A Cooperative Multicast Scheduling Scheme for Multimedia Services in IEEE 802.16 Networks

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Outline

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IEEE 802.16 also known as WiMAX (Worldwide Interoperability for Microwave Access).

The radio coverage ranges of WiMAX networks are measured in kilometres which makes IEEE 802.16 based networks suitable for constructing metropolitan area networks (MANs), delivering performance comparable to traditional cable, DSL or T1 offerings.

IEEE 802.16 employs TDMA (Time Division Multiple Access) as the access method and the policy for selecting scheduled links in a given time slot.
802.16 Network

- IEEE 802.16 network consisting of a BS and multiple subscriber stations (SSs).

- An SS could be a mobile user, a residential customer or an office building.

- IEEE 802.16 standard supports two modes for operation: Mesh mode and Point-to-MultiPoint (PMP) mode.

- In the PMP mode, there is a centralised base station (BS) and several subscriber stations (SSs). These SSs establish connections to the BS and communicate with each other through the BS. On the other hand, in the mesh mode, these SSs can help each other to relay packets or directly transmit data between these SSs.
802.16 Network
Multicasting

- Efficient mechanism for one-to-many transmissions over wireless channels to broadcast information to multiple users simultaneously.

- They form a key technology for supporting various multimedia services like IPTV, mobile TV etc.
Multicast Scheduling: A challenging issue

- In a multicast network, users requesting the same data can be logically grouped as a multicast group.

- These users in the group are distributed at different locations and experience different fading and path-loss due to time-varying wireless channels.

- The data rates supported by different users vary depending on the channel conditions.
Previous Work

- The previous schemes achieve a good tradeoff between the throughput and the fairness, but they do not consider how to deal with the negative impacts of bad channel conditions on the achieved throughput.

- The ones which consider the channel conditions, do not give details on how to efficiently select MGroups and how to guarantee the reliable transmission to users far from the BS.

- Most existing studies focus on designing reliable routing protocols in the network layer or efficient error-control and recovery schemes in the transport layer. Little work has been carried out on reliable multicast scheduling at the media access control (MAC) layer.
Cooperative Multicast Scheduling Scheme

- The proposed cooperative multicast scheme is based on a two-phase cooperative transmission model.

- In the first phase, the BS multicasts data at a high rate and users in good channel conditions help relay the received data to the remaining users in the second phase.

- Multiple SSs are grouped into different MGroups according to their subscribed services. A SS may access multiple channels simultaneously and thus belongs to several MGroups.
Channel Model

Assumptions:

- PMP mode is considered.
- To achieve cooperative multicasting, a transmission burst assigned for multicast transmission is divided into two phases.
- There are two main categories of cooperative schemes, amplify-and-forward (AF) and decode-and-forward (DF). In this paper, DF scenario is considered, since in a multicast scenario, all Mgroup members need to decode the received data and this procedure does not increase the complexity of MGroup members.
Channel Model

- Radio signals are transmitted over a propagation wireless channel, suffer from signal reflection, diffraction, and scattering. In this paper, both large-scale path loss attenuation and small-scale fading are considered in the channel model.
- Path loss attenuation can be modelled as:
  \[ PL(d) = PL(d_0) + 10 \cdot k \cdot \log_{10}(\frac{d}{d_0}) \]
- Rayleigh fading is applied to describe small scale fading, where the PDF of the perceived SNR is:
  \[ f(\gamma) = \frac{1}{\gamma} e^{-\gamma/\gamma} \]
Selecting Multicast Group

- The first key step is to select an appropriate MGroup for service at the beginning of each MAC frame, then the BS can efficiently multicast data to all group members in the selected Mgroup. Two approaches are used to select MGroups for services –

  - Random MGroup selection
  - Channel-aware MGroup selection
Random Mgroup Selection

- The BS randomly selects an MGroup for service with a pre-defined probability.

- The probability for MGroup i to be served in a MAC frame can be decided based on the total number of Mgroups.

- Flexible and easy to implement.
Channel-Aware MGroup Selection

- MGroup selection is based on the normalized relative channel condition given by –

$$i^* = \arg \max_i X_i,$$

$$X_i = \frac{\sum_{j \in G_i} \gamma_{i,j} / \overline{\gamma}_{i,j}}{N_i}$$

- where $X_i$ represents the normalized relative channel condition of MGroup $i$, $G_i$ represents the set of all group members in MGroup $i$, $N_i$ is the total number of group members in MGroup $i$, $\overline{\gamma}_{i,j}$ and $\gamma_{i,j}$ denote the average channel condition and the instantaneous channel condition of the $j$ th group member in MGroup $i$. 
Channel-Aware MGroup Selection

- The BS selects MGroup $i^*$, which has the maximum value of the normalized relative channel condition, for service in each MAC frame.

- To implement the channel-aware MGroup selection, the BS should have the knowledge of the channel state information (CSI) of each MGroup member which is sent through the uplink channel.

- Based on the CSI of each MGroup member, a preference metric vector is obtained, $X = [X_1, X_2, \cdots, X_M]$ and updated at the beginning of each frame.

- The BS selects the MGroup with the largest value of preference metric and allocates the corresponding transmission bursts to this Mgroup.
Cooperative Multicast Transmission

- A two-phase transmission scheme is used to efficiently multicast data in the downlink transmissions, where a downlink burst is divided into two phases.
- In Phase I with time duration $T_1(i)$, the BS multicasts data to all group members of $MGroup_i$ at a high data rate of $R_1(i)$ such that only a certain portion of group members in $MGroup_i$ can successfully decode the data.
- In Phase II, the members which have received the data transmit it to the ones which haven't received with $R_2(i)$ such that $R_1(i) \times T_1(i) = R_2(i) \times T_1(i)$.
- These rates are determined based on long term channel conditions and not on instantaneous conditions.
- It is possible to extend the two channel-phase transmissions to $m$-Phase transmissions ($m > 2$). However, a large $m$ involves more parameters and computation overhead.
Cooperative Multicast Transmission

(a) DL Burst # $i(TS_i)$

Phase-1 ($R^1_i$) | Phase-2 ($R^2_i$)

(b) BS does the transmission;
SSs with Good channel conditions;

(c) SS does the transmission;
SSs with Bad channel conditions.
Service Probability

- Service probability is defined as the probability that an MGroup is selected for service in a MAC frame.
- For the random MGroup selection, each MGroup is served by a pre-defined probability.
- For the channel-aware MGroup selection, the MGroup with the largest normalized relative channel condition is selected.

\[ \pi_i = Pr(X_i = \max(X_1, X_2, ..., X_M)) \]
Coverage Ratio

- It is defined as the percentage of group members that can support $R_1(i)$.

- $C = 50\%$ means that the BS transmits at the rate of $R_1(i)$ such that on average half of the group members in $MGroup_i$ can receive the data successfully in Phase I, and $R_2$ $i$ should be set in such a way that the remaining half of group members can successfully receive the same data in Phase II.
Throughput Analysis

- The probability that a group member in MGroup \( i \), \( SS_{i,j} \), can successfully receive the data in Phase I, is given by-

\[
Pr \left( E_{i,j}^1 \geq (2^{R_i^1} - 1)N_0 \right) = e^{-((2^{R_i^1} - 1)N_0)/E_{i,j}B}
\]

where \( E_{i}(i,j) \) is the received signal power of \( SS_{i,j} \) in Phase I, and \( N_0 \) is the white Gaussian noise level.

- If \( SS_{i,j} \) fails to receive the data in Phase I, it is still possible to successfully receive data in Phase II. Let \( E_{2}(i,j) \) be the received signal power of \( SS_{i,j} \) in Phase II, and \( Pr(G_g(i)) \) be the probability that \( G_g(i) \) is the set of cooperative transmitters in Phase II. Thus, the probability that \( SS_{i,j} \) can successfully receive the data in Phase II is given by-

\[
Pr \left( E_{i,j}^2 \geq (2^{R_i^2} - 1)N_0 \right) = \sum_{G_g \subseteq C_{i,j}} Pr(G_g) Pr \left( E_{i,j}^2 \geq (2^{R_i^2} - 1)N_0 | G_g \right)
\]
Throughput Analysis

- The group throughput achieved by MGroup $i$, which is the summation of the throughput of all group members in Mgroup $i$, is given by

$$Th_{i}^{CMS} = \sum_{j=1}^{N_{i}} Th_{i,j}^{CMS}$$

- The network throughput, which is the total throughput of all MGroups in the network, is given by

$$Th^{CMS} = \sum_{i=1}^{M} Th_{i}^{CMS}$$
Extreme Case

- There could be a case where none of the group members can support the data rate $R_1(i)$.

- The probability of such case is studied analytically and the probability comes out to be less than $10^{-11}$.

- Therefore, the impact of the extreme cases on the throughput is negligible.
Simulation Results

- The performance of the proposed multicast scheduling scheme (denoted as CMS) is compared with the scheme specified in 3GPP (denoted as Conserve) by extensive simulations with Matlab.
- The IEEE 802.16 network is composed of one BS and 50 SSs. SSs are randomly distributed in the coverage area of the BS, which is a circle centered at the BS with a radius of 8 km.
- Rayleigh flat fading channel described is applied.
- There are 10 MGroups in the system and each group includes 20 members which are randomly selected from the 50 SSs.
- The simulation is repeated 50 times with different random seeds and calculate the average value.
Throughput Performance

![Throughput Performance Graph](image)
Throughput Performance
Throughput Performance with AMC
Throughput Analysis with AMC
Service Probability

![Graph showing service probability for different indices of MGroups. The graph compares CMS_C (Sim) and CMS_C (Ana) with a nearly flat line indicating similar service probabilities across indices.]
Power Consumption

[Graph showing the relationship between normalized power consumption and the number of group members in each MGroup.]

- Conserve
- CMS
- CMS_C

The number of group members in each MGroup

Normalized power consumption
Impact of Coverage Ratio
Conclusion

- A cooperative multicast scheduling scheme for multimedia services is proposed in IEEE 802.16 networks.

- By using two-phase transmissions to exploit the spatial diversity of multiple users in the multicast scenario and the channel-aware MGroup selection mechanism, the proposed scheme can achieve high throughput and maintain good fairness performance.
Limitations

- The impact of the mobility and service differentiation in multicast services is not considered.

- The throughput fluctuates for some of the group members and thus all the users do not get equal quality of service.

- Power Consumption increases with increase in number of group members.
References

- A Cooperative Multicast Scheduling Scheme for Multimedia Services in IEEE 802.16 Networks by Fen Hou, Student Member, IEEE, Lin X Cai, Student Member, IEEE, Pin-Han Ho, Member, IEEE, Xuemin (Sherman) Shen, Fellow, IEEE, and Junshan Zhang, Member, IEEE.

- Scheduling in Multihop WiMAX Networks, Debalina Ghosh. Ashima Gupta, Prasant Mohapatra, Department of Computer Science, University of California.
Thank You