}$ to a specific MCS. *RB* is the number of resource blocks assigned to the user.

• **Step 3:** map the obtained $SINR_{eff}$ to the corresponding CQI value which is achieved by a BLER less than 10% in Single Input Single Output transmission mode (SISO) over Additive White Gaussian Noise (AWGN) channel.

• **Step 4:** user will send the obtained CQI to its eNodeB which is responsible for selecting the corresponding MCS level, as listed in Table 1.

• **Step 5:** calculate the average $\overline{MCS_g^v}$ value of all the *g-th* group where $\overline{MCS_g^v} = average(MCS_g^v)$. Then, calculate the standard deviation σ of MCSs values of all users using equation (11).

$$\sigma_g = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(MCS_i - \overline{MCS_g^v}\right)^2} \tag{11}$$

• **Step 6:** calculate the upper threshold T_{up} and the lower threshold T_{low} for all users using equations (12) and (13).

$$T_{up}^g = \overline{MCS_g^v} + \sigma_g \tag{12}$$

$$T_{low}^g = \overline{MCS_g^v} - \sigma_g \tag{13}$$

The T_{up}^g and T_{low}^g values will be used to select users with abnormal MCS level who are deviated away from the average of users' MCS.

• **Step 7:** each group g in $\mathcal{K}$ set will be splitted into three subgroups (S_g^b, S_g^m, S_g^w), where

$$S_w^g = \{MCS_i|\ \forall\ MCS_i < T_{low}^g\},$$

$$S_b^g = \{MCS_i|\ \forall\ MCS_i > T_{up}^g\},$$

$$S_m^g = \{MCS_i|\ \forall\ MCS_i \le T_{low}^g, MCS_i \le T_{up}^g\},$$

Table 1. CQI and their interpretations.

CQI Index	Modul-ation	Code rate x1024	SE [bit/s/Hz]
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	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

Table 2. Simulation parameters.

Parameter	Value
Carrier Frequency	2GHz
Path loss	*PL(db)=128.1+37.6 *log₁₀d*
Thermal noise	–174 dBm /Hz
Downlink Bandwidth	3 MHz
Symbols for TTI	12
Sub-Frame Length	1 ms
Frame Type	FDD
eNodeB radius	1 km
eNodeB Power transmission	43 dBm
Modulation Schemes	QPSK, 16QAM, 64QAM (dynamic)
No. of users	20-100 UEs
No. of E-MBMS group	1
User transmission power	23 dBm
User distribution	Randomly and uniformly distributed
User speed	3 km/h
User mobility model	Random direction
CQI scheme	Full Bandwidth
Application flows	Video
Video rate	440 kbps
Simulation time	20 Second

4. Simulation and Results
LTE simulator (LTE-Sim) has been used to evaluate the proposed mechanisms after an extremely modifications and extensions of its functions and classes to support E-MBMS network. LTE-Sim is an open source framework simulator developed by G. Piro and F. Capozzi [18].

4.1. Simulation scenario
The proposed RRM mechanism has been compared to the CMS in term of cumulative goodput, fairness, and spectrum efficiency (SE). For simplicity, only E-MBMS has been activated in the simulation. Thus, the whole bandwidth was assigned to the E-MBMS. For more accurate, each scenario was performed with different number of UEs who uniformly distributed. Each scenario was repeated 20 times, then the average value was calculated. A realistic video trace files with 440 Kbit/s was used, which is available in [19]. The main simulation parameters are listed in Table 2.

4.2. Simulation results
The first evaluation metric experimented is cumulative goodput and the results are shown in Figure 3. The proposed subgrouping mechanism increases the system performance in term of goodput. Simulation results demonstrate that the cumulative goodput of the proposed mechanism is better than the cumulative goodput of the CMS. This gain due to the using of subgroup technique which is no more limited by the WCG as in the CMS.

The second evaluation metric is the fairness index (FI) of all UEs [20]. The FI is defined by equation (14).

$$FI = \frac{(\sum_{k=1}^{K} r_k)^2}{K\ \sum_{k=1}^{K} (r_k)^2} \tag{14}$$

where r_k denotes the goodput of the k^{th} user, and FI value is variance between $(1/K) \leq FI \leq 1$.

The maximum FI (FI=1) can be obtained when all user are served with the same rate. As shown in Figure 4, the maximum fairness is achieved by CMS. The FI of the proposed subgrouping mechanism is less than the FI of the CMS. The FI of the proposed subgrouping mechanism decreased as the number of UEs increased, because the subgroups size increases as the UEs increase. Nevertheless, the FI of proposed mechanism is close the optimal value because each group was split to only three subgroups, which means three different rates available for all UEs group.

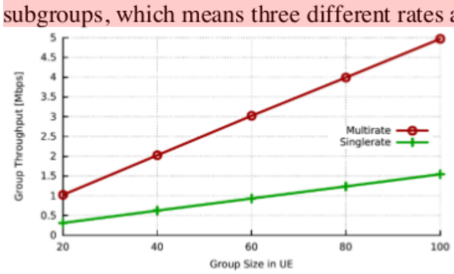

Figure 3. Cumulative Goodput difference between proposed mechanism and the CMS.

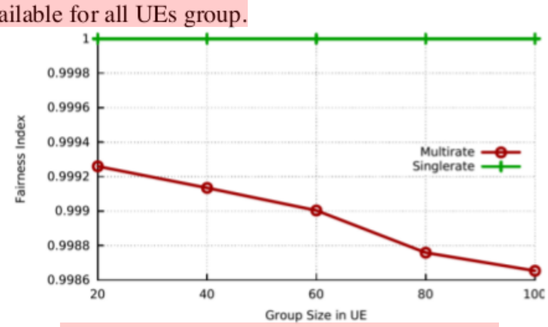

Figure 4. Fairness Index difference between proposed mechanism and CMS.

5. Conclusion
In this paper, an efficient and low complex subgrouping mechanism was proposed to improve the performance of the E-MBMS. The SINR of a group UEs have been used to split the UEs into several subgroups. The StD and average of the UEs SINR were used as a criteria to classify the UEs according to their SINR. The simulation results showed that the proposed subgrouping mechanism improves the goodput of the E-MBMS compared to the Conventional Multicast Scheme, while keeping the fairness between all UEs in acceptable level.

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