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Bit and Packet Error Rate evaluations for Half-Cycle stage cooperation on 6G wireless networks

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ABSTRACT

The excellent features of the sixth generation (6G) of wireless technology enthuses researchers to apply advanced and complex techniques on mobile communication networks, which is what this paper explores. As a result of the ability of 6G to exchange vast data rates and network programming, the Cooperative Network Coding (CoNC) technique can be implemented to improve the connectivity and diversity within 6G applications.

Though CoNC is usually implemented at the second stage, this paper proposes dividing the first stage into two Half-Cycle stages, and then applying CoNC at the second Half-Cycle stage. The resulting Bit Error Rate (BER) behaviour is investigated on the physical layer for direct data exchange in 6G local mobile networks over an Additive White Gaussian Noise (AWGN) channel. Partial Unit Turbo Code (PUTC) (4,2,1,4) and (8,4,3,8) are used by each mobile node as the forward error correction technique, which means that each mobile acts as a Base Station (BS) for other mobiles in the local network by applying CoNC on the received packets, and then each mobile node (or BS), either Amplify-and-Forward (AF), or Decode-re-encode-amplify and Forward (DF), acts. When full connectivity is not achieved at the end of the first two Half-Cycle stages, new Half-Cycle stage transmissions follow, and the BER behaviour for all additional Half-Cycle stages is obtained. The results illustrate that applying CoNC at the second Half-Cycle stage of the first general stage produces a limited BER loss. To mitigate the damage in the BER, a soft-decision PUMTC decoder is also proposed.

1. Introduction

Over the last five generations of wireless communication, it was proven that each generation required around ten years to be thoroughly investigated and implemented; hence starting research on 6G at such an early stage is justified by the expectation of ten further years until 6G becomes wholly established. Additionally, it is essential to understand that research on 6G means simply working on the techniques that 5G cannot deliver until the arrival of 6G. The desire to explore and achieve this future technology has resulted in making “6G techniques” one of the most searched key terms on Google in recent times; a clear indication of how mainstream the public interest in this field is.

The evaluation of 6th generation wireless communication was recently proposed in [1], where the potential 6G challenges and the expected future technologies were investigated. In [2], the future vision for 6G was summarised in four key terms: intelligent, deep, holographic, and ubiquitous connectivity. As such, proposing Cooperation Network Coding (CoNC) satisfies most of the 6G vision, moreover, [2] presents the technologies that are regarded theoretically as crucial for 6G.

5G already provides the feature of network programming as presented in [3] and [4]; hence 6G is expected to introduce more powerful network programming that could enable the application of Linear Network coding (LNC) technology to improve the communication connectivity for high data rates, mainly in lossy channels where packet losses are expected. On that basis, this

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Table 1
Relative memory complexity of coders [16].

Block code	PUM code	UM code	Convolutional code
M = 0	M < k	M = k	M > k

paper proposes applying CoNC on 6G and investigating the Bit Error Rate (BER) for the proposed CoNC scenarios.

Network Coding (NC) as a technique was proposed in [5] for a wired multicasting communication scenario, where different packets with equal m-bits sizes were XORed (combined) in one m-bits packet at the physical layer, causing a significant drop in the amount of the propagated packets, resulting in the improvement of the data rates and power efficiency [6–9]. On the other hand, a network is named a cooperative system when network nodes cooperate in delivering each other's information, whether NC is applied or not [10,11]. Accordingly, when linking the NC technique with the cooperation principle, another improvement is achieved regarding diversity and the Packet Error Rate (PER). However, there is a relatively small loss in the BER when using Decode-Re-encode-Amplify and Forward (DF) Base Station (BS). The BER loss when applying Amplify-and-Forward (AF) BS for a small number of nodes, is regarded as acceptable, though it is not as good as DF [11]. Furthermore, [11] shows how implementing CoNC in an erasure channel significantly decreases the Automatic Repeat Request (ARQ).

In [12], NC was applied to an enormous, high-dimensional data transference, such as in Smart Grid, where security and denoising matters were considered. More recent work that involves NC on Smart Grids can be found in [13,14], and the references therein. The research work in [15] introduces a technique to decompose the overall network to small building blocks of physical NC, which is unlike the proposed work in this paper. This paper is focused on the general physical layer network, primarily to evaluate the effect of applying CoNC at the first stage in terms of two Half-Cycle stages on 6G local mobile network nodes, and then broadcasting additional new Half-Cycle stages when required to achieve full connectivity between all nodes, taking into consideration that 6G provides the ability to program the network as shown in [3] and [4].

The forward error correction techniques applied in this paper are the Partial Unit Memory Turbo Code (PUMTC) (4,2,1,4) and (8,4,3,8) as in [16], where PUMTC is considered as a convolutional code with multiple-input. The maximum free Hamming distance in PUMTC depends on the number of the input memory registers and the number of the input bits achieved in [16]. In PUMTC, the number of memory registers is more than zero and fewer than the number of the input bits, which makes it hold an intermediate position between block (zero memory units) and convolutional codes (the number of memory units is more than the number of input bits), as shown in [16–18], where M is the memory size, i.e. the number of registers, and k is the number of input bits to the encoder.

Table 1 shows that the Partial Unit Memory (PUM) code exploits the advantages of both block and convolutional codes, which qualifies PUM to be a suitable and highly recommended forward error correction code for future 6G applications. Judiciously linear error correction codes were introduced in [19] as a novel idea to improve physical layer communication reliability, however [19] neither introduced the principle of soft-decoding in the middle nodes, nor applied CoNC at the first stage. More work was performed on PUMTC, such as the work in both [20, 21], where in [20] a comprehensive theoretical background for using CoNC on wireless network physical-layer is introduced, and in [21] PUMTC was presented to combine data on the physical layer where the cooperation starts after the first stage in a hard-decision decoding manner. The most recent work for the application of CoNC on the physical layer has been presented in [22], where soft and hard decision encoder–decoder PUMTC was used to show the advantages of performance of the soft-decision encoder–decoder over the hard-decision, on a cluster of Wireless Sensor Networks (WSNs). More related work on using CoNC on WSN application was introduced in [23–25], where in [23] the CoNC improved the diversity. In [24], a cooperative relay was proposed to enhance the mechanism of the retransmission, and in [25], CoNC was applied to improve the routing performance.

Applying CoNC on higher layers, such as the network layer, has been introduced for different purposes and applications [26–28]. Unlike the work presented in this paper, [26] proposed CoNC performance analysis over a lossy channel that connects M users and a destination, where the CoNC starts after the first stage, i.e. no cooperation at the first stage. In [27], a deterministic CoNC was applied on Long Term Evaluation advanced communication system (LTE), which shows that CoNC is such an excellent technique to enhance the reliability of the system, even when used in a lossy erasure channel. Again, in [27], the CoNC starts after the first stage.

The proposed work in this paper builds upon [28] that suggested using CoNC over a lossy erasure channel at the first stage. As such, the BER loss for Half-Cycle stage transmission that occurred after applying CoNC at the first stage is investigated for a 6G local wireless mobile network. Moreover, soft-decision PUMTC decoding is used to evaluate the system BER's performance to mitigate the loss in the BER which occurs from combining different packets, as shown in [18].

The rest of the paper is organised as follows: Section 2 explains the system model, Section 3 introduces the basic concepts of the proposed system model, followed by Section 4, which shows the recommended protocols for 6G local mobile networks based on CoNC, including the proposed NC combination algorithms on the physical layer. The simulation results for the proposed hard and soft-decision PUMTC (4,2,1,4) and (8,4,3,8) are shown in Section 5, to explain results of the BER loss as a trade-off for the obtained gain in the PER. Finally, Section 6 concludes the paper.

2. System model

In this paper, a local 6G mobile network that consists of N nodes is assumed to be implemented to exchange data between the N nodes, over AWGN channels, where $N \geq 2$.

Building on [28], the proposed work in this paper is focused on discovering the impact of applying CoNC at the first stage of transmission in terms of the loss in BER, as a result of combining the packets when PUMTC (4,2,1,4) and (8,4,3,8) are used as a forward error correction technique. The obtained BER is then compared with the "benchmark" scenario, which is regarded as the system to be compared with, where neither NC nor cooperation is applied. Moreover, PUMTC soft-decision decoder is proposed to improve the BER as, shown in [22].

Communication via the traditional approach ends after the first stage when each mobile receives the N-1 other local mobile network's packets, otherwise, a second transmission stage follows by repeating the first stage, rather than sending new data. Accordingly, each member of the local 6G mobile network N_i transmits its m-bits PUMTC encoded packet x_i where $i = 1, 2, \ldots, N$, for all local network's nodes. Each packet is sent in its own corresponding time internal slot specified for it by using Time Division Multiplexing Access (TDMA), to avoid the overlapping transmission for the N nodes.

Fig. 1 1illustrates a 6G local mobile network cluster for four nodes ($N = 4$) transmitting their packets at the first stage, where no Base Station (BS) is implemented:

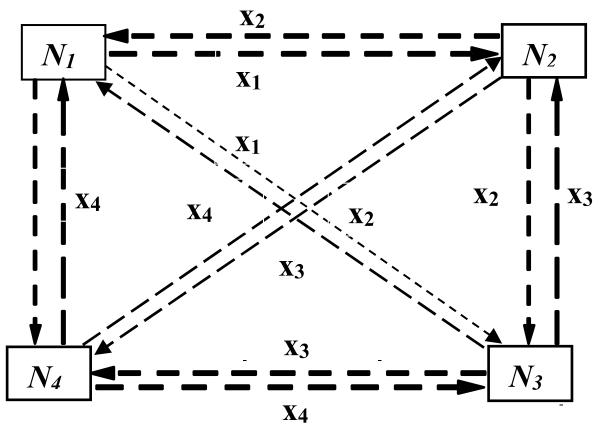

Fig. 1. 6G local mobile network example for the first stage when N = 4 nodes where N_i broadcasts x_i to N_j node, j = 1, 2 …, N and i≠j.

The PUMTC encoded packet x_i is sent to the other nodes in the local network through the Up-Link (UL) channel. The packet received by the N-1 nodes becomes a soft value packet, i.e. the transmitted packet with the added UL channel AWGN, as shown in (1):

$$s_{i-j} = x_i + z^{UL}_{i-j}, \tag{1}$$

where s_{i-j} is the received soft value at node j for the packet sent from node i, and z^{UL}_{i-j} is the UL channel noise per the unit power for the channel between the nodes i and j.

So, the first transmission stage applies neither NC nor cooperation techniques; moreover, all nodes broadcast their packets at the same time, i.e. all nodes are in transmission mode, and all of them broadcast in one full single stage. When each node receives the N-1 local network's packets and manages to decode them correctly, the first stage is confirmed to be completed.

3. Preliminaries: Half-Cycle stages transmission system

When not all N mobiles in the local network manage to decode the N-1 other local network's packets correctly, the second transmission stage follows. In the benchmark scenario (where NC is not applied), each local network's node only amplifies the received N-1 soft values before forwarding them to the other N-1 nodes in the local network. Accordingly, the received soft values at each node that transmitted from the second stage are shown in (2):

$$\hat{s}_{i-j} = A_{AF} s_{i-j} + {z_{i-j}}^{DL} = A_{AF}\left(x_{i-j} + {z_{i-j}}^{UL}\right) + {z_{i-j}}^{DL}, \tag{2}$$

where $\hat{s}_{i-j}$ is the received soft value after the second stage for the packet sent from nodes i to j with ${z_{i-j}}^{DL}$, which is the Down Lind (DL) channel, AWGN noise occurred on the channel between nodes i and j, and $A_{AF} \geq 1$ is the amplification factor.

To enhance the performance, before transmitting each node, it could Decode-Re-encode the received packet from the first transmission stage, and then amplify it (DF system) to remove the noise effect from the UL channel, and hence avoid the noise aggregation.

When each node applies NC on the received packets, the amplified combined NC soft values are shown in (3):

$$C_{n(i-k)} = A_{AF}\left(x_{i-n} + z^{UL}_{i-n} + x_{k-n} + z^{UL}_{k-n}\right) = A_{AF}\left(s_{i-n} + s_{k-n}\right) \tag{3}$$

where $C_{n(i-k)}$ is the soft value of two combined packets received from nodes i and k at node n as an example, taking into consideration that more than two packets can be combined.

Each node can either combine the received packet directly as soft values or perform hard-decision decoding and then combine the resulting values. Moreover, the DF system can also be applied before the soft value combination. In the case of hard-decision values, the destination uses a hard-decision decoder to decode the received packets and then XORing the decoded packets to retrieve the desired information. Accordingly, the network coded packet received at the N-1 nodes is shown in (4):

$$s_{nr(i-k)} = A_{AF}\left(x_{i-n} + z^{UL}_{i-n} + x_{k-n} + z^{UL}_{k-n}\right) + z^{DL}_{c-n} = A_{AF}\left(s_{j-n} + s_{k-n}\right) + z^{DL}_{c-n} \tag{4}$$

where $A_{AF} \geq 1$ is the amplification factor applied at the N nodes on the noisy combined packet, $s_{nr(i-k)}$ is the combined soft value of nodes i and k that were received at node n, and z^{DL}_{c-n} is the DL channel AWGN added to the combined packet from the DL channel between node n and the receiver node. As a result, the retrieved packet at node n after the hard-decision encoding is given (5):

$$\hat{s}_{rn(i-k)} = \hat{x}_{j-n} \oplus \hat{x}_{k-n} \tag{5}$$

where $\hat{s}_{rn(i-k)}$ is the retrieved combined packet resulting from XORing the retrieved packets $\hat{x}_{j-n}$ and $\hat{x}_{k-n}$, respectively at the N-1 nodes. Fig. 2 shows the block diagram for hard-decision retrieving steps.

After obtaining the hard-decision values for all the received packets by each node, XORing retrieving processes is applied via the usual Jordan Gaussian Elimination (JGE) processes.

In the soft-decision scenario, which is shown in Fig. 3, each receiving node performs the soft-decision decoding directly on the received soft value of the combined packet, i.e. without applying the hard-decision decoding. As a result, the PUMTC decoded soft value for the combined packet is then used to retrieve the soft value of the desired information packet.

The soft value of $s_{nr(i-k)}$ is then passed to a hard-decision decoder to retrieve the desired final information data using the traditional JGE process.

The PER for the full reception at each node, and for the whole network after the two stages for this scenario (benchmark scenario when CoNC is not applied), is shown in [10].

4. Proposed method: Physical layer Half-Cycle stages CoNC system

The proposed CoNC in [28] over a lossy channel and an AWGN channel is investigated in this section. The BER is obtained using a soft and hard decision PUMTC as a forward error correction technique.

The physical layer of the two Half-Cycle transmission stages is presented in the following sub-sections.

4.1. BER for the first stage CoNC system in terms of Half-Cycle model

The investigated BER is obtained by implementing PUMTC on the proposed CoNC scenario applied at the first stage. The work presented in [28] shows excellent PER improvement resulting from using CoNC at the first stage, where the two Half-Cycle stages of transmission method is proposed over an erasure channel. The BER and PER effect resulting from using CoNC in the Half-Cycle scenario is shown for some adapted combination algorithms, taking into consideration that the N local mobile network's nodes are divided into odd nodes (nodes with odd numbers), and even nodes (nodes with even numbers), regardless as to whether N is an odd or even number. Odd and even-numbered nodes are described in this paper as odd and even sub-clusters, respectively.

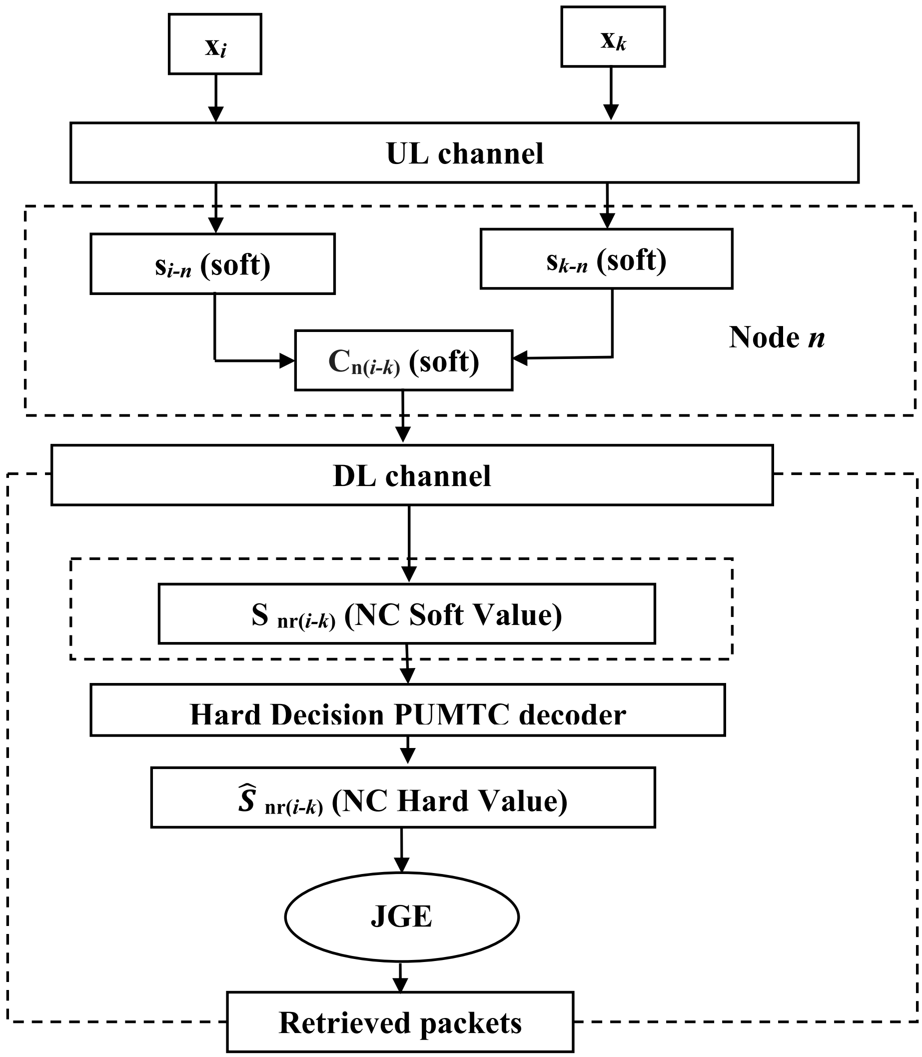

Fig. 2. Hard-decision retrieving processes for the proposed 6G local network scenario.

The first Half-Cycle transmission stage is designed to broadcast either odd or even sub-cluster packets, while the non-broadcasting sub-cluster nodes remain in receipt mode only. First Half-Cycle stage broadcasting is confirmed as successfully completed when each node of N successfully manages to decode all the odd sub-cluster packets. Accordingly, at the first Half-Cycle stage broadcast, neither NC, nor cooperation is applied.

The CoNC technique is being applied at the second Half-Cycle stage, where the even sub-cluster nodes take turns to broadcast. The odd sub-cluster nodes are in receipt mode only, whilst the even sub-cluster nodes are in both transmission and receipt modes. CoNC can be applied at the second Half-Cycle sub-cluster nodes in several algorithms. However, in this paper, deterministic combination algorithms are adapted due to the deterministic NC advantages published in [19,26–28]. Accordingly, the proposed CoNC combination algorithm at the second Half-Cycle stage is as follows: each node from the N/2 even sub-cluster nodes combines all of the received odd packets from the first Half-Cycle stage to its packet. As a result, the even sub-cluster will be broadcasting N/2 packets at the second Half-Cycle stage transmission. At the end of the two Half-Cycle transmission stages, there will be N transmitted packets, which means that dividing the first stage into two Half-Cycle stages does not change the total amount of transmitted packets, which is N. Accordingly, the proposed scenario is claimed to have no extra transmitted packets, compared with the traditional single-stage transmission.

As an example, the first Half-Cycle stage transmission is shown in Fig. 4, for a local mobile network of six nodes. The odd sub-cluster starts the broadcasting (transmission and reception mode) while the even sub-cluster remains only in receipt mode. It is noted that the first Half-Cycle broadcasting does not apply CoNC, hence why it is called a "selfish mode" Half-Cycle stage.

Where $\mathrm{x}_{\mathrm{i-1h}}$ is the broadcast PUMTC encoded packet from node i at the first Half-Cycle stage while i = 1, 2, …, N and i≠j.

After the first Half-Cycle stage broadcasting, each node of N will be receiving N/2 encoded packets with the UL channel AWGN ($\mathrm{s}_{(\mathrm{i-j})}$) as below:

$$\mathrm{s}_{(\mathrm{i-j})-1\mathrm{h}} = \mathrm{x}_{(\mathrm{i-j})-1\mathrm{h}} + \mathrm{z}^{\mathrm{UL}}_{(\mathrm{i-j})} \tag{6}$$

where i = 1, 2, …, N and i≠j. At the first Half-Cycle stage, just odd nodes are broadcast, so, $\mathrm{x}_{(\mathrm{i-j})-1\mathrm{h}} = 0$ for even nodes, i.e. when i is even, as a result, $\mathrm{s}_{(\mathrm{i-j})-1\mathrm{h}}$ will be zero. Accordingly, for the presented example of N = 6, node one will be receiving:

$$\mathrm{s}_{(1-3)-1\mathrm{h}} = \mathrm{x}_{(1-3)-1\mathrm{h}} + \mathrm{z}^{\mathrm{UL}}_{(1-3)} \tag{6a}$$

$$\mathrm{s}_{(1-5)-1\mathrm{h}} = \mathrm{x}_{(1-5)-1\mathrm{h}} + \mathrm{z}^{\mathrm{UL}}_{(1-5)} \tag{6b}$$

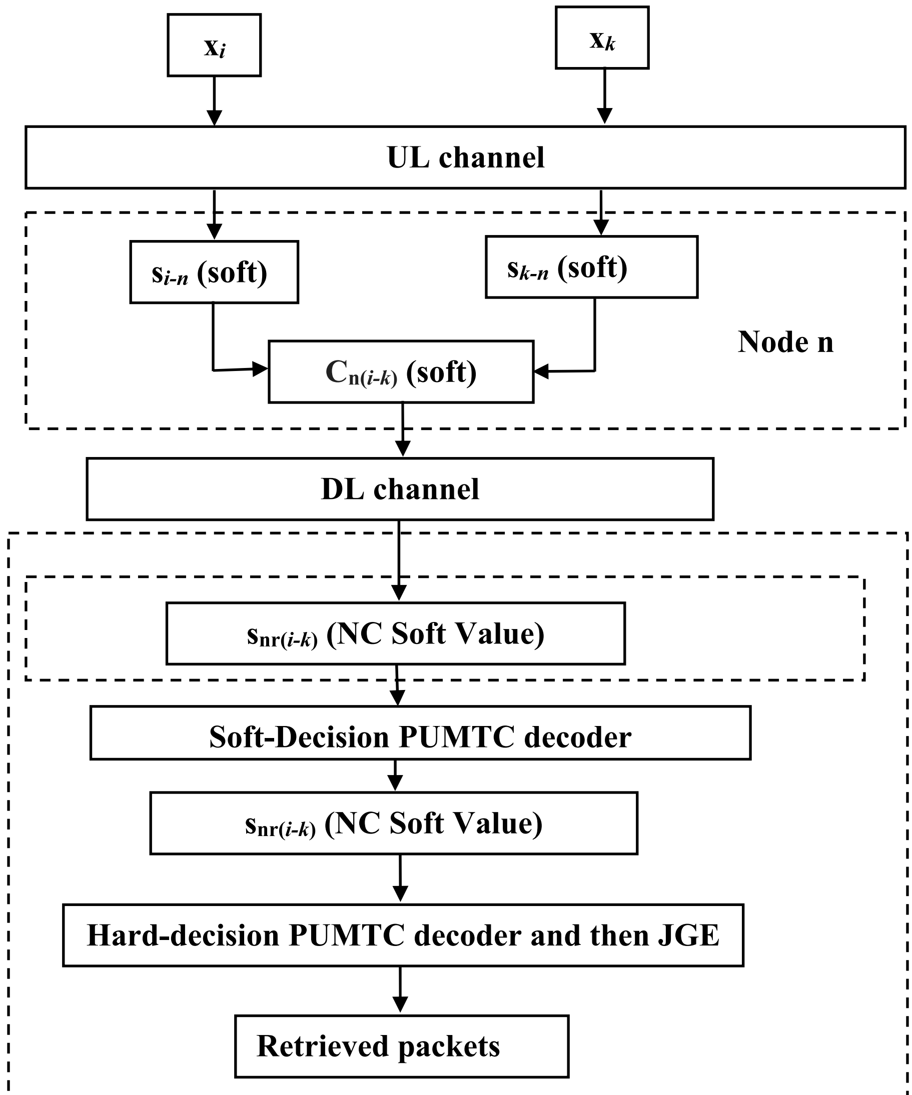

Fig. 3. Soft-decision decoding retrieving processes for the proposed 6G local network scenario.

$$s_{(1-2)-1h} = s_{(1-4)-1h} = s_{(1-6)-1h} = \text{zero} \tag{6c}$$

where $s_{(i-j)-1h}$ is the received packet at node i that is sent from node j at the first Half-Cycle stage.

After the first Half-Cycle stage, the second Half-Cycle stage follows. Only the even sub-cluster nodes are in transmission mode, where all the N nodes are in receipt mode. So, instead of just sending the even nodes packets separately in this Half-Cycle stage, the even nodes apply CoNC at the odd sub-cluster nodes received from the first Half-Cycle transmission stage. The CoNC can be applied in deterministic and non-deterministic ways. Moreover, the deterministic combination algorithms are many, such as odd-even combination [28], next neighbour, random combinations [10], and others. The main criteria that should be taken into consideration when choosing the combination algorithm are the number of combined packets and the routing algorithm i.e. AF or DF, and the relative BER resulting from the noise aggregation.

In this paper, the BER for most common combinations is investigated when adapted at the second Half-Cycle stage. Then, the combination algorithms vary when more than two Half-Cycle transmission stages are needed.

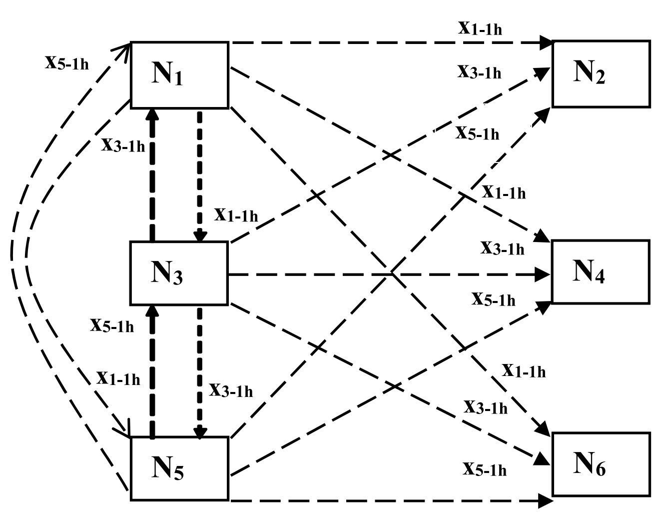

Fig. 4. Selfish mode odd Half-Cycle broadcasting stage.

4.2. Odd-even combination second Half-Cycle stage CoNC transmission

In the odd-even combination algorithm that is recommended for the second Half-Cycle stage, each node in the even sub-cluster nodes combines its packet to the odd sub-cluster packets received from the first Half-Cycle stage, resulting in sending one combined packet per even node, instead of sending the even sub-cluster nodes separately, as shown below for the example of $\mathrm{N}=6$ represented in Fig. 5:

$$\mathrm{C}_{(2-2h)} = \mathrm{x}_2 + \mathrm{s}_{(1-2)-1h} + \mathrm{s}_{(3-2)-1h} + \mathrm{s}_{(5-2)-1h} \tag{7a}$$

$$\mathrm{C}_{(4-2h)} = \mathrm{x}_4 + \mathrm{s}_{(1-4)-1h} + \mathrm{s}_{(3-4)-1h} + \mathrm{s}_{(5-4)-1h} \tag{7b}$$

$$\mathrm{C}_{(6-2h)} = \mathrm{x}_6 + \mathrm{s}_{(1-6)-1h} + \mathrm{s}_{(3-6)-1h} + \mathrm{s}_{(5-6)-1h} \tag{7c}$$

Accordingly, the combined received packets by the N nodes after the second Half-Cycle stage are the same as the transmitted packets, but with the UL channel noise. For example, the received combined packet from node two at node five, is $\mathrm{C}_{r(2-5)-2h}$:

$$\mathrm{C}_{r(2-5)-2h} = \mathrm{C}_{(2-2h)} + z^{UL}_{(2-5)} \tag{8}$$

The total transmitted packets after the first two Half-Cycle stages are the three selfish PUMTC encoded odd sub-cluster packets (x_1, x_2, and x_3), plus the three CoNC combined packets in Eqs. (7a)–(7c). When each node receives N-1 packets (five in our example of six nodes), besides its known packet, each node can decode and then retrieve the N-1 neighbour packets using JGE processes. The gained PER resulting from applying the second Half-Cycle with odd-even combination is shown in [28] for a cluster of WSNs.

It is essential to understand that the even sub-cluster nodes can perform DF to eliminate the UL AWGN channel's effect, and hence to avoid the channel noise aggregation.

The received combined packets by the N nodes after the second Half-Cycle stage become three selfish packets, which are sent by the odd sub-cluster stage at the first Half-Cycle stage, in addition to the other received three combined packets that are sent by the even sub-cluster at the second Half-Cycle stage. If each node manages to decode the received packets correctly, then the receipt packets matrix at node four, as an example is:

$$\begin{bmatrix} \mathrm{C}_{r(1-4)-1h} \\ \mathrm{C}_{r(3-4)-1h} \\ \mathrm{C}_{r(5-4)-1h} \\ \mathrm{x}_4 \\ \mathrm{C}_{r(2-4)-2h} \\ \mathrm{C}_{r(6-4)-2h} \end{bmatrix} = \begin{bmatrix} \hat{\mathrm{x}}_1 & \hat{\mathrm{C}}_{r(2-4)-2h} & \hat{\mathrm{x}}_3 & \mathrm{x}_4 & \hat{\mathrm{x}}_5 & \hat{\mathrm{C}}_{r(6-4)-2h} \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{9}$$

where $\hat{\mathrm{x}}_i$ is the decoded uncombined packet received from node i at the first Half-Cycle stage, $\hat{\mathrm{C}}_{r(2-4)-2h}$ is the decoded combined packet at node four received from node two at the second Half-Cycle stage, and $\hat{\mathrm{C}}_{r(6-4)-2h}$ is the decoded combined packet at node four received from node six at the second Half-Cycle stage. It is taken into consideration that Eq. (9) is for the received packets at node four. Consequently, node four knows its packet. Moreover, the decoded combined packets received from nodes four and six are combined in a deterministic algorithm that assures that the received matrix rank equals N [28].

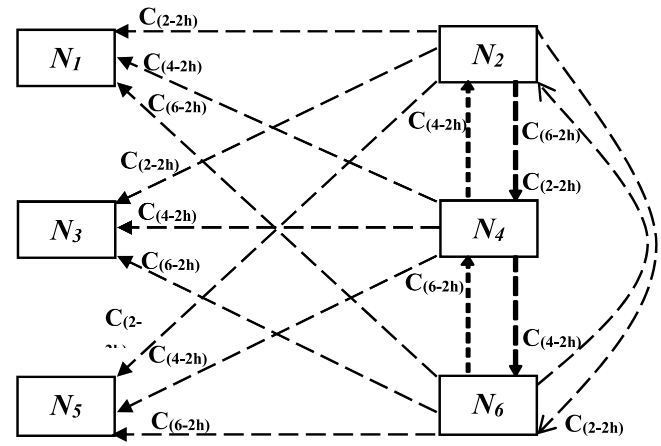

Fig. 5. The combined broadcast packets from the even sub-cluster (second Half-Cycle stage).

4.3. BER for third CoNC proposed Half-Cycle stage algorithm

In full stage communication, when not all N nodes manage to decode the N received packet correctly, a second full stage follows, unlike the proposed work in this paper, where the Half-Cycle stage is needed to follow, i.e. broadcasting N/2 fewer packets. The third Half-Cycle stage proposed in this paper applies CoNC on the received packets from the previous two Half-Cycle stages, considering that any combination algorithms can be suggested in this stage, including random combination, or all the received packet combination algorithms.

Deterministic combination requires a smaller header address [11,12], which is the reason it is recommended in this work, as shown in [28]. Accordingly, the third Half-Cycle stage suggested may have various deterministic combinations. It is enough to adapt one CoNC algorithm to explain the proposed work in this paper, so, a single packet combined to cross sub-cluster packets Half-Cycle stage algorithm is introduced. The proposed algorithm in this Half-Cycle stage tends to combine the transmitter node's packet to all the received packets from the cross sub-cluster nodes. For example, if the third Half-Cycle stage transmission is proposed to be for the odd sub-cluster, each odd node at the odd sub-cluster combines its PUMTC encoded packet to the received combined packets from the even sub-cluster nodes, resulting in N/2 new novel linearly independent equations.

As this paper assumes those odd nodes started transmitting single packets at the first Half-Cycle stage, the odd sub-cluster therefore is applicable to the third Half-Cycle stage. Accordingly, the transmitted packets in the third Half-Cycle stage for the example of $\mathrm{N}=6$ are:

$$C_{(1-3h)} = x_1 + C_{r(2-1)-2h} + C_{r(4-1)-2h} + C_{r(6-1)-2h} \tag{10a}$$

$$C_{(3-3h)} = x_3 + C_{r(2-3)-2h} + C_{r(4-3)-2h} + C_{r(6-3)-2h} \tag{10b}$$

$$C_{(5-3h)} = x_5 + C_{r(2-5)-2h} + C_{r(4-5)-2h} + C_{r(6-5)-2h} \tag{10c}$$

If DF is applied at all nodes, then each node decodes and re-encodes the received packet before combining it with its packet. Moreover, the decoding and re-encoding could be either soft or hard decision values, as explained in Section 2.

For the proposed work in this paper, a comparison between the BER resulting from PUMTC applying either a hard or soft decoding decision is shown in the results in Section 5.

Therefore, as the third Half-Cycle stage transmits N/2 unique packets that cause the total transmitted packets at the end of the third Half-Cycle to become 3N/2, this results in nine packets in our example of six nodes. When successful decoding is acknowledged at each node after the end of the third Half-Cycle stage, each node applies JGE processes to retrieve the full information, considering the requisite rank of the JGE matrix that is N-1 excluding the receiver node's packet, or N including the receiver node's packet, as each node knows its packet [28].

4.4. BER for fourth CoNC Proposed Half-Cycle stage algorithm

If the N nodes could not retrieve the full information, a fourth Half-Cycle stage of transmission follows. The combination for the fourth Half-Cycle stage can be any deterministic combination algorithm, such as adding the even sub-cluster nodes' packet to the received packets from the previous Half-Cycle stages. For simplicity, the same combination algorithm proposed for the third Half-Cycle stage is assumed to be applied on the fourth Half-Cycle stage, at the even sub-cluster nodes, as shown below:

$$C_{(2-4h)} = x_2 + C_{r(1-2)-2h} + C_{r(3-2)-2h} + C_{r(5-2)-2h} \tag{11a}$$

$$C_{(4-4h)} = x_4 + C_{r(1-4)-2h} + C_{r(3-4)-2h} + C_{r(5-4)-2h} \tag{11b}$$

$$C_{(6-4h)} = x_6 + C_{r(1-6)-2h} + C_{r(3-6)-2h} + C_{r(5-6)-2h} \tag{11c}$$

In Eqs. (11a)–(11c), each even sub-cluster node combines its packet to the received packets from the third Half-Cycle stage, taking into consideration that combining the received packets from the second Half-Cycle stage is possible too, however, not adopted in this paper. Moreover, it is important to understand that the received packets from the second Half-Cycle stage have better BER than the received packets from the third Half-Cycle stage because of the less aggregated AWGN channel added through the UL and DL channels, however, [28] shows that combining the packets from the third Half-Cycle stage produces better PER as a result, increasing the amount of pivots of the unique linear independent equations and enhancing the JGE process.

When combining the even sub-cluster packets to the received packets from the third Half-Cycle stage, the fourth Half-Cycle transmitted packets will be simply:

$$C_{(2-4h)} = x_2 + C_{r(1-2)-3h} + C_{r(3-2)-3h} + C_{r(5-2)-3h} \tag{12a}$$

$$C_{(4-4h)} = x_4 + C_{r(1-4)-3h} + C_{r(3-4)-3h} + C_{r(5-4)-3h} \tag{12b}$$

$$C_{(6-4h)} = x_6 + C_{r(1-6)-3h} + C_{r(3-6)-3h} + C_{r(5-6)-3h} \tag{12c}$$

where $C_{r(1-6)-3h}$ is the transmitted combined packet from the third Half-Cycle stage ($C_{(1-6)-3h}$) with the AWGN channel.

When not applying DF on the N nodes, the combination of Eqs. (10a)–(10c) is strongly recommended. Even still, when DF is implemented at the N nodes, the BER difference can be regarded as negligible with PUMTC forward error corrections, as illustrated in the simulation results.

Finally, it is essential to emphasise that any combination from the received three previous Half-Cycle stages are possible, including combining all the received packets from throughout the three previous stages. However, the deterministic combinations are recommended because of the shorter header length [28]. At the end of the fourth Half-Cycle stage, if each node manages to decode the received packets correctly, then the received packets matrix at node four, for example, resulting from the third and the fourth Half-Cycle stages are:

$$\begin{bmatrix} C_{r(1-4)-3h} \\ C_{r(3-4)-3h} \\ C_{r(5-4)-3h} \\ x_4 \\ C_{r(2-4)-4h} \\ C_{r(6-4)-4h} \end{bmatrix} = \begin{bmatrix} \hat{C}_{(1-3h)} & \hat{C}_{(2-4)-4h} & \hat{C}_{(3-3h)} & x_4 & \hat{C}_{(5-3h)} & \hat{C}_{(6-4)-4h} \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{13}$$

where $\hat{C}_{(i-jh)}$ is the decoded combined packet at the N nodes (four in this example) received from node i at the jthHalf-Cycle stage.

It is crucial to notice that Eqs. (9) and (13), are for the received packets at node four, bearing in mind that node four knows its packet. Moreover, the decoded combined packets received from nodes four and six are combined in a deterministic algorithm. As a result, the received matrix rank equals to N [28].

If full connectivity is not declared by the end of the fourth Half-Cycle stage, the next Half-Cycle stage follows. However, in this paper, only four Half-Cycle stages are investigated because it is sufficient to prove the applicability of the proposed system.

The PER gained from applying CoNC is shown in [10,11,28] for different combinations, where this paper investigates the drop in BER as the trade-off for the gained PER. Fig. 6 illustrates the CoNC system that consists of four Half-Cycle stages.

5. Simulation results

The proposed scenario BER behaviour is simulated using the Matlab program for PUMTC (4,2,1,4) and (8,4,3,8). The simulation results for both AF and DF have been obtained for hard and soft-decision decoding processes over an AWGN channel. Moreover, the transmission over a lossy channel is simulated to show the benefit in Packet Error Rate (PER) from applying CoNC, and hence evaluate the overall behaviour of the proposed system, i.e. the trade-off between improving the PER and the deterioration of the BER.

First of all, in the lossy channel, the simulation stops running when collecting a minimum of 100 faulty packets for the N nodes, where the defective packet means the failure of any local network's node i to decode any received packet correctly from the rest of the network's members, i.e. the error of full connectivity between all the local network's members.

The simulated proposed system in the AWGN channel applies BPSK modulation PUMTC (4,2,1,4) and (8,4,3,8) that was published in [16], with its EXIT charts' capacities approaching performance shown in [18]. The performed PUMTC has a rate of 1/3 based on (4,2,1,4) and (8,4,3,8) code components, and 1000 bits pseudo-random interleaver. The amplification factor of the transmitted signal is set at 4, and the decoding iteration at 4, because these two values show the most explicit effect of the proposed CoNC. Finally, the BER simulation curves have been obtained by transmitting a minimum of 10^8 bits with a minimum of 100-bit errors to ensure the reliability of the collected results.

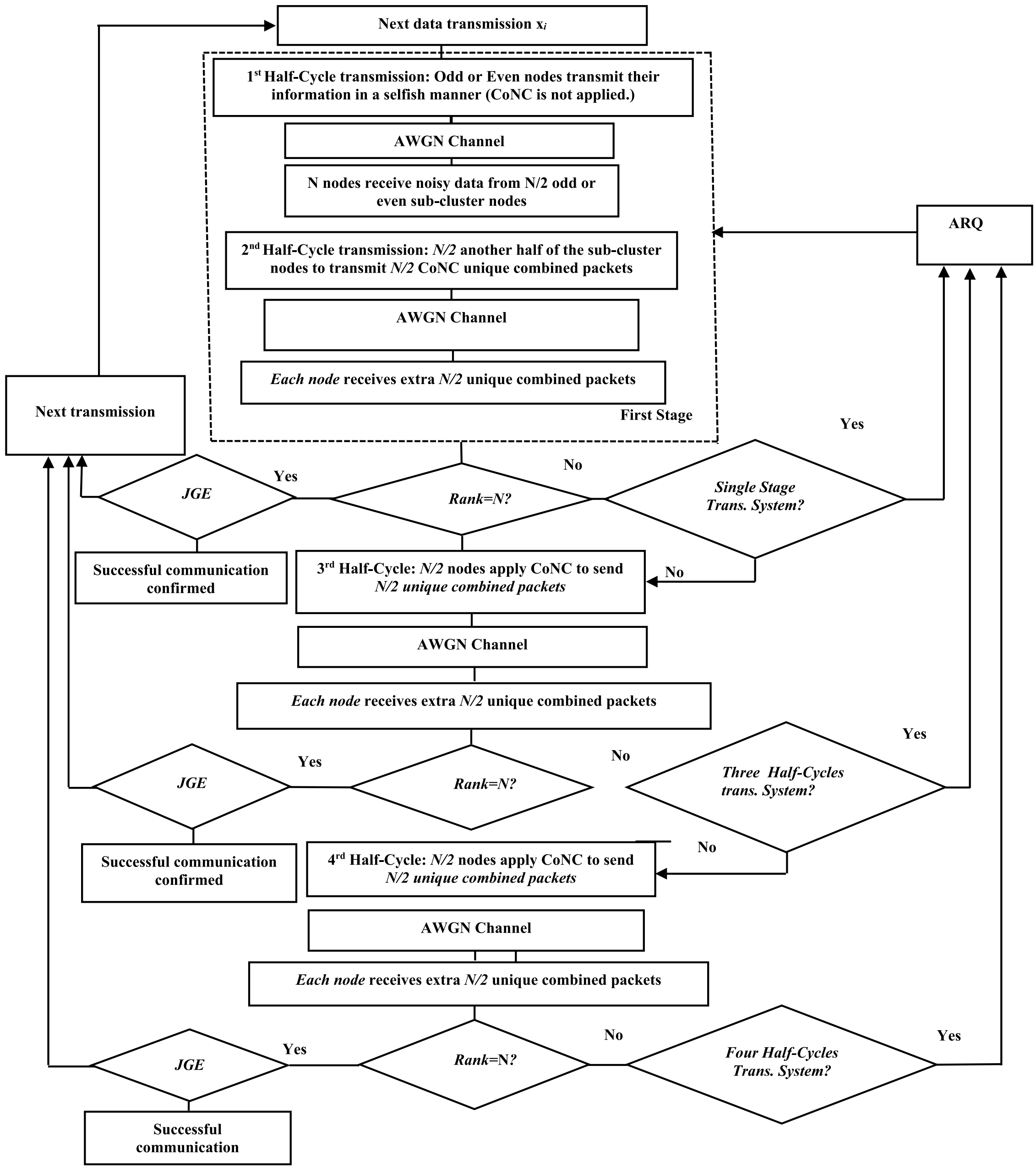

Fig. 6. 6G local network Half-Cycle transmission stages block diagram, for four Half-Cycle stages when applying the CoNC system after the first Half-Cycle stage.

Before showing the BER behaviour, it is essential to illustrate the gained PER from applying CoNC at the first stage and then the following Half-Cycle transmission stages.

Fig. 7 declares that applying CoNC at the first stage (second Half-Cycle stage) improves the PER by around 10%. Moreover, when increasing the number of nodes, the gained PER improves. Fig. 8 compares two full stages in selfish mode, with four Half-Cycle stages, for a local mobile cluster of 15 nodes when the erasure probability increases from 0.05 to 1. Fig. 8 shows the well-performing PER outcome resulting from applying CoNC. Indeed, three Half-Cycle stage transmissions outperform two complete selfish stages though the three Half-Cycle stages transmit N/2 fewer packets. The full benefits of using Half-Cycle stage CoNC transmission can be found in [28], and this paper shows how applying a Half-Cycle stage Network cooperation system suits 6G applications more than transmitting the data in one single stage, because it requires less processing power and processing time, which is the reason it is recommended for the 6G system.

The PER improvement is not obtained without any trade-off, i.e. the drawback of the PER improvement is at the cost of the BER, as a consequence of combining different packets, it results in noise aggregation for the combined packet. This is in addition to the fact that there is a longer processing time delay, which is shown in Fig. 9.

The normal behaviour for PUMTC (4,2,1,4) and (8,4,3,8) is initially introduced, when increasing the amplification factor from 2 to 10, and most importantly, adding the influence of applying DF on the received node before forwarding it to the other cluster's members. Decoding and re-encoding the data at the cooperator node tends to improve the BER significantly. Moreover, increasing the amplification factor improves the BER on a much smaller

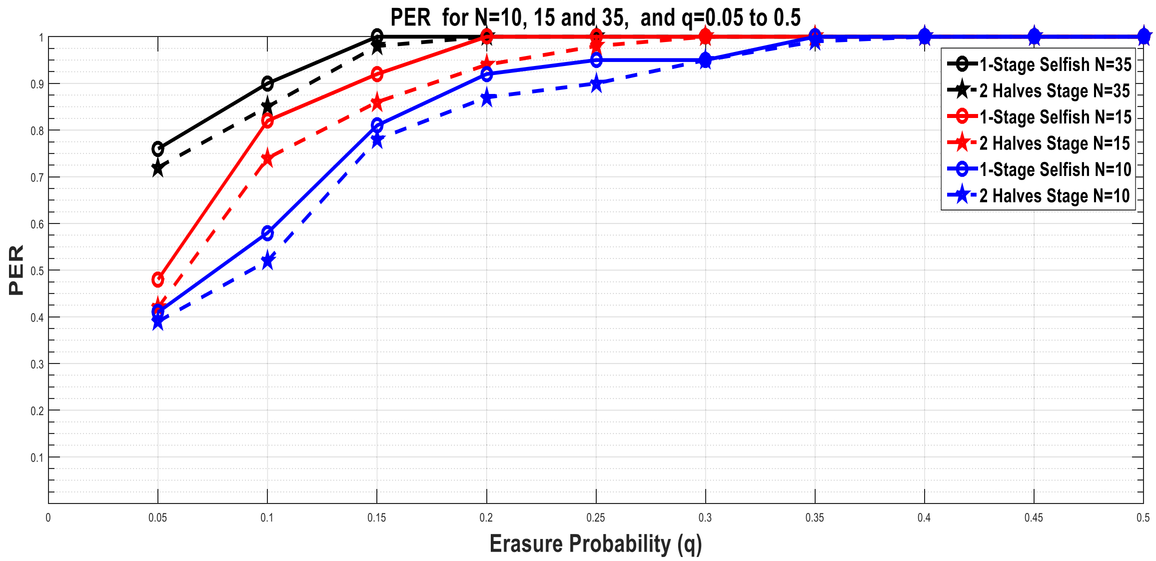

Fig. 7. The gained benefit of PER from applying CoNC at the first stage for a different number of nodes, compared with selfish mode for various channel erasure probabilities [28].

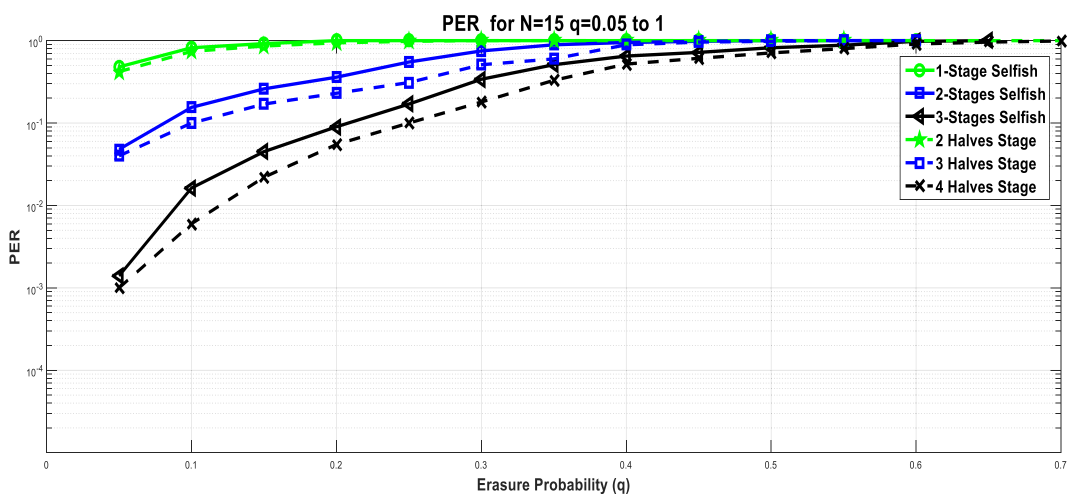

Fig. 8. The gained benefit of PER from applying CoNC at four Half-Cycle stages compared with two selfish stages for 15 nodes at various channel erasure probabilities [28].

scale. However, the gained improvement is at the cost of the processing time, and the system complexity.

Accordingly, based on the BER results obtained, DF outperforms AF, but it requires more processing power and time; on the other hand, for a small number of users, AF can replace DF, as the difference in BER is acceptable.

The effect of applying soft and hard decision decoding processes is shown in Fig. 10 for a cluster of just five local mobile network nodes on AF systems, to prove that soft-decision provides better performance even with a small number of nodes and without applying DF.

The BER for applying CoNC at the first stage (second Half-Cycle stage) is shown in Fig. 11 for AF system. It is clear from Fig. 11 that increasing the number of nodes results in a worsened BER performance, as evidenced by the noise aggregation when combining more packets. Moreover, Fig. 11 shows how applying the soft-decision technique improves the BER, which is demonstrated in Fig. 10. It takes into account that the soft-decision decoder is simpler than the hard-decision decoder, as it does not require a hard-decision block before feeding the data to the decoder. Fig. 12 illustrates the BER of DF PUMTC (4,2,1,4) for the same amount of local mobile network's cluster nodes, as in Fig. 11. It is noted that DF PUMTC performs well as it has a very small BER, which is supported by the decoding and the re-encoding that removes the noise from the UL and DL channels, before applying CoNC. Moreover, it is clear that the soft-decision PUMTC (4,2,1,4) outperforms the hard-decision one, but on a smaller scale compared to AF, which is justified by removing the noise through the decoding and re-encoding processes.

The small BER improvement is combined with the advantage of simplifying PUMTC by removing the hard-decision processes, which is regarded as a significant achievement. In addition, comparing Fig. 11 with Fig. 10 shows that DF outperforms AF, which is expected. Moreover, the critical point to note is that PUMTC (4, 2,1,2) is not a very powerful forward error correction code when

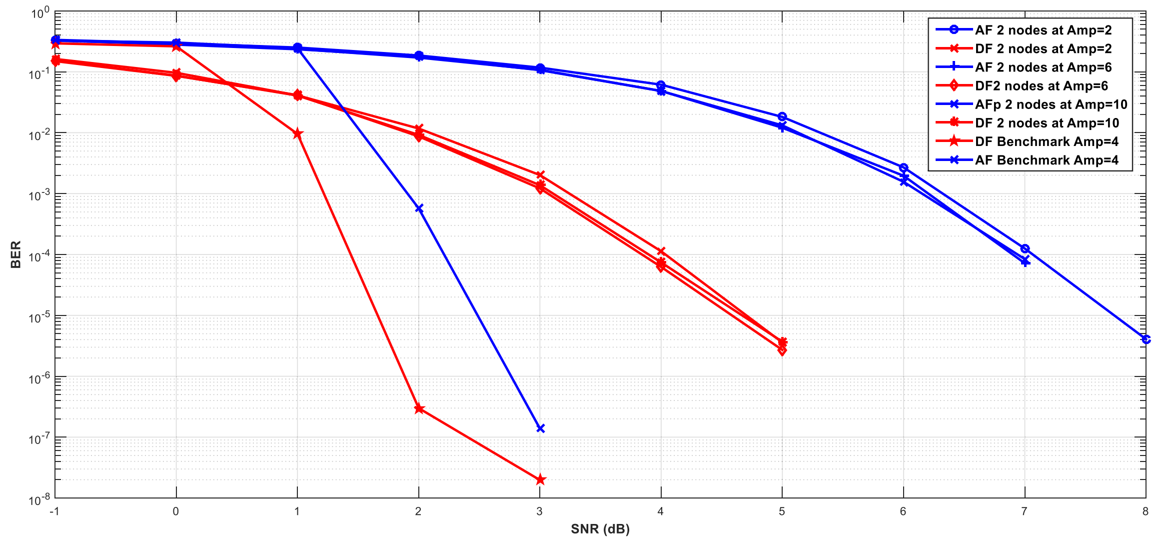

Fig. 9. BER performance for AF and DF 4 decoding iteration systems based on (4,2,1,4) PUMTC. The figure demonstrates the significant BER improvement resulting from DF [11].

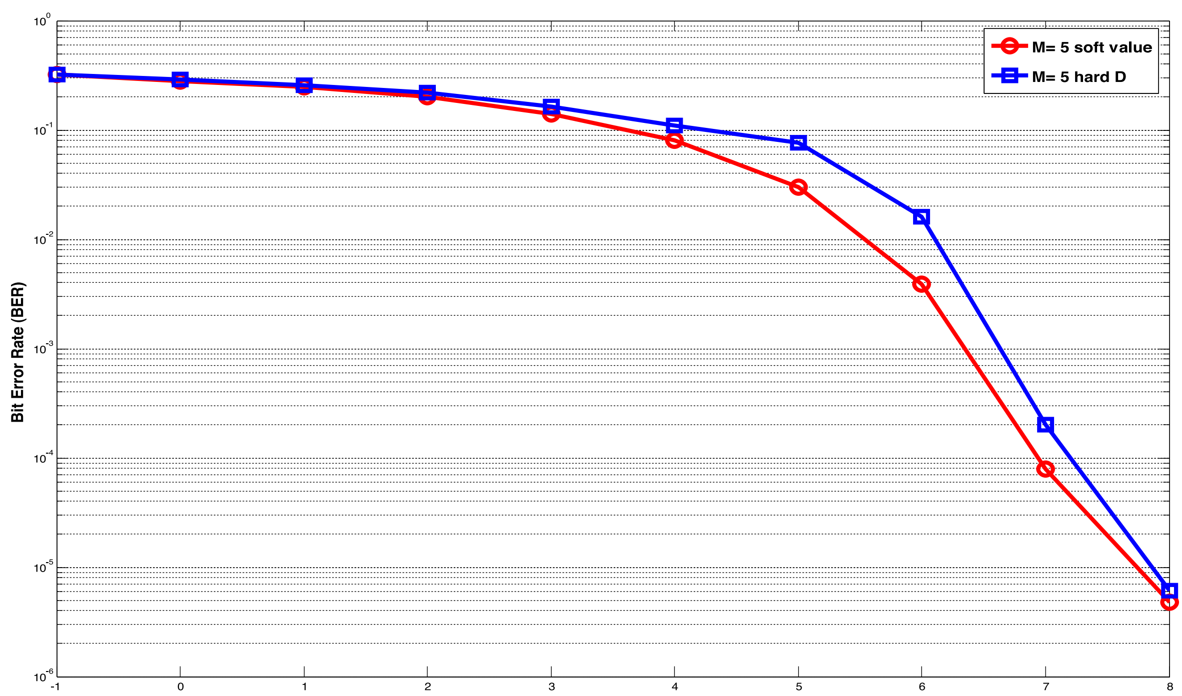

Fig. 10. BER for (4,2,1,4) PUMTC applying soft and hard-decision decoding, on five nodes when just amplifying the CoNC received packet before retransmitting it [22].

compared with PUMTC (8,4,3,8) presented in [11]. Fig. 12 gives the full picture for PUMTC when comparing AF and DF for PUMTC (4,2,1,4) and PUMTC (8,4,3,8) for hard and soft-decision decoders. Fig. 13 shows how PUMTC (8,4,3,8) is powerful and evidences the negligible BER improvement when applying the soft-decision decoding processes, however, the advantages of simplifying the decoding processes are regarded as a remarkable success.

6. Conclusion

In this paper, the behaviour of Bit Error Rate (BER) resulting from applying Cooperative Network Coding (CoNC) on the physical layer at the first transmission stage of a suggested 6G local network, is presented. Implementing CoNC at the first stage resulted in 10% better Packet Error Rate (PER), besides the advantage of sending Half-Cycle stages instead of full stage transmission when full connectivity is not obtained. Partial Unit Memory Turbo Code (PUMTC) is used as the forward error correction code. Soft-decision decoding is performed on Amplify-and-Forward (AF) and Decode-Re-encode-Amplify and Forward (DF) systems, using PUMTC with the components of (4,2,1,4) and (8,4,3,8), as a recommended modification for PUMTC. The soft-decision decoding is then compared with the usual PUMTC hard-decision decoding. The results show that the suggested soft-decision processes improved the BER behaviour for PUMTC by around 0.4 dB for the AF system; moreover, the improvement

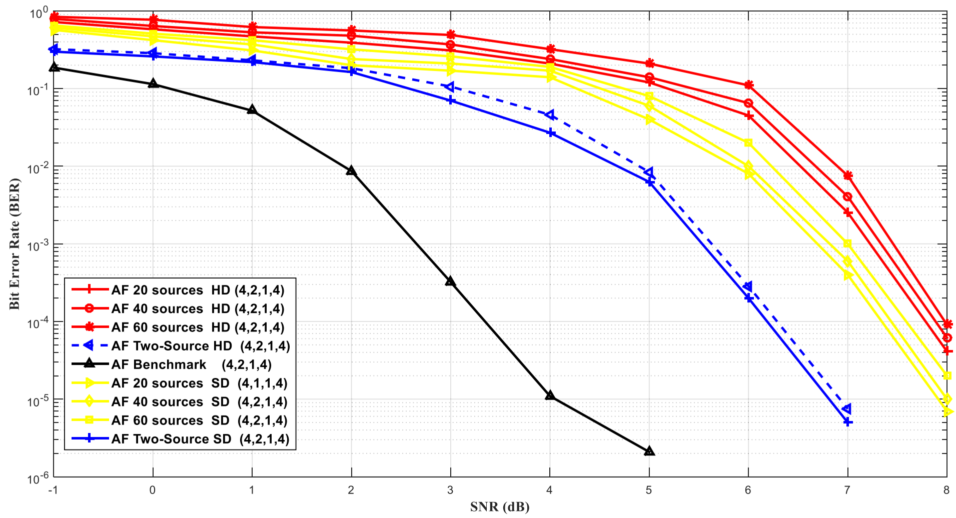

Fig. 11. The BER of AF for four Half-Cycle stages with hard and soft-decision PUMTC (4,1,2,4) for differing numbers of nodes.

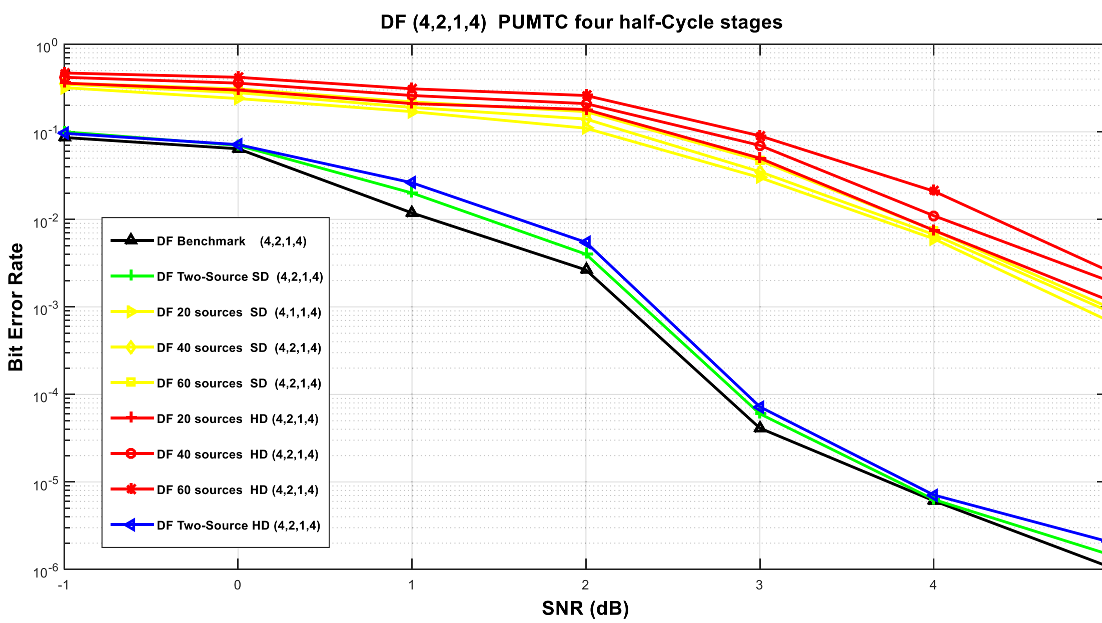

Fig. 12. The BER of DF PUMTC (4,2,1,4) soft and hard decision, for different local mobile networks' cluster sizes.

is around 0.1 dB in DF. Furthermore, the soft-decision processes simplified the system by removing the hard-decision process.

Moreover, this paper shows that the decline in BER, resulting from applying CoNC at the first stage, is regarded as acceptable; in fact, in PUMTC (8,4,3,8), the loss in BER is negligible. Additionally, the paper shows that sending new Half-Cycle stages when needed resulted in further improvement of the PER, hence decreasing the automatic repeat request significantly. Results show that the system of three Half-Cycle stages outperforms the two selfish transmission stages, although the three Half-Cycle stages transmit fewer N/2 packets than the two selfish stages. Finally, it is essential to state that the obtained results match the theoretical principles in terms of improving the PER when applying the idea of Half-Cycle transmission stages and the obtained BER for the whole system.

Future work is planned to be directed to apply the proposed CoNC algorithms over multi-path routing networks introduced in [29] to re-optimise the number of paths, which is expected to be shorter as a result of applying CoNC. Moreover, applying CoNC over big data broadcasting systems, and wireless body communication networks such as in [30] are under consideration as an anticipated research area.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

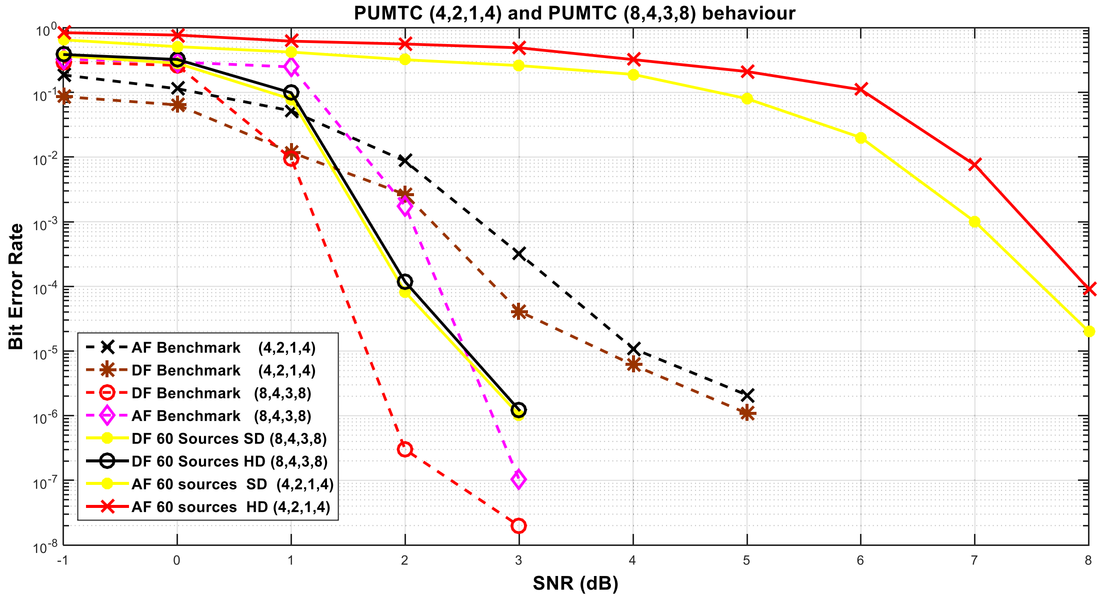

Fig. 13. PUMTC (4,2,1,4) and PUMTC (8,4,3,8) behaviour for a local network size of 60 nodes with both hard and soft-decision decoding.

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