Hybrid Hierarchical Routing Protocol for WSN Lifetime Maximization

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***Abstract*—**Conceiving and developing routing protocols for wireless sensor networks requires considerations on constraints such as network lifetime and energy consumption. In this paper, we propose a hybrid hierarchical routing protocol named HHRP combining both clustering mechanism and multipath optimization taking into account residual energy and RSSI measures. HHRP consists of classifying dynamically nodes into clusters where coordinators nodes with extra privileges are able to manipulate messages, aggregate data and ensure transmission between nodes according to TDMA and CDMA schedules. The reconfiguration of the network is carried out dynamically based on a threshold value which is associated with the number of nodes belonging to the smallest cluster. To show the effectiveness of the proposed approach HHRP, a comparative study with LEACH protocol is illustrated in simulations.

***Keywords*—**Routing protocols, energy optimization, clustering.

I. Introduction

IN these last decades, potential applications have been performed in the fields of WSN [1]-[4]. For such applications, routing protocols, and particularly those based hierarchical architectures are very important to ensure an efficient communication between nodes and the base station (BS). Actual challenges concern how to reduce energy consumption in order to extend WSN lifetime. In this context, clustering plays an important role in the minimization of the number of nodes that take part in long distances communications with the BS through cluster-heads CHs nodes and consequently reduce the energy consumption of the whole network by increase the network lifetime. Based on their operating mode and type of applications, several routing methods based clustering concepts [5]-[9]. The most studied ones are LEACH and its variants, which is the first hierarchical cluster-based routing protocol for WSN classifying the nodes into clusters [10]-[12]. In each cluster, a coordinator node with an extra privilege called CH has the ability to create and manipulate messages using TDMA and CDMA schedules for aggregating and sending data from nodes to the BS.

Implementing these protocols increases the network performances in term of energy consumption but suffer from many drawbacks in that CH nodes selection is randomly and not uniformly distributed. These protocols are quite efficient but find their limitations promptly when the density of the networks is large. For hierarchical topologies, CHs overloading may lead the network to an overconsumption of energy and therefore, reducing its lifetime which is one of the major challenges in WSN.

Conceiving and developing a routing protocol for WSN requires considerations on the nature of processed data, how they are exploited, and which mechanism or concept should be implemented in order to ensure robustness and stability of the network. This paper proposes a hybrid hierarchical routing protocol named HHRP using both clustering mechanism and multipath optimization taking into account residual energy and signals strengths. It decides, automatically, how CH nodes are elected and optimize paths to reach the BS according to RSSI measures.

This paper is organized as follows: in Section II, the network and system models are described. A detailed presentation of the proposed HHRP using both a clustering mechanism and a multipath optimization is given in Section III. To test the effectiveness of the proposed approach, we have conducted in Section IV, a comparative study between HHRP and a standard routing protocol LEACH. Finally, conclusions are drawn in Section V.

II. Network Architecture and Energy Model

A. Topology and Network Architecture

As it is illustrated in Fig. 1, the proposed approach requires a hierarchical topology including a set of clusters automatically built according to residual energy and location of nodes. Each cluster consists of a set of nodes called member nodes NMs with a coordinator called Cluster-Head or CH. It performs treatments and relays information in a single hop between NMs and corresponding CHs, and/or in a multi-hop to the BS via other CH nodes. It depends on coverage area and signal range of nodes. The more nodes are distant from the BS; the more they use other nodes services to reach the destination. Communication is provided on two hierarchical levels: intra-cluster and inter-cluster.

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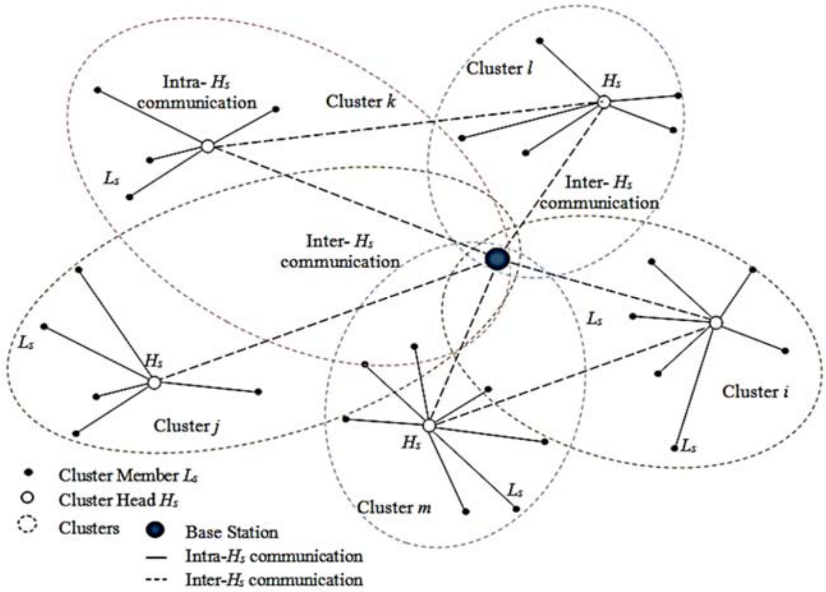

Fig. 1 WSN topology and architecture

Intra-cluster communications (Intra-Hs communication) concern messages exchanged, in a given cluster, between NMs and their corresponding CH. Such messages may include, for example, slots allocation or simply membership messages of NMs to CHs. In contrast, inter-cluster communications (Inter-Hs communication), concern messages between CHs-CHs-BS or CHs-BS.

CH node located so far from the BS can reach the destination via several neighbors. Thus it should take into account several constraints imposed by the application for optimal path selection. It can reach the BS on one or more hops (multi-hops).

B. Energy Model

As described in [13], [14], communication phase requires substantial amounts of energy, which can be expressed by a model including both transmitter and receiver communications. Transmitting k bits of data over a distance d can be defined as follows:

$$\mathrm{E_{T_x}(k,d) = kE_{elec}(k,d) + E_{Tx_{amp}}(k,d).} \quad (1)$$

where:

$$\mathrm{E_{TX_{amp}}(k,d) = k\varepsilon_{amp}d^2} \quad (2)$$

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

$$\mathrm{E_{R_x}(k,d) = E_{RX\_elec}(k) = kE_{elec}.} \quad (3)$$

E_{elec}, $\mathrm{E_{Tx_{amp}}}$ and $\varepsilon_{\mathrm{amp}}$ represent respectively transmitter/receiver electronic energy, amplification energy and amplification factor.

Based on (1) and (3), average energy consumption in each CH node can be computed as follow:

$$E_{moy} = p_r\left(E_{T_x}(k,d) + E_{R_x}\left(\frac{T_{inter}}{T} - k\right)\right) + (1-p_r)\left(E_{R_x}\left(\frac{T_{inter}}{T}\right) + E_{R_x}\left(\frac{T_{intra}}{T}\right)\right) \quad (4)$$

p_r and T represent respectively the probability that each node has k bits of data to be sent and the required time for transmitting a byte of data. T_{inter} and T_{intra} denote the communication time between CHs nodes and the BS, and the communication time between CHs nodes and MNs per round respectively.

In the first term of (4), for a given probability P corresponding to an inter-CH communication phase, all CHs nodes exchange information with the BS with an energy consumption equivalent to $E_{Tx}(k,d)$. The rest of the time $\left(T_{inter}/T - k\right)$ corresponds to the listening time where energy consumption is $E_{Rx}\left(T_{inter}/T - k\right)$. The second term of (4) corresponds to a probability $(1-p_r)$ where the CH node does not transmit any data to the BS. He spends all his time for inter-CHs communication in listening mode consuming energy of $E_{Rx}\left(T_{inter}/T\right)$. During intra-CH communication phase, CH node switches to a receive mode consuming $E_{Rx}\left(T_{intra}/T\right)$.

III. Proposed HHRP Description

In this section, we present a hybrid hierarchical routing protocol (HHRP) based on dynamic clustering mechanism. The approach consists of classifying dynamically nodes into clusters where a coordinator node or CH node with extra privileges is capable to manipulate messages, aggregate data and ensure transmission between nodes and the BS according to TDMA and CDMA schedules. Using the proposed HHRP, the network

Open Science Index, Computer and Information Engineering Vol:8, No:10, 2014 publications.waset.org/10004818.pdf

Open Science Index, Computer and Information Engineering Vol:8, No:10, 2014 publications.waset.org/10004818.pdf

reconfiguration is carried out dynamically based on a threshold value which is associated with the number of nodes belonging to the smallest cluster. The algorithm is illustrated in Fig. 2.

In the beginning, in the first round, based on 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 selection of a given node as a CH and the suggested percentage of CH nodes (10%) which is given by:

$$n_{CH} = (10\%)n. \quad (5)$$

That election can be expressed as follows:

$$T(n) = \begin{cases} \frac{P}{1-P\left(r \bmod \left(\frac{1}{P}\right)\right)} & if\ (n \in G) \\ 0 & otherwise \end{cases} \quad (6)$$

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 $\left(1/P\right)$ 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.

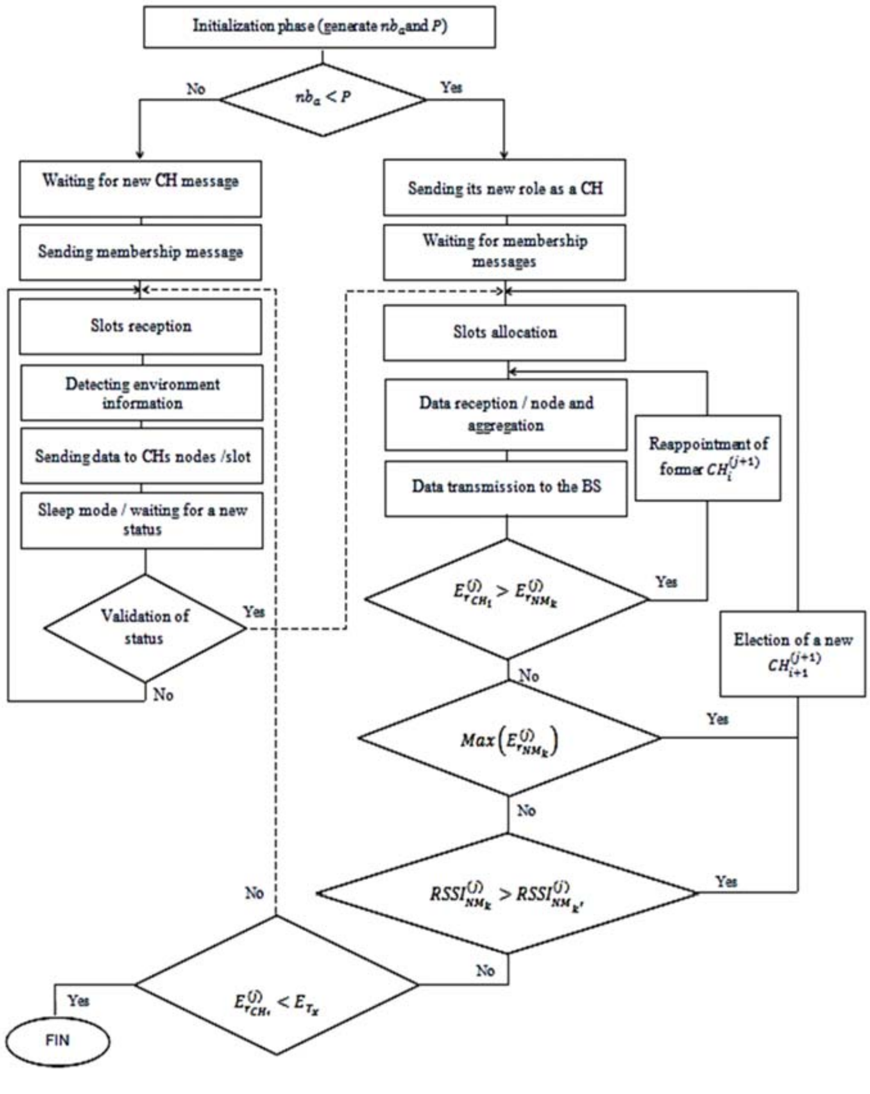

Fig. 2 HRRP Algorithm

$$A\ given\ node\ (i)\ is: \begin{cases} Potentially\ CH\ if\ nb_a \leq P \\ MN\ else \end{cases}$$

In this round, nodes recognize all their neighbours and according to RSSI measures, CHs nodes can build an optimal tree to reach the BS. More RSSI value is important; more the corresponding node can be elected to route messages $Message_{Init_{SB}}: \left(ID_{N_i}, ID_{N_j}, P, R_d, RSSI_i^{(j)}\right)$ where ID_{N_i} and ID_{N_j} respectively represent identifiers of destination N_i and source N_j, P is the probability generated by the BS for electing new CH node.

In TinyOS, a radio component-type CC2420 of a MicaZ sensor, RSSI values provided by the physical layer in ZigBee

Open Science Index, Computer and Information Engineering Vol:8, No:10, 2014 publications.waset.org/10004818.pdf

protocol are single-byte averaged over 8 periods of approximately 128μs. The power of radio signal is calculated by the following formula:

$$P = RSSI_{val} + Offset_{RSSI} \ \ [dBm] \quad (7)$$

where $Offset_{RSSI}$ is a compensation value defined empirically and estimated approximately to $-45dBm$.

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.

For a given round (*j*), CH node evaluates MN nodes residual energy $E^{(j)}_{r_{NM_k}}$ in order to elect a new CH node. A node having highest energy is elected as a new CH for the next round (*j*+1). Thus, based on RSSI measures, we can estimate the optimal path to reach the BS. If $E^{(j)}_{r_{NM_k}}$ *is* smaller than $E^{(j)}_{r_{CH_i}}$, former CH node is reappointed in his role as a coordinator.

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 the network dynamically by forming new clusters during the phase of initialization. CH nodes are selected according to a random probability given in (6) and all MN inform their memberships for the 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:

$$E^{(j)}_{MN} = E^{(j)}_{MN_{init}} - \left(kE^{(j)}_{i} + k\varepsilon_{amp} d^2_{toCH}\right) \quad (7)$$

where $E^{(j)}_{MN}$ and $E^{(j)}_{MN_{init}}$ represent respectively remaining energy and initial energy of MN (*i*).

Once determined, energy is compared to minimum energy for transmitting data E_{TX}.

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

$$E^{(j)}_{CH} = E^{(j)}_{CH_{init}} - \left(k \frac{N}{N_{CH}} E_{elec} + kE^{(j)}_{tra} d^2_{toBS}\right) \quad (8)$$

$E^{(j)}_{tra}$, represents the energy dissipated by the power amplifier. When whole nodes have been already selected as CH nodes, former CH informs the BS to 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 show the efficiency of HHRP approach, a comparative study has been conducted with LEACH routing protocol. For this purpose, we use TOSSIM and POWERTOSSIM [12], [13]. WSN dedicated simulators with an object-oriented programming language NesC as a development tool. As it's illustrated in Table I, some parameters such as the dissipated energy of power amplifier, Amplifier parameter, and initial energy have been initialized. The WSN consists of a set of sensor nodes randomly deployed in the operational environment over an area of 100×100, with a same initial energy. The BS is identified as node number 0.

TABLE I
Initial Parameters

E_{tra} [J/bit/m^2]	ε_{amp} [J/bit/m^4]	E_{init} [pJoules]
1.29×10^{-15}	10×10^{-12}	20

A number of experiments were performed taking into account the density of the network. Thus, we have proposed networks with 50, 100, 150 and 200 nodes.

Fig. 3 shows residual energies remain for different networks: 50, 100, 150 and 200 sensors nodes during rounds. HHRP approach performs better than LEACH. For example, a network with 100 nodes, the proposed approach keeps the network operating whereas in LEACH, the network dyes since round number 50 (Fig. 3 (b)). In the same manner, for 50, 150 and 200 nodes, HHRP maintains the network alive longer than in LEACH.

Fig. 4 demonstrates the system lifetime defined by the number of sensor nodes remain alive over time for different WSN: 50, 100, 150 and 200 nodes. It can be observed that the network lifetime for HHRP approach increases significantly compared to LEACH routing protocol. The improvement is based for some reasons. The first one is that the network update is not performed each round by the BS as in LEACH. This allows avoiding additional communications, thus fewer messages and low energy consumption. HHRP maintains the network alive longer than in LEACH.

Fig. 5 shows end-to-end delays between source and target nodes cause mainly by route discovery process and queue in the data packet transmission. Only data packets that successfully delivered to the destination are considered. It is quite clear that the average end-to-end delays have increased in the case of LEACH, due to overhead increased but it is less in HHRP, and it has been showed that average end-to-end delay will increase in LEACH as a number of nodes increases more than in HHRP. From these results, end to end delays increases with time which is a limitation of LEACH protocol. So, even if HHRP includes two types of information: intra- and inter-CHs and uses a Multihop communication in the inter-CHs case to reach the BS, it gives better results. The gain in term of elapsed time for any data to reach its destination varies between 5%-10%.

V. Conclusion

Energy efficiency is one of the most considered problems in WSN. It's a big challenge. In this paper, we have proposed a hybrid hierarchical routing protocol named HHRP using both a clustering mechanism and a multipath optimization based on residual energy and RSSI measures. The purpose is to distribute the load of long range transmissions between the BS and the rest of sensor nodes uniformly. The main factor for energy balancing and end-to-end delays is the efficient dynamic clustering and CHs selection that uses residual energy and RSSI measures for distances estimation. From the obtained results, it shows that the use of energy at CHs nodes is optimized and thus leads to increase the lifetime of the network, and a multi-hop inter-CHs communications play an important role for that. Using this mechanism, the architecture of the network can be more scalable even if the density is high. The reconfiguration of the network is carried out dynamically based on a threshold value which is associated with the number of nodes belonging to the smallest cluster. To show the effectiveness of the proposed approach HHRP, a comparative study with LEACH protocol is illustrated in simulations.

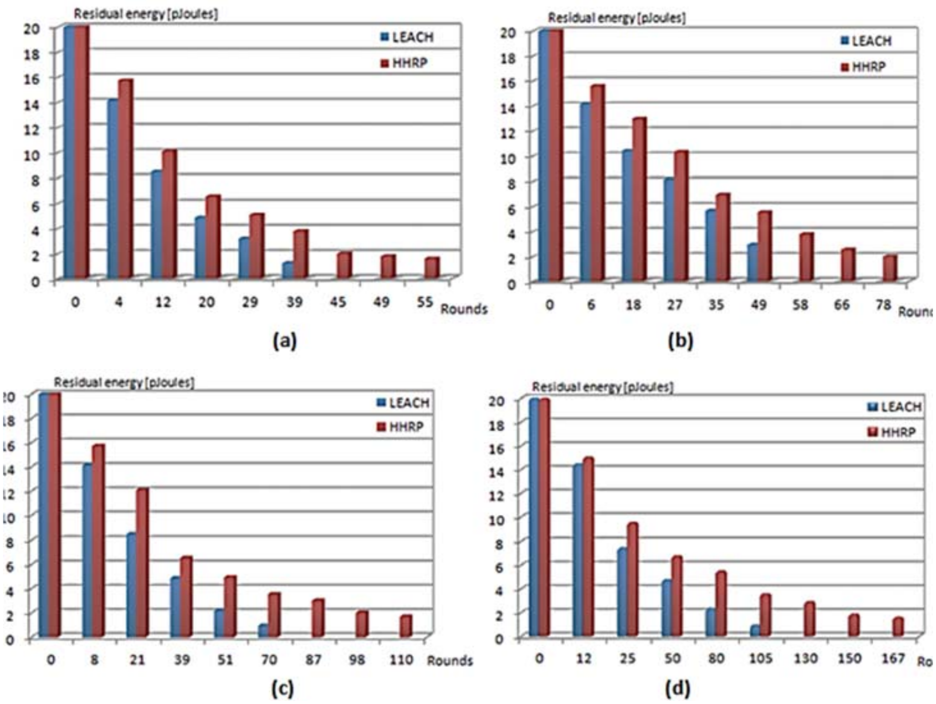

Fig. 3 Residual energy for different networks

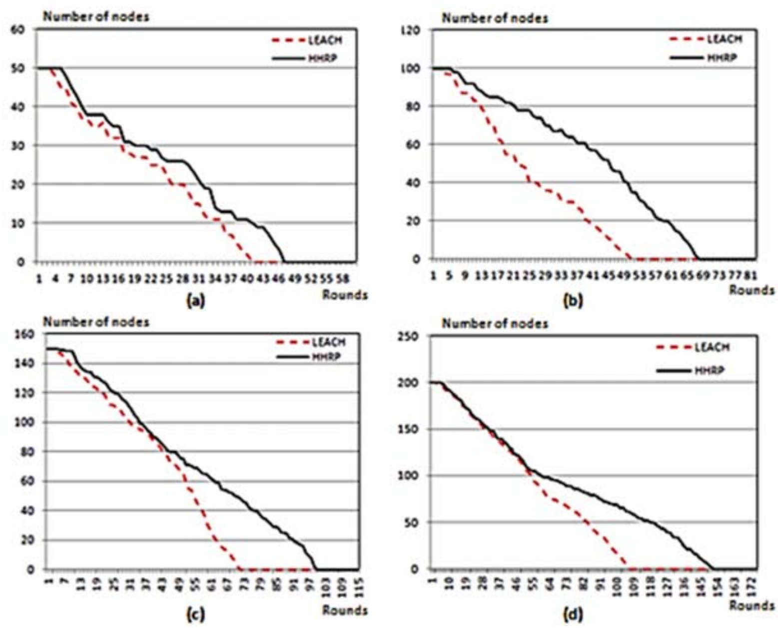

Fig. 4 Networks lifetime

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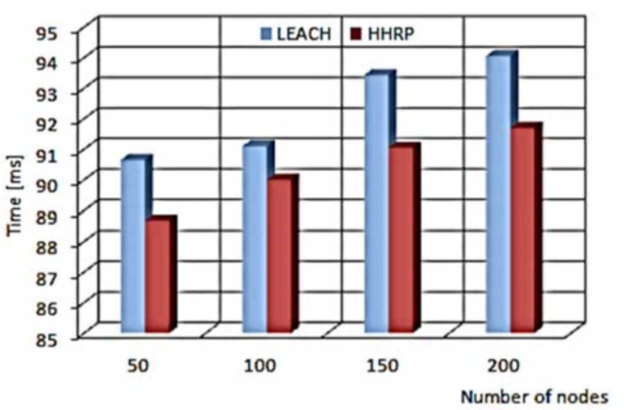

Fig. 5 End-to-end delays

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Open Science Index, Computer and Information Engineering Vol:8, No:10, 2014 publications.waset.org/10004818.pdf

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