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Routing Energy Efficient Protocol For Wireless Sensor Networks

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Abstract
Energy constraint of wireless sensor networks makes energy saving and prolonging the network lifetime become the most important goals of routing protocols. In this paper, we propose an Routing Energy Efficient Protocol (REEP) for wireless sensor networks to minimize energy consumption and transmission delay. REEP organizes sensor nodes into a set of horizontal chains and a vertical chain. Chain heads are elected based on the residual energy of nodes and distance from the header of upper level. In each horizontal chain, sensor nodes transmit their data to their own chain head based on chain routing mechanism. REEP also adopts a chain-based data transmission mechanism for sending data packets from the chain heads to the base station. The simulation results show that REEP outperforms LEACH, PEGASIS and ECCP in terms of network lifetime, energy consumption, and number of data messages received at the base station, transmission delay and especially energy × delay metric.

Keywords
Wireless sensor network, Hierarchical routing protocol, Energy efficient, Chain-based routing

I. Introduction

Wireless sensor networks have emerged as state of the art technology in gathering data from remote locations by interacting with physical phenomena [1,2]. A wireless sensor network is composed of hundreds or thousands of sensor nodes which are usually battery-powered and deployed in an unprotected environment to collect the surrounding information and then transmit report messages to a remote base station. The base station aggregates and analyzes the report messages received and decides whether there is an unusual or exceptional event occurrence in the deployed region.

Energy efficiency has been known as the most important issue in the research of wireless sensor networks. Hierarchical techniques have emerged as a popular choice for achieving energy efficiency in wireless sensor networks.Most of the hierarchical routing protocols proposed by researchers have used clustering approach for routing in wireless sensor network and a few hierarchical routing protocols use chain based data transmission mechanism in wireless sensor network. In this paper, a Routing Energy Efficient Protocol (REEP) for wireless sensor networks are proposed to minimize energy consumption and transmission delay and especially energy × delay metric. REEP organizes sensor nodes into a set of horizontal chains and a vertical chain. Chain heads are elected based on residual energy of nodes and distance from the header of upper level. In each horizontal chain, sensor nodes transmit their data to their own chain head based on chain routing mechanism. REEP also improves the data transmission mechanism from the chain heads to the base station via constructing a chain among the chain heads.

Performance of the proposed protocol was evaluated via simulations and it was compared with performance of LEACH, PEGASIS and ECCP. The simulation results show that the proposed protocol can outperform in terms of network lifetime, energy consumption, number of data messages received in the base station, transmission delay and especially energy × delay metric.

II. Literature Survey

Recently, a lot of hierarchical routing protocols for reducing energy consumption of wireless sensor nodes have been proposed. In this section, some of the hierarchical routing protocols in wireless sensor networks are reviewed.

One of the most popular cluster-based routing protocols in wireless sensor networks is LEACH. The operation of LEACH is divided to rounds. Each round begins with a setup phase when the clusters are organized, followed by a steady state phase when data are transmitted from the nodes to the cluster head and on to the base station. LEACH randomly selects a few nodes as cluster heads and rotates this role to balance energy dissipation of the sensor nodes in the network [11,12].

LEACH-Centralized [12] uses a centralized clustering algorithm. In the setup phase, base station receives all the information about each node regarding its location and energy status. The base station runs local algorithm for the formation of cluster heads and clusters and broadcasts a message that contains the cluster head ID for each node. The steady state phase of LEACH-C is identical to that of the LEACH protocol.

In [12], LEACH with fixed clusters (LEACH-F) was proposed. LEACH-F is based on clusters that are formed once in the first setup phase by the base station and then fixed. The cluster head position rotates among the sensor nodes within the cluster. LEACH-F uses the same centralized cluster formation algorithm as LEACH-C. The fixed clusters in LEACH-F do not allow new nodes to be added to the system and do not adjust their behavior based on nodes' death.

PEGASIS [13] is an improvement of the LEACH protocol. The main idea in PEGASIS is to form a chain among sensor nodes so that each node receives from and transmits to a close neighbor. The gathered data move from node to node, get fused and eventually a designated node transmits them to the base station. In PEGASIS, the chain construction is done in a greedy fashion with the assumption that all the nodes have global knowledge of the network. PEGASIS outperforms LEACH by eliminating the overhead of dynamic cluster formation, minimizing the distance non-leader nodes must transmit, limiting the number of transmissions and receiving among all nodes and using only one transmission to the base station per round.

TEEN [14] is a routing protocol for time critical applications to respond to changes in the sensed attributes such as temperature. After the clusters are formed, the cluster head broadcasts two thresholds to the nodes. These are hard and soft thresholds for the sensed attributes. The hard threshold aims at reducing the number

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of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest. The soft threshold will further reduce the number of transmissions if there is little or no change in the value of sensed attribute. One can adjusts both hard and soft threshold values in order to control the number of packet transmissions. The advantage of this scheme is its suitability for time critical applications and also the fact that it significantly reduces the number of transmission.

APTEEN [15] is an extension of TEEN and aims at capturing periodic data collections and reacting to time critical events. APTEEN allows the sensor node to send its sensed data periodically and react to any sudden change in the value of the sensed attribute by reporting the corresponding values to their cluster heads. The main drawbacks of TEEN and APTEEN are the overhead and complexity associated with forming clusters at multiple levels.

An Energy Efficient Clustering Protocol (EECPL) [16] has been proposed to enhance lifetime of wireless sensor networks. EECPL considers a cluster head and a cluster sender for each cluster. The cluster head creates and distributes the TDMA schedule, which specifies the time slots allocated for each member of the cluster. The cluster sender is responsible for sending the aggregated data to the base station. The idea in EECPL is to form a ring among the sensor nodes within cluster so that each sensor node receives from a previous neighbour and transmits to the next neighbour. Upon receiving the aggregated data from previous neighbours, cluster senders transmit the aggregated data to the base station directly.

HEED [17] periodically selects cluster heads according to a hybrid of their residual energy and a secondary parameter such as node proximity to its neighbours or node degree. HEED does not make any assumptions about the distribution or density of nodes or about node capabilities. The clustering process terminates in O(1) iterations and does not depend on the network topology or size. The protocol incurs low overhead in terms of processing.

III. REEP

In PEGASIS that is a chain based routing protocol for wireless sensor networks, a chain is formed among the sensor nodes so that each node receives from a previous neighbor and transmits to a next neighbor. PEGASIS significantly induces a much longer data transmission delay because of the large number of hops in a long chain. In ECCP [21] that is a cluster-chain based routing protocol for wireless sensor networks, sensor nodes are organized into clusters. When a sensor node dies in the cluster, ECCP suffers from cluster formation overhead. ECCP increases transmission delay compared with LEACH. In ECCP, each node maintains a neighborhood table to store information of its neighbors that causes waste of memory space of sensor nodes. For selecting the leader of the cluster heads, the cluster heads send their location information to the base station. Based on the received information, the base station creates a chain of cluster heads and sends it to the cluster heads. This causes waste of time and energy. In ECCPTC [22] that is a cluster-chain based routing protocol for wireless sensor networks, sensor nodes react immediately to sudden changes in the value of a sensed attribute. ECCPTC considers higher priority for time critical data compared with non-time critical data so that time critical data are immediately transmitted to the base station. In ECCPTC, transmission delay of non-time critical data is increased. The main drawbacks of ECCP and ECCPTC are the higher overhead associated with forming clusters when a sensor node dies in the cluster. Also, ECCP and ECCPTC use a complex hybrid clustering approach for reducing energy consumption.

In order to avoid these situations, we propose an Routing Energy Efficient Protocol (REEP) for wireless sensor networks to minimize energy consumption and transmission delay. The proposed protocol organizes sensor nodes as a set of horizontal chains and a vertical chain. In each chain, a node is selected as chain head. For selecting the chain heads in horizontal chains, REEP considers residual energy of nodes and distance of nodes from the header of upper level that does not need to reselect leader of the vertical chain. This causes time and energy saving. In each horizontal chain, sensor nodes transmit their data to their own chain head based on chain routing mechanism. REEP also adopts a chain based data transmission mechanism for sending data packets from the chain heads to the base station. REEP does not use a complex hybrid approach for reducing energy consumption as ECCP.

In the proposed protocol, the network is divided to a set of strips as shown in Fig.1. It is assumed that "h" is height of each strip and there are "k" strips in the sensor network, computed by "k=L/h", where "L" is length of wireless sensor network.

In each strip, a chain is formed among the sensor nodes and a chain head is selected. In order to balance energy consumption among all sensor nodes in the network, the chain head's role should be rotated among the sensor nodes to prevent their exhaustion.

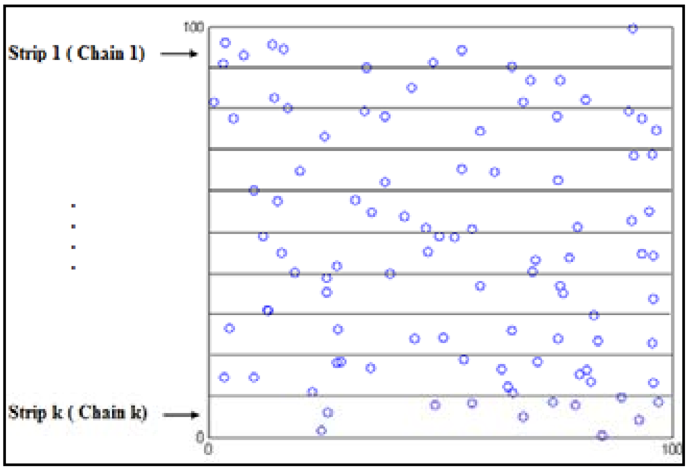

Fig. 1 : A sensor network with k strips (chains)

The operation of the EECRP protocol is organized as rounds. Each round of this protocol consists of the following phases.

- Setup phase
- Data transmission phase

A. Setup Phase

Setup phase consists of three stages:

1. Selection of Chain Heads

In this stage, each node directly sends a control packet with information about its current location and energy level to the base station. Since control packet size is small, each node directly sends it to the base station. Base station uses this information to select the chain heads. Base station selects the header of each strip based on the residual energy of nodes and the distance of nodes from the header of upper level. Base station is located at the highest levels and calculates the "CHSV" of each node (Chain Head Selection Value) using Eq. (4); then, it selects the node with the highest CHSV in each strip as the chain head.

2. Creation of Horizontal Chains

After the selection of chain heads, the base station applies the greedy algorithm used in PEGASIS to make a chain among the sensor nodes in each strip (horizontal chain) so that each sensor node receives data from a previous neighbour, aggregates its data with the one received from its previous neighbour and transmits the aggregated data to the next neighbour. The chain is formed from the furthest to the nearest node from the chain head.

3. Creation of a Vertical Chain

REEP also creates a chain among the chain heads (vertical chain). The selection of chain heads in horizontal chains is done in such a way that does not need to reselect the leader of the vertical chain and chain head of strip 1 (level 1) acts as the leader of chain heads so that all the chain heads send data to the leader node through the chain; finally, the leader node aggregates data and transmits them to the base station. This saves most of the chain heads from the high power transmissions to the distant base station and protects them from early exhaustion.

Once the chains are formed, the base station broadcasts a message that contains the chain and chain head ID for each node. If a node's chain head ID matches its own ID, the node is a chain head.

B. Data Transmission Phase

The data transmission phase is divided to several frames and sensor nodes transmit and receive data at each frame. Data transmission phase consists of two stages.

1. Data transmission among sensor nodes in horizontal chains

For gathering data in each frame, sensor nodes in each chain transmit their data to their own chain head using the chain based routing. REEP uses a simple control token passing approach initiated by the chain head to start data transmission from the ends of the chain. The cost is very small since the token size is very small. The two end nodes in a chain transmit data and tokens to their individual neighbouring nodes in parallel

. Each sensor node receives data and token from previous neighbour, aggregates the data with its own data and transmits aggregated data and token to the next neighbor in the chain. The data are transmitted in an alternative way until all the data are transmitted to the chain head node.

2. Data Transmission among Chain Heads in the Vertical Chain

In this stage, base station generates a token and transmits it to the end chain head node in the vertical chain. Each chain head aggregates its neighbour's data with its own data and transmits aggregated data to the next neighbour in the vertical chain. Finally, the aggregated data are delivered to the base station by the leader node in the vertical chain.

Fig. 2 shows data transmission in EECRP. As shown in Fig. 2, nodes c6, c16, c26, c36, c46, c56, c65, c75, c85 and c95 are chain heads and form a vertical chain to send their data to the base station. Node c6 is the leader of the vertical chain because it has the shortest distance from the base station. to the base station.

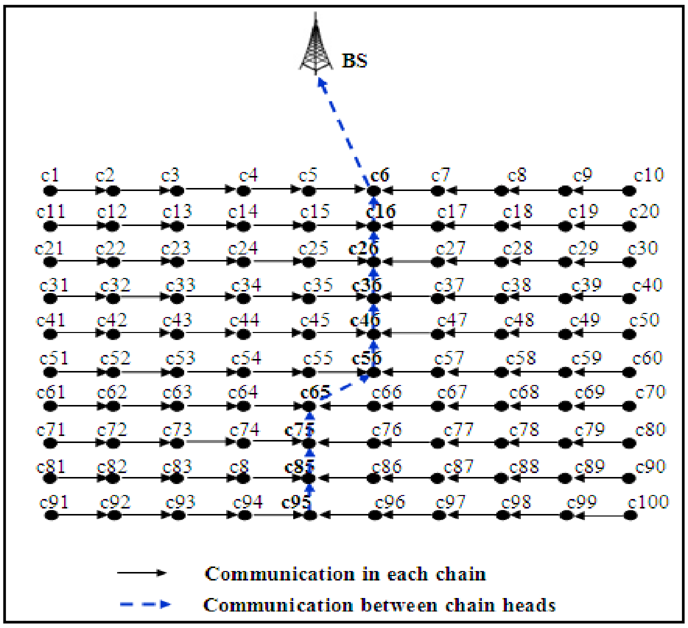

Fig. 2 : Data transmission in REEP

IV. Expected Results

PEGASIS in terms of network lifetime with different locations of the base station. The time of the last node to die in REEP is longer than other protocols and sensor nodes remain alive for longer time. This is mainly because most of the nodes transmit to their nearest neighbours in the chain. For selecting the chain heads in horizontal chains, REEP also considers residual energy of nodes and distance of nodes from the header of upper level that eliminates the need for reselecting leader of the vertical chain.

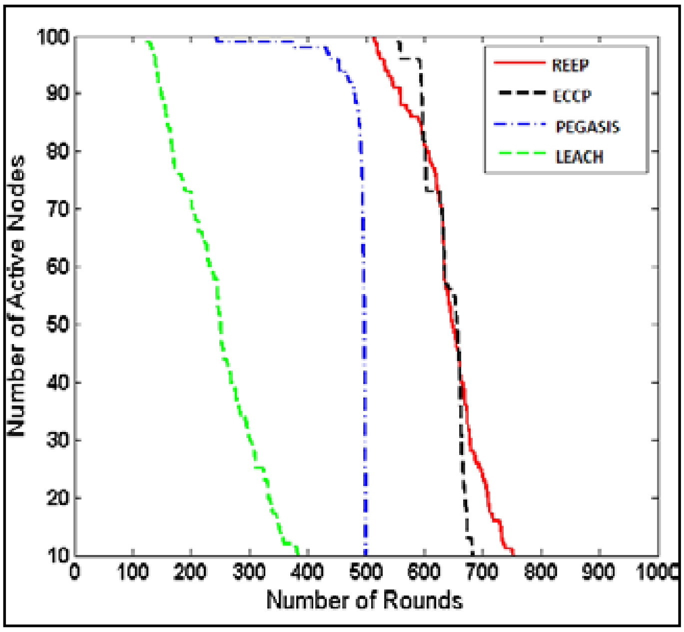

Fig 4.1 Number of active nodes per round with BS location at (50,175)

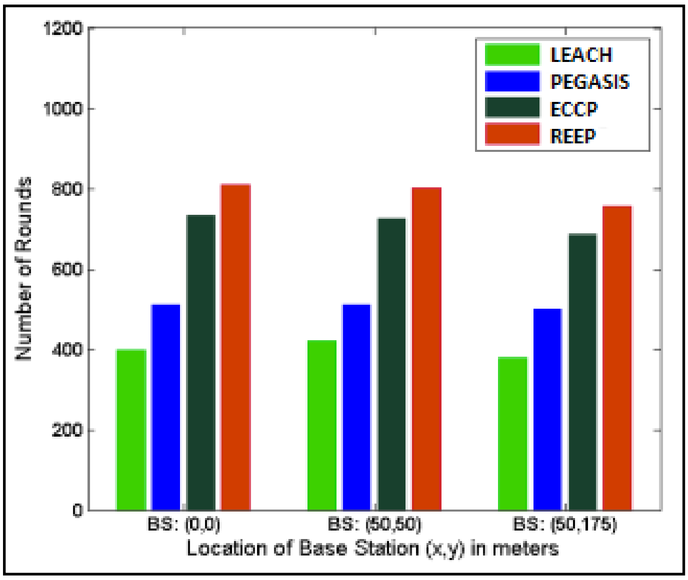

Fig. 4.2 : Performance comparison of the network lifetime using LND metric with BS locations at (0, 0), (50, 50) and (50,175)

V. Conclusion

In this paper, we have proposed an Energy Efficient Chain based Routing Protocol (REEP) for wireless sensor networks. The main goal of REEP is to minimize energy consumption, transmission delay and especially energy × delay metric. REEP can meet both requirements for a prompt-response and energy-saving applications. REEP organizes sensor nodes into a set of horizontal chains and a vertical chain so that each sensor node receives from a previous neighbor and transmits to the next neighbor. Furthermore, REEP improves the data transmission mechanism from the chain heads to the base station via constructing a chain among the chain heads. By chaining the nodes in the network, REEP offers the advantage of small transmit distances for most of the nodes and thus helps them to be operational for a longer period of time by conserving their limited energy. Simulation results demonstrate that the proposed protocol significantly outperforms LEACH, PEGASIS and ECCP in terms of network lifetime, energy consumption, number of data messages received in the base station, transmission delay and especially energy × delay.

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