A Two-Level Cluster based Routing Protocol for Wireless Sensor Networks

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Abstract

Wireless sensor networks have emerged as a promising technology for a wide range of important applications. Energy conservation and prolonging the network lifetime are significant challenges in the design and implementation of wireless sensor networks. Clustering techniques have emerged as a popular choice for prolonging the lifetime of a wireless sensor network. In this paper, we propose a Two-Level Cluster based Protocol (TLCP) for wireless sensor networks to minimize the energy consumption and maximize the lifetime of wireless sensor networks. TLCP organizes sensor nodes into clusters and improves the data transmission mechanism from the cluster heads to the base station via constructing a cluster among the cluster heads. Simulation results show that our proposed protocol has better performance than LEACH and CBRP in terms of network lifetime, stability period, instability period, energy consumption and network throughput.

Keywords: *Clustering, Wireless sensor network, Two-level Protocol, Lifetime*

1. Introduction

Wireless sensor networks are a special kind of Ad hoc networks that became one of the most interesting areas for researchers [1]. Typically, a wireless sensor network comprises of hundreds or thousands of low cost sensor nodes [2]. A sensor node consists of small sensors able to detect light, sound, temperature and motion, an intelligent computing device that enables the processing of raw data collected from the sensors, and communication capabilities with other nodes through wireless networks [2, 3, 4]. There are many practical applications of wireless sensor networks. Some of the most promising application areas are environmental monitoring, battlefield tracking and disaster recovery operation, building control systems, and smart entertainment devices that adjust audio and video signals based on their surroundings [5].

One of the most important challenges in the design and implementation of wireless sensor networks is to extend the network lifetime by minimizing energy consumption with limited resources [6]. Clustering is a key routing method for large-scale wireless sensor networks, which effective extends the lifetime and the expansibility of network [7].

In this paper, we propose a Two-Level Cluster based Protocol (TLCP) for wireless sensor networks. The main goal of TLCP is to minimize the energy consumption and maximize the lifetime of wireless sensor networks. Our proposed protocol organizes sensor nodes into clusters and forms a cluster among the cluster heads so that each cluster heads transmits its aggregated data to the header of this cluster and only the header can transmit data directly to the base station. Simulation results show that our proposed protocol has better performance than LEACH and CBRP in terms of network lifetime, stability period, instability period, energy consumption and network throughput.

The remaining of the paper is organized as follows: Related work is reviewed in section 2 and our proposed protocol is described in Section 3. In Section 4 network and radio energy model are presented and in Section 5 simulation results are illustrated. In section 6 conclusion of the paper will be presented.

2. Related Works

In the literature, a lot of protocols to reduce energy consumption have been proposed. One of the most well-known clustering approaches is LEACH [8,9] that utilizes a randomized rotation of local cluster head to evenly distribute the energy load among the sensors in the network. The operation of LEACH is broken up into rounds which each round consists of two phases, the set up phase and the steady state phase. In the setup phase, each node decides whether or not to become a cluster head for the current round. This decision is based on the threshold *T(n)* given by Eq.(1).

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

Where P is the predetermined percentage of cluster heads, r is the current round, and G is the set of nodes that have not been cluster heads in the last $1/P$ rounds.

The cluster head nodes fuse and aggregate data arriving from nodes that belong to the respective cluster and send an aggregated data to the base station in order to reduce the amount of data and transmission of the duplicated data.

Lee et. al., [6] proposed an Efficient Cluster Head Election (EECHE) algorithm in wireless sensor networks which improves the performance of clustering. EECHE divides cluster area into two perpendicular diameters, and then elects cluster head by the density of member nodes and the distance from cluster head. EECHE consists of three steps. Each step of EECHE is described as follows.

1. Local Grouping: divides cluster area into two perpendicular diameters to get four quadrants.
2. Compare the node density: that is the number of cluster members in each quadrant and select candidate quadrants.
3. Compare the node distance: that is from the nearest cluster head in candidate quadrants and select following cluster head.

Bajaber and Awan [10] proposed a Centralized Dynamic Clustering (CDC) algorithm for wireless sensor networks. In each cluster, cluster head collects the data from all the cluster members, aggregates the data, transmits aggregated data to the base station and selects new cluster head for next round. If any sensor node dies in the cluster, the cluster head sends a message to the base station to forms the clusters, otherwise cluster heads use residual energy levels to select new cluster heads for next round.

In [11], we proposed an Energy Efficient Cluster-Chain based Protocol (ECCP) for wireless sensor networks. ECCP uses a hybrid clustering approach and divides sensor nodes into clusters by using multiple metrics and constructs a chain among the sensor nodes within each cluster so that each sensor node receives from a previous neighbor and transmits to a next neighbor. ECCP also adopts chain based data transmission mechanism for sending data packets from the cluster heads to the base station. Clustering phase is not performed in each round of ECCP. If any sensor node dies in the cluster, the clustering phase is done in the next round.

In [12], we extended ECCP and proposed an Energy Efficient Cluster-Chain based Protocol for Time Critical applications (ECCPTC) in wireless sensor networks to maximize network lifetime and minimize energy consumption and transmission delay of time critical data. For reducing transmission delay of time critical data, ECCPTC considers higher priority for time critical data and introduces a threshold parameter. In ECCPTC, time critical data are immediately transmitted to the base station.

Zarei et. al., [13] proposed a distributed and energy efficient protocol, called CBRP for data gathering in wireless sensor networks. CBRP clusters the network by using new factors and then constructs a spanning tree for sending aggregated data to the base station. Only the root node of this tree can communicate with the base station node by single-hop communication. The main drawback of CBRP is the much communication overhead due to the many number of non-data messages exchanged between sensor nodes.

HEED [14] selects cluster heads randomly based on probability but it distributes cluster heads more uniformly across the sensor network by multiple iterations and smaller cluster ranges. The approach sets the probability of selecting cluster heads by each node's residual energy at the first iteration of each round, doubles the probability before going to the next iteration, and terminates the operation when the probability reaches 1. At any iteration, each node can become a cluster head with its own probability if hearing no cluster head declaration from its neighborhood.

3. Two-level Cluster based Routing Protocol

In this section, we propose a Two-Level Cluster based Protocol (TLCP) for wireless sensor networks to minimize the energy consumption and maximize the lifetime of wireless sensor networks. The operation of TLCP is broken up into rounds which each round consists of a set-up phase and steady-state phase.

3.1. Setup Phase

This phase consists of two stages.

3.1.1. Formation of Clusters among Sensor Nodes: The proposed protocol uses a probability function while considering use of node residual energy and average energy of the network in current round for cluster configuration; in contrast, LEACH only utilizes a probability function. Eq. (2) shows the computation of the threshold value for a cluster head selection.

$$T(s_i) = \begin{cases} \dfrac{P}{1 - P(r \bmod \frac{1}{P})} * \dfrac{E_{res}(i)}{E_{ave}} & if\ i \in G \\ 0 & otherwise \end{cases} \qquad (2)$$

Where P is the desired percentage of cluster heads, r is the current round number, G is the set of nodes that have not been cluster heads in the last $1/P$ rounds, E_{res} is the current residual energy of node, E_{ave} is the average residual energy of the network at round r. E_{ave} can be obtained by Eq. (3).

$$E_{ave} = \frac{1}{N}\sum_{i=1}^{N} E_{res}(i) \qquad (3)$$

To compute E_{ave} by Eq. (3), each node should have the knowledge of the total energy of all nodes in the network.

In the setup phase, each node decides whether to become a cluster head based on threshold calculated by Eq. (2). This decision is made by the nodes by choosing the random number between 0 and 1. If the number is less than threshold $T(s_i)$ calculated by Eq.(2), the node becomes a cluster head for the current round.

After the election of cluster heads, each cluster head broadcasts an advertisement message using a non persistent CSMA MAC protocol and invites the other nodes to join its cluster. Depending on the signal strength of the advertisement messages, each node selects the cluster head it will belong to and sends a join-request message back to the chosen cluster head using a non persistent CSMA MAC protocol. When the clusters formed, each cluster head creates a time division multiple access (TDMA) scheme and broadcasts it to the sensor nodes in its cluster.

3.1.2. Formation of a Cluster among Cluster Heads: In this stage, cluster heads send their location information and residual energy to the base station. Based on the received information, the base station calculates the weight of each cluster head by using Eq. (4) and selects the node with highest weight among the cluster heads as the header of the second-level cluster. Base station sends the header's ID to the cluster heads.

$$Weight(CH_i) = E_{res}(i) * \frac{1}{dis_{to\ \ BS}^{2}} \qquad (4)$$

Where $E_{res}(i)$ denotes residual energy of node i and $dist^{2}_{to\ BS}$ is the distance node i to the base station.

The building of a cluster among the cluster heads reduces energy consumption and makes cluster heads transmit to the header node instead of transmitting directly to the far away base station.

3.2. Steady-state Phase

Once the clusters are established, the nodes transmit their data messages towards the cluster head during their allocated transmission slot. Once the data from all sensor nodes in the cluster are received, the cluster head performs data aggregation on the collected data and reduces the amount of raw data that needs to be sent to the header node. Once the data gathering and the data aggregation in the last frame of a round are completed, the data transmission in the second-level cluster are begun. In this stage, the header of the second-level cluster creates TDMA scheme and sends it to the cluster heads. Cluster heads send their aggregated data to the header of the cluster heads in the second-level cluster during their allocated transmission slot. The header of the second-level cluster performs data aggregation. Finally, the aggregated data are delivered to the base station by the header node that has highest residual energy and shortest distance to the base station among cluster heads. Figure 1 shows data transmission in TLCP.

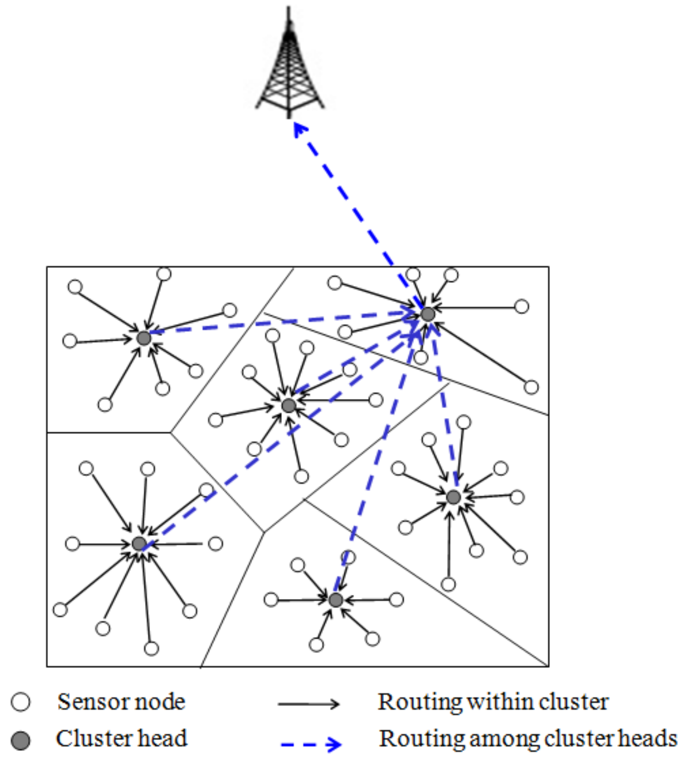

Figure 1. Data Transmission in TLCP

4. Network and Radio Energy Model

Network and radio energy model are described in this section.

4.1. Network Model

During the phrase of cluster initialization, we assume the following properties about the sensor networks.

- All sensor nodes cannot move after being deployed.
- The base station is located far from the sensor nodes and immobile.
- All sensor nodes are homogeneous and have the same initial energy supply.
- The base station has a constant power supply and so, has no energy constraints.
- Nodes are location-aware.
- The bidirectional channel is defined throughout the entire network.

4.2. Radio Energy Dissipation Model

The energy model of our study is the same as in [8, 9]. Energy model for the radio hardware energy dissipation where the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics is shown in Figure 2.

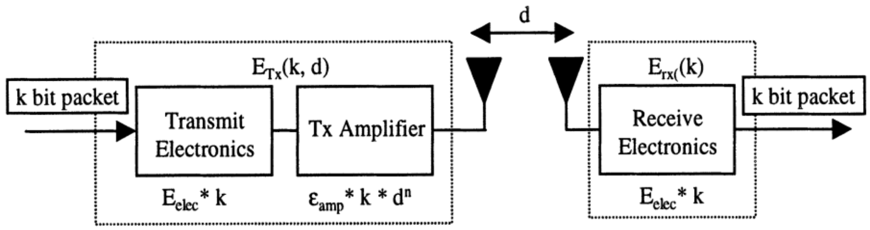

Figure 2. Radio Energy Dissipation Model [8, 9]

In this model, both the free space (d^2 power loss) and the multipath fading (d^4 power loss) channel models were used, depending on the distance between the transmitter and receiver. If the distance is less than a threshold, the free space *(fs)* model is used; otherwise, the multi path *(mp)* model is used. Eq. (5) is used to calculate the transmission energy, denoted as $E_{Tx}(k, d)$, required for a *k* bits message over a distance of *d*.

$$E_{Tx}(k,d) = \begin{cases} kE_{elec} + k\varepsilon_{fs}d^2, & d < d_0 \\ kE_{elec} + k\varepsilon_{amp}d^4, & d \geq d_0 \end{cases} \qquad (5)$$

To receive an *k*-bit message, the energy required is calculated by Eq.(6).

$$E_{Rx}(k) = kE_{elec} \qquad (6)$$

The electronics energy, E_{elec}, depends on the factors such as the digital coding, modulation, filtering, and spreading of the signal, whereas the amplifier energy, $\varepsilon_{fs}d^2$ or $\varepsilon_{amp}d^4$, depends on the distance to the receiver and the acceptable bit-error rate.

5. Simulation and Results

To validate the performance of our protocol, we simulate TLCP using a network with 100 nodes randomly deployed between (x = 0, y = 0) and (x=100m, y = 100m). We assume that the base station is located far away from the sensing area. It was placed at location (x = 50m, y = 175m). The length of each data packet is 4000 bits and the length of each broadcast packet is 200 bits. The initial power of all nodes is considered to be 0.3J. Electronics energy E_{elec} is 50nJ/bit, transmitter energy ε_{fs} is 100pJ/bit/m^2, amplifier energy ε_{amp} is 0.0013pJ/bit/m^4 and the energy for data aggregation E_{DA} is 5nJ/bit/signal. The simulation is done in MATLAB.

For performance comparison, we mainly take account of the following performance parameters:

- Network lifetime: These are a number of rounds that elapse before the first node, half of the nodes and the last node respectively, run out of energy.

- Stability period: Stability period is defined as the time interval before the death of the first node.
- Instability period: Instability period is defined as the time interval between the death of the first node and the last node.
- Load balancing: Load balancing is defined as the percentage of the total remaining energy of the network when the first node dies.
- Energy consumption: Total energy consumed by all sensor nodes in receiving, sending and aggregating the data packets.
- Network throughput: Defined as the total number of data packets received at the base station.

5.1. Simulation Results

Figure 3 demonstrates the number of active nodes over the simulation runs. It also shows the time span from the first node dies to the last node dies in different routing protocols. It can be observed that TLCP has better performance than other protocols in terms of network lifetime, stability period and instability period. At the aspect of balancing energy consumption for all nodes in the networks, it shows that our proposed protocol always outperforms LEACH and CBRP.

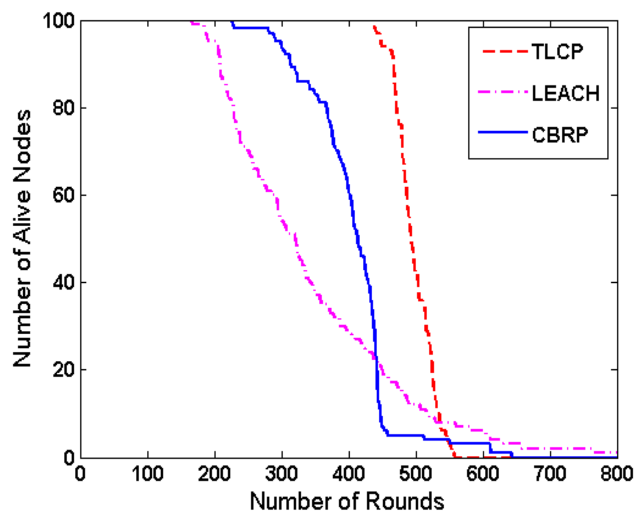

Figure 3. The Number of Active Nodes over Round

Figure 4 demonstrates the residual energy of the network during the simulation runs. It can be observed that the residual energy of the network in the case of TLCP is higher than that of the other protocols. Table1 shows the percentage of the total residual energy of the network when the first node dies. If this parameter in a protocol is lower than that in other protocols, the protocol has better performance in terms of load balancing.

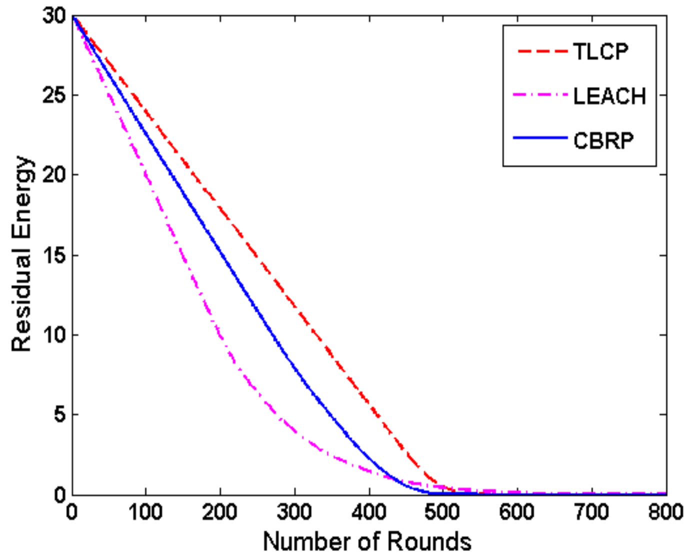

Figure 4. The Residual Energy of the Network over Round

It is clear from Table 1 that our proposed protocol has better performance than other protocols in terms of load balancing.

Table 1. The Percentage of the Total redualsi Energy of the Network when the First Node Dies

Routing Protocol	Remaining Energy
LEACH	42%
CBRP	43%
TLCP	13%

Figure 5 shows the energy consumption of the network during the simulation runs. It can be observed that TLCP uses less energy compared to LEACH and CBRP in each round.

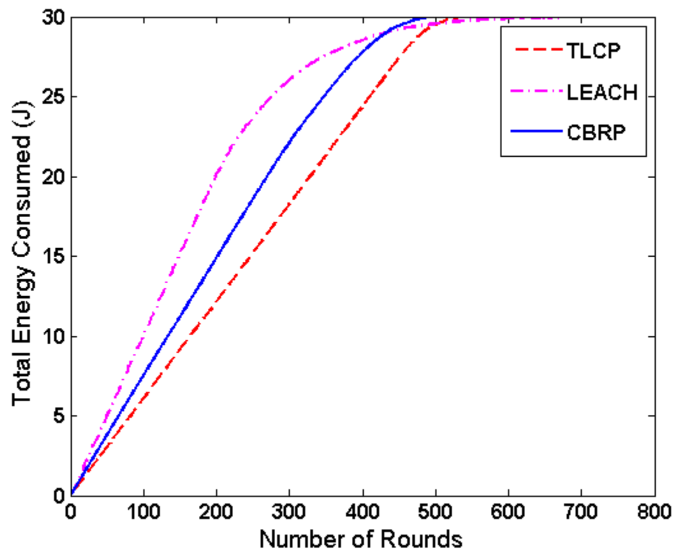

Figure 5. The Total Energy Consumption of the Network over Round

Figure 6 presents the number of data messages received by the base station for LEACH, CBRP and TLCP. It shows that the data messages delivered by TLCP to the base station are better than the others ones; this means that TLCP has better throughput than other LEACH and CBRP.

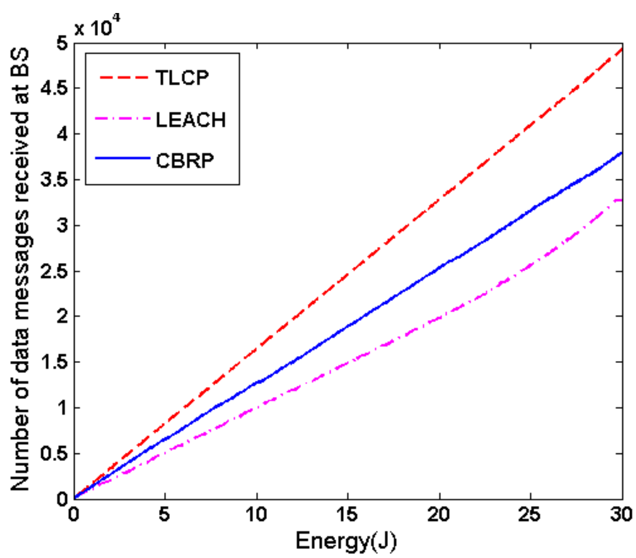

Figure 6. The Number of Data Messages Received at the Base Station over Energy

The above results show that TLCP can extend network lifetime and stability period, balance energy, reduce energy consumption and instability period and increase the number of data messages received at the base station.

6. Conclusion

In this paper, a Two-Level Cluster base Protocol (TLCP) for wireless sensor networks was proposed that aims at maximizing the network lifetime and minimizing the energy consumption. TLCP organizes sensor nodes into clusters and forms a cluster among the cluster heads so that each cluster head transmits its data to the header of this cluster instead of transmitting directly to the far away base station and only the header can transmit data directly to the base station. We evaluated the performance of TLCP by comparing it with LEACH and CBRP. The simulation results show that TLCP is more efficient in terms of network lifetime, stability period, instability period, balancing energy consumption among sensor nodes, energy consumption and network throughput than other protocols.

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