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Leach-D Protocol for Efficient Communication in Mobile Wireless Sensor Networks

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Abstract - Wireless sensor network (WSN) is composed of several sensor nodes capable of communicating wirelessly to a centralized base station. These sensor nodes can be either static or dynamic based on the type of application in use. Data packets can be collected periodically or based on the occurrence of the monitored events, to which sensor nodes respond by transmitting the measured parameters to the base station for analysis purposes. The researchers in the field are currently focusing on finding a tradeoff balance between the energy consumption, packet delivery latency and the packet reception rate in an environment where sensors are statically deployed. However, the mobility issue has to be taken into account to overcome additional challenges that are mostly inherited by ad-hoc networks. In this paper, we put much emphasis on leach protocol categorized as a cluster-based routing protocol to improve its performance under the criteria of high mobility. The results prove the efficiency of the proposed leach-d protocol as it minimizes the overall energy consumption and packet delivery latency whilst it maintains a considerable packet reception rate.

Keywords - *Wireless Sensor Networks, Mobility, Leach-d protocol, Military Application.*

1. Introduction

Wireless sensor networks introduce many challenges related to security. Commonly, the WSN application scenarios are associated with large-scale systems composed of tiny battery-powered devices, with very limited computational resources. The limited energy source, memory, and CPU, as well as large infrastructure-less system architecture, put demanding requirements concerning efficiency and scalability of security mechanisms and protocols used within WSN. This is also a reason why many well-known and tested security mechanisms deployed for the internet infrastructure and traditional wireless communications systems do not fulfill requirements introduced by the WSN.

WSNs have emerged as an excellent tool for military applications involving intrusion detection, various parameters monitoring, information gathering and, smart logistics support in an unknown deployed area. These networks can provide different services to military and air force like information collection, battlefield surveillance and attack detection. Because of their capabilities of real-time transmission, WSNs play an important role in military operations.

These networks offer several advantages over traditional sensor devices such as fault tolerance, robustness, and low budget deployment.

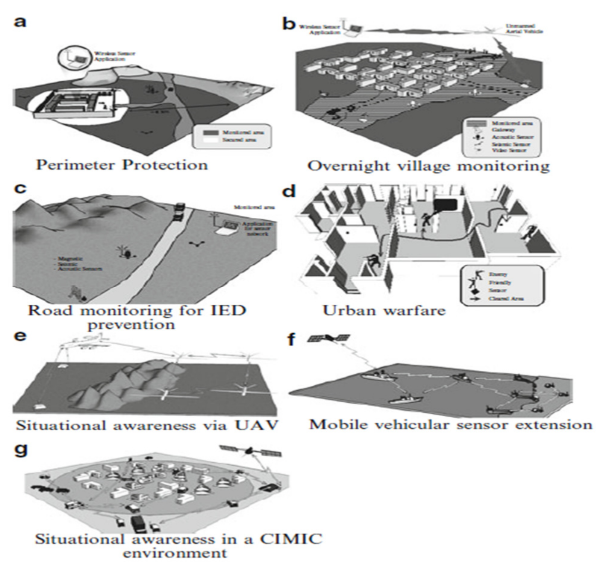

Figure 1: Military uses case [1]

The above section on the military use of wireless sensor networks provides an overview of the main objectives that military decision-makers intend to achieve through the application of wireless sensor networks. This section presents realistic use cases for military wireless sensor networks from which the wide variety of requirements for sensors and their networking capabilities can be deducted. The establishment and analysis of such use cases are typically part of a systematic review of defense requirements undertaken by operational analysts with the intent to trigger research, development, and procurement to meet future operational requirements [1].

In this paper we have proposed an improved version of a cluster-based routing to handle mobility in wireless sensor networks; we used a round estimation period [3] to regulate data transmission within the clusters in a very mobile environment. The rest of our paper is organized as: section II describes the related work. Section III depicts the improved version of the Leach protocol for MWSNs. Section IV shows the simulation results & discussion. Finally, Section V concludes the paper and enlightens future work.

2. Related Work

In recent research on wireless sensor networks, there has been an important focus on improving the communication between sensors by presenting new solutions related to QoS, MAC and routing protocols. Several solutions have been exploited from which we distinguish the clustering approach.

LEACH routing protocol is considered as a typical cluster-based routing protocol which is based on rotating the cluster head role among all sensor nodes to equalize the energy consumption and achieve an extended network lifetime. The functioning time is divided into consecutive rounds where each round is composed of two phases. During the first phase, each sensor node competes to elect itself as a cluster head based on specific formulas defined in [4][5]. When the cluster head is selected, sensor nodes proceed with data transmission in the steady-state phase and during their affected time slot selected via TDMA mechanism. M. Akbar et al. proposed in [6] a Mobile Balanced Energy-Efficient Network Integrated Super Heterogeneous (MBEENISH), which is a hybrid protocol used in four-level heterogeneous WSN models. The protocol utilizes the benefits of both clustering and sinks mobility to maximize network efficiency. It presents a new mathematical sink mobility model to maximize the network lifetime and guarantee a stabilized period.

An improved version of LEACH named M-LEACH and LEACH-C have been proposed to take advantage of multi-hop routing and regulating cluster formation which has proven a better performance compared with LEACH. K. Thanigaivelu and K. Murugan presented in [7] a novel cluster-based method. A Grid-based clustering (GBC) along with dual CHs are configured by a mobile sink node to achieve an enhanced energy balance in the network and prevent the energy hole problem for an extended network lifetime. D Seong et al. [8] proposed a novel mobile sink operation method in which the probe priority of the mobile sink is determined from data priority to increase the QoS. The authors used the mobile sink to reduce the routing hot spot. In [8], the authors proposed EADEEG distributed clustering algorithm which elects cluster heads depending on the residual energy of the sensor node and its neighbors. EADEEG presented a good cluster head distribution and a prolonged lifetime performance. In [9], authors handled the mobility constraint by proposing an improved version of the LEACH protocol named LEACH-Mobile, which consisted of adding the membership declaration to LEACH protocol so that to guarantee the addition of sensor nodes to a particular cluster during the steady-state. The mean concept of LEACH Mobile protocol is to specify whether a sensor node is able to communicate with a cluster-head during its affected time slot, if no response has been received from the cluster-heard in a threshold interval, the sensor node is declared out of the cluster and will afterward join a new cluster after receiving acknowledgment from its cluster head.

The LEACH-Mobile protocol has been proven to outperform the LEACH protocol in terms of packet reception rate but still has high energy consumption due to the increased amount of control packets being sent.
Jin Wang et al. [10] proposed an energy-efficient routing algorithm to handle the sink mobility and increase the WSN lifetime for real-time application. The mobile CHs collect data from the network before sending it to the sink node located in the center of the interest field. All moving CHs provide a connection with the base station during the report. Three schemes are adapted to the CHs movement to minimize communications and improve network lifetime. The requirement of resource-rich mobile CHs is the main limitation of this system. Another cluster-based routing protocol named CBR Mobile-WSN was proposed in [11]. It consisted in receiving data from cluster member and non-member sensor nodes. Cluster member sends their data using TDMA mechanism whilst non-member sensor nodes can use a free time slot to communicate its data to the cluster head efficiently using the received signal strength parameter. CBR Mobile-WSN justified better flexibility when adapting to traffic rate and mobility changing characteristics. Moreover, it has been highlighted that packet loss reduction reaches a value equals to 25% compared to the LEACH-Mobile routing protocol [16].

Muhammad Ali Khan et al. [12] presented fixed mobility based reactive protocol named "Mobile Sink based Data Gathering Protocol (MSDGP)", using a clustering based on the amount of sensed data and residual energy. MSDGP achieved less energy consumption and provided an extended network lifetime through implementing a single message CH selection and introducing a mobile sink instead of a static sink. By using greedy policy and dynamic programming, H. Zhao et al. [13] proposed a tree-based heuristic topology control algorithm, called MLS to maximize the network lifetime in large scale wireless sensor networks with mobile sinks. The algorithm introduces a predefined delay tolerance level for a sensor node to store data temporarily and transmit it to the mobile sink at the most suitable distance to achieve an extended network lifetime. F. Tashtarian et al. [14] studied how to determine a trajectory for a mobile sink without considering any predefined rendezvous points or virtual structures. The trajectory, which is named the Continuous and Optimal Trajectory (COT), makes a significant gain in terms of the network lifetime. M. Nabi et al. [15] proposed a MAC protocol (MCMAC) to support the cluster mobility for TDMA-based Medium Access Control (MAC) protocols in Wireless Sensor Networks (WSNs). MCMAC protocol exploits a hybrid contention-free and contention-based communication approach to support cluster mobility.

3. Leach-D Protocol for Mobile Wireless Sensor Networks

3.1 Working principle of LEACH protocol

The LEACH protocol (Low-energy Adaptive Clustering Hierarchy) presented by Heinzelman and al. [12] assumes a dense sensor network of homogeneous, energy-constrained nodes, which shall report their data to a sink node. In LEACH, a TDMA-based MAC protocol is integrated with clustering and a simple "routing" protocol. LEACH randomly selects a few sensor nodes as cluster heads (CHs) and rotates this role to evenly distribute the energy load among the sensors in the network. In LEACH, the cluster head (CH) nodes compress data arriving from nodes that belong to the respective cluster and send an aggregated packet to the base station to reduce the amount of information that must be transmitted to the base station. The protocol is organized in rounds and each round is subdivided into a setup phase and a Steady-state phase (Figure 2).

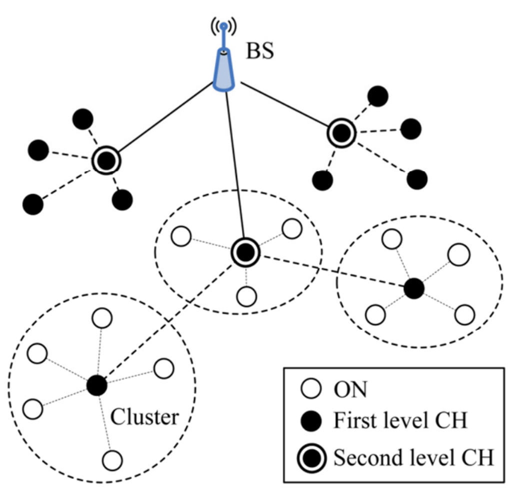

Fig.2 Custer Formation in Leach [16]

In the first phase, the cluster heads are selected and the clusters are formed, and in the second phase, the data is transferred to the base station. During the first phase, the cluster heads election process is triggered to select the future cluster heads. The election process of the cluster head is: the node selects a random value from 0 to 1. If the value of the current round is less than the set threshold T (n), the node becomes the cluster head T (n) is calculated as follows:

$$T(n) = \frac{P}{1-P\left(r \bmod \frac{1}{P}\right)} \ \forall\, n \in G \qquad (1)$$

Where p is the desired cluster head's percentage in all sensor nodes, the actual LEACH algorithm proceeds in 1/P rounds (assuming, for simplicity, that 1/P is an integer value). In each round, a set of cluster-heads of expected size nP (n the total number of nodes) of nodes is elected from the set G of nodes that have not yet served as a cluster-head (initially, and after every 1/P rounds, G encompasses all nodes). At the beginning of round r, each node in G becomes a cluster-head with probability P / (1 − P · (r mod 1/P)). This probability increases with every round, such that in round 1/P − 1, all as-yet-unelected nodes will become a cluster-head with probability 1, ensuring that every node is serving as a cluster-head exactly once in some round. In round 1/P, the process starts afresh.

3.2 LEACH-Dynamic protocol "Leach-D"

This current work is based on the approach Round Estimation Period for cluster-based routing in Mobile Wireless Sensor Networks [3]. The technique enhance the performance of cluster-based routing protocol for MWSNs. A probabilistic approach is used to balance the reconfiguration frequency of cluster forming for data transmission within a mobile environment. This approach takes into account the incoming and leaving sensor nodes starting from the beginning of the next round to the end of cluster member construction. The results proved the efficiency of our technique, as it increased the performance of cluster based routing protocols in terms of energy consumption, end to end delay and throughput. As pre-mentioned in the above subsection, LEACH is based on rotating the cluster head role among all sensor nodes to equalize the energy consumption in the network, thus achieving an extended lifetime. In our case of study, we consider a wireless sensor network with mobility constraints, where the mobile wireless sensor network is subject to a high frequency of topology reconstruction. The constant topology change will increase the packet delivery latency especially for event-based data collection where packets have to be received within a specific time interval for precaution purposes. Another consequence may include high energy consumption as the sensor has to stay an active state for a prolonged period. Therefore, if

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there is not a pre-embedded duty cycle algorithm put in place to regulate the time activity of sensors' transceivers, then the sensors' batteries will drain their energy rapidly leading to the network losing its performance in a very short time.

To resolve the mobility constraint, we propose "Leach-D" a dynamic version of leach protocol to increase packet reception rate, minimize the energy consumption and also the end-to-end delay. Our new algorithm consists in distributing sensors in an area where they can move following a random or a pre-established mobility pattern, in a way that data is collected and sent back to the base station via cluster heads.

At time t_i , the sensor s_j belongs to the level $Level_k$ which is defined as follows:

$$Level_k = dist(S_j, BS)/distThreshold \ , \ Level_k \in \mathbb{N}$$

Where:

- $dist(S_i, BS)$: is the distance between a sensor node s_j and the base station BS.
- $distThreshold$: Indicates the distance enabling communication between two sensor nodes and it equals to:

$$distThreshold = d_0 . 10^{P_r/10.pathLossExponent}$$

Where:

- d_0: is the reference distance.
- pathLossExponent: is the rate at which signal decays and:
- $P_r = \text{maxTxPower} - \text{signalDeliveryThreshold} - \text{PLd0} + 3\ \text{sigma}$

Where:

- maxTxPower: is the maximum power of transmission.
- signalDeliveryThreshold: is the sensor node sensitivity.
- PLd0: refers to the power decay in dB for the reference distance.
- sigma: defines the standard deviation of the path loss variation.

If the value of $Level_k$ is small, then the sensor node is considered close to the base station. The distance between two consecutive levels refers to the distance threshold that allows the communication between two sensor nodes.

Our deployment scenario is based on a military use for border surveillance, in the case of the cluster-based network the sensor nodes form clusters that can represent in the real case separate surveillance zones, in each case, cluster is elected a cluster leader who receives the information from the other nodes specific to the cluster and then the cluster leaders represented in the figure by the military vehicle route this information to the base station.

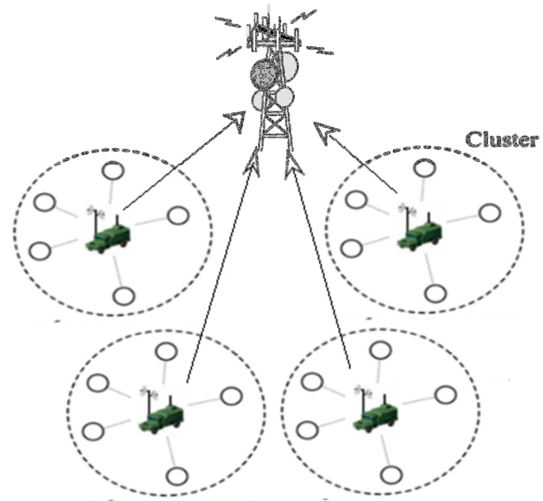

Fig. 3 Military Scenario

Leach protocol select a cluster head by choosing a random number from 0 to 1 periodically. By setting the threshold T (n), the node will become a CH for the current round if the number is less than T (n).

In our case of study, we put additional constraint to select the set G of nodes that did not participate in the CH election in the last 1/p round. Thus, for a sensor node s_j to belong to the G set, the following $Contraint_j$ has to be verified:

$$Constraint_j = \beta.(Level_p - Level_c)/\alpha.E_{remained}(S_j)$$

Where:

- $E_{remained}(S_j) > 0; \ Constraint_j \geq 0; \alpha, \beta \in \mathbb{N}^*$
- $Level_p$ and $Level_c$ represent the previous and the current level respectively.
- $E_{remained}(S_j)$ is the remained energy in sensor S_j.
- α, β are the weighting coefficients used to prioritize either minimizing either the end to end delay or the energy consumption concerning the application requirements.

$Constraint_j$ ensures that the packets are forwarded to a cluster head closer distance to the base station, and with higher energy batteries. A positive value of $Constraint_j$ indicates that the cluster head is heading towards an upper level closer to the base station. However, if the $Constraint_j's$ value is negative, then the cluster head is believed to take a very long path before reaching the final destination. To this end, it's crucial to find a tradeoff balance between the energy consumption and packet delivery latency.

To avoid a void G set of cluster head, a tolerable latency is introduced relative to the number of rounds during which the sensor node was not selected as a cluster head. Let R_T be the minimal value of round number above which latency is tolerated. [2]

If $Level_c = \delta\, Level_p$ and $1/P_{S_j} \geq R_T$ Then $S_j \in G,\ \forall \alpha, \beta \in \mathbb{N}^*, 1 < \delta \leq \mu_{max}, \mu_{max} \in \mathbb{N}^*$

μ_{max} is defined as the application threshold latency, determined by the type of data collection i.e. event-based and periodic-based data collection.

4. Simulation Setup

We performed our simulation in OMNET++ based simulation framework named Castalia 3.3 designed for WBSNs and WSNs. We used three metrics to evaluate the efficiency of our approach: energy consumption, average packet loss, and End-To-End packet delivery.

The simulation parameters are described in table 1. The packet generation rate is constant and equals to 5 packets / sec. The initial energy level of each sensor node is assumed to be 18720J.

Table1: Simulation Parameters

Parameter	*Value*
Number of sensor nodes (step increase)	From 50 to 300 (50)
Network dimension in m(l × L × h)	40×40×10
Simulation Time	200s
Deployment type	Random waypoint model
Radio Model	CC2420
Initial energy	18720 Joules
MAC Layer	bypass Mac
maxTxPower	0.0
Signal Delivery Threshold	-60
d_0	0.5
PLd0	55
Sigma	4.0
pathLossExponent	2.4

In our simulation, we varied the size of the deployed sensors to highlight their impact on the aforementioned metrics. As can be seen in figure 4, our proposed algorithm improves the efficiency of leach protocol in terms of the average energy consumption.

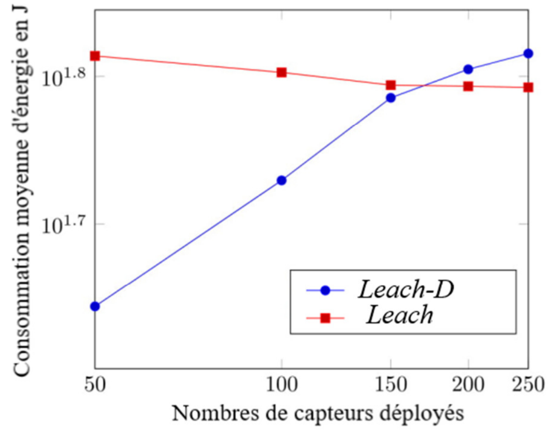

Fig.4. Average energy consumption in *J*

When the number of deployed sensors increases, the average energy consumed by the improved leach protocol increases as well to attain a maximal value equals to 65.41 *J* for 250 deployed sensors. The leach protocol seems to drain much more power as it goes from 65.16 *J* for 50 deployed sensors to 62.27 *J* for 150 deployed sensors. The energy consumption seems to gradually decrease as the number of sensors gets high, but at a certain point (150 deployed sensors), it shows a better performance compared with our proposed algorithm as the energy consumption increasing difference is equal to -0.10275 *J* versus 1.59074 *J* for our algorithm. This behavior may favor leach protocol over our proposed version for large scale networks when it actually reflects it's inconvenient as its performance is highly dependent on the random mobility of the sensors. The radio model used in our simulation is CC2420 which consumes 62 *mW* when the transceiver is in the reception state versus 57.42 *mW* in case of transmission state. The transceiver's transmission power is correlated to the energy of transmission and the frequent transmission from one state adds a considerable amount to the overall energy consumption.

Based on the radio model characteristics, it's deducted that a network where the sensors are in the reception state for a prolonged period will eventually consume more energy compared with a very active network. The high mobility of the sensors makes it difficult to maintain the established clusters intact during the same round. Hence, at time t_i, a sensor node may be either an isolated node or belongs to one or many clusters with a specific role.

Based on the results being found in figure 4, the Leach protocol consumes more energy for staying in the reception state during several rounds. There is a correlation between the number of deployed sensors and the average energy consumption; in other words, when the number of deployed sensors increases, the probability

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of forming more clusters increases too, enhancing though the probability of the cluster heads being within the communication range of the base station, moreover, the sensors will spend more time in the transmission state, transmitting data to cluster head as a cluster member of transmitting the aggregated data to the base station as a cluster head, which explains the decreasing value of the average energy consumption with respect to the number of deployed sensors.

The Leach-D protocol is based on the multichip approach where a packet might be transmitted through different levels before it reaches the base station. Thus, the energy consumption is more likely to increase when the number of deployed sensors increases as more sensors will be in the reception state independently to the previous number being deployed. The amount the energy consumed depends on the mobility factor which affects the state of the transceiver. As the number of deployed sensors surpasses 150, the average energy consumption tends to gradually increase due to the probability of a sensor node to be affected to a cluster (if not many) during a certain round. Therefore, the number of packets being exchanged will likewise increase leading to a small increase in energy consumption (1.59074 *J*) relatively to the number of deployed sensors.

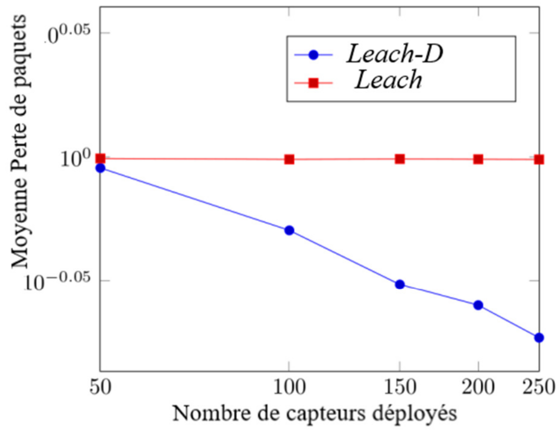

Fig.5. Average packet loss

As can be seen in figure 5, our Dynamic Leach protocol decreases considerably the average packet loss rate compared with leach protocol concerning the number of deployed sensor nodes. This behavior was expected as the Leach-D algorithm is based on the multihop data forwarding; therefore, more packets are delivered to the base station compared with leach protocol where the cluster head is responsible to forward data directly to the base station in a very mobile environment. Leach protocol causes more packets to be lost in the way independently to the number of sensors being deployed, whilst our improved version ensures better collaboration between cluster heads for a minimal packet loss, which explains the results being found in figure 5.

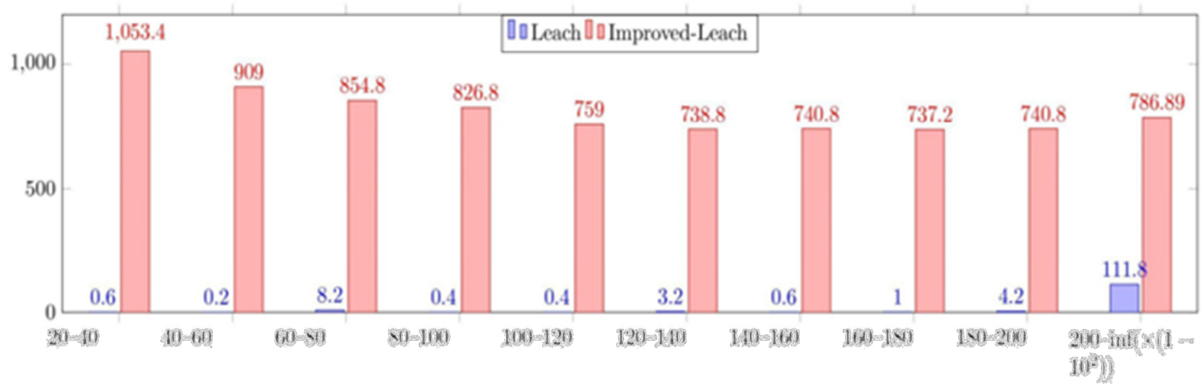

Fig.6. End-To-end delay

As can be seen in figure 6, the Leach-D protocol ensures the reception of data or management packets within different time intervals where the maximum average number of packets (78689 packets) are received in less than 200ms versus 111.8 for leach protocol; the results being found prove that our proposed algorithm enhances the overall performance of the network in terms of packet delivery latency as it guarantees the reception of packets in an amount of time below 200 ms versus 40ms as a minimum value corresponding to 1053.4 packets received. The higher amount of packet received within different time intervals is due to the amount of time required for multihop communication. The Leach protocol is based on a direct transmission to the base station, resembling thus to a client/server communication, which minimized the packet delivery latency, however, when the environment becomes very mobile, the direct transmission to the destination loses its advantage and the need for intermediate sensors to forward data becomes a necessity. The non-negligible portion of packets at [200... inf [bucket is a sign of oncoming saturation for both leach protocol and the proposed improvement.

5. Conclusion and Future Work

Many routing protocols have been conceived to resolve the mobility issue in mobile wireless sensor networks. The cluster-based routing protocols is considered as a subtype category of routing protocols which represents a basic design to develop routing protocols destined to overcome WSN challenges with the existence of the mobility constraint. In this paper, we presented an improved version of the Leach protocol to mitigate the effect of mobility on communication between sensor nodes based on an estimated round period for cluster formation. The three following metrics were considered: the packet delivery ratio, the end-to-end delay, and the energy consumption. The results showed that the proposed improved version gives good results compared with leach protocol in a dimension equals to 40×40×10 m. The overall performance proves that the proposed algorithm minimizes the overall energy consumption and packet delivery latency whilst it maintains a considerable packet reception rate. As future work, we will be focusing on conceiving a new synchronization schema to mitigate collisions between sensor nodes within the same cluster. The schema has to take into account the mobility constraint and propose a flexible synchronization time while maintaining optimal network performance.

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