An Efficient Transmission Scheme Based on Adaptive Demodulation in Wireless Multicast Systems

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Abstract. To raise the transmission rate of wireless multicast system, an efficient transmission scheme based on adaptive demodulation (ADS) is proposed. Firstly, the working principle how ADS can exploit user's transmission ability better is described. Then, the bit mapping method of ADS is formulated. Finally, to analyze the transmission ability of ADS, the expression of transmission rate is derived. Numerical results show that the transmission rate of ADS is much higher than the existing schemes.

Keywords: Multicast scheduling · Transmission rate · Adaptive demodulation

1 Introduction

Multicast transmission is defined as a unidirectional point-to-multipoint bearer service in which data is transmitted from a single source entity to multiple recipients, which is a remedy to the inefficient resource usage [1–3]. Dynamic resource allocation schemes for multicast services have been extensively studied [4–8]. However, in these literatures, transmission rate would be determined by the worst channel gain, which is very low. Being motivated by recent advances in erasure codes and fountain codes [9, 10], opportunistic multicast scheduling (OMS) schemes have been proposed to improve the system throughput performance. The main idea of OMS is that during each transmission time interval (TTI), BS only transmits data to a group of users that have fine channel gains, and with the help of erasure and fountain codes, each user can recover the original message as long as a minimum set of encoded bits are received.

Some literatures that have focused on OMS should be emphasized. In [11, 12], the authors proposed to transmit data according to the user whose instantaneous signal-to-noise ratio (SNR) is the median of the ordered list of the users. The scheme in [13] predefines a transmission rate, and the data is only transmitted during the TTI that more than a defined number of users can support the predefined rate. In [14], the

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authors proposed to only transmit data to a ratio of users that have fine channel gains during each TTI. The scheme in [15] transmits data according to a selected SNR threshold and only the user with a SNR that is larger than the threshold can receive data. However, the mentioned OMSs are all fixed-rate schemes. In these schemes, once the bits are modulated and transmitted, according to the received SNR, each user just has two choices: if the received SNR is higher than the SNR requirement, the bits are demodulated and collected, otherwise, the bits are abandoned, which would restrict the system performance.

To overcome the problems in OMSs and raise the transmission rate of multicast system, we introduce a novel transmission scheme based on adaptive demodulation (ADS). In ADS, as the bits are modulated a high level modulation and coding scheme (MCS), each user can adaptively select one MCS level to demodulate bits according to the channel state information (CSI). For the users with fine channel condition, the bits are demodulated by the original MCS, and all the bits are received. For users with poor channel conditions which can't demodulate bits by the original MCS, the bits will be demodulated by a lower level MCS, and several bits can still be received.

The rest of the paper is organized as follows. In Sect. 2, the system model is introduced. In Sect. 3, for ADS, the working principle is described, the bit mapping method is formulated, and the expression of transmission rate is derived. Simulation results and comparisons are shown in Sect. 4. Finally, we draw our conclusion.

2 System Model

Consider a wireless point-to-multipoint downlink system supporting multicast service for a group of K users. Fading coefficients of the BS-user link remain constant within each transmission time interval (TTI), but may vary independently from one TTI to the next. At the BS side, the bits are processed by a rateless encoding scheme and turn into a continuous bits stream. Then, during each TTI, several encoded bits are mapped to the constellation of a selected MCS. At the user side, every user collects the bits demodulated in every TTI, and as L bits are collected, the original data can be recovered. If all the users have received L bits, transmission terminates.

The system supports a set of different MCSs $M = \{m_1, m_2, \cdots, m_{|M|}\}$. γ_{m_i} denotes the required SNR of MCS m_i and c_{m_1} denotes the corresponding number of bits carried in one TTI. For multiple phase shift keying (MPSK), γ_{m_i} can be given by

$$\gamma_{m_i} = \begin{cases} \frac{1}{2T}\left[Q^{-1}(p_e)\right]^2, & \text{if } c_{m_i} = 2 \\ \frac{1}{4Tc_{m_i}}\left[\frac{Q^{-1}(p_e c_{m_i}/2)}{\sin(\pi/2^{c_{m_i}+1})}\right]^2, & \text{if } c_{m_i} \geq 2 \end{cases} \tag{1}$$

where p_e is the required BER, T is the length of one TTI, and $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{+\infty} e^{-t^2} dt$. To facilitate the following discussion, we assume $\gamma_{m_1} < \gamma_{m_2} < \cdots < \gamma_{m_{|M|}}$ and $c_{m_1} < c_{m_2} < \cdots < c_{m_{|M|}}$. We use $\gamma_k(n)$ to denote the received SNR of user k over TTI n. If $\gamma_{m_i} \leq \gamma_k(n) < \gamma_{m_{i+1}}$, m_i can be defined as the desired MCS level of user k in the $n-$th TTI, because with m_i, user k can get the maximum number of bits.

3 Transmission Based on Adaptive Demodulation

In OMS, during each TTI, BS selects a MCS m_i to modulate the bits. Then, at the user side, each user would compare the received SNR $\gamma_k(n)$ with the required SNR γ_{m_i}, each user has two choices: (1) if $\gamma_k(n) \geq \gamma_{m_i}$, all the bits would be correctly demodulated; (2) otherwise, none of the bits would be received. However, in this scenario, if the received SNR of user k satisfies $\gamma_{m_{i-1}} \leq \gamma_k(n) < \gamma_{m_i}$ $(i > 1)$, user k has the ability to receive $c_{m_{i-1}}$ bits. Thus, OMS cannot fully exploit each user's transmission ability.

3.1 The Main Idea of ADS

To exploit each user's transmission ability better, we designs ADS for Phase Shift Keying (PSK). The main idea is that if the bits are modulated by a high level MCS, each user can adaptively demodulate bits with each user's desired MCS level. The number of bits received by each user during one TTI are determined by each user's channel condition, thus, each user can take full use of the channel condition. To demonstrate how ADS works, the transmission of multicast bits modulated by 8PSK is given as an example, which is shown in Fig. 1.

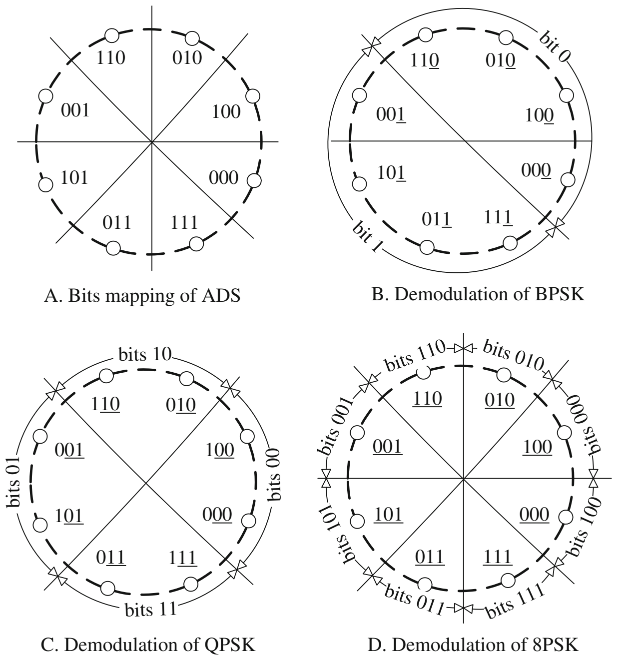

Fig. 1. Bits mapping and demodulation of ADS as $|M| = 3$

During each TTI, $|M| = 3$ bits are mapped to the constellation of 8PSK. According to the received SNR, each user selects the desired MCS level from $[m_1, m_2, m_3] =$ [BPSK,QPSK,8PSK] to decode data. For example, during TTI n, if $\gamma_{BPSK} \le \gamma_k(n) < \gamma_{QPSK}$, BPSK is the desired MCS level of user k, and according to Fig. 1B, user k can receive 1 bit. Similarly, user k would receive 2 bits or 3 bits, if $\gamma_{QPSK} \le \gamma_k(n) < \gamma_{8PSK}$ or $\gamma_k(n) \ge \gamma_{8PSK}$. Thus, each user can receive as many bits as the received SNR can support, though the bits are modulated by a high level MCS 8PSK.

3.2 The Bit Mapping Method of ADS

ADS is based on a special bit mapping scheme. Thus, in this section, we propose the bit mapping method according to PSK, which can be formulated as follows:

Algorithm: Bit mapping of ADS

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Initialization:  Ω = zeros(2^|M|, |M|);
for  m = 1 : |M|
    for  i = 1 : 2^(m-1)
        down = 2^(|M|-m) · (2i - 1) + 1;
        upper = i · 2^(|M|+1-m);
        for  j = down:upper
            Ω[j, |M| + 1 - m] = 1;
        end
    end
end
```

In ADS, $|M|$ is the number of bits transmitted during one TTI. Ω is a $2^{|M|} \times |M|$ matrix, and the bits in one row would be mapped to one constellation point. We can select one constellation point as the starting constellation point (SCP). On the transmitter side, the bits of $\underbrace{00\cdots0}_{|M|}$ in the first row are mapped to the SCP, and the bits in the n - th row are mapped to the n–th constellation point in counterclockwise direction. On the user side, if m_i is the desired MCS level to demodulate bits, all the constellation points are divided into 2^i sets, where SCP is the first point of the first set. With the process of ADS, the $2^{|M|-i}$ constellation points in each set would contain i bits identical data, thus, they can be treated as one demodulation point, and the i identical bits are the decoded data of each set.

3.3 The Transmission Rate of ADS

In this section, to analyze the transmission ability of ADS, we derive the expression of transmission rate.

In multicast system, transmission would terminate as long as every user collects L bits. Thus, the number of TTIs used to completed transmission should be expressed as

$$N = \min\{N : [\min_k \sum_{n=1}^{N} c_k(n)] \geq L\} \tag{2}$$

where $c_k(n)$ is the number of bits received by user k during TTI n.

The received SNR of user k during TTI n is

$$\gamma_k(n) = P|h_k(n)|^2/N_0, \ \forall k \tag{3}$$

where N_0 denotes the power density of additive white gaussian noise (AWGN), $h_k(n)$ is the instantaneous channel gain of user k during TTI n and P is the transmitting power.

According to $\gamma_k(n)$, the number of bits that each user can receive is

$$c_k(n) = \begin{cases} c_{m_{|M|}}, & if\ \gamma_k(n) \geq \gamma_{m_{|M|}} \\ c_{m_i}, & if\ \gamma_{m_i}(n) \leq \gamma_k < \gamma_{m_{i+1}} \\ 0, & if\ \gamma_k(n) < \gamma_{m_1} \end{cases} \tag{4}$$

where $m_i = \{m_1, m_2, \cdots, m_{|M|-1}\}$.

Assume that the channel gains of different users obey the same distributed function, and during each TTI, the probability that m_i is selected as the desired MCS is identical for all the users, which is denoted by p_{m_i}. With the help of Appendix, p_{m_i} is given by

$$p_{m_i} = \begin{cases} [F_{|h|^2}(\frac{N_0\gamma_{m_{i+1}}}{P}) - F_{|h|^2}(\frac{N_0\gamma_{m_i}}{P})], & if\, m_i \neq m_{|M|} \\ 1 - F_{|h|^2}(\frac{N_0\gamma_{m_i}}{P}), \ \ if\ \ m_i = m_{|M|} \end{cases} \tag{5}$$

where $F_{|h|^2}(\cdot)$ is the cumulative distribution function (CDF) of the channel gain.

Let $C_{k,N}$ be the number of bits received by user k during N TTIs. $C_{k,N}$ can be expressed as

$$C_{k,N} = \sum_{n=1}^{N} c_k(n) \tag{6}$$

By invoking the central limit theorem, for sufficiently large number of TTIs, we can approximate $C_{k,N}$ as a Gaussian distributed random variable such that

$$C_{k,N} \sim \mathrm{N}(N\mu, N\sigma^2) \tag{7}$$

$$\mu = \sum_{m=m_1}^{m_{|M|}} p_m c_m \tag{8}$$

$$\sigma^2 = \sum_{m=m_1}^{m_{|M|}} p_m [c_m - \sum_{m=m_1}^{m_{|M|}} p_m c_m]^2 \tag{9}$$

Let $C_{\min,\mathrm{N}} = \min_k C_{k,N}$, and by lemma 2 in [14], we can get the mean value of $C_{\min,\mathrm{N}}$

$$E[C_{\min,\mathrm{N}}] \approx \sqrt{N}\sigma\lambda + N\mu \tag{10}$$

$$\lambda = (1-\varepsilon)\Phi^{-1}(\frac{1}{K}) + \varepsilon\Phi^{-1}(\frac{1}{Ke}) \tag{11}$$

where $\varepsilon \approx 0.5772$ is the Euler-Mascheroni constant, $e \approx 2.7183$ is the Euler's number, and $\Phi(\cdot)$ is the standard Gaussian CDF.

Transmission would terminate as long as every user receives L encoded bits. By setting $E[C_{\min,\mathrm{N}}] = L$, we get

$$\mu N + \sigma\lambda\sqrt{N} - L = 0 \tag{12}$$

We find that (12) is a quadratic equation about $\sqrt{N}$, so the value of N can be obtained by the standard quadratic-root formula

$$N = (\frac{-\sigma\lambda + \sqrt{(\sigma\lambda)^2 + 4\mu L}}{2\mu})^2 \tag{13}$$

The transmission rate of ADS can be obtained by

$$R\_ADS = L/(N \cdot T) \tag{14}$$

where T is the length of every TTI.

4 Numerical Results

In this section, the performance of ADS is estimated. In simulation, the BS wants to transmit L = 10000 bits data to users, and transmission terminates as long as 10000 bits are received by every user. The BER requirement is $p_e = 10^{-4}$. The system supports six MCSs: BPSK, QPSK, 8PSK, 16PSK, 32PSK and 64PSK. The channel gain of BS-user link is $h = \sqrt{x^2 + y^2}$, where both x and y are Gaussian random variables with mean 0 and variance 0.5. The duration of one TTI is 1 ms. The power spectrum density of AWGN is -90 dB. The numerical results are averaged over 10000 channel realizations.

As comparison, the opportunistic multicast scheduling scheme (OMS) in [14] and the conventional scheme (CON) are simulated. In OMS, an optimized ratio of the users would be served and the MCS level would be determined by the worst channel gain of the selected users. In ADS, during each TTI, 6 encoded bits are mapped to the constellation of 64PSK.

Figure 2 shows the transmission rate according to the value of SNR. It can be seen that ADS performs better than other simulated schemes. For a given value of SNR, OMS and CON would determine the MCS level according to the channel condition of a selected user, and only the users whose channel condition are better than the selected user can correctly demodulate the bits. Though some users with fine channel conditions can support high level MCS, they have to receive small number of bits determined by the selected user, which is a waste of resource. However, in ADS, the bits are modulated by high level MCS, but each user can decode bits according to the current channel condition. The users with fine channel condition can receive more bits and the users with bad channel condition receive fewer bits, which can take full use of each user's channel condition.

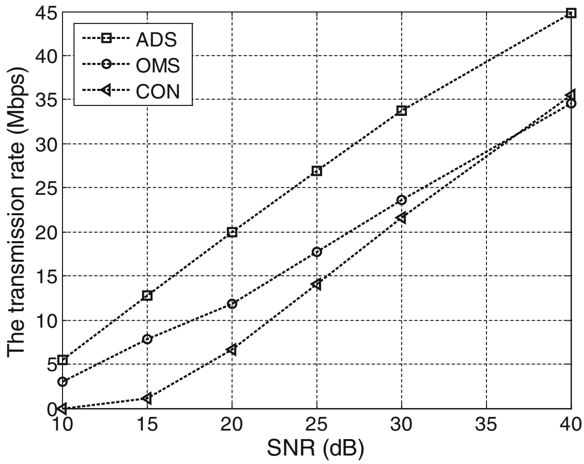

Fig. 2. Transmission rate comparison of ADS, OMS and CON as SNR increases

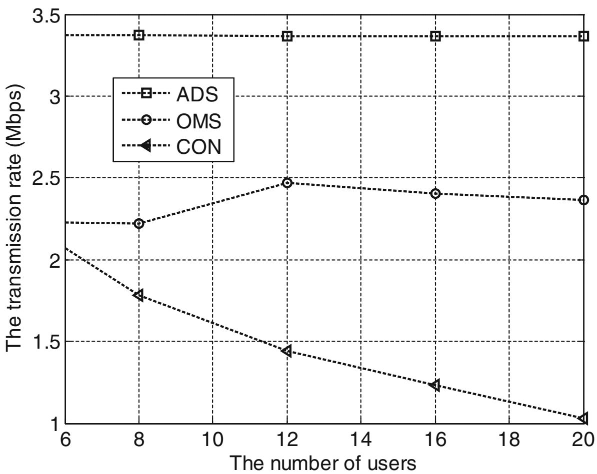

Fig. 3. Transmission rate comparison of ADS, OMS and CON as the number of users increases

As the number of users that subscribe to the multicast service increases, the transmission rates of ADS, OMS and CON are presented in Fig. 3. It is observed that the transmission rate of ADS is higher than OMS and CON. It is because ADS can exploit each user's transmission ability better. Besides, as the number of users increases, the transmission rate of ADS is a constant. It is because ADS modulates bits with the highest level MCS in each TTI, so the transmission rate doesn't decrease as the number of users increases.

5 Conclusions

This paper presents an adaptive demodulation mapping scheme (ADS) to raise the transmission rate of wireless multicast system. Different from the previous literatures, in ADS, every user can adaptively select a suitable modulation and coding scheme (MCS) to demodulate bits according to the channel state condition, which can utilize each user's channel condition better. Numerical results show that ADS can significantly raise the transmission rate for different number of users and for different values of SNR compared with the existing schemes.

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