Two-Hop Relaying in LTE-A Downlink

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INTRODUCTION

The third generation (3G) long term evolution advanced (LTE-A) standard is a part of the Third Generation Partnership Project (3GPP) and it is the next evolution step of LTE. The 3G LTE-A standard requires a higher signal-to-noise ratio (SNR) than is typically experienced in widearea cellular networks to be able to use higher order modulation and coding schemes. A long distance between a transmitter and a receiver causes high path loss and thereby the required SNR levels cannot be reached. To improve the SNR and achieve cost-effective throughput enhancement and coverage extension, different layers of relaying have been introduced in the LTE-A framework. A wide range of relay types can be envisioned, ranging from simple repeaters, which are already used today as a low cost tool for coverage improvement, to more advanced solutions where the relay can be seen as a small base station [1]. Three different layers of relaying are proposed for LTE-A: layer-1 (repeater), layer-2 (relay) and layer-3 (wireless router). Layer-1 supports a simple amplify-and-forward (AF) protocol and layers two and three support the decode-and-forward (DF) protocol. [1, 2]

The main focus will be on a fixed relay station and non-cooperative types of relaying where the destination does not hear the source. The fixed relay station is one possible solution to achieve the target SNR and data rates in LTE-A. The relaying system corresponds to a two-hop communication system where the relay is assumed to be placed on a rooftop to ensure line of sight (LOS) conditions toward the base station. The relay-to-terminal link is also assumed to be a LOS channel. The cell size of the relay station can be described as an urban microcell, which models one possible scenario.

RELAY PROTOCOLS

The main focus is on layer-1 AF and layer-2 DF relaying protocols, since they present the most known relay types. Also other relaying protocols exist but most of them have complexities higher than the AF relay but lower than the DF relay.

Linear amplification is the only operation that the AF relay does for the received signal. Basically, the received signal is multiplied by a gain matrix and then forwarded to the destination. The received signal at the destination contains following parts.

$$\mathbf{y}_2 = \mathbf{H}_2\mathbf{G}\mathbf{H}_1\mathbf{x}_1 + \mathbf{H}_2\mathbf{G}\mathbf{n}_1 + \mathbf{n}_2 \tag{1}$$

In (1), $\mathbf{y}_2$ denotes the received signal vector at the destination, $\mathbf{H}_2$ denotes the channel matrix of the channel between the relay station (RS) and the destination, $\mathbf{G}$ denotes the amplification matrix at the RS, $\mathbf{H}_1$ denotes the channel matrix of the channel between the source and the RS, $\mathbf{x}_1$ denotes the transmitted signal vector from the source, $\mathbf{n}_1$ denotes the noise vector at the RS, $\mathbf{n}_2$ denotes the noise vector at the destination. In (2), it can be seen that the overall noise at the destination is $\mathbf{n}_{tot}=\mathbf{H}_2\mathbf{G}\mathbf{n}_1+\mathbf{n}_2$. The total impact of the channels is needed to be estimated at the destination since the signal goes through two channels. The total channel matrix between source and destination is $\mathbf{H}_{tot}=\mathbf{H}_2\mathbf{G}\mathbf{H}_1$, which consists of both channel matrixes and the amplification matrix. [3, 4]

The more complex DF relay protocol includes signal processing such as demodulation, decoding, encoding and modulation. The biggest advantage compared to layer-1 relays is that no noise is amplified and DF relays can suppress noise from the received signal. The transmitted signal does not contain any additional degradation and the DF relay can modify the decoded signal before transmission. A DF relay can change modulation, coding scheme and transmit power for every transmission. The destination does not need CSI of the first channel because it assumes that the relay successfully decodes the source signal. There is no point in forwarding erroneous bits if decoding fails. The DF relay requests retransmission and tries to decode again after maximum ration combining, if decoding fails. The same kind of HARQ schemes as at the base station and the terminal can be used in DF relays. [2, 5]

SYSTEM MODEL

The work is focused on the single user link-level perspective. Different transmission and relaying schemes are analyzed by the simulations in terms of various error ratios and throughput outcomes. The effect of other terminals and cells are not taken into account. The basic two-hop system model describes the behavior of the source, relay and destination. The simulator is mainly designed for the LTE standard but since LTE-A is backwards compatible with LTE the main structure is the same. In throughput calculations, all information bits are discarded and not counted in if at least one frame error is detected in the received transmission time interval (TTI) block which can be seen in Fig. 1. The used frame structure does not correspond to the LTE frame structure.

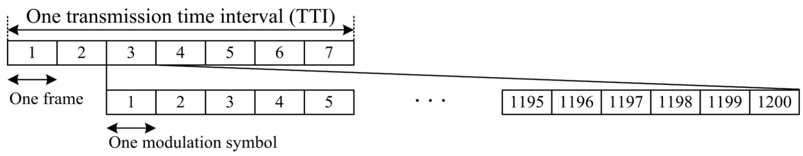

Figure 1: Structure of TTI block.

Perfect channel state information (CSI) and level of AF relay gain are assumed to be known at the destination. Simulations with the AF protocol are made with three different gains: nine and half decibels SNR gain, six decibels SNR gain and the last one does not provide any SNR gain. The link between the base station and the relay station is called the relay link and the link between the relay station and the terminal is called the access link in this work. Channel variations are continuous for the entire duration of the simulations and different SNR values are used in the access link to model different kinds of scenarios. The channel model between the source and the relay is based on the Wireless World Initiative New Radio (WINNER) B5a cluster delay line (CDL) channel model parameters and the channel between the relay and the destination is based on the WINNER B1 CDL channel model parameters [6]. The main simulation parameters used can be seen from Tab. 1.

SIMULATION RESULTS

The simulation results for the AF and DF relaying systems with access link performance are presented in the following figures. Simulation results for an AF relay with a 2×2 antenna configuration and a 40 dB SNR in the relay link are presented in Fig. 2. A 40 dB SNR in the relay link is enough for QPSK and 16-QAM modulations but 64-QAM

Table 1: Simulation parameters

Carrier Frequency	5 GHz
Bandwidth	20 MHz
Number of/used subcarriers	2048/1200
Modulation schemes	QPSK, 16-QAM, 64-QAM
Channel code	Turbo coding
Code rate	1/2
MIMO scheme	VBLAST, Spatial multiplexing
Terminal speed	120 km/h
Detector type	List sphere detector K-BEST
HARQ scheme	Chase combining
Maximum number of retransmissions	3
Number of simulated frames	10000

modulation cannot reach the maximum throughput with any gain. An AF relaying system can improve throughput with nine and half decibels SNR gain compared to access link results when access link SNR is between zero and six decibels. The simulation results for a DF relay with a 2×2 antenna configuration and a 40 dB SNR in the relay link are presented in Fig. 3. A 40 dB SNR in the relay link is enough for all modulation schemes in DF relaying and the DF relay does not cause any additional degradations.

The simulation results for an AF relay with a 4×4 antenna configuration and a 50 dB SNR in the relay link are presented in Fig. 4 and the corresponding simulation results for the DF relay are presented in Fig. 5. The impact of noise amplification and forwarding can especially be seen with higher level transmission schemes like 64-QAM and 4×4 antenna configuration. DF relaying can also in this case offer the same throughput with the same SNR values as the access link. The access link channel simulation results are also plotted in the figures, but they equal to those of DF relaying and are therefore under DF relaying results.

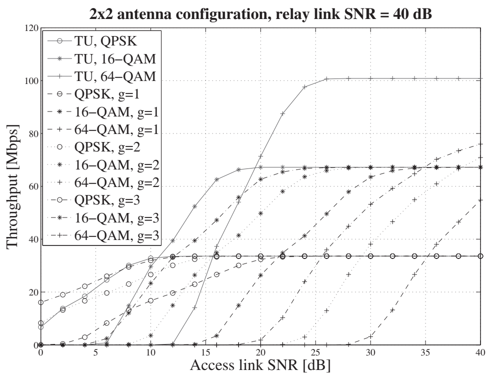

Figure 2: AF relaying throughput in 2×2.

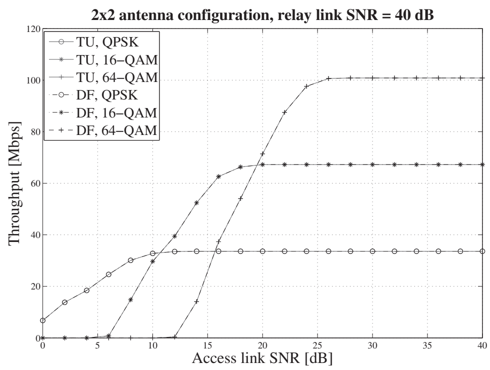

Figure 3: DF relaying throughput in 2×2.

CONCLUSIONS

The AF and DF relaying protocols were assumed to behave differently since the impact of the relay on the system makes a major difference. Simulations confirm the assumption that an AF relay suffers from noise amplification and forwarding. More vulnerable higher order modulation and coding schemes do not reach the same performance with an AF relay than with a DF relay. Higher antenna configurations also affect AF relaying performance by increasing the required SNR in both links. When adequate conditions in the relay link can be guaranteed, the AF relay offers higher throughput with 2 × 2 and

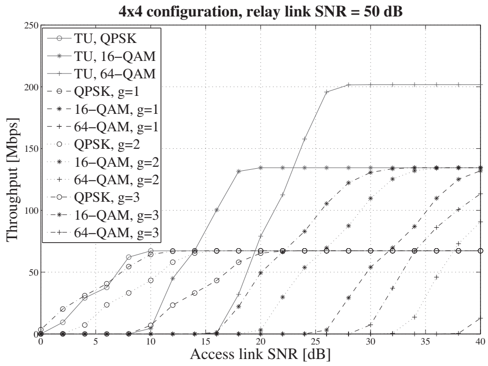

Figure 4: AF relaying throughput in 4×4.

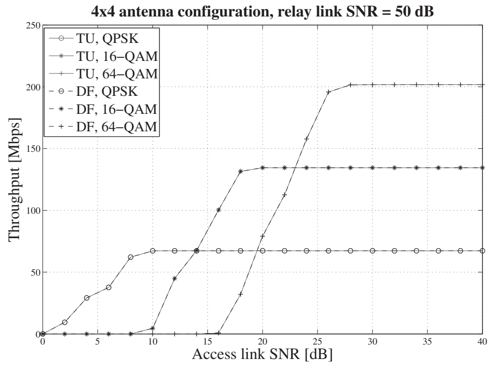

Figure 5: DF relaying throughput in 4×4.

4×4 antenna configurations and QPSK modulation with low SNR levels in the access link than DF relaying. The AF relay can amplify the received signal and therefore the signal is stronger at the destination with AF relaying. In other cases, DF relaying achieves the maximum throughput with a lower SNR value in the access link than AF relaying. A DF relaying does not offer similar SNR gain, but in good enough conditions relaying corresponds to access link performance. Overall AF relaying system performance can be increased by using higher gains. When using higher gains, the relay also needs higher transmission power and therefore amplification is limited. The main reasons for the performance differences are noise amplification in the AF relay and the DF relay offering coding gain in both links.

The relay link limits total system performance with both relay types when it cannot offer the maximum throughput. In the case of AF relaying, the total noise levels increases too much and the destination cannot decode successfully, although HARQ retransmissions are used. In the case of DF relaying, the DF relay does not transmit anything to the destination if the relay cannot decode successfully. The relay link is more important than the access link for all relaying protocols since the operator can affect relay link conditions.

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