Capacity Analysis for Multi-hop WiMAX Relay

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Abstract: Wireless relay has been proposed as the solution to extend the coverage of a single base station. In this paper, capacity degradation due to multi-hop relay has been analyzed in a WiMAX relay system. It has been shown that the achievable user access capacity decreases dramatically with the increase of hop number. Moreover, using higher-level modulation or higher turbo-coding rate can significantly enhance the achievable access capacity at each hop. In the end, several recommendations have been presented for the feasible application of a multi-hop WiMAX relay system.

Keywords: WiMAX, multi-hop relay, coverage extension.

I. Introduction

WiMAX system has been widely accepted as the next-generation high-speed wireless communication system for future broadband services due to the high capacity, large coverage, and strong QoS support it can provide. All kinds of advanced technologies, such as orthogonal frequency division multiplexing, adaptive modulation and coding, adaptive antenna array, space-time coding, and even multiple input and multiple output, have been applied in such a system to combat multi-path fading and to improve system performance [1]-[3]. It has been reported that present WiMAX system is able to support a transmission range up to 31 miles, and its data rate can be up to 75Mbps per channel on both the uplink and downlink [2]. However, the coverage of a WiMAX base station can be very small in non-line-of-sight (NLOS) environment due to the high frequency band applied and the high data rate required by WiMAX systems [4]. Because wireless relay can be used to extend the coverage or enhance the capacity of a single base station, it has become one of the hot topics in WiMAX standardization after the finalization of IEEE 802.16e. The purpose of this paper is to evaluate the feasibility of multi-hop relay for coverage extension in the WiMAX network.

II. Multi-hop relay scenario for coverage extension

The analyzed scenario is described in Fig.1. As shown in the figure, the scenario consists of a single base station (BS) and several relay stations (RSs). The whole frame duration of RSs can be divided into two parts. In one part of frame duration, RS works as a base station serving local subscribers to aggregate local traffic. While in the other frame part, RS communicates with neighboring BS or RS for traffic relaying. In the upstream, all the local traffic from RS is first relayed to central BS, hop by hop, and then transported to wireless access network controller (WANC). In the downstream, traffic from WANC gets to BS at first and then hops to the destined RS. Compared with the traditional scenario where each BS is connected to WANC by a wire line, multi-hop relay can significantly extends the coverage of a single BS without any extra wire-line connection. Hence the deployment cost will be significantly lower down. However, due to that each RS uses one part of its frame

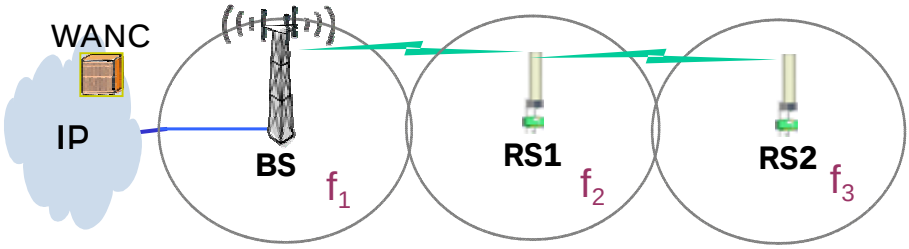

Fig. 1 Multi-hop relay scenario for coverage extension

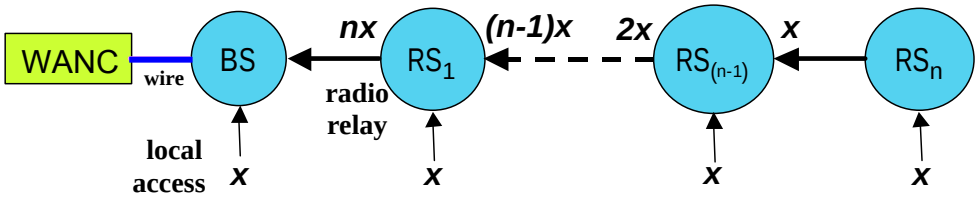

Fig. 2 Traffic amount in wireless relay links

duration for local traffic transportation and neighboring traffic relaying, user access capacity of each RS or BS is inevitably reduced. Although the high capacity of WiMAX system can greatly alleviate this reduction, a careful hop-number design and the application of high-efficiency modulation and coding are still necessary in order to provide subscribers a satisfied performance. The rest of this paper focuses on the analysis of the access-capacity reduction taking into account the hop number as well as the different modulation and coding schemes.

III. Performance analysis

To simplify the analysis, we have assumed that:

- Each BS and RS has the same transmission power and antenna height (30m).
- Each BS and RS occupies the same channel bandwidth.
- Subscriber is uniformly distributed in each cell served by a BS or RS.
- All the RSs use the same modulation and coding schemes for traffic relaying.
- Cost-231 Hata model is used for NLOS environment modeling [5]-[6].

Therefore, each BS and RS has the same radio coverage, and the amount of local access traffic processed by each RS or BS is also the same. Let the local traffic from each cell be denoted by x and the hop number denoted by n, the detailed traffic amount transported at each hop could be calculated as shown in Fig.2.

From Fig.2, it can be easily found that the amount of traffic to relay increases dramatically with the hop number, and the bottleneck in multi-hop relaying lies in the first relay station RS_1. Assumed that the total traffic transported in each frame duration is 1, the normalized achievable access traffic x_{max} can be expressed as

$$x_{\max} = \frac{\alpha}{2n-1+\alpha} \qquad (1)$$

where α is the ratio between spectral efficiency of the radio relay link and the average spectral efficiency of local access links. In this paper, only spectral efficiency caused by modulation and coding is considered. For example, the spectral efficiency is equal to 1 for QPSK modulation

Table-1 Required SNR for different modulation and coding schemes

Radio Relay Link	Min. SNR	α
QPSK-½:	9.4 dB	0.4634
QPSK-¾:	11.2 dB	0.6951
16QAM-½:	16.4 dB	0.9268
16QAM-¾:	18.2 dB	1.3902
64QAM-⅔:	22.7 dB	1.8536
64QAM-¾:	24.4 dB	2.0853

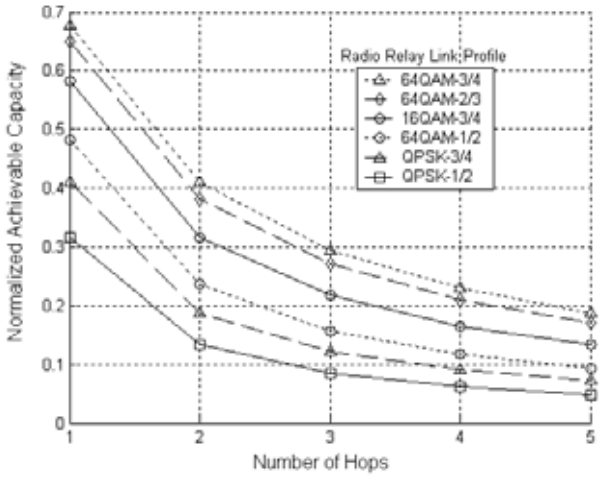

Fig. 3 Normalized achievable capacity versus number of hops for different modulation and coding schemes in radio relay link.

and 1/2 turbo coding, and 4.5 for 64QAM and 3/4 turbo coding. According to the required signal-to-noise ratio (SNR) for different modulation and coding schemes specified in IEEE 802.16 (as shown in Table-1 [7]), the average spectral efficiency for user access links is 2.158 if subscribers are uniformly distributed in the whole cell area and the BS or RS is 30 meters high. The corresponding values of α are also computed and listed in Table-1 when different modulation and coding schemes are applied in the radio relay link.

Fig. 3 shows the normalized achievable user access capacity as a function of the hop number when different modulation and coding schemes are applied in the radio relay link. With the increase of hop number, the achievable user access capacity decreases dramatically. For example, when 64QAM-3/4 is used, 68% of the whole capacity can be used for user access in 1-hop case while only 29% of the whole capacity can be used for user access in 3-hop case. Also, using higher-level modulation scheme or higher turbo-coding rate can significantly enhance the access capacity. In the 2-hop case, achievable access capacity can reach 41% for 64QAM-3/4 radio relay link, and only 14% for QPSK-1/2 relay link. Therefore, although multi-hop relay may be applicable, a hop number less than 3 is recommended and the link budge of relay link between BS and RS (or between RS and RS) should be carefully planed in order that advanced 64QAM-3/4

can be applied.

IV. Conclusions

Wireless relay has been proposed as a solution to extend the coverage of a single base station. This paper has analyzed the reduction of user access capacity due to multi-hop relay when it is used for coverage extension in a WiMAX system. It has been shown that with the increase of hop number, the achievable user access capacity decreases dramatically. Also, using higher-level modulation scheme or higher turbo-coding rate can significantly enhance the achievable access capacity. As a result, for the feasible application of a multi-hop WiMAX relay system, it is recommended that: (i) radio processing of relay station should be enhanced to support 64QAM-3/4 in the radio relay link; (ii) hop number should not be larger than 3 in order that there's enough capacity left for local user access.

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