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Deterministic Half-Cycle Transmission Cooperative Network Coding for Wireless Sensor Network over Erasure Channels

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Abstract— Network coding (NC) and a cooperative network are two well-matched technologies; accordingly, the Cooperative NC (CoNC) is defined as the aggregation of data from different users in such a way that users help each other to transmit and receive their data. Researchers applied CoNC over a cluster of Wireless Sensor Network (WSN) at the first stage (two half-cycle stages), and then extended it to the second stage when needed over erasure channels. The required protocol for this network is proposed. Extra half-cycle can be transmitted if full connectivity is not obtained in the first two half-cycle stages, taking into consideration that two extra half-cycle protocols are proposed in this paper. The proposed protocol provides the ability for the network to lose one packet between each couple of users in the second half-cycle 10% of the transmitted packets in the first stage results in decreasing the Automatic Repeat Request (ARQ) significantly in the first stage. Moreover, the protocol saves 50% of the number of the transmitted packets in next stage(s) if needed. A mathematical model is constructed using full reception matrix which is well calculated. It demonstrates improvement of the full decoding and the simplicity of solving the Jordan Gaussian Elimination matrix due to using the proposed deterministic combination protocols. The results confirm that the idea of half-cycle transmission is applicable. This leads to the preservation of the number of re-transmitted packets, and better Packet Error Ratio (PER) which allows obtaining better bandwidth and less transmission traffic.

Keywords— Cooperative network, Erasure channel, Network coding, Packet error ratio, Reception matrix.

I. INTRODUCTION

Network Coding (NC) is such an old technique that was proposed in [1] over wireline network in a multicasting information scenario. It results in a significant improvement in data rate and power consumption, mainly because NC technique tends to transmit less number of combined packets through the uplink channel rather than to transmit a large original number of packets separately (uncombined).

Network Cooperation is a technique where a user cooperates with other users to improve the diversity, the channel bandwidth and the power consumption by transmitting fewer packets over the network and decreasing the number of Automatic Repeat Request (ARQ) for the lost packets over the network. Accordingly, when the network joins the principle of NC and cooperation, it is called Cooperative NC (CoNC) network in [2] and [3]. In wireless communication, cooperation and CoNC are widely used mainly because of the broadcasting nature of the network, where all users in the network can receive all the other user's packets; and hence apply cooperation or CoNC before forwarding them to the rest of users in the same network [2] and [3].

In [3], CoNC is applied in a Base Station (BS) for WSN over Additive White Gaussian Noise (AWGN) channels. Bit Error Rate (BER) is provided to show how practical it is to use CoNC with Decode-Re-encode-Forward BS for a large number of nodes. Amplify and Forward (AF) BS is recommended for such a small number of users because of the cumulative noise when combining the packets. However, unlike the proposed work in this paper, [3] started the CoNC after the first stage as in [2].

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In [4], CoNC is applied over a network with a BS, where NC is applied cooperatively in a single BS such applications result in the improvement of the Packet Error Rate (PER) as well as ARQ because the network has good tolerance to losing a large number of the transmitted packets over the investigated erasure channel with the guarantee of the full connectivity.

However, unlike the proposed work in this paper, [4] started cooperation in the second stage at the BS and at all the nodes in the network, which lost the benefits of the CoNC in the first stage. Moreover, the network nodes and the BS can only transmit N packets in each transmission stage, where N is the number of connected nodes in the whole network. Unlike the proposed work in this paper, it is possible to transmit $N/2$ packets in each additional stage (half-cycle transmission).

The proposed work investigates the benefits that can be gained from applying CoNC over the first stage and the advantage of sending half stage ($N/2$) packets in the second stage instead of sending full stage (N packets). The application of CoNC contributes to reducing the number of the transmitted packets, i.e., better channel bandwidth and less power consumption and ARQ.

In [2] and [5], CoNC was applied on WSN over Rayleigh Fading channel, represented by Finite State Markov Chain (FSMC), which provides an acceptable practical results for using CoNC over WSN when a certain number of users are placed in equal distance for a destination. In [6], CoNC was applied over an erasure channel for the application of Long Term Evaluation mobile network. It shows how network performance improved significantly in term of power consumption and data rate.

In [7], [8], and [9], NC was investigated over the physical layer with different forward error correction codes and different scenarios to prove that NC and/or CoNC are practical bandwidth techniques with such acceptable BER over the physical layer. In [10], two senders communicate through one relay with two receivers in a full duplex channel model which is proposed to provide good understanding of NC behavior.

The recent work in [11] provides a useful coding algorithm that fits the dynamical network by taking the advantage of the feedback three-receiver scenario.

The feedback advantage for WSN has been recently investigated in [12] for a practical blind instant decoding network over a lossy feedback environment. Though [12] is far from the proposed work in this paper, it shows how quickly and importantly WSN is in need for applying new techniques such as CoNC over dynamic networks.

It is important to assure that it is possible to apply the feedback scenario in the proposed work to gain more bandwidth saving and power consumption.

In [13], [14], and [15], most of the recent work applied over WSN has used CoNC with different important techniques. I believe it gives good and important knowledge about the most updated CoNC WSN techniques which differ from the proposed work in that our proposed CoNC starts in the first stage and is applied in each half-cycle rather than in the full stage.

The rest of the paper is organized as follows: Section 2 explains the system model; Section 3 introduces the proposed system model; and Section 4 shows the proposed protocol for WSN based on CoNC. The simulation results are shown in Section 5 to show the benefits gained by applying the proposed technique. Finally, Section 6 concludes the paper.

II. SYSTEM MODEL

In this paper, a WSN allows N nodes to exchange data over erasure channels, where $N \geq 2$ nodes $N_1, N_2, ..., N_N$ is investigated.

In the traditional method of communication which is called "benchmark" scenario, communication is performed in one or two stages. Thus, if all the nodes receive the entire neighbor packets (*N*-1), communication will end and new data will be transmitted. Otherwise, a second stage follows by repeating the first stage. Accordingly, in the benchmark scenario, neither NC nor cooperation is applied in both stages.

Based on the above, each node broadcasts its packet separately, i.e., uncombined and alone without any cooperation with any of the other nodes. This means that N_i broadcasts the packet X_i where i=1, 2, ..., *N*, in its own corresponding time internal slot is specified by using Time Division Multiplexing Access (TDMA) to avoid overlapping transmission for the *N* nodes. It is assumed that each node transmits the same information packet length to the whole network. Fig. 1 shows the WSN nodes for four nodes (*N*=4) for the first stage in the benchmark scenario.

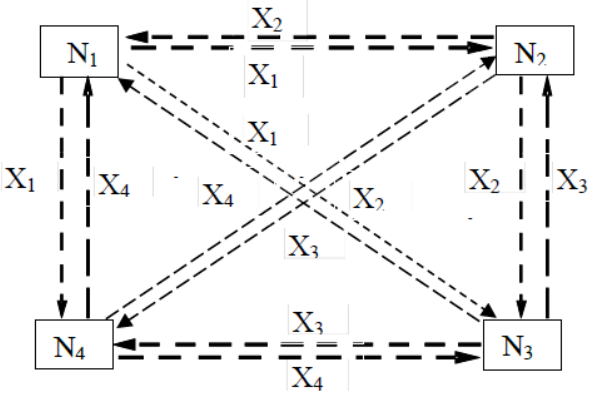

Fig. 1. WSN example for the first stage when *N*=4 nodes where N_i broadcasts X_i to N_j node, j=1,2…, *N* and $i\neq j$ [16]

The probability of not receiving the packet between any two users is *q*, which is assumed to be the same for all channels. Moreover, each node informs the *N*-1 neighbors and decodes the entire packets successfully by broadcasting a simple feedback message, which is assumed to be transmitted.

So, at the end of the first stage, each node receives a maximum of *N*-1 nodes, taking into consideration that each node knows its own packet. So, at the end of the first stage, each node receives a maximum of *N*-1 nodes, taking into consideration that each node knows its own packet at end of the second stage, each node receives a maximum of 2(*N*-1) packets, i.e., twice of *N*-1 packets if all packets are successfully received. The PER, for full reception at each node and for the whole network after the first and second stages for this case (benchmark scenario when CoNC is not applied), is shown in [4].

It is easy to notice that the benchmark suffers from many serious disadvantages. If one channel in the network is not connected (regarded dead) with other nodes, the communication will never be completed. Repeating the same packets in the second stage does not carry any new information to improve the PER for the network; and finally, sending all the packets in the second stage is regarded as bandwidth and power inefficient scenario.

The proposed protocol in this paper is mainly directed to solve the above disadvantages and ensure better bandwidth, power consumption and PER network, which is introduced in the following section.

III. PROPOSED HALF CYCLE CONC SYSTEM

The proposed CoNC is applied over the first stage of transmission, which is possible when applying the two half-cycle transmission.

A. First Stage Proposed Half-Cycle CONC System Model

We propose a simple and practical deterministic combining protocol that tends to apply CoNC in the first stage in order not to lose the benefits that can be obtained from this useful technique, taking into consideration that the proposed protocol does transmit the same number of packets (*N* packets) after the first stage (two half-cycle stages).

The proposed combination strategy is regarded as a simple NC operation over a binary field, where combined packets are added using the simple XORing addition. Only one bit header is required to inform the receiver whether the received packet is simple (uncombined) or combined as a result of using a deterministic combination in the second half-cycle.

Indeed, if the *N* sensor cluster nodes are divided into two sub-clusters, where each cluster contains *N*/2 nodes, and the sub-cluster sensor nodes transmit their packet at a separate stage, we can assume that each sub-cluster is considered a half-cycle transmission; and communication will be performed in term of a half-cycle instead of full ones. To simplify the protocol, it is assumed that the nodes with odd numbers form the first sub-cluster while the rest (even numbers) nodes form the second sub-cluster. Clearly, if *N* is even number, then we will have two sub-clusters with *N*/2 nodes in each sub-cluster; and if *N* is odd, then the odd sub-cluster will have one more node than the even sub-cluster. Whether *N* is odd or even does not change the proposed protocol algorithm.

First of all, the odd nodes (odd sub-cluster) transmit their packets, where the even nodes (even sub-cluster) remain in the receiving mode. Accordingly, the first half-cycle transmission ends while each node in the whole network knows all the odd sub-cluster nodes in the case of full reception no CoNC is applied in the first half-cycle stage. At the end of the first half-cycle stage, each node will receive odd sub-cluster nodes.

In the second half-cycle stage, even sub-cluster nodes will be in a transmission mode, while odd and even sub-cluster nodes will be in a receiving mode.

The even sub-cluster nodes will apply CoNC in this half-cycle stage instead of sending their separate nodes. The second half-cycle stage begins after the end of first half-cycle stage where CoNC is applied over the second half-cycle stage. In the second half-cycle stage, each even node will add all the received odd node packets to its own packet, ending up with sending *N*/2 packets in the second half-cycle as well. The packets transmitted after the first stage remain the same as in the full stage scenario which is *N*. An example of six sensor nodes (*N*=6) is shown in Fig. 2 in which the odd sub-cluster first half-cycle transmission is shown.

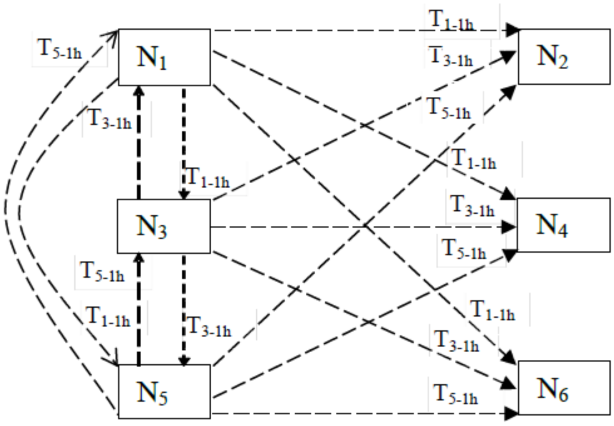

Fig. 2. First half-cycle transmission where CoNC is not applied [16]

$T_{i\text{-}1h}$ is the transmitted packet from node *i* at the first half-cycle while *i*=1, 2, ..., *N*.

It is clear that each node will know all the *N*/2 odd packets in case of full reception as shown in (1) which represents Jordan Gaussian Elimination (JGE) matrix in the full reception scenario:

$$\begin{bmatrix} T_{1-1h} \\ T_{2-1h} \\ T_{3-1h} \\ T_{4-1h} \\ T_{5-1h} \\ T_{6-1h} \end{bmatrix} = \begin{bmatrix} X_1 & X_2 & X_3 & X_4 & X_5 & X_6 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{1}$$

where X_i is the transmitted packet from node *i*, where *i*=1, 2, ..., *N* [16].

From (1), we notice that the odd nodes transmit their own packets separately and alone. This results in (2), (3), (4) and (5):

$$T_{1-1h} = X_1 \tag{2}$$

$$T_{3-1h} = X_3 \tag{3}$$

$$T_{5-1h} = X_5 \tag{4}$$

$$T_{2-1h} = T_{4-1h} = T_{6-1h} = 0 \tag{5}$$

In the second half-cycle transmission, CoNC is applied in a deterministic manner where each even node combines the received packets from the odd nodes from the first half-cycle with its own packet.

The transmitted packets in the second-cycle (from even nodes) are given in (6):

$$\begin{bmatrix} T_{1-2h} \\ T_{2-2h} \\ T_{3-2h} \\ T_{4-2h} \\ T_{5-2h} \\ T_{6-2h} \end{bmatrix} = \begin{bmatrix} X_1 & X_2 & X_3 & X_4 & X_5 & X_6 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 & 1 \end{bmatrix} \tag{6}$$

Where T_{i-2h} is the transmitted packet from node *i* in the second half-cycle while *i*=1, 2, ..., *N*. From (6), even sub-cluster nodes apply CoNC by transmitting their own packets combined with the packets received in the first half-cycle [16]. Fig. 3 shows the second half-cycle:

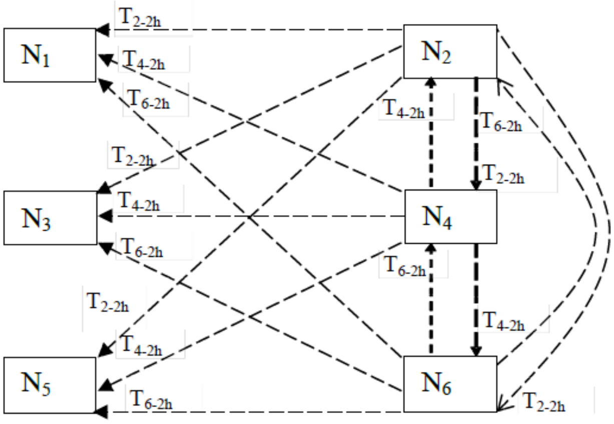

Fig. 3. The transmitted packets in the second half-cycle by the even sub-cluster nodes **A** after applying CoNC [16]

In Fig. 3, each node in the even sub-cluster broadcasts its own packet combined with the odd packets received in the first half-cycle:

$$T_{2-2h} = X_2 \oplus X_1 \oplus X_3 \oplus X_5 \tag{7}$$

$$T_{4-2h} = X_4 \oplus X_1 \oplus X_3 \oplus X_5 \tag{8}$$

$$T_{6-2h} = X_6 \oplus X_1 \oplus X_3 \oplus X_5 \tag{9}$$

$$T_{1-2h} = T_{3-2h} = T_{5-2h} = 0 \tag{10}$$

At the end of the first stage, i.e., the first odd sub-cluster and second even sub-cluster, each user will be able to have $T_{i\text{-}jh}$ different packets where i=1, 2, ..., N; and j=1 and 2, taking into consideration that N_i node replaces its own packet (X_i) with $T_{i\text{-}jh}$ where j=1 and 2; and i=j; node 2 replaces $T_{2\text{-}2h}$ with X_2 at its end.

In conclusion, each user receives five different packets at the end of the first stage as shown in Eq. (11) at the forth (N_4) node:

$$\begin{bmatrix} R4_{1-1h} \\ R4_{3-1h} \\ R4_{5-1h} \\ R4_{2-2h} \\ R4_{4-2h} \\ R4_{6-2h} \end{bmatrix} = [X_1 \quad X_2 \quad X_3 \quad X_4 \quad X_5 \quad X_6] \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 & 1 \end{bmatrix} \tag{11}$$

Where $R4_{i\text{-}jh}$ is the received packet at node 4 from node i in j half-cycle where i=1, 2... N and j=1 and 2 [16].

For (11), we find out that $R4_{4\text{-}2h}$ is equal to X_4 because node 4 knows its own packet.

When comparing (11) with traditional first stage transmission where CoNC is not applied, we can conclude the following gained advantages:

- Theory 1: The N transmitted packets after the first stage i.e., two half-cycle as in (11) give N linearly independent equations with rank N receiving matrix.
- Theory 2: Any node in the even sub-cluster can decode all users even in the case of losing one packet of odd sub-cluster nodes. Accordingly, the WSN gains the ability to lose N/2 packets over the whole network because the received matrix (11) consists of N pivots, where any N-1 of them can give full rank matrix. Each user knows its own packet and replaces it with the lost one to make the received matrix decodable by using JGE method, which confirms that the receiver has to receive rank N linear independent equations to be able to decode the N packets [4]. Equation (11) proves this for node 4 as an example when N=6. So, if any of the odd nodes is not received at the decoding node (node 4), the rest of the received matrix can solve the problem as it has rank N receiving matrix.
- Theory 3: The combination adapted in the second half-stage is a deterministic combination, which simplifies the GJE significantly [3]; equation (11) shows this clearly.
- Theory 4: If any packet transmitted from the second half-stage is not received at any node in the whole network, the system will not be able to decode its node packet as the remaining rank of the received matrix is less than N. In such a case, network goes for extra transmission stages; and it is the same if more than one odd packet is not received at the even nodes.

- Theory 5: The CoNC proposed in the first stage, precisely, in the second half-stage, does not require any extra transmitted packets as each node is transmitting one packet through this half-cycle.
- Theory 6: The network needs ARQ in the case of not full reception, i.e., when one user in the WSN fails to recover all neighbor packets. Accordingly, the proposed protocol decreases the number of the required ARQ as each node in the even sub-cluster is tolerant not to receive one packet of an odd node from the odd sub-cluster.
- Theory 7: If not full reception is declared by the *N* nodes, the second transmission stage follows in term of a third half-cycle where just *N*/2 nodes are in a transmit mode; and all *N* nodes are in a receiving mode.

B. The Second and Third CoNC Proposed Half-Cycle Stage Protocols

Based on theory 7, if not full reception is declared by the N nodes, a third half-cycle follows. It is important to understand that any combination strategy can be adapted in this half-cycle. However, deterministic strategies are proposed in this work to maintain the bit header needed to confirm the received packets and the combined packets.

The proposed third-cycle in this paper is as follows: the third half-cycle proposed could have many different deterministic strategies as explained below:

B.1. Single Odd Packet Combined to all Even Packets Half-Cycle Protocol

In this proposed protocol, the odd sub-cluster takes the term of transmission, where odd nodes will combine all the received packets from the even sub-cluster nodes with their packet, resulting in *N*/2 new novel linearly independent equation. For the example of six WSN nodes, as a result, the transmitted packets in this half-cycle are given below:

$$T_{1-3h} = X_1 \oplus X_2 \oplus X_4 \oplus X_6 \tag{12}$$

$$T_{3-3h} = X_3 \oplus X_2 \oplus X_4 \oplus X_6 \tag{13}$$

$$T_{5-3h} = X_5 \oplus X_2 \oplus X_4 \oplus X_6 \tag{14}$$

$$T_{2-3h} = T_{4-3h} = T_{6-3h} = 0 \tag{15}$$

At the end of the third half-cycle, a maximum of nine unique linearly independent equations are received by the *N* nodes.

$$\begin{bmatrix} T_{1-1h} \\ T_{3-1h} \\ T_{5-1h} \\ T_{2-2h} \\ T_{4-2h} \\ T_{6-2h} \\ T_{1-3h} \\ T_{3-3h} \\ T_{5-3h} \end{bmatrix} [X_1 \quad X_2 \quad X_3 \quad X_4 \quad X_5 \quad X_6] \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 \end{bmatrix} \tag{16}$$

Equation (16) shows that an additional three (*N*/2) unique packets are added in a deterministic algorithm, which gives extra three unique linearly independent equations in illustration of six nodes WSN.

Each node will need to evaluate the received matrix rank to ensure obtaining the rank *N* matrix, taking into consideration that each user knows its own packet; hence, *N*-1 rank is enough because the single node packet is a novel independent linear equation.

Accordingly, each node is more likely to recover the un-decoded packet from the first stage, and even more tolerant not to receive more packets. If full reception is not declared, the system goes for the fourth half-cycle.

B.2. N-1 Combined Packets by the Even Nodes Half-Cycle Protocol

In this deterministic half-cycle, the even sub-cluster takes turn to transmit; and they combine all packets excluding their own packets. The reason that each node excludes its own packet is to obtain maximum unique combinations and, hence, avoid repeating the same packets while the odd nodes are in a receiving mode as shown in the following equations:

$$T_{2-4h} = X_1 \oplus X_3 \oplus X_4 \oplus X_5 \oplus X_6 \tag{17}$$

$$T_{4-4h} = X_1 \oplus X_2 \oplus X_3 \oplus X_5 \oplus X_6 \tag{18}$$

$$T_{6-4h} = X_1 \oplus X_2 \oplus X_3 \oplus X_4 \oplus X_5 \tag{19}$$

$$T_{1-4h} = T_{3-4h} = T_{5-4h} = 0 \tag{20}$$

At the end of this half-cycle, each node will receive a maximum of twelve (2*N*) unique independent equations as shown in (21):

$$\begin{bmatrix} T_{1-1h} \\ T_{3-1h} \\ T_{5-1h} \\ T_{2-2h} \\ T_{4-2h} \\ T_{6-2h} \\ T_{1-3h} \\ T_{3-3h} \\ T_{5-3h} \\ T_{2-4h} \\ T_{4-4h} \\ T_{6-4h} \end{bmatrix} [X_1 \quad X_2 \quad X_3 \quad X_4 \quad X_5 \quad X_6] \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix} \tag{21}$$

Any deterministic combination can be proposed in term of half-cycle. In this work, simulation results show the PER gained from using the proposed combination strategies in (21).

Full reception probability is such a tedious mathematic process to find out following the same analysis adapted in [4]. However, simulation analysis is enough to give such a clear idea about the behavior of the PER though [4] is unlike the proposed work in that it deals with applying CoNC in full stages rather than half-cycle transmission. Moreover, the communication precool in [4] is proposed for a destination that receives all the data from all nodes in the network. Fig. 4 shows the block diagram for four half-cycle CoNC systems.

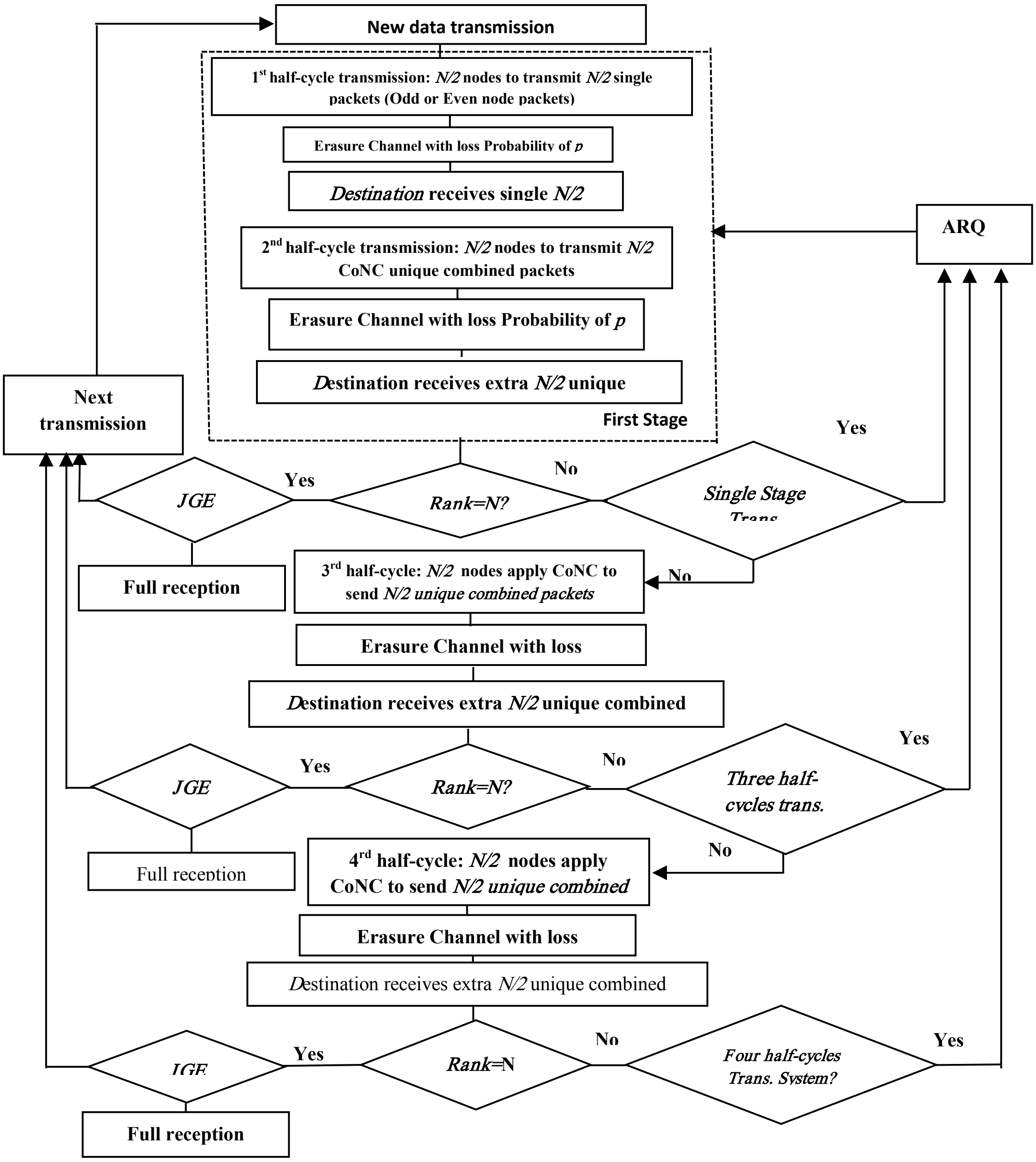

Fig. 4. Block diagram for four half-cycles CoNC system

IV. SIMULATION RESULTS

The proposed scenario is simulated using Matlab program, where a different number of WSN cluster size is simulated. The program runs till collecting a minimum of 100 errors, where the error is identified as the failure of any user i to receive any packet from the N-1 members in the cluster. So, we are seeking full connectivity between the N cluster nodes. Moreover, the results are collected at node 4, and hence, seek to receive the other N-1 packets.

The collected results for the proposed combining protocol are compared with the benchmark results, where CoNC is not applied; and each node sends its own packet separately.

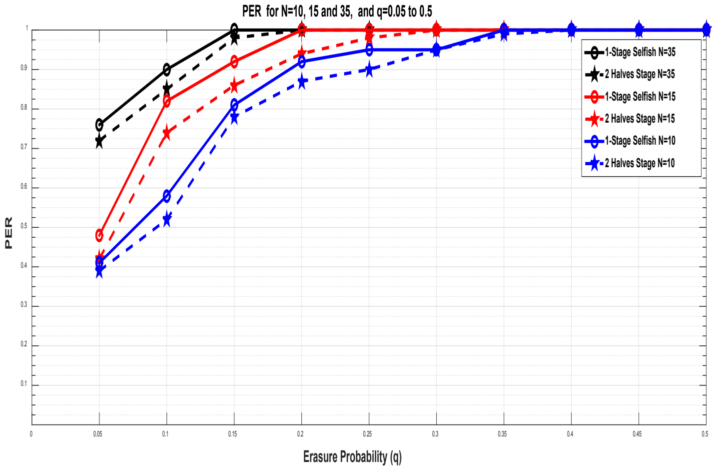

Fig. 5. PER for single stage selfish system compared with the proposed two half-cycle for a cluster size of 10, 15 and 35 with q changes from 0.05 to 0.5 [16]

Fig. 5 shows that the proposed protocol improves the PER by almost 10% and confirms the theoretical point of view. Moreover, it is clear that when the cluster size increases, full connectivity becomes more and more difficult in the benchmark scenario and in the proposed two half-cycle scenarios. However, it is clear that the proposed protocol maintains the 10% improvement even for a large number of nodes.

More importantly, the results show that applying transmission in a half-cycle gives us the opportunity to apply CoNC in the first stage and a half-cycle scenario. This constitutes the main purpose to prove in this work. In Fig. 6, full connectivity for a cluster of 10 nodes (5 nodes each half-cycle) is illustrated.

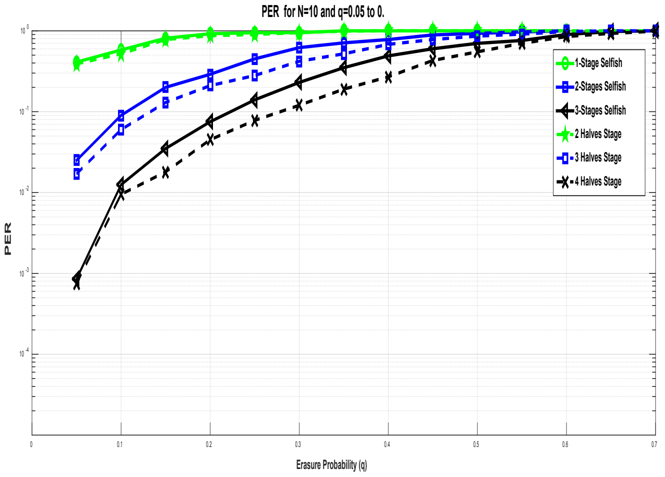

Fig. 6. A cluster of N=10 nodes PER is shown for Benchmark single, two, and three stages of transmission compared to two half-cycle, three half-cycle and four half-cycle transmission

Fig. 6 shows that two half-cycle stages slightly overperform a single stage transmission as shown in Fig. 5. However, when the protocol goes to the third half-cycle, it is clear that it overperforms the two single stages though it uses 1.5*N* transmitted packets instead of 2*N*. This contributes to saving power transmission and having better bandwidth and less traffic. The same notice can be obtained when comparing the fourth half-cycle with two and three single stages, as the former significantly overperforms two single stages though it has the same number of transmitted packets (2*N*). In fact, its overperformance of the three single stage leads to saving the *N* transmitted packets.

Figs. 7 and 8 show the exact behavior when changing the number of users to 15 and 35 as shown below:

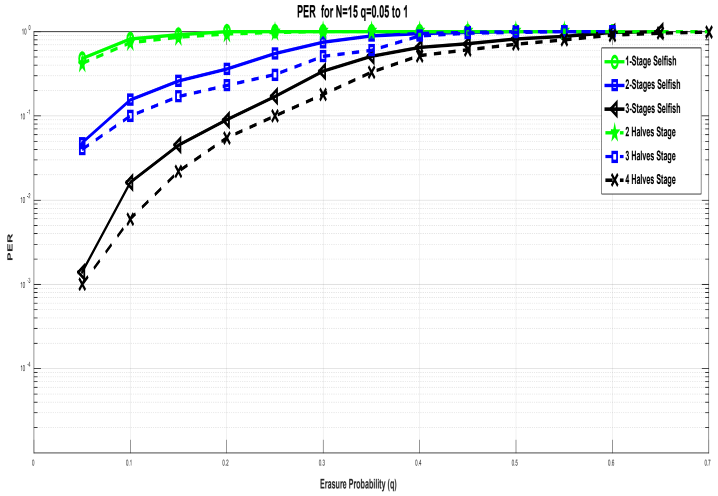

Fig. 7. A cluster of N=15 nodes PER is shown for Benchmark single, two, and three stages of transmission compared to two half-cycle, three half-cycle and four half-cycle transmission

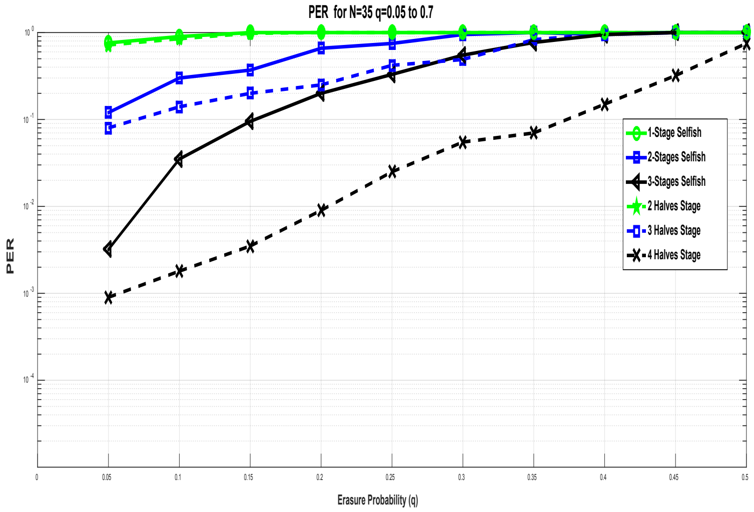

Fig. 8. A cluster of N=35 nodes PER is shown for Benchmark single, two, and three stages of transmission compared to two half-cycle, three half-cycle and four half-cycle transmission

Figs. 7 and 8 show that the larger the number of WSN nodes, the better improvement obtained when applying the proposed protocol. This is simply justified by increasing the ability to drop more packets and the number of the nodes that can exploit the proposed CoNC protocol.

V. CONCLUSION

In this paper, the joint network coding for a Wireless Sensor Network (WSN) is applied over erasure channels where Cooperative Network Coding (CoNC) technique is applied at the first stage in term of two half-cycle transmission with optional extra half-cycle transmission stages. If full connectivity is not obtained in the two half-cycle stages, two extra half-cycles are proposed in this paper. The proposed scenario provides better throughput and lower power consumption with better Packet Error Rate (PER) and less traffic.

The proposed protocol enables the network to lose one packet between each couple of users in the second half-cycle. This results in decreasing the Automatic Repeat Request (ARQ) significantly in the first stage. Moreover, the protocol saves 50% of the number of the transmitted packets in next stage(s) if needed, i.e., sending extra *N*/2 packets in the extra stage rather than *N* packets.

The full reception matrix de-coding method is well calculated; and it proves the improvement of the full decoding and the simplicity of solving Jordan Gaussian Elimination matrix due to using the proposed deterministic combination protocols in the half-cycle stages.

Finally, the results are totally equivalent to the theoretical principles; and they confirm that half-cycle transmission is applicable and leads to decreasing the number of re-transmitted packets and having better PER, better bandwidth and less transmission traffic.

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