New approaches for Relay selection in IEEE 802.16 Mobile Multi-hop Relay Networks ⋆

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Abstract. The IEEE 802.16 mobile multi-hop relay (MMR) task group 'j' (TGj) has recently introduced the multi-hop relaying concept in the IEEE 802.16 WirelessMAN, wherein a newly introduced *relay station (RS)* is expected to increase the network performance. In this context, we consider the problem of path selection where several RSs might exist between the base station (so called, MR-BS) and the mobile station (MS). We propose a backward compatible signaling mechanism and a path selection algorithm based on the expected link throughput (ELT). To the best of our knowledge, this is the first contribution that presents path selection algorithm in the IEEE 802.16 networks. Performance of the proposed scheme is compared with shortest hop and no-relay schemes and we show our schemes significantly improves the performance in terms of throughput and latency.

1 INTRODUCTION

The existing IEEE 802.16 [1,2] family of standards popularly known as WiMax focuses on providing a broadband wireless access in the metropolitan area network. Although, initially developed for a *point-to-multipoint (PMP)* single hop communication, multi-hop relaying is recently receiving greater attention in the IEEE 802.16 working group (WG), specifically after the commencement of the IEEE 802.16j MMR task group (TG). The main objective of this TG is to introduce a relay station dedicated for relaying data between MR-BS and MS so as to enhance the network coverage and the throughput. Fig. 1 shows the topology of the IEEE 802.16j network. MR-BS is a fixed base station connected to the access network. RSs in general are divided into fixed RS (FRS) installed in a fixed location, nomadic RS (NRS) installed for a temporary duration where events occur and mobile RS (MRS) installed in vehicle such as bus, trains etc. RS can be deployed either in planned or unplanned manner due to which several access links are offered to MSs. Referring to Fig. 1, MS2 can be served either by NRS or FRS through either of three unique paths (MR-BS→FRS1→FRS2, MR-BS→FRS1→NRS and MR-BS→NRS). In such case, at least one *path* from

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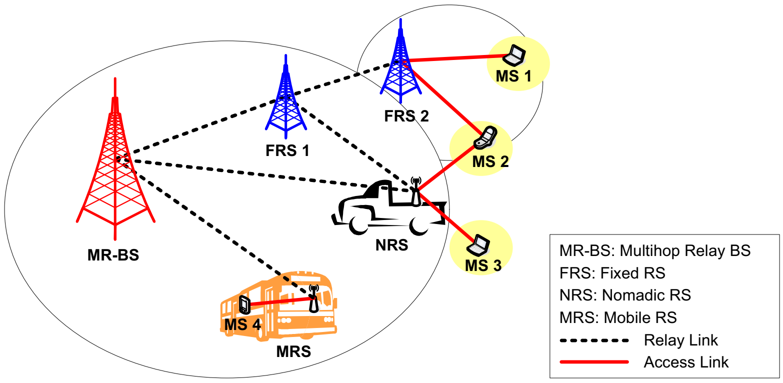


Fig. 1. The IEEE 802.16j Network Topology with several paths and RSs available for relaying between MR-BS and MSs

MR-BS to MS (hereafter just called path) must be selected to forward data packets. For this purpose a naive way would be to let MR-BS randomly choose a path or let all RSs forward the data. However, relaying by all or randomly selected RS might be prohibitive in terms of performance and resource utilization [3]. For example, a relay serving a large number of users might become a bottleneck eventually dropping the packets and enforcing retransmissions. This leads to unnecessary consumption of bandwidth, higher latency and poor QoS. In this paper, we present a centralized path selection algorithm in the medium access control sub-layer (MAC) of the MR-BS. Although there can be distributed approaches, they require RSs of higher complexity with similar capability to that of MR-BS. We assume RSs that are simple and controlled by MR-BS (e.g., for scheduling and resource allocations) such that the installation cost is minimum. We propose a selection metric named expected link throughput (ELT) based on the bandwidth availability and the data-rate to maximize the achievable throughput.

For this purpose, we introduced a new signaling features in the MR-BS and RS during the network entry of the MS and when normal communication is in progress. However, no extra operations are applied on the MS enabled with the legacy protocols [1, 2] for backward compatibility [4]. For the performance analysis we extended IEEE 802.16 implementation on the Qualnet simulator version 3.9.5 to support multi-hop relaying. We compare our path selection scheme with single-hop no relays and shortest hop path. We show that the multi-hop schemes and a better path selection protocol enhances throughput with comparable delay.

2 RELATED WORK

We review path selection protocols by segregating (1) RS selection algorithm and 2) related signaling schemes. Since the multi-hop concept is newly established in the IEEE 802.16 networks, we review the closely related RS selection algorithms from the cellular networks. Next, we will briefly summarize the signaling mechanisms for path selection protocols discussed in the current IEEE 802.16j meetings.

[5,6] presents the relay selection in cellular networks with peer-to-peer relaying. They propose selection algorithms based on the distance, path-loss [5] and the signal interference to noise ratio (SINR) [6]. The coverage improvements obtained due to proper RS selection and transmit power selection is presented in this paper. They also show the throughput improvement due to relaying with best performance in order of SINR, path-loss and distance. The algorithms presented in these papers are centralized and does not consider any specific signaling mechanism. The evaluation is performed only for the two-hop relaying.

Several path management schemes are being discussed and presented as the part of contributions in the IEEE 802.16 TGj meetings. Related contributions [7–10] propose centralized and distributed signaling mechanisms for the routing path creation, management and data forwarding. [8,9] considers routing path to be established either during the network entry of RS or MS. RS maintains the routing table such that it can forward the packets accordingly. However, these schemes does not consider strategies for selecting appropriate RSs along the path while more than one path exists. In contrary, our proposed scheme is compatible to support such management and forwarding protocols.

Several protocols are proposed in the IEEE 802.16j during the time when this paper is being written. Most of those proposals are not presented with the evaluation and are accepted with the consensus in the IEEE 802.16j meeting for considering it as a standard. While the process of standardization is long, we propose much simpler RS devices that can be implemented with very small changes in the infrastructure already existing for deployment.

3 PRELIMINARIES

In this section we describe MAC management messages and the connection identifiers used in our proposed path selection scheme.

3.1 Connection Identifiers (CID)

In the IEEE 802.16 MAC, CIDs are used to identify the data flow between MR-BS and MS. The 16 bit CID is allocated by the MR-BS and is included in the generic MAC header of both management and data messages. Different classes of CIDs are described in [1]. *Basic CID* is used with control and management messages and to identify MS (instead of 48-bit MAC address). The *Initial ranging CID* is temporarily used by MS during the network entry. The *Broadcast CID* is used with broadcast MAC management messages. *Transport CID* identifies a data flow between MR-BS and MS.

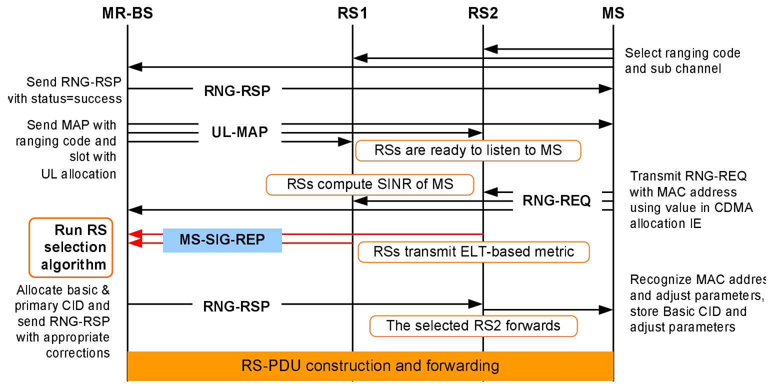


Fig. 2. The example for the proposed CDMA initial ranging during the network entry of MS. RS2 is selected as an access RS. (MS assumed in-coverage of MR-BS and RSs).

3.2 MAC Management Messages

The description of the following MAC management messages suffices the understanding of our proposed schemes:

- *DCD and UCD* are downlink and uplink channel descriptors generated by the MR-BS that consists of channel information and burst profiles.
- *Downlink MAP (DL-MAP)* and *Uplink MAP (UL-MAP)* describes the bandwidth allocations for downlink and uplink transmissions respectively, with the time offsets for all stations to transmit data. These messages are transmitted periodically by the MR-BS using Broadcast CID.
- *Range Request (RNG-REQ)* and *Range Response (RNG-RSP)* messages are used for ranging operation. Prior is transmitted by MS to request appropriate transmit power corrections, while the later is replied by MR-BS with needed adjustment (e.g. time, power etc).
- The *Report Request (REP-REQ*) is sent by MR-BS to achieve the channel measurement report from MS. In its response, MS replies with the *Report Response (REP-RSP)*.
- The proposed control message *Mobile Station Signal Report MS-SIG-REP* is used for (1) holding the ELT metric of each RS in path and (2) to signal MR-BS for running the path selection alogrithm.

4 PROPOSED SCHEMES

In this section, we describe our proposed signaling scheme, our proposed path selection metric and algorithm for path selection. We assume that the network topology is known to the MR-BS prior to running the path selection. All RSs are centrally controlled including their resources such as bandwidth and scheduling etc.

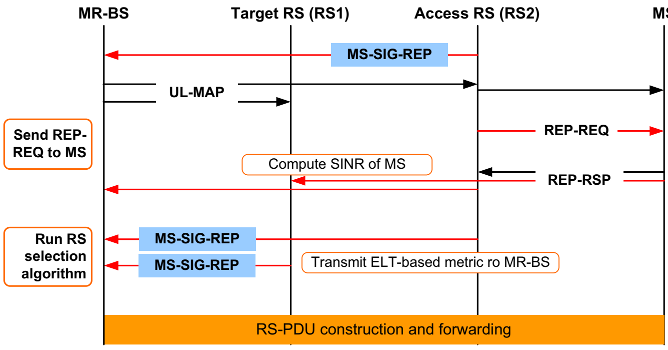


Fig. 3. The proposed intra-BS handover for RS path selection signaling (Target RS1 with better signal is selected in place of access RS2).

4.1 RS Selection Signaling

The main purpose of the signaling mechanism is to enrich the MR-BS with the path information and their corresponding metrics. The path selection is performed in two situations. First, during initial ranging when the MS joins the network and second, if the MS needs to switch RS (so called intra-BS handover).

In the legacy protocol, the initial ranging is performed for adjusting the transmission parameters of the MS. We embed our signaling scheme during this process to perform path selection as illustrated in Fig. 2. First MS scans the periodically broadcasted MAC management messages such as DCD, UCD, DL-MAP, UL-MAP and achieves synchronization. MS then decodes the initial ranging contention period and transmit the randomly generated ranging code. If the signal quality from MS or forwarding RS is good, MR-BS transmits RNG-RSP with success status. Otherwise MS restarts ranging or scan for the new MR-BS if the status is continue or abort, respectively. In the next step upon success, MR-BS includes the bandwidth allocation and the time offset for the MS to send the RNG-REQ message in the following UL-MAP. In our proposed scheme, RSs learn about this timing from the same UL-MAP and prepare to measure the signal quality. RSs upon hearing RNG-REQ construct a proposed MS-SIG-REP report with the MS MAC address (included in the RNG-REQ) and the corresponding ELT metric. The ELT metric is computed at each upstream RS if there is several RSs in path and piggy-backed with the report until it reaches to the MR-BS. Finally, MR-BS collects the path and metric information to execute path selection algorithm.

The signaling for path selection during the intra-BS handover is shown in Fig. 3. The RS that has been previously selected to serve MS (called access RS) continuously monitors the signal quality. If it degrades below the certain threshold, the access RS sends REP-REQ to the MS and notifies MR-BS about the handover by transmitting MS-SIG-REP. MR-BS includes the time offset for the expected REP-RSP and the Basic CID of MS in the next UL-MAP. As in the previous case, RSs prepare to measure signal quality while receiving REP-RSP

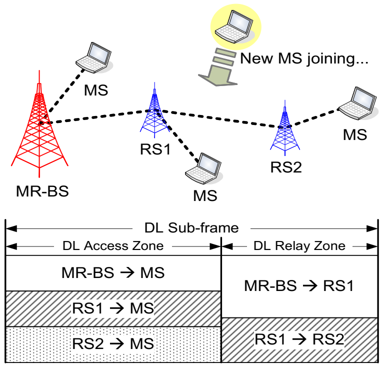


Fig. 4. Example topology and DL sub-frame allocations.

from MS. This process is followed by constructing and forwarding MS-SIG-REP to the MR-BS. Note that in the IEEE 802.16j topology it is possible that MS is outside the coverage of MR-BS. To support such scenarios RSs might forward the control and management messages.

4.2 Path Selection Algorithm

From the signaling mechanism, MR-BS receives the MS-SIG-REP from the several link-disjoint paths containing the ELT metrics of both relay and access links. MR-BS collects these messages for a predefined time t seconds after the first message is received. Each RS computes ELT (T_{exp}) of the link between itself and its downstream node as shown in eq. 1.

$$T_{exp}(j) = BW_{avail}(i) \times Data\_rate(j) \quad (1)$$

where, BW_{avail}(i) is the available bandwidth of the i^{th} relay node and the Data_rate(j) is the data-rate on link j supported by the i^{th} RS w.r.t. the received signal to noise ratio (SNR). The available bandwidth is the product of the number of slots and the sub-channel over the downlink subframe. The lowest threshold of the SNR required for a successful communication according to the given modulation scheme is according to the Table. 1. The example for the intuition of the path selection based on expected bandwidth is depicted in Fig. 4. We consider a frame structure in [11], in which the access and relay zones are defined as a portion of the frame used for MR-BS/RS to MS and RS transmissions respectively. In this figure, the area filled with diagonal line is the allocated bandwidth for RS1, and the dotted area is for RS2. Rest is allocated to MR-BS itself. Areas represent the maximum bandwidth for each RS which is used for delivering data to MSs. Available bandwidth is amount left after reducing the current used bandwidth to the total allocated bandwidth. Assuming a new MS joins the network, RSs will require additional bandwidth, thus the RS having more available bandwidth might offer better performance.

Table 1. PHY throughput VS SNR for DL PUSC [12]

Modulation/ code rate	Max. PHY throughput (Mbit/s)	SNR@ 0.01 CBLER (dB)	Cell range(m) with fade margin
QPSK-1/2	7.14	6.0	512
QPSK-3/4	10.71	9.2	421
16-QAM-1/2	14.28	10.3	392
16-QAM-3/4	21.42	14.9	290
64-QAM-2/3	28.56	19.0	222
64-QAM-3/4	32.13	21.2	192

In the path selection scheme, MR-BS enumerate all the received candidate paths $(p_1..p_n)$, where n is the number of disjoint paths. For each path we find the minimum ELT (T_{min}). The minimum ELT for a i^{th} path p_i is denoted by $T_{min}(i)$. Finally we select a path (p_{sel}) with the maximum among the minimum $T_{min}(i)$ as shown in eq. 2.

$$p_{sel} = \underset{n}{\text{argmax}}\{T_{min}(1), T_{min}(2), ...T_{min}(n)\} \tag{2}$$

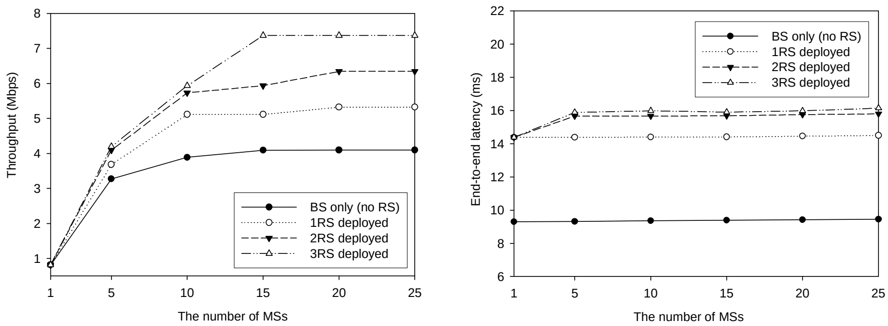
In other words, p_{sel} is the path that has the highest throughput. Thus, our proposed scheme selects a path with the maximum achievable throughput by eliminating the bottleneck links.

5 Performance Evaluation

We now present the results based on the performance evaluation conducted in the Qualnet simulator version 3.9.5. For doing so, we implemented RS features for forwarding the data in the IEEE 802.16 library.

5.1 Simulation Environment

First, we simulated two-hop relaying where only one RS is present between the MR-BS and MS. 3 RSs are placed uniformly about 120 degree apart and 25 MSs are randomly distributed. In the second part, we placed the 6 RSs linearly for observing the performance with more number of hops. In the third part, we randomly distributed 8 RS and placed one MS to compare our scheme with the shortest hop path selection. The CBR traffic is generated in MR-BS and one connection to each MS is established. The transmit power of each node is 15dB and we use 2-ray ground pathloss model. The frame size is fixed at 20ms, divided into 10ms for downlink and uplink. A downlink frame is further divided for MR-BS/RS to transmit towards the downlink. Since the frame size is fixed, downlink duration for each RS is reduced with increasing hops. Following



(a) (b)

Fig. 5. Average throughput and end-to-end latency in 2-hop topology

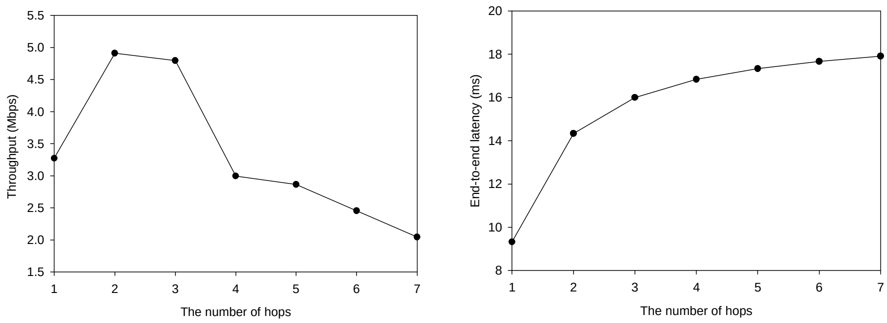
physical parameters as shown in Table. 1 are used to calculate the achievable PHY throughput corresponding to the received SNR [12].

Throughput is defined as a ratio of the total number of bytes received to total simulation time (50ms). Average end-to-end latency is the time required for each packet to reach MS from the MR-BS. The delivery ratio is the ratio of received number of packets in all MSs to the total number of packets sent.

5.2 Simulation Results

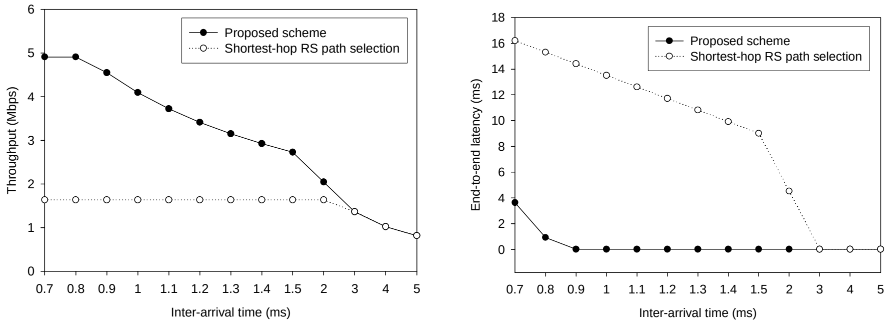
Fig. 5(a) shows the average throughput as the number of MS increases. The no-relaying case shows very low throughput due to low rate than the multi-hop RS topology. As the number of RS is increased, throughput also increases. This means, more RSs participate between two end points. For the fixed number of RS, throughput saturates to the maximum level with the increasing number of connections. Even though the physical data-rate used for one-hop is high (20Mbps), we observe that the maximum application layer throughput is 7Mbps due to the MAC overhead. The end-to-end latency for each packet is slightly affected when the relay is added. The result is shown in Fig. 5(b). The latency is observed even with no RS due to the frame gap between downlink and uplink. In our scheme, latency increases more because of the delayed frame allocation for RS to MS than from BS to MS. The average latency remains almost the same regardless of the number of RSs increased in the deployment region.

Now we present the results for the linear topology. From Fig. 6(a) we see that the throughput nearly doubles from no-relay to one-hop case. As in the previous case, this is due to the use of higher data-rate. However, the benefit achieved from the higher rate while increasing the hop is reduced due to sub-divided frames for each RS. Thus, as the number of hops increase, throughput reduces. Additionally MAC overhead also reduces the throughput at each hop. Again, from Fig. 6(b), the delay also increases with the number of hops. This is due to extra processing required at each RS. The per packet end-to-end latency



(a) (b)

Fig. 6. Average throughput and end-to-end latency with 1 to 5 RSs placed linearly between MR-BS and MS



(a) (b)

Fig. 7. Average throughput and end-to-end latency vs inter-arrival time with RSs randomly distributed between MR-BS and MS .

increases slowly because all RS transmit the packet in the same downlink frame consecutively.

In this third set of simulation, we present the throughput and latency comparison of our path selection scheme with the shortest hop-relay selection, in which shortest-hop relay path is selected between MR-BS and RS. We decrease the inter-arrival time from 5ms to 0.7ms to increase the traffic in the network. From Fig. 7(a), we observe almost 50% improvement in the throughput of our proposed scheme. The shortest hop relay uses lower data rate due to longer hop distance between the MR-BS to RS and RS to MS. The low average end-to-end latency as shown in Fig. 7(b) is due to packet loss, which shows around 90% improvement by our scheme. Therefore we show that the our path selection strategy shows better performance.

6 Conclusion

We have presented efficient path selection signaling and algorithm for the IEEE 802.16 based multi-hop networks. The proposed algorithm uses unique selection metric that effectively selects high throughput path. We carefully considered reuse of messages and operations already present in the existing standards for backward compatibility. The performance results show the 50% increase in throughput with 90% drop in the average latency with the ELT based path selection compared to that of shortest-hop.

Many issues in IEEE 802.16 based multi-hop networks are open both in PHY and MAC layer. Critical issues such as multi-hop frame structure, scheduling mechanism, support for QoS and many other requirements are under development. In future, we will consider more extensive simulation to compare our scheme with other RS selection schemes.

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