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Rate Adaptation for Cooperative Relaying in Next Generation Mobile WiMAX Networks

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Abstract—**Distributed space-time coding (DSTC) is an important physical (PHY) layer technique to enable cooperative relaying in wireless networks. DSTC exploits spatial diversity gain and achieves a higher end-to-end throughput performance compared to direct transmission and single relay cooperation. In particular, randomized distributed space-time coding(R-DSTC), a novel variation of DSTC, further enhances the performance of conventional DSTC in a mobile environment due to its decentralized relay recruitment. This paper presents a medium access control (MAC) protocol (called CoopMAX) for WORLDWIDE Interoperability for Microwave Access (WiMAX) systems to provide cooperative relaying with DSTC and R-DSTC techniques by use of fixed and mobile relays. CoopMAX explores a joint PHY layer and MAC layer optimization for rate adaptation. The efficiency of CoopMAX is investigated and simulation results are also provided.**

Keywords: **WiMAX, DSTC, MMR, MAC**

I. INTRODUCTION

Over a past decade, WiMAX system has attracted great research attention [1]. The latest IEEE 802.16m WiMAX standard aims at developing advanced techniques to support higher system capacity and extended cell cover- age. In order to provide high throughput for subscribers at the cell edge, the concept of Mobile Multi-hop Relaying (MMR) [2] (defines a framework for multi-hop transmission) may be suggested. The functionalities of RS in a WiMAX system include relaying the data packets as well as signaling messages [2], which can increase the end-to-end throughput, but suffers in a fading environment, where the RS may fail to decode the source signal and thus cannot deliver it to the destination. WiMAX allows multiple RSs, [2] coordinated using a distributed space-time code (DSTC) [3], to provide a higher spatial diversity gain. By selecting an optimal set of relays in a centralized manner, DSTC can outperform the direct transmission and single-RS cooperation schemes. However, DSTC performance is degraded in a mobile environment, where coordinating distributed relays becomes difficult. In contrast, Randomized Distributed Space-Time Coding(R-DSTC) [4] (a novel variation of DSTC) addresses the deficiencies of DSTC by using decentralized relay recruitment, and results in robust multi relay cooperation in a mobile environment.

PHY layer principles of DSTC and R-DSTC are examined in [3-4], an efficient MAC layer is desired to realize the anticipated performance gains in a network. A standard contribution [5] discusses DSTC based cooperative relaying in the context of next generation WiMAX networks, but an explicit protocol is not described and thus the impact of protocol overhead is not evaluated. In addition, only fixed RSs are employed in [6], which limits the attainable diversity gain.

The main contribution of this paper to establish a novelcross-layer design that exploits the PHY/MAC layer benefits of cooperative relaying in a WiMAX system. We propose a MAC layer protocol, called Cooperative WiMAX (CoopMAX), which is in compliance with WiMAX standards, to support both DSTC and R-DSTC based PHY layer. We allow the use of mobile subscribers and femto/ picocell BSs (fBSs/pBSs) as relays in our design.

2. WIMAX MAC LAYER DESIGN FOR R-DSTC CHANNEL ESTIMATION

In this section, a MAC layer protocol, called CoopMAX, is designed to incorporate both DSTC and R-DSTC based cooperative channel estimation. Channel estimation here refers to obtaining the channel statistics for the AL and RL. WiMAX channel statistics are measured in terms of average carrier to interference plus noise ratio (CINR). For both DSTC and R-DSTC, the obtained channel statistics are used by rate adaptation schemes to optimize data rates and the STC dimension over RL. In this section, we develop two channel estimation schemes. The first scheme called global channel estimation gathers the complete two-hop channel statistics for both AL and RL, while the second scheme is called limited channel estimation that simply measures the channel statistics of the direct link between the tSS and the BS.

A Global Channel Estimation: In this scheme, the channel statistics between a tSS and each potential helper (AL), and between helpers and the BS (RL), are periodically obtained. The global channel estimation is performed on all nodes (tSSs and helpers) through theproactive mode and passive mode as follows.

a) Proactive Mode: The proactive mode is triggered by the BS with a period depending on the speed of channel variation. In the IEEE 802.16e standard, a dedicated resource block, known as the sounding zone [1], is reserved for channel estimation. A sounding zone refers to several time/frequency slots in an OFDMA basedWiMAX frame and consists of a number of sounding bands. Each SS is assigned a specific sounding band to transmit a given sounding sequence that the BS can hear for channel measurement. This operation is called channel sounding. In WiMAX, each connection between a subscriber and the BS is identified by a connection ID (CID), which is assigned by the BS. Such CID assignment information is included in the uplink MAP (UL MAP) message in each frame and can be decoded by all nodes. Before channel sounding is initiated, each node in the system is first assigned a CID for sending sounding signals. In order to obtain the channel statistics for both hops, the BS periodically probes all nodes (helpers andtSS) by broadcasting these sounding CIDs in UL MAP over the downlink. Then, all nodes transmit their sounding waveforms associated with their CIDs in the sounding zone. Additionally, when channel sounding is performed, the BS instructs all nodes with relaying functionality to overhear the sounding signals from each other. Consequently, each node establishes a table that records the received CINR for the link between itself and every other node (tSSs, helpers and BS) in the system. In this table, all nodes are distinguished by their CIDs. According to [1], multiple nodes are allowed to generate and multiplex orthogonal sounding signals in a shared sounding band for bandwidth efficiency. Since WiMAX is based on time division duplex (TDD) technique, we assume the channel reciprocity occurs between helpers and tSS, and thus the received CINR at a tSS indicates the channel statistics for theAL (from that tSS to a helper).

Over the RL, the BS measures the sounding signals from all nodes and learns the channel statistics for the second hop. As specified in [1], the BS sends a channel information report request (REP-REQ) message to each node which then replies with a report response (REP-RSP) message. The REP-RSPmessage contains the measured CINR values corresponding to the connection IDs (CIDs) of the associated nodes. Therefore, the BS gathers the channel statistics for both ALand RL. Based upon the channel statistics, rate adaptation, which will be discussed in Section IV, is conducted to optimize the end-to-end transmission rate.The proactive mode is initiated in a periodic fashion, such that the BS can collect and update global channel statistics for each pair of nodes. However, this consumes dedicated bandwidth for channel sounding as well as REP-REQ/REPRSP handshaking. This may lead to a substantial overhead in a mobile network where the channel statistics vary frequently.

b) Passive Mode: As mentioned above, the proactive mode makes use of periodic channel sounding. Between two consecutive sounding zone allocations, the passive mode can be used to update the channel statistics over the AL and RL. Compared with channel sounding, the passive mode consumes much less dedicated bandwidth. Instead of using a sounding zone, over the AL, a tSSdecodes the WiMAX frame header to locate which time/frequency slots in the frame are used by its potential helpers to transmit signals. Thus, the tSS can dynamically monitor and update the channel statistics between itself and its potential helpers for the AL by use of channel reciprocity. Similarly, the ongoing traffic from the potential helpers are also captured by the BS over the relay link. Then, the BS can retrieve the latest channel condition of the AL from a tSS by reusing REP-REQ/REP-RSP handshaking as mentioned in proactive mode. Compared to a dedicated sounding zone, only marginal bandwidth is needed by such handshaking processing. However, the accuracy of the passive estimation depends on how frequently the helpers will transmit signals. If some idle-mode helpers only transmit data traffic in an intermittent manner, the BS and the tSS subscriber cannot continuously monitor the average channel statistics between itself and the helpers, leading to a reduced accuracy in the passive estimation.In a stationary environment, the overall overhead for the above channel estimation is acceptable since the global channel statistics are relatively stable. Thus, global channel estimation is applicable for both DSTC and R-DSTC techniques in a stationary scenario.

B. Limited Channel Estimation: In a mobile WiMAX system where the channel statistics change frequently, the global channel estimation can be very costly in terms of signaling load. Furthermore, the accuracy of the channel estimation degrades as mobile speeds increase. We expect that the performance of DSTC, which needs to identify a good set of helpers a priori, is degraded in a mobile scenario, where the BS is unable to track helpers quickly and accurately. However, with R-DSTC, the helpers self-select on-the-fly and hence the limited channel estimation scheme may suffice. In such an environment, we will assume that the locations of RSs are known and all other helpers are uniformly and randomly located in a WiMAX cell, and only the channel statistics between the tSS and the BS is obtained usingREP-REQ and REP-RSP messages as defined in [1].For both global and limited channel estimation, the channel measurements are sampled and averaged over multiple times to derive average channel statistics (e.g. average CINR). Based on the obtained average CINR, the BS chooses the optimal transmission parameters, including data rates over both hops and STC dimension.

3. RATE ADAPTATION

Rate adaptation adjusts the transmission parameters in such a manner that the end-to-end throughput is maximized based on the current channel statistics of the network acquired at the BS. In CoopMAX, the transmission parameters that we optimize over include transmission rates for AL and RL, along with the underlying STC dimension. For DSTC based cooperation, the designated set of helpers, denoted by HS, also need to be determined for each tSS. We assume a single cell WiMAX network is comprised of one BS, M1 RSs, M2fBSs/pBSs, and N SSs that are uniformly located in the cell. Thus, the number of potential helpers is at most M1 + M2 + N 1. We let r1 and r2 denote the allowable rates for the AL and RL,respectively, where (r1; r2) 2 fR1; : : : ; Rp; : : : ; RKr g withR1 << Rp << RKr , where Kr is the number of rate levels in WiMAX. We also denote L as the dimension ofthe underlying STC codeword, where L 2 fL1; L2; : : : LKLg, where KL is the number of available STC codes. Here KLdepends on complexity considerations. When L = 1, DSTC falls back to a single-helper cooperation, which is also evaluated in section V. The BS chooses the best combination of these parameters, denoted by S to optimize the end-to-endthroughput and delay, while maintaining an end-to-end packet error rate (PER) bounded by a threshold . For DSTC based cooperation, S = fr1; r2; L; HSg, while for R-DSTC based cooperation, S = fr1; r2; Lg. Table I lists all the parameters used. Based on the amount of channel statistics available, we will present two rate adaptation schemes for CoopMAX, called rate adaptation with global channel estimation and rate adaptation with limited channel estimation.

A. Rate Adaptation with Global Channel Estimation (RA-GC)

Assuming a global knowledge of channel statistics, the BS does an exhaustive search to find the optimum S that maximizes the end-to-end throughput as follows

$$S^* = \arg\max_{S} \left\{ 1/(\frac{1}{r_1} + \frac{1}{r_2 \times r_c}) \right\}, \ s.t. \quad P_p(S), \le \gamma,$$

where Pp(S) denotes the end-to-end PER corresponding to S and rc is the STC code rate. The calculation of Pp(S) for DSTC and R-DSTC are carried out by simulations as formulated in [6].

B. Rate Adaptation with Limited Channel Estimation (RA-LC)

This type of rate adaptation is preferred in a mobile environment where the global knowledge of channel statistics is unavailable or costly to obtain. In RA-LC, the BS only knows the channel statistics between itself and the source tSS, along with the total number of potential helpers, as estimated in helper discovery phase (Section III-A). Then, the BS selects the optimum transmission parameters S by exhaustive search while ensuring the average PER over all possible locations of other nodes, EfPp(S)g, is bounded by . Here the expectation is taken with node distribution, as given by

$$S^* = \arg\max_{S} \left\{ 1/(\frac{1}{r_1} + \frac{1}{r_2 \times r_c}) \right\}, \ s.t. \quad \mathrm{E}\{P_p(S)\} \le \gamma,$$

In contrast to RA-GC, since RA-LC scheme has limited channel knowledge, a good set of helpers cannot be effectively predefined, limiting applicability of DSTC. Thus,RA-LC will only be applied to R-DSTC based cooperation. For both RA-GC and RA-LC, when direct transmission achieves higher end-to-end throughput than any cooperative scheme, direct transmission is employed at the best rate R^*_{direct}

C. Complexity Analysis for Rate Adaptation

For all schemes, the optimal transmission parameters are obtained by searching through all possible S. Given the locations of all nodes, for each tSS using RA-GC, the computational complexity is given by O(Kr) for the direct scheme; $O((N+M_1+M_2-1)\times K_r \times K_r \times K_L)$ for the single-helper, R-DSTC-GC and R-DSTC-LC; and

$$O(\sum_{n=1}^{K_L}\{(N+\underset{n}{M_1}+M_2-1)\times K_r \times K_r\})$$

Thus, RA-GC and RA-LC results in a linear complexityin rate adaptation with respect to the number of stations for Coop MAX with a Single-Helper, and R-DSTC schemes, but an exponential complexity for CoopMAX with the DSTC scheme. In addition, when using RA-LC, assuming the distribution of stations is known by the tSS, the R-DSTC-LC scheme does not need to recalculate the optimal parameters even when potential helpers move their locations as long as the number of potential helpers remains the same in a cell.

4. SIMULATION RESULTS

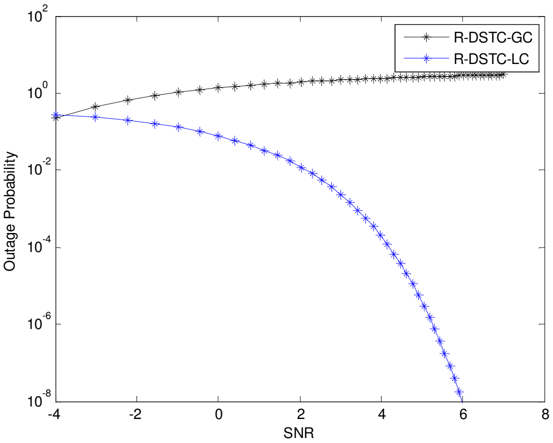

Fig. 1. Outage probability Vs SNR of the proposed system.

In Fig.1, outage probability versus SNR is plotted. Network aggregated outage probability with mobility in a single cell with $M1 = 6$ RSs, $M2 = 10$ fBSs/pBSs and N SSs were considered. In simulation results, first physical layer performance metrics of all transmission strategies, using MATLAB under Rayleigh fading channels over all Links for each strategy over either a single hop or two hops were studied. These simulation results demonstrate the effectiveness of the proposed technique.

5. CONCLUSIONS

In this paper, CoopMAX protocol for cooperative relaying in WiMAX systems is introduced with marginal modifications to IEEE 802.16 standards. In addition to using fixed RSs, CoopMAX also recruits fBSs/pBSs as new fixed relays and SSs as mobile relays, showing pronounced performance cooperative gains. R-DSTC based CoopMAX is shown to be robust to mobility by an opportunistic use of all types of relays. While the terminology and detailed specifications in this paper are for WiMAX, similar results and conclusions can be drawn for using cooperative relays in time division duplex (TDD) based TD-LTE.

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