Reducing Feedback Load of Opportunistic Multicast Scheduling over Wireless Systems

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***Abstract*—Opportunistic multicast scheduling (OMS) requires the subscribers to feed back their instantaneous channel conditions frequently, and the feedback load increases linearly as the number of subscribers in the system increases. In this letter, we propose a Weakly Consistent OMS scheme for feedback reduction. The contribution of the proposed scheme is twofold: 1) feedback load is reduced while the multicast throughput performance remains comparable with the case of full feedback, and 2) no precise knowledge of the wireless fading channel is required. Performance evaluation through realistic WiMAX simulations shows that our proposed scheme can significantly reduce 65% of the feedback load while achieving 98% multicast throughput performance compared with the case of full feedback.**

***Index Terms*—Feedback reduction, opportunistic multicast scheduling (OMS).**

I. INTRODUCTION

OPPORTUNISTIC multicast scheduling (OMS) allows wireless systems to exploit the *multi-user diversity* in multicast transmissions, by intelligently choosing a PHY layer transmission rate at each multicast transmission instance [1], [2]. Once the multicast transmission rate is determined, the targeted subscribers (i.e., the scheduled subscribers) are chosen since only the subscribers with better channel conditions can successfully recover the information delivered at that transmission rate; those subscribers not scheduled in the previous transmission instance may be scheduled later as soon as their channel conditions become better due to the fading channel fluctuation. Thus, OMS allows the wireless systems to ride the peaks of the fading channel fluctuation in multicast transmissions by dynamically allocating the wireless channels to the subset of subscribers that have strong instantaneous channel conditions.

For this, the subscribers need to feed back their instantaneous signal-to-noise ratios (SNRs) received from the BS to the scheduler frequently, so that OMS can effectively determine the multicast transmission rate at each transmission instance accordingly. Clearly, the feedback load increases linearly as the number of subscribers in the system increases, which may interfere the uplink traffic. Most previous research on reducing feedback load of opportunistic scheduling has focused on opportunistic unicast transmissions [3]. In this letter, we focus on reducing feedback load of opportunistic multicast transmissions over wireless systems. Our goal is to keep the feedback information minimal, while minimizing the performance impact on OMS.

In the literature, Qu et al. [4] investigated the impact of feedback frequency on the performance of OMS in feedback limited environments, and Le-Dang et al. [5] proposed to use an SNR-threshold scheme to assist the scheduler to implicitly decide the transmission rate. Although Le-Dang et al. [5] stated that the best OMS throughput can be achieved by considering at the BS only (a) *average received SNRs of the subscribers* and (b) *the fading type of the BS-subscriber links*, we argue that their approach merely works when the characteristics of the BS-subscriber links can be described using solely the average received SNRs (e.g., the Rayleigh fading channel). To handle a more realistic fading channel where the received SNR of a subscriber is the superimposition of path loss (large-scale effect), Rayleigh fading (small-scale effect), and shadowing, their approach still needs the subscribers to feed back their cumulative distribution functions (CDFs) of received SNRs [5].

As the heavy feedback load caused by previous OMS schemes [1], [2] comes from the frequent SNR feedback demanded by the frequent multicast transmission rate adjustment, to reduce the feedback load in OMS without precise knowledge of the wireless fading channel, we propose a Weakly Consistent OMS scheme where the transmission rate determination is periodically adjusted according to the recent channel conditions of the subscribers.

II. SYSTEM MODEL

We consider the multicast channel of a time-slotted wireless system. A single cell is considered wherein a BS is located in the center serving $|\mathbf{N}|$ subscribers that are requesting the same information from the BS ($\mathbf{N}$ denotes a set of subscribers). The wireless fading channel between the BS and the subscribers is assumed to be quasi-static with the fading coefficients remaining the same throughout a time slot and temporal changes independently from one time slot to another. We assume the wireless system supports a set of different modulation and coding schemes (MCSs), i.e., $\mathbf{M} = \{m_1, m_2, \cdots, m_{|\mathbf{M}|}\}$. Different MCSs support different transmission rates, and each one of them has an SNR requirement for a subscriber to successfully recover the multicast information. Specifically, the SNR requirement of the MCS m_i ($i = 1, 2, \cdots, |\mathbf{M}|$) is

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$\tau(m_i)$, and the amount of data that can be carried in a time slot using the MCS m_i is $C(m_i)$. We further assume

$$\tau(m_1) \leq \tau(m_2) \leq \cdots \leq \tau(m_{|\mathbf{M}-1|}) \leq \tau(m_{|\mathbf{M}|}), \quad (1)$$

and

$$C(m_1) \leq C(m_2) \leq \cdots \leq C(m_{|\mathbf{M}-1|}) \leq C(m_{|\mathbf{M}|}). \quad (2)$$

Let r_n be a random variable describing the SNR received by the subscriber n ($n \in \mathbf{N}$) and γ_n^k is the SNR received by this subscriber in the k-th time slot. If the scheduler applies the MCS m_i in the k-th time slot, the subscriber n can successfully recover the data carried in this time slot only if $\gamma_n^k \geq \tau(m_i)$; on the contrary, if $\gamma_n^k < \tau(m_i)$, the subscriber n can not recover the information carried in this time slot. To enable efficient and reliable content reception at each subscriber, we assume the source data are encoded by rateless erasure coding (fountain codes) [2], and a subscriber can fully recover the original source symbols of the multicast content once the same number of encoded symbols are received, regardless of which encoded symbols are received. We further assume the feedback from a subscriber to the opportunistic scheduler is error free.

III. PROPOSED WEAKLY CONSISTENT OMS SCHEME

Our basic idea for reducing the feedback load of OMS is to allow the scheduler to apply the same MCS in a sequence of time slots. Thus, MCS adjustment and SNR feedback are not necessary at every time slot and the feedback load can be reduced while a comparable multicast throughput performance can still be achieved. To determine the MCS to be used in a sequence of time slots, the concept of a subscriber's *reception probability* (*RP*) is introduced, which is defined as the probability that a subscriber can successfully recover the information carried in a time slot under a given MCS. Specifically, the *RP* of the subscriber n under the MCS m_i is

$$P_n(m_i) = 1 - F_{r_n}(\tau(m_i)), \quad (3)$$

where $F_{r_n}(\cdot)$ is the CDF of the SNR received by the subscriber n. We can obtain from (1) and (3) that

$$P_n(m_1) \geq P_n(m_2) \geq \cdots \geq P_n(m_{|\mathbf{M}-1|}) \geq P_n(m_{|\mathbf{M}|}). \quad (4)$$

From (2) and (4), we can also observe that the subscriber n will have different potential throughput in receiving multicast contents from the BS (i.e., $P_n(m_i) \cdot C(m_i)$) if different MCS m_i is used. Since the throughput performance of OMS is constrained by the subscriber with worst reception throughput [1], [2], we know that if we want to use a fixed MCS in a sequence of time slots, the MCS needs to be carefully chosen to let the worst reception throughput across all the subscribers in the system be maximized. Therefore, we determine an optimal MCS $\widehat{m}_{opt}$ to be used in a sequence of time slots as follows

$$\widehat{m}_{opt} = \arg\max_{m \in \mathbf{M}} \{\min_{n \in \mathbf{N}} [P_n(m)] \cdot C(m)\}. \quad (5)$$

In (3), the exact $P_n(m_i)$ of the subscriber n under the MCS m_i can only be available when the scheduler knows precisely the characteristics of the wireless fading channel (i.e., the CDF of the received SNR). In our Weakly Consistent OMS scheme, we use an exponentially weighted moving average (EWMA) filter [3] to estimate $P_n(m_i)$:

$$\widehat{P}_n^k(m_i) = (1-1/t_c) \cdot \widehat{P}_n^{k-1}(m_i) + (1/t_c) \cdot I[\gamma_n^k \geq \tau(m_i)], \quad (6)$$

where $\widehat{P}_n^k(m_i)$ is the estimated *RP* of the subscriber n under the MCS m_i at the k-th time slot, t_c is the length of the update window, and

$$I[\gamma_n^k \geq \tau(m_i)] = \begin{cases} 1, & \text{if } \gamma_n^k \geq \tau(m_i), \\ 0, & \text{if } \gamma_n^k < \tau(m_i). \end{cases}$$

The proposed Weakly Consistent OMS scheme contains the Subscriber side algorithm (depicted in Algorithm 1) and the BS side algorithm (depicted in Algorithm 2). In Algorithm 1, at each time slot, a subscriber tries to receive the multicast content from the BS, measures its channel condition, and estimates its *RPs* under different MCSs (lines S.5-S.7). Periodically (i.e., every K time slots), the subscriber reports its *RPs* to the BS (lines S.2-S.4, where the reports of the *RPs* can optionally be spread into several time slots to avoid feedback bursts). On the other hand, in Algorithm 2, the BS periodically updates the *RPs* of the subscribers and determines the optimal MCS $\widehat{m}_{opt}$ to be used in the following K time slots (lines B.2-B.5); in each time slot, the BS sends out the multicast content using the MCS $\widehat{m}_{opt}$ (line B.6).

Algorithm 1 Subscriber side algorithm

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S.1: repeat for the $k$-th time slot
S.2:     if $k$ mod $K$ equals to $0$
S.3:         report its RPs to the BS;
S.4:     endif
S.5:     try to receive the multicast content carried in the
             $k$-th time slot;
S.6:     measure the received SNR $\gamma_n^k$;
S.7:     estimate its RPs $\{\widehat{P}_n^k(m_i), \forall m_i \in \mathbf{M}\}$ using (6);
S.8: until leaving the multicast group
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Algorithm 2 BS side algorithm

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B.1: repeat for the $k$-th time slot
B.2:     if $k$ mod $K$ equals to $0$
B.3:         update the RPs from all subscribers;
B.4:         determine $\widehat{m}_{opt}$ using (5);
B.5:     endif
B.6:     schedule multicast content to be delivered in the
             $k$-th time slot using $\widehat{m}_{opt}$;
B.7: until end of the data flow
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Note that if we assume the average feedback load of *full feedback* [2] to be 1 (i.e., each subscriber has one SNR feedback per time slot), we have that of our scheme $|\mathbf{M}|/K$ (i.e., each subscriber has $|\mathbf{M}|$ *RP* feedbacks per K time slots). Clearly, as long as we have $K > |\mathbf{M}|$, our scheme is able to reduce the feedback load in the system.

IV. NUMERICAL RESULTS AND CONCLUDING REMARKS

We evaluate our proposed scheme through realistic IEEE 802.16-2009 WiMAX [6] simulations. A cell with three sectors is considered, where a BS is located in the center and several subscribers are initially placed uniformly random across the cell. The BS provides one multicast group and all multicast subscribers join the multicast group. The adopted system parameters follow the suggestion of WiMAX Forum [1]. We consider a 10 MHz spectrum in the 2.5 GHz range for our simulations. To simulate the wireless fading channel, the COST 231 Hata propagation model is used for path loss along with the ITU Pedestrian B power delay profile for the small-scale fading and an 8dB log-normal shadowing. The duration of each time slot is 5ms, and there are seven MCSs supported: QPSK 1/2, QPSK 3/4, 16-QAM 1/2, 16-QAM 3/4, 64-QAM 1/2, 64-QAM 2/3, and 64-QAM 3/4.

We compare simulation results computed by using: i) the full feedback scheme [2], ii) our proposed Weakly Consistent OMS scheme, and iii) the SNR-threshold scheme [5]. As the SNR-threshold scheme lacks the capability to handle non-Rayleigh fading channels [5], we adapt the *RP* estimation & feedback mechanism in our proposed scheme to the SNR-threshold scheme so that it can derive its parameters to be used (e.g., the threshold SNR value). For a fair comparison, the feedback intervals in our proposed scheme and the SNR-threshold scheme are set to 100ms (i.e., $K = 20$). All our simulation runs are averaged over 2000 scheduling time slots, and each result is the average over 1000 simulation runs. We vary the number of multicast subscribers in the system from 10 to 100 to see the simulation results.

Figure 1 shows the average feedback load per time slot. It can be observed that, with different multicast group sizes, both our proposed scheme and the SNR-threshold scheme can reduce 65% feedback load compared with that of the full feedback scheme (as they use the same feedback mechanism). In Fig. 2, we compare the normalized system throughput in multicasting (i.e., the normalized worst data reception throughput across all the subscribers, which corresponds to the latency for all the subscribers to receive a single copy of information from the BS [2]). It can be seen that as the group size grows, the performance of our scheme gets closer and closer to that of the full feedback scheme. This is because the proposed scheme determines the MCS based on the *RPs* of the subscribers and its performance remains similar as the group size increases, whereas the full feedback scheme determines the MCS based on instantaneous SNRs of the subscribers and its performance drops as the group size increases. As the group size increases to 100, the performance difference between our scheme and the full feedback scheme is only 2%. Similarly, the performance of the SNR-threshold scheme increases as the group size increases, whereas its performance is 6.5%-8.3% lower than that of our proposed scheme. The reason is that the SNR-threshold scheme [5] considers maximizing the average reception throughput across all the subscribers but not the worst reception throughput, which results in a longer latency for all the subscribers to receive a single copy of information from the BS, i.e., lower system performance in multicasting.

In this letter, we presented a scheme for reducing feedback load of OMS over wireless systems. The novelty of our work is that the proposed scheme does not need to know precisely the characteristics of the wireless fading channel between the BS and each subscriber. Performance evaluation through realistic WiMAX simulations shows that our scheme significantly reduces the feedback load, while providing a comparable throughput performance in multicasting compared with that of the full feedback scheme.

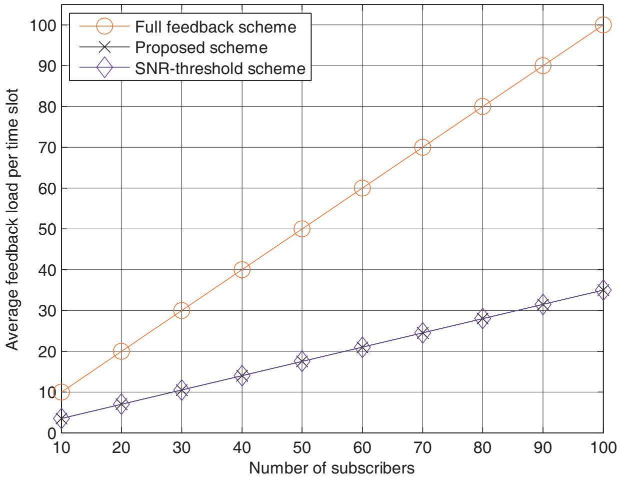

Fig. 1. Average feedback load per time slot.

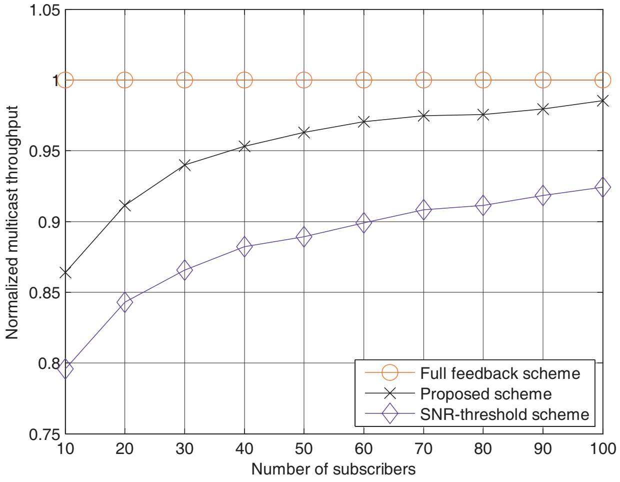

Fig. 2. Normalized system throughput in multicasting.

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