Forwarding and Routing Stateless Multi-Hop Protocol for Wireless Sensor Networks

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***Abstract*—Energy conservation can be achieved by the use of clustering routing protocols in Wireless Sensor Networks (WSN). They have a great impact on the system lifetime. In these WSNs, the concepts of communication between Cluster Head (CH) nodes and Base Station (BS), data aggregation and round can be approached in a different way. This paper studies a cluster-based multi-hop routing protocol. The proposed approach introduces a progressive data aggregation, and a sequential data request during a round. Simulation results show that the new Forwarding and Routing Stateless Multi-Hop (FRSM) protocol extends network lifetime (improved by 50%) and lowers energy consumption. The comparison with an existing cluster-based protocol shows better performances.**

***Index Terms*—clustering, geographic routing, greedy forwarding, perimeter forwarding, network lifetime.**

I. Introduction

In general, a WSN consists of a large number of small and cheap sensor nodes that have limited energy, processing power and memory storage capacity. They usually monitor areas, collect data and report them to the Base Station. Due to the achievement in low-power digital circuits and wireless communication facilities, many applications of the WSN are developed and are already been used in building monitoring, military object and object tracking. They can also be used in hostile area where it is difficult to replace embedded batteries [1]. Hence, energy is the fundamental resource constraints. Its conservation represents one of the two issues addressed by this work to prolong the network lifetime. On the other hand, node's role and functions relative to network communication or the network topology cause some nodes to die quicker than the others. It is then essential to balance load among nodes. That constitutes the second purpose of this work.

The overall energy consumption can be reduced by allowing only a portion of the nodes, which are called Cluster Heads (CHs), to communicate with the base station (BS). Thus the data sent by each node is then first collected by Cluster Heads and compressed. After that, the aggregated data is transmitted to the BS. Low Energy Adaptive Clustering Hierarchy (LEACH) [2], is one of the first clustering protocols that was proposed for reducing power consumption. LEACH forms clusters by using a distributed algorithm, each node has a certain probability of becoming a CH per round, and the task of being a Cluster Head is rotated between nodes. A non-CH node determines its cluster by choosing the CH that can be reached with the least communication energy consumption. At the data transmission step, each Cluster Head sends an aggregated packet to the base station by a single hop communication. A well-known evolution of LEACH is Hybrid Energy-Efficient Distributed (HEED) [3]. In HEED, the initial probability for each node to become a tentative Cluster Head depends on its remaining energy, and the final CHs are selected according to the intra-cluster communication cost. HEED also consider one-hop communication between CH nodes and base station. Although clustering can reduce energy consumption, it has some problems. The main problem is that energy consumption is concentrated on the Cluster Heads, which have to transmit over long distance.

In the following, the BS is within the transmission range of every CH. Thus, each CH node can forward the data to the base station directly. However, it consumes much more energy in this way, and that does not necessarily balance the energy consumption among the network. So, a cluster routing method with equalized energy expenditure must be found. As mentioned in [4], short hops are generally more energy-efficient than one-hop with a few long hops. So, we propose a multi-hop routing between CHs in order to minimize energy consumption during transmission. Thus, GPSR (Greedy Perimeter Stateless Routing) protocol [5] [6] and his energy aware evolution GEAR (Geographical and Energy Aware Routing) [7] are two approaches aiming to improve the extensibility of the network in the presence of a large number of nodes. Their main advantages lie in the fact that the propagation of information on topology is necessary only for one hop. GPSR and GEAR make greedy forwarding decisions and perimeter forwarding using information about a router's immediate neighbors in the network topology. Consequently by using the same path to BS, the GPSR protocol leads to a premature failure of the nodes constituting the preferred way. Other approaches were proposed to improve the performance of clustering. EEUC [8] tackles the hot spot issue ; the Cluster Heads closer to the base station are burdened with heavy relay traffic and tend to die early. EEUC partitions the nodes into clusters of unequal size, and clusters closer to the base station have smaller sizes than those farther away from the base station. EECS [9] extends LEACH by realizing a localized election of Cluster Heads and a near uniform distribution of them. In cluster formation phase, a non-Cluster Head node chooses its Cluster Head by considering not only saving its own energy but also balancing the load of Cluster Heads. A

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new weighted function is then introduced.

In this paper, we propose and evaluate a Forwarding and Routing Stateless Multi-Hop (FRSM) Protocol for WSNs mitigating the considered problems. FRSM combines a clustering scheme with a multi-hop routing while addressing the mentioned premature failure of the nodes by a rotation of roles. It consists of two phases: one relates to cluster management in sensor area, and the other handles the data transmission between clusters and the BS. In order to improve the efficiency, we consider an aggregation of data of each cluster during the transmission from a source CH to the BS. Hence, this work introduces a progressive data aggregation and a sequential data request during a round. In the present primary study, we choose not take into account energy remaining in sensors. Therefore we only evaluate the coupling method between clustering, multi-hop routing and aggregation method. This early evaluation aims to quantify the contribution of this coupling. For that reason, comparisons will be made with a single-hop protocol, namely, LEACH protocol. Simulation model is choosen to make those comparisons feasible. Future work will address comparisons with other multi-hop protocols.

The paper is organized as follows: Section II describes our FRSM protocol and its algorithm. In Section III, simulation context and results will be presented and discussed. Finally, in Section IV, conclusions will be given.

II. Forwarding and Routing Stateless Multi-hop Protocol

Forwarding and Routing Stateless Multi-Hop Protocol (FRSM) is proposed in order to increase the lifetime of the network, and to ensure the balance of energy consumption. The idea is to adopt GPSR protocol with Cluster Head elections by LEACH protocol. Data gathering is performed with a new algorithm: furthest CH data request, inter-CH data aggregation.

A. Assumptions and modeling of the system

We assume a wireless sensor network model with the following hypothesis: the system lifetime is the main objective and latency is not a major criteria. We consider a multi-hop homogeneous WSN where all nodes are alike. Each node can reach the BS if needed by controlling the transceiver power. Nodes location is recorded in the BS memory (using additional GPS function). The nodes have uniform initial energy allocation and the nodes are stationary. This assumption about node mobility is typical for sensor networks. The sensing field dimension is $100m * 100m$ and we consider that the BS is located at ($X_{BS} = 50, Y_{BS} = 0$) in a two-dimensional XY plane.

The network is organized into clusters under the control of Cluster Heads. The BS collects the overall data using a sequential data request towards CHs. Each node senses the environment at a fixed rate and sends to the Cluster Heads. During the CHs selection process, each node n computes a random number between 0 and 1. If this number is lower than a threshold $T(n)$, the nodes becomes a Cluster Head. $T(n)$ is given by the following equation for the current round number (r) :

$$T(n) = \begin{cases} \frac{p}{1-p*(r \, mod \frac{1}{p}})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

where p is the average number of Cluster Heads during a round (10% will be considered in the simulation section). G is the group of nodes that have not been Cluster Head in the last $1/p$ rounds, otherwise $T(n)$ equals zero.

B. FRSM algorithm

The solution relies on the following algorithm :

1) $T(n)$ is calculated at each node to elect CH_i.
2) Cluster creation: all nodes organize themselves into clusters, under the control of the closest CH using the k-means algorithm [10].
3) Flooding phase to inform the BS and each CHs of other CH's position.
4) Physical data and CH identity aggregation is done in each cluster.
5) Furthest CH (defined as CH_{F1}), which has not been yet interrogated, is activated by the BS.
6) CH_{F1} sends its packets to a forwarding CH (which is closest to the BS, defined as CH_2) using GPSR routing algorithm.
7) Data aggregation and identity aggregation are computed at this second CH_2 (Data from CH_{F1} and from CH_2, and CH_2 and CH_{F1} identities).
8) From CH_2, data are sent to a third CH using GPSR routing algorithm (CH_3), which will again perform data and identities aggregation.
9) After x hops, the BS is reached. The data are then stored. Furthest CH (CH_{F2}), which has not been interrogated in the present round, is contacted by the BS.
10) Data are routed through inter-CH, which has never sent data during the current round. If needed RF transceiver is tuned to reach the BS.
11) This data collect process is repeated until each cluster have sent their data.
12) A new round begins with $T(n)$ calculation at each node (return to step 1).

Route or next hop selection is done on geographical routing basis as introduced in GPSR [5]: greedy forwarding, is used wherever possible, and perimeter forwarding, is used in the regions greedy forwarding cannot be. In greeding forwarding, a forwarding node make a locally optimal, greedy choice in choosing a packet's next hop. Upon receiving a greedy-mode packet for forwarding, a node searches its neighbor table for the neighbor geographically closest to the packet's destination. If this neighbor is closer to the destination, the node forwards the packet to that neighbor. When no neighbor is closer, the node marks the packet into perimeter mode. GPSR forwards perimeter-mode packets using a simple planar graph traversal. When a packet enters perimeter mode at node x bound for node D, GPSR forwards it on progressively closer faces of the planar graph, each of which is crossed by the line xD.

III. Simulation and Discussion

To evaluate the performance, our algorithm has been simulated in Matlab and the results were compared with LEACH. It is noted that the comparison with GPSR is illogical because GPSR does not consider clusters and CHs. Before presenting the simulation results, the radio model and some important parameters should be described.

A. Radio model

We use a simple model for the radio hardware energy dissipation introduced by [11] [12], where the transmitter and receiver dissipate energy to run the radio electronics (see Fig. 1). It was initially used to calculate the power consumption of LEACH protocol.

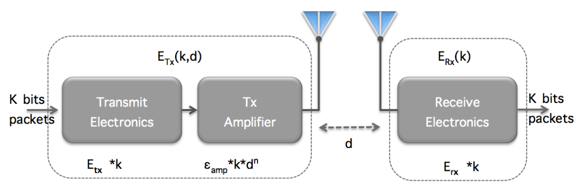

Fig. 1. Radio energy dissipation model

Power control can be used to invert this loss by appropriately setting the power amplifier. If the distance is less than a threshold, the free space (fs) model is used; otherwise, the multipath (mp) model is used. Energy consumed during transmission (E_{Tx}) is calculated with :

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-elec}(k,d) \qquad (1)$$

while developing:

$$E_{Tx}(k,d) = \begin{cases} E_{tx} \cdot k + \epsilon_{fs} \cdot k \cdot d^2, & if \quad d \leq d_o \\ E_{tx} \cdot k + \epsilon_{mp} \cdot k \cdot d^4, & if \quad d > d_o \end{cases} \qquad (2)$$

where E_{tx} is the transmit energy consumption by the radio transceiver for one transmission, k is the size of the message in bits, E_{fs} and E_{mp} represent the energy consumed by the radio amplifier, depending on the transmission distance d, and d_0 equals $\sqrt{\frac{E_{fs}}{E_{mp}}}$.

The energy consumed during message reception is calculated by:

$$E_{Rx}(k) = E_{Rx-elec}(k) = E_{rx} \cdot k \qquad (3)$$

where E_{rx} is the receiving energy consumption by the radio transceiver and k is the size of the message in bits. Energy consumption during reception is only calculated when a message is received, i.e., the radio transceiver only expends power during message reception. Power consumption for the calculation operations is much weaker than the communication energy. In addition, data aggregation also costs some energy and the energy consumption for aggregating a certain data signal is represented as E_{da}. E_{da} is calculated by applying the following [13]:

$$E_{da} = 5 \,\text{nJ/bit} \qquad (4)$$

TABLE I
Parameters used in our simulation

Radio model	Description	Value
E_o	Initial energy	$100\ mJ$
E_{tx}	Transmitting energy	$0.208\ mJ/packet$
E_{rx}	Receiving energy	$0.121\ mJ/packet$
E_{da}	Consume Energy data aggregation	$5\ nJ/bit$
ϵ_{fs}	Transmit amplifier free-space	$10\ pJ/bit/m^2$
ϵ_{mp}	Transmit amplifier for two-way	$0.0013\ pJ/bit/m^4$
Other parameters	Description	Value
n	Number of nodes	100
p	CHs selection probability	10%
k	Packet size	320 bits
BS	Base station located	$(50,0)$

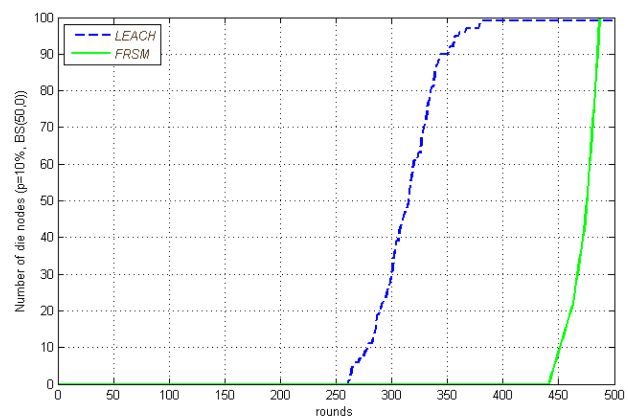

Fig. 2. Comparison of the number of dead nodes over time.

The energy consumption of each aggregation node for aggregating the data from itself and m neighbor nodes is represented as:

$$E_{DA} = (m+1) \cdot k \cdot E_{da} \qquad (5)$$

The parameters used for the simulations of the implemented protocols are shown in Table I. Those parameters are taken from Chipcon RFIC datasheet [14].

B. Simulation results- Base station located at (50,0)

Fig. 2 gives the comparison between FRSM protocol and LEACH protocol in term of the lifetime per rounds. It is clearly shown that our FRSM algorithm outperforms LEACH in the number of alive nodes. If the lifetime metric is defined as number of rounds for which the first node died, FRSM can reach 442 rounds, whereas LEACH only reaches 261 rounds. For half of the nodes being alive, FRSM can reach 475 rounds, but LEACH only reaches 315 rounds. The lifetime metrics are improved by 50% for FRSM. Besides, the noticeable nearly linearity of the FRSM curve starting at 442th round proves the efficiency of load balancing.

Considering the two protocols, the remaining energy of nodes over the number of rounds has been presented (see Fig.

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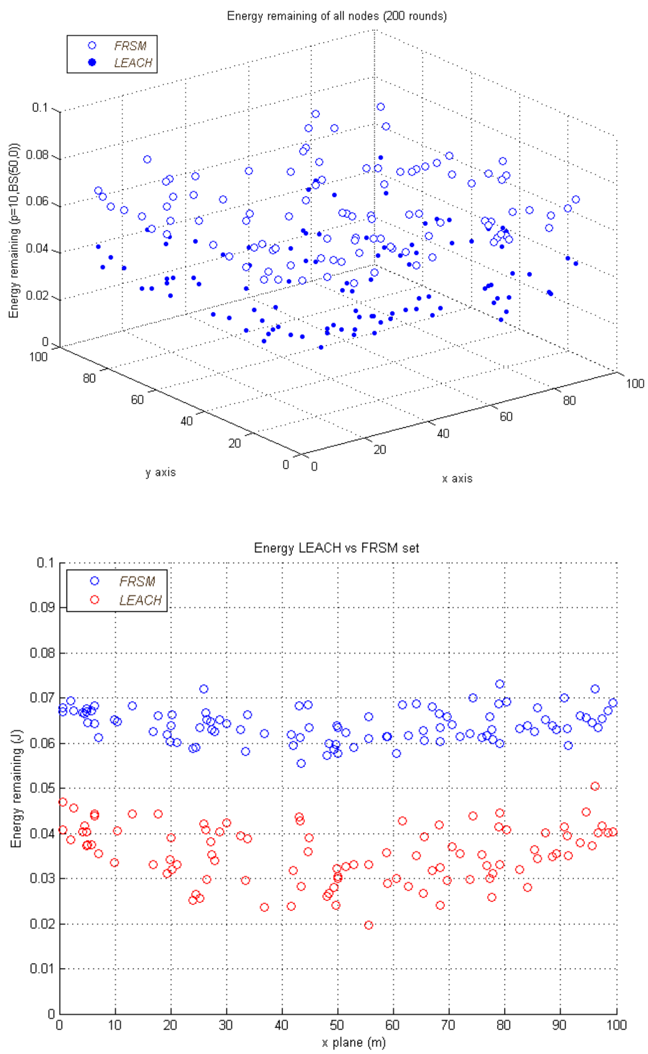

Fig. 3. Energy remaining after 200 rounds in the XY plane and X axis.

3) in the XY plane and in X axis. We show that the FRSM has much more desirable energy expenditure than the LEACH protocol. As the number of rounds is equal to 200, the average remaining energy of all the nodes in the networks for FRSM and LEACH are respectively 0.064 J and 0.035 J. So, the FRSM exhibits a 80% reduction in energy consumption over LEACH.

IV. Conclusion and Future Works

The Forwarding and Routing Stateless Multi-hop protocol for wireless sensor networks has been introduced in this paper. We adopt the cluster-based algorithm to make sure the well-balanced energy in the network. Thus, shorten communication distance among Cluster Heads and progressive aggregation data during transmission, were considered to reduce the global communication energy consumption. Based on specific network assumptions, simulation results show that this method obtains satisfactory performance on prolonging the network lifetime (increased by 50%). To go further, other points are under study: simulation of a fairly comparison with HEED, measurements on a more accurate energy consumption model and the use of energy aware information's for the routing process.

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