Multi-Hop Low Energy Fixed Clustering Algorithm (M-LEFCA) for WSNs

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***Abstract*—The limited battery supply of sensor nodes is one of the most important factors which restrict the lifetime of the wireless sensor networks (WSNs). As a consequence, the wide deployment of WSNs in the recent years led to the necessity of extending the lifetime through energy efficient mechanisms. Previous studies have shown that instead of implementing direct transmission in a WSN field to collect data, clustering can significantly improve the energy-efficiency and thus the lifetime. The traditional LEACH and LEACH based algorithms have evolved from this idea. In this paper, separating from the LEACH based algorithms, a fixed clustering and multi-hop routing algorithm for WSNs is proposed. The multi-hop low energy fixed clustering algorithm (M-LEFCA) selects the nearest forward neighbour CH node as a relay node to provide multi-hop routing between CHs instead of using direct transmission between CH nodes and the base station (BS). The simulation results indicate that, M-LEFCA further improves the lifetime and number of packets delivered to the BS, reduces the energy dissipation significantly.**

Keywords—clustering; multi-hop; energy-efficient routing; wireless sensor networks.

I. INTRODUCTION

WSNs are able to perform data collection, aggregation and communication from an environment by using many distributed individual sensor nodes through radio communications. By sensing the environmental events within their respective ranges, the sensor nodes collect data of interest and communicate the data through the nodes until the data finally reaches to the BS for final processing. WSNs have become increasingly useful in a variety of critical applications, such as environmental monitoring, smart offices, battlefield surveillance, and transportation traffic monitoring. Consequently, in the recent years, a diverse range of WSNs have been deployed.

According to the participating way of the nodes, routing protocols used for WSNs can be classified into three categories, namely, direct transmission, multi-hop routing and clustering protocols. With direct transmission, each sensor node directly transmits its sensed data to a remote receiver. Thus, the sensor nodes do not require any type of communication amongst themselves. With multi-hop routing, each sensor node transmits its data to the remote receiver through other sensor nodes in the network.

When clustering is employed, a cluster head (CH) is responsible for conveying any information obtained by the nodes in its cluster. The CHs may aggregate and compress the data before sending it to the BS. It has been shown that clustering is an efficient and scalable way to organize WSNs since clustering approaches reduce the overall energy consumption in the network. Consequently, many different cluster based routing algorithms have been developed.

LEACH [1] is a simple and efficient round based adaptive routing protocol. Sensor nodes form clusters without any help from an external agent or a node in the network. LEACH divides the time into frames called a round. Every round consists of two phases. In the set-up phase the CHs are elected and clusters are formed. In the steady-state phase, collected data is transmitted to the BS.

Modified LEACH (ModLEACH) [2] includes an efficient CH replacement scheme and dual transmitting power levels. Multi power levels are used to reduce the packet drop ratio, collisions and interference from other signals. When a node becomes a CH, the routing protocol informs it to use high power amplification and when a node becomes a regular cluster member, the mode of that node becomes low level power amplification mode. Threshold based CH changing mechanism is used in ModLEACH to provide more efficient CH replacement. If the energy of the existing CH drops below the threshold, a new CH for that cluster is elected and the cluster is formed again. ModLEACH outperforms LEACH in terms of network lifetime and CH formation.

There are also heterogeneous cluster based WSN routing protocols. Stable Election Protocol (SEP) [3] is a successful protocol for WSNs and contains advanced nodes which are fitted with extra energy resources. SEP uses a weighted election probability

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based approach to determine CHs according to the residual energy of each node. The results of the simulations of the SEP show that, SEP provides significant energy savings, lifetime gains and throughput improvement when compared with LEACH for both homogeneous and heterogeneous scenarios.

Our proposed M-LEFCA uses multi-hop intra cluster communication approach. It selects optimum forward neighbor CHs as relay nodes (RNs) and CHs transmit the collected cluster data to the BS by using these forward RNs. M-LEFCA aims to decrease energy consumption and prolong network lifetime by combining clustering and multi-hop approaches.

II. Multi-hop Low Energy Fixed Clustering Algorithm (M-LEFCA)

M-LEFCA uses a fixed clustering approach. While the clusters who are far away from the BS use RNs to transmit the collected data, neighbour clusters to the BS transmit their collected data directly to the BS. M-LEFCA is composed of two phases. In the set-up phase the CHs are elected, the clusters are formed and RNs are determined. In the steady-state phase data collected from each cluster is transmitted to the BS by using RNs or directly. CH and RN changes also occur in the steady-state phase if needed.

A. *Set-up Phase of M-LEFCA*

The location of the BS is known by all nodes in the field. This knowledge is provided from BS during depletion of the sensor nodes by sending location information to the network. In each cluster, the CHs are determined according to the intelligent CH selection mechanism [4] which is performed by BS. After determination of the CHs, the member nodes join to the nearest CH according to the CH ADV messages. Fig. 1. shows a CH ADV message. The message contains member node ID, CH ID, CH location and ADV header.

Member ID	CH ID	CH Location	ADV Header

Fig. 1. CH ADV Message Structure of M-LEFCA

To find RNs, each CH should know the location information of other CHs. To provide this, the CHs broadcast their location information by using CH ADV message. Hereby, each member and CH learn the location information of all initial CHs. According to this location information, each CH node selects the nearest forward neighbour CH node in the direction of BS as a RN as shown in Fig. 2. When a CH node selects the nearest neighbour CH node as a RN, it should inform it about this selection. It sends selection notification message to the neighbour CH. When neighbour CH receives this message, it learns that it is being used as a RN. This selection notification message includes the ID of the selected CH and ID of the CH which uses that node as a RN.

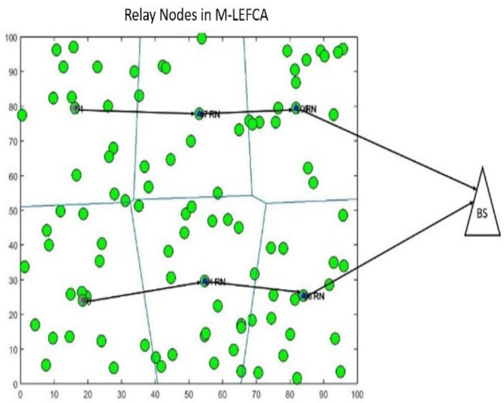

Fig. 2. Multi-hop Relay Node Determination in M-LEFCA

B. *Steady State Phase of M-LEFCA*

The steady state phase of M-LEFCA is divided into time frames called as rounds. At each round, the data collected from the sensor field are transmitted to the BS with the assistance of RNs, if needed new CHs and thus RNs are elected.

An M-LEFCA round initiates with data transmission. The CHs gather the cluster data from their associated members by using a TDMA schedule similar to the LEACH algorithm. Then, the CH nodes transmit the collected data from their clusters to their respective RNs. The RNs collect and aggregate the incoming data and forward the data to the next RN. This process continues until all data reach to the neighbour CHs of the BS. At this point, last CHs (RNs) transmit data directly to the BS.

Similar to LEFCA [4], a threshold value (ThV) based CH determination mechanism is used in M-LEFCA. If the residual energy of any CH drops below ThV, it elects new CH randomly from the alive members. The existing CH notifies about the new selection to its cluster members by broadcasting the ID of the new CH in its cluster. If the new elected CH needs to use a RN, it should select a new nearest forward CH node as a RN and should inform that CH node with selection notification messages. The newly selected CH can function as a RN at any time, thus, other CH nodes should be notified about its location information.

The CHs are selected by the BS only once after the deployment of the sensor nodes. In the later rounds of the algorithm, the current CHs make this decision and inform the new CHs about their selection.

The RN selection based mechanism of M-LEFCA aims to delay draining of the batteries of the remote CHs by decreasing the transmission distance of them significantly. M-LEFCA also aims to prolong the lifetime of WSNs by utilizing RNs. The usage of RNs in M-LEFCA causes additional network costs because of the usage of some additional notification messages. However, M-LEFCA provides extra energy savings and lifetime improvement when compared to existing WSN routing protocols. By reducing the energy consumption of far CH nodes, M-LEFCA provides a more uniform distribution of alive nodes throughout the sensor field. As a consequence, M-LEFCA prolongs lifetime of remote clusters. Hence, M-LEFCA may be a suitable candidate for applications where it is critical to gather information from all parts of the network such as fire rescue, earthquake measurements and disaster reliefs.

III. SIMULATIONS OF M-LEFCA

The simulations are conducted with MATLAB. 100 sensor nodes are randomly deployed in a 100 m x 100 m field and the BS is placed outside of the sensor field with coordinates of (150,50). M-LEFCA divides the network into 10 clusters for all the realized simulations. Same simulation parameters as LEACH [1] which are shown in Table I are used for all the simulations in this paper. Each simulation is realized for 100 independent iterations and the averages of these iterations are presented. M-LEFCA is compared with the traditional LEACH protocol, as well as successful LEACH successors such as ModLEACH and SEP in terms of number of alive nodes (lifetime) and residual energy.

TABLE I. SIMULATION ENVIRONMENT PARAMETERS

Parameters	Values
Network area	100 m x 100 m
Number of nodes	100
Base station coordinates	(150,50)
Initial energy per node	2 J
Data packet size	6400 bits
Control Packet Size	200 bits
Transceiver Energy (E_{elec})	50 nJ/bit
Aggregation Energy per Bit (E_{DA})	5 nJ/bit/signal
Free Space Amplifier Energy (ε_{fs})	10 pJ/bit/m^2m^2
Multipath Amplifier Energy (ε_{mp})	0.0013 pJ/bit/m^4m^4
Iterations	100

A. Residual Energy

Fig. 3 illustrates the total residual energy of the WSN per round. For this simulation study a ThV of 0.05 J is selected for M-LEFCA. Although SEP starts with %25 more initial network energy due to its heterogeneous structure, M-LEFCA preserves energy carefully by fixed clustering and CH abusement and consequently provides significant savings not only for SEP but also LEACH and ModLEACH.

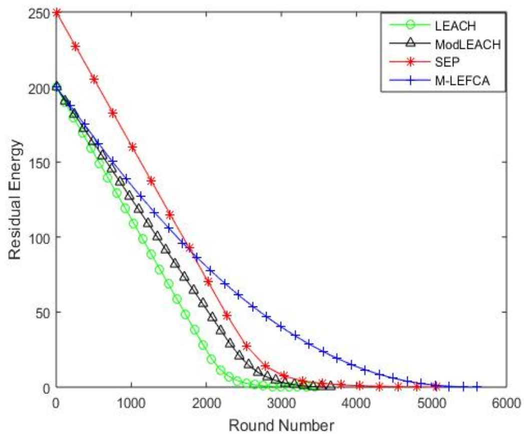

Fig. 3. Comparison of Total Residual Energy

B. Number of Alive Nodes

Fig. 4 shows the number of alive nodes of the WSN per round. Under M-LEFCA, the network lifetime increases to approximately *6000* rounds. Although node deaths start earlier under M-LEFCA since the CHs are abused due to low ThV values, the rate of the node deaths is significantly lower than other protocols, resulting in a longer lifetime. Note that, the initial node death can be delayed under M-LEFCA by chosing larger ThV values.

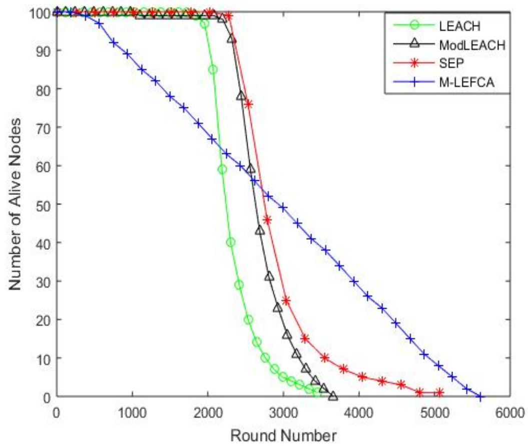

Fig. 4. Round Number vs Alive Nodes

C. Network Lifetime

For each algorithm, the simulations are repeated 100 times for different topologies and the maximum and average observed lifetimes are presented in Table II as well as the initial network energies. M-LEFCA's conservative energy consumption ratio prolongs the lifetime of a WSN significantly. M-LEFCA outperforms LEACH and its variants. When M-LEFCA is compared with novel routing algorithms such as SEP and ModLEACH, extended lifetimes are also observed although M-LEFCA begins with lower initial energy.

TABLE II. NETWORK LIFETIME COMPARISON

Algorithm	Average Lifetime	Maximum Lifetime	Initial Network Energy
M-LEFCA	5774	6015	200 J
SEP	5059	6177	250 J
ModLEACH	3742	4123	200 J
LEACH	3478	4216	200 J

IV. CONCLUSIONS

Providing energy-efficiency and promoting green solutions [5] for WSNs has become an essential research area. By using a fixed number of clusters, reducing the number of CH changes and utilizing multi-hop routing between CHs, M-LEFCA minimizes the cluster formation overhead. When compared with other protocols significant improvements are obtained in terms of energy consumption, network lifetime and number of packets delivered to the BS. M-LEFCA extends the lifetime of the WSNs, while reducing the energy consumption.

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