Energy Optimization Mechanism in Wireless Sensor Networks

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***Abstract*—Nowadays, wireless sensor networks (WSN) present a lot of interest in several research areas due to their wide range of applications. One of the most critical problems is how to ensure a better and efficient communication taking into account some constraints such as network lifetime and energy consumption. In this context and as an alternative, several papers focusing on the conception and development of robust routing protocols have been undertaken these last decades. In this paper, we propose a robust hierarchical routing protocol using a dynamic clustering mechanism (HRP-DCM) which consists to build clusters wherein coordinators nodes with extra privileges called Cluster-Head (CH) are able to create and manipulate messages using TDMA schedule and aggregate data according to CDMA method. The effectiveness of the proposed approach is illustrated in simulations.**

Keywords-routing; energy; clustering; Wireless sensor

I. Introduction

Wireless sensor networks (WSN) consist of a large number of cooperative devices having characteristics such as sensing, processing and communication deployed randomly or not in known or unknown environments in porder to ensure and achieve specific and precise tasks. Nowadays, their implementation becomes more and more important for performing potential applications for a variety of fields such as medical monitoring, military operations [1], rescue missions, climate changes and so on [2-3]. For such tasks and applications, these devices are usually deployed in remote places, sometimes inaccessible highlighting constraints such as extended network lifetime and energy consumption that should be optimized in order to insure efficiently and continuously communications between nodes. In this context, designing a routing mechanism using clustering-based approaches provide significant improvements in term of give better results energy consumption optimization and lifetime extension [4]. They present the advantage of minimizing the number of nodes that take part in long distance communication with the base station (BS) through the CH nodes use and, consequently, reduce the energy consumption of the network.

The first protocols using clustering-based approaches and most studied one is Low Energy Adaptive Clustering Hierarchy (LEACH) [5][7]. The idea is to classify nodes into clusters where a coordinator node or CH node with extra privileges is capable to manipulate massages, aggregate data and ensure transmission between nodes and the BS according to TDMA and CDMA schedules. LEACH increases network performances in term of energy consumption but suffer from many drawbacks in that CH nodes selection is randomly and not uniformly distributed in the network. CH nodes can be located for example at the edges of the cluster. The implementation uses time intervals called rounds within it performs according to three phases: announcements and training clusters, scheduling and transmission phases.

The remainder of this paper is organized as follows: Section 2 presents a background on some WSN routing protocols works and some basics. Section 3 describes the robust hierarchical routing protocol HRP-DCM. Section 4 concerns some simulations that have been conducted to show the effectiveness of the proposed approach. A comparative study with a standard routing protocol [5] and LEACH-M method [6] is illustrated. Finally, in section 5, we dress some conclusions.

II. Background

As in LEACH, Energy-LEACH consists of several rounds in which CH nodes are elected [4]. It improves the CH nodes selection procedure and uses residual energy of nodes as a main metric. In the first round, all nodes have the same probability to become CH nodes. According to a certain probability, the BS proceeds for electing randomly new CH nodes and in the next rounds, knowing that residual energy of each node is different, new CH nodes are determined. It means that nodes having more residual energy become coordinator nodes rather than nodes with less energy. Unlike to LEACH and E-LEACH protocols where communications are ensured in a single-hop whatever the distance between nodes, in Multihop-LEACH protocol, optimal paths between nodes and CH nodes in

MOBILWARE 2013, November 11-12, Bologna, Italy

DOI 10.4108/icst.mobilware.2013.254303

order to communicate with the BS [8]. Some CH nodes play the role of relay stations and are able to converse each other. Tow-Level-LEACH is a variant proposed by *loscri and al* in [9] which consists to build a two-level hierarchy for a better consumed energy optimization. The protocol uses the concept of *data-fusion* in order to avoid the overload of data, which is very effective for large networks. Thus, large energy gains can be achieved by performing the data fusion, thereby requiring much less data to be transmitted to the BS. The TL-LEACH uses randomized rotation of CH nodes and the corresponding clusters, adaptive and self-configuring cluster formation. Vice-LEACH is a new version proposed in [10]. The objective is to ensure continuously the network operation by electing a vice-CH node within same functionalities as CH node. Thus, if a CH node has no ability to ensure its prerogatives in the network, a Vice-CH node can replace it and play the same role as a CH node. This extends the network life time without discontinuities. LEACH-Centralized [11] is similar to LEACH in operation except cluster formation. In LEACH-C, the CH selection is carried out at the BS. During the setup phase, BS receives from other nodes information about their current locations and remaining energy levels. BS uses the remaining energy level to determine the candidate set for CH node. The average node energy is computed and the node has remaining energy falling below this value will be removed from the candidate set. This algorithm attempts to minimize the total energy that non CH nodes use to transmit their data to CH nodes by minimizing the total sum of squared distance between nodes and their cluster head nodes. Once the cluster head nodes are determined, BS broadcast to all nodes the information including cluster head nodes, clusters member node and transmission schedule for each cluster. Nodes use this information to determine its TDMA slot for data transmission. In [6], authors proposed an improved LEACH protocol called LEACH-M where clusters formation is performed only once, minimizing by this way energy consumption and maximizing in the same time the lifetime of the network. Unlike in LEACH where nodes select their membership to given CHs nodes more than once, LEACH-M elects CH nodes having a highest energy by sending a membership message to the BS. Election of new CH nodes for each new round is ensured directly by old CH nodes and not by the BS. Thus, the number of control messages and overloading of the network is limited. Even if energy consumption gain is 10% comparatively to LEACH, the main drawback of LEACH-M is that network can stop running once all member nodes (MN) for a given cluster are elected as CH nodes. In other words, only cluster with high number of MN continues to operate in the network by electing other new CH nodes. All other nodes remaining to other clusters set their status to a sleep mode. Thus, the network should reorganize and initialize itself according to LEACH protocol procedure.

Implementing these types of protocols require determining the number of clusters before starting the cluster process. It's one of the key parameters that determines the lifetime of the sensor network. Thus, if there are fewer clusters, non-Cluster Head nodes are likely to spend too much energy transmitting data to their CHs because most of the clusters will be of a large size. This also means that fewer sensor nodes are CH and can result in less total energy being consumed to communicate with the BS. However, if there are too many clusters, the energy consumed by non-CH nodes to transmit data to their CH decreases. At the same time, more CH nodes are required to transmit the data over a large distance to the BS. Therefore, in order to minimize the energy consumption the clustering mechanism must be able to find the optimal number of clusters all the time.

Based on these observations, we propose and study in this paper a hierarchical routing protocol using a dynamic clustering mechanism (HRP-DCM) considering both residual energy of sensor nodes and distances between CH and non-CH nodes.

III. HIERARCHICAL ROUTING PROTOCOLE BASED DCM

A. Energy Model

The proposed robust hierarchical routing protocol based on dynamic clustering mechanism (HRP-DCM) consists to classify dynamically nodes into clusters where a coordinator node or CH node with extra privileges is capable to manipulate massages, aggregate data and ensure transmission between nodes and the BS according to TDMA and CDMA schedules. The reconfiguration of the network is carried out dynamically based on a threshold value which is associated to the number of nodes belonging to the smallest cluster.

As in LEACH-M protocol [6] and as described in [14], the energy consumption model for transmitting *k* bits of data over a distance d, can be defined for both transmission and reception phases. In fact, the transmitter consumes:

$$E_{TX}(k,d) = k \cdot E_{elec} + k \cdot \varepsilon_{amp} \cdot d^2 . \quad (1)$$

and the energy used to receive k-bits of data is:

$$E_{RX}(k,d) = k \cdot E_{elec} . \quad (2)$$

Parameters E_{elec} and ε_{amp} represent respectively transmitter/receiver electronic energy and amplification energy.

B. Energy Optimization Approach

The proposed robust hierarchical routing protocol implementation (Fig.1) passes first by considering some assumptions concerning the network. Nodes are homogeneous and randomly distributed in the environment. Communication between nodes is insured in a single hop and each node can operate according to two modes: sleep and wakeup modes.

In the beginning, in the first round, as in LEACH protocol that uses time intervals for electing new CH nodes, the BS announces a new round in which new clusters are created and each node decides whether or not to become a CH. The decision is based on a probability of election of a given node as a CH and the suggested percentage of CH nodes [5% to 15%]. That election can be expressed as follows:

$$T(n)=\begin{cases}\dfrac{P}{1-P\cdot\left(r\cdot \bmod\left(\frac{1}{P}\right)\right)} & if \quad (n\in G)\\ 0 & otherwise\end{cases} \quad . \qquad (3)$$

where P and r denote respectively the percentage of nodes wishing to be CH and the iteration of the current round. G represents the set of nodes that hasn't been a CH during the last $\left(\frac{1}{P}\right)$ iterations. A random number between 0 and 1 is assigned to a node n. If the number is less than a threshold $T(n)$, the node becomes a CH for the current round and notifies its neighbors of its election.
After the first round, in each cluster, the election of a new CH node is computed by the previous CH according to residual energy criterion.

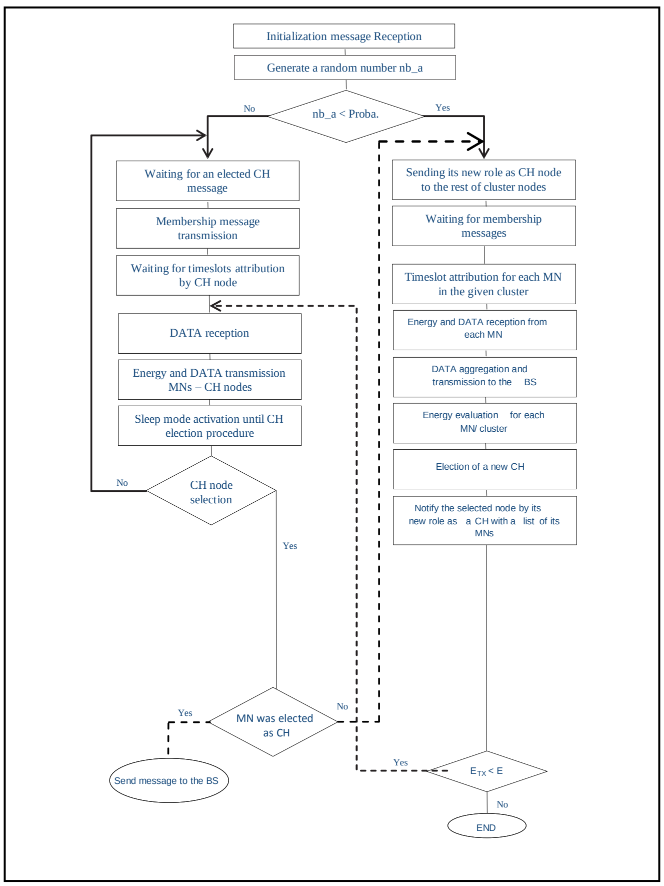


Figure 1. HRP-DCM Algorithm

Once nodes belonging to the smallest cluster were all elected as CH nodes, the last CH node informs the BS that no other node can be elected as a new CH. Thus, the BS re-organizes dynamically the network by forming new clusters during the phase of initialization. CH nodes are elected according to a random probability given in (3) and all MN inform their memberships for given clusters. During rounds, each CH node elects a new one according to a remaining residual energy until that MN cannot be elected as a CH node. After that, the BS is informed that the cluster is not able to possess a CH for the next round, because all nodes in the cluster have been elected. Therefore, the BS computes a new probability in order to form new clusters.

The energy calculated for each MN can be defined as follows:

$$E_{MN-rest}(i)=E_{init}(i)-\left[k\cdot(E_i+\varepsilon_{amp}\cdot d_{toCH}^2)\right]. \quad (4)$$

Where $E_{MN\text{-}res}(i)$ and $E_{init}(i)$ represent respectively remaining energy and initial energy of MN i. Parameter k is the size of the packet sent by node i to CH node. ε_{amp} is an amplification parameter.
Once determined, energy is compared to minimum energy for transmitting data E_{TX}. The pseudo-code is illustrated bellow:

if $E_{NM-rest}(i) < E_{TX}$ **then**
  the nodes is exhausted;
  else
    $E_{NM-rest}(i)$ is sent to the CH
    $E_{NM-rest}(i)$ will be compared to $E_{NM-rest}$ of the other members nodes of the cluster
    $E_{init}(i) \leftarrow E_{NM-rest}(i)$
  end
end

Pseudo-code 1.

The energy associated to each CH node is computed as follows:

$$E_{CH-rest}(j)=E_{init}(j)-\left[k\cdot\left(E_{ele}\left(\frac{N}{N_{CH}}\right)+E_{two-ray-amp}\cdot d_{toBS}^4\right)\right]. \quad (5)$$

where E_{ele} is the energy dissipated to transmit or receive electronics, $E_{two\text{-}ray\text{-}amp}$ is the energy dissipated by the power amplifier.
Thus, that energy is compared to minimum energy for transmitting data E_{TX} (Pseudo-code 2).

if $E_{CH-rest}(i) < E_{TX}$ **then**
  the nodes is exhausted;
  else
    CH become again member node of the cluster
    $E_{init}(i) \leftarrow E_{CH-rest}(i)$
  end
end

Pseudo-code 2.

CH node evaluates MN nodes residual energy in order to elect a new CH node. For a given cluster, a node having highest energy is elected as a new CH and if all nodes have been already selected as CH nodes, the last CH informs the BS which re-organize the network. It determines a new number of clusters for a new round and the probability of election.

IV. Simulations and Analysis

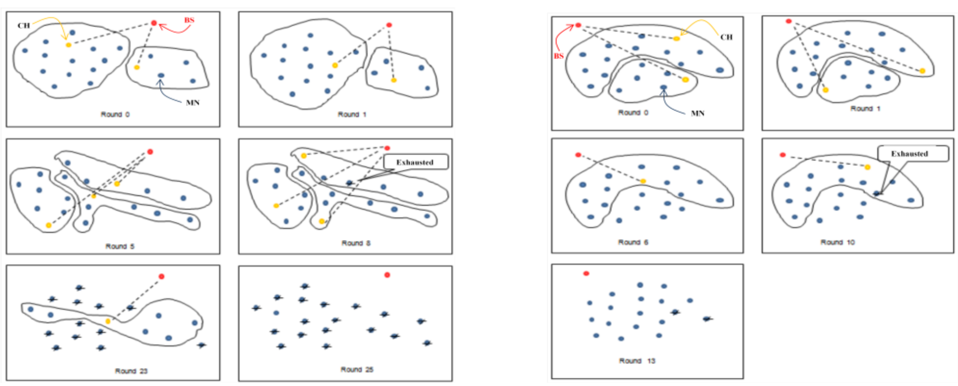
To evaluate the efficiency of HRP-DCM, a comparative study has been conducted with LEACH and LEACH-M. We use dedicated simulators for WSN: TOSSIM and POWERTOSSIM [12-13] with an object-oriented programming language NesC as a development tool. At the beginning, all network nodes have a same level of energy randomly deployed in operational environment over an area of 100×100. The BS is identified as node number 0. Parameters such as dissipated energy of power amplifier, Amplifier parameter, initial energy … have been initialized, so that:

- $E_{\text{two-ray-amp}} = 1.29 \times 10^{-15}$ J/bit/m^2
- $\varepsilon_{\text{amp}} = 10 \times 10^{-12}$ J/bit/m^4
- $E_{init} = 20$ pJoules

To demonstrate the scalability of the network, experiments were performed by taking into account the density of the network (ex. network with 20 and 50 nodes).

When implementing HRP-DCM and LEACH-M protocols, the topology of the network changes during rounds, some nodes die due to the lack of energy or change their roles: MN-to-CH or CH-to-MN.

Using HRP-DCM approach, at the beginning, in round 0, two clusters are built with two CH nodes. The number of rounds is defined as the number of nodes belonging to the smallest cluster. For that purpose, a threshold value *TH-val* corresponding to the number of nodes for a given cluster including minimum number of MNs is defined. Here the threshold value *TH-val* = 4. Thus, 4 rounds remain to be performed with the same topology (network with two clusters). From round 1 to round 4, the topology still unchanged. Once all nodes have been elected as CH nodes, the last node playing the role as a CH informs the BS that no other node can be elected as a new CH. After that, in round 5, as in LEACH-M approach, the network reorganizes itself and a new topology is generated. The BS re-organizes dynamically the network by forming new clusters via an initialization phase. The CH nodes are elected according to a random probability and all MN inform their memberships for a given clusters. In this case, three clusters are generated. This means that 3 nodes have changed their roles MN-to-CH or CH-to-MN (Fig. 2 (a)). A new smallest cluster consisting of 5 nodes allows that 4 rounds are required with the same topology (3 clusters). Thus, the network structure still unchanged until round number 9, where the clustering mechanism reorganizes the network. We observe that in round 8, the network loses its first node. This process continues operating until round 25 where only one node still alive.



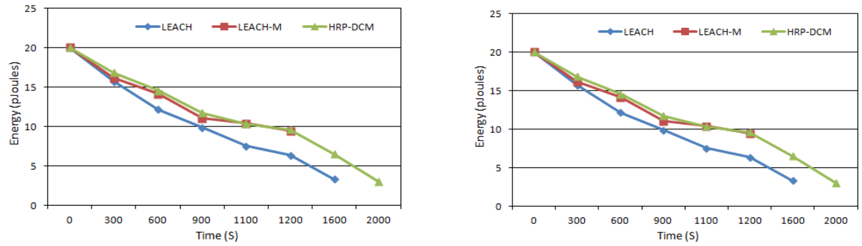
(a) (b)

Figure 2. Network topologies using HRP-DCM and LEACH-M

In LEACH protocol, clusters topology and of MN nodes roles change during rounds making the network very energy consumer. This problem was solved in LEACH-M. The number of clusters is determined after the first round, and each CH node elects a new CH node in the same cluster taking into account residual energy of each MN. Unlike HRP-DCM approach, in LEACH-M, the number of rounds is defined as the number of nodes belonging to the biggest cluster. For that purpose, a threshold value *TH-val* corresponding to the number of nodes for a given cluster including maximum number of MNs is defined. Here the threshold value *TH-val* = 13 (Fig. 2 (b)). During rounds, each CH node elects a new one according to a remaining residual energy until that MN cannot be elected as a CH node. Thus the BS is informed that the cluster is not able to possess a new CH for the next round (all nodes have been elected as a CH node in the cluster). Therefore, the BS computes a new probability in order to form a new topology with new clusters. In LEACH-M, in the initialization phase, two clusters are generated including 14 and 6 nodes each one. According to the obtained results, from round 6, only one cluster (most significant cluster with 13 nodes) still operates. The second cluster including 6 nodes stops operating even if its MNs enjoy of a sufficient energy leading them to continue working in the network. We observe also that in round 10, the network loses its first node. After 13 rounds the network stops operating and becomes inactive. This is a main drawback using LEACH-M approach.

Obtained results concerning the average-energy consumed during time respectively for a network including 20 and 50 nodes confirm that HRP-DCM approach gives better results than LEACH-M and LEACH approaches (Fig. 3(a) and (b)). With HRP-DCM, nodes operate longer extending ultimately the network lifetime. More the network is large, more the lifetime is extended.

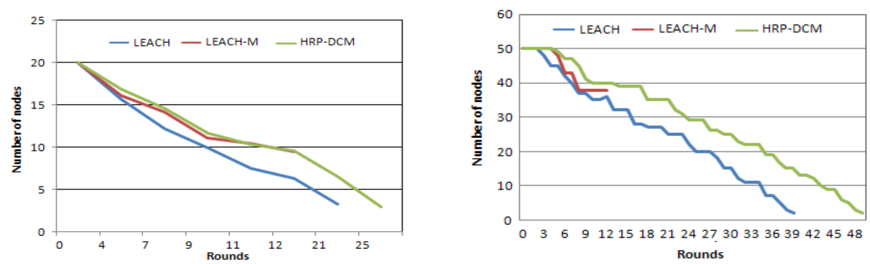
When no CH node is elected in a given cluster, the BS is informed and thereby a new election probability is determined leading to reorganize dynamically the network with new generated clusters. Unlike LEACH-M and LEACH approaches, MNs do not communicate with the BS for a given round. Only CH nodes are able do that reducing by that energy consumption in the network. In LEACH protocol, energy consumption is greater than in two other protocols. This is due to the fact that after each round, the network re-organizes itself and all nodes communicate directly with the BS.



(a) (b)

Figure 3. Average energy consumption using HRP-DCM, LEACH-M and LEACH

Fig. 4 (a) and (b) show nodes remaining alive over time respectively for a network with 20 and 50 nodes. We observe that HRP-DCM takes some advantage over LEACH and LEACH-M as the first node dies after a significantly higher number of rounds increasing the lifetime of the network.



(a) (b)

Figure 4. Topology of the network during rounds

V. Conclusions

In this paper, we have presented a study on WSN routing protocols focusing particularly on the optimization of energy consumption and network lifetime extension. For this purpose, we have proposed a robust hierarchical routing protocol based on dynamic clustering mechanism (HRP-DCM). The approach consists to classify dynamically nodes into clusters where coordinators nodes with extra privileges are able to manipulate massages, aggregate data and ensure transmission between nodes and the BS according to TDMA and CDMA schedules. The network reconfiguration is carried out dynamically based on a threshold value which is associated to the number of nodes belonging to a smallest cluster. Obtained results show that the HRP-DCM approach performs better than LEACH and LEACH-.

References

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless sensor networks: A survey,” Computer Networks, vol.38, 2002, pp.393-422.

[2] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “A survey on sensor networks,” IEEE Communications Magazine, vol.40, 2002, pp.102-114.

[3] C.Y. Chong, and S.P. Kumar, “Sensor Networks: evolution, opportunities and challenges,” Proc. IEEE, 2003, pp.1247-1256.

[4] Y. Tang, M.T. Zhou, and X. Zhang “Overview of routing protocols in wireless sensor networks,” Journal of Software, vol.7, 2006, pp.410-421.

[5] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-efficient communication protocol for wireless micro-sensor networks,” Proceedings of the 33rd Hawaii International Conference on System Sciences, vol.2, 2000, pp.3005-3014.

[6] H. Aoudia, Y. Touati, A. Ali-Cherif, and P. Greussay, “Hierarchical routing approach-based energy optimization in wireless sensor networks,” Proceedings of the 10th ACM International Symposium on Mobility Management and Wireless Access, Paphos, (Cyprus Island), 2012, pp.131-134.

[7] K. Akkaya, and M. Younis, “A Survey on Routing for Wireless Sensor Networks,” Journal of Ad Hoc Networks, vol.3, 2005, pp.325-349.

[8] X. Fan, and Y. Son, “Improvement on LEACH protocol of wireless sensor network,” International Conference on Sensor Technologies and Applications, 2007, pp.260-264.

[9] V. Loscri, G. Morabito, and S.A. Marano, “Two-Level hierarchy for low-energy adaptive clustering hierarchy,” Proceedings of the 62nd IEEE Vehicular Technology Conference, vol. 3, 2005, pp.1809-1813.

[10] M.B. Yassein, A. Al-Zoubi, Y. Khamayseh, and W. Mardini, “Improvement on LEACH protocol of wireless sensor network,” Journal of Digital Content technology and its Applications, vol.3, 2009, pp.132-136.

[11] D. Bhattacharyya, T.H. Kim, and S. Pal, “A comparative study of wireless sensor networks and their routing protocols,” Sensors, vol.10, 2010, pp.10506-10523.

[12] P. Levis, N. Lee, M. Welsh, and D. Culler, "TOSSIM: Accurate and scalable simulation of entire TinyOS applications," Proceedings of the 1st ACM Conference on Embedded Networked Sensor Systems, 2003, pp.126-137.

[13] P. Levis, S. Madden, D. Gay, J. Polastre, R. Szewczyk, A. Woo, E. Brewer, and D. Culler, "The emergence of networking abstractions and techniques in TinyOS," Proceedings of the 1st ACM Symposium on Networked Systems Design and Implementation, vol.1, 2004, pp.1-14.

[14] H. Yan, and B. Sikdar, "Optimal cluster head selection in the LEACH architecture," Proceedings of IEEE International Conference on Performance, Computing and Communications, New Orleans (LA), 2007, pp.93-100.