A Cross-Layer Routing Protocol for Wireless Sensor Networks

Pallavi Yarde, Sumit Srivastava and Kumkum Garg

Abstract In the era of Internet of things (IoT), the sensors play an important role and also face a challenge of energy consumption. Sensors in wireless sensor networks (WSNs) deals with accumulation and processing of data and forward that to the remote locations, generally considered as cloud. Generally, communication is done between the nodes which are placed at a far locations in the field. Hence, the energy consumption required to communicate the nodes plays an important role. In this paper, the proposed algorithm is based on low-energy adaptive clustering hierarchical (LEACH) routing algorithm named as multi-hop cluster LEACH (MC LEACH) algorithm. The proposed protocol is a cross-layer routing protocol that deals with physical, MAC, and network layers for the analysis of energy consumption at individual node as well as in whole network.

Keywords Wireless sensor networks · Cross-layer optimization · LEACH
MC LEACH

1 Introduction

There is a big resolution occurred with Internet of things (IoT) in the field of wireless sensor networks (WSNs). The aim of IoT is to communicate the data gathered into sensors network to remote location with one of wireless technologies. The data from network should reach to remote location, generally called sink with minimum delay and energy consumption. Delay and energy consumption are very important quality of service (QoS) measuring metrics. There are numerous delay measuring protocols available for WSN [1–4]. The proposed work focuses on optimizing energy dissipation in whole network. Each layer of communication network model plays a

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vital role. When these different layers work in collaboration then it is considered as cross-layer optimization. The proposed protocol also implemented using cross-layer approach. Here, three layers, network, media access control (MAC), and physical layers, work in coordination to analyze energy consumption, number of dead nodes, and number of alive nodes. The proposed protocol is based on low-energy adaptive clustering hierarchy (LEACH) protocol with some add-ons. The function of the proposed protocol refers to the probability as well as distance for selecting cluster head. The cluster head selection process involves probability, distance among the nodes and sink, and also energy of nodes. The number of cluster heads makes a chain to propagate the processed data to remote sink, hence called multi-hop protocol. The proposed protocol MC LEACH involves functions like selection process for cluster heads, gathering data, processing of data, and designing a chain, i.e., choosing the best path to reach to the sink. These functions involves role of network layer, MAC layer, and physical layer in collaboration to as a cross-layer function.

2 Existing Work

There exist many protocols which are energy efficient and also focus on cross-layer optimization. These protocols use different QoS metrics as measures of performance like delay [5–8], throughput, network lifetime, residual energy [9–14]. Some of the protocols also implemented with cross-layer optimization. The proposed protocol is based on LEACH protocols with some modifications. Most of sensor nodes in WSN protocols directly transmit accumulated data to the sink instead; this protocol supports selecting a cluster head to each designed clusters in rotation. The proposed protocol also supports cross-layer optimization.

Packet size: The amount of data (raw data and supporting information) in bits used to travel between source and destination is considered as a packet. The size of packet may vary or of fixed size.

Traffic: Highly dense network has too many packets transmission and hence some of packets may have a chance to drop. This is because of collision or stop-and-wait situation at the node. This introduces a delay in communication.

Scalability: It is an ability to enhance number of nodes in the network. The number of nodes should be enhanced up to optimization level only, so that maximum delay cause can be avoided there.

An energy-efficient differentiated directed diffusion (EDDD) protocol was proposed in 2006 [15]. The data in network may be destined to the node from its surrounding or from a node to the other node. The first type of data is considered as real-time (RT) data, while other one is considered as best-effort (BE) data. This protocol has a capability to differentiate between these two data and work accordingly to avoid maximum delay.

A cross-layer priority-based congestion control protocol (PCCP) was proposed by Wang et al. [16]. It is a routing protocol. Here, there are two data queues generated: one at MAC layer and other at network layer. The node calculates the time consumed by a packet to wait and communicate and estimates the probability of congestion and actual congestion happened. Based on this, it notifies other nodes about congestion and avoids further delay in communication.

3 Proposed Work

The proposed protocol, multi-hop clusters LEACH (MC LEACH), is a cross-layer optimized routing protocol which focuses on media access control) (MAC) and network layers. The proposed protocol is a cross-layer routing protocol, which emphasizes minimized energy consumption for communication.

3.1 Network Structure

The different energy-level sensor nodes are considered to be randomly spread in bounded area and considered as heterogeneous network. Whole network nodes are divided into normal and advanced nodes. The complete network is virtually divided into number of clusters with each has a radius R. A sink is also placed at the center of the network. Sink received sensed data from network. Sending sensed data directly to the sink may exhaust sensor nodes easily. The proposed protocol follows LEACH, in which each cluster is appointed to of the node as a head called cluster head (CH). Here, the responsibility of CH is to gather the data from surrounding sensor nodes of its own cluster and to process that data and finally send it to the sink [17]. In MC LEACH protocol, each sensor node calculates the distance between all the remaining nodes and sinks. When a node is elected as CH, it already knows the distance between itself and the sink as well as between all available CHs of the network. The distance is calculated using the Euclidian distance formula.

In Fig. 1, each cluster head calculates the distance between all remaining cluster heads and the sink. Here, we have four clusters C1, C2, C3, and C4. Each cluster has a cluster head (black circles). The distances between all cluster heads are d23, d12, d13, d24, d34, and d14. The distances between clusters C1, C2, C3, C4 and the sink are d1, d2, d3, and d4, respectively.

3.2 Cluster Setup and Selection of Cluster Head

Each sensor node is initiated with a specific amount of energy. The selection of cluster head in a cluster depends on the probability like LEACH protocol and on energy of individual nodes; i.e., the node with highest probability and energy among the cluster nodes will be selected as CH.

Each node manages a routing table. The routing table contains information of its own and neighboring nodes of its cluster. The parameters stored with routing table are

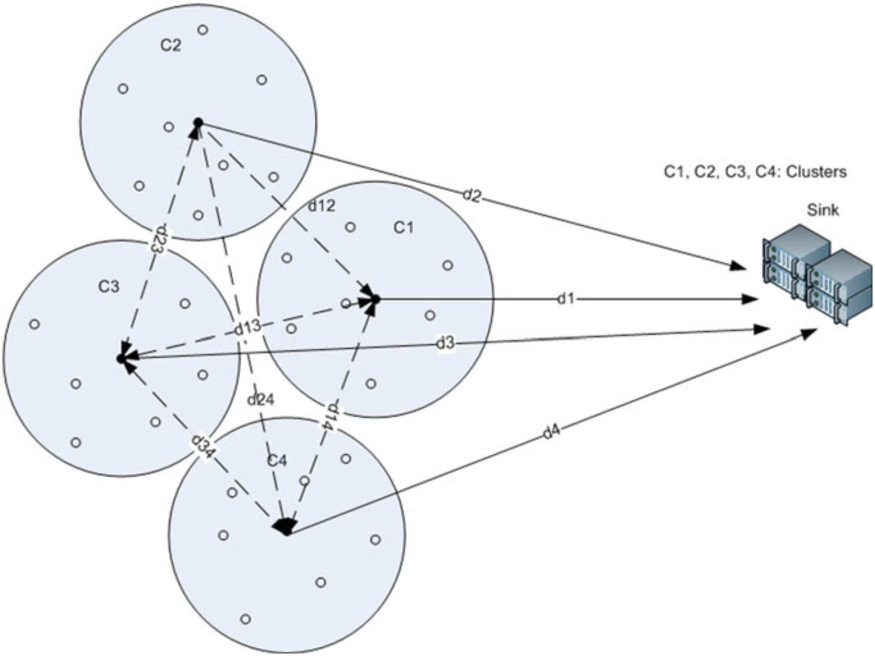

Fig. 1 Architecture of wireless sensor networks for MC LEACH protocol

probability to be cluster head, residual energy, and distance between the nodes. Like LEACH protocol, the node becomes cluster head on the basis of probability and also with an additional parameter residual energy. The node with maximum probability and residual energy among the nodes in a cluster will be selected as cluster head. Each node selects a random number where $0 < r < 1$. If, $r <$ threshold $T(n)$, then one of the criteria for selecting that node as cluster head fulfills. The threshold calculation is given in Eq. 1.

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

where n is nth node for which threshold is calculated, G is the group of sensor nodes, and P is the probability of node to become cluster head.

Once the criteria of threshold fulfills, the energy of sorted nodes is compared and the node with maximum energy and threshold greater than value r is selected as cluster head for a round. This process keeps repeating for each round; i.e., for each round, number of clusters and cluster head are created.

3.3 Cluster Setup

Once the cluster is formed, the responsibility of sensor nodes is to introduce themselves with the other nodes of cluster. The nodes broadcast message signal consisting of node details like their node id and residual energy. Based on receive signal strength indicator (RSSI) [18], the node calculates the distance between the message sending node and itself.

Each cluster of MC LEACH protocol has a cluster head and sensor nodes. The cluster setup details for MC LEACH are shown in Fig. 2. Here, each node is initiated with a specific energy level. When a cluster is formed, each sensor node broadcasts about its presence in the network and calculates distance between itself and sink. The calculated distance is Euclidian distance. The setup phase further works in twofolds, intra-cluster and inter-cluster.

Intra-cluster Setup Phase Once the cluster is formed and CH is selected, the remaining nodes of cluster must know about the CH. Hence, CH broadcasts a message in cluster about its identification. When this message is received by remaining nodes in cluster, they calculate the distance between themselves and CH with the parameter receive signal strength indicator (RSSI).

$$P_r(d) = C\frac{P_t}{d^{\propto}} \tag{2}$$

where $P_r(d)$ is the received power by receiver at distance d expressed in dBm, C is proportionality constant whose value depends on communication model, P_t is the power used by transmitter to send the message, and α is called distance–power

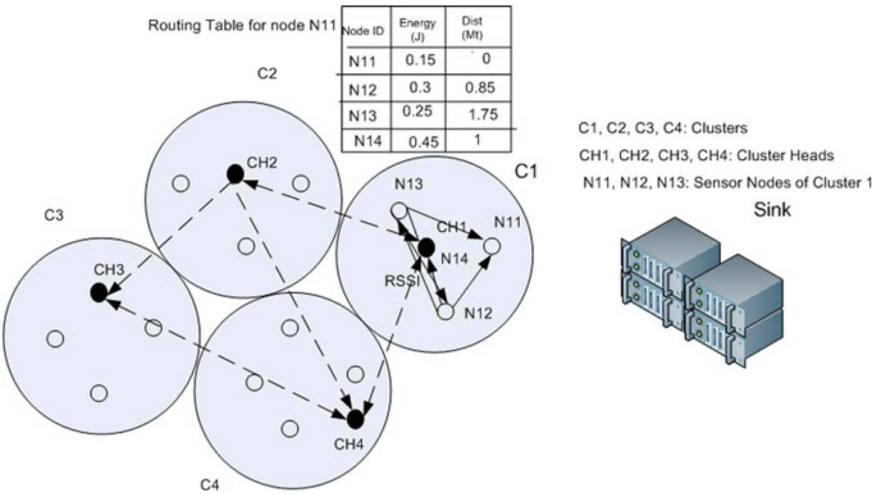

Fig. 2 Cluster setup in MC LEACH protocol

gradient. The broadcast signal also consists of the information of residual energy of sensor node. Hence, a routing table is formed at each node consisting of node id, residual energy, and distance between the nodes and itself. A cluster head is selected for a round on the basis of Eq. 1.

Inter-cluster Setup Phase Each CH transmits their initial route to sink to check whether any other CH is in its path to the sink. If it observes so, it updates its routing table for designing the path to the sink. Once it is done, each sends a message to all remaining CHs of different clusters of the network consisting of node ID and residual energy. Again with RSSI parameter, each CH designs a routing tree keeping itself as a root node and sink as an end node. This sorting is done by binary search algorithm (BSA). This routing tree results in the optimized path between each CH and the sink, and a chain is also formed to transmit the data from different CHs to the sink.

3.4 Steady-State Phase

The proposed algorithm is based on cross-layer optimization. Three layers, physical (PHY), media access control (MAC), and network (routing) layers, work in collaborative manner to fulfill the desired criteria. Once routing tree is formed, communication among the nodes starts.

All sensor nodes of cluster forward their sensed data to CH. CH then processes gathered data, and finally send to the sink. Instead, all CHs of network design the chain according to level of residual energy and distance to sink. The CH, whose residual energy and distance to the sink are least among all CHs available in network, will be the last node of the chain, i.e., nearest node to the sink and vice versa. If the energy level of two nodes is equal, then second parameter, i.e., distance, is the decision parameter. Here, to design an optimized chain route, PHY and MAC layers play their roles. This routing table as well as routing tree will also update in parallel with this calculation of designing the optimized chain (path) to the sink.

$$E_T = k^* E_{\text{cluster}} \tag{3}$$

4 Network Model and Result

Whole experimental setup is done in MATLAB R2017a. Here, a data-gathering WSN is considered, where N consistent sensors are randomly deployed in an area with the sink located at the center [19]. The network is experimented with a number of sensor nodes between 200 and 1000 to handle a thin sensor network and a very heavy one. The simulation is done for 3000 rounds. The remaining simulation parameters are summarized in Table 1. The path between the cluster head and sink is shown in Fig. 3.

Table 1 List of parameters considered for MC LEACH protocol

Parameters	Value
Sink location for network	$X_{bs} = Y_{bs} = 50$
Percentage of cluster heads (P) in network	0.1
E_0 (J)	0.5
E_{Tx1}, E_{Rx1} (mJ)	1
E_{Tx2}, E_{Rx2} (mJ)	0.1
E_{DA} (nJ/bit)	5
Maximum number of rounds	3000
E_{elec} (nJ/bit)	50
ε_{amp} (nJ/bit)	50
ε_{fs} (nJ/bit)	10

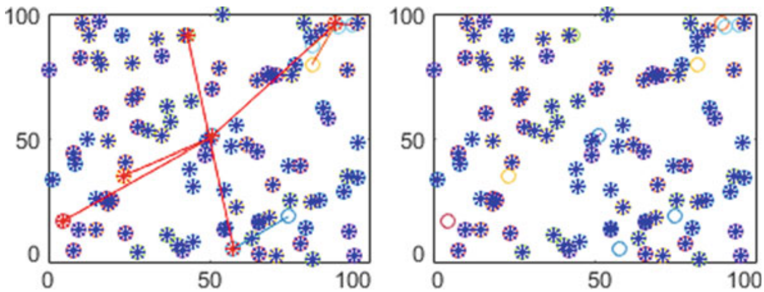

Fig. 3 Path between CH and sink for MC LEACH protocol

The analysis of this protocol is compared with low-energy adaptive clustering hierarchical (LEACH) protocol for residual energy and communication delay parameters (Fig. 4).

5 Conclusion and Future Scope

MC LEACH protocol has been simulated on MATLAB and analyzed. The output results of his protocol show that energy consumption gets affected in a positive manner if the number of hops toward the sink can be changed rather than using a single hop. The introduction of multi-hops communication has substantially improved LEACH by discovering the best path between the source CH and the destination. Simulation results in terms of dead nodes and residual energy. The proposed work can also be analyzed for the delay. Hence, the communication can be faster and can be implemented in delay-conscious applications.

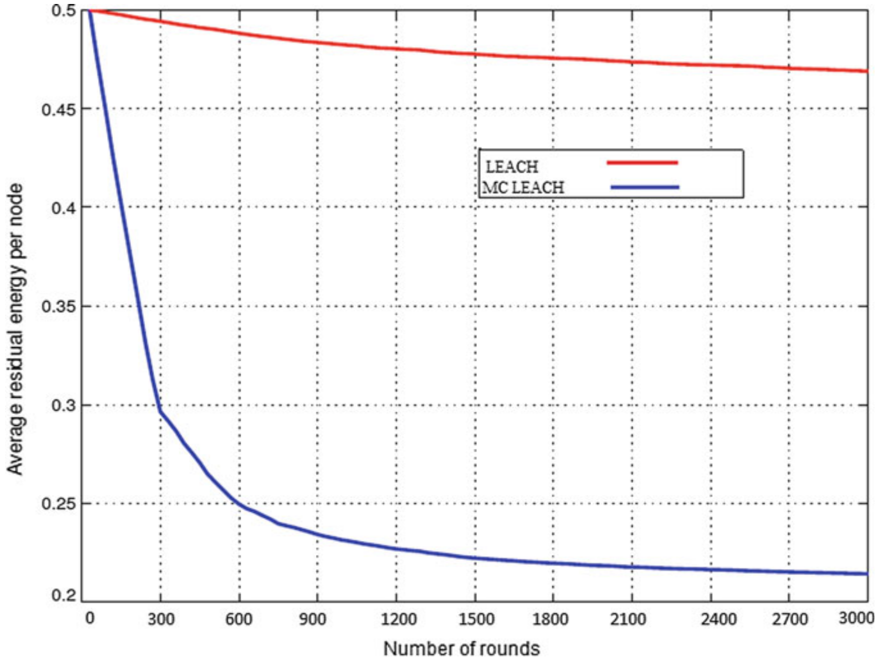

Fig. 4 Comparative analysis of LEACH and MC LEACH protocol for residual energy in the network

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