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PERFORMANCE IMPROVEMENT OF A NEW MAC PROTOCOL FOR ULTRA WIDE BAND WIRELESS SENSOR NETWORKS

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ABSTRACT

Wireless Sensor Networks (WSN) emerges as a useful networks type that completes monitoring systems. Energy, Packets Delivery Ratio (PDR) and Latency optimization in such kind of networks is essential. Further, integrating Network Coding (NC) with efficient scheduling and synchronization in the Medium Access Control (MAC) layer improves nodes functioning and copes with many problems. Mainly, essential ones are in relation with energy waste and transmission lose and collision. In this work, the benefits while introducing the network coding technique are demonstrated and evaluated. Mainly, regarding the energy consumption, PDR and Latency improvement in the MAC layer of Impulse Radio-Ultra Wideband (UWB) based WSN. Particularly, the network coding implementation is performed in the SWIMAC as a new MAC protocol and the simulation experiments are run in order to assess its resulting effect.

Keywords*: WSN; IR-UWB; SWIMAC; ALOHA; WideMac; Network Coding; Energy consumption; PDR; Latency.*

1. INTRODUCTION

Throughput and energy efficient communications in wireless sensor networks are major challenges to disseminate large data objects. In fact, dissemination is performed to carry critical commands, event's critical data, or code updates from a sink node to a set of other nodes in the network [1]. Achieving the above mentioned challenges becomes more defiant when the sensors use duty cycling to preserve their energy. With this technique, nodes usually switch periodically between active and sleep states, which directly influences the communication's reliability [2]. Since that, some sensors may lost some packets at some time slots due to the fact that they are in their sleep mode. Meanwhile, even when some nodes are in their active mode they may fail to receive some packets due to the unreliability of wireless communication such as collision or interference. Accordingly, these nodes had to schedule retransmission of such packets. This operation contributes to energy waste and increases the delay of data dissemination cycle.

With the quickly increasing of all kinds of network traffic, energy efficiency in WSN is becoming an important metric. To improve the WNS' energy efficiency, throughput should be maximized while energy consumption should be minimized.

The theory Network Coding has become a discipline in its own right which has opened up a large number of perspectives.

Its basic principle is to allow intermediate nodes to perform coding operations on packets from different sources to produce an output stream in order to approach theoretical bandwidth limits to increase throughput [3]. Another advantage of network coding that appears in WSN is the ability to reduce the amount of energy consumed. Therefore, NC is becoming a critical technology of the future for WSN.

The main advantages and features of IR-UWB make it attractive for a wide range of wireless applications. Due to these advantages and its ultra-low power consumption, IR-UWB has been selected by the IEEE 802.15.4a standard as the alternative wireless transmission technology in the WNS' PHY layer of the IEEE 802.15.4 standard. In addition to that, the features and advantages of NC motivate and lead the authors of [4] to introduce its use in the field of WSN to improve the energy efficiency and the throughput. All these points led us to study the good impact of the application of NC in line WSN based on IR-UWB.

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In this paper, our main objectives are energy consumption minimization, PDR improvement and latency reducing. According to these raisons, we proposed the NC technique to improve the performance IR-UWB based WSN in terms of energy consumption, PDR and Latency. Especially; we implement the NC at the Medium Access Control (MAC) layer using SWIMAC protocol.

This work is limited to a context where the sensor nodes are considered stationary (not mobile).

Our research methodology is as follows: In the first step, we state some limits and constraints of the literature works concerning the power consumption, PDR and Latency in this type of network. In the second step, we aim to answer to the problems cited the previous step by applying our approach. This approach concern the introducing and implementing the Network Coding (NC) for MAC protocol in IR-UWB base WSN. In third step, we show and validate the good impact of our approach by simulation results.

The present paper is organized as follows. In Section 2 we present the related works. Section 3 introduces WSN. We present SWIMAC protocol in Section 4. Section 5 presents the NC implementation for SWIMAC. The results are presented in section 6; finally, Section 7 concludes the paper.

2. RELATED WORKS

Since the first adoption of Un-Slotted and Slotted ALOHA as MAC protocols to go with the new IEEE802.15.4a standard where a detailed analysis is presented in [6], several IR-UWB MAC-PHY models have been proposed to cope with many challenging problems related to this standard's characteristics[6]. The first set of protocols were ALOHA-like models where Slotted ALOHA over IR-UWB is studied in [7] using an existing simulation platform. Further, Multichannel distributed protocols such as M-ALOHA, MPSMA, BSMA are introduced in [8,9] with detailed performance evaluation.

WideMac [10] is well-suited for IR-UWB MAC-PHY models due to its design as a WSN MAC protocol. It is duty-cycle efficient protocol that uses beacon message to announce its readiness to communication. It shortly listens for incoming communication lows right within a wake-up period. Accordingly, a candidate transmitter node waits for the destination's beacon and contends for medium access. Once it receives the desired beacon, it schedules a transmission attempt within a time lag in order to avoid collisions with the other transmitter nodes. This duty-cycle principle enhances energy saving as nodes' wake-up is well optimized because nodes remain in their sleep mode most of the time.

Due to the fact that the network nodes are sleep in the T_{sleep} periods which occupy a wide range in the T_W periods, SWIMAC was presented in [11] as an ultra-low energy consumption MAC protocol for IR-UWB based WSN.

3. WIRELESS SENSOR NETWORS

WSN may be defined as a set of smart devices, called sensors, which are able to sense and transmit information about the environment on which they are deployed. These devices collect information for users interested in monitoring and controlling a given phenomenon and transfer them to a collected point called sink node (see figure 1). The latter make the information available to a local control or to a remote control through a gateway where the users can access via Internet. So as to obtain information, users use applications that communicate with the network through queries [12].

The technology WSN has a great improvement in recent years due to the contribution of more research in this area. The ability of a sensor network to use communications without infrastructure has allowed the deployment of sensor nodes with limited resources nearest or far the phenomenon studied. A sensor network is composed of a large number of sensor nodes which consist of sensing, data processing, a power supply unit, and communicating components. With that ability, sensor nodes deployed anywhere will provide intelligence and a better understanding of the environment to the end user.

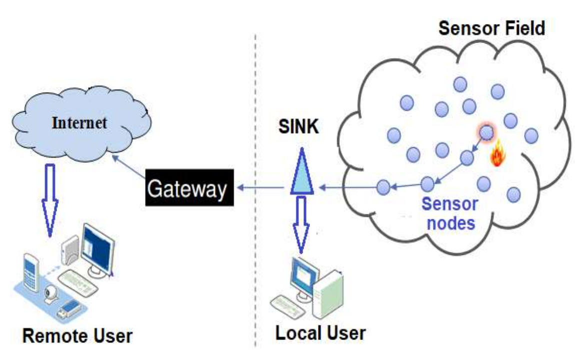

Figure 1: Simplified Architecture of a Sensor Network

The applicable area of WSN includes military sensing, environmental monitoring [13], Internet of Thinks (IoT) [14], multimedia [15], Intelligent Vehicular Systems [16], agriculture [17] and health monitoring [18] etc. WSN networks have not yet achieved widespread deployments, although they

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have been proven capable to meet the requirements of many applications categories. WSN has some limitations as lower computing power, smaller storage devices, narrower network bandwidth and very lower battery power.

4. SWIMAC PROTOCOL

Due to the good behaviors which are low radiated power, low complexity, high multipath resolution and resistance to fading of IR-UWB, its uses at the PHY layer has been envisioned for WSN. Because of this PHY layer advantages and the nature of the targeted application, the envisioned MAC protocols for IR-UWB based WSN have been proven to be ALOHA, WideMAC and SWIMAC.

SWIMAC is a new MAC protocol designed for IR-UWB based WSN. It makes all nodes periodically (period T_W) and synchronously wake up [11], transmit a beacon message announcing their availability and listen for transmission attempts during a brief time T_{Listen}.

A single period structure illustrated in Figure 2. This period starts with a known and detectable synchronization preamble and is followed by a data sequence which announces the node address and potentially other information, such as a neighbor list or routing table information (for instance, cost of its known path to the sink). A small listening time follows T_{Listen}, during which the node stays in reception mode and that allows it to receive a message. ΔT is the time added to T_{Sleep} to make the synchronization between the nodes. The whole period composed of T_{beacon} and T_{Listen} is called T_a (time of activity); and its very small compared to the time window T_W. This period is followed by a long sleeping period T_{Sleep} during which nodes save energy by keeping the radio in its sleeping mode.

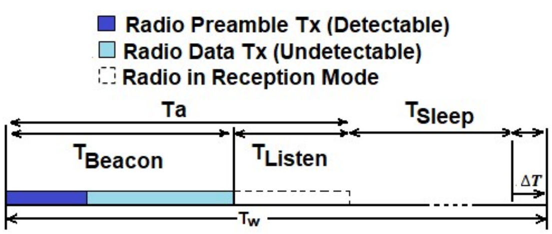

Figure 2: Detailed View of a SWIMAC Period

When a node has a message to transmit, it first listens to the channel until it receives the beacon message of the destination node. This beacon message contains a backoff exponent value that must be used by all nodes when trying to access this destination. If this value is equal to zero, the source node can transmit immediately. Otherwise, it waits a random backoff time, waits for the destination beacon, and transmits its data packet. Because of the unreliability of the wireless channel, packets are acknowledged. If a packet is not acknowledged, or if the destination beacon was not received a retransmission procedure using the backoff algorithm is initiated, until the maximum number of retransmissions maxTxAttempts is reached.

4.1 SWIMAC Operating Diagrams

SWIMAC uses a backoff algorithm to manage retransmissions and avoid collisions. The access to a contention window CW is chosen randomly for a transmitting node with a value between 0 and 2^{BErec}-1.

Thus, this transmitting node can only send its packet in the window allocated by the backoff algorithm. In the particular case where the value of the chosen window is equal to 0, the transmission occurs in the current window. Hence, the node is considered in a receiver status RX when it has no packets to send, or when it has not yet reached the allocated contention window for transmission. Otherwise, it is considered in transmitter status TX.

The TX or RX status refers to the protocol's operating mode during a complete window period TW. This status does not change during the entire TW period and has no relation to the two TX or RX radio states. This fact is normal as during a TW period the radio state is switched several times from one state to another as needed.

The SWIMAC operations vary according to its status. The two subsections below describe its operation in the two cases TX and RX status.

4.1.1 TX Statut

After waking up, and during this transmitter status TX, the node sends its beacon, and can send a packet, as it can also receive a data packet and acknowledge it. If a synchronization procedure is required, the node will make it before it goes to sleep. This operation is detailed in figure 3. This figure shows that a node can be in one of the following six states: SLEEP, SEND_BEACON, WAIT_DATA_BEACON,SEND_DATA, SEND_ACK, WAIT_ACK.

Between the two states SLEEP and SEND_BEACON, the node constructs the fields of the beacon to be sent and goes to the SEND_BEACON state or starts the second synchronization procedure and returns to the SLEEP state. The beacon in the case of a synchronization request is sent with the fields (RS

= True, IS = True, SN = @ Dest: the destination node Address). While it is sent with the field (RS = False) in the case of a normal beacon. After sending the beacon, it goes to the WAIT_DATA_BEACON state where it waits for receiving a beacon or a data packet after resetting the local variable ReqS (Require Synchronization)- to false.

In the WAIT_DATA_BEACON state:

- If it correctly receives a data packet, it goes to the SEND_ACK state to acknowledge it and decrements the value of the local backoff exponent (BE). And if it can't decode the packet because of a collision for example, it doubles the BE value. Then it checks synchronization requests and returns to the SLEEP state.
- If the waiting time is due, the node decrements the value of the contention window CW, then it returns to the SLEEP state after it checks synchronization requests.

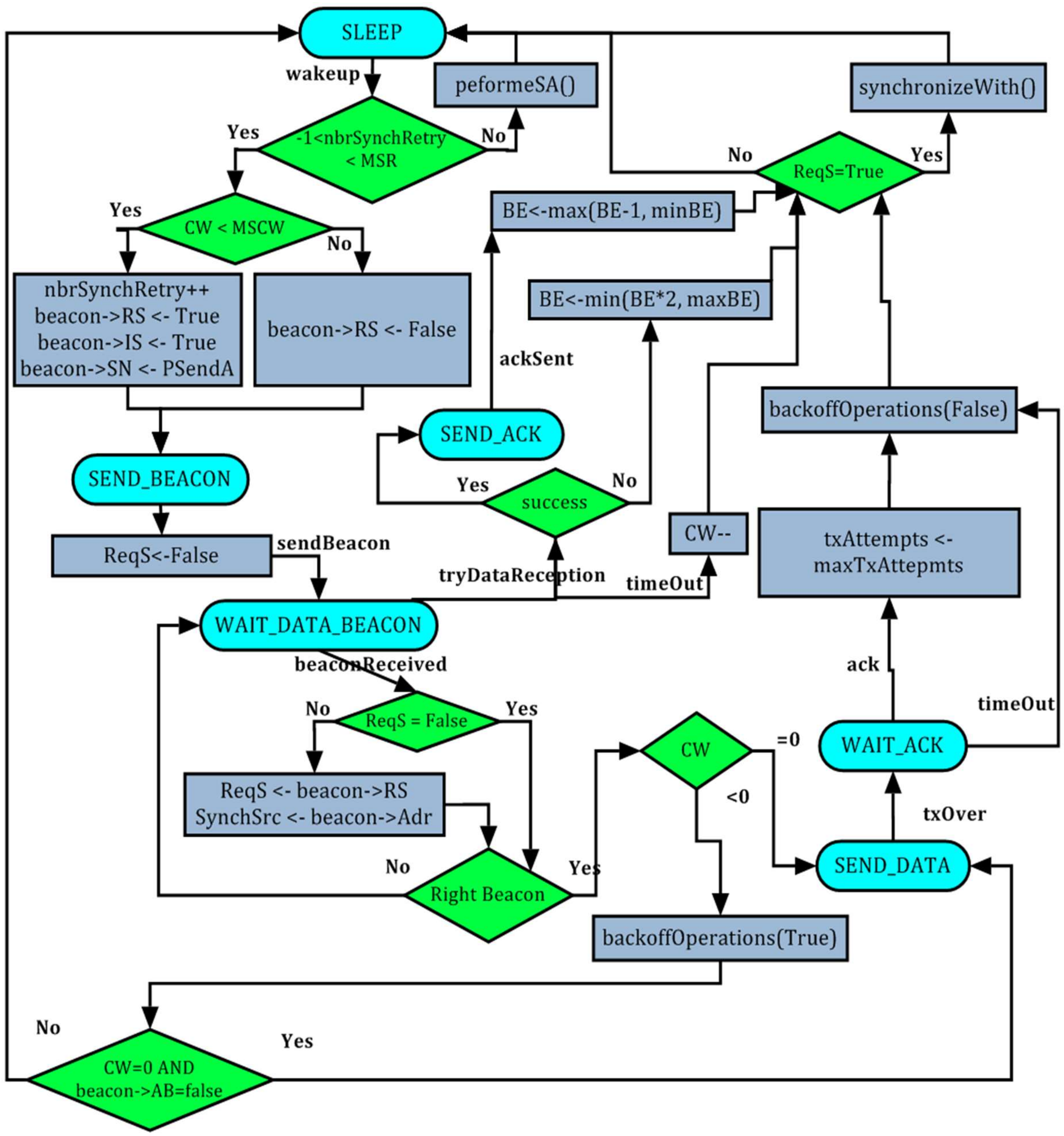

Figure 3: TX Statut Diagram

- If it receives the expected beacon:
  - First reception (CW <0): it executes the backoff operation with the value of the window returned by the NBO () function (see algorithm 2) and passes to the SLEEP state. In the particular case where the value of the window is equal to 0 with an AB flag equal to false, the node switches to the transmission state SEND_DATA.
  - Not first reception (CW = 0): the node passes to the SEND_DATA transmission state.

In the SEND_DATA state, the node waits for data transmission to complete and then enters the WAIT_ACK state. In this last state, the node deletes the packet from its queue and reinitializes its variables (CW and txAttempt) in the following two cases: when it receives the expected acknowledgment or when it fails to receive the latter by exceeding its maximum retransmissions number maxTxAttempt. Also, in the same case where it fails to receive the acknowledgment without reaching the retransmission number maxTxAttempt, the node increments this retransmission number (these Operations are performed in the backoffOperations (False) procedure, see algorithm 3). In these three cases, and before returning to the SLEEP state, the node checks whether there has been a synchronization request.

4.1.2 RX Statut

After waking up and during the reception state, the node sends its beacon and can receive a data packet and acknowledge it. Moreover, the node performs a synchronization procedure before it goes to sleep if it is requested. This operation is detailed in figure 4. Unlike TX, in the RX status, the node does not send any data packets. This is why the two states SEND_ATA, and WAIT_ACK are ignored. The other states have been kept with almost the same operations.

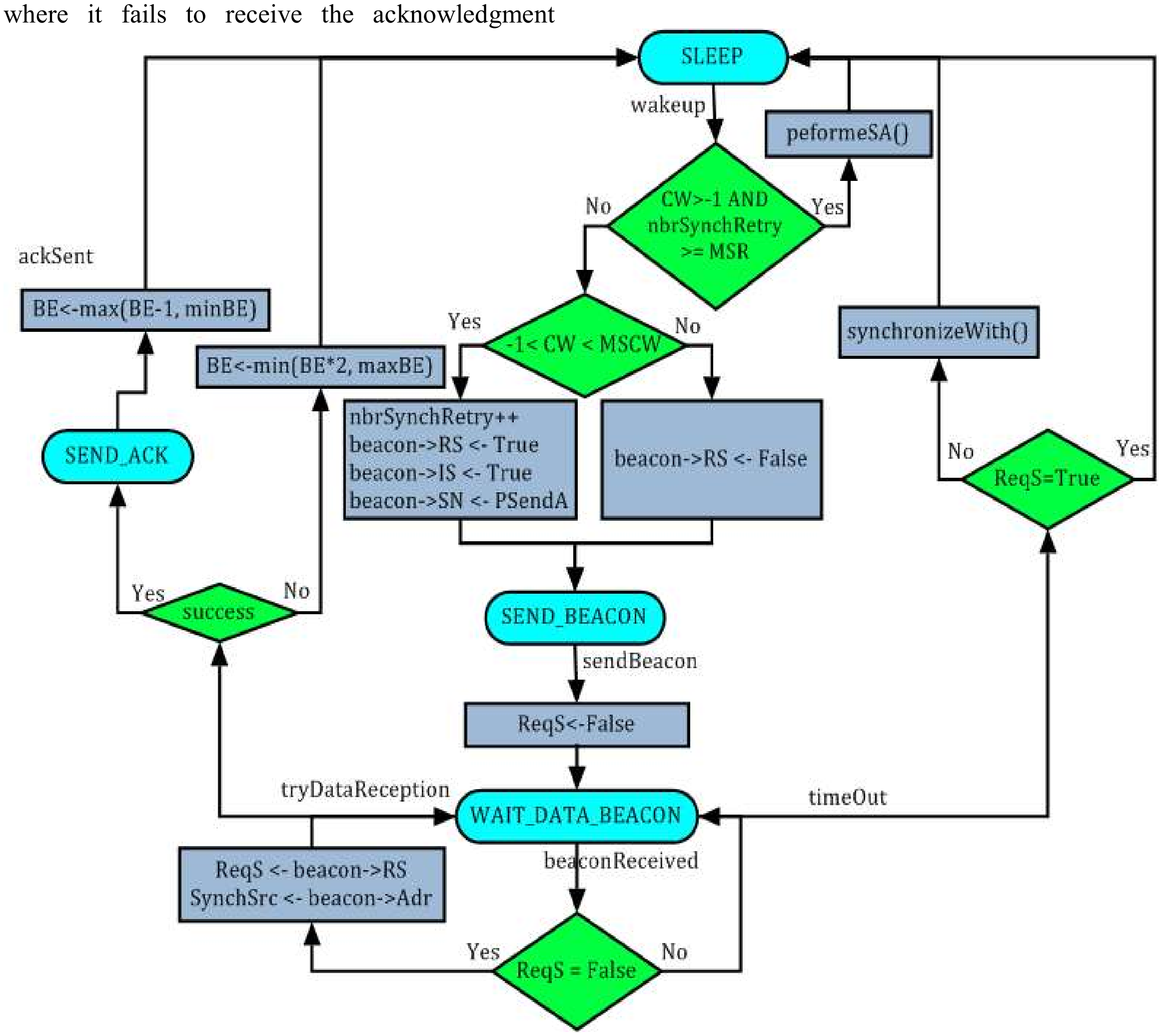

Figure 4: RX Statut Diagram

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4.2 Backoff Algorithm

The principle of the backoff algorithm used by the SWIMAC protocol is called M-BEB (*Modied Binary Backoff Exponent*) [19]. As a summary of its operating principle, the two algorithms 1 and 2 respectively represent the policy of maintaining the local BE and the function NBO() making it possible to calculate the new contention window. The latter takes as parameter, the backoff exponent received in the beacon from the destination node.

Algorithme 1. Policy of Maintaining the BE Locally.

```
BE ← minBE ;
For each reception attempt:
if decoding fails then
      BE ← min(BE*2,maxBE);
else
      BE ← max(BE-1,minBE);
end if
```

Algorithme 2. NBO() Function for Calculating the Contention Window.

```
Inputs: BErec
Outputs: The Contention Window
N ← random(0, 2^BErec - 1) ;
return N ;
```

The backoff operations performed in the backoffOperations (...) procedure consist of calculating the value of the contention window and updating the variables managing the number of retransmission, as well as the number of synchronization attempts with a node on failure to retransmit a message; this procedure removes it from its queue.

Algorithme 3. backoffOperations(newCW) Performing the Backoff Operations.

```
Inputs: newCW : Boolean
if txAttempts < maxTxAttempts then
    if newCW = True then
      CW ← NBO(BErec);
  end if
    txAttempts ← txAttempts+1;
else
    CW ← -1;
    txAttempts←0;
    delete Pckt ;
    if nbrSynchRetry ≠ -1 then
   nbrSynchRetry ← 0;
  end if

end if
```

4.3 Power Consumption Models

Each normal T_W interval starts with a beacon frame transmission followed by a packet or a beacon reception attempt, during this start a node must enter transmission mode ($E_{SetupTx}$), transmit its beacon ($T_{Beacon}P_{Tx}$), switch to reception mode (E_{SwRxTx}) and ttempt a packet reception ($T_{Listen}P_{Rx}$). These costs are regrouped in the beacon energy E_{Beacon}.

$$E_{Beacon} = E_{SetupTx} + T_{Beacon}P_{Tx} + E_{SwTxRx} + T_{Listen}P_{Rx} \quad (1)$$

In addition, during a time L, a node must sometimes transmit a packet E_{Tx} or receive one E_{Rx}, and sleep the rest of the time E_{Sleep}, the following average power consumption is given by:

$$P_{SWIMAC} = \frac{1}{T_W}(E_{Beacon} + E_{Tx} + E_{Rx} + E_{Sleep}) \quad (2)$$

Where: $$E_{Tx} = K.C_{Tx}(P_{out}).V_B.T_{Tx} \quad (3)$$

$$E_{Rx} = K.C_{Rx}.V_B.T_{Rx} \quad (4)$$

$$E_{Sleep} = C_{Sleep}.V_B.T_{Sleep} + \Delta E \quad (5)$$

- K the message length in bytes,
- P_{out} the transmission power,
- C_{Tx}, C_{Rx} and C_{Sleep} represent the current intensities for the three modes,
- T_{Tx} the time of transmission
- T_{Rx} the time of reception.

5. NC IMPLEMENTATION FOR SWIMAC

Network coding is used to improve throughput, minimize power consumption and scalability. It enables a node to combine incoming packets then transmits the combination on each of its outgoing links [20].

5.1 Complexity Constraints

Energy is still a major concern because of the way how nodes use to supply energy, as well as difficulty of human intervention.

While high-end mobile devices have recently become commercially available, these devices are

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for the most part battery-powered and resource-constrained. While they are capable of implementing complex video encoding algorithms, the real-time execution of such algorithms will drain the battery of the device very quickly. This leads to a tradeoff between data rate requirements and power constraints. Reducing the complexity of the compression algorithm to conserve energy at the encoder decreases the resulting encoding efficiency, resulting in larger amounts of data that need to be transmitted. Figure 5 shown example of NC application which a node forward transmission with and without NC.

With the XOR network coding, the intermediate nodes are allowed to combine all the incoming packets by applying the XOR operation [21]. Figure 5 shows the principle of XOR network coding where the relay node r1 and the two source nodes S1 and S2 share the common wireless channel. Assume the capacity of network is 1 bit at a time. In this figure, because of the capacity constraint node S1 will transmit data packet A to r1 which store in the buffer corresponding to S1. Similarly, node S2 will transmit data packet B to r1 which store in the buffer corresponding to S2. Finally, Node r1 broadcast the coded packet A xor B. For r1 this whole process involves three transmissions instead of four for the normal forwarding process. The received packet (A xor B) by r2 will be broadcasted by this node.

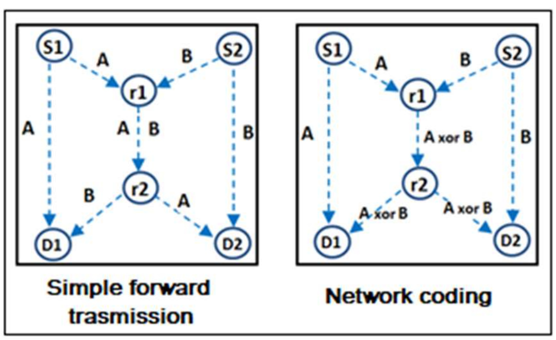

Figure 5: Forward Transmission with and Without NC

5.2 Instantly Decadable Network Coding

Instantly Decadable Network Coding (IDNC) has several advantages, like the use of simple XOR binary to encode/decode packets in the binary domain, no buffer requirement, and very fast progressive decoding of packets. These benefits are very favorable in many applications that are rigorous in terms of delay and processing power[22].

IDNC is performed in two principal phases. In the first phase, the source broadcast all the n packets one by one. Then according to the received packets at the destinations, the source distributes instantly decodable packets so as to maximize the number of users who can immediately recover one lost packet. This problem is highly relevant in practice, and yet only solved in heuristic ways. The first phase transmission scenario is depicted in figure 6a. As depicted in figure 6b, without employing IDNC and in order to recover lost packets, the source node S has to retransmit 5 packets.

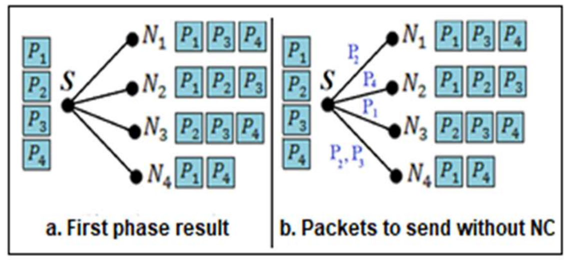

Figure 6: Broadcast Without IDNC

By application of the IDNC, the source node **S** broadcast only two coded packets in the second transmission phase.

$$CP1 = P1 \oplus P2 \quad (6)$$

$$CP2 = P3 \oplus P4 \quad (7)$$

- The Xor operator denotes by the symbol $\oplus$.
- With CP_1, node N_1, N_3, N_4 recover respectively packets P_2, P_1, and P_2.
- With CP_2, node N_2 and N_4 recover packets P_4 and P_3 respectively.

The problem of finding coded packets to send in order to recover lost packet in the first phase draws on the state feedback matrix. A state feedback matrix $SFM = [fi, j]$ is built based on the reception feedback of destination nodes.

$$f_{i,j} = \begin{cases} 1 & \text{if node } i \text{ received the packet } j \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

Hereafter, we give the state feedback matrix corresponding to the example shown in figure 6.

$$\text{SFM} = \begin{array}{c} \\ \end{array} \begin{array}{c|cccc} & P_1 & P_2 & P_3 & P_4 \\ \hline N_1 & 1 & 0 & 1 & 1 \\ N_2 & 1 & 1 & 1 & 0 \\ N_3 & 0 & 1 & 1 & 1 \\ N_4 & 1 & 0 & 0 & 1 \end{array} \quad (9)$$

After the construction of this SFM, the sender initiates a coded transmission phase which is also subject to erasures. In this phase, the sender sends network coded packets to efficiently complete the broadcast of the packets' generation.

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5.3 NC Implementation

The simplicity of the implementation and the low requirements in terms of coding and decoding cost are the mean advantages of NC using XOR coding technique. To enhance the performance of SWIMAC for IR-UWB based WSN the implement of this variant is recommended due to these mean advantages.

In addition to the reception buffer, the good implementation of XOR coding in SWIMAC protocol requires the use of an additional separate buffer for each incoming flow from the neighbors' nodes. Furthermore, in the case of the current node is a relay, the following policy is used: This node stores every incoming packet to its corresponding buffer. At its transmission phase, it creates a coded packet by xoring two packets each one from an incoming buffer. And it transmits uncoded packets only, if one of buffers is empty. So, after the reception of acknowledgment (successful transmission) its drops the corresponding packet from the corresponding incoming buffer. On the other hand, if it is a simple source node, the only uncoded packets are transmitted.

In SWIMAC protocol, for the time interval TW of each node the synchronization phase must result in the assignment of a transmission scheme. The three possible schemes are: RRS, RSR, and SRR where R denotes 'Receive' and S denotes 'Send'. An example of the synchronization process results is shown in figure 7. As depicted in this figure, RSR scheme was assigned to node N1, SRR scheme was assigned to node N2, and RRS scheme was assigned to node N3, etc.

For example, the node N3, wakes up at time t_0, sends its beacon, wait for two receptions from its neighbors for two time intervals ∅. Finally, it sends a packet at time t_1 equals to:

$$t_1 = t_0 + 4\emptyset \quad (10)$$

∅ represent the time interval parameter in which the current node must wait to receive the package from a neighbors nodes. Additionally, it must take into account the error of synchronization between the moments of awakening of these neighbor nodes.

T_a is the wake up interval (activation interval) of a node given by:

$$T_a = t_1 - t_0 + \emptyset = 5\emptyset \quad (11)$$

Hence, T_a is composed of the following:

- The time required to send the beacon of synchronization,
- The time required to receive the packet from the first neighboring node,
- The time required to receive the packet of the second neighboring node,
- The time required to transmit the packet to the neighboring nodes,
- The time required to receive the acknowledgments.

Without NC, in a line network the transmission scheme for SWIMAC is characterized by Sending two packets, receiving two packets, and eliminating two packets. This scheme is used as every relay node has to forward exactly one packet to each incoming flow. Therefore, we can notice and conclude that the use of NC in this SWIMAC protocol leads the following improvements: collisions avoidance, number of transmissions' minimization, overhearing minimization, and activation period shortening. This last fact is given as the node is staying in its active state only to achieve reception and transmission's operations. For the rest of period Tw the node must be in sleeping (inactive) state.

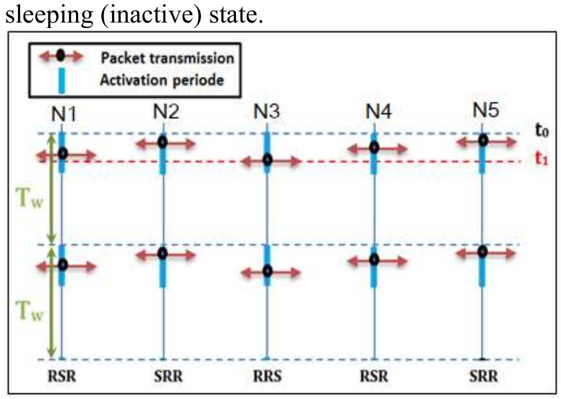

Figure 7: SWIMAC Optimal Transmissions' Synchronization with NC

6. RESULTS

6.1 Simulation Parameters

The total number of nodes varies from 20 to 160 nodes. Each source node periodically generates a packet within a period of 1S. Table 1 show the simulation parameters of SWIMAC, WideMAC an ALOHA. So, to test our proposition we used the line network where two source nodes placed at the end of the two directions transmit packets to each other.

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Table 1: SWIMAC, WIDEMAC and ALOHA Parameters

Protocol	Parameter	Value
SWIMAC and WideMAC	Tw	0,041s
	Ta	0,00187s - 0,0076s
	∅	0,00039s - 0,00151s
	maxTxAttempts	20
	minBE	1
	maxBE	6
ALOHA	maxTxAttempts	30
	minBE	1
	maxBE	12
All	macAckWaitDuration	0,00038s

6.2 Energy Consumption

Energy optimization was and is an interesting issue that is still the factor in the development of IR-UWB- based WSN protocols especially in the MAC and physical layers. This factor directly affect the network's lifetime. The results obtained using the parameters cited in table 1 are presented in this section.

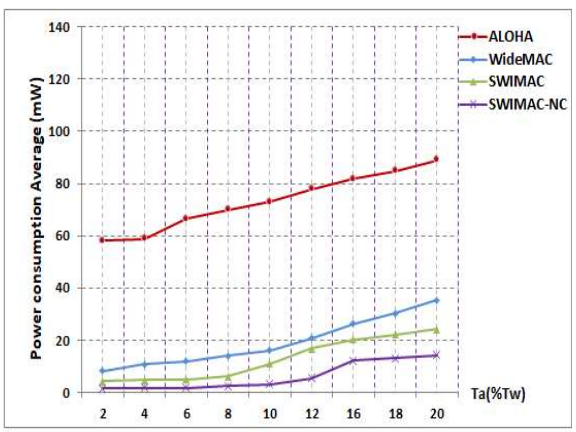

Figure 8: Nodes Power Consumption Average Versus Ta

The variation of power consumption with the active time Ta varies from the value Ta=2%Tw to 20%Tw and the number of nodes fixed to 40 nodes is shown in figure 8. This figure shows that the power consumption of SWIMAC-NC is remarkably less than SWIMAC, WideMAC and ALOHA MAC protocols. It shows also that the power consumption of ALOHA is very more than all other protocols due the retransmission packets caused by the collision. The fact of low power consumption of SWIMAC-NC is the key feature of this protocol due to the introduction of Network coding into SWIMAC that has helped to the decrease in the power consumption of SWIMAC. This consumption was down from 58.2mW for ALOHA, 8.3mW for WideMAC, 4.7mW for SWIMAC to 1.7mW for SWIMAC-NC in the case of Ta = 2% Tw and from 88.84mW for ALOHA, 35.3mW for WideMAC and 24.3mW for SWIMAC to 14.21mW for SWIMAC-NC in the case of Ta = 20% Tw.

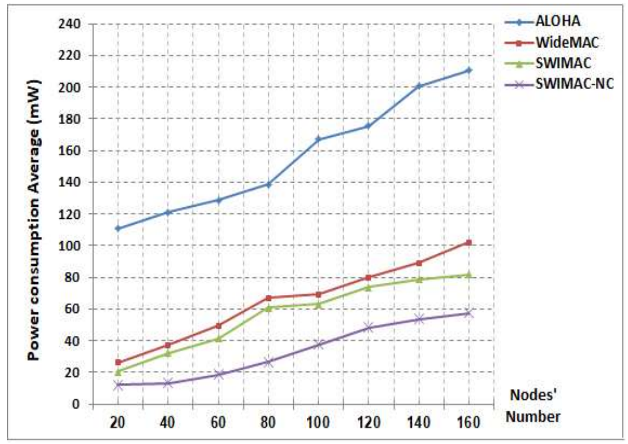

Figure 9: Nodes Power Consumption Versus Nodes' Number

Figure 9 depict the result obtained by a Ta=20%Tw and varying the nodes' number from 20 nodes to 160 nodes. It shows that the power consumption of SWIMAC-NC is remarkably less than SWIMAC and ALOHA MAC protocols. It shows also the linear dependence between the power consumption and the nodes' number.

6.3 Packets Delivery Ratio

PDR is the mean parameter that affects directly the quality of service. This parameter is defined by the ratio of data packets received by the destinations to those generated by the sources.

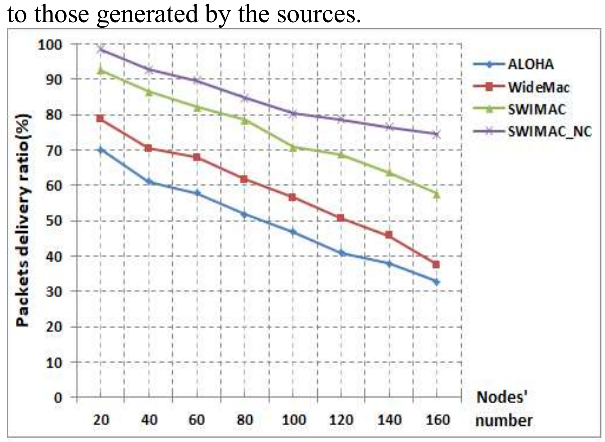

Figure 10: Packets Delivery Ratio

In any MAC, to ensure an acceptable quality of service protocol we were obliged to study the PDR parameter inasmuch as the latter is a direct result of the efficiency of the MAC protocol and due to the dropping MAC frames observed during the transmission mode, Figure 10 shows the remarkable improvement in terms of PDR in the SWIMAC protocol when using NC compared to the ALOHA, WideMac and SWIMAC without NC. These experiments prove the benefits of introducing the NC mechanism in the transmission packets.

6.4 Latency

The packets delay in WSNs is a critical metric especially for time-sensitive applications. This performance parameter depends on the distance or hop count separating the initial and end nodes. Accordingly we performed the following experiment where we record the achieved end-to-end delay with regard to different nodes count settings.

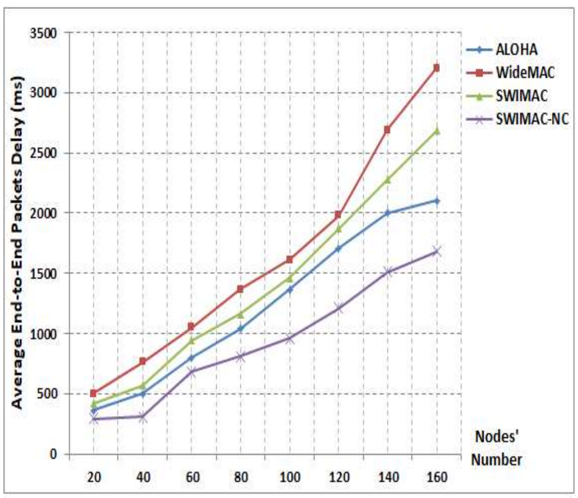

Figure 11: End-to-End Packets Delay (Latency)

The obtained results are shown in figure 11 where the sensors count N takes 20, 40, 60, 80, 100, 120, 140, and 160. Also, ALOHA, WideMac and the two versions of SWIMAC denoted SWIMAC and SWIMAC-NC are compared. WideMac and both implementations of SWIMAC use a time window T_a=15%T_w. Thus, with N=20 and N=160 respectively, the figure shows an end-to-end delay average realization for ALOHA of 360.4ms and 2083.47ms. WideMac performs 512.7ms and 3217.7ms. The last both SWIMAC implementations (with and without NC) attain respectively 260.25ms and 348.3ms for N=20, and 1638.1ms and 2750.2ms. Hence, this experiment demonstrates the benefits of the NC implementation in SWIMAC as the latency improvement for this protocol reaches 33.84% for N=20 and 67.88% for N=160. However, if the energy consumption is neglected, this experiment illustrates the good realization of ALOHA with regards to this time metric as nodes are put in their active periods all the time and the transmission of packets increase and, thus, their lost as well as the end-to-end packets' delay are minimized.

In light of results presented in literature in terms of power consumption, PDR and Latency, the experiments results obtained in this work show the ultra-low power consumption, the PDR improvement and the latency value the minimizing. These three performances are achieved thanks to the duty-cycling property, the low complexity of IR-UWB and the minimizing of the forwarded and retransmitted packets to the neighbors nodes using the Network Coding (NC).

7. CONCLUSION

Throughput and Energy consumption in WSN are among the main concerns in MAC layer. Researchers are constantly developing new strategies to optimize these two metrics for IR-UWB based WSNs due to their impact on improving the network's life time. Besides, with the emerging use of Network Coding in wireless communications, we introduced it in this work as a key feature SWIMAC-NC protocol to improve the performance of IR-UWB-based WSN. It led to a significant gain in terms of energy consumption and communication Throughput compared to the ALOHA, WideMAC and the original SWIMAC protocols.

Indeed, the experiments results demonstrate the ultra-low energy consumption due to the duty-cycling property, the use of IR-UWB and the communication optimization using NC. Mainly, this last minimizes retransmissions as well as the forwarded packets to neighboring nodes.

In other words, the choice of results analysis criteria (energy consumption, PDR and Latency) is justify by the direct effect of this thee parameters and the network's MAC layer Protocol performance in the case of IR-UWB based WSNs.

As a future work, we intend to implement a new adapted routing protocol that will fit to SWIMAC-NC to extremely exploit its features to foster monitoring some systems and environments using IR-UWB-based WSN.

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