Energy Efficient Multi-Hops Clustering Protocol for Wireless Sensor Networks

Saad Harous, and Zibouda Aliouat

Abstract— Wireless Sensor Networks (WSNs) are been used in many applications such as: health care monitoring, environmental/Earth sensing, industrial monitoring, data logging. But in order to reach their potential, researchers must find solution to some difficulties which are slowing down the wide spread use of these networks. These difficulties are inherent to their constrained specificities which require adapted solutions unrelated to classical wire networks. The number of packets sent/received by WSN has a huge impact on the amount of energy consumed. In order to reduce this number and to ensure at the same time WSN successful operation, hierarchical clustering protocols have been developed. In this paper, we present Well Balanced TEEN (WB-TEEN) and Well Balanced with Multi-hops intra-cluster TEEN (WBM-TEEN): two hierarchical routing protocols, based on nodes clustering and improving the well-known protocol Threshold sensitive Energy Efficient sensor Network protocol (TEEN). This improvement is accomplished in a way such that the number of nodes in each cluster is balanced and the total energy consumption between sensor nodes and cluster heads is minimized by using multi-hops intra-cluster communication. Simulation results (using NS2 simulator) show that the proposed protocols exhibit better performance than Low Energy Adaptive Clustering Hierarchy (LEACH) and TEEN in terms of energy consumption and network lifetime prolongation.

Keywords— Wireless Sensor Networks, hierarchical Routing Protocols, Clustering, Energy-Efficiency, TEEN.

I. Introduction

Wireless sensor networks (WSNs), composed of a huge number of cheap sensor nodes, are widely used in various fields such as environmental monitoring, traffic monitoring, disaster salvage, target tracking, security monitoring, industrial control and monitoring, home automation and defense [1, 2, 3, 4]. Sensor nodes which integrate sensing, computing and communicating functions can communicate with each other via wireless radio. These sensor nodes are densely deployed in the field of interest that maybe an isolated area that is difficult to reach. So we need to maximize the lifetime of sensor nodes by optimizing the use of energy. As the transmission range of sensor node is short, wireless sensor networks are multi-hop networks. Sensor nodes act as both data generators and data routers.

S. Harous is with the College of Information Technology, United Arab Emirates University, P.O Box 17551, Al Ain, UAE,. (E-mail: harous@uaeu.ac.ae).

Z. Aliouat is with the Department of computer Science, Ferhat Abbas Sétif 1 University, Sétif, Algeria (e-mail: aliouat_zi@yahoo.fr).

Furthermore, clustering is an effective method to reduce energy consumption of sensor nodes in large wireless sensor networks. Many recent studies have showed that clustering is an effective routing scheme in increasing the scalability and lifetime of wireless sensor networks [5, 6]. Thus sensor nodes are grouped into clusters in which one of the nodes is designated as cluster head [7]. A cluster head collects data from other wireless sensor nodes in its cluster, directly or in a multi-hop manner. Typically, data collected from nodes of the same cluster are highly correlated. Data can be fused during the data aggregation process thus reducing the consumption of energy. The fused data will be then transmitted to the base station. This hierarchical network is organized in layers: the lower layer consists of sensor nodes in each cluster for intra-cluster communication, and the upper layer consists of Cluster Heads (CHs) for inter-cluster communication [8]. An effective approach to improve efficiency is to arrange the network into several clusters, with each cluster electing one node as its cluster head.

The radio is the most power-consuming module of a sensor node. Another further solution to preserve energy, the nodes should use “sleeping mode”, i.e. they turn their radios off but are still able to sense the environment. Once the event of interest is sensed by a node in “sleeping mode”, the node turns its radio on.

The rest of the paper is organized as follows: section 2 presents the problems encountered in the routing protocols when the network is scaled up. Section 3 reviews related work. In section 4 our system model and the routing protocol TEEN which is the basis of our proposed protocols are presented. Section 5 discusses the proposed improvements to TEEN protocol. In section 6, we introduce WB-TEEN protocol with multi-hop intra-cluster. Section 7 provides the simulation results using NS2 of the four protocols. Performance evaluation is presented in section 8. Finally we present our conclusion in section 9.

II. Problematic

When studying the routing problem in WSN, a lot of constraints must be taken into account. Indeed, as the number of deployed nodes increases, the problem becomes more complex. The basic routing protocols (in which all nodes are considered homogeneous and communicate directly among themselves without any other intermediary) operate in a satisfactory manner when the density of the network is small. But when this density increases (thousands of nodes), these protocols lack efficiency.

In order to increase network scalability, the hierarchical topologies were introduced. The WSN is then partitioned into subsets of nodes facilitating the management of the network and ensuring a better energy resource management [6]. Therefore the basic routing protocols do not support the network scalability attribute. A solution to this problem is to adopt the hierarchical routing and the clustering organization. A hierarchical network is based on the concept of standard-node/master-node where the standard nodes deliver their messages to their master which then delivers them to the base station (sink). The hierarchical topologies were introduced for the purpose of distributing the nodes on several levels of responsibility. The task of routing is entrusted to certain nodes called 'master nodes' or Cluster-Heads (CH). The CHs can be special nodes, with powerful resources or similar to the simple standard nodes, periodically elected depending on their residual energy level [9].

In the hierarchical topologies, during the packets routing, an aggregation of the data may be carried out by the CH. This will reduce the number of messages circulating in the network, thus implying a reduction in energy consumption (Rhee et al., 2004). Hierarchical routing protocols have been designed to ensure efficient use of energy by reducing the number of messages sent to the sink. They are classified according to the following two approaches: chain-based approach and cluster-based approach.

However, the energy consumption of sensor nodes is asymmetric. Cluster heads consume more energy than the other nodes due to their roles that are receiving data from cluster members, aggregate data and sending it to the base station. The energy consumption of cluster heads is affected by the number of cluster members and the distance from the base station. In order to optimize the energy consumption of cluster heads, we must balance the number of nodes among clusters.

III. RELATED WORK

LEACH (Low Energy Adaptive Clustering Hierarchy) is one of the most popular hierarchical protocols [6]. This protocol adopts the time-driven model and uses a distributed clustering (the formation of clusters and the election of the cluster-heads are realized at the node level). LEACH assumes that the nodes are homogeneous and the routing of packets to the base station is done in a single hop via the cluster-heads as shown in Figure 1.

The nodes have the possibility to become cluster-head on the basis of election probabilities. By using Time Division Multiple Access (TDMA): protocol allowing access the communication medium, protocol LEACH is intended for time-driven applications. So, in this type of application, data are propagated in a periodic way. However, this kind of protocol is unsuitable for event-driven applications where a reactive behavior is necessary for the proper functioning of the system.

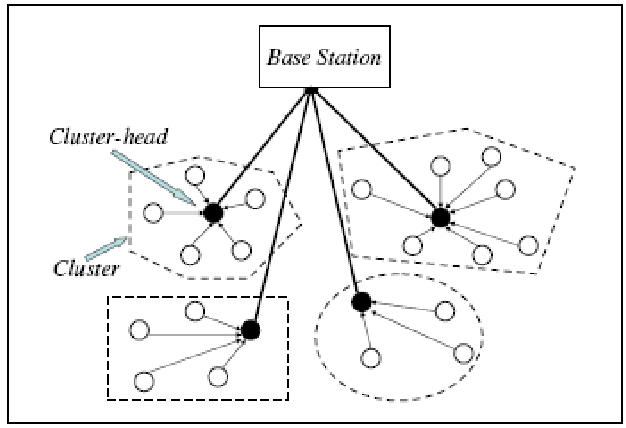

Figure 1: LEACH Protocol Architecture

PEGASIS [10] is considered to be an enhanced descendant of LEACH. In this protocol, rather than organizing nodes in clusters, chains of nodes are formed in a greedy way so that each node transmits and receives from a close neighbor and eventually one node is selected to transmit to the base station. Although, PEGASIS achieves higher energy conservation when compared to LEACH, it suffers however from certain disadvantages. Among them is that the single leader can become a bottleneck for the network. Another one is the excessive delay which is caused by distant nodes on the chain.

Manjeshwar and Agrawal [11] have proposed a technique of clustering called TEEN (Threshold sensitive Energy Efficient sensor Network protocol) for critical applications where the change of certain parameters may be sudden. The architecture of the network is based on a hierarchical grouping at several levels (Figure 2) where the closest nodes (to each others) form clusters. Then the process of clustering goes to the second level until the base station is reached.

After the formation of clusters, each cluster-head transmits, to its members, two thresholds: Hard Threshold (HT), is the threshold value of the monitored parameter and a Soft Threshold (ST) representing a small change in the value of the monitored parameter. The node, that detects the occurrence of this small variation ST, transmits an alert message to the base station indicating this change. Therefore, ST reduces the number of transmissions since it does not allow the transmission if there is little or no change in the value of the monitored control parameter [11]. At the beginning, the nodes listen to the medium continuously and when the value captured from the monitored parameter exceeds the hard threshold, the node transmits the information. The value captured is stored in an internal variable called SV. Then, nodes have no longer to transmit data unless the current value of the controlled parameter becomes greater than the hard threshold or differs from the SV value by a quantity greater or equal to the ST value. Since the transmission of a message consumes more energy than data sensing, energy consumption by TEEN protocol is then less important than in proactive routing protocols or protocols that transmit data periodically such as LEACH. However, the main drawback of this protocol is that if the thresholds HT and ST are not received, then the nodes never communicate, and no data will be transmitted to the end users; therefore, the base station would be unable to know the nodes that have exhausted their energy.

In [12] nodes use uneven competition ranges to construct clusters of uneven sizes. Clusters far away from the BS have smaller sizes in order to preserve some energy for long-distance data transmission. Therefore, the energy consumption among cluster heads is balanced effectively. The cluster head can be rotated based on the energy level of cluster head to minimize the unnecessary energy waste. Each node acts as cluster head no more than once during the whole network lifetime. Therefore, the energy-driven cluster head rotation scheme proposed here is not suitable for multi-hop networks, because the energy level is assigned to be very precise.

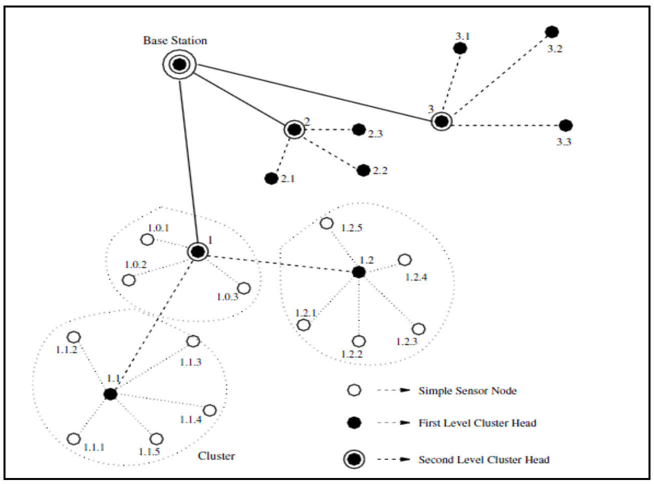

Figure 2. Hierarchical clustering TEEN [11]

IV. Network Model

We adopted the following assumptions to model the network in a reasonable way:

- There are *N* homogeneous nodes that are deployed over a large geographic area (sensing field).
- Each sensor node has a unique pre-configured identifier (id).
- After deployment, all the sensor nodes and the Base Station (BS) are stationary.
- The BS is out of the sensor field and its location is known by all nodes. This is a common hypothesis used with the intention to preserve BS (a costly node) from environmental problems arising in sensing field.
- All the nodes can use power control to vary the amount of transmission power.

The energy model we use is adopted from [2]. To transmit k-bits of data to a distance d, the amount of energy consumed by the radio is computed by the formula:

$$E_{TX}(k,d) = \begin{cases} k * E_{elec} + \in_{fs} * d^2, & d < d0 \\ k * E_{elec} + \in_{mp} * d^4, & d \geq d0 \end{cases} \quad (1)$$

Where E_{elec} (E_{elec} = 50nJ/bit) is the energy consumed by the circuitry and $\in$mp ($\in_{mp}$ = 0.0013pJ/bit/m^4) the energy consumed by radio transmission. Depending on the distance between the transmitter and receiver, free space ($\in_{fs}$= 10nj/bit/m^2) or multi-path fading ($\in_{mp}$) channel models is used (1). Therefore, as the distance d and the number of bits k increase, the energy spent for data transmission increases. Hence, the best way to achieve energy conservation is by compressing the data to be transmitted and by reducing the distance using multi-hops communication. Threshold distance d_0 (d_0=75m) (1).

To receive k bits of data, the amount of energy consumed by the radio is computing using the following formula:

$$E_{RX}(k) = k * E_{elec} \quad (2)$$

A. TEEN Protocol

The lifetime of the sensor network is split into equal periods of time known as rounds. The algorithm works in rounds similar to the LEACH protocol. Each round is made up of an initialization phase, a search phase and a transmission phase as shown in Figure 3. The initialization phase is composed of two sub phases: an announcement phase and groups' organization phase.

The initialization phase aims to determine CHs nodes. We adopt the idea presented in LEACH based on the probability for each node in the network to become a CH node and select 5% CH nodes. After this, each node generates a random number between 0 and 1, the nodes that generate a number less than 0.05 start the CH selection process. Once a node is selected as cluster head, it sends a broadcast message. Other nodes find the nearest cluster based on the strength of received signal and join the cluster and then inform the cluster head. When the cluster head receives all the joining information, it produces a TDMA and thresholds (*HT*, *ST*) messages. After receiving this message, during the transmission phase, cluster members send data within their respective time slot if necessary, or turn off the wireless communication device in order to reduce energy consumption.

In the transmission phase, we use single-hop intra-cluster routing. All the nodes transmit their data directly to the CH, and their transmission powers are dependent on their distances to the CH. CHs send the aggregated data to the BS directly.

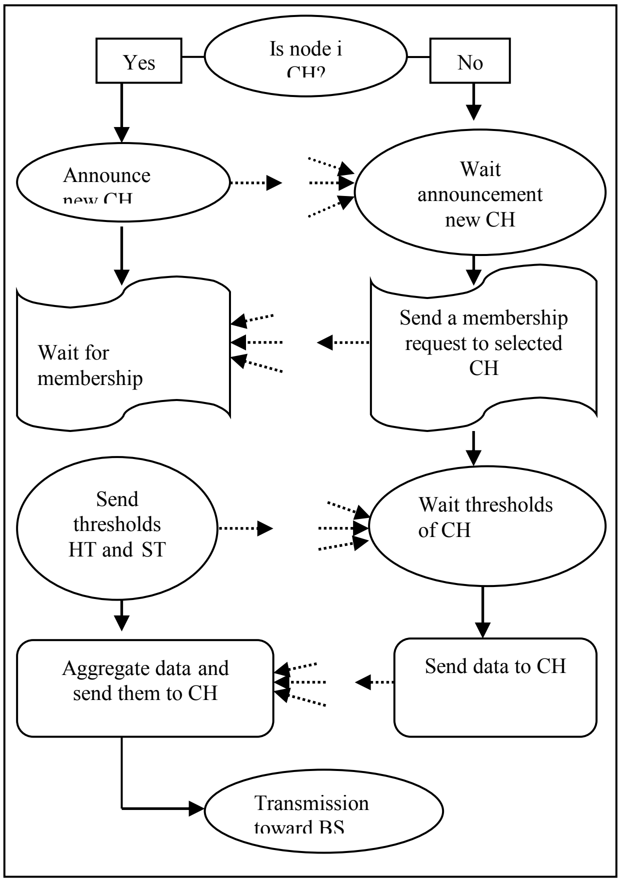

Figure 3. Initialization, Search and Transmission Stages in TEEN

B. *Simulation*

The parameters and the corresponding values (Table 1) are used for the simulation purpose:

EEE 802.11 b is the wireless communication standard used in the simulation tests performed. The main advantage of this standard is the achievement of low energy consumption.

Figure 4 shows that protocol TEEN consumes less energy than the protocol LEACH: the reason is that in the reactive TEEN protocol, the soft threshold reduces the number of transmissions in contrast with the proactive protocol LEACH where data are transmitted periodically.

Figure 5 represents the number of nodes alive as a function of simulation time. In the protocol LEACH, at the moment t=460, all nodes are dead but this happens at later time (t=560) in protocol TEEN.

In LEACH protocol, nodes that are far away from the base station die quickly contrary to the closest ones because of the use of single hop communication. Unlike TEEN that uses the HT and ST thresholds, as well as the use of a multi-hop communication toward the base station reduces the energy consumption, therefore maximizing the battery lifetime which implies a longer lifetime of the network.

Parameters	Values
Surface of deployment	(0 ,0) ×(100,100)
Base station position	(50,175)
Number of sensors	100-400
Initial energy of a sensor	2 Joules
Period duration (round)	20s
Duration of simulation	3600s
Number of clusters	5%
Size of control package	8 Bytes
Packets size	512 Bytes
Soft Threshold	2
Hard Threshold	45

Table 1: Simulation Parameters

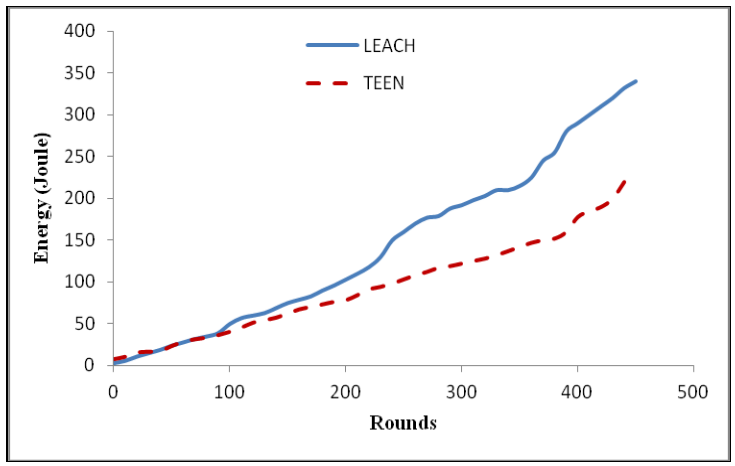

Figure 4. LEACH and TEEN Energy Consumption

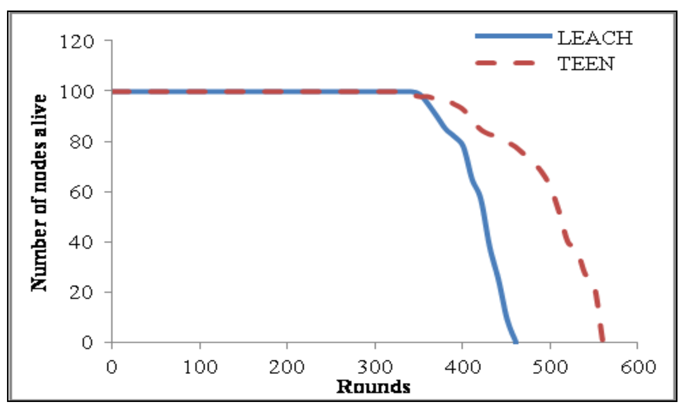

Figure 5: Number of Nodes Alive in LEACH and TEEN

V. TEEN PROTOCOL'S IMPROVEMENTS

A. Problem Statement

Among the disadvantages of TEEN protocol we have studied, appears the problem of groups disparity. The random selection of Cluster-Heads in TEEN allows nodes to be self-organized into clusters without spending a lot of energy. However, this does not guarantee to obtain clusters with similar number of member nodes; which causes great energy dissipation. To remedy this inconvenience, proposed the protocol WB-TEEN (Well Balanced TEEN) [13]: an improvement of protocol TEEN which enables clusters balancing i.e. avoiding clusters formation with a significant difference in sizes.

B. WB-TEEN Protocol

The main objective of our proposal is the minimization of energy consumed obtained from the balancing process of clusters (All clusters have almost the same number of member nodes). After being elected CH, a node must inform the other nodes non-CH of its new rank. For this, a warning message ADV, containing the identifier of the CH, is broadcasted to all non-CH nodes. This broadcast is sent out in order to ensure that all non-CH nodes have been informed. Each node has to inform its CH of its desire of belonging to the cluster, and sends it a JOIN_REQ message. The CH with the strongest signal (the closest to CH) will be chosen. In case of equal signals strength, the node randomly chooses their CH. The cluster head calculates its degree, defined by:

$$Degree = \frac{N - CHnbr}{CHnbr} + 1 \qquad (3)$$

Where CHnbr is a number of cluster heads and N is a Total number of nodes in the network (3).

On the reception of the JOIN_REQ message, if the number of nodes has not reached the degree of the CH, then the node is added to this cluster. Otherwise, the CH rejects the membership request, and invokes the Negative_CH procedure. This procedure sends a negative message to the node informing it that its request has been rejected. The concerned node then chooses another CH from its list (the following CH) and sends another JOIN_REQ and so until it joins a cluster. After the formation of all clusters, each CH sends out the two thresholds HT and ST to its members.

C *Simulation Results*

WB-TEEN protocol consumes less energy than TEEN protocol (Figure 7), since in the protocol TEEN it is possible to have some CHs managing clusters with significant number of nodes, while at the same time, there exists some other CHs managing clusters with only a few nodes, contrary to the protocol WB-TEEN where all clusters have almost the same number of nodes. This load balancing has been achieved by changing the clusters formation rules.

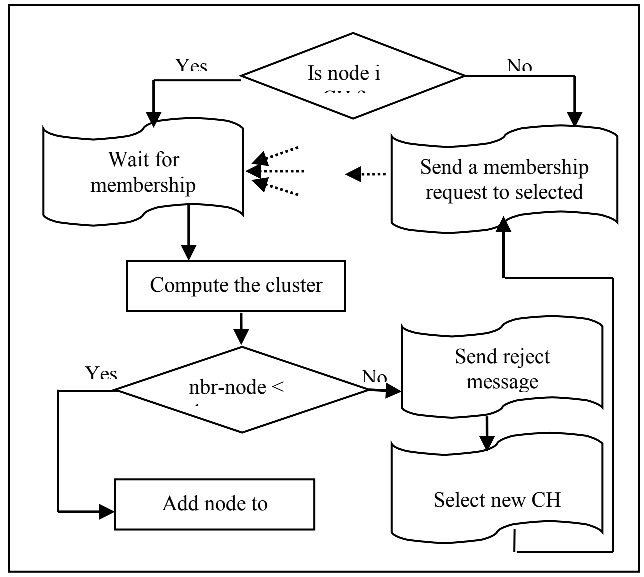

Figure 6: Clustering Stages in WB-TEEN

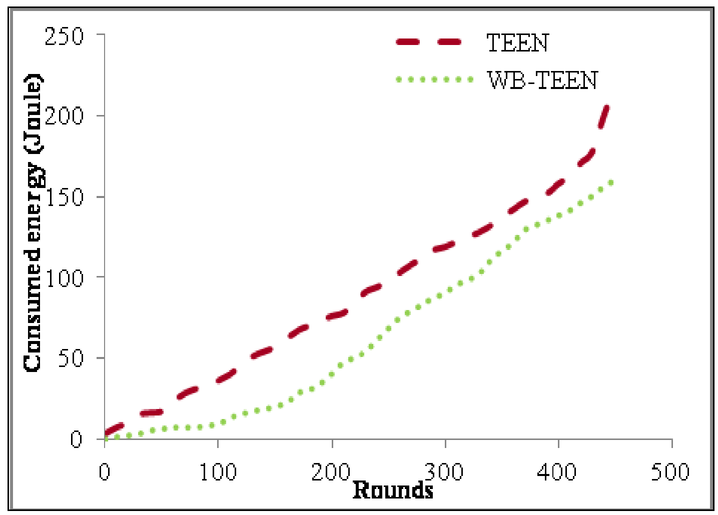

Figure 7: Energy Consumption in TEEN and WB-TEEN

Figure 8 represents the number of nodes alive during the simulation. We note that the protocol WB-TEEN extended significantly the network lifetime compared to TEEN. This improvement is accomplished because the nodes remain alive due to clusters load balancing which prevents the situation where the CHs can be concentrated in a part of the network. Consequently, an energy consumption balancing of the CHs leads to the increase of the network lifetime. This is very important because it contributes to the success of the network mission. In the protocol WB-TEEN, the number of nodes alive at time t=500 is 70 while in the protocol TEEN the number of nodes alive at that time is zero. This result is also important because it allows the network consolidation connectivity and therefore increases its lifetime duration.

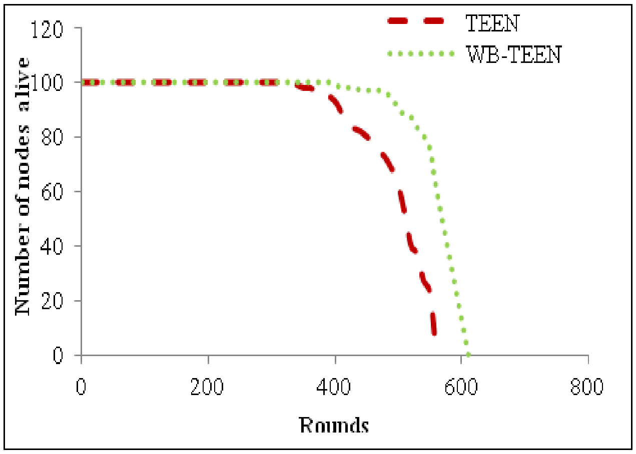

Figure 8. Number of Nodes Alive in TEEN and WB-TEEN

VI. WB-TEEN WITH MULTI-HOP INTRA-CLUSTER

According to the study we conducted about the protocol TEEN and the proposal protocol WB-TEEN, we conclude that the nodes located far away from the CH die more quickly than those which are closer to the CH. To improve and regulate the energy consumption of distant nodes, we propose to make nodes to communicate with their immediate neighbors and not directly with the CH since single hop communication is more costly in terms of energy than multi-hops nodes communication.

Our improvement for WB-TEEN protocol is called WBM-TEEN (Well Balanced TEEN with Multi-hop intra cluster communication), which refers to the fact that all nodes in the cluster, communicate with their closest neighbors to send or receive data. This enables each node to consume small amount of energy to reach the CH. The latter transmits all data received from the nodes belonging to its cluster to another CH on a higher level until the base station is reached.

A. Energy Consumption

Figure 9 shows the energy consumed as a function of simulation time; as illustrated, the protocol WBM-TEEN consumes less energy than WB-TEEN protocol. This improved result is obtained due to the use of multi-hop routing within the clusters instead of a routing with only single hop as in WB-TEEN. This increases the reliability of the protocol by the ability to find an alternative path in case of failure of the used path. In addition, our new proposal WBM-TEEN performs data aggregation at the level of a CH, which significantly reduces the energy consumption.

B. Energy Consumption

As illustrated in Figure 10, the batteries of the nodes in the protocol WBM-TEEN last longer (100 nodes are alive at time t=500) than that of WB-TEEN (only 70 nodes are alive at a similar time t=500) so, the improvement obtained by WBM-TEEN is about 41%. In effect, the protocol WBM-TEEN allows a higher rate of energy conservation, since it uses a multi-hop intra-clusters communication.

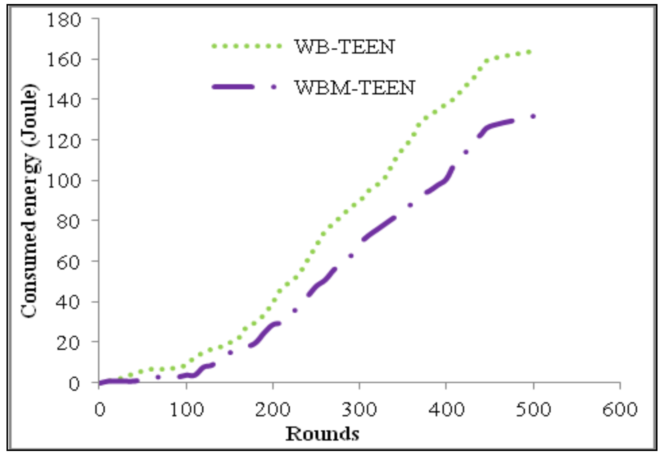

Figure 9: Energy Consumption in WB-TEEN and WBM-TEEN

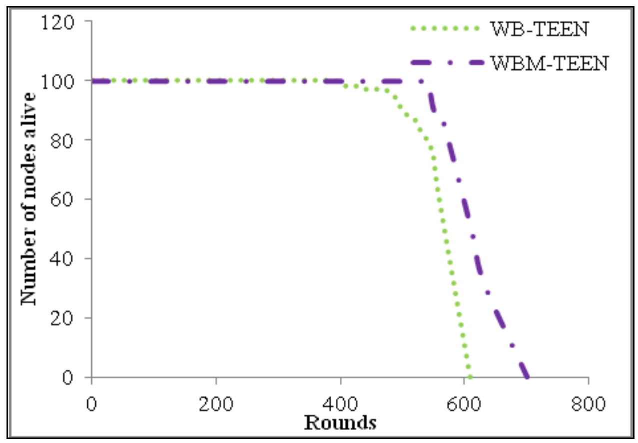

Figure 10: Number of Nodes Alive in WB-TEEN and WBM-TEEN

VII. COMPARISON OF THE FOUR PROTOCOLS

Figure 11 shows a comparison of energy consumption between the 4 protocols. The energy is consumed based on the operations performed such as capture operation, data processing and data communication. For this reason, we tried to optimize the data processing for the protocols TEEN, WB-TEEN, WBM-TEEN compared to LEACH. In addition, we have also performed a comparison of energy consumption between the simple nodes, and between the CH and the BS.

Figure 12 shows a comparison of the number of nodes that remain alive between the 4 protocols depending on the time of simulation. Each sensor node must effectively manage its energy in order to keep the wireless sensor network in a consistent operational state.

The WSN lifetime is closely linked to the energy used by the sensor nodes. It is clear that number of nodes alive in WBM-TEEN is greater than in LEACH and other proposed algorithms for the same period of time. As it is shown in Fig. 12, in case of LEACH algorithm, system nodes begin to die after about 400 rounds, while in WBM-TEEN algorithm nodes keep up their normal activities until the 620th round, namely 55% of improvement.

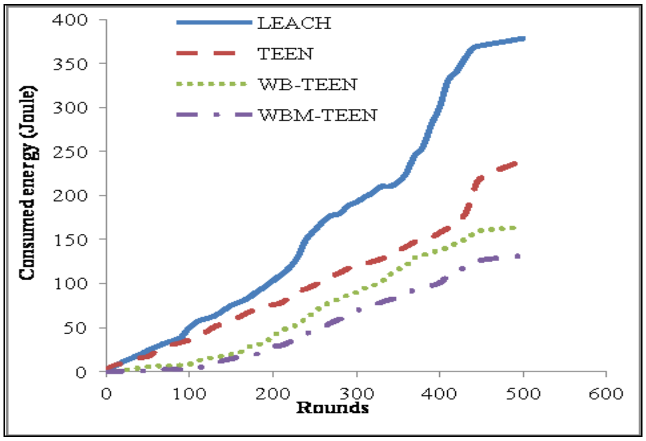

Figure 11. Energy Consumption by Various Protocols

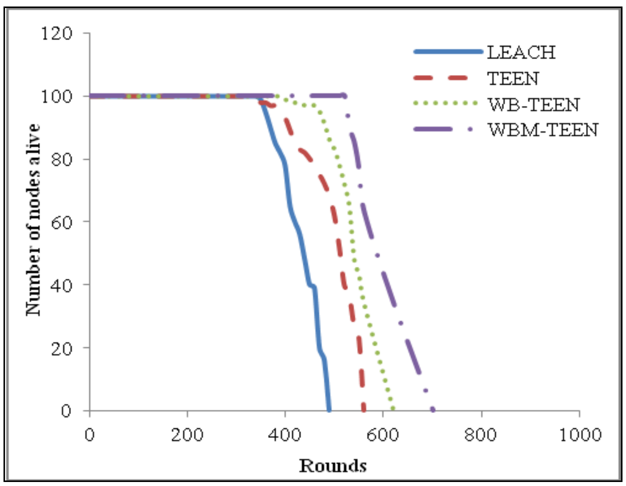

Figure 12. Number of Nodes Alive in Various Protocols

VIII. Performance Evaluation

Figure 13 and Figure 14 show the residual energy consumption of nodes in WBM-TEEN and LEACH with 200 and 400 nodes respectively. WBM-TEEN clearly exhibits better performance than LEACH in terms of scalability. Under the same energy consumption condition, the number of nodes remaining alive in LEACH protocol is less than the number of nodes remaining alive in WBM-TEEN protocol. The energy consumption optimization gained is about 40%.

In LEACH, all the nodes should take turns to be a cluster head to communicate with the BS, and since the distance between each node and the BS is different, the energy consumption for each node is different. As a result, some node with higher energy consumption will die soon. As Figure 15 shows, the network lifetime of WBM-TEEN is over 150 and 400 rounds longer than that of LEACH for the cases of 200 and 400 nodes respectively.

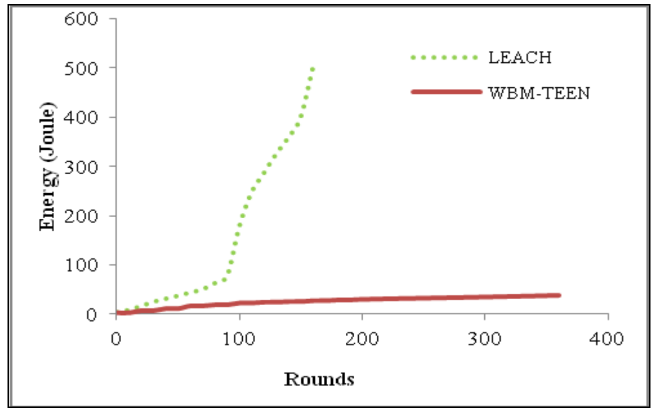

Figure 13: Energy Consumpton (200 nodes)

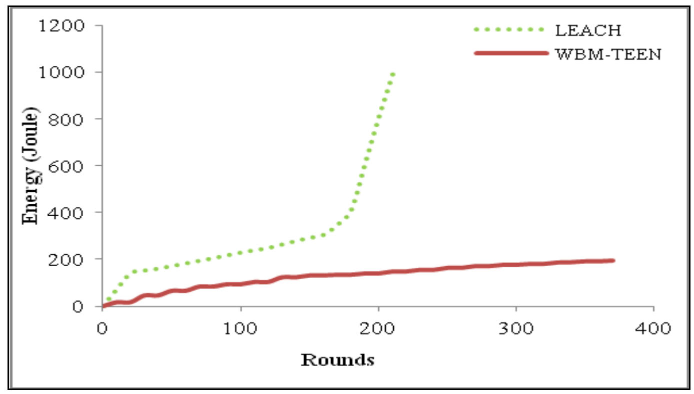

Figure 14: Energy Consumption (400 nodes)

IX. Conclusion

The interest in wireless sensor networks is constantly increasing. Due to their promising development, the applications of WSN tend to invade all areas. However, to make a real change in network domain, WSN have to overcome difficulties which hamper their maturity. Among these obstacles, the energy problem is the most important one. In the meantime of new technology offering us batteries with long duration and auto-rechargeable, providing an abundant and recurrent energy, for now the only option available is researchers devotion to strive designing protocols that optimize the use of this valuable energy.

In this paper, we are interested in the problem of saving the energy of sensor nodes for different routing protocols, because communication of messages is the most energy consumer activity in WSN.

After having studied two well-known protocols (LEACH and TEEN) we devised two variants protocols: WB-TEEN and WBM-TEEN which consume energy more efficiently than the original protocols while keeping their basic principles. The performance of our proposed protocols is very good since the energy consumption optimization extends the WSN lifetime by more than 40 %.

REFERENCES

[1] Akyildiz I. F., Su W., Sankarasubramaniam Y., and Cayirci E. (2002) 'A survey on sensor networks', IEEE Communications Magazine, vol. 40, No.8, pp.102-114.

[2] Zheng J. and Jamalipour A. (2009) 'Wireless Sensor Networks: A Networking Perspective', A John & Sons, Inc, and IEEEE, 2009..Available: http://www.halcyon.com/pub/journals/21ps03-vidmar.

[3] Yick J., Mukherjee B., Ghosal D. (2008) 'Wireless sensor network survey', Computer Networks, Vol. 52, No. 12, pp.2292-2330.

[4] Collotta M., Giuffre T., Pau G., Scata G., (2014) 'Smart Traffic Light Junction Management Using Wireless Sensor Networks', WSEAS Transactions on Communications, 13(6), pp. 648-658.

[5] Aliouat Z. and Aliouat M. (2012) 'Effective Energy Management in Routing Protocol for Wireless Sensor Networks', Proc. 5th International Conference on New Technologies, Mobility and Security (NTMS'12), Istanbul Turkey, 2012, pp.1-5.

[6] Heinzelman WR., Chandrakasan A., Balakrishnan H. (2000) 'Energy-efficient communication protocol for wireless Micro-sensor networks, Proc. of the 33rd Annual Hawaii International Conference on System Sciences, (HICSS '00), Maui, pp.1–10.

[7] Jung E.H., Lee S.H, Choi J.W. and Park Y.-J. (2007) 'A cluster head selection algorithm adopting sensing-awareness and sensor density for wireless sensor networks', IEICE Trans. Communications, Vol. 90, No.9, pp.2472–2480.

[8] Bandyopadhyay S. and Coyle E. J. (2003) 'An energy efficient hierarchical clustering algorithm for wireless sensor networks', Proc. 22nd Annual Joint Conf. of the IEEE Computer and Communications Societies, (INFOCOM 2003), San Francisco, California, USA, pp.1713–1723.

[9] Al-Karaki J. N. and Kamal A. E. (2004) 'Routing techniques in wireless sensor networks: A survey', IEEE Wireless Communications Mag., vol. 11, No. 6, pp.6–28.

[10] Lindsey S., Raghavendra C.S. (2002) 'PEGASIS: Power-efficient gathering in sensor information systems', Proc. of IEEE Aerospace Conference, USA, pp.1125–1130.

[11] Manjeshwar A. and Agrawal D. P. (2001) 'TEEN: a routing protocol for enhanced efficiency in wireless sensor networks', Proc. 15th Int. Symp. Parallel and Distributed Processing, (IPDPS 2001), San Francisco, California, USA, pp; 2009–2015.

[12] Yu J. and Qi Y. (2011) 'An energy-driven unequal clustering protocol for heterogeneous wireless sensor networks', Journal of Control Theory and Applications, Vol. 9, No. 1, pp.133–139.

[13] Harous S., Aliouat Z., (2015) 'A Balanced Clustering Protocol to Improve Wireless Sensor Networks Energy Consumption', 14th International Conference on Software Engineering, Parallel and Distributed Systems (SEPADS15), pp. 114-119, Dubai, UAE, February 22-24.