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RESEARCH ARTICLE

Energy Saving Multi-Relay Technique for Wireless Sensor Networks Based on Hw/Sw MPSoC System

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ABSTRACT Currently, we are witnessing a wide range of Wireless Sensor Networks (WSNs) in various fields of application. In most cases, these networks contain numerous battery-powered sensor nodes. Therefore, the lifetime of WSNs is intrinsically dependent. For this purpose, different studies have been conducted to reduce the power consumption. We propose a new technique for reducing the power consumption of clustered WSNs. We considered clusters in which sensors transmitted data to a Cluster Head (CH) by cooperative communication based on the Bit Error Probability (BEP) criterion for the multi-relay technique. Therefore, the proposed technique uses a multi-relay to reduce the transmission power to communicate between the source and destination which respects the predefined reliability level. The proof of the described technique was performed using a multiprocessor architecture. Second, we used an efficient software/hardware (Sw/Hw) architecture that utilized accelerator modules. The experimental results demonstrate significant gains in terms of energy consumption and workload compared to the SW implementation.

INDEX TERMS Energy saving, multi-relay, WSN, sensor node, Hw/Sw, MPSoC.

I. INTRODUCTION

IoT has become a new evolutionary paradigm of Information and Communication Technology (ICT) [1]. In IoT, interconnected thinks generate gigantic quantities of data that need to be collected, stored, treated, envisioned, and evaluated. The IoT can have many applications such as smart homes, E-health, pipeline-controlled, and smart cities, [2], [3].

Wireless Sensor Networks (WSNs) have been used in various applications owing to the maturity of their underlying technologies. Hence, they have become increasingly popular in many fields including research, health, environment, security, and surveillance [4], [5]. They are composed of a large number of sensor nodes (SNs) that are used to monitor the surrounding areas and communicate with other nodes.

Since SNs run with limited resources, the WSNs are integrally constrained. Currently, Wireless Energy Transfer (WET) research is being developed as a promising innovation to recharge SNs battery wirelessly [46]. However, this axis still suffers from some handicaps such as the time of the recharging operation and the behavior of the WET when faced with large numbers of SN. Therefore, diminishing the energy of each SN enhances the lifetime of the network. The architecture of an SN is composed of four layers: sensing, processing and storage, communication, and power source [6]. Thus, battery devices remain a major problem for WSNs. Many studies have been conducted to resolve this crucial issue faced by SNs. Many techniques have been proposed, some of which affect only one of the four layers of an SN; others tend to have an impact on all four layers combined [7], [8], [9], [10].

In the present work, we propose the use of a technique that acts on the processing and communication layers of an SN to reduce power consumption and, consequently, increase its lifetime. The communication layer consumes the greatest amount of energy in WSNs [11]. Our first contribution

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consists of establishing a new low-power communication technique based on the use of multiple-relays to ensure communication between a source (S) and a destination (D). We will investigate variable power transmission in a cooperative multi-relay technique. We investigate to proof the study on power transmission from a single-relay [12] to a multi-relay technique.

Although, most SNs are microcontroller unit (MCU) [13], the use of new technologies has a great potential in this domain. In this respect, real-time constraints, time to market, and energy savings favor the use of high-performance technologies such as Digital Signal Processor (DSP) [14], Application-Specific Integrated Circuit (ASIC) [15], and Field-Programmable Gate Array (FPGA) [16]. The use of the FPGA platform contributes to the improvement of WSN performance owing to the HW block. This HW block decreases execution time by transforming a SW complex function into HW modules [11]. In addition, the FPGA can be used as a reconfigurable part of an SoC. Atitallah et al. [17] present a system architecture based on an FPGA to process and interface the Zigbee transceiver and acquisition unit. Furthermore, the second contribution treats the processing layer using two types of architecture: multiprocessor system on chip (MPSoC) and hardware accelerators based on an FPGA platform. The architectures make it possible to accelerate the workload and, consequently, reduce the power consumption of the SN.

This paper is structured as follows. The first section addresses the constraints of WSNs and surveys the different energy consumption decreasing techniques that exist in the literature. The next section details the proposed multi-relay cooperative communication technique. The last section is dedicated to the design of a multiprocessor, Hw/Sw architecture suitable for CH.

II. STATE OF THE ART

This section presents an overview of the existing techniques to save energy in an SN.

A. SENSOR NODE LAYERS

The architecture of an SN is composed of four parts: sensing layer, power supply, communication layer, and processing layer. These layers can exchange information with each other to provide the required processing. As illustrated in Figure 1, a basic SN node comprises:

- a power source: the power supply feeds all node components. The SN generally uses batteries. Energy consumption at the SN is attributed to three basic components: energy consumed for measurement, communication energy, and processing energy, as shown in Figure 2.
- a sensor (sensing layer): humidity, temperature, accelerometer, video camera, pressure, …etc. Sensors accumulate data from physical measurements and transform them into analogic/numerical signals for processing and analysis.

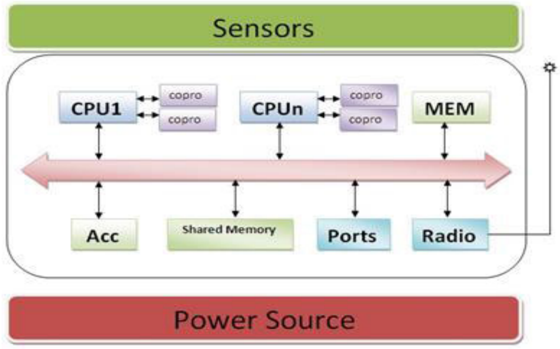

FIGURE 1. Sensor node components.

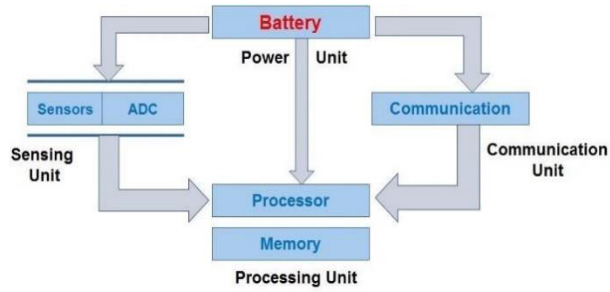

FIGURE 2. Basic energy consumption components in a sensor node.

- a radio (communication layer): this layer is essentially based on a communication protocol which must ensure that data is being exchanged between the various components of the WSN. It is the most power-consuming unit (70% of the total consumption of power).
- a processing unit: Most SNs use a micro-controller as the processing unit, which results in limited processing capabilities. In addition, to reduce the power consumed by the entire platform, the nodes operate at low frequencies, which has a direct impact on the performance of the executed algorithms. Indeed, the more workload the algorithm takes, the more energy it consumes. To address this problem, research has been conducted to design a more powerful node processing unit. One of the proposed solutions is the use of DSPs, as reported in [19]. Other more recent works have proposed to equip the sensor node with a fairly powerful processing unit based on new technologies, such as FPGAs. These technologies can contain Hw/Sw architectures with a high performance and low power consumption.

B. POWER MANAGEMENT TECHNIQUES

Many factors influence the probability errors in the transmission; therefore, the entire packet is re-sent once again. Thus, the first factor that must be addressed is the reduction in same-packet re-sending. The consumption of a single transmission was 20 mA [20]. In addition, other works use the peak/wake technique to reduce consumption. The sensor node resides in deep sleep until it is awakened by its neighboring wake-up receptors only when needed [21]. This approach makes it possible to obtain a very low power consumption rate in this state.

1) FREQUENCY AND VOLTAGE MONITORING

This technique consists of operating microprocessors under different frequency and voltage settings, the objective of which is to use the resources of the system optimally. Dynamic Voltage Scaling (DVS) can increase energy savings by varying the voltage provided to a set of components in a system. Therefore, it can decrease global power while guaranteeing real-time constraints [22].

2) ENERGY-EFFICIENT ROUTING PROTOCOLS

Many studies have been dedicated to implementing energy-efficient routing protocols and/or improve the ones already in existence [45]. RPL [23], Low-Energy Adaptive Clustering Hierarchy (LEACH) [24], distributed energy-efficient clustering (DEEC) and Threshold Sensitive Energy Efficient sensor Network (TEEN) [25] are the popular used energy saving protocols in WSNs. The authors of [24] present an improved hierarchical LEACH protocol to conserve energy and. The TEEN protocol is proposed in [25]. In this protocol only the CH near to the gateway sends data directly. In [26], an enhanced version of the RPL is proposed which uses composite routing metrics. Finally, a multi-level heterogeneous routing protocol based on LEACH is proposed in [27] and termed DEEC. Its CH selection is based on the average and residual energy. Thus, the SN having greater residual energy, has a better chance of becoming a CH.

3) DATA AGGREGATION

We can aggregate the data to reduce the number of transmission operations by reducing repetitive and unnecessary information transfers. The aggregating node collects data from some SN and composes a message that summarizes significant information [28], [29].

4) WORKLOAD

Many research undertakings have focused on determining the proportional workload impact on the power consumption of the system. For this purpose, two techniques have been proposed; the first is based on algorithmic optimization to reduce complexity, while the second uses hardware components that reduce the processing time and, therefore, the amount of energy consumed by this crucial operation [39].

5) MACHINE LEARNING ALGORITHMS

The authors of [47] presented in their survey, the impact of the use of Machine Learning (ML) in the context of WSN. Some of these have the advantage of reducing the energy consumption of the WSN. However, these algorithms have certain limitations. The major one is, their complexity which requires high performance calculations and consequently increase the consumption of energy.

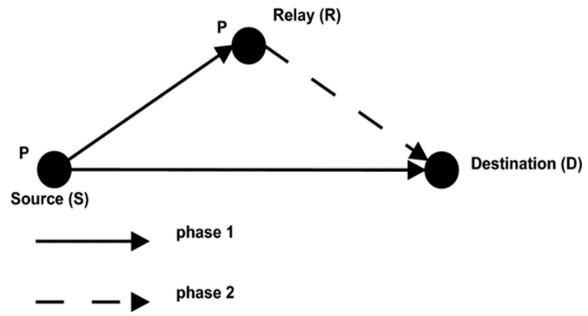

FIGURE 3. Cooperative communication.

6) COOPERATIVE COMMUNICATIONS

Cooperative communication exploits the broadcast of the wireless, as presented in Figure 3. If needed, the relay will resend the same source packet to the destination in all transmissions. This is to reduce the probability error [31].

III. MULTI-RELAY PROPOSED TECHNIQUE

The application of relay techniques offers an important progress to the performance in relay networks at the expense of long-packet delays [2]. A new metric was used in [32] for energy saving cooperative transmission techniques in WSNs. In [32], the authors, have reduced the energy per transmission distance by selecting the cooperative nodes and transmission energy. Sheng et al. [33] proposed energy-efficient relay technique using the outage probability as the optimization criterion. Moreover, a new multi-node relay selection decode-and-forward cooperative scenario was proposed in [34] based on the available partial Channel State Information at the source and the relays. The authors demonstrated that their proposed approach achieved full diversity and a significant increase in bandwidth efficiency.

Many works minimize link outage probability to optimize energy allocation among relay nodes. Reference [18] present an approach that uses cooperative or non-cooperative transmission to minimize the consumed energy, based channel metrics and transmission range.

In our case we use the bit error probability "BEP" for a selective scheme with the purpose of minimization of energy consumption. Therefore, the main contribution of our work is to choose relays which will repeat packet sending using the least energy amount with a predefined BEP threshold. Thus, our selective relaying approach contributed to energy saving.

A. WSN TOPOLOGY

In the present work, we use the low energy adaptive clustering hierarchy (LEACH) algorithm [24]. This is the original and illustrative of all the hierarchical topology control algorithms. We consider that the WSN is divided into clusters. Each one contains a set number N of randomly distributed nodes. One of them is selected as a Cluster Head (CH) (see Figure 4). The CH repeats the sensed information from the remaining N–1 SN within the cluster.

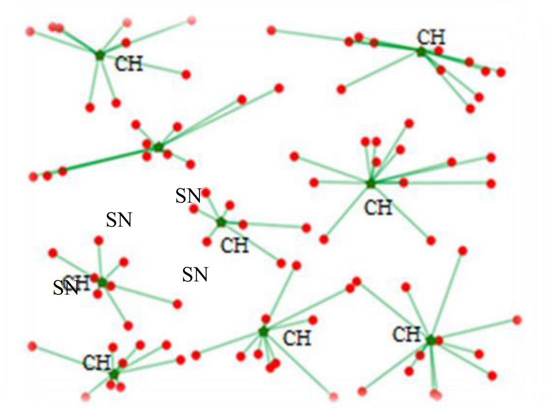

FIGURE 4. WSN topology.

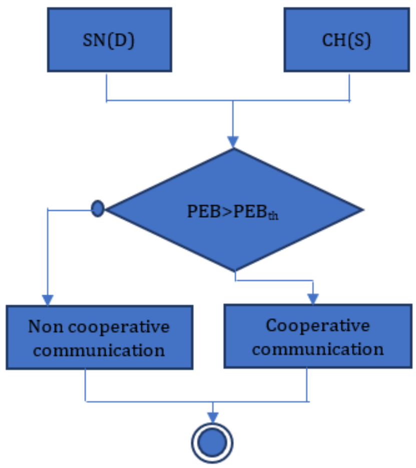

FIGURE 5. Cooperative transmission principle.

B. PROPOSED SYSTEM MODEL

Figure 5 presents the proposed system models of communication for a clustered WSN. These models are established for both cooperative and non-cooperative transmission. Based on these models, we optimize node energy consumption using an efficient and cooperative transmission technique.

Any SN in a cluster needs to send a message to the CH which is designated by the LEACH clustering algorithm. It is the SN that is in charge of assembling information from the different SNs. We note the source by S and the destination by D. The communicated signal XS hence travels via diverse channels before arriving at its destination. A relay R (or set of relays Ri) can contribute by providing to a destination a copy of the original signal (when it invited to do this) as shown in Figure 6. Therefore, the selected relays can re-send the signal XR to D using the Amplify-and-Forward (AF) or the Decode-and-Forward (DF) relaying strategy.

Maximum Ratio Combining (MRC) technique is used to receive and combine all the signals (YS,D) and (YRi,D).

In our work, we use the same equations that we propose and detail in [12]. To calculate the BEP, we use equation (1) for non-cooperative communication and equation (2) for cooperative communication. More details about each parameter and

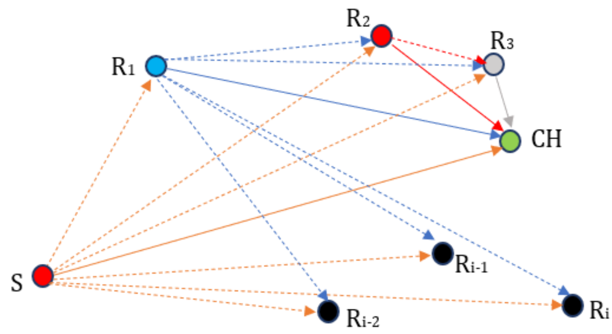

FIGURE 6. Cooperative transmission.

its significance are provided in [12].

$$Pe_d\left(\epsilon\right) = \frac{1}{2}\left(1 - \sqrt{\frac{1}{1+\frac{1}{\sigma_{SD}^2}}}\right) \tag{1}$$

$$\begin{aligned} Pe\left(\epsilon \mid R_{set}\right) =& Pe_d\left(\epsilon \mid R_{set}\right) Pe_{prop}\left(\epsilon \mid R_{set}\right) \\ &+ \left(1 - Pe_d\left(\epsilon \mid R_{set}\right) Pe_{coop}\left(\epsilon \mid R_{set}\right)\right. \end{aligned} \tag{2}$$

C. RELAY SELECTION ALGORITHM

The proposed relay selection algorithm, illustrated in Figure 7, is essentially based on the use of BEP expressions. The CH executes the relay selection algorithm to determine the all the nodes whose source node SNR received greater than a predefined threshold value, denoted Peth. Then, it selects the optimal relays, i.e. those which offer the lowest transmission power combination in the source-destination and relay-destination links while keeping the BEP within the range of a predefined Peth threshold. As a result, the CH chooses between the direct and cooperative types of communication. If the first type is chosen, then the CH communicates to the source the transmission power to be used. However, when the second type is chosen, it selects all the relays that will intervene by fixing the lowest transmission power to be used for each one.

We search the better transmission power ES,D for S to D without relay and the S-cooperative D energy noted ESc,D, the energy of each relay to D noted ERi,D with multiple relays for a BEP in the range of a Peth, respecting the power system constraints

$$\sum_{i=1}^{n} E_{Ri,D} + E_{Sc,D} < E_{S,D}$$

The steps of our technique are abridged in the following:

- computation of the transmits power ES,D that preserves the BEP for direct broadcast in the range of Peth;
- selection of the optimal relays whose couple $(\sum_{i=1}^{n} E_{Ri,D}, E_{Sc,D})$ has the lowest sum;
- choice between non-cooperative and cooperative communication schemes base on transmission power.
- The cooperative communication is selected if it can minimize the energy with the same PEB Peth. Otherwise, a direct transmission is used.

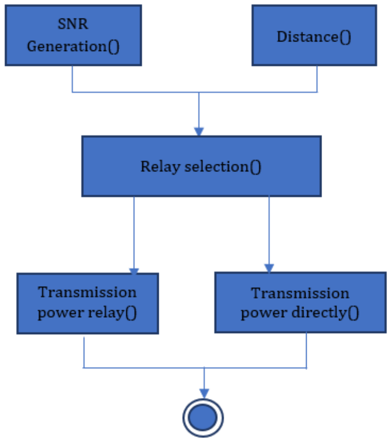

FIGURE 7. Cooperative transmission algorithm.

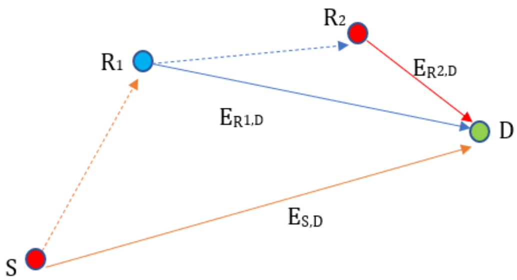

FIGURE 8. Energy transmission for the cooperative technique.

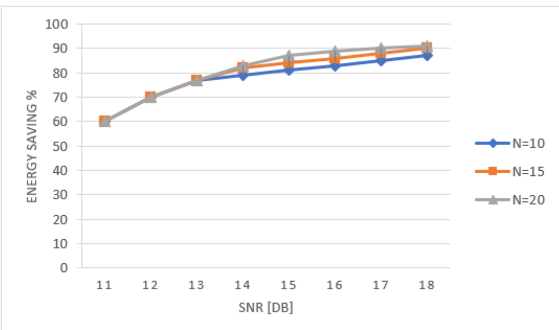

FIGURE 9. Energy saving by using multi-relay technique with BEP in the range of Peth = 10^{-3} and different N values.

So, the CH has to solve an NP-complete problem to select the best solution (set of nodes) to be used to send the packet from S to D with the minimum consumed energy while maintaining a PEB Peth (Figure 8.). Using this exact method consumes a lot of CH resources. To resolve this issue, we propose to use a heuristic method based on the genetic algorithm.

The optimization problem can be formulated as:

F1=MIN($\sum_{i=1}^{n} E_{Ri,D} + E_{Sc,D}$)

Under constraint

Peb(ERi,D;Esc,D) $\approx$ Peth and $\sum_{i=1}^{n} E_{Ri,D} + E_{Sc,D} < E_{S,D}$

where Ri = {R1,R2,…Rn}; n is the number of nodes having source-node SNRs that exceed a predefined threshold Peth.

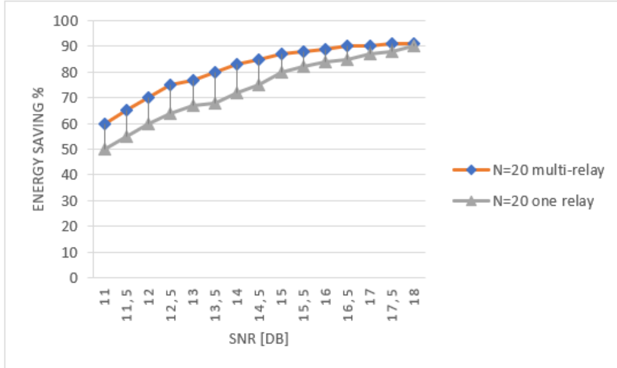

FIGURE 10. Energy saving by single and multi-relay technique with BEP in the range of Peth = 10^{-3} and N=20.

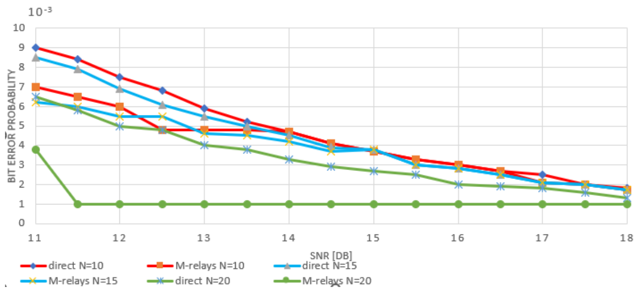

FIGURE 11. BEP comparison between Cooperative and Non-Cooperative Communications with BEP in the range of Peth $\approx 10^{-3}$ and different N values.

D. SIMULATION RESULTS OF PROPOSED TECHNIQUE

In this subsection, we report on the experimental results for the proposed relay selection algorithm. We performed several tests to identify the most appropriate number of iterations for the genetic algorithm. We use a fixed value (20) for the population size of the genetic algorithm.

Figure 9 demonstrates the large energy saving potential cooperative communication can generate. Indeed, it can attain more than 80%. Moreover, we note the great impact of the density N of nodes within a WSN. As expected, a higher number of nodes N provides a good result for choosing relays and, consequently, good power efficiency.

Figure 10 shows a comparison between the single relay technique presented in [12] and our multi-relay technique under the same conditions with a number of nodes equal to 20. We notice a significant decrease in the percentage of energy consumed.

In Fig. 11 and 12, we plot the BEP with and without the multi-relay technique. We note, the improved reliability, especially in the moderate SNRs region. Thus, our multi-relay technique not only achieves substantial energy saving but also improves the level of reliability.

IV. TOWARD AN EFFICIENT ARCHITECTURE OF SN

Most WSNs are based on MCUs. They are characterized by their time to market, power consumption and low cost [13]. However, the new generations of SNs require more and more intensive computing capabilities, especially when the SN

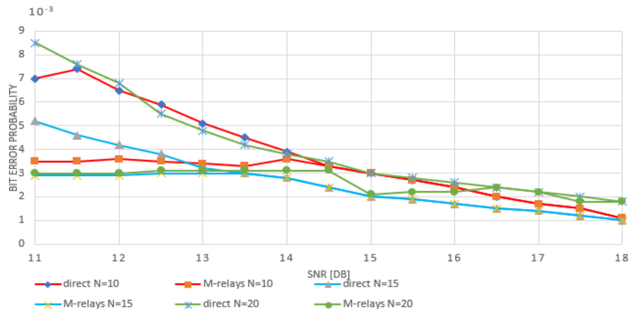

FIGURE 12. BEP comparison between Cooperative and Non-Cooperative Communications with BEP in the range of Peth $\approx 10^{-4}$ and different N values.

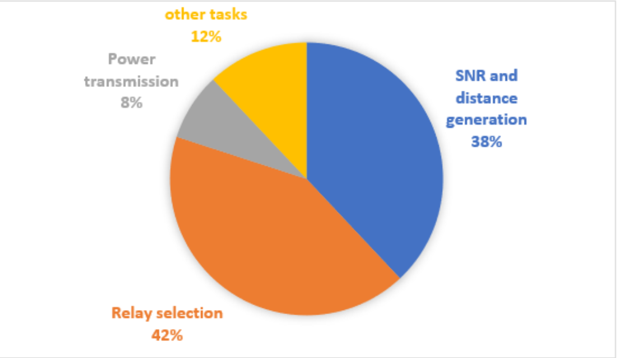

FIGURE 13. Profiling results of the proposed multi-relay technique.

is chosen as a CH and has to execute different complex programs for a rather large number of SNs in order to ensure the required functionalities. Therefore, the use of MCUs presents a major handicap since they have less resources compared to other platforms due to their low frequency and small memory size [36]. Another alternative is the DSP, which is a processor specialized in signal processing, but has a high-power consumption rate. This is the obstacle to using it in WSN applications. Currently, the FPGA is a new way to be used to make a WSN with powerful computation capabilities, low power consumption and, especially, the possibility to do parallel processing when several units request particular treatments [14]. FPGAs allow a faster prototyping based more on custom logic than software. In this regard, many works ([37], [38], and [39]) have used different types of FPGAs to propose a sensor node with very high performance for different types of applications such as routing and network security. The use of FPGAs in this type of system offers the possibility to define a custom architecture that allows the SN to meet its different constraints using either hardware accelerators or multiprocessor architectures. In [18], the authors propose a specific SoC architecture targeting the SN digital block to reach energy efficiency. They report that their proposed FPGA-based design saves up to 24% of power and reduces excess area by 24.3% compared to the reference SoC-MCU. The authors in [40] use an architecture to achieve the transmission and routing process by specific accelerators. They demonstrate that more than 90% of power consumption could be saved. In [41] the authors, outline a node board based on WSN (IRIS and MICAz from Crossbow Technologies) to ameliorate the SN performance.

A new SoC architecture is suggested in [42] for the hard-core ARM processor-based routing protocol. It uses an HW block to decrease the execution time of SN, thereby decrease the consumed energy of routing function. Experiments yield significant results: more than a 60% decrease in power consumption as well as up to 40% in execution time compared to the software solution. A data compression algorithm for a WSN in an IoT application is accelerated using a Nexys 4 hard-core embedded processor in [43]. In [44] authors use a reconfigurable and multiprocessors system with a DE0 board.

To evaluate the performance of our technique, we have chosen to implement an embedded system. We choose the NIOS-II processor. The goals of this first design are to validate the proposed technique and profile it as well as to analyze the performance of each task. We use the Stratix-III FPGA board.

As detailed in Figure 7, our proposed technique is composed of four tasks: SNR, distance generation, relay selection and determination of transmission power. The processing time is 88 ms.

To identify critical workload tasks, we use profiling technique. This technique gives the execution time, the iteration number and memory occupation. Figure 13 represents the CPU time consumed during the execution of each of the different tasks of the algorithm made by the hardware timer.

From Figure 13, we remark that the both functions: Relays selection (42% of CPU time) and generation SNR-Distance (38% of CPU time) are the most complex tasks. Based on the profiling results, we can deduce that these two functions are promising candidates to accelerate their processing time. In fact, given the good regularity of the equation of the generation SNR-distance function, it can be replaced by hardware blocks coupled to the NIOS-II processor. Meanwhile, the relays selection function based on the genetic algorithm can be parallelized on the MPSoC architecture.

In the remainder of this section, we are interested in the implementation of our technique on an MPSoC architecture and the design and implementation of the generation SNR-distance blocks in hardware form.

A. MPSoC ARCHITECTURE FOR SENSOR NODE

In this sub-section, we present all the steps to perform the implementation of our technique on an MPSoC platform.

First, we remark that the execution time of our technique is short and promising, but a problem arises when several SNs want to communicate with the CH simultaneously. With the increase in the number of processing programs, the CH must create the adequate hardware architecture to respect the temporal constraint. The use of a multi-core system can improve the performance of this technique and accelerate its processing capacity.

Therefore, we used the Stratix-III platform on which we can put a large number of soft-core processors (NIOS-II).

TABLE 1. Execution time for different multiprocessor architectures.

TIME (ms)/TASK	1CPU	2CPUs	4CPUs
SNR and distance generation	266.72	143.45	76.32
Relay selection	295.62	154.26	81.64
Power transmission	56.32	31.2	17.24
Other tasks	84.48	45.04	25.36
Total time	703.94	373.95	200.56
Gain percentage	-	47%	71.5%

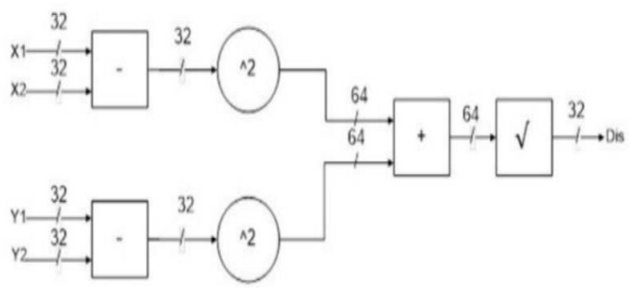

FIGURE 14. SNR generation task schema.

We have distributed the necessary treatments equally to quickly process the requests of each SN. Consequently, the same treatment will be running on all the processors, each one deals with one SN.

Each processor core is configured to run all ''SNR and Distance generation'', ''relay selection'', and ''determination of transmission power'' modules using the features of the SN. All the processors communicate using shared memory. Each CPU runs its own code with its own input parameters. CPU0 is the master of the system. This master is responsible for initializing the system and controlling the startup of the slave CPU. CPU0 also communicates and shares the UART with other CPUs. All the CPUs communicate via an event flag. Before starting slave CPUs, CPU0 initializes the flag to 0 and owns the UART. When the flag is different from zero, CPU1 owns the UART. Each processor does its own processing. Once a slave CPU finishes its processing, it writes the result onto the shared memory and informs CPU0 so that it sends it to the corresponding SN.

Table 1 illustrates the execution time results obtained by our technique using different numbers of CPUs when eight SNs want to communicate simultaneously with the CH. We note that we can reach 71% acceleration of the execution time.

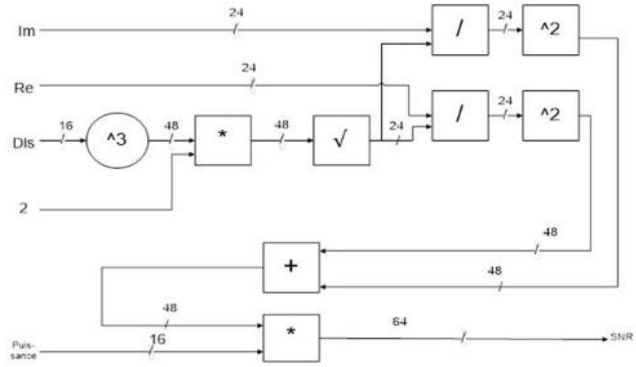

FIGURE 15. Distance generation task schema.

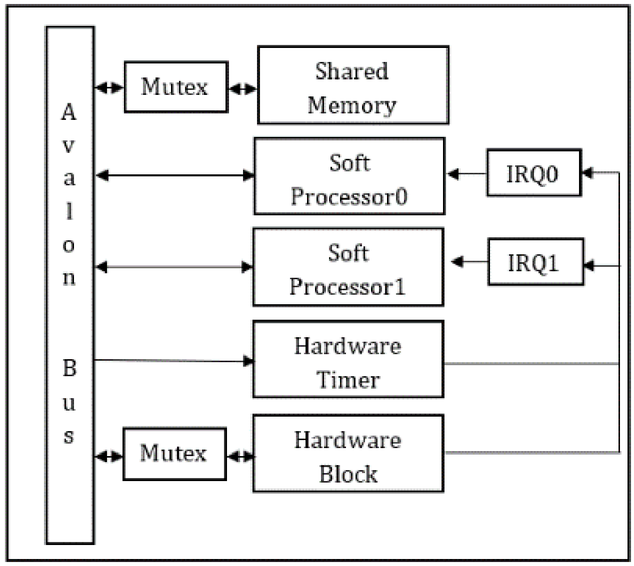

FIGURE 16. Proposed architecture for SN.

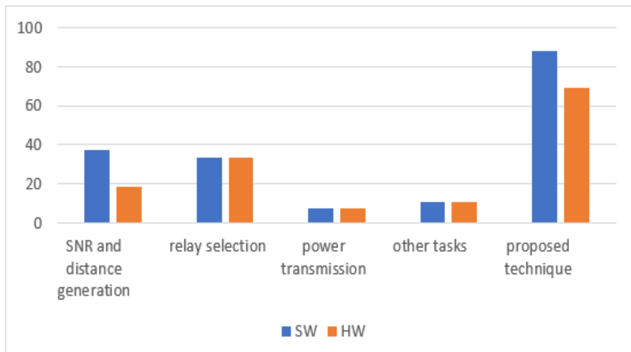

FIGURE 17. Execution time (ms) evaluation of the proposed technique using Hw accelerator.

B. DESIGN OF AN HW ACCELERATOR

We proceed to the design of the hardware block for the generation of the SNR-Distance function in order to integrate it as a hardware accelerator in the algorithm of the proposed technique. Figures 14 and 15 depict the block diagram of this function. As shown in Figure 16, the designed system consists of NIOS-II processors linked to an external memory, a hardware block and the Avalon bus. Exclusive access is provided by the hardware mutex to ensure that no two processors can access this block simultaneously. The set is added to the bus IPs file. Therefore, the system will switch from one to the other according to its needs when executing the Sw code. The execution times are measured using the hardware timer.

TABLE 2. Execution time for different Hw/Sw multiprocessor architectures.

TIME (MS)/TASK	1CPU	1CPU+HW-ACC	2CPU+HW-ACC
SNR AND DISTANCE GENERATION	266.72	133.59	76.32
RELAY SELECTION	295.62	295.62	154.26
POWER TRANSMISSION	56.32	56.32	31.2
OTHER TASKS	84.48	84.48	45.04
TOTAL TIME	703.94	476.42	270.5
GAIN PERCENTAGE	-	23.33%	61.58%

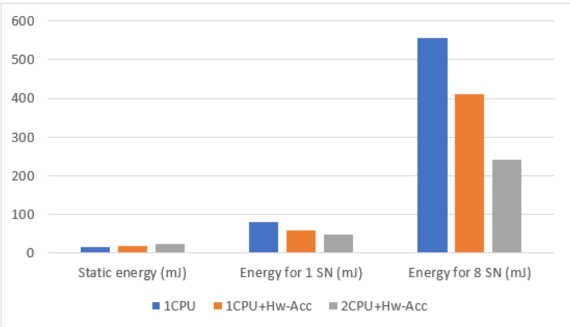

FIGURE 18. Energy consumption (mJ).

C. EXPERIMENTAL RESULTS

To measure the impact of the HW block, we claculate the workload of both Sw and Hw prototypes. According to the execution time of the whole algorithm, we notice a huge acceleration in the execution time, amounting to nearly 50% (Figure 17). It is noticeably reduced compared to the Sw version, thereby decreasing energy consumption.

Table 2 present the impact of the use of booth multiprocessor architectures and Hw accelerator

To assess the consumed energy of our SN architecture, we use the static power of the basic architecture and we add the consumption of all components on the static and dynamic power (due to the execution of Sw).

Then, we compute the consumption energy of different implementations. Figure 18 shows the power consumption measurements of different system architectures. We notice an important reduction of power when using the Hw accelerators and multiprocessor architectures. Indeed, we can attain more than 60% of energy conservation when using a multiprocessor Sw/Hw system with a high workload of the CH.

V. CONCLUSION

Energy saving for WSNs is a very important challenge, as the nodes are in most cases operating with limited energy resources and are powered by batteries. Therefore, there is an urgent need to develop energy-saving transmission techniques. The communication task is one of the greatest energy-consumption tasks in wireless sensor networks. Therefore, addressing power reduction at this level is essential to extend battery life in WSNs. Cooperative routing has received a lot of attention recently because it exploits the broadcast nature of wireless channels to improve performance over traditional routing.

Our contribution in this paper was energy saving subject to the BEP for a selective multi-relaying technique. Indeed, we proposed a novel multi-relay selection algorithm using a BEP to lower the amount of energy required. It provided an efficient way using a genetic algorithm to select the smallest broadcast energy requirement for communication between source and CH. Based on this selection algorithm, the CH chose either to communicate directly or using cooperative communication to minimize node energy consumption, while the required reliability level was respected. The experimental findings revealed significant energy conservation rates (up to 90%) compared with direct transmissions.

Our second contribution in this paper consisted in using an adequate architecture that allowed the reduction of not only the processing time but also energy consumption. We used a system based on a multiprocessor architecture and a hardware acceleration block. This type of architecture showed its effectiveness when we have a lot of processing to do. It allowed the system to respect its temporal constraints while reducing energy consumption by more than 60%. This statistically proved the energetic benefits of using this type of architecture in the CH.

In the future, we propose to integrate the multi-relay cooperative communication technique into a communication protocol and test it in a real system.

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