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# Investigation on uplink collaborative contention-based bandwidth request for WiMAX three hop relay networks

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ABSTRACT

This paper suggests a collaborative contention bandwidth request (BR) mechanism for worldwide interoperability for microwave access (WiMAX) three-hop relay networks. By complimenting message and code BR in three hops of a link, the proposed framework enables low block error rate (BLER), packet dropping and signaling overhead while preserving the connection throughput and access delay requirements of best effort (BE) services. With three hops between base station (BS) and mobile station (MS) via relay station 1 (RS1) and relay station 2 (RS2), there take place eight possible BR mechanisms with message and code BR. Among eight BR mechanisms, message-message-code (MMC) BR performs better with message dominant BR and code-message-code (CMC) BR performs better with code dominant BR. Further, with CMC BR, the BLER is reduced by 5.88%, packet dropping is reduced by 8.68%, medium access control (MAC) overhead is reduced by 7.6%, MAC wastage is reduced by 4.47%, connection delay is reduced by 28.30%, queuing delay is reduced by 8.65%, queue size is reduced by 15.25% and throughput is improved by 11.51% than MMC BR mechanism.



## 1. Introduction

Worldwide interoperability for microwave access (WiMAX) Multihop network has gained interest to provide broadband wireless connectivity to rural areas (Kuo-Chih and Tzu-Chi, 2009). Relay stations (RSs) with WiMAX multihop networks play a vital role for coverage extension (to overcome coverage hole and shadowing) and throughput enhancement (Wen-Hwa et al., 2011). However, these performance improvements with relay station have to be realized with good network planning in order to benefit both the network users and providers (Ismael and Yusof, 2010).

Relay in WiMAX network can be classified in two types namely transparent relay and non-transparent relay. The mobile stations (MSs) under the vicinity transparent relay station transmit the control information (ranging and bandwidth request) through base station (BS) air interface and communicate the data through RSs. However, MSs with non-transparent relay convey both control and data signals through RS. In this paper, we consider non-transparent relay since we assume that MS is out of coverage from BS. With the aim of providing broadband wireless connectivity, the WiMAX multihop relay network must provide instantaneous bandwidth to the mobile users with high data rate and reduced connection or access delay (Bharathi, 2008). Recently, cooperative relays for spectrum sensing have been proposed by utilizing distributed space time coding for decode and forward systems (Yulong, 2012a, 2012b).

The main challenge with non-transparent relay is bandwidth request and grant mechanism. The straight forward solution to bandwidth request mechanism is to assign dedicated bandwidth or polling based bandwidth request. However, such mechanisms suffer from low spectral efficiency and complex frequency planning. Further, the network expansion is in need of additional bandwidth with contention free bandwidth request mechanism. Hence, the optimum solution to bandwidth request (BR) is through contention mechanism.

The contention BR mechanism with line of sight connectivity between MS and BS has been well defined in the literature (Qiang et al., 2010; Fallah et al., 2008; Chuck et al., 2010; Qiang and Ling, 2010; Esmailpour and Nasser, 2011; Liao and Yen, 2009; Staehle and Pries, 2007). The bandwidth request mechanisms for WiMAX networks are classified into two categories based on their physical layer. Accordingly, the WiMAX standard defines contention resolution with message bandwidth request when orthogonal frequency division multiplexing (OFDM) is the physical layer. Recently, orthogonal frequency division multiple access (OFDMA) based physical layer in WiMAX supports both message based and code division multiple access (CDMA) or code bandwidth request (Namsuk et al., 2010; Qi and Maode, 2011; Elmabruk and Irfan, 2010; Ruiqin Miao et al., 2010).

Although extending the message or code BR with single hop networks to multihop networks seems to be a straight forward

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solution, many issues with existing BR mechanisms are to be considered. There always exists a tradeoff between message based and code BR with single hop networks. The former suffers from low contention efficiency, high access delay amid low signaling overhead with increase in the number of stations. The latter performs well with high contention efficiency, low access delay whereas the signaling overhead is very high when compared to message based bandwidth request. Further, the performance of code BR reduces with increase in the number of codes (with increase in the number of stations) allocated for BR.

Further, the number of hops in a network depends on the spectral efficiency, path loss exponent and average receive signal to noise ratio (SNR) of the network. The spectral efficiency reduces with increase in the number of hops and with reduction in path loss exponent and average receive SNR. Therefore, in this study, the number of hops is chosen as three so as to meet the optimum situation as in (Feng and Cimini, 2012; Marcin et al., 2004). The purpose of this paper is to suggest an optimum contention based BR mechanism for WiMAX three hop relay network by concatenating the message and code BR. The main objective is to derive maximum throughput and minimum connection delay with reduced signaling overhead from the proposed BR for resource allocation of best effort services.

The rest of the paper is organized as follows: the works related to bandwidth request with WiMAX relay network are discussed in Section 2. The problem definition is specified in Section 3 and the proposed collaborative bandwidth request mechanism over three hops is explained in Section 4. Modeling of code message code (CMC) bandwidth request mechanism is derived in Section 5. The performance evaluation of the collaborative bandwidth request mechanisms is discussed in Section 6 and concluding remarks are given in Section 7.

## 2. Related works

There has been several studies on resource management in multihop wireless networks, but most of them focused either on transparent relay based routing of data from MS to BS or polling BR with non-transparent relay nodes. There are very few methods with contention BR with relay networks but those methods were proposed as a tradeoff between throughput and delay with very high signaling overhead.

Kuo-Chih and Tzu-Chi (2010) have considered consecutive bandwidth request scheme (CBRS) to overcome collisions due to contention when bandwidth request by relay stations is made with contention based bandwidth request. Dusit et al. (2009) have considered relay centric radio resource management and formulated chance constrained assignment problem (CCAP) to optimize the amount of bandwidth reserved for relay station.

Zakhia and Kamal (2010) have presented the problem with placement of relay stations to preserve bandwidth in next generation wireless networks. Salem et al. (2010) have made modification over the distributed relay mode and proposed user based dynamic routing to reduce the feedback overhead. Sang-Wook and Dong-Ho (2008) have analyzed CDMA based bandwidth request for mobile multihop relay systems in terms of signaling cost and access delay.

Kim et al. (2009) suggested a hybrid radio resource management scheme for real time and non real time traffic that combines scheduling based multiple access (SMA), orthogonal resource hopping based multiple access (ORHMA) and window based virtual bandwidth multiple access (W-VBMA) scheme to reduce the overhead associated with relay networks. However, the authors have not considered the number of retransmission attempts and its effect on the signaling overhead.

Zih-Hong et al. (2007) have proposed a simple theoretical model to evaluate the signaling cost of the centralized scheduling in IEEE 802.16 mesh networks and identified the factors affecting the signaling cost. The advantage of message based mechanism over CDMA based mechanism in terms of signaling overhead is given in (Sung-Min and Jae-Hyun, 2010). Sung-Min and Jae-Hyun (2010) have adopted message based mechanism for short message services in single hop WiMAX systems by adopting piggy back scheme with periodic control message for bandwidth request.

Although many techniques have been proposed to increase the throughput and extend the coverage with relay based networks, the target performance is achieved with either additional resource (bandwidth) at RS or with extra signaling overhead (Wang and Wang, 2008; Yuehong et al., 2008; Ardian et al., 2009). Nevertheless, no methods have exploited the combined performance of message and code BR for multihop WiMAX relay networks. Further, no works have been proposed to improve the performance of WiMAX relay networks by means of contention based bandwidth request with reduced signaling overhead. Therefore, in this paper, a heuristic contention based bandwidth request mechanisms is proposed to improve the performance with reduced signaling overhead.

The resource management and network topology (tree type) model with WiMAX relay networks presented in this paper is made heuristic with combined message and code BR under varying traffic load and number of contending stations. The proposed BR functionality at RS will be very helpful for immediate deployment at rural areas where coverage expansion is essential without much frequency planning.

## 3. Problem definition

An efficient design of contention resolution improves the probability of transmission but the probability of success in WiMAX multihop relay network depends only if bandwidth request is successful on all hops. With increase in the probability of successful transmission, the contention efficiency and hence the throughput also increase with reduced access delay. The contention efficiency with multihop network is defined as the ratio of number of slots with successful bandwidth request at all the hops to the total number of slots allocated for executing the bandwidth request. Further, the ratio between the number of ranging slots allocated for bandwidth request and the total number of data slots in the uplink affect the network performance.

The contention resolution with code-based bandwidth request suffers from transmission failure due to static detection threshold at the RSs. The detection threshold has to be chosen as an optimum value since larger value of detection threshold increases the probability of miss and smaller value increases the probability of false detection. However, the detection threshold at the RS is fixed and RSs were not in a position to adjust the detection threshold according to the current channel conditions. This motivated in combining the code and message BR with WiMAX multihop relay. The message and code bandwidth request mechanisms as unified request mechanism is an advantageous one when they are carried out at appropriate hops.

## 4. Proposed collaborative bandwidth request mechanisms for WiMAX three hop relay network

In WiMAX relay network, the stations of interest are base station (BS), relay stations (RSs) and mobile stations (MSs) as shown in Fig. 1. Further, in multihop network, the MS may not be in line of sight with the BS and involve multiple hops to establish the connectivity. One or more RS are required to establish the connectivity between BS and

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