# IR-HARQ vs. Joint Channel-Network coding for Cooperative Wireless Communication

Mohamed S. AbuZeid, Yasmine A. Fahmy, Magdy M. S. El-Soudani
Electronics and Communications Department – Faculty of Engineering - Cairo University

***Abstract*—Wireless communication systems demand the use of many coding techniques for data retransmission between sending and receiving end points to achieve the required system capacity over variant channel conditions. Different developed techniques are introduced such as channel coding, network coding and joint coding to achieve this target. As an improvement for wireless communication systems, cooperative wireless communication is illustrated to increase system throughput and enhance system capacity. This paper investigates different data retransmission schemes in cooperative wireless communication systems scenario. More specifically, two considered techniques are compared, Incremental redundancy Hybrid Automatic repeat Request (IR-HARQ) and joint Channel Network coding (NC-HARQ) from throughput and complexity perceptions. The system throughput is derived in both cases to compare the advantages and disadvantages for each technique. Simulations are conducted for different number of end-point receivers to confirm obtained results persistence and trends. Both simulations and theoretical analysis confirm the advantages of the IR-HARQ over the NC-HARQ. Higher throughput and better system capacity is introduced using IR-HARQ when it is compared with NC-HARQ, in addition to decreasing retransmission complexity.**

***Index Terms*— IR-HARQ, NC-HARQ, Joint Channel Network Coding, Throughput, Cooperative Communication.**

## I. Introduction

There are many different schemes used for reliable data retransmissions over noisy wireless channels. Traditionally Automatic Repeat reQuest (ARQ), where the data is retransmitted until correctly received and checked by Cyclic Redundancy Check (CRC) bits, is usually used. Forward Error Correction (FEC) is another technique where a channel correcting code is used to correct erroneous data and prevent the need of retransmission resulting in improving the channel throughput.

Hybrid Automatic Repeat Request (HARQ) [1][2] is a technique that merges the ARQ and FEC techniques where user data and CRC bits are protected by an error correcting code to increase the probability of successful transmission.

Another HARQ model is the incremental redundancy HARQ (IR-HARQ) where the source data is encoded by a mother code and selected numbers of parity bits are transmitted. If a retransmission is requested, additional selected parity bits are transmitted. At the receiver, it combines the old and new received parity bits to try recovering the source data [2][3] .

Finally, Network Coding (NC) [4] has been introduced as one of the promising schemes used for effective and reliable data transmission over wireless networks [4][5][6][7]. In NC, lost packets from different receivers are combined, these packets are broadcasted at certain time slots to different receivers. At the receiving ends, each receiver has the ability to extract its lost packets by performing modulo 2 additions between the received combined packets and earlier successfully transmitted packets. This procedure is repeated till all the receivers get all the source data packets [5].

In [6], joint channel network coding is introduced for single hop wireless network. In this scheme, NC is used for combining maximum number of lost packets and channel coding techniques are also used to protect packets against errors. It shows better performance when compared with some other basic schemes like (ARQ, HARQ, and NC itself) for 2 receivers.

In this paper, joint channel network coding is considered and compared with (IR-HARQ) for cooperative wireless communication system for different number of receivers.

The system throughput is derived for general number of receivers under both schemes, NC-HARQ and IR-HARQ.

The paper structure is as follows. In Section II, the Cooperative system model is introduced. In Section III, analytical and theoretical derivations are presented. In IV, simulation results are revealed. Finally in section V, a conclusion is introduced.

## II. Cooperative Model

Cooperative communication introduces the broadcast advantage and space diversity for wireless transmission. One of the most known cooperative protocols is the Cooperative-ARQ (C-ARQ) in [8]. There are some researches consider joint network channel coding for multiuser model [9].

Hereby, the considered cooperative model consists from a single source and M cooperating nodes. When the source transmits a packet to a certain receiver Rx, all the M-1 neighbors receive a copy. In C-ARQ, if Rx loses a packet, it requests a retransmission from its neighbor/cooperative receivers. Any cooperator node that correctly received this packet earlier can perform the retransmission instead of the source, so nearby receiver acts as secondary source. In case there is no node has the correct copy of the packet, Rx requests a retransmission from the source itself [8].

In similar manner, consider a cooperative wireless communication system as shown in Fig.1, the source transmits data packets to different receivers for the first transmission via wireless channels (highlighted in solid), where there is an additional link between source and one of the receivers (R1). If one or more receivers rather than R1, after first transmission from source to all receivers, gets erroneous bits, first it requests a packet retransmission from R1 which acts as a secondary source. This actually introduces cooperative communication model. If it gets erroneous packet from the cooperative receiver R1, it requests for a retransmission from primary source. NC-HARQ or IR-HARQ is used for lost packet retransmission from secondary source to different receivers. In the same context, assume the redundant link between source and R1 "secondary source" carries retransmissions to R1 using IR-HARQ, where receivers feedback (ACK/NAK) are considered error free.

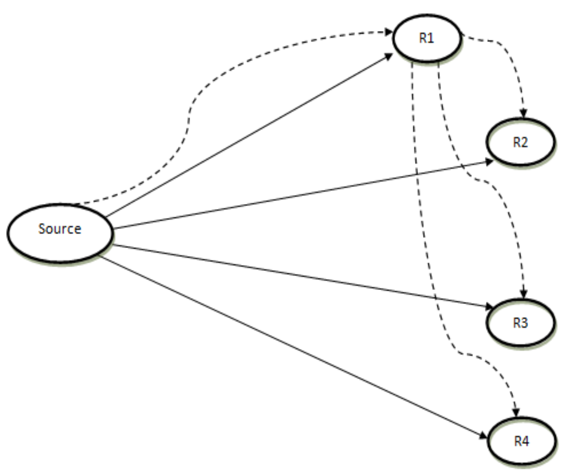


Fig. 1: Cooperative Wireless Communication Model, Single Source and 4 Receivers

## III. Analytical Derivations

Throughout this paper, the throughput (or bandwidth efficiency) is defined as the ratio between the transmitted source information bits and the total number of bits needed to correctly receive these information bits. In this section, the throughput is derived for both cases IR-HARQ and NC-HARQ.

First assume the IR-HARQ case where $K$ information bits are transmitted, $N_o = K + r_1$ is the number of the initial $K$ information bits and $r_1$ the CRC bits transmitted for the purpose of error detection, $N_{FEC}$ is the number of FEC added parity bits that are divided into $L-1$ parity segments. The transmission begins with transmitting the information bits with the CRC bits. In case of successive failures, the first segment of redundancy bits is transmitted then the second, until the last segment of redundancy bits. If the failure persists, the transmitter repeats the process starting from the transmission of the information and CRC bits.

Define $E(Y=j)$ as the expected value of the total number of individual retransmissions for CRC and parity bits segments to reach $j$. This number is divided into $E(Y_o = j_o)$ the expected value of the number of required transmission attempts of the $N_o$ bits to reach $j_o$ and $E(Y_i = j_i)$ the expected value of the number of required transmission attempts to deliver parity bits segment number $i$ of length $N_i$ to all receivers.

The IR-HARQ throughput is then given as follows:

$$\eta_{IR-HARQ} = \frac{K}{N} = \frac{K}{\sum_{i=0}^{L} N_i * E(Y_i = j_i)}$$

Where $E(Y_i = j_i)$ is given as:

$$E(Y_i = j_i) = \left\lfloor \frac{E(Y=j)}{L} \right\rfloor \quad \text{for} \quad i \geq E(Y=j) - L\left\lfloor \frac{E(Y=j)}{L} \right\rfloor$$

and

$$E(Y_i = j_i) = \left\lfloor \frac{E(Y=j)}{L} \right\rfloor + 1 \quad \text{for} \quad i < E(Y=j) - L\left\lfloor \frac{E(Y=j)}{L} \right\rfloor$$

Next assume the joint channel network coding (NC-HARQ) as a retransmission technique [6]. For the first transmission, packet is encoded by CRC error detecting code and then protected by FEC parity check bits. At receiving ends, received packets are decoded using FEC decoder then pass through CRC decoder for error detection. If data is not delivered successfully to all receivers, NC is introduced to combine maximum possible combinations of lost packets from different receivers via modulo 2 additions and retransmit these combined packets in certain time slots.

Hereby, combined packets are encoded with CRC for error detection and protected with FEC parity bits for error correction. At receiving end, decoding operation is applied to check whether there are lost packets or not. If there is at least one or more receiver request for retransmission, the combined packet is rebroadcasted to all receivers till we get a successful transmission. Table-I shows an example for NC-HARQ scheme with four receivers where the lost packets are marked with "X".

In case that more than one receiver lost the same packet, this packet is retransmitted individually without combing it with other lost packets. For example packets (2, 5) in Table-I are retransmitted individually using HARQ till having successful retransmission for these packets to all receivers.

After eliminating packets that are retransmitted individually, the remaining packets are combined via modulo 2 additions, for example (4 $\oplus$ 1 $\oplus$ 3) as shown in Table I. it is retransmitted in certain time slots to all receivers.

TABLE-I
NC-HARQ LOST PACKETS EXAMPLE

| Packets | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| R1 | 1 | X | 3 | X | 5 |
| R2 | X* | 2 | 3 | 4 | X |
| R3 | 1 | X | X | 4 | 5 |
| R4 | 1 | X | 3 | 4 | X |

*X is representing lost packets

Each receiver extracts its lost packets by performing modulo 2 additions between received combined packets and earlier successful received packets found within the combination at the same receiver. For example R1 extracts packet number 4 by performing modulo 2 additions between combined packet with earlier successfully received packets (1,3)

There are different sets of lost packets combinations according to the received ACK/NAK feedback. 2 different lost packets from 2 receivers are combined at least, and up to 4 different packets combination from different receivers.

Remaining packets that don't have pairs are retransmitted individually to all receivers. Only one receiver extracts this packet and it is ignored by other receivers which received it earlier in previous transmissions.

In the following part, theoretical derivations are introduced for NC-HARQ throughput (bandwidth efficiency).

An analytical expression for NC-HARQ is obtained as proved in [6], maximum frame/packet error rates from different receivers are considered as a dominant rate.

In the following derivation, frame error rates from all receivers are considered in order to get more accurate expression for throughput.

Without loss of generality, NC-HARQ throughput can be given by

$$\eta_{NC-HARQ} = \frac{K}{(K + r_1 + N_{FEC}) * E(Y_{NC})}$$

Where $E(Y_{NC})$ is the expected number of the retransmission attempts required to deliver source packets data successfully to different receivers using NC-HARQ.

Assume $P_i^j$ is the packet error rate at receiver $R_i$ at transmission attempt number $j$ where $j$ is the number of required transmission attempts to deliver a packet successfully to all the $M$ receivers. Then we have

$$E(Y_{NC} = j) = \sum_{j=1}^{\infty} j * P(Y_{NC} = j)$$

Where

$$P(Y_{NC} = j) = P(Y_{NC} \le j) - P(Y_{NC} \le j-1)$$

$$P(Y_{NC} = j) = \prod_{i=1}^{M}(1 - P_i^j) - \prod_{i=1}^{M}(1 - P_i^{j-1})$$

Then the expected number of the required retransmission attempts to deliver source packets data successfully to different receivers can be re-written as:

$$E(Y_{NC} = j) = \sum_{i=1}^{M}\left(\frac{1}{1-P_i^j}\right) - \sum_{\substack{\forall i,d \\ i \ne d}}^{M}\left(\frac{1}{1-P_i^j P_d^j}\right)$$

$$+ \sum_{\substack{\forall i,d,l \\ i \ne d \ne l}}^{M}\left(\frac{1}{1-P_i^j P_d^j P_l^j}\right) - \sum_{\substack{\forall i,d,l,m \\ i \ne d \ne l \ne m}}^{M}\left(\frac{1}{1-P_i^j P_d^j P_l^j P_m^j}\right) + \ldots\ldots$$

## IV. SIMULATION RESULTS

In this section and for the purpose of simulation we consider that same packets are transmitted to different receivers in a broadcasting model. Receivers' feedbacks (ACK/NAK) are considered as error free. The transmitted packet is considered as erroneous packet, if it includes at least one bit error. MATLAB is used to obtain different system throughput at different SNR that represents AWGN time variant channels. Same FEC & CRC header size are used for both NC-HARQ and IR-HARQ.

For the considered IR-HARQ, source data is encoded with error detecting code (CRC) and FEC parity bits are all included in one segment. First transmission is sent including data and error detecting CRC bits. If it is received successfully, the FEC parity bits are not sent. If transmission is not successful, FEC parity bits are sent. This procedure is repeated till deliver all packets to all receivers.

Hereby, Reed Solomon RS (127,123) is used for FEC and CRC-19 is used for error detection.

For NC-HARQ, Reed Solomon RS (127,123) for FEC and CRC-19 for error detection are also used. If more than one receiver lost the same packet, this packet will be retransmitted individually without any combination to these receivers. Other lost packets from different receivers are combined (using Modulo 2 additions). At this stage, there are different numbers of packets combinations that could be present according to lost packets hierarchy. For example, in case of 4 receivers, up to 4 lost packets could be combined and retransmitted to different receiving ends.

MATLAB Simulations are conducted for different number of receivers, 2 and 4 receivers are considered. Simulation results reveal the obtained throughput for variable number of receivers.

Figure 2 shows different throughput for 2 and 4 receivers for IR-HARQ and NC-HARQ.

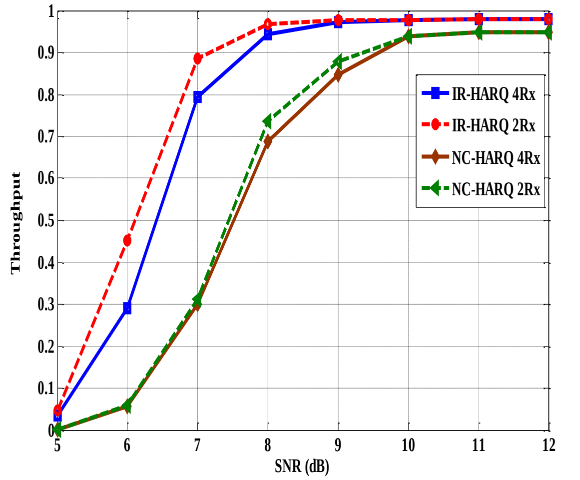


Fig. 2: Throughput comparison with different number of receivers, M=2, 4

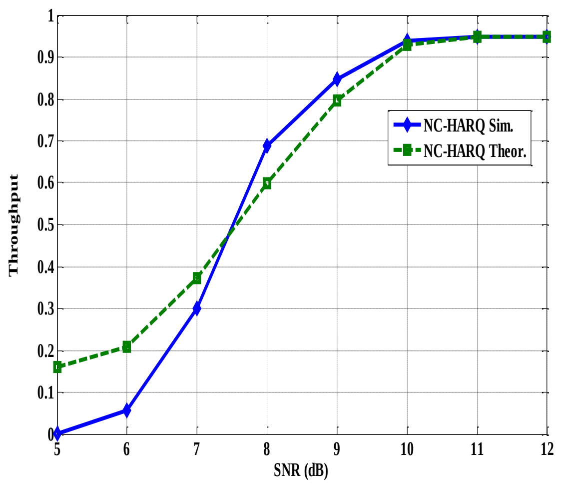


Fig. 3: NC-HARQ Simulation Vs Theoretical results, M=4

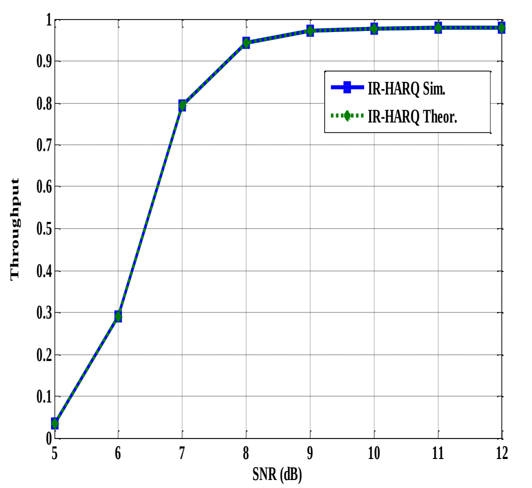


Fig. 4: IR-HARQ Simulation Vs Theoretical results, M=4

As shown in Fig.2, IR-HARQ throughput is much better when compared with joint channel network coding (NC-HARQ) for different channel conditions and different number of receivers. Also as number of receivers increase, system throughput is decreased accordingly.

In order to confirm the theoretical and the simulation results, Fig. 3 and 4 illustrates a study for both theoretical derivations and simulation results for 4 receivers for NC-HARQ and IR-HARQ respectively.

## V. Conclusion

In this paper, IR-HARQ is proposed for cooperative wireless communication system. It achieves higher throughput and better bandwidth efficiency when compared with joint channel network coding scheme (NC-HARQ) for different number of receivers. Both simulation results and theoretical proofs show IR-HARQ throughput advantages over NC-HARQ.

In the same context, some challenges face the use of NC-HARQ, especially for large scale wireless communication systems as the complexity degree of the retransmission scheduling increases. This accordingly extends transmission time and corresponding delays in packet reception.

Especially for lost packets combining and retrieval at different receivers.

Adding more enhancements for network coding, more complicated model should be introduced that implies combining more numbers of lost packets before retransmission. In this case, the retrieval mechanism complexity increases accordingly, which might add more delay at receiving ends to extract its packets via Modulo 2 additions with earlier successful received packets.

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**Mohamed S. AbuZeid** received the B.Sc. in Electronics and Communications engineering from Cairo University, Egypt in 2006.
He is currently a Master Degree student in Electronics & Communications Department, Cairo University.
His research interests include wireless communication, Network Coding and joint channel network coding.
(email: moh_sayed_abuzeid@yahoo.com)

**Yasmine A. Fahmy** received the B.Sc., M.Sc. and Ph.D. degrees in Communication and Electronics engineering from Cairo University, Egypt on 1999, 2001 and 2005 respectively.
She is presently an assistant professor at the Electronics and Communications Department, Faculty of Engineering, Cairo University, Egypt.
Her current field of interest includes wireless communication and channel coding techniques. Since 2010, she has been with the Center of Wireless Studies (CWS), Cairo University. (email: yasfahmy@aucegypt.edu)

**Magdy M. S. El-Soudani** received the B.Sc. and M.S. from Cairo University in 1978 and 1980 respectively, and his Doctorate d' Ingénieur from ENST, Paris, France in 1983.
He is a professor of communication at the Electronics and Communications Department, Faculty of Engineering. Cairo University, Egypt
He is the Director of the National Telecommunication Institute (NTI), Ministry of Communications and Information Technology (MCIT) of Egypt.
Senior Member (SM) of the Institute of Electrical and Electronics Engineers (IEEE), Also member of the Consultation Board for Electrical Engineers, Egyptian Engineers' Syndicate. He is co-founder of the Scientific Society of Telecom Engineers (SSTE) in 1986, and member of the board of directors since that time. SSTE is an NGO society that cares about the Telecom sectors technical problems and skills of its engineers as well the influence of Telecom on the society.
His main fields of research include channel coding (Error Correcting Techniques), Security systems (with applications in Wireless Networks).
The current research work also includes but not limited to the Turbo and LDPC codes, Security Systems (including, identification schemes, intrusion detection, Firewalls, wireless security, ..).
More than thirty papers have been published in specialized technical journals or presented at international conferences. (email: Melsoudani@yahoo.com)