Smart Hybrid-ARQ (SHARQ) for Cooperative Communication via Distributed Relays in LTE-Advanced

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***Abstract*—The work described in this paper proposes two Smart Hybrid-Automatic Repeat Request (SHARQ) schemes with incremental redundancy, that are developed for a dual-hop network of two relays implementing cooperative communication. In a dual-hop network consisting of multiple relays, one of the most challenging tasks is to determine an appropriate trade-off point between the end-to-end block-error rate (BLER) and an additional delay caused due to HARQ retransmissions in two hops. The retransmissions can either be initiated at the relay nodes or at the source node. HARQ protocol for such a network, should therefore be capable of dynamically deciding the node-of-retransmission.**

The SHARQ schemes proposed here are designed intelligent in a way that they take into account the presence of two relays and the benefit of using cooperative schemes. Basically the system developed here, intends to provide the combined benefits of diversity gain from cooperative schemes and the throughput improvement from SHARQ in a best possible way. This paper explicitly compares the most basic case of single relay system without HARQ and cooperation with the most advanced scenarios of cooperative communication with SHARQ schemes. It is observed that the latter of the two above scenarios results in throughput improvement of almost 4dB in terms of SNR.

***Keywords*: 3GPP, Cooperative Communication, Decode and Forward, Delay Diversity Scheme, Distributed Alamouti Scheme, Hybrid-ARQ, LTE-Advanced, Macro-diversity, MIMO.**

I. Introduction

Relayed communication as an individual technology has been studied for decades [1], but more recently, it has become one of the hot research topics in the field of mobile communications. Moreover, the extension of Multiple Input Multiple Output (MIMO) to a relay network has coined a new terminology which is described as a Distributed Communication System via Relays or Cooperative Communications. In a distributed system, different relays are considered as antennas of a single user, for which, the multiple antenna techniques can be implemented. The key motivation for developing this system is to exploit macro-diversity gain, obtained as a result of uncorrelated fading along independent channel paths from relays to destination [2].

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However in order to attain system level improvement in terms of throughput, Hybrid ARQ (HARQ) needs to be designed for cooperative relays. HARQ protocol with incremental redundancy has been proven to provide strong robustness against multipath fading channel [3]. For a distributed system of cooperative relays, the HARQ protocol is expected to significantly improve the end-to-end performance by efficient retransmission schemes which reduce the overall error rate of the system. A single-hop communication retransmits the packet with an incremental redundancy when a Negative Acknowledgement (NACK) is sent from destination to source. However for a system illustrated in Fig. 1, the implementation of HARQ retransmissions becomes much more difficult as there are four independent links which correspond to retransmissions between four pairs of transmitter and receiver.

For such a relaying system, most of the studies in the past

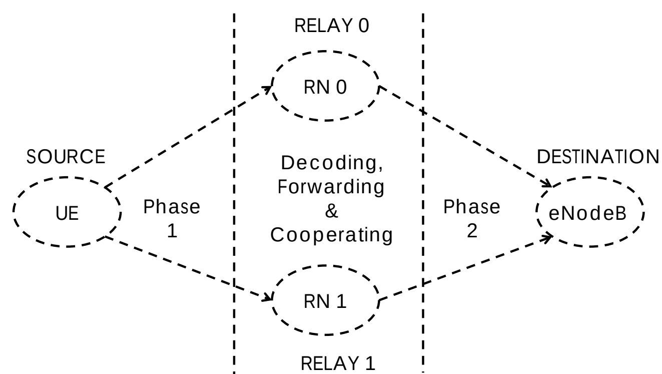

Fig. 1. Distributed System Representation

have resorted to broadcasting of NACK from the destination to all nodes which results in retransmission from the source as well as the relay stations [4, 5]. However, such retransmission schemes are found more useful in case of selective relaying than in case of cooperative communication via relays. In this paper, we have developed two different SHARQ schemes that take into account the benefits of cooperation of the two relays and intelligently decide whether to initiate retransmissions at the source or at the relays. This decision is reached based on the three main factors: BLER, overall delay and end-to-end throughput. The criterion for the system design is to have maximum throughput with reduced delay and minimum possible BLER. These SHARQ schemes are discussed in detail with the help of flowchart diagrams in Section III. Before that, Section II briefly describes the system model and the cooperative schemes.

II. System Model and Cooperative Schemes

As indicated in Fig. 1, the system consists of a source node as user equipment (UE), a destination which is an eNodeB and two relay nodes in the between the source and destination. The phase 1 between the source and the two relay nodes, therefore consists of two independent uplink channels and phase 2 from the relay nodes to the destination also consists of two independent channels. The relay nodes determined here are Type 1 according to Release 10 LTE-A specifications [6]. The simulator for this research is developed for a uni-directional transmission of information from source to destination via decode-cooperate-forward technique at the relay nodes.

A. Channel Modeling

For artificial reverberation of the multipath channel as in a real environment, the simulator uses a Tapped-Delay Line (TDL) channel which follows a Ricean model [7]. The channel model implemented is frequency selective with an exponential decaying power-delay profile (PDP) with each channel path being independent of each other in both the phases. However the two links in phase 1 have a same signal-to-noise ratio for experimentation.

B. Cooperative Schemes

In this paper, the two cooperative schemes implemented for a relaying network are: Delay Diversity Scheme and Distributed Alamouti Scheme which are basically derived from the transmit diversity schemes described for MIMO systems in LTE [8]. From the implementation point of view in a system, the two schemes have a very contrasting nature in terms of the trade-off between complexity and diversity gains. In this work, linear delay diversity is implemented which attains diversity gain by introducing frequency selectivity in the overall channel of the radio link [9].

The extension of Alamouti Scheme to a distributed system of relays is defined as Distributed Alamouti Scheme. Distributed Alamouti has been studied in the past demonstrating significant diversity gain [10], therefore in order to exploit significant diversity gains and for providing the solutions to challenging tasks involved, the distributed Alamouti scheme is preferred. The fundamental steps performed for distributed Alamouti scheme are similar to that of a standard scheme in MIMO systems.

However, a major hurdle in successful implementation of the Alamouti scheme in distributed system of two relays is to obtain separate channel estimates of the two individual channel paths i.e. from relay 0 to destination and relay 1 to destination. This is possible only when the reference signals of the two channels do not interfere with each other as they are required for correct channel estimation at the receiver. Since they are transmitted from both the relays at the same time and on the same resource blocks, therefore the best possible solution is to have the reference signal of one relay orthogonal to the reference signal of other relay within the same set of subcarriers. In this way, they will have a zero cross-correlation and can be easily separated at the receiver.

The technique developed for extracting separate channel estimates for distributed Alamouti is explained in detail in *Chapter 3* of [11].

III. Smart Hybrid-ARQ (SHARQ) Schemes

With the ultimate goal of any communication system to have an improved end-to-end performance, it becomes imperative to develop efficient HARQ schemes with incremental redundancy, which utilizes the cooperative schemes to maximum benfit and lead to a complete system. In a cooperative system of distributed relays, there is a need of Smart HARQ (SHARQ) schemes which is able to exploit the following benefits of cooperative system in addition to its inherent performance enhancing capability of reducing the system's block error rate.

1. The cooperative system of distributed relays establishes end-to-end link in two phases, phase 1 being from source to relays and phase 2 is from relays to destination, with phase 2 establishing the link even when just one relay decodes the signal. HARQ scheme should therefore be devised in a smart way which initiates retransmissions from source only when signal is decoded incorrectly at both the relays.
2. In phase 2 of cooperative system, error performance is expected to be better when both relays forward and exploit the macro-diversity. If the destination decodes the signal incorrectly, then two possibilities exist due to existence of cooperative relays: One is to have retransmission in phase 2 and the other is to have retransmission in phase 1 (if retransmissions in phase 1 are not exhausted).

Based on these possibilities, two Smart HARQ (SHARQ) schemes are devised for the cooperative system.The two schemes described here are based on the principal condition that source initiates retransmissions only when it receives Negative Acknowledgement (NACK) from both the relays. The reception of NACKs from the relay nodes can be facilated by Coordinated Multipoint Reception in LTE-A [12]. The source does not retransmit when it receives NACK from just one of the two relays in the system, it rather waits for ACK or NACK from the other relay and if it receives ACK from that relay, it does not retransmits. On the contrary, when the source receives ACK from both the relays, it automatically sets the retransmissions counter to maximum number so that phase 1 is shut for transmission of that particular packet.

Based on these principal conditions, SHARQ scheme I and SHARQ scheme II are developed. Both the schemes are schematically explained with the help of flowchart diagrams.

A. SHARQ Scheme I

In phase 2 of a system, two states can exist depending upon the decoding at the two relays in phase 1. If both relays decode correctly, then cooperative communication takes place in phase 2, otherwise when only one of the two relays decode correctly, its a single relay forwarding scenario. As illustrated in Fig. 2, SHARQ I is based on having retransmissions in phase 2 irrespective of the state of the system, which means if the final destination decodes incorrectly, the scheme initiates retransmissions in phase 2 between forwarding relay(s) and destination and continue till the destination decode correctly or till maximum number of retransmissions is exhausted for phase 2. However when the retransmissions for phase 2 are exhausted, then it demands retransmissions in phase 1 if the number of retransmissions were not exhausted initially, but the scheme is smart in a sense that it doesn't demand retransmissions in phase 1 if already both relays were forwarding in phase 2.

The notions used in the flowchart are described as: decode_error_0 and decode_error_1 represent the errors in decoding at relay node 0 and relay node 1 respectively and decode_error is for the destination node. Similarly NACK_0 and NACK_1 indicate the NACK flag for relay node 0 and relay node 1 respectively and NACK is for the destination node. HARQ_Count_1 keeps the counter for number of retransmissions in phase 1 and HARQ_Count_2 is for phase 2.

B. SHARQ Scheme II

SHARQ scheme II is based on system aware retransmissions in phase 2. Contrary to scheme I, SHARQ II does not initiate retransmissions in phase 2 only on the condition if destination decodes signal incorrectly as shown in Fig. 3. When destination decodes incorrectly, it sends NACK to the forwarding relay(s), and it is at this stage that SHARQ II acts different than SHARQ I. Instead of initiating retransmissions in phase 2 after receiving NACK from destination, the relay(s) instead send NACK to the source and the source starts retransmissions if it had not exhausted the maximum number of retransmissions. Therefore SHARQ II is described as system dependent retransmission scheme.

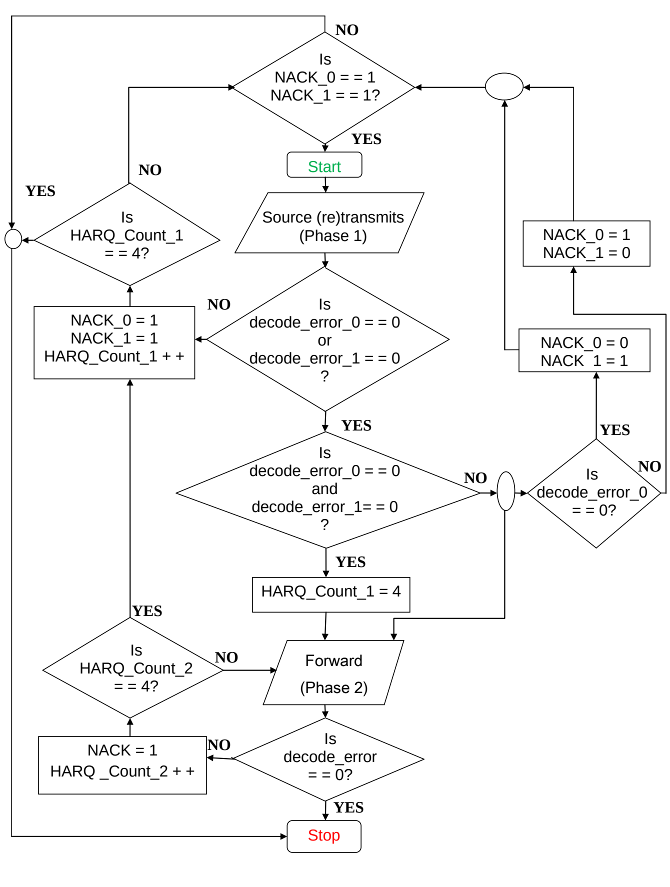

Fig. 2. SHARQ Scheme I Algorithm

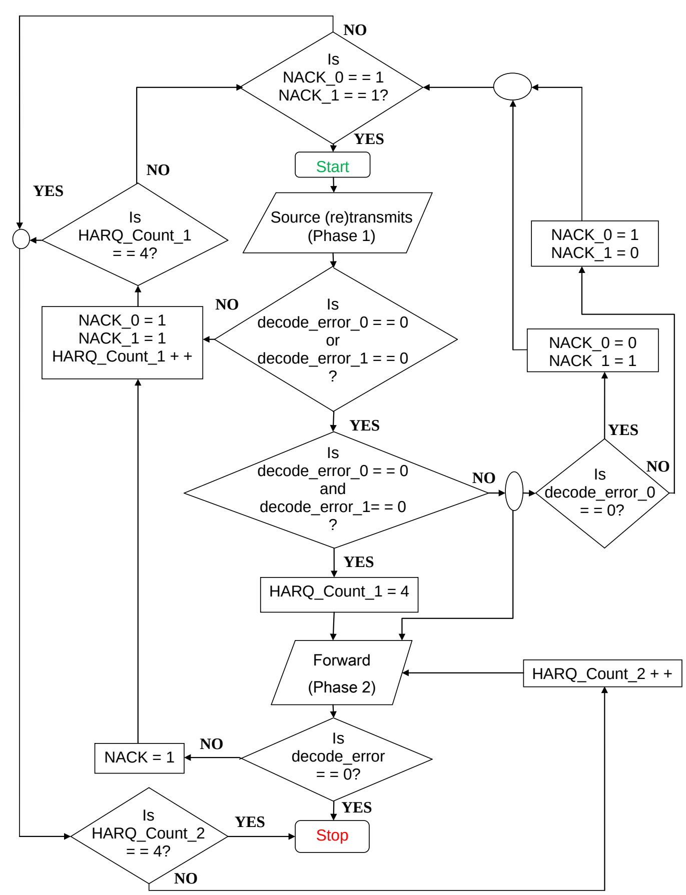

Fig. 3. SHARQ Scheme II Algorithm

C. *SHARQ I and SHARQ II Comparison*

SHARQ scheme II aims to exploit cooperative communication in a better way than the SHARQ I and relies more on diversity gain for system performance enhancement. Retransmissions in phase 1 are favored rather than in phase 2 of the system since the probability of correctly decoding the signal at both relays is increased for this case which in turn results in cooperative communication in phase 2. With cooperative communication in phase 2, the error performance is expected to improve, however there might be an overall increased delay due to 2-hop transmission of NACK from destination to relay and then further to source. *Which scheme is better than the other?* Perhaps it is qualitatively not possible to compare the performance of two schemes and therefore the quantitative results for both the schemes are analyzed in next section to provide an answer to this question. The performance measuring parameter i.e. throughput is formulated in the equation below for the system developed in this work.

$$Throughput = (1 - BLER) * (1/Delay(HARQ)) * (TBS) * (Number\_of\_Symbols) * 100$$

Delay (HARQ) is delay caused due to retransmissions. This factor varies for different relaying scenarios and therefore the true performance of such system is given by the throughput rather than just the BLER. BLER is basically the end-to-end error rate from source to destination. TBS is the transport block size and Number_of_Symbols represents the useful symbols in 1 transmission time interval (tti).

IV. Simulation Results

The simulator is developed on an LTE-compliant platform described as OpenAir Interface platform [13]. Being LTE compliant platform, the parameter's values used are basically a subset of that defined in the 3GPP LTE release 8 specifications [14, 15, 16]. Table 1 lists the parameters for the simulations carried out in order to obtain the results of the schemes described in previous sections.

Parameters	Values
Bandwidth Allocated	5MHz (25 RBs)
Maximum Transmission Bandwidth	4.5MHz
Useful Subcarriers	300
Subcarrier Spacing	15KHz
Sampling Frequency	7.68MHz
Simulation Window	1 Subframe
Modulation and Coding Scheme	1
Number of OFDM symbols per slot	6
Cyclic prefix length	128 samples
Number of Transmit Antennas (all nodes)	1
Number of Receiving Antennas (all nodes)	2
Ricean Factor	20dB
Delay Spread	1μs
Maximum HARQ Rounds	4

TABLE I
Simulation Parameters

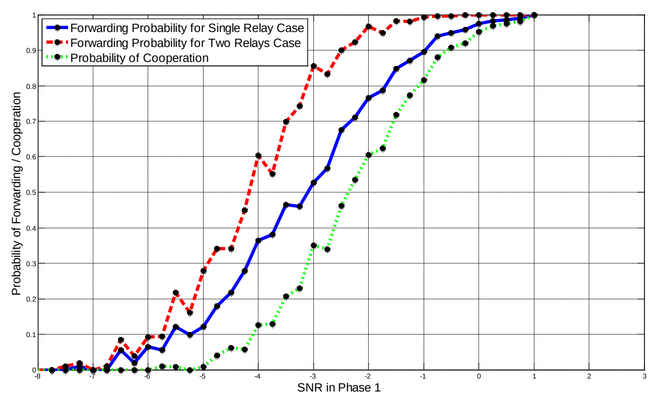

Fig. 4. Phase 1 SNR vs Probability of Forwarding/Cooperation

Fig. 4 indicates the probability of forwarding/cooperation at the relay station(s) in a single relay case and two relays case developed for cooperative communication. As can be seen from the figure, the two-relay case begins with an added advantage of having higher probability of correctly decoding the signal at one of the two relays. The plot in Fig. 4 can also be explained conceptually in a truth table format as indicated in Table 2.

Relay 0	Relay 1	Forwarding	Cooperation
NACK	NACK	No	No
NACK	ACK	Yes	No
ACK	NACK	Yes	No
ACK	ACK	Yes	Yes

TABLE II
Probability of Forwarding/Cooperation

Fig. 5 gives a complete picture in terms of performance enhancement for all the possible scenarios that have been implemented in this research work. All the three relaying scenarios with SHARQ schemes stand out in the figure from the viewpoint of BLER improvement which advocates the necessity of employing HARQ with incremental redundancy in any modern wireless system. The Distributed Alamouti scheme implemented with SHARQ I gives the best performance in terms of end-to-end BLER of the system.

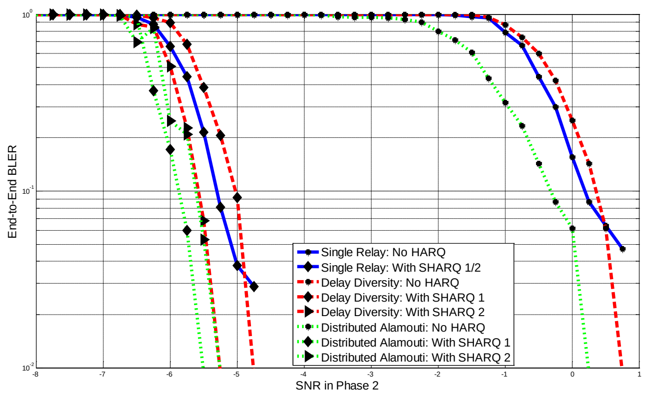

Fig. 5. Phase 2 SNR vs End-to-end BLER for all Scenarios

However, the BLER error rate of any system without the HARQ gives a clear picture of the system's performance, but when HARQ schemes are implemented in any system, the true performance of the system cannot be determined solely on the basis of end-to-end BLER. Therefore the end-to-end throughput of a system gives more reliable information about its performance. The main reason for this difference in the reliability of BLER and the throughput is the inclusion of delay caused due to HARQ schemes in throughput computation.Fig. 6 therefore compares the throughput performance for all the possible combinations of relaying scenarios and HARQ cases to find out the most favorable one among all possible scenarios. The Distributed Alamouti Scheme is concluded

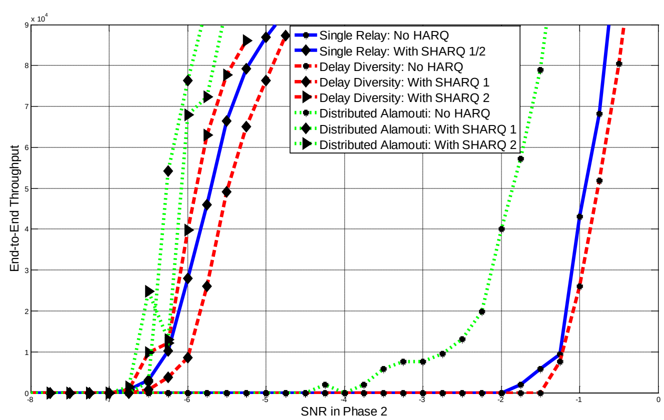

Fig. 6. Phase 2 SNR vs End-to-end Throughput for all Scenarios

to be the most reliable mode of cooperation among two relays for significant performance enhancement as compared to single relay case. The distributed Alamouti system performs exceedingly well when implemented along with the SHARQ schemes by decoding perfectly even at very low values of SNR on phase 2 (uplink).

V. Conclusion

The research work carried out here developed a strategy based on the combination of relaying technology and co-operation among relays by implementing transmit diversity schemes derived from multiple antenna techniques in MIMO systems. In the process, it also gives a very prominent solution for extracting separate channel estimates in order to perform distributed Alamouti scheme. This process of separate channel extraction has a lot of potential scope for even MU-MIMO systems. But most importantly, in order to attain an improved performance at the system level, this work primarily developed new yet very effective SHARQ schemes for cooperative system of distributed relays which are successful in significantly reducing the end-to-end BLER with minimal HARQ delay.

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