A Mobile Multi-hop Relay Base Station (MRBS) – Relay Station (RS) Link Level Performance of Coding/Modulation Schemes, on the Basis of the REWIND Research Program

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Abstract. Among the essential aims of the European REWIND Research Program is to proceed to the algorithmic research and technology development of appropriate Mobile Multi-hop Relay networks based on the WiMAX technology, so that to increase coverage and throughput issues. The present work provides a description of the related link-level algorithms and simulations. The study performed evaluates the link-level performance of various coding and modulation schemes with different antenna configurations over several links. In particular, it studies the "backhaul channel" which is required to support the aggregate cell traffic. High-rate convolution turbo codes combined with high-order modulation schemes are employed. The performance and gains associated with multiple-antenna deployments such as MISO and MIMO techniques are evaluated.

Keywords: CTC (Convolutional Turbo Coding), IEEE 802.16j standard, MIMO (Multiple-Input, Multiple-Output) techniques, MISO (Multiple-Input, Single-Output) techniques, Mobile Multi-hop Relay (MMR) specification, MMR Base Station (MRBS), Relay Station (RS), WiMAX.

1 Introduction

There are various choices available for operators when deploying Base Stations (BSs) to improve indoor or outdoor coverage or to increase network capacity. These can include macro-cells, micro-cells, or pico-cells in an outdoor environment; pico-cells in public indoor locations (or within enterprise buildings), and; femto-cells for residential use ([1], [2]). The primary difference between these cells (performance-wise)

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is the size of coverage. Macro-cells are these BSs with the longest range, but are also the most expensive to purchase, deploy and maintain. Micro-, pico- and femto-BSs are used to fill in coverage gaps and establish coverage in buildings where macro-cell signals can hardly penetrate. A significant side-effect of placing a large number of BSs in a region is that each one needs a dedicated broadband backhaul connection. Thus, micro-, pico-, and femto-cells can use either wireline or wireless links for their backhaul, depending on the cost, availability and scalability of different solutions. In particular, they can support in-band backhaul to enable operators to use their spectrum holdings to carry backhaul traffic to the nearest macro-BS or to the nearest micro-cell or pico-cell with wireline backhaul.

Under these circumstances, the *IEEE 802.16j Mobile Multi-hop Relay (MMR) specifications* [3] are aimed to extend BS reach and coverage, while minimizing wireline backhaul requirement. A relay-based architecture will allow operators to use in-band wireless backhaul while retaining all the standard WiMAX (Worldwide Interoperability for Microwave Access) functionality and performance ([4], [5]). For example, as shown in Fig.1 the MMR Base Station (MRBS) provides the primary area of coverage. It also has a backhaul connection, such as leased copper, fiber optics, or microwave radio link. The Relay Station (RS) extends the BS coverage. A mobile subscriber station (SS) can connect to a BS (i.e. a MRBS or a RS). Some "combined" BS/RS deployments can also "reduce" (or "eliminate") Network coverage "holes"; or can be used to serve temporary network deployments for disaster/emergency situations and for special events [6].

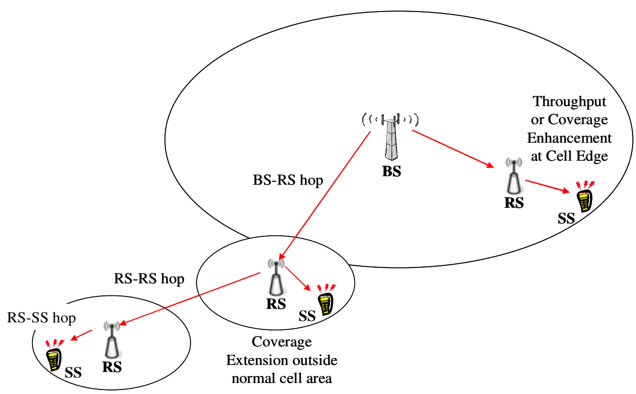

Fig. 1. Enhancement of "cell" edge performance through BS coverage extension by using RSs

In the above usage cases/scenarios it is clear that the backhaul channel has to support the aggregate cell traffic and is therefore crucial to study and optimize. We assume an in-band wireless backhaul connection, utilizing the same channel in the 2.5GHz frequency band as it is used for the WiMAX network deployment. The channel models assumed throughout are WiMAX-related, in 2.5GHz frequency band, using the WiMAX System Evaluation Methodology.

As the in-band backhaul link utilizes the WiMAX channel bandwidth, which is used for access, and in order to minimize the overhead of the relay backhaul link on the overall access capacity, it is essential that the spectral efficiency of the backhaul links will be as highest as possible. In a network of macro-BSs and multiple relays around each BS, the overall network performance is highly dependant on the backhaul links capacity performance [7]. The backhaul link's performance is subject to typical link budget and SNR (signal to noise ratio) performance, taking into account the overall interference pattern, in the network level.

The present work originates from the "core" context of the EU-funded "*REWIND*" Research Project (*ICT-FP7, Grant Agreement No.216751*), which intends to develop a specific Relay Station (RS) implementation on the basis of the WiMAX technology; in particular, *REWIND* will proceed to the algorithmic research and technology development of the corresponding MMR-based networks in order to increase coverage and throughput issues. An essential part of the Project is responsible for the design of the novelty software and hardware functional areas of the corresponding RS product, mainly including: algorithmic research and simulations; system architecture and requirements specifications, and; DSP (Digital Signal Processing) and MAC software code development and integration.

2 Essential Assumptions

The present work provides a description of the RS-MRBS link level algorithms and simulations. Thus, we evaluate the link-level performance of various coding and modulation schemes with different antenna configurations over several links. In particular, we study the backhaul channel which shall then be used as a "building block" for the network-level simulation. High-rate convolution turbo-codes combined with high-order modulation schemes are employed.

The performance and gains associated with multiple-antenna deployments such as MISO (Multiple-Input, Single-Output) [8] and MIMO (Multiple-Input, Multiple-Output) ([9], [10]) techniques are also evaluated. Obtained results can then be utilized by the system level simulation procedures.

In particular, a MATLAB environment[1] was developed for running Link Level BER (bit error rate) / BLER (block error rate) (PER) performance tests, focusing on: (i) WiMAX-compliant modem configurations and reference channel models, and; (ii) Enhanced backhaul configurations.

This can support laboratory debugging / testing as follows:

- On the transmitter (Tx) by exporting waveforms to signal generator;
- On the receiver (Rx) by importing recordings from VSA (vector signal analysis) and a logic analyzer;
- By generating board configuration scripts according to system design and settings.

The simulated Relay Station contains 2 Transmit (Tx) antennas and up to 6 (i.e. 2, 4, or 6) Receive (Rx) antennas, operating in MIMO receiver techniques ([11], [12]), in order to increase the spectral efficiency of the link between the MR-BS (Multi-hop

[1] MATLAB is a high-level language and interactive environment that enables you to perform computationally intensive tasks faster than with traditional programming languages such as C, C++, and FORTRAN.

Relay Base Station) and the RS. The setting is based on the premise that no more than 2 Downlink (DL) streams "share" the same time and frequency resource in the MRBS-RS link. Therefore, the MRBS-RS link is a two-stream backhaul utilizing 2 to 6 Relay receive antennas. For the simulation environment, we have utilized several statistical path-loss, shadowing and indoor loss models ([13], [14]). The simulation Environment is built as a MATLAB project. It can be compiled as a stand-alone application (currently on Linux).

3 MRBS-RS Link Level Simulations

Mobile radio channels can be narrowband (i.e., flat fading channels) or broadband (i.e., frequency selective fading channel). So, different channel models have to be developed and examined. In mobile radio channels, the high mobility causes rapid variations across the time-dimension, the large multi-path delay spread causes severe frequency-selective fading, and the large multi-path angular spread causes significant variations in the spatial channel responses. For best performance, the transmitter and receiver algorithms must accurately track all dimensions of channel responses (space, time, and frequency) [15].

This section describes the main building blocks employed for the link-level simulation. These are divided into: Transmitter, Channel, and Receiver. The reason for using these "blocks" is to provide realistic results (rather than theoretic ones) able to capture the effect of various practical issues that can be generally modelled as "implementation loss". Each specific "block" is described as follows:

The *Transmitter block* contains the following modules:

- A burst modulator (which consists of a payload FEC (Forward Error Correction) encoder and a randomizer);
- A symbol builder (which includes a frequency domain 2 OFDM (Orthogonal Frequency Division Multiplex) streams constructor according to zone / burst permutation type [16], MCS (modulation/coding schemes), and proper MIMO settings);
- A beam-former (considered for the mapping of the 2 streams onto N Tx antennas);
- A Decision Feedback Equalization-DFE (which includes IFFT (inverse Fast Fourier Transform), CP (Cyclic Prefix), windowing, sampling rate conversion and timing correction, carrier frequency correction and digital up-conversion, I/Q pre-compensation [17]).

The *Channel simulator block* contains the following modules:

- A MIMO fading channel simulator [18];
- Carrier frequency offset;
- Phase noise, and;
- Timing offset.

The *Receiver block* contains the following modules:

- A DFE scheme able to perform I/Q post-compensation, carrier frequency correction and digital down-conversion, sampling rate conversion and timing correction, CP removal, FFT (Fast Fourier Transform);

- Automatic Gain Control (AGC);
- Preamble sync;
- A pilots tracking "block" possessing CFO (Clock Frequency Offset) and STO (Symbol Timing Offset), as well as several specific "estimators", i.e.: channel estimators; noise variance estimator; MMSE (minimum mean square error) equalizer taps estimator; post-MMSE CINR (carrier-to-interference and noise ratio) estimator);
- A symbol decomposer (containing a frequency domain 2 OFDM streams spatial equalizer);
- A LLR (log-likelihood ratio) computation "block" [19];
- A Burst demodulator (able to perform a physical-to-logical reorder of LLRs, and including a payload FEC decoder and de-randomizer).

3.1 Simulation Parameters

The following set of specific parameters has been assumed for the simulations:

The *channel models* used have considered the following cases:

- AWGN (Additive White Gaussian noise) [20];
- ITU Pedestrian B [21];
- Backhaul Type A (derivative of SUI-1[2]) [22].

The *coding scheme* has been based both on convolution turbo coding and on a specific encoding scheme (as defined in IEEE 802.16e specifications).

The *modulation schemes* have comprised square QAM (Quadrature Amplitude Modulation) constellations from QPSK (Quadrature Phase Shift Keying) to 256QAM depending on link conditions and SNR operation region.

The following simulations have been realized either by using Matrix A (STC: Space-Time Coding [23]) (i.e. the case of scenarios 1 and 2) or Matrix B (MIMO-SM (Spatial Multiplexing)) (i.e. the case of scenario 3) smart antenna methods, as described in the following sections.

3.2 Simulation Results

Scenario 1: Here, the objective was to realize a reference performance measure in Single-Input, Single-Output (SISO) antenna system [24]. To this aim, we have considered an AWGN channel, with various combinations of coding rates and modulation schemes.

Fig.2 presents the BER performance in various modulation and coding schemes. The steepness of the performance curves is due to the so-called water-fall region (WFR), associated with the turbo codes used.

Scenario 2: In the above usage cases/scenarios it is clear that the backhaul channel has to support the aggregate cell traffic and is therefore crucial to study and optimize. We assume an in-band wireless backhaul connection, utilizing the same

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[2] Stanford University Interim (or "SUI") models were used for evaluation of suggested 802.16 physical layer modifications.

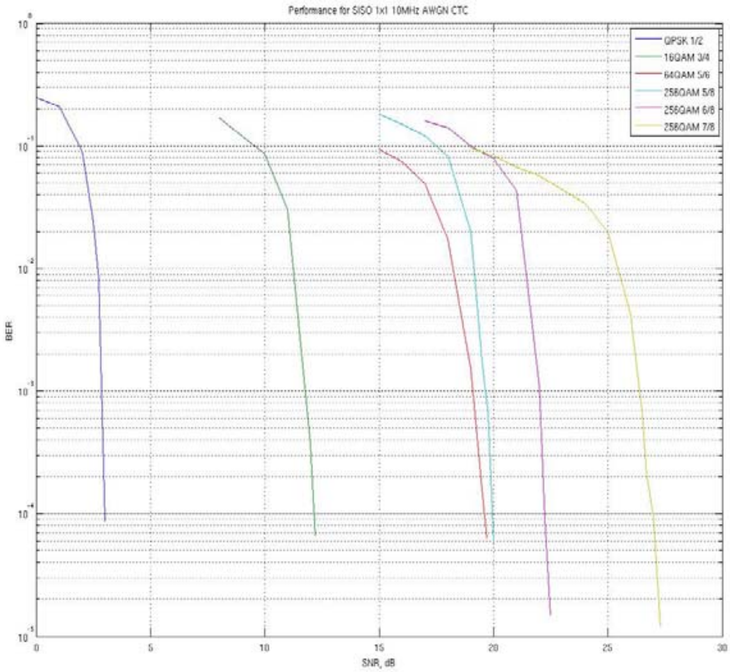

Fig. 2. BER performance for SISO channel with CTC (Convolutional Turbo Code)

channel in the 2.5GHz frequency band as it is used for the WiMAX network deployment. The channel models assumed throughout are WiMAX-related, in 2.5GHz frequency band, using the WiMAX System Evaluation Methodology.

In this scenario, the objective was to measure the obtained diversity gains by using multiple Receive antennas (from 2, 4 or 6 antennas); a single transmit antenna has been used throughout. For this scenario the channel was the backhaul channel Type A.

Fig.3 presents the BER performance in different modulation and coding schemes, with 2, 4 or 6 receive antennas. The results show significant gains in performance (about 8-10 dB) due to receive diversity obtained by multiple receive antennas.

Scenario 3: In this scenario, the essential objective was to determine the SNR regions required for optimized backhaul link performance, with high-level modulation schemes (16, 64 and 256QAM modulations) combined with turbo coding and various antenna configurations.

Two transmit antennas have been assumed for transmitting two independent streams.

The set of curves depicted in Fig.4, presents the BER performance in different modulation and coding schemes, and summarizes the extensive simulation results collected for the backhaul channel.

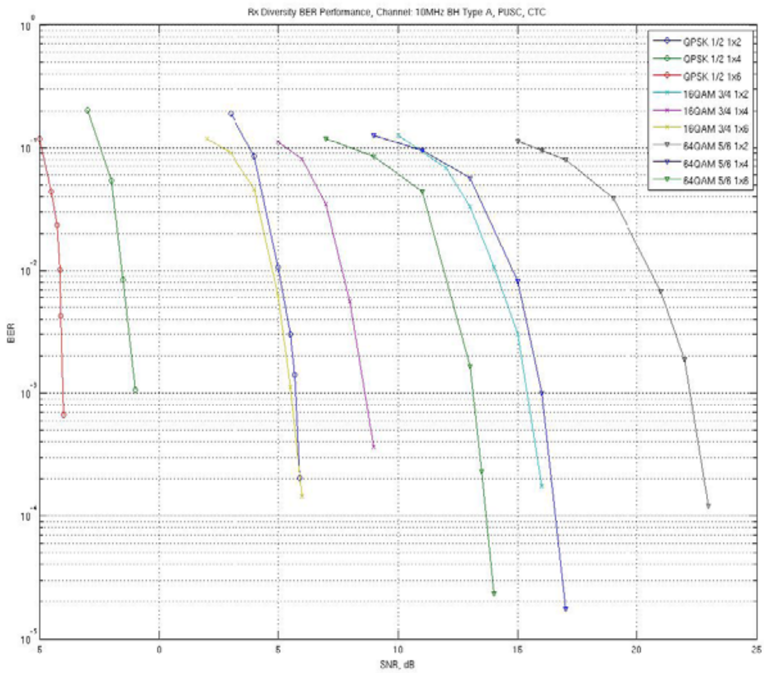

Fig. 3. BER performance for Receive-diversity (SIMO channel) with CTC

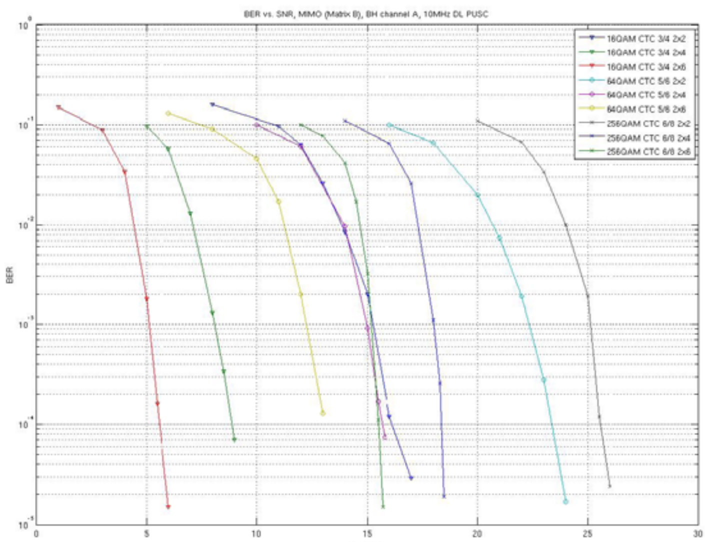

Fig. 4. Matrix-B, MIMO 2x2, BH Channel

The following Table 1 summarizes the obtained results for BER=10^{-4}.

Table 1. Several Results for different parameter combinations

QAM constellation	Coding rate	Spectral efficiency [bps/Hz]	Antenna configuration Tx/Rx	Required SNR [dB]
16	3/4	6	2x2	16.5
			2x4	9
			2x6	6
64	5/6	10	2x2	23
			2x4	16
			2x6	13
256	6/8	12	2x2	25.5
			2x4	18
			2x6	15.5

Note that very high operating rates (spectral efficiencies) can be obtained in the backhaul link using smart antenna array configurations. It is apparent that increasing the number of receive antennas from 2 to 4 provides a gain of about 7dB, while increasing the number to 6 receive antennas provides additional gain of about 3dB.

4 Conclusion

The present work evaluates, by simulation, the link-level performance for various coding and modulation schemes with different antenna configurations, with the aim to develop an innovative RS product on the basis of the IEEE 802.16j MMR specifications. Several practical links have been taken into account ([25], [26]), focusing on: WiMAX-compliant modem configurations and reference channel models; enhanced backhaul configurations and channel models.

Multiple receive antennas employing maximum ratio combining (MRC) for a single transmit stream offer substantial diversity gain compared to a single receive antenna when using the ITU pedestrian B channel model. When using a 2x2 antenna configuration over the ITU pedestrian B channel, Matrix B offers no SNR gains as compared to Matrix A when the spectral efficiency and BER/BLER conditions are the same for both schemes.

Considering the backhaul link, denoted backhaul Type A (SUI-1), using 2 streams and 2 transmit antennas, spectral efficiencies of up to 12 bps/Hz are achievable with as little as 15.5dB SNR when the receiver employs 6 receiving antennas (25.5dB SNR is required to achieve the same spectral efficiency with only 2 receive antennas).

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