ENERGY EFFICIENT AND FAULT TOLERANT ROUTING PROTOCOL FOR MOBILE WIRELESS SENSOR NETWORKS

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Keywords: Mobile wireless sensor networks, routing protocol, energy efficient, fault tolerance

Abstract

Due to the frequently changing network topology, it is a great challenging work to design energy efficient and fault tolerant routing protocols for Mobile Wireless Sensor Networks (MWSN) applications such as wildlife monitoring, battlefield surveillance and health monitoring. In MWSN, however, most existing routing protocols either do not support node mobility well or do not have fault tolerance. This paper proposes an Energy efficient and Fault Tolerant Clustering Protocol (EFTCP) for MWSN. The proposed EFTCP has high fault tolerance through providing an alternate for each cluster head node. And EFTCP can also reach efficient message transmission by the method that cluster heads adaptively allocate timeslots to their member nodes according to the amount of data needed to send. Simulation results show that EFTCP-MWSN has much longer lifetime than LEACH-Mobile, and more efficient than FTCP-MWSN as to message transmission.

1 Introduction

Wireless Sensor Network is composed of a large number of sensor nodes with limited energy. For the environment where nodes are densely deployed may be hostile, it is unrealistic to supplement energy by replacing the battery [1, 2]. Thus to develop energy efficient routing protocols for resource constrained WSNs is of highly importance. Clustering-based routing protocols are considered as more energy efficient as cluster heads (CHs) in such protocols can not only efficiently manage the work/sleep scheduling mechanism of member nodes, but also extract useful information from a large amount of raw sensed data from member nodes and transmit the useful and limited amount of information to the base stations (BS) [3, 4, 5]. However, most existing clustering protocols of WSN are mainly designed for static sensor mobile, and do not take the mobility of nodes into account well [6, 7]. Thus they do not fit many applications in WSN like habitat monitoring, animals tracking, search and rescue, Tracking Vehicles, RoboMote, parasitic-mobility, medical care, and disaster response applications.

To alleviate this problem, some new clustering protocols are proposed. For example, Low Energy Adaptive Clustering Protocol (LEACH) [8, 9] is enhanced as LEACH-Mobile [10] and LEACH-Mobile-Enhancement [11]; Cluster Based Routing protocol for Mobile Nodes in Wireless Sensor Network (CBR Mobile-WSN) [3] is presented to support mobility of sensor nodes. These protocols assume that if a non-CH sensor node does not receive data request packet from CH, or CH does not receive data from a non-CH node after sending data request packet, the non-CH node has moved from its previous cluster. Then, the moved non-CH node tries to find a new CH node or cluster. The CH also discards the non-CH node from its allocated timeslot and allocates this free timeslot to a new mobile member node of the cluster. However these protocols are not Fault Tolerant.

The literature [12] proposes a Fault Tolerant Clustering Protocol for Mobile WSN (FTCP-MWSN). But the protocol allocates the same number of timeslot to member nodes, and thus it is not message transmission efficient. In this paper, we introduce an energy efficient and fault tolerant Clustering protocol for Mobile Wireless Sensor Networks (EFTCP-MWSN), which is fault tolerant and message transmission efficient. The contributions of this paper are as follows.

1. Supports mobility of sensor nodes for the following scenario. Data from all sensor nodes that are attached to mobile objects such as elderly people in health monitoring are sent to BS rather than ensuring network coverage and reducing sensing overlap.
2. Achieves fault tolerance by selecting Alternative Cluster Head (ACH). The member node with least mobility factor is selected as an ACH. Once CH fails, ACH will work as a CH.
3. Allocates different number of timeslot to member nodes.

We allocate much more timeslots to the node which sends data frequently.

The remainder of the paper is organized as follows. Section 2 presents some existing mobile clustering protocols of WSN. Section 3 presents the working principles of EFTCP-MWSN. Section 4 presents theoretical analysis on the energy consumptions of EFTCP-MWSN protocol and also simulation results. The summary of this paper with future research directions are presented in section 5.

2 Related works

Low Energy Adaptive Clustering Protocol (LEACH) [8] works well for homogeneous networks, where node has the same initial energy. The LEACH operations are mainly in two major phases – Set-up phase and Steady-state phase. In Set-up phase, a node A is selected as a cluster head (CH) if a random number (between 0 and 1) chosen by A is less than a threshold value. In Steady-state, each non-CH node sends data at its allocated timeslot to CH that aggregates and sends data to base station. Whether it has sensed data, non-CH node will send data at its allocated timeslot, which is not energy efficient. Moreover it doesn't support mobility of sensor nodes.

Thus, the work done by Do-Seong Kim D.S and Chung Y.J. [10] propose LEACH-Mobile (LEACH-M) routing protocol that has the setup phase as the LEACH. If the mobile sensor node does not receive the data transmission from cluster head within an allocated time slot according to TDMA schedule, it sends a "join-request" message at next TDMA time slot allocated. Then it decides the cluster to which it will belong for this moment by receiving cluster "join-ack" messages back from specific cluster heads. The LEACH-M protocol achieves definite improvement in data transfer success rates as mobile nodes increase compared to the non-mobility centric LEACH protocol. LEACH-M handles node mobility well, if the cluster heads are more or less stationary. But it is not true in all the cases, as the cluster head election happens from the same set of mobile nodes.

To alleviate this problem, Kumar G.S. et al. propose LEACH-Mobile-Enhanced (LEACH-ME) [11], where a node with the lowest mobility factor is selected as CH. Mobility factor is calculated based on the number nodes movement outside of a cluster. More elaborately, mobility factor is calculated in an extra timeslot of a frame by multiplying node's velocity with the time required to move a node from a position to another. In steady phase, a non-CH node x might not receive data request packet from CH due to the mobility of x to a new location. In this case, if CH does not receive any acknowledgement from x in two timeslots in consecutive frames, CH assumes that x has moved and deletes the timeslot of x. However, LEACH-ME consumes much energy for determining mobility factor of each node in extra slots.

The work done by Samer A.B. Awwad et al. proposes [3] Cluster Based Routing protocol for Mobile Nodes in WSN (CBR Mobile-WSN) that reduces the energy consumptions and packets losses rate of LEACH-M. Each CH keeps some free timeslots for incoming mobile nodes from other clusters to join its cluster. If node x loses contact with the CH x will try to join in a new cluster to avoid packets loss. In another scenario, if x moves and does not receive data request message from CH, x sends its data to the free CH to avoid packet loss. If x has not been assigned any timeslot it goes back to the sleep mode. This phenomenon reduces energy consumptions of CBR-Mobile.

However these protocols cannot detect the failure of sensor nodes. Latful Karim et al. propose a Fault Tolerant Clustering Protocol for Mobile WSN (FTCP-MWSN) [12]. In this protocol, a special packet is sent by a non-CH node if it has no sensed data to send to the CH at its allocated timeslot and thus, saves energy by not sending data at every timeslot. At the end of a round, a node with the least mobility is selected as a new CH. The mobility of a node is the ratio of the number movements of a node inside and outside of its cluster. Moreover, if CH does not receive data from a node x at its allocated timeslot the CH deletes x from the member list, discards the timeslot of x and also notifies BS the ID of x. If x moves to a new cluster it sends a join request to the CH of this new cluster. If CH accepts the join request it sends the ID of x to BS. Thus, if BS receives the ID of node x in two consecutive frames, BS assumes that node x has moved. Otherwise, node x is considered as a failed node.

To achieve fault tolerance, MEFC [13] protocol proposed by Latful Karim et al. achieves fault tolerance by selecting Alternative Cluster Head. If two neighbouring nodes a, b are same hops from the BS it selects a as a CH, which is at the least Euclidian distance from the BS to achieve energy efficiency. And node b will be selected as Alternate CH. In steady phase, BS sends "HELLO PACKET" to a CH at its allocated timeslots if the BS does not receive any data packet. The BS assumes that the CH has failed and selects an ACH to work as a CH if the CH does not send any "ACK-HELLO" packet or data packet at the following timeslot.

3 EFTCP-MWSN protocol

In this section, we present the working process of the proposed energy efficient and fault tolerant Clustering protocol for Mobile Wireless Sensor Network, i.e. EFTCP-MWSN, in detail.

```
Algorithm 1:Cluster Formation, Initial CH Selection
for i ← 1 to NumberofNodes do {
    CHprobNode[i] ← random(0,1)
  if CHprobNode[i] ≤ CH Probability then
      CH ← Node[i]
 }
CHs broadcast their positions and IDs.
non-cluster head sensor nodes select CH according to
the received signal strength
for each node j in a cluster i do {
  CH[i] subscribes events to node j
}
```

Figure 1: Pseudo code of initial state algorithm

3.1 Setup Phase

In setup phase, the node with the lowest mobility factor in a cluster is selected as a CH if its residual energy is above a threshold value. The mobility factor is calculated as the ratio of the number of times a node enters different clusters to the number of times a node changes positions within a cluster. Once CHs are selected they broadcast their positions and IDs. After non-cluster head sensor nodes have received advertisement messages from one or more cluster heads, the sensor nodes compare the received signal strength for received advertisement messages. After deciding the cluster it will belong, the sensor node sends registration message to inform the cluster head. During this phase, all cluster heads must be kept awake.

After cluster head receives registration messages from the nodes that would like to join cluster, the cluster head creates a number of TDMA timeslots based on the number of nodes. Besides that, the cluster head also maintains some free timeslots which are used to support mobility in the network. And the member node with least mobility factor is selected as an ACH. ACH is placed at the fist position of TDMA. Once the network operation starts and nodes move at a fixed (low) velocity, each node keeps track of the number of movements inside and outside of its current cluster based on which node's mobility is calculated at each round. Figure 1 gives the Pseudo code of initial state algorithm.

```
Algorithm 2: Mobility Calculation, ACH Selection,
Timeslot Allocation, New CH Selection
for each frame f in round do {
  for each node j of a Cluster k ← t[k][j] do {
    if(node[k][j] has an sensed event) then
      n[k][j]++ //the number of node j sending data
    if(node[k][j] receive ACK from CH || node[k][j]
receive ACK from ACH at following slot) then {
        ++In[node[k][j]]
    } else {
          notify BS the ID of node[k][j] sending
            MOVED-NODE
        Broadcast JOIN-REQUEST
        CH within shortest communication range replies
        with ACK-JOIN & notify BS the ID of
        node[k][j] using NEW-NODE
      }
    if BS receives NEW-NODE&MOVEDNODE
         for node[k][j] in two consecutive frames
        then
              mark node[k][j] as a moved-node
                  ++Out[node[k][j]]
        else
              mark node[k][j] as failed
  }
    if( CH[K] has failed) then
        CH[k] selects ACH as CH
}
for  next round {
calculate the number of timeslot allocated to node j
selects new CH with least mobility
selects the new ACH with least mobility from member
nodes
}
```

Figure 2: Pseudo code of Steady state algorithm

3.2 Steady Phase

In steady phase, the data transmission from sensor nodes to their cluster heads is begun according to their TDMA schedule. The BS subscribes to each node for some event of interests. Once a node x senses such an event, it will transmit the sensed data packets at their allocated timeslots. Otherwise, the node x sends a small sized special packet to notify CH that it is still alive or within the communication range of CH. If a CH does not receive any data or special packet from x at its allocated timeslot, there are two cases caused by it. One is x has moved out of the cluster, the other is CH has failed. If CH fails, ACH will be selected to work as a CH. In order to determine which case, node x will send data to ACH at the flowing timeslots. If x does not receive any data packet from ACH, x assumes that it is no longer attached to its CH due to mobility. Then x broadcasts a "JOIN-REQUEST" packet and the CHs that are within the communication range of x and also have free timeslot replies x with an "ACK-JOIN" packet. Then x registers to the cluster of the CH from which x receives the "ACK-JOIN" packet with the highest signal strength. This new CH of x then allocates a timeslot for x and notifies BS. If a CH does not receive any data or special packet from x at its allocated timeslot and CH doesn't fail, the CH assumes that the node x either has moved out of the cluster or failed. Then CH deletes the node x from its members list and also the timeslot allocated to x.CH also notifies BS the ID of x. If BS receives the ID of node x in two consecutive frames, BS assumes that node x has moved. Otherwise, node x is considered as a failed node. As shown in Figure 2, the pseudo code of steady state algorithm is presented.

In this protocol, CH and ACH is selected in setup phase and ACH has the least probability to lose in contact with CH. Thus the failure of a CH can be detected by ACH in steady phase. ACH send data to its cluster head at allocated timeslots. If CH receives the data packet related to the event of interest, it will send "CHACK PACKET" to ACH. If ACH does not receives any data packet at the following timeslot the ACH assumes that the CH has failed and make itself work as a CH. Moreover the probabilities of a node to send data packet may be different. The number of timeslot is calculated by the Equation (1).

$$t_x = \frac{n_x}{sum_x} \times T \qquad (1)$$

In Equation (1), n_x represents the sending data times of node x; sum_x is the total sending data times of the cluster which node x belongs to; T represents the length of frame.

3.3 New Features

In LEACH-M and LEACH-ME protocol, CH sends DATA-REQUEST to nodes and nodes also send data packets at every timeslot while In EFTCP-MWSN protocol, events are subscribed to sensors and when these events occur sensor nodes send data packets; otherwise, sensors send small size special packets, which consume much less energy as compared to large data packets. Moreover, to achieve reliability or detect the failure of nodes, CH sends the ID of the sensor nodes to BS, which has been moved out of the cluster and also the ID of the node which join into new cluster. And it also provides ACH, allocates much more timeslots to the nodes which send data frequently and doesn't need extra timeslot to calculate mobility of nodes. On another hand, in LEACH-M, a node requires timeslots in two consecutive frames to determine whether it has moved and then requests for join the new cluster. This results more packet losses, which is not the case for the EFTCP-MWSN protocol since a node does not wait timeslots in two consecutive frames to determine that. Table 1 presents the comparison of EFTCP-MWSN (EFTCP) protocol with LEACH-M (M), LEACH-ME (ME) and FTCP-MWSN (FTCP) on some important features.

Features	M	ME	FTCP	EFTCP
Subscribed events to nodes	N	N	Y	Y
Send special packets to CH	N	N	Y	Y
Detect fault nodes	N	N	Y	Y
Provide ACH	N	N	N	Y
Allocate same timeslots	Y	Y	Y	N
Require extra timeslot	N	Y	N	N
Support mobility	Y	Y	Y	Y

Table 1: Comparison of routing protocols

4 Performance Evaluation

The following subsections present mathematical analysis, simulation setup, and results with performance analysis.

4.1 Performance Analysis

The energy consumptions of a node for sending data packet of size n_{data} bytes to Cluster Head at the distance d is

$$E_{data}\left(n_{data}, d\right) = n_{data}\left(E_{elec} + d^2 \varepsilon_{elec}\right) \quad (2)$$

Similarly, energy consumptions of a node for sending a special packet of size n_{spec} bytes to CH at the distance is

$$E_{spec}\left(n_{spec}, d\right) = n_{spec}\left(E_{elec} + d^2 \varepsilon_{elec}\right) \quad (3)$$

In Equations (2) and (3), E_{elec} represents the energy consumptions of radio for driving the transmitter and ε_{elec} represents the transmitter amplifiers energy dissipation. We assume that the probabilities of a node to send data and special packet are p_{data} and p_{spec} respectively. Hence, the total energy consumptions of a node considering that each node either sends the subscribed data packet or special packet is

$$E = \left(p_{data} \times n_{data} + p_{spec} \times n_{spec}\right)\left(E_{elec} + d^2 \varepsilon_{elec}\right) \quad (4)$$

As the size of the special packet is much smaller than that of the data packet, we assume that

$$n_{data} = k \times n_{spec} \quad (5)$$

In Equations (5), $k \geq 2$ is a constant.

$$E < n_{data}\left(E_{elec} + d^2 \varepsilon_{elec}\right)$$
$$\Rightarrow E < E_{Tx(LEACH-M)} \quad (6)$$

From Equation 6 we find that the transmission energy consumptions of a node in the EFTCP-MWSN protocol are less than that of the LEACH-M protocol. LEACH-ME consumes more energy than LEACH-M for determining mobility factor of each node in extra slots. From this analysis, we can conclude that the proposed EFTCP-MWSN protocol is more energy efficient than that of the existing LEACH-M and LEACH-ME protocols.

4.2 Simulation

We simulate the performance of EFTCP-MWSN protocol using NS2. Table 2 shows the network parameters and their respective values.

Parameter	Value
Number of nodes	100
Network size	$100m*100m$
Max speed	$1\ m/s$
Expected number of CH per round	5%
Sensors communication range	25 meters
Initial node energy	1 *Joule*
Sensing energy consumption	5 *nJoule/bit*
Energy consumptions in sleep state	0.005 *nJoule*/sec
Special packet size	25 Bytes
Data packet size	525Bytes
Base station position	(50,55)

Table 2: Simulation parameters and their values

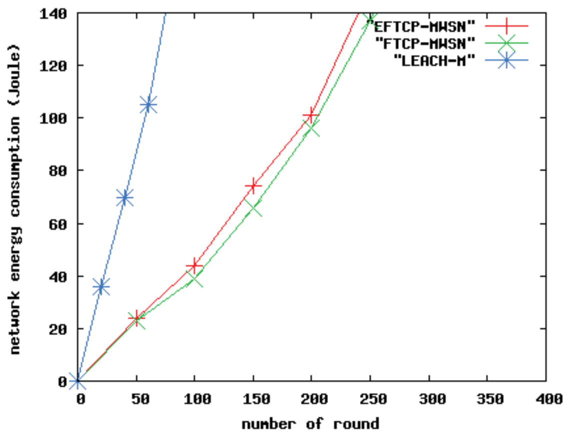

Figure 3: Comparison of network energy consumption

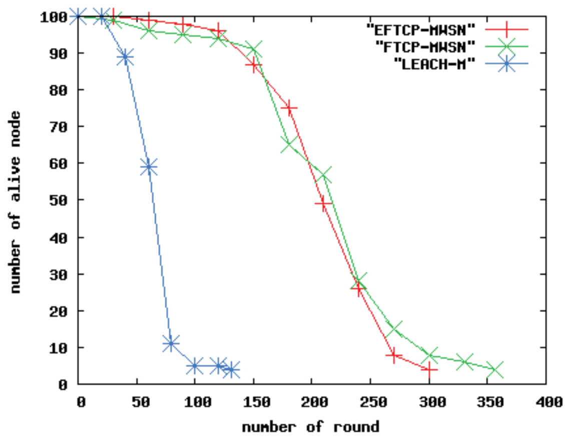

Figure 4: Comparison of network lifetime

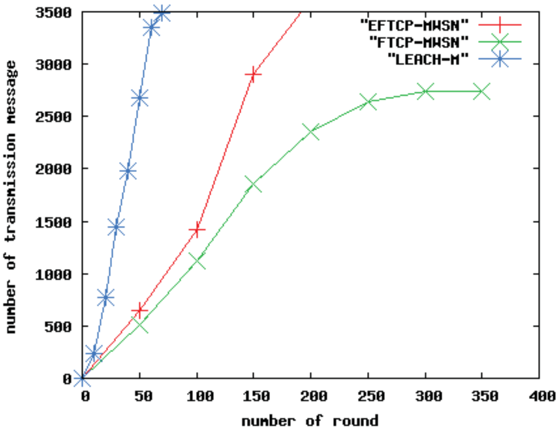

Figure 5: Comparison of message transmission number

As shown in figurer 3-6, we measure the performance of EFTCP-MWSN protocol and compare with existing LEACH-M and FTCP-MWSN protocols in terms of number of transmission message, and network lifetime under the 0.1 failure probabilities of CHs.

Figure 3 illustrates that the network energy consumptions of EFTCP-MWSN and FTCP-MWSN are much lower than LEACH-M. This is because if there is no sensed data, node of EFTCP-MWSN and FTCP-MWSN will send a small special packet instead of data packet which consumes much less energy as compared to large data packets. As sending more data packets consumes much more energy, figure 4 demonstrates that the network lifetime of EFTCP-MWSN and FTCP-MWSN are much higher than the existing LEACH-M protocols. Figure 5 shows that the number of message transmission of EFTCP-MWSN is higher than FTCP-MWSN. This is because that CH allocates much more timeslots to the nodes which send data frequently in EFTCP-MWSN. And EFTCP-MWSN provides ACH which greatly reduce energy consumption of member nodes finding new CH after the current CH fails.

5 Conclusion

In this paper, we propose a new routing protocol called EFTCP-MWSN which supports the mobility of sensor nodes. The proposed protocol reach high fault tolerance since it not only can detect failure nodes but also provide alternative CH to avoid serious losses resulted by the failure of CH. Moreover, EFTCP-MWSN protocol improves the efficiency of data transmission for CHs can allocate much more timeslots to the nodes with more frequent data sending. Performance analysis and simulation results show that EFTCP-MWSN protocol is more energy efficient in terms of network lifetime than several existing important and typical protocols such as FTCP-MWSN and LEACH-M.

Acknowledgements

This work is supported by the National Natural Science Foundation of China under Grants no. 61262081 and 61272526; the Provincial Applied Fundamental Research Project under Grant no. KKSY201203027; the Fundamental Research Funds for the Central Universities under Grants no. ZYGX2012J083.

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