

An energy efficient cluster-chain based routing protocol for time critical applications in wireless sensor networks

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Abstract

In this paper, we propose 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. ECCPTC considers higher priority for time critical data than non-time critical data so that time critical data are immediately transmitted to the base station. ECCPTC uses a threshold value for reducing transmission delay of time critical data. ECCPTC organizes sensor nodes into clusters by using multiple metrics and constructs a chain among the sensor nodes within cluster so that each sensor node receives non-time critical data from a previous neighbor and transmits to a next neighbor. ECCPTC also adopts a chain based data transmission mechanism for sending non-time critical data packets from the cluster heads to the base station. Simulation results show that our proposed protocol significantly outperforms LEACH, CBRP and PEGASIS in terms of network lifetime, stability period, instability period, energy consumption, transmission delay of time critical data and the total number of data received at base station.

Keywords: Wireless sensor network, Clustering protocol, Chain based routing, Energy efficient, Time critical data

Introduction

The technological advances in micro-electronics and low-power wireless communication have facilitated the development and application of wireless sensor networks in recent years. Among the ever-expanding applications of wireless sensor networks, practical installments on military and medical fields, environmental monitoring, industrial control and daily living facilities are being hotly pursued (Chuang *et al.*, 2009; Xie *et al.*, 2011). 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 needed information and then transmit report messages to a remote base station (Jin *et al.*, 2008; Chuang *et al.*, 2009). 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 (Jin *et al.*, 2008).

As sensor networks have limited and non-rechargeable energy resources, energy efficiency is a very important issue in designing the topology and routing protocols, which affects the lifetime of sensor networks greatly (Jabari Lotf *et al.*, 2008; Jin *et al.*, 2008; Kang *et al.*, 2011; Xie *et al.*, 2011). Although energy efficiency is usually the primary concern in wireless sensor networks, the requirement of low latency communication is getting more and more important in many applications.

Clustering techniques have emerged as a popular choice for achieving energy efficiency and scalable performance in large scale sensor networks (Chen *et al.*, 2009; Chang, 2010; Aslam *et al.*, 2011). Using a clustering approach, sensors can be managed locally by a cluster head, a node elected to manage the cluster and be responsible for communication between the cluster and the base station. Clustering provides a convenient framework for resource management. It can support

many important network features within a cluster, such as channel access for cluster members and power control, as well as between clusters, such as routing and code separation to avoid inter-cluster interference. Moreover, clustering distributes the management responsibility from the base station to the cluster heads (Denga *et al.*, 2011).

There are a lot of cluster based routing protocols in wireless sensor network which a few of them have considered the quick transmission of time critical data. In this paper, we propose 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. ECCPTC considers higher priority for time critical data than non-time critical data so that time critical data are immediately transmitted to the base station. ECCPTC uses a threshold value for reducing transmission delay of time critical data. ECCPTC organizes sensor nodes into clusters and forms a chain among the sensor nodes within cluster so that each sensor node receives from a previous neighbor and transmits to a next neighbor. Cluster heads are elected based on residual energy of nodes, distance from neighbors and the number of the neighbors of nodes. ECCPTC also adopts a chain based data transmission mechanism for sending data packets from the cluster heads to the base station. Through simulation contrasted with previous works, we show that our proposed protocol can outperform in network lifetime, stability period, energy consumption, the total number of data received at base station, transmission delay of time critical data and communication overheads.

Related work

Recently, various clustering techniques to reduce energy consumption of sensor nodes have been developed. Grouping a large number of sensors into

clusters and keeping them communicate regularly are quite complex (Qian *et al.*, 2006). Here, we mention some of the most recent work in different views of clustering.

Low-energy adaptive clustering hierarchy (LEACH) (Heinzelman *et al.*, 2000 & 2002) is one of the most popular distributed cluster-based routing protocols in wireless sensor networks. The operation of LEACH is divided into rounds, where each round begins with a setup phase for cluster formation, followed by a steady state phase, when data transfers to the base station occur. LEACH randomly selects a few nodes as cluster heads and rotates this role to balance the energy dissipation of the sensor nodes in the network. The cluster head nodes fuse and aggregate data arriving from nodes that belong to the respective cluster and send aggregated data to the base station in order to reduce the amount of data and transmission of the duplicated data. Data collection is centralized to base station and performed periodically. The LEACH protocol is energy efficient but the expected number of clusters is pre-defined. Another disadvantage of LEACH is that it does not guarantee good cluster head distribution and assumes uniform energy consumption for cluster heads.

PEGASIS (Lindsey and Raghavendra, 2002) is an improvement of the well known LEACH protocol for clustering based communication in sensor networks. Rather than forming multiple clusters, PEGASIS forms a chain from sensor nodes so that each node receives from and transmits to a neighbor and only one node is selected from that chain as leader node to transmit to the base station. The main objectives of PEGASIS are to increase the lifetime of network and allow only local coordination between nodes that are close together so that the bandwidth consumed in communication is reduced. PEGASIS eliminates the overhead caused by dynamic cluster formation in LEACH, and decreases the number of transmissions and receptions by using data aggregation. However, this achievement faded by the excessive delay introduced by the single chain for the distant node.

TEEN (Manjeshwar & Agrawal, 2001) designed 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 sensed attributes. The hard threshold aims at reducing the number 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 adjust 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 (Manjeshwar & Agrawal, 2002) is an extension to TEEN and aims at capturing periodic data collections and reacting to time-critical events. Once a

node senses a value beyond hard threshold, it transmits data only when the value of that attribute changes by an amount equal to or greater than soft threshold. The main drawbacks of TEEN and APTEEN are the overhead and complexity associated with forming clusters at multiple levels.

A distributed and energy efficient protocol called CBRP (Zarei *et al.*, 2010) proposed 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 much communication overhead due to a lot of control messages exchanged among sensor nodes.

A Cluster Based Energy Efficient Routing Protocol (CBERP) (Lee *et al.*, 2010) proposed for Wireless Sensor Networks. CBERP divides nodes into clusters and selects the headers that gather and transmit the data from their member nodes as in LEACH-C. However, CBERP advances header selection mechanism by utilizing a number of candidate nodes to reduce overhead. After selecting the headers in this way, it forms a chain of the headers and sends data to the base station through the chain as in PEGASIS.

An energy efficient clustering protocol (EECPL) (Bajaber & Awan, 2010) proposed to enhance lifetime of wireless sensor networks. EECPL elects a cluster head and a cluster sender in each cluster. The cluster head is responsible for creating and distributing the TDMA while cluster senders responsible for sending the aggregated data to the base station. EECPL organizes sensor nodes into clusters and uses ring topology to send data packets so that each sensor node receives data from a previous neighbor and transmits data to a next neighbor. Upon receiving the aggregated data from previous neighbors, cluster senders transmit the aggregated data to the base station directly.

Network model

In this paper, we consider a sensor network consisting of N sensor nodes uniformly deployed over a vast field to continuously monitor the environment. During the phrase of cluster initialization, we assume the following properties about the sensor networks.

- Sensor nodes and the base station are all stationary after deployment.
- The base station is located far from the sensors.
- All nodes in the network are homogenous and energy-constrained.
- Nodes are location-aware, i.e. equipped with GPS-capable antennae.
- Radio channel is symmetric, i.e., the energy consumption for transmitting a message from one node to another is the same as on the reverse direction.

Radio energy dissipation model

The energy model of our study is the same as in (Heinzelman *et al.*, 2000 & 2002). Eq. (1) is used to calculate the transmission energy, denoted as $E_{Tx}(k, d)$ required for a k bits message over a distance of d .

$$E_{Tx}(k, d) = \begin{cases} kE_{elec} + k\epsilon_{fs}d^2, & d < d_0 \\ kE_{elec} + k\epsilon_{amp}d^4, & d \geq d_0 \end{cases} \quad (1)$$

To receive this message, the energy required is as Eq. (2).

$$E_{Rx}(k) = kE_{elec} \quad (2)$$

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

From Eq. (2), one can see that receiving data is also a high overhead procedure. Thus, the number of transmission and receiving operations must be cut to reduce the energy dissipation.

If a node spends energy E_{DA} to aggregate one bit, then the energy used in aggregating m data packets to a single packet is as Eq.(3).

$$E_{fuse}(m, k) = m * k * E_{DA} \quad (3)$$

Delay analysis

For the clustering schemes, a popular node scheduling approach is adopted where the intra-cluster communication is scheduled by TDMA (Time Division Multiple Access) and the inter-cluster communication is scheduled by CDMA (Code Division Multiple Access) (Jin *et al.*, 2000). Assuming there are N sensor nodes in the network and the delay of each transmission is regarded as 1 unit time. The delay is analyzed as follows.

In LEACH, the delay for transmitting data packets to the cluster heads is dependent on the maximum number of nodes in the clusters. If all clusters have similar sizes and there are K clusters in the network, the maximum delay of a round is calculated as Eq. (4)

$$T = \left(\frac{N}{K} - 1\right) + K + C \quad (4)$$

Thus, in clustering protocols such as LEACH, the maximum delay for transmitting time critical data packets or non-time critical data packets to the base station is T and minimum delay for transmitting the first data packet to the base station is dependent on the cluster sizes.

In PEGASIS, the transmission delay is dependent on the network size. In this case, the delay is N unit time.

In our proposed protocol, time critical data packets are immediately sent to the base station using CSMA MAC protocol. The maximum delay for transmitting time critical data packets to the base station is dependent on the number of time critical data packets and the minimum delay for transmitting the first data packet to the base station is one unit of time or two units of time.

ECCPTC- the proposed protocol

In conventional clustering protocols (Heinzelman *et al.*, 2000 & 2002), cluster heads manage the member nodes and collect data from them. Each cluster head collects data from the member nodes, aggregates the data, and then sends the aggregated data to the base station. Since the cluster heads have responsibility for the collecting, aggregating, and sending data to the base station, they drain energy much faster than the member nodes, reducing the network lifetime. Some of the clustering protocols (Heinzelman *et al.*, 2000 & 2002; Manjeshwar & Agrawal, 2001, 2002; Lee *et al.*, 2010; Zarei *et al.*, 2010) periodically recluster the network in order to distribute the energy consumption among all sensor nodes in a wireless sensor network. These protocols suffer from cluster formation overhead. They consume much energy due to the cluster formation overhead.

In PEGASIS that is chain based routing protocol for wireless sensor networks, is formed a chain among the sensor nodes so that each node will receive from and transmit to a close neighbor. PEGASIS significantly induces much longer data transmission delay because of large number of hops in a long chain.

Using of cluster and chain structure in routing of wireless sensor networks makes sensed data by the sensor nodes wait for the scheduled transmission time of a node to get transmitted. This delay in transmission is intolerable in case of time critical data which needs to be sent quickly to the base station.

In order to avoid this situation, we propose an Energy Efficient Cluster-Chain based Protocol for Time critical applications (ECCPTC) in wireless sensor network to maximize network lifetime and minimize energy consumption and transmission delay of time critical data.

For reducing transmission delay of time critical data, proposed protocol introduces a threshold parameter. If the sensed data value by a sensor node is equal to or greater than threshold value, the sensed data are considered as time critical data and should be immediately transmitted to the base station.

The proposed protocol organizes sensor nodes into clusters and adopts chain based data transmission mechanism for data transmission within clusters and among cluster heads.

In the start of the network operation, the base station sends the threshold value for all sensor nodes in the network. The operation of the ECCPTC protocol is organized into rounds. Each round of this protocol consists of the following phases: 1) Clustering phase; 2) Chain formation phase and 3) Data transmission phase.

Clustering phase

Clustering phase consists of two stages.

Cluster head election: In the clustering phase, each node broadcasts a message which contains information about its current location (possibly determined using a GPS receiver) and residual energy using a non-persistent

CSMA MAC protocol within radio range r . All nodes within the radio range of one node can be seen as the neighbors of the node. After receiving the message, each node computes the distance to its neighbors and generates CHSV (Cluster Head Selection Value) using Eq. (5).

$$CHSV_i = RE_i * \sum_{j=1}^{number\ of\ neighbors} \frac{1}{dis^2(v_i, v_j)} \quad (5)$$

Where RE_i denotes residual energy of node i and $dis(v_i, v_j)$ is the distance node i to node j .

Each node broadcasts its CHSV using a non-persistent CSMA MAC protocol within radio range r and the node with the highest CHSV among its neighbors is selected as cluster head.

Formation of cluster: Each cluster head broadcasts an advertisement message (ADV) which contains the node's ID and a header that distinguishes this message as an announcement 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 (Join-REQ) which contains node's ID and the cluster head's ID back to the chosen cluster head using a non-persistent CSMA MAC protocol.

Because of much overhead of clustering phase, the phase is not performed in each round. If any sensor node dies in cluster, the cluster head sends a message to base station and informs it that the sensor nodes should hold the clustering phase at the beginning of next round, otherwise sensor nodes use residual energy levels to select new cluster heads for next round.

Chain formation phase

This phase is divided into Chain formation within clusters and Chain formation among cluster heads.

Chain Formation within Clusters: When the clusters formed, each cluster head creates a chain among the sensor nodes within its cluster so that each sensor node receives non-time critical data from a previous neighbor, aggregates its data with the one received from its previous neighbor and transmits aggregated data to a next neighbor. The chain within cluster is formed in the order from the furthest to the nearest node from the cluster head. Once the chain formation within the cluster is completed, cluster head sends the chain to the sensor nodes within its cluster.

Chain Formation among Cluster Heads: In this stage, 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. In ECCPTC, the base station applies the greedy algorithm used in PEGASIS to make a chain among the selected cluster heads. The chain is formed in the order from the furthest to the nearest node from the base station, and nearer nodes have better opportunities to be the leader. All the cluster heads send their non-time critical data to the leader node along the chain, finally the

leader node transfers the collected data to the base station.

Data transmission phase

Data transmission phase is divided into several frames which sensor nodes transmit and receive data at each frame. ECCPTC considers higher priority for time critical data than non-time critical data so that time critical data is immediately transmitted to the base station. This phase consists of two stages.

Time critical data transmission: For gathering data in each frame, if the sensed data value by a sensor node is equal to or greater than threshold value, the sensor node sets a bit in header of data packet to indicate it is time critical data and immediately sends the data directly to its cluster head using CSMA MAC protocol. Then, the cluster head sends data directly to the base station using CSMA MAC protocol. If time critical data are received by a cluster head that is waiting to access the channel to send time critical data, the cluster head will aggregate time critical data and send aggregated data to the base station. Hence, the use of threshold parameter enables us to reduce transmission delay in the case of time critical data. Once the time critical data transmission is completed, the cluster head creates and distributes TDMA schedule which specifies the time slots allocated for each member of the cluster to transmit non-time critical data.

Non-time critical data transmission: After the transmitting of time critical data to the base station, sensor nodes in each cluster transmit their non-time critical data to their own cluster head during their allocated TDMA slot using the chain based routing. Each sensor node receives data from previous neighbor, aggregates with its own data, and transmits to the next neighbor. The data are transmitted in an alternative way until all data are transmitted to the cluster head node.

If a node that has transmitted its time critical data to the base station receives data from previous neighbor, the node only transmits received data to the next neighbor in the chain and does not need to perform data aggregation.

Once the cluster heads receive data from previous neighbors in clusters, data transmission among cluster heads is begun. In this stage, leader node generates a token and then transmits it to the end cluster head node in the chain of cluster heads. Each cluster head aggregates its neighbor's data with its own data and transmits aggregated data to the next neighbor in the chain of cluster heads. Finally, the aggregated data are delivered to the base station by the leader node in the chain of cluster heads that has the shortest distance from the base station.

Since data transmission distances between cluster heads are greater than data transmission distances between sensor nodes within the cluster, the cluster heads drain energy much faster than sensor nodes within cluster.



Fig. 1 Pseudo code of the ECCPTC

Base station sends a threshold value to all sensor nodes

Phase 1: Clustering phase

Each node broadcasts a message in the range r

Each node receives the messages from all nodes in the range r

Each node computes distance from all neighbors and computes CHSV

$$CHSV_i \leftarrow \frac{E_{res_i}}{\sum_{j \in N(i)} dist(v_i, v_j)}$$

if $CHSV_i > CHSV$ of all its neighbors nodes (all nodes in the range r)

Node i acts as cluster head (CH)

Clusterheads(i) $\leftarrow$ True

end

Each CH broadcasts an adv_Msg in the range r

Each non-CH sends a Join_REQ to closest CH

Phase 2: Chain formation phase

if clusterheads(i) = True

Creates a chain from its farthest node to its nearest node in the cluster

Sends the chain to the members of its cluster

Sends (location i) to the BS

The BS creates a chain among CHs and sends the chain to all CHs

if distance (i, BS) < distance of all CH nodes to BS

Header (i) $\leftarrow$ True

end

Phase 3: data transmission phase

if sensed data value $\geq$ threshold value

time_critical(i) $\leftarrow$ True

node i sends its data to its cluster head and the cluster head transmits the received data to BS

end

if clusterheads(i) = True

Creates TDMA schedule and broadcasts it to the all nodes in its cluster

end

if clusterheads(i) = False

if time_critical (i) = False

node i aggregates its data with the data of previous node and sends

aggregated data and Residual_Energy to the next node in the chain

else

node i sends received data of previous node and Residual_Energy to the next node in the chain

end

end

if clusterheads(i) = True

if header(node i) = False

CH node i aggregates its data with the data of previous CH node and

sends aggregated data to the next CH node in the chain of CHs

else

header node i aggregates its data with the data of previous CH node and sends aggregated data to the BS

end

end

During the data transmission phase

node i : if state(node i) = dead

alive_node(r) $\leftarrow$ alive_node(r) -1

end

if alive_node(r) = alive_node (r -1) // r indicates current round

// r -1 indicates previous round

CH $\leftarrow$ node i that has the highest Residual_Energy in each cluster

Cluster heads (CH) $\leftarrow$ True // node i is cluster head

else

CH sends a message to BS to do clustering phase

The BS broadcasts the synch pulse in the network

node j : if the synch pulse is received

The node j becomes ready to hold the clustering phase for next round

end

end

In order to balance energy consumption among all sensor nodes in the network, cluster head's role should be rotated among the sensor nodes to prevent their exhaustion. ECCPTC uses residual energy for cluster head's rotation so that the sensor node with the highest residual energy in the cluster is selected as cluster head for next round. In the last frame of a round; sensor node sends data to the next neighbor; also it sends its residual energy. Based on the collected information, the sensor node compares its energy levels with the energy level of previous neighbor and selects higher energy level and sends the information and aggregated data to the next neighbor. Once the data are received by cluster head, the node with the highest residual energy is selected as cluster head for next round.

If any sensor node dies in cluster, cluster head sends a message to the base station and informs it that sensors should hold the clustering phase at the beginning of the upcoming round. After that, the base station sends specific synchronization pulses to all nodes. When each node receives the pulse, it prepares itself to perform clustering phase. Fig. 1 shows the pseudo code of the ECCPTC.

Simulation and results

To evaluate the performances of ECCPTC discussed in the previous section, we presented these simulations by MATLAB and compared its performance with other protocols such as LEACH, CBRP and PEGASIS. For performance comparison, we mainly take account the following performance parameters: network lifetime, stability period, energy consumption, the total number of data messages received at the base station, transmission delay of time critical data and communication overhead.

Simulation setup

The simulations are carried out with a random network topology with 100 sensor nodes are randomly distributed in the monitoring area with a size of 100 m*100 m and a base station located at position (50,175). All sensor nodes periodically sense the environment and transmit the data to the next neighbors. All parameters of simulations are shown in Table 1. In our simulation scenario, sensor nodes sense the temperatures in different regions. During each round of simulation runs, each node is assigned a random temperature between 0 degree Fahrenheit and 100 degree Fahrenheit. For our experiment, the threshold is chosen to be 70 degree Fahrenheit. If the sensed data value by a sensor node is equal to or greater than 70 degree Fahrenheit, a critical event is occurred and should be immediately sent to base station.

Simulation results and analysis

Network lifetime, stability period and instability period: Stability period is defined as the time interval before the death of the first node. Instability period is defined as the time interval between the death of the first node and the last node (Ezzati & Benalla, 2010). Without longer stability period, more information could not be able to

collect from the sensor field even though the life time of the network is high. So prolonging the stability period is crucial for many applications (Rashed *et al.*, 2011).

Fig. 2 shows the total number of nodes that remain alive over the simulation time. Fig. 3 shows the performance comparison of the network lifetime using FND and LND metrics. FND (First Node Dies) is defined as the time required for the first node to run out of energy and LND (Last Node Dies) is defined as the time required for the last node to run out of energy. Since more than one node is necessary to perform the clustering algorithm, the Last Node Dies represents overall lifetime of wireless sensor network when 90% of sensor nodes die.

It is clear from Fig. 2 and Fig. 3 that ECCPTC has better performance than other protocols in terms of network lifetime, stability period and instability period. The stability period of the ECCPTC was prolonged than LEACH, CBRP and PEGASIS and the instability period was shortened for ECCPTC compared to LEACH, CBRP and PEGASIS. It means ECCPTC can better balance energy consumption in the network. The ECCPTC has more active sensor nodes than the other protocols at any time. This is mainly because each sensor node receives data from the previous neighbor, aggregates with its own data and transmits to the next neighbor in the chain. ECCPTC also considers residual energy of nodes, distance from neighbors and the number of the neighbors of nodes to elect cluster heads in clustering phase.

Table 1. Simulation parameters

Parameters	Values
Network size	(0,0) to (100,100)
Number of nodes	100
Base station location	(50,175)
Data packet size	500 Bytes
Broadcast packet size	25 Bytes
Initial energy of nodes	0.3 J
E_{elec}	50 nJ/ bit
ϵ_{fs}	100 pJ/ bit/ m ²
ϵ_{amp}	0.013 pJ/ bit/ m ⁴
E_{DA}	5 nJ/ bit/signal
d_0	87.7 m
Cluster radius r	20 m
Threshold	70

Energy consumption: Fig. 4 demonstrates the energy consumed by all nodes during the simulation runs. It is obvious that ECCPTC uses much less energy compared to other protocols. The reducing of energy consumption of ECCPTC is mainly due to the small transmit distances of most of the nodes as they need to transmit only to their

Fig. 2. The number of active nodes over round

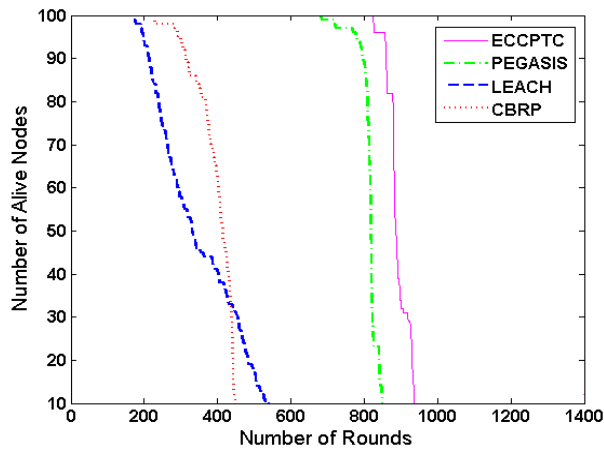


Fig 3. Performance comparison of the network lifetime using FND and LND metrics

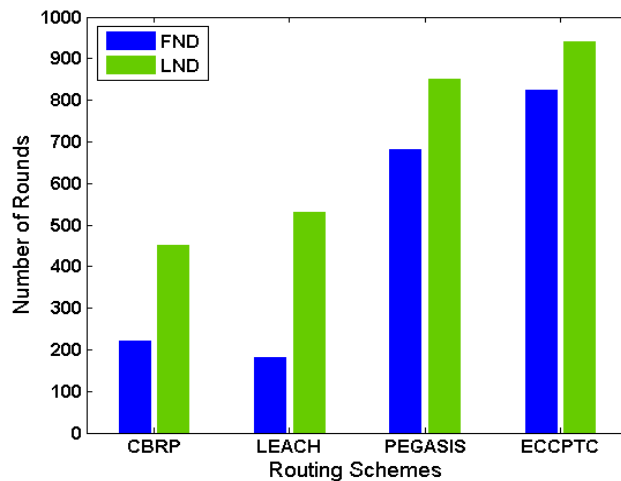


Fig. 4. The total energy consumption of the network over round

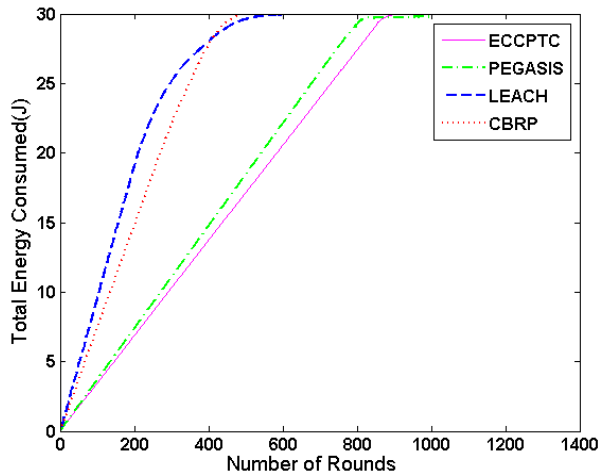


Fig. 5. Number of data messages received at base station over round

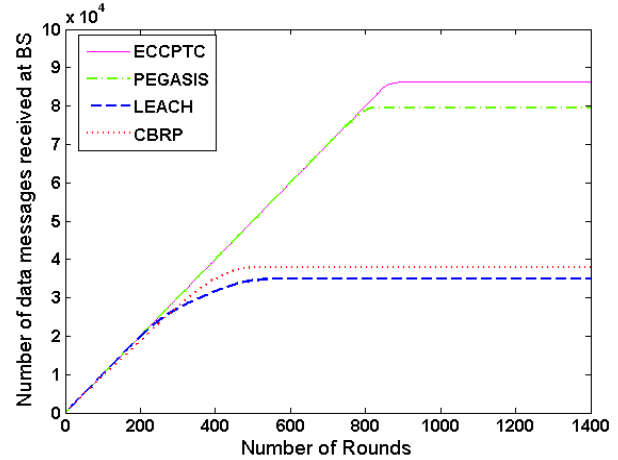


Fig. 6. Number of data messages received at base station over energy

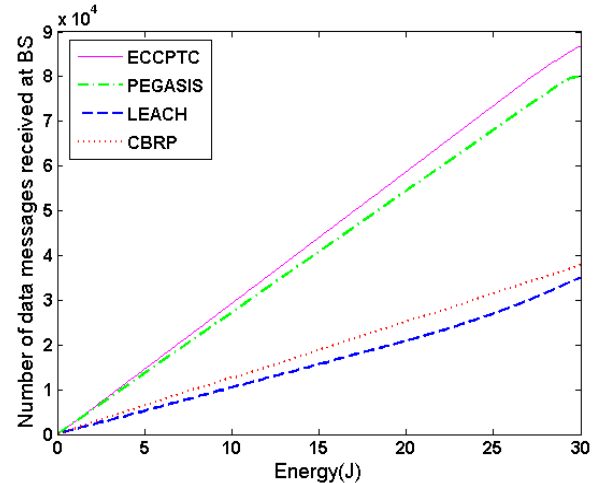


Fig. 7. Transmission delay of time critical data in different routing protocols

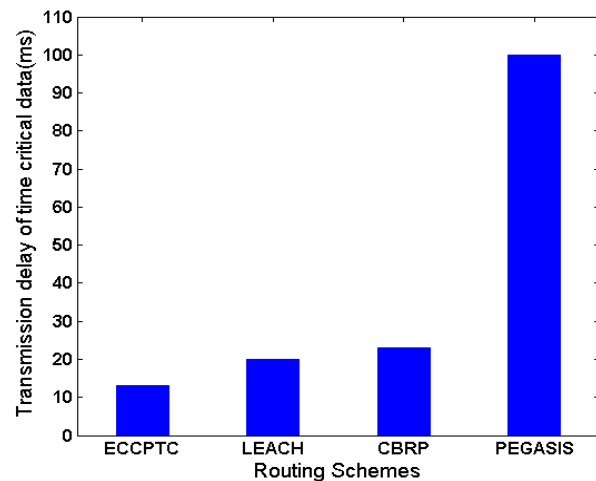
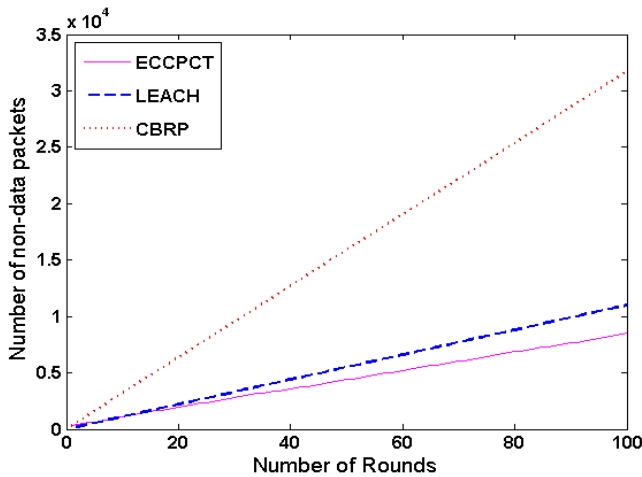


Fig.8. Communication overhead



nearest neighbors in the chain instead of transmitting directly to the far away base station or cluster head. LEACH and CBRP also consume more energy due to the cluster formation overhead. Since ECCPCT does not perform clustering phase in each round, it reduces energy consumption of the network. ECCPCT also has better performance than PEGASIS. This is mainly due to the multiple chains are constructed in ECCPCT which causes the chains to have smaller length than the single chain in PEGASIS. This reduces the amount of data to be aggregated and propagated along the chain which results in more savings in the energy consumption of the nodes. Total number of data messages received at the base station: Fig. 5 and Fig. 6 show that the total number of data messages received at the base station in ECCPCT is greater than other protocols. This is mainly due to ECCPCT increases the network lifetime.

Transmission delay of time critical data: We assume that 20% of data in the network are time critical data. Fig. 7 shows the maximum transmission delay of time critical data in different routing protocols. ECCPCT reduces transmission delay of time critical data about 35%, 43% and 87% compared with LEACH, CBRP and PEGASIS respectively. This is mainly because ECCPCT has considered higher priority for time critical data than non-time critical data so that time critical data are immediately transmitted to the base station using CSMA MAC protocol.

Our proposed protocol can meet both requirements for a prompt-response and energy-saving applications. Communication overhead: Communication overhead is defined as the total number of non-data messages transmitted during transmitting 10000 data messages. Less value of the communication overhead indicates better protocol.

Fig. 8 clearly shows that ECCPCT has minimum control overhead compare to other protocols. LEACH and CBRP suffer from cluster formation overhead. They consume more energy due to the cluster formation overhead. Additionally, each sensor node transmits data

to its cluster head even if the cluster head resides farther from the base station. CBRP also needs to send a lot of control messages to make the final selection of cluster head in each round, thus it has more overhead than other protocols.

Since ECCPCT does not perform clustering phase in each round and uses the residual energy for cluster head's rotation, it reduces a large amount of communication overhead.

In summary, the above results show that ECCPCT can extend network lifetime, reduce energy consumption and transmission delay of time critical data, increase number of data messages received at the base station and reduce communication overhead.

Conclusion

In this paper, a novel Energy Efficient Cluster-Chain based Protocol for Time critical applications (ECCPCT) in wireless sensor networks proposed. The main goal of ECCPCT is to maximize network lifetime and stability period and minimize energy consumption and transmission delay of time critical data. For reducing transmission delay of time critical data, ECCPCT introduces a threshold parameter. ECCPCT organizes sensor nodes into clusters and constructs a chain among the sensor nodes within cluster so that each sensor node receives non-time critical data from a previous neighbor and transmits to a next neighbor. Furthermore, ECCPCT improves the non-time critical data transmission mechanism from the cluster heads to the base station via constructing a chain among the cluster heads. By chaining the nodes in each cluster and using a separate chain for the cluster heads, ECCPCT 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. We evaluated the performance of ECCPCT by simulating and comparing it with LEACH, CBRP and PEGASIS. The simulation results show that ECCPCT has better performance than other protocols in terms of network lifetime, stability period, instability period, transmission delay of time critical data, energy consumption and the total number of data received at the base station.

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