On the Multihop Relays with Multiple Antennas for LTE-A

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Abstract— In this paper, we analyze cooperative communications for broadcast/multicast wireless communication systems based on the LTE-A standard. Multihop relays utilizing the same frequency bands as the base station are considered. These relays are equipped with multiples antennas (MIMO), at least the double of those employed at the base station side. The simulation results show that multihop relays achieve an improvement of power efficiency, while keeping the average coverage and the overall network throughput unchanged. This can be viewed as an energy-efficient wireless transmission technique, which contributes to the implementation of the green cell networks concept, as it allows a reduction in the carbon emission footprint.

1. INTRODUCTION

Operators are required to continuously improve system capacity and coverage while cost saving and with a reduced carbon emission footprint. Many solutions are envisaged to meet these desiderates, but small cells deployments look promising as a way to improve coverage and capacity demand. LTE-Advanced (LTE-A) will be extensively deployed on 2.6 GHz band. As the majority of mobile traffic is generated indoors, coverage improvement is essential. Heterogeneous networks with many types of small cells will increasingly be deployed to address the need of coverage and capacity improvements.

Many solutions could be employed to improve the backhaul coverage. Fiber is an attractive solution, however very expensive and requiring a long time to deploy. The challenges with backhaul can be addressed by self-backhauling relay nodes.

Relay Nodes (RN) were introduced in 3GPP Release 9 as a special type of eNodeB that is not directly connected to the core network. A RN receives data which was forwarded by an eNodeB that is connected to the Evolved Packet Core (EPC) (see Figure 1). Upon receiving such data, the RN sends it to the User Equipments (UE) that are under its area of coverage. This is a very interesting option for operators, as usually RN present structures less expensive to deploy and to maintain, as compared to eNB. They can provide temporary network deployment and an outage of the services in an area (e.g., when a sporadic event that concentrates a lot of people in the same geographical area takes place, such as a summer festival). The use of a RN allows a fast deploying and inexpensive way to solve the problem, and can also provide coverage in small areas not covered by eNodeB (eNB).

In [1, 2], four relay architectures are proposed and studied. Those architectures differ from each other in terms of expected behaviour of the RN/DeNB[1] and how the data is sent within the EPC until it reaches the UE. That study concludes that an architecture where RN acts as a proxy for S_1/X_2 has the most overall benefits, having been incorporated in 3GPP Release 10 (LTE-Advanced). Type 1 half-duplex in-band relay does not transmit any signal to UE when it is supposed to receive data from the DeNB. The relay then configures these sub-frames as Multicast/Broadcast Single Frequency Network (MBSFN) sub-frames when UEs are not supposed to expect any downlink transmission.

In this paper, we consider Type 1 RN with advanced Multiple Input Multiple Output (MIMO) schemes with support of 4 antennas for enhancement to relay backhaul. The objective is to achieve the DeNB throughput in spite of its in-band half duplex mode.

We first analyse Base Station cooperation with MIMO and next we replace some BSs by Fixed Relays assuring that the overall throughput of the network is kept the same, but with an improved power efficiency. The 3GPP Release 10 (LTE-Advanced) parameters will be taken as reference in our system level simulations.

Section 2 presents the system model; the system level simulations are presented in Section 3; numerical results are then plotted in Section 4; finally, our conclusions are drawn in Section 5.

[1] DeNB stands for Donor eNB.

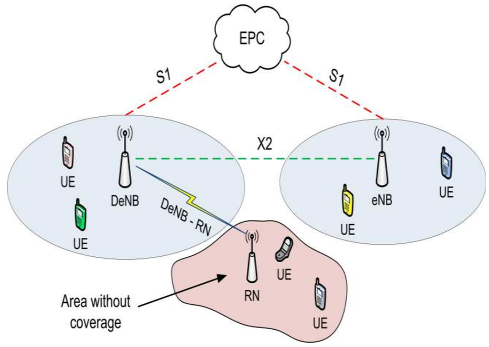

Figure 1: Example of relay node in E-UTRAN.

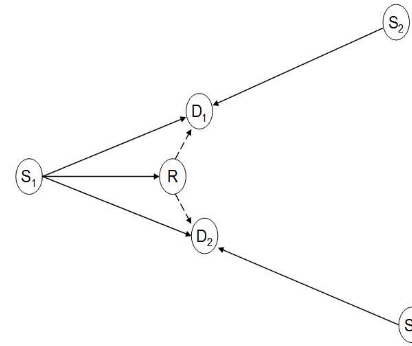

Figure 2: Cooperative multicast/broadcast network.

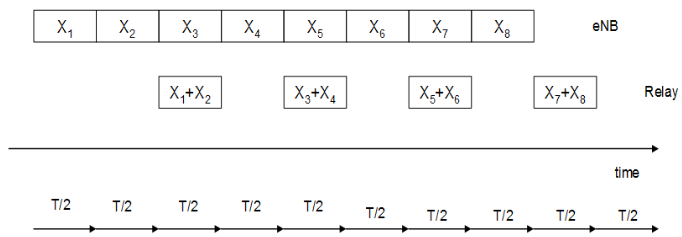

Figure 3: Time division channel allocation.

2. SYSTEM MODEL

The typical Multicast/Broadcast Multimedia Service (MBMS), such as video and audio, tends to be delay-sensitive and distortion-tolerant. Scalable video coding has been used for robust and flexible video transmissions, in which the source video is encoded into multiple streams with different priorities and transmitted using unequal error protection schemes. The basic streams, which contain the data with higher priority and describe the source at a basic quality are transmitted under higher protection. The enhancement streams with lower priority data, which are encoded progressively to further refine the quality of the basic stream. Under such a joint source and coding scheme, the multicast throughput can be improved, since users with different channel realizations can decode different number of streams, obtaining heterogeneous quality of service. We implement the unequal error protection function with hierarchical modulation and/or multi-layer transmission/spatial multiplexing (MIMO), as described in the following sub-section. We apply it to the relay-based cooperative multicast/broadcast cellular network.

Consider the system model as shown in Figure 2. It consists of 6 nodes with three source S_1, S_2 and S_3, one relay R and two destinations D_1 and D_2. This 2-destination case can easily be extended to the multiple-destination case. In practice, the source may usually select a relay which is located between the source and destinations, where the R-D channels have relatively higher channel gains than the corresponding S-D channels. Two scenarios are considered: In the first scenario designated as Single Cell (SC) the sources transmit different signals, so S_2 and S_3 interfere with S_1. The source node S_1 transmits the same signals to both D_1 and D_2. In the second scenario, designated as Single Frequency Network (SFN), the nodes S_1, S_2 and S_3 transmit the same signals to destination nodes. In any scenario only S_1 exploits R as a relay.

In this paper, a time division mechanism is assumed. Moreover, we shall assume that the relay node works in a half-duplex mode, while source nodes work in full-duplex mode (see Figure 3). Meanwhile, all channels are assumed to present mutually independent Rayleigh fadings. In conventional cooperation schemes [3] such as Decode-and-Forward (DF), the source transmits a signal X_n in the first half time-slot, then the relay forwards the same symbol in the second half time-slot. In here, source transmits in every time slot continuously, while Relay stores the signals received and decode-and-forward in the first half time-slot of the next time-slot. Assuming that signal X_n is QPSK (Quadrature Phase Shift Keying) modulated, then the signal forwarded by relay has Hierarchical 16QAM (16 Quadrature Amplitude Modulation) modulation and/or MXN MIMO QPSK modulated. As a result, the spectral efficiency can be improved. It can exploit an increased diversity, while reducing the outage probability and increasing the coverage.

2.1. Multi-layer Transmission

Multi-layer Transmission and Space Division Multiple Access (SDMA) belong to the same group, entitled Spatial Multiplexing (SM), whose principles are similar but whose purposes are quite different. As long as the antennas are located sufficiently far apart, the transmitted and received signals from each antenna undergo independent fading.

The primary goal of the MIMO based on multi-layer transmission scheme is to achieve higher data rates in a given bandwidth, whose increase rate corresponds to the number of transmit antennas [7, 8]. An example of the multi-layer transmission scheme is the Vertical — Bell Laboratories Layered Space-Time (V-BLAST). In the Multi-Layer MIMO, the number of receive antennas N must be equal or higher than the number of transmit antennas M. The increase of symbol rate is achieved by "steering" the receive antennas to each one (separately) of the transmit antennas, in order to receive the corresponding data stream. This is achieved through the use of the nulling algorithm. With the sufficient number of receive antennas it is possible to resolve all data streams, as long as the antennas are sufficiently spaced so as to minimize the correlation [4].

As depicted in Figure 4, two different Multi-Layer MIMO schemes are considered: scheme 1 and scheme 2 [4]. Scheme 1 directly allows an increase of the data rate whose increase rate corresponds to the number of transmit antennas. Scheme 2 allows the exploitation of diversity, without achieving an increase of data rate. The transmit diversity combining is achieved using any combining algorithm, namely the Mean-Square Error (MSE) based or the Maximum Ratio Combining (MRC). In case of the scheme 2 (depicted in Figure 4(b)), the antenna switching is performed at a symbol rate, where the red dashed lines represent the signal path at even symbol periods, in case of two transmit antennas. The diversity is achieved because each symbol is transmitted by different antennas, at different symbol periods. Output signals are then properly delayed and combined to provide diversity.

In Multi-Layer MIMO, the symbol with the highest Signal to Noise Ratio (SNR) is first detected using a linear nulling algorithm such as zero forcing (ZF) or minimum mean square error (MMSE) [7]. The detected symbol is regenerated, and the corresponding signal portion is subtracted from the received signal vector using typically a Successive Interference Cancellation (SIC) algorithm. This cancellation process results in a modified received signal vector with fewer interfering signal components left. This process is repeated, until all symbols from different transmit antennas are detected.

3. SYSTEM-LEVEL SIMULATIONS

The considered system level simulator was originally developed as part of the work produced in [4]. The simulator was built in JAVA programming language, due to its characteristics such as portability, multi-platform compatibility, and ease of usage and configuration by users with low experience and familiarization with programming languages.

The core of the System Level Simulator (SLS) is composed by a discrete event generator with some grade of abstraction. The events generated consist of individual tasks such as Channel Quality

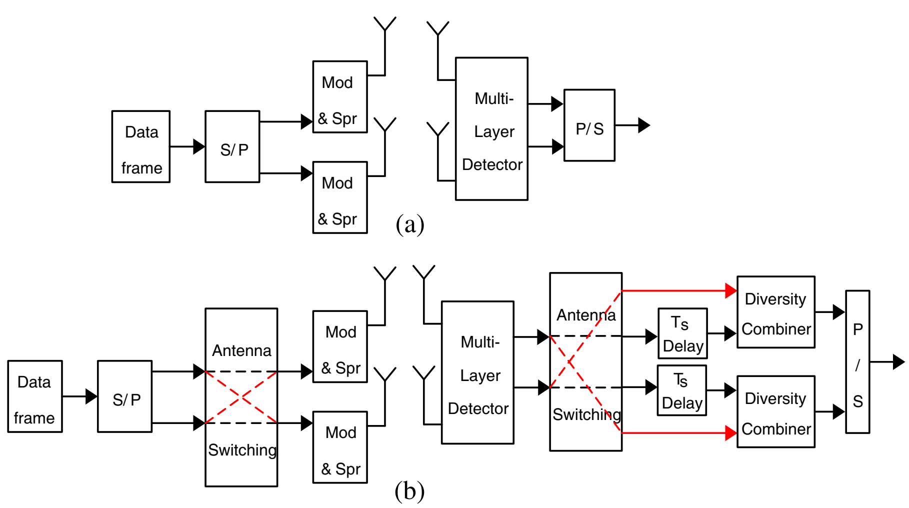

Figure 4: Generic diagram of the 2×2 multi-layer MIMO. (a) Scheme 1 and (b) scheme 2.

Indicator (CQI) reporting, packet processing, radio resources management, etc.. Propagation, traffic and mobility models are also part of the SLS, and have great impact in the results that will be obtained, especially in terms of coverage and radio link SNR estimation. Moreover, fast-fading and shadowing conditions are emulated, since channel conditions for every eNB/UE combination are time-varying and location dependent.

A scenario with nineteen sites was configured as the simulation environment. Moreover, two different configurations were assumed:

a) Nineteen sites corresponding to nineteen eNBs without RNs;
b) Nineteen sites corresponding to seven eNBs plus twelve RN.

The differences between these two configurations can be seen from Figure 5(a), where the black triangular shapes and the hexagons represent the location and coverage of eNBs respectively. From (b), the red triangular shapes and the yellow hexagons represent the location and coverage of RNs. The general parameterization used for all system-level simulations follows the 3GPP recommendations [5, 6]. The more specific parameters used for simulations can be obtained from Table 1.

4. SIMULATION RESULTS

In the system level simulations, mobile users receive blocks of bits transmitted from base stations. Each block undergoes small and large scale fading, as well as multi-cell interference. In terms of coverage or throughput, the SNR of each block is computed taking into account all the above impairments. Based on the comparison between the reference SNR at a Block Error Rate (BLER) of 1%, and the evaluated SNR, it is decided whether the block is or not correctly received. This is achieved for all the transmitted blocks, for all users, in all 57 sectors of the 19 cells, during 500 seconds.

Figure 6 presents the coverage as a function of the percentage of transmitted power from the base station (E_C/I_{0r}), for MIMO 2×2 and 4×4, coding rate 1/2 and SC scenario. This corresponds to a scenario where there is interference with different patterns due to different frequency reuse

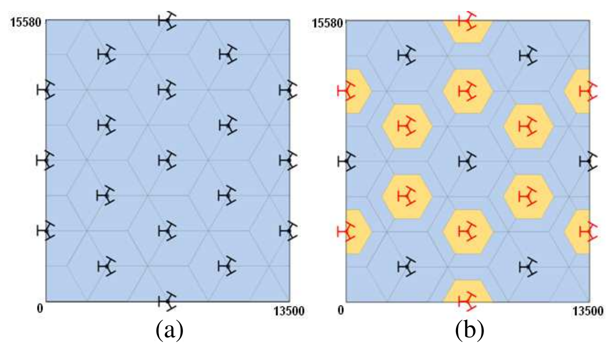

Figure 5: (a) Only eNBs scenario; (b) eNBs mixed with RNs.

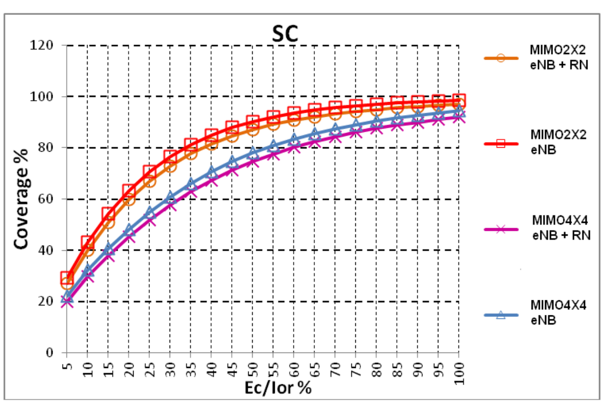

Figure 6: Coverage of SC scenario with and without relays.

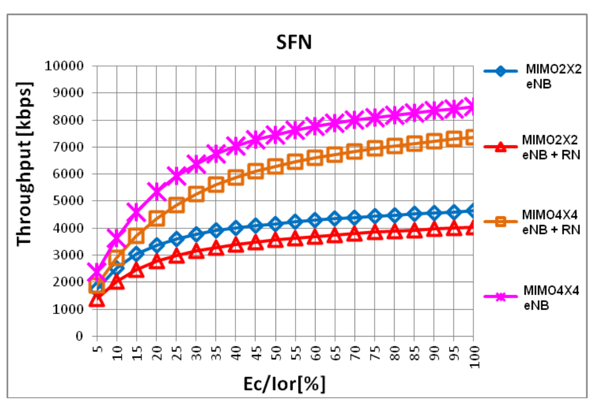

Figure 7: Throughput of SC scenario with and without relays.

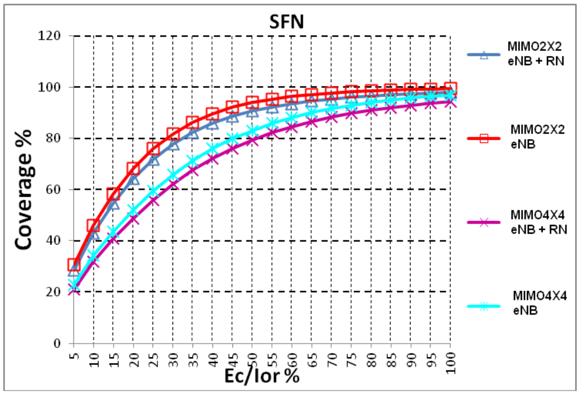

Figure 8: Coverage of SFN scenario with and without relays.

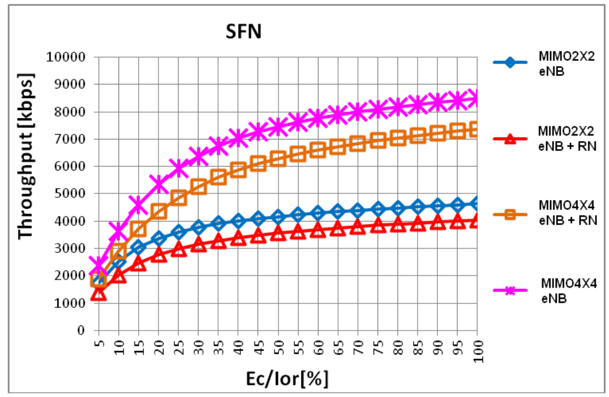

Figure 9: Throughput of SFN scenario with and without relays.

Table 1: Parameterization for SC and SFN simulation scenarios.

Parameter	Values
Cell Radius	2250 [m]
Modulations	H-16QAM
Coding rate	1/2
Number sectors per base station site	3 sectors/site
Sites layout	• 19 eNB • 7 eNB + 12 RN
eNB base station power/sector	• 46 [dBm] or 40 [W]
RN base station power/sector	• 34 [dBm] or 2.5 [W]
Number UEs per sector	20

factors. We have chosen the frequency reuse of 1/3 in all simulations. All interfering sites transmit with the maximum power of 90%, according to the parameters indicated in Table 1. The cell radius R is 2250 meters (inter-site-distance 3900 m), and for the reuse factor chosen the reference coverage of 95% is achieved by all the schemes. However, it should be noticed that coverage values of MIMO 4×4 are lower than those of MIMO 2×2 due to higher levels of spatial interference. One of the curves almost superposed corresponds to configuration plotted in Figure 5(a) (eNB, without relays) and the other to Figure 5(b) (eNB+RN, with relays).

Figure 7 presents the average throughput distribution as function of E_C/I_{0r} for coding rate 1/2 and the SC scenario, with the cell radius of $R = 2250$ meters, 2×2 and 4×4 MIMO, and with frequency reuse of 1/3. We observe that the maximum throughput is achieved with MIMO 4×4, in spite of its lower coverage due to higher spectral efficiency. Due to higher interference levels and lower transmitted power of relay nodes, the throughput achieved by the configuration of Figure 5(b) (with relays) indicates a loss of about 1 Mbps compared to the simulation of Figure 5(a) (only base stations). Figure 8 corresponds to Figure 6, but for the single frequency network (SFN). For comparison purposes, the reuse factor of 1/3 is kept. The coverage values are only slightly higher than for SC. This means that the users that are being served by the relay nodes are much closer to them, as compared to the base stations of the adjacent cells. All the schemes achieve the reference coverage with lower E_C/I_{0r}.

Figure 9 corresponds to Figure 7 but for the SFN. For comparison purposes, the reuse factor of 1/3 was also kept. The comparison between the two figures indicates slightly higher throughput values of Figure 9, as compared to those of Figure 7. Again, using 4×4 antennas, instead of 2×2, allows increasing the maximum throughput from around 5000 kbps to 8500 kbps. Coding rate 1/2 continues to be used to enable higher coverage values (and throughput).

5. CONCLUSIONS

We have analyzed cooperative communications with fixed multihop relays, working in half-duplex mode and equipped with multiple antennas MIMO. A cellular network was considered, where some of the BSs have been replaced by fixed relay stations with much less transmitted power, while keeping the same global area. We have confirmed that, by using multihop relays, it is possible to keep the average coverage and the overall network throughput, while achieving an improvement of power efficiency. This can be viewed as an energy-efficient wireless transmission technique, which contributes to the implementation of the green cell networks concept, as it allow a reduction in the carbon emission footprint.

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