Cooperative Multicast Scheduling Scheme for IPTV Service over IEEE 802.16 Networks

Fen Hou1, Lin X. Cai1, James She1, Pin-Han Ho1, Xuemin (Sherman) Shen1, and Junshan Zhang2

University of Waterloo, Waterloo, Ontario, Canada1
{fhou, lcai, james, pinhan, xshen}@bbsr.uwaterloo.ca
Arizona State University, Tempe, AZ, USA2
junshan.zhang@asu.edu

Abstract – Exploiting the broadcast nature of wireless communications, multicast transmission is an efficient way to improve the network throughput by transmitting the same contents to multiple receivers simultaneously. It has been considered as a key technology for supporting emerging services in next-generation IEEE 802.16 based wireless metropolitan area networks (WMANs), such as Internet Protocol TV (IPTV) and mobile TV. Therefore, it is critical to devise efficient multicast scheduling schemes to support these multimedia services. In this paper, we propose a novel multicast scheduling scheme, using downlink cooperative transmission for achieving high throughput not only for all multicast groups but also for each group member. Extensive simulations are conducted to demonstrate the effectiveness and efficiency of the proposed scheme.

I. INTRODUCTION

With the increasing demand on multimedia applications, multimedia multicast services have been attracting great attention from both academia and industry. Multimedia Broadcast Multicast Service (MBMS) has been standardized by the third generation partnership project (3GPP) [1]. Internet Protocol TeleVision (IPTV), as one of the most important broadband multimedia applications, is expected to contribute immense market value to the service providers in next generation wireless networks [2]. Meanwhile, IEEE 802.16 networks have been considered as a promising alternative to cable and digital subscriber line (DSL) for providing high-quality broadband wireless multimedia services, due to its capability of providing QoS satisfaction [3]. Therefore, how to fulfill efficient multicast transmission is a critical issue for supporting IPTV services over IEEE 802.16 networks.

Multicast scheduling plays a critical role in achieving efficient multicast transmissions. In general, the users aiming to receive the same copy of data are logically grouped as a multicast group, and each user is called a group member of the multicast group. A simple multicast scheduling scheme could be developed by taking a default transmission rate for each multicast group and scheduling each group in the round-robin fashion. The current CDMA 2000 1xEV-DO networks take such an approach with a fixed rate of 204.8 kbps [4]. This scheme is inefficient since it always uses a fixed rate for data transmission and does not consider the diverse channel conditions of multiple members in a multicast group.

Another general approach in selecting the transmission rate of a multicast group is that all the group members can support this rate. Note that each multicast group may have multiple group members possibly subject to different channel conditions at a time instant. Thus, the overall throughput bottleneck would be easily formed by the group member with the worst channel condition if the base station (BS) intends to satisfy all group members in a multicast group, which leads to the underutilization for the group members with good channel conditions. This approach is too conservative and especially inefficient when the group members with bad channel conditions only account for a small part of the members of a multicast group.

To properly select a transmission rate at the BS, the inter-group proportional fairness is proposed in [5], in which the BS schedules the multicast groups based on the proportional fairness policy and the transmission rate is selected in such a way that the summation of $\log T_g^k$ for all multicast groups is maximized, where $\log T_g^k$ is the group throughput for multicast group $k$. Rate optimization for threshold based multicast policies is studied in [6].

Aforementioned studies are focused on alleviating the negative impact caused by the diverse channel conditions between the BS and multiple group members of a multicast group. They do not exploit any potential advantages provided by the channel diversity in multicast scenario. On the other hand, cooperative communication is a promising technology that can greatly improves the system performance by exploring the broadcasting nature of wireless channels and cooperation among multiple users. Cooperative communication used for unicast transmissions has been extensively studied [7], [8], [9]. However, little work applies cooperative communication technique for multicast transmissions. In this paper, we propose a novel cooperative multicast scheduling scheme that exploits the spatial diversity gain across multiple users in a network by using a two-phase cooperative transmission. By taking the advantage of the channel diversity of multiple group members and cooperative communication, the proposed scheme can significantly improve the transmission rate and maintain the reliability of the downlink transmission for SSs with bad channel conditions.
channel conditions, thus resulting in significant throughput enhancements for both multicast group and individual group member.

Different from previous work on cooperative unicast communications, the proposed cooperative multicast scheduling focuses on network performance study based on different network scenarios. First, the partner(s) or cooperator(s) in unicast cooperative transmission are usually fixed, e.g., pre-placed relay stations, for protocol design and implementation simplicity. In multicast scenario with all users in a multicast group requesting the same data, basically any user with good channel conditions can forward the received data to the remaining users in the same group; and thus the cooperative transmitters are variable. Second, most previous studies in unicast cooperative transmission focus on the performance study in the physical layer (PHY), in terms of outage probability, bit error rate (BER), and optimal power allocation, etc. In addition, different from unicast transmissions, multicast services are inherently unreliable (due to no acknowledgement), and we need to carefully determine critical parameters for multi-user cooperation to assure high throughput for all users.

The remainder of the paper is organized as follows. The cooperative multicast scheduling scheme is proposed in Section II. The performance of the proposed scheme is investigated in Section III. Simulation results are presented in Section IV to demonstrate the efficiency of the proposed scheme, followed by concluding remarks in Section V.

II. THE COOPERATIVE MULTICAST SCHEDULING (CMS) SCHEME

We consider an IEEE 802.16 network composed of one BS and multiple subscriber stations (SSs) which are classified into several multicast groups according to their subscribed services. For simplicity, we refer to multicast groups and the SSs consisting of a multicast group as MGroups and group members, respectively. The Rayleigh flat fading channel is assumed throughout.

Fig. 1 illustrates the media access control (MAC) structure and the principle of the proposed cooperative multicast scheduling. At the MAC layer, the time domain is divided into MAC frames of equal duration. Each MAC frame consists of a downlink sub-frame (DL subframe) followed by an uplink sub-frame (UL subframe). Each DL subframe is composed of a frame header and several downlink bursts. An MGroup is selected at each frame. For instance, MGroup \( i \) is selected at the frame \( n \) and the BS assigns downlink burst \( i \) (denoted as \( T{S_i} \)) to it. In our proposed scheme, the time interval of \( T{S_i} \) is divided into two phases, depicted in Fig. 1(a). In Phase I, BS multicasts data, at a high data rate of \( R_{1i} \), to the group members of MGroup \( i \), aiming to guarantee that a certain percentage of SSs in MGroup \( i \) can successfully decode the data, depicted in Fig. 1(b). After Phase I of time duration \( T_1 \), some SSs in MGroup \( i \) can successfully receive the transmitted data (denoted them as SSs with good channel conditions) while others may only be able to decode part of the data (denoted them as SSs with bad channel conditions). In Phase II of time duration \( T_2 \), all SSs with good channel conditions cooperatively transmit the received data simultaneously at the rate of \( R_{2i} \) and satisfies \( R_{1i} + T_1 = R_{2i} + T_2 \) to assure all members in the MGroup can receive the same data, as shown in Fig. 1(c). It is worth noting that \( R_{1i} \) and \( R_{2i} \) are much higher than the default conservative rate in the worst case scenario and the two-phase high rate transmission can outperform one phase low rate transmission [10]. By taking the advantage of the spatial diversity gain of wireless channels in Phase II, the cooperative multicast scheduling scheme can significantly improve achieved throughput of each MGroup. How to select an MGroup during each frame and then how to select the rate of \( R_{1i} \) and \( R_{2i} \) will be elaborated further as follows.

A. Multicast Group Selection

Different MGroups have different sets of group members distributed at different locations. Generally, different group members have different long-term channel conditions which depend on their geographical environments and their distance from the BS. On the other hand, due to fast fading, different group members may experience different instantaneous channel conditions at each frame, even if they have similar long-term channel conditions. In the multicast scheduling scheme, to exploit the multi-group channel diversity gain, the selection of an MGroup should consider the channel conditions on the group basis, rather than a single group member basis. If an MGroup is selected based on the best channel condition among all members in an MGroup, ignoring the channel conditions of the remaining group members, the achieved group throughput may not be high if most of the other group members are experiencing bad channel conditions. If a scheme selects an MGroup based on the sum of channel conditions of all group members, it may lead to serious fairness problem because MGroups which are close to the BS and have good channel conditions are more likely to be scheduled and thus dominate the bandwidth consumption. Considering the fairness performance while exploiting the multi-group channel diversity, we proposed a criterion of selecting an MGroup based on the
normalized relative channel condition, which is given as,
\[
X_i = \frac{\sum_{j \in G_i} \gamma_i^j / \gamma_i^j}{|G_i|} \tag{2}
\]
where \(X_i\) represents the normalized relative channel condition of MGroup \(i\), \(G_i\) represents the set of all group members in MGroup \(i\), \(|G_i|\) is the total number of group members in MGroup \(i\), \(\gamma_i^j\) and \(\gamma_i^j\) denote the average channel condition and the instantaneous channel condition between the \(j\)-th group member in MGroup \(i\), \(SS_{ij}\), and the BS, respectively.

Based on (1), BS selects the MGroup \(i^*\), which has the maximum value of the normalized relative channel condition, to be served in each DL sub-frame. In summary, by considering the different channel conditions of multiple MGroups, the proposed scheme exploits the multi-group channel diversity for achieving a high network throughput. Meanwhile, by averaging out the long-term channel conditions and normalizing the total number of MGroup members, the proposed scheme can obtain good fairness performance.

B. Cooperative Transmission

After an MGroup is selected for service, the next step is to efficiently multicast data to all group members in the selected MGroup. If the transmission rate is determined based on good channel conditions, the group members with bad channel conditions cannot successfully decode the received data. On the contrary, if the transmission rate is determined based on the bad channel conditions, the wireless resources would suffer from underutilization because the group members in good channel conditions use a conservative low rate for data transmissions. This dilemma is mainly caused by the diverse channel conditions of group members in the same MGroup. To exploit the diversity gain of the wireless channels, a two-phased cooperative transmission scheme is used to efficiently multicast data to all group members. During the Phase I, the BS multicasts data to all group members at a high transmission rate determined by the channel conditions of a certain portion of the group members. That is, the rate is chosen to guarantee the reliable transmissions of the group members in good channel conditions. Therefore, the transmission rate is much higher than the conservative rate considering the worst channel condition in the MGroup. However, due to the high transmission rate in Phase I, the remaining group members that are in relatively poor channel conditions may not be able to successfully decode all the transmitted data in Phase I and have to use Phase II cooperative communications for achieving the reliable transmission. Denote \(S^g\) the set of group members that can successfully receive the data in Phase I and \(S^b\) the remaining members in the MGroup. In Phase II, all members in \(S^g\) cooperatively transmit the same data to those members in \(S^b\). In this way, group members located in different locations form a virtual MIMO system, in which group members in \(S^g\) are transmitters and those in \(S^g\) are receivers. Although the channel condition between the BS and group members in \(S^b\) are relatively poor during this frame, it is very likely that there are some group members in \(S^g\) close to the \(S^b\) members and have good channel conditions. By exploiting the spatial diversity gain of wireless channels in Phase II, the transmission rate for reliable multicast transmission can be significantly improved. Note that in Phase II, the downlink transmission to any one of the members in \(S^b\) is a virtual multiple-input-single-output (MISO) system because multiple members in \(S^g\) are transmitting data to one receiver. The signal power received at a group member in \(S^b\) is the sum of signal powers from all cooperative transmitters. Thus, a group member in \(S^b\) is able to successfully receive the data in Phase II even at a very high data rate. In the proposed scheme, the group members in bad channel conditions still have a high probability to successfully receive the data when both the first and the second phases use high transmission rates. By using appropriate parameters for two-phase cooperative transmissions, i.e., the transmission rates in both Phases I and II, the proposed scheme can achieve high throughput for each group member, consequently a high group throughput and network throughput. Furthermore, the proposed scheme can satisfy the reliable transmission for the members with bad channel conditions as well.

The selection of transmission rate in Phases I and II (i.e., \(R^1_i\) and \(R^2_i\)) is critical to the system performance. For easy implementation, in the proposed scheme, \(R^1_i\) and \(R^2_i\) are determined based on the long-term channel conditions of all group members in MGroup \(i\) and the coverage ratio, \(C\), which is defined as the percentage of group members that can support \(R^1_i\). For instance, \(C = 50\%\) means that the BS transmits at a rate of \(R^1_i\) such that on average half of the group members of the MGroup \(i\) can receive the data successfully, and \(R^2_i\) is set in such a way that the remaining group members in MGroup \(i\) can successfully receive the data in Phase II. Note that \(R^1_i\) and \(R^2_i\) are decided based on the long-term channel conditions of group members, instead of the instantaneous channel conditions, so that BS does not need to reconfigure the transmission rates frequently.

III. PERFORMANCE ANALYSIS

In this Section, an analytical model is developed to investigate the performance of the proposed scheduling scheme in terms of steady-state service probability of each MGroup and achieved throughput of each group member. The notations used in the rest of the paper are listed in TABLE I.

A. Steady-State Service Probability for MGroup \(i\)

Steady-state service probability is defined as the probability that an MGroup is selected to be served at an arbitrary frame when the system is stable. Based on (1), the MGroup with the best average channel condition in a frame is selected to be served. We define a random variable \(Y^j_i = \frac{\gamma_i^j}{\gamma_i^j}\), then \(X_i\) can be expressed as \(X_i = \sum_{j \in G_i} Y^j_i\). For a Rayleigh fading channel, \(\gamma_i^j\) follows exponential distribution with mean \(\gamma_i^j\). Therefore, \(Y^j_i\) also follows the exponential distribution [11], and its probability distribution function is given by
The total number of MGroups
$G_i$ The set of all members in MGroup $i$
$G_{ij}$ The set of members that can successfully receive data in Phase I
$G_{ij}^n$ The set of members that fails to receive data in Phase I
$n_{ij}$ The total number of group members in the MGroup $G_i$
$R_i^1$ The transmission rate of the BS in Phase I for MGroup $i$
$R_i^2$ The transmission rate in Phase II for MGroup $i$
$X_i$ The normalized average channel condition of MGroup $i$
$SS_{ij}$ The $j$-th group member in MGroup $i$
$G_i^*$ The set of members that can successfully receive data in Phase I
$G_i^n$ The set of members that fails to receive data in Phase I
$\phi$ The instantaneous SNR for the channel between $SS_{ij}$ and the BS
$\gamma_{ij}$ Coverage ratio used to decide the transmission rate in Phase I

<table>
<thead>
<tr>
<th>M</th>
<th>The total number of MGroups</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_i$</td>
<td>The set of all members in MGroup $i$</td>
</tr>
<tr>
<td>$G_{ij}$</td>
<td>The set of members that can successfully receive data in Phase I</td>
</tr>
<tr>
<td>$G_{ij}^n$</td>
<td>The set of members that fails to receive data in Phase I</td>
</tr>
<tr>
<td>$n_{ij}$</td>
<td>The total number of group members in the MGroup $G_i$</td>
</tr>
<tr>
<td>$R_i^1$</td>
<td>The transmission rate of the BS in Phase I for MGroup $i$</td>
</tr>
<tr>
<td>$R_i^2$</td>
<td>The transmission rate in Phase II for MGroup $i$</td>
</tr>
<tr>
<td>$X_i$</td>
<td>The normalized average channel condition of MGroup $i$</td>
</tr>
<tr>
<td>$SS_{ij}$</td>
<td>The $j$-th group member in MGroup $i$</td>
</tr>
<tr>
<td>$G_i^*$</td>
<td>The set of members that can successfully receive data in Phase I</td>
</tr>
<tr>
<td>$G_i^n$</td>
<td>The set of members that fails to receive data in Phase I</td>
</tr>
</tbody>
</table>

The probability that $SS_{ij}$ can successfully receive the data in Phase II is given by
\[
Pr[\gamma_{ij} \geq 2^{R_i^2} - 1] = 1 - G(\gamma_{ij}^2) = 2^{R_i^2} - 1
\]
where $G(.)$ function is the CDF of $\gamma_{ij}^2$.

The throughput achieved by the group member $SS_{ij}$ is given by
\[
Th_{ij}^1 = \pi_i \cdot [R_i^1 \cdot Pr[\gamma_{ij}^1 > 2^{R_i^1} - 1] \\
+ R_i^2 \cdot Pr[\gamma_{ij}^1 \leq 2^{R_i^1} - 1] \cdot Pr[\gamma_{ij}^2 \geq 2^{R_i^2} - 1]]
\]

The network throughput is given by
\[
Th = \sum_{i=1}^{M} \sum_{j=1}^{n_i} Th_{ij}^1.
\]

<table>
<thead>
<tr>
<th>Transmission power of BS’s</th>
<th>41.8 dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission power of SS’s</td>
<td>30 dBm</td>
</tr>
<tr>
<td>DL/UL sub-frame duration</td>
<td>0.5 ms0.5 ms</td>
</tr>
<tr>
<td>OFDM symbol duration</td>
<td>20.5µs</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Noise figure</td>
<td>7 dB</td>
</tr>
<tr>
<td>Pass loss exponent</td>
<td>4.375</td>
</tr>
<tr>
<td>Close-in Reference distance</td>
<td>100 m</td>
</tr>
<tr>
<td>Frequency band</td>
<td>3.5GHz</td>
</tr>
<tr>
<td>Number of MGroups</td>
<td>10</td>
</tr>
<tr>
<td>Coverage ratio $G_i$</td>
<td>50%</td>
</tr>
</tbody>
</table>

### IV. Simulation Results

In this section, simulations are conducted to demonstrate the efficiency and effectiveness of the proposed scheme. We simulate an IEEE 802.16 WirelessMAN-OFDM network composed of one BS and 50 SSs. SSs are randomly distributed in the coverage area of the BS, which is a circle with a radius of 8 km. The group members in each MGroup is randomly selected from these 50 SSs. Other simulation parameters are listed in TABLE II. We repeat the simulation 50 times with different random seeds and calculate the average value.

To verify the efficiency of the proposed scheme, we compare the achieved throughput of the proposed scheme (denoted as CMS) with that of the scheme specified in 3GPP (denoted as Conserve), where the transmission rate of BS selects the sending rate in a conservative way such that all group members of the selected MGroup can support this rate.

Fig. 2 shows the steady-state service probability of each MGroup for the proposed scheme. It is observed that each MGroup obtains almost the same service probability, which illustrates that the proposed scheme can achieve good fairness performance in terms of channel access. In addition, the analytical results match the simulation results very well, which verifies the accuracy of the proposed analytical model.

The achieved throughput of each group member for an MGroup is shown in Fig. 3. It is observed that CMS outperforms Conserve in terms of the throughput for all group members by exploiting the multi-group channel diversity. Some
The impact of the coverage ratio $C$ on the network throughput is shown in Fig. 4. It is observed that the maximum network throughput is achieved with $C = 0.55$. In addition, a medium value of parameter $C$ is better than a relatively large or relative small value.

V. CONCLUSIONS

We have proposed a cooperative multicast scheduling scheme for achieving high throughput in IEEE 802.16 networks. By using two-phase cooperative transmissions to exploit the spatial diversity gains in the multicast scenario, the proposed scheduling scheme can significantly improve the throughput not only for all MGroups, but also for each group member. In addition, the proposed MGroup selection can provide good fairness performance in terms of channel access. Extensive simulations have been conducted to validate the efficiency of the proposed scheme and the accuracy of the analytical model. The proposed scheme can also be extended to other wireless networks in general.

REFERENCES


