Opportunistic Multicast Scheduling with Coding in OFDM-based Wireless Cellular Networks

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***Abstract*—In this paper, resource allocation problem for multicast service in OFDM-based wireless cellular networks is investigated and a coding-based opportunistic scheduling scheme is proposed. In the proposed scheme, according to frequency resource and time resource, layered coding and erasure-correction coding are adopted, respectively. Layered coding divides the data into base layer and enhancement layer, which transmits the data in different rates to maximize the system capacity; erasure-correction coding compensates for the possible packet loss due to instantaneous channel information. To complete subcarrier allocation and bit loading for the coding-based scheme, a practical algorithm is designed. As only the users' mean channel gains are required, the proposed scheme reduces the overheads required for instantaneous channel information and is suitable for a fast time-varying fading environment. Numerical results show that the coding-based scheme can get significant performance improvement compared with the scheme without coding.**

***Index Terms*—Multicast service, OFDM, erasure-correction coding, layered coding, QoS requirement**

I. Introduction

Orthogonal frequency division multiplexing (OFDM) has emerged as one of the most promising transmission techniques for future wireless communication systems [1]. The OFDM combats against frequency-selective fading and supports a high data rate by dividing the whole frequency bandwidth into many orthogonal narrowband sub-channels. Broadcast/multicast service (BMS) is defined as a unidirectional point-to-multipoint (PTMP) bearer service in which data is transmitted from a single source entity to multiple recipients, which is a remedy to the inefficient resource usage [2], [3]. The main efficiency improvement is obtained from the fashion that different users in the cell can share the same resource to receive the same service.

Many researches have been carried out on the subcarrier and power allocation for OFDM-based multicast system [4]-[7]. In [4], different (multiple description coding) MDC layers are carried over different subcarriers, and users with good channels are allowed to receive data from more subcarriers than users with poor channel conditions. The research in [5] focuses on SISO-OFDM system, and the scheme is based on the current standards such as IEEE 802.6 or 3GPP LTE for multicast service that consider the worse user very much which may waste the resource. The shortcoming in [5] is solved in [6]. However, it doesn't consider the fairness between the users, and if one user has poor channel gains on all the subcarriers, it wouldn't receive any data. In [7], to ensure all the users receive the same content, the users are divided into two groups, and two subcarriers cooperate with each other to transmit the same data. The users in group one receive data from one subcarrier, and the users in the other group receive data from the cooperative subcarrier.

By recent advances in erasure codes and fountain codes, opportunistic multicast scheduling (OMS) schemes [8]-[10] have been proposed recently to better balance the tradeoff between multiuser diversity and the multicast gain. [8] and [9] adopt the median OMS scheme where the best half of the users are served in each time slot. However, the fixed selection ratio is not the best choice. [10] researches the optimal user selection ratio that minimizes the total number of time slots required for all users to successfully receive the common set of messages. However, these studies assume a perfect knowledge of the channel conditions of all the users in the multicast group, which causes too heavy feedback load.

In [11], erasure-correction coding is adopted in opportunistic multicast scheduling scheme. The scheme sends only one copy to all users in the multicast group at a transmission rate based on a selected SNR threshold. The scheme only needs the average SNR and the fading type of environment, which can significantly reduce the feedback load. However, there are several defects. Firstly, it can not be applied to the OFDM-based systems. Secondly, the scheme is based on the assumption that the average SNR is the same for all BS-user links, which is impractical.

To overcome the defects in [11], in this paper, we consider the resource allocation problem for multicast service in OFDM-based systems. Our objective is to maximize the system throughput given the total power constraint. Compared with [11], the novel points can be concluded as follows. Firstly, layered coding and erasure-correction coding are associated to schedule the multicast service, which can get better throughput performance. Secondly, the scheme can be used to the OFDM-based system. Thirdly, the scheme is still available as the users have different average SNRs.

The rest of the paper is organized as follows. In Section II, the system model is introduced and our objective is described. In Section III, the proposed resource allocation scheme and corresponding algorithm are elaborated in details. Simulation results and comparisons are shown in Section IV. Finally, we draw our conclusion.

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II. System Model and Problem Formulation

Consider that the OFDM-based system supports multicast service for a group of K users over N independent subcarriers with total bandwidth B. The power constraint is P_T. We assume that fades over the BS-user communications links in each time slot are independent, identically distributed (i.i.d) and quasi-static, i.e., any BS-user link fade remains unchanged during a given time slot, but it varies independently from one time-slot to another. The channel gain between user k and BS is given by $\overline{h_k}|g_n^k|^2$, where $\overline{h_k}$ denotes the mean channel gain of user k to BS and $g_n^k = x_n^k + jy_n^k$ for Gaussian random variables x_n^k and y_n^k with zero-mean and variance $1/2$. As only the mean CSI is available, for each user, the mean channel gains in different subcarriers are identical, thus, equal power allocation is reasonable. The power allocated to each subcarrier is $\frac{P_T}{N}$.

For user k, the received power over subcarrier n in each time slot is given by

$$p^k = \frac{P_T}{N}\overline{h_k}|g_n^k|^2 \tag{1}$$

We can get the probability density function of p^k

$$f(p^k) = \frac{N}{P_T\overline{h_k}}\exp(-\frac{Np^k}{P_T\overline{h_k}}) \tag{2}$$

Let $g(c)$ denote the required power to correctly decode c bits information. In the case of M-ary quadrature amplitude modulation (M-QAM), $g(c)$ can be represented as

$$g(c) = \frac{N_0}{3}[Q^{-1}(p_e/4)]^2(2^c - 1) \tag{3}$$

where p_e is the required bit error rate (BER), N_0 denotes the variance of the additive white Gaussian noise (AWGN), and $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{+\infty} e^{-t^2}dt$. In order to decode c bits information correctly, the received power over each subcarrier must satisfy

$$p^k \geq g(c) \tag{4}$$

We can calculate the probability that user k receives correct data over one subcarrier

$$p(k,c) = \int_{g(c)}^{+\infty} f(p^k)dp^k = \exp(-\frac{Ng(c)}{P_T\overline{h_k}}) \tag{5}$$

Define each user' sum rate over all the subcarriers as user data rate, and the sum of user data rates as the system data rate. Our objective is to maximize the system data rate, while ensure the minimum user rate satisfy QoS requirement. The optimization problem can be formulated as follows:

$$\max \sum_{k=1}^{K}\sum_{n=1}^{N} R_n^k \tag{6}$$

Subject to:

$$\min_k(\sum_{n=1}^{N} R_n^k) \geq R_{req} \tag{7}$$

$$c = \{1, 2, \cdots, c_{\max}\} \tag{8}$$

where c_{max} is the maximum value of c and R_n^k is the average data rate of user k over subcarrier n, it is related with the resource allocation strategy.

III. Resource Allocation Schemes

A. Resource Allocation Scheme without Coding (RAS)

In traditional multicast system, the data must be correctly received by all the users, thus, the probability that all the users receive correct data from one subcarrier is

$$p_n = \prod_{k=1}^{K} p(k,c) \tag{9}$$

With the assumptions in section II, on average, the optimization problem in (7) can be solved by

$$R_{ras}(c) = \max_c K\frac{1}{T}Nc\prod_{k=1}^{K} p(k,c) \tag{10}$$

In RAS, all the users have to receive data at the same data rate, and for the users with fine channel gains, it is a waste of resource. Besides, in one time slot, if one user fails to receive the data, the transmitter has to retransmit it. Thus, we are motivated to find a new kind of resource allocation scheme which is more flexible and intelligent.

B. Proposed Resource Allocation Scheme and Algorithm

1) Resource Allocation Scheme with Coding (RAS-C): According to frequency resource and time resource, in the following scheme, erasure-correction coding and layered coding are performed respectively.

According to frequency resource, multicast data is processed by FGS video coding technique and is encoded into base layer bits and enhancement layer bits. The base layer is the mandatory component and the bits should be received and decoded by each user. In additional, the enhancement layer is an optional component that contains the residual information representing the difference between the original video frame and the base layer. The video quality improves in proportion to the number of successfully received enhancement layer bits. In order to transmit base layer bits and enhancement layer bits respectively, we divide all the subcarriers into two groups. This is the coding scheme according to frequency resource.

According to time resource, in each subcarrier, erasure-correction coding is adopted. As shown in fig. 1, coding is performed among time slots. The data is partitioned into x packets with equal number of bits. Erasure-correction coding encodes x packets information into y associated packets, and

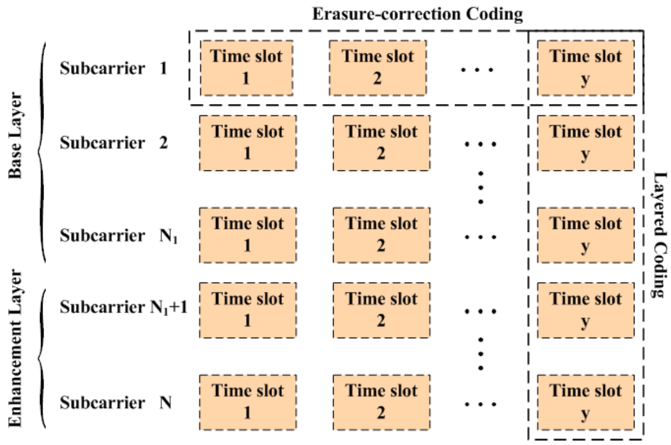

Fig. 1. Packet-level coding structure using erasure-correction coding.

the coded packets are transmitted over y time slots. The original data can be recovered as long as any x packets of data are correctly received by user, regardless of the specific received sequence of encoded packets of data.

In base layer, all the data must be correctly received by each user. If the data is transmitted without coding, the average available data rate over subcarrier n is

$$R_{ba.ras,n}(c)=K\frac{1}{T}c\prod_{k=1}^{K}p(k,c) \tag{11}$$

As erasure-correction coding is adopted, the probability that at least x non-erased packets are received by each user is

$$\begin{aligned}&P_{ba,ras-c}\{i\geq x\}\\&=\prod_{k=1}^{K}\{\sum_{i=x}^{y}\left(\begin{array}{c}y\\i\end{array}\right)[p(k,c)]^{i}[1-p(k,c)]^{y-i}\}\end{aligned} \tag{12}$$

Over each subcarrier, $x*c$ bits data are transmitted during y time slots, thus, on average, the throughput over one subcarrier can be expressed as

$$R_{ba,ras-c,n}(x,y,c)=K\frac{xc}{yT}P_{base,ras-c}\{i\geq x\} \tag{13}$$

where T is time slot.

In enhancement layer, in order to increase system data rate, we just need to make sure the users with fine channel condition receive correct data. Thus, the average available data rate over each subcarrier is

$$R_{en,ras,n}(c)=\frac{1}{T}c\sum_{k=1}^{K}p(k,c) \tag{14}$$

$$\begin{aligned}&P_{en,ras-c}\{i\geq x\}\\&=\sum_{k=1}^{K}\{\sum_{i=x}^{y}\left(\begin{array}{c}y\\i\end{array}\right)[p(k,c)]^{i}[1-p(k,c)]^{y-i}\}\end{aligned} \tag{15}$$

$$R_{en,ras-c,n}(x,y,c)=\frac{xc}{yT}P_{en,ras-c}\{i\geq x\} \tag{16}$$

2) Algorithm for RAS-C: In order to perform subcarrier allocation and bit loading for RAS-C, a practical algorithm is proposed. The proposed algorithm contains the algorithm for base layer (depicted in Algorithm 1) and the algorithm for enhancement layer (depicted in Algorithm 2).

In algorithm 1, the algorithm determines the best value of c, if erasure-correction coding is not adopted by base layer (Line Ba.1). Then, the proper values of x and c are determined as erasure-correction coding is adopted (Line Ba.2-Ba.7). By comparing ${R^*}_{ba,ras,n}$ and ${R^*}_{ba,ras-c,n}$, we can determine whether erasure-correction coding should be adopted (Ba.8). Finally, the number of subcarriers used to transmit base layer data is determined (Ba.9).

On the other hand, in algorithm 2, we firstly determine the number of subcarriers used to transmit enhancement layer data (En.1). In the following steps, the algorithm determines whether erasure-correction coding should be adopted and the reasonable values of the corresponding parameters.

Algorithm 1 Algorithm for Base Layer:	
Ba.1	${R^*}_{ba,ras,n}=\max\limits_{c}R_{ba.ras,n}(c)$
Ba.2	For x=1:y
Ba.3	$\quad R_{ba,ras-c,n}(x,y)=\max\limits_{c}R_{ba,ras-c,n}(x,y,c)$
Ba.4	$\quad {R^*}_{ba,ras-c,n}=\max\limits_{x}R_{ba,ras-c,n}(x)$
Ba.5	End
Ba.6	$x_1=\arg\max\limits_{x}R_{ba,ras-c,n}(x)$
Ba.7	$c_1=\arg\max\limits_{c}R_{ba,ras-c,n}(x_1,y)$
Ba.8	$R_{ba,n}=\max\{{R^*}_{ba,ras,n},{R^*}_{ba,ras-c,n}\}$
Ba.9	$N_1=\left\lceil\frac{R_{req}}{R_{ba,n}}\right\rceil$

Algorithm 2 Algorithm for Enhancement Layer:	
En.1	$N_2=N-N_1$
En.2	${R^*}_{en,ras,n}=\max\limits_{c}R_{en,ras,n}(c)$
En.3	For x=1:y
En.4	$\quad R_{en,ras-c,n}(x,y)=\max\limits_{c}R_{en,ras-c,n}(x,y,c)$
En.5	$\quad {R^*}_{en,ras-c,n}=\max\limits_{x}R_{en,ras-c,n}(x)$
En.6	End
En.7	$x_2=\arg\max\limits_{x}R_{en,ras-c,n}(x)$
En.8	$c_2=\arg\max\limits_{c}R_{en,ras-c,n}(x_2,y)$
En.9	$R_{en,n}=\max\{{R^*}_{en,ras,n},{R^*}_{en,ras-c,n}\}$

IV. Simulation Results

In this section, in order to analyze the performance of the proposed scheme, the performances of the schemes without coding (RAS), with layered coding (RAS-LC) and with erasure-correction coding (RAS-ECC) are simulated as comparisons. In order to further simplify the simulation, we assume that the OFDM-based system only provides one multicast service and all the subcarriers join the multicast service.

The system model introduced in section II is employed. The following assumptions are used in this paper if there are no special introductions. The transmitted signals experience

TABLE I
BASIC SIMULATION PARAMETERS

Number of subcarriers	64
Number of users	8
Maximum transmit power	10W
Total bandwidth	10MHz
AWGN PSD	-100dBW/Hz -80dBW/Hz
BER	1e-4
Pathloss expontent	2
The radius of the cell	1.5 km
Base layer required data rate	5Mbps

slowly time-varying fading channel, thus, the channel coefficients can be regarded as constants during each time slot. The users are uniformly distributed in a cell. The basic parameters listed in table I are used. The numerical results are averaged over 5000 channel realizations.

The data rates of RAS, RAS-ECC, RAS-LC and RAS-C schemes for multicast service in OFDM-based system are shown in Fig. 2. From Fig. 2, two conclusions can be derived. Firstly, RAS-C, RAS-ECC and RAS-LC all outperform RAS. It implies that coding is essential to allocate resource. For RAS-LC, enhancement layer data needn't to be correctly received by all the users, thus, enhancement layer data can be transmitted with a higher data rate. For RAS-ECC, without ensuring all the packets be correctly received, each user can recover the original data as long as more than a fixed number of packets are correctly received. For RAS-C, it can take advantage of both RAS-LC and RAS-ECC, thus, its performance is the best. Secondly, as power is low, RAS-ECC outperforms RAS-LC, however, as power increases, RAS-LC get a better performance. It is reasonable. As power is low, the data rate over each subcarrier is low, and most of the subcarriers are used to transmit base layer data. For base layer, RAS-LC is without coding and its performance equals to RAS, while RAS-ECC is based on erasure-correcting coding, which has better performance. As power increases, for RAS-LC, more and more subcarriers are used to transmit enhancement layer data; however, for RAS-ECC, the probability of each user to correctly receive data approaches to 1, thus, the advantage of RAS-ECC is weakened.

In Fig. 3, the capacity of RAS-C with Req=[1,2,3,4,5] Mbps are presented and compared. We can see that the system capacity decreases as Req increases. It is because that as the value of Req increases, more subcarriers are needed to transmit base layer data, which causes low data rate.

We vary the number of subcarriers, N, from 32 to 64. Fig. 4 and Fig. 5 depict the resulting total data rate and per-subcarrier data rate, respectively. We fix the bandwidth of each subcarrier. From Fig. 4, we can observe that, as expected, the total data rates of all the schemes increase as the number of subcarriers increases. This is because the total bandwidth increases in proportion to the number of subcarriers. However, in Fig. 5, the per-subcarrier data rates of the schemes all decease. The reason is that, the power allocated to each subcarrier decreases. In Fig. 4 and Fig. 5, by comparing the total data rate and per-subcarrier data rate between RAS-ECC and RAS-C, we can

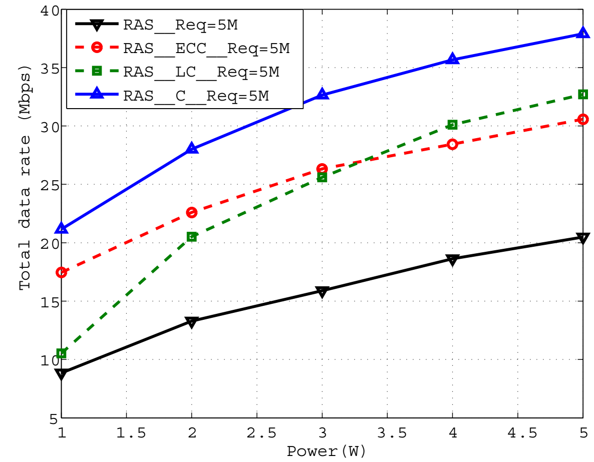

Fig. 2. Performance comparison of RAS, RAS-ECC, RAS-LC and RAS-C schemes for multicast service.

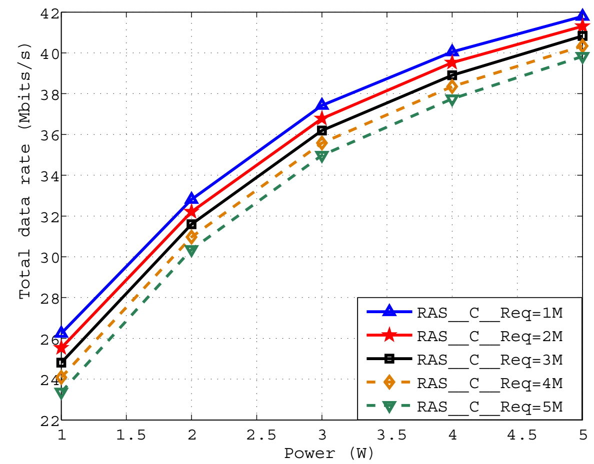

Fig. 3. Performance comparison of RAS-C scheme with Req=[1, 2, 3, 4, 5] Mbps for multicast service.

observe that if the number of subcarriers is lower than 40, the performance of RAS-ECC is better than RAS-LC, however, the results will be opposite if the number of subcarriers is larger than 40. When the number of subcarriers is low, most of the subcarriers are used to transmit the base layer data, which transmits in traditional scheme, and the advantage of RAS-LC can not be reflected, while RAS-ECC uses erasure-correction coding, thus, the performance of RAS-LC is worse than RAS-ECC. As the number of subcarriers increases, more and more subcarriers are allocated to transmit enhancement layer data, and the performance of RAS-LC significantly improved.

V. CONCLUSION

In this paper, a coding-based resource allocation scheme for multicast service is proposed to maximize the system throughput while satisfy the QoS requirement, where layered coding and erasure-correction coding are adopted. By performance

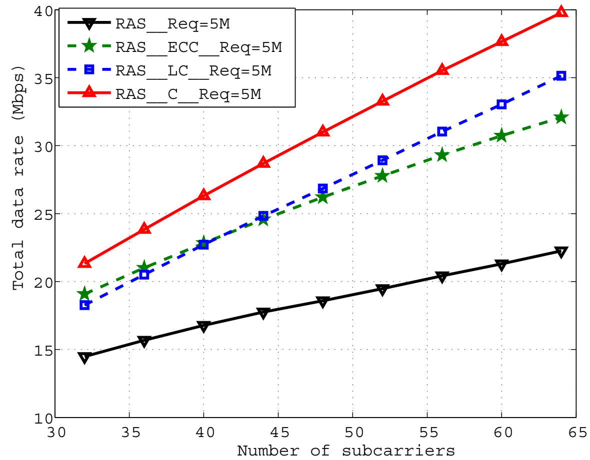

Fig. 4. Total data rates with respect to the number of sub-subcarriers.

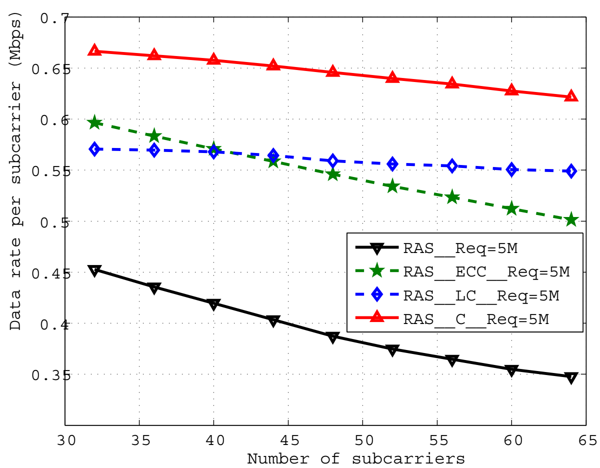

Fig. 5. Per-subcarrier data rates with respect to the number of sub-subcarriers.

comparisons, the following conclusions can be get. Firstly, as the resource (power or bandwidth) is abundant, layered coding is more efficient, otherwise, erasure-correction coding is more efficient. Secondly, by taking advantage of both layered coding and erasure-correction coding, the proposed scheme can obtain significant performance improvement over a wide power or bandwidth range. Finally, only the users' mean channel gains rather than exact knowledge of the instantaneous channel gains are required, which significantly reduces the system complexity and the resources for channel estimation and feedback signaling.

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