3GPP TSG RAN WG1 Meeting #56
R1-090775
Athens, Greece, February 9th – 13th, 2009

Source: Alcatel-Lucent
Title: TDMA H-ARQ Code for Layer-2 Relay in LTE-Advanced
Agenda Item: 12.5
Document for: Discussion and Decision

1. Introduction

This contribution introduces a new error coding protocol that utilizes Layer-2 (L2) Relay (RN) for cooperative communication with LTE-Advanced capable terminals. The proposed coding protocol, termed "Time Division Multiple Access (TDMA)" relay code, is able to exploit the cooperative capability of the RN in a manner that is both practical and superior to existing Multi-Hop (MH) based relay techniques. In particular, by using a simple adaptation of H-ARQ error correcting codes, gains of up to 5 dB gain from the point-to-point (non-RN enabled) channel can be achieved. This L2-based protocol can be practically implemented without significant coordination between the LTE-A capable terminal and the RN. Note that existing H-ARQ codes, including the standard 3GPP turbo-code can still be supported, albeit without the same performance benefit.

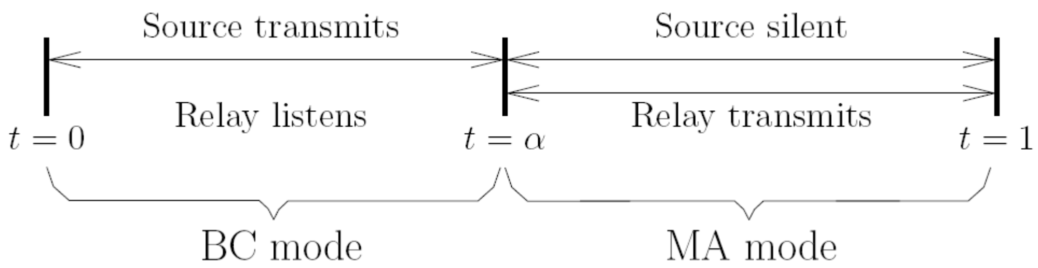

Figure 1. Time-axis representation of TDMA relay coding protocol. During the MA mode, the relay transmits rate-compatible parity to the BC mode transmission.

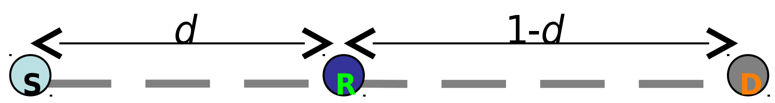

Figure 2. Linear model for relay geometry.

2. System model

The TDMA relay channel can be interpreted as a half-duplex relay channel, in which the source (the eNB) broadcasts a message during the Broadcast (BC) mode and is silent during the Multiple Access (MA) mode, while the RN transmits. See Figure 1. The system is decode-and-forward (L2-based), in the sense that the RN is required to reliably decode the source message. The destination terminal is assumed to receive both the eNB and the RN transmissions. The optimal channel coding strategy for the above described TDMA relay channel consists of:

(1) The eNB targets a throughput (for a given resource block shared between source and relay) that is near the TDMA relay capacity.

(2) The eNB transmits a BC mode codeword based on target throughput in (1). Note that the effective BC mode code rate (between eNB and RN) approaches the eNB-RN capacity, according to the TDMA capacity expression.

(3) The RN sends rate-compatible parity bits (compatible with the BC mode received bits) during the MA mode.

The BC/MA time-slotted structure is easily adapted to existing H-ARQ packet error control mechanisms. In order to maximize the spectral efficiency, the LTE-A capable terminal is required to report Channel Quality Information (CQI) regarding its channel to both the eNB and the RN receivers.

In this contribution, in order to facilitate a link-level comparison between different relay coding strategies, the RN is assumed to be on a unit-line between the source and destination. See Figure 2. In the theoretical examples that follow, the RN is assumed to be half-way between the source and the destination. A wireless propagation path loss exponent of 3 is further assumed.

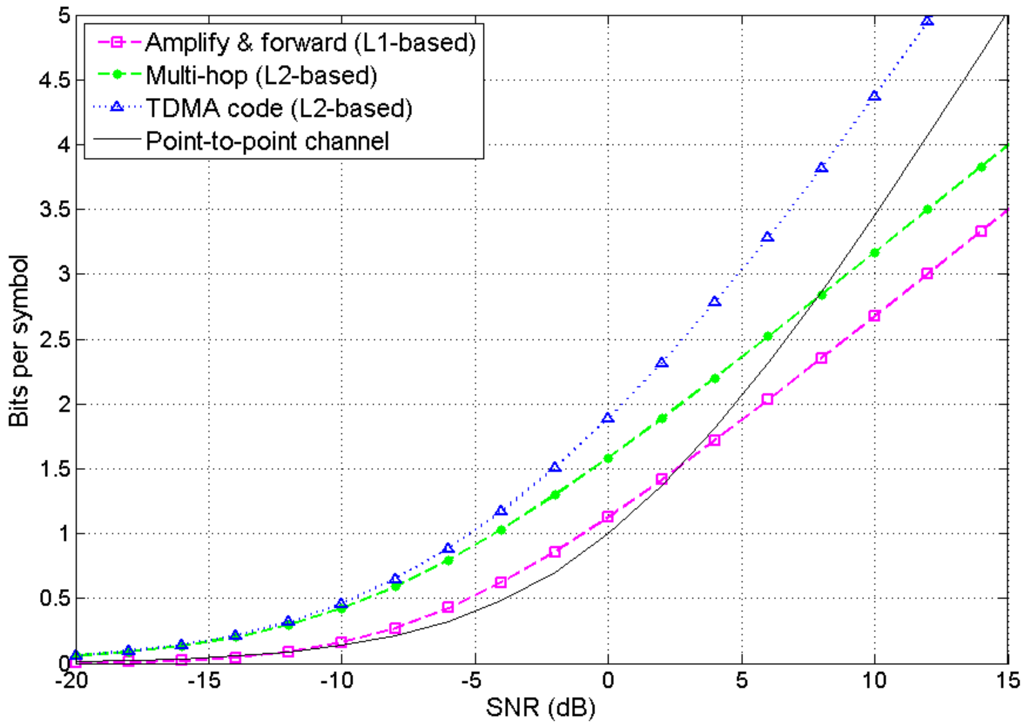

Figure 3. Capacity of the TDMA relay code compared to multi-hop code and L1-based repeater. (All symbols are Gaussian.) Time- and power-sharing parameters are optimized where applicable.

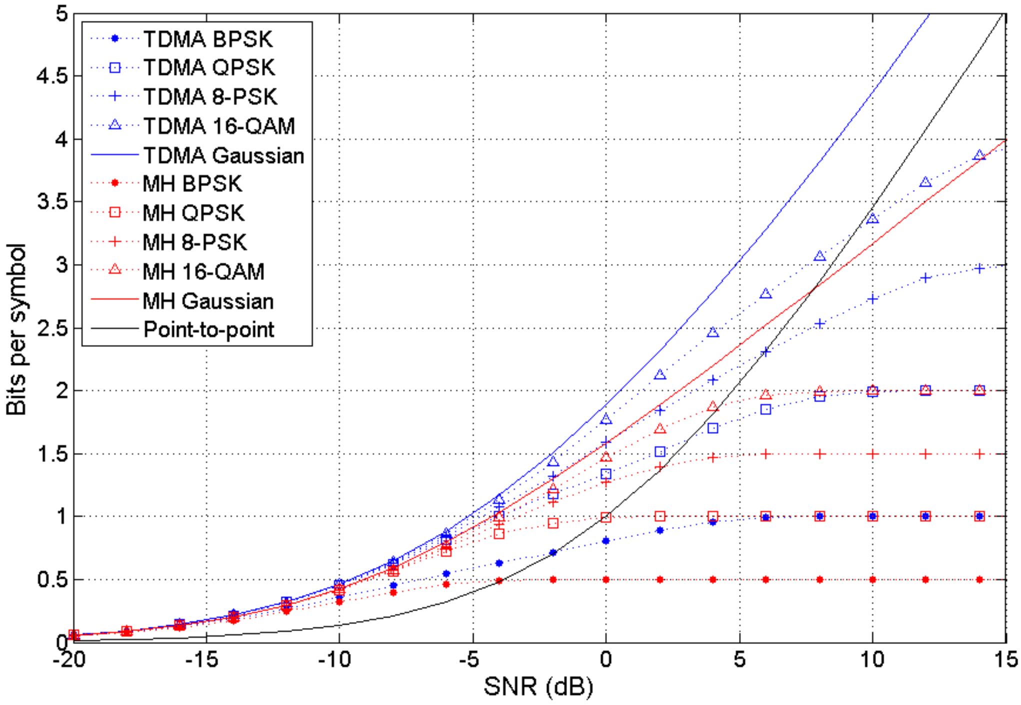

Figure 4. Throughput of the TDMA and multi-hop relay codes with specific QAM alphabets.

3. Capacity analysis

In order to evaluate any benefit for using the RN, a total power budget, P, used by the source and RN transmitters, is fixed, and comparisons are made to a point-to-point channel (without relay) with the same source power, P. The above constraint yields the same average energy per symbol for both the relay enabled and point-to-point channel.

The relay channel and non-cooperative channel are further assumed to use the same total time and bandwidth. The above assumptions are made to facilitate a link level comparison of different relay strategies. Other criterions, such as interference avoidance and/or coverage enhancement, are readily accommodated within this framework but are not treated here.

A time-sharing parameter (between BC and MA modes) and a power-sharing parameter (between source and RN transmitters) are determined by the TDMA relay capacity expression. Figure 3 shows the capacity results, using Gaussian alphabets, for the TDMA code as compared to a Multi-Hop (MH) L2-based relay and an L1-based repeater (amplify-and-forward relay). Figure 4 shows the rates achieved using QAM alphabets for both the TDMA and MH codes. (The time- and power-sharing parameters have been optimized in the MH code results. The power-sharing parameter has been optimized in the L1-based code results.)

The results show a large gain in the spectral efficiency for TDMA code over MH code for a given alphabet. This is because, in the MH code, the destination receiver does not decode the BC mode signal, and thus no cooperative coding benefit is gained. In the TDMA code, a full utilization of the spectrum is achieved. The capacity of the TDMA code shows as much as 5 dB gain over point-to-point capacity, while doubling the QAM rate of the MH code (at high-SNR).

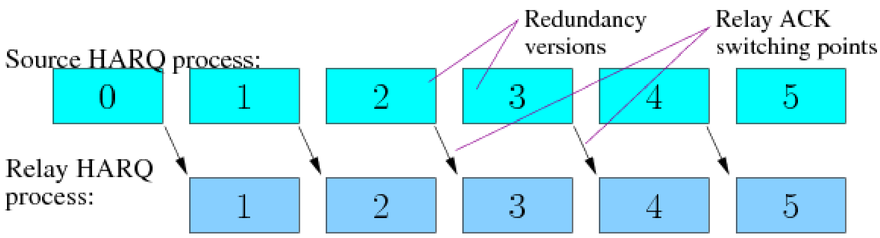

Figure 5. Depiction of a single H-ARQ process (corresponding to one code word) for TDMA relay code.

4. Interaction with H-ARQ

The proposed TDMA relay code is adapted well to the LTE H-ARQ packet error protection mechanism in the sense that pre-existing ACK/NACK and CQI shared resources can potentially be re-used for RN enabled transmissions. This is can potentially be done transparently and is a point of discussion.

In the LTE H-ARQ protocol, a given code word is segmented into packets (here referred to as H-ARQ packets) that represent different redundancy versions for a given source message. The H-ARQ packets are transmitted in a prescribed order until the destination receiver transmits an acknowledgement of successful decoding (ACK).

In the TDMA relay protocol, the source transmits H-ARQ packets for a given source message only until the RN acknowledges a successful decoding (termed RN ACK). Once the RN has decoded the source message, MA mode is enabled, and the RN sends any further required H-ARQ packets, until a destination ACK is received.

Gaps between scheduled H-ARQ packets are referred to as RN ACK switching points, where the RN can send an ACK if it has decoded the source message. The RN ACK indicates that the RN will continue any further required H-ARQ transmissions. The average RN ACK switching point is dictated by the optimal time-sharing parameter, α, as given by the TDMA capacity formulation.

In Figure 5, the above described TDMA H-ARQ code is depicted. Note that the source and RN H-ARQ encoders (redundancy versions) can be the same, and thus off-the-shelf rate-compatible codes, including legacy 3GPP turbo-codes, can be re-used within the TDMA H-ARQ framework. However, the overall spectral efficiency of the TDMA relay channel is maximized by choosing a RN encoder that is optimized for the specific relay channel geometry.

5. Conclusion

This contribution has introduced a new error coding protocol for L2-based RN enabled channels for discussion in the 3GPP LTE-Advanced standard. We have shown significant gains in the spectral efficiency, as compared to the point-to-point channel and MH relay channel, with the TDMA relay cooperative coding protocol.

In order to maximize the spectral efficiency for a given RN-enhanced link, the eNB requires CQI regarding both the eNB-UE channel and the RN-UE channel. Facilitating these feedbacks is an item for discussion.

6. References

[1] G. Kramer, M. Gastpar, and P. Gupta, “Cooperative strategies and capacity theorems for relay networks,” *IEEE Trans. Inform. Theory*, vol. 51, no. 9, pp. 3037–3063, Sept. 2005.

[2] A. Host-Madsen and J. Zhang, “Capacity bounds and power allocation for wireless relay channels,” *IEEE Trans. Inform. Theory*, vol. 51, no. 6, pp. 2020–2040, June 2005.

[3] N. Jacobsen and R. Soni, “Design of rate-compatible irregular LDPC codes based on edge growth and parity splitting,” in *Proc. IEEE Vehicular Tech. Conf. (VTC)*, Baltimore, MD, Sept. 2007.