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FTEAP: A Fault Tolerant Energy Adaptive and Power Aware Clustering Protocol for Wireless Sensor Networks

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Abstract: Progress in wireless communication has made possible the development of low cost wireless sensor networks. Wireless sensor networks (WSNs) with a large number of small sensor nodes can be used for monitoring and controlling the physical environment from remote location with better exactness. This network due to the shared wireless communication medium and deployed unpleasant surroundings is fault prone. This paper introduces the new fault tolerant protocol to reduce overall power consumption, maximize the network lifetime in a wireless sensor network. Proposed FTEAP protocol, aims to decrease the consumption of the network resources in each round of data communication and aggregation and it is a fault tolerant technique that guarantees trustworthy of the communications between sensor nodes and base station by selecting strongest node as cluster-head and electing a reserved cluster-head. Simulation results demonstrate that the proposed algorithm has higher efficiency and can achieve better network lifetime and energy consumption.

Keywords: Fault tolerant; wireless sensor networks; clustering algorithm; energy-efficient; network lifetime

INTRODUCTION

Nowadays progress in MEMS (Micro-electro-mechanical systems) and wireless network technology have made the progression of small, cheap, low power distributed devices, which are capable of local processing and wireless communication, a reality. Such devices are called wireless sensor nodes. A wireless sensor network is a system of small, wirelessly communicating nodes where each node is equipped with multiple components. A variety of sensors may be joined to the sensor node to measure properties of phenomena. These networks are very useful in applications such as environmental monitoring which involves monitoring air soil and water, condition based maintenance, habitat monitoring, seismic detection, military surveillance, inventory tracking, seismic, medical data-gathering and etc, because of their low cost, small size and wireless transformation. Sensor networks consist of many small, self organized nodes that form an AD-HOC network that reports sensed data to the common node which is called sink. Due to the deployment of a large number of sensor nodes in uncontrolled or even harsh or hostile environments, it is common for the sensor nodes to become faulty and unreliable [1-6]. Fault is an incorrect state of hardware or program as a consequence in the failure of components [7].

Clustering is an effective way to reduce energy consumption in the wireless sensor network. For this reason the network subdivided into smaller groups called clusters and each cluster would has a head at a time, in many cases it is referred to cluster-head (CH), while other nodes join cluster as members. These member nodes forward sensed data to CH that are processed and forwarded to base station through hierarchy of CHs. A CH may be elected by the sensors of cluster or pre-assigned by the network designer. A CH is answerable for transmitting any information sensed by the nodes in its cluster and may aggregate and compress the data before sending it to the base station. Data aggregation decreases data packet size by eliminating the information redundancy. Clustering is also useful for spatial reuse of the bandwidth due to the node clustering and robust and scalable in the face of topological changes caused by node failure, insertion or removal [8, 9].

Routine clustering algorithms stand with the problem of unequal energy consumption. Cluster-heads drain energy much faster than cluster members and so the network lifetime is reduced. In order to balance the energy consumption and extend network lifetime, the role of CH must be rotated among various members. Various designs in homogeneous sensor network are used to rotate the role of CH among member nodes periodically based upon some probability function. Moreover, CHs are also prone to hardware or software failures. To handle these faulty CHs, some fault tolerant mechanism is required for proper functioning of the network.

In this paper, we propose and evaluate a new fault tolerant energy-adaptive and power-aware clustering (FTEAP) protocol for wireless sensor networks. In our considered wireless sensor network, nodes send sensing information to the cluster-head and cluster-head transmit them to base station. Certain clustering algorithms with special method periodically replacing cluster-heads and selecting reserved cluster-heads then cluster-heads aggregate the data of cluster nodes and send it to the base station.

We assume that all the nodes of the network are spread homogeneously, initially all node's battery power is equal, all sensor nodes have limited energy and the base station is fixed and not located between sensor nodes and most of the nodes are static and only a few are mobile[10].

The rest of this paper is organized as follows. In section II, LEACH will be briefly discussed. In section III, the proposed algorithm will be introduced. In section IV, we evaluate our mechanism compared with LEACH by simulation. Finally, in section V, we will summarize our paper and discuss about future research.

RELATED WORKS

Hierarchical or cluster-based routing, originally proposed in wire line networks, are well-known techniques with special advantages related to scalability and efficient communication [7]. In recent years, many protocols and algorithms for clustering have been proposed. Usually there are many differences between their cluster-head selection and clustering organism. But generally most of the current popular clustering algorithms, such as LEACH [11], PEGASIS [12] and HEED [13] are not fault tolerant. LEACH is the most popular clustering algorithm. Many of cluster-head selection algorithms are based on LEACH's architecture. [14] Is proposed to elect the cluster-heads according to the energy remaining in each node. This clustering protocol is called LEACH-E. In the rest of this section, we review LEACH algorithm and discuss its limitations.

LEACH (Low Energy Adaptive Clustering Hierarchy)

In LEACH protocol, Energy Efficiency is achieved by being cluster-head in turn, and then distributing impartially the total networks energy to unique node, thus makes low energy consuming and increases network lifespan. Cluster-head election depends on the whole numbers of cluster-head in networks and times that nodes have been cluster-head until now. Principles of this protocol are:

- The base station fixed.
- All the nodes in the wireless sensor network have the same initial battery power and are homogeneous in all other ways.

In the first phase, algorithm chooses a node stochastically, the principal explained in the coming: every sensor nodes generate a random number between 0 and 1, if the random number is lower than threshold, then it will be chosen as a cluster-head, otherwise it cannot be cluster-head threshold calculate by (1).

$$T(i) = \begin{cases} \dfrac{p}{1 - p * (r \bmod \frac{1}{p})} & \mathrm{i} \in G \\ 0 & \text{otherwise} \end{cases} \qquad (1)$$

Where P is the desired percentage of cluster-heads (e.g. P=0.05) in the current round, and G is the set of nodes that have not been cluster-heads in the last 1/P rounds, r is the number of the current round.

A flowchart of LEACH's distributed cluster formation algorithm is shown in Fig. 1.

Despite many advantages in using the LEACH protocol for cluster organization, cluster-head selection and increasing network lifetime, there are a few features that the protocol does not support.

LEACH assumes nodes power energies homogeneous. In real wireless sensor networks, sensor nodes energy is spread heterogeneously.

THE FTEAP PROTOCOL

In this section, we introduce the details of FTEAP protocol. The major application of the wireless sensor network is monitoring the remote environment. Data of individual nodes are usually not very important. Since the data of sensor nodes are correlated with their neighbor nodes, data aggregation can increase reliability of the measured parameter and decrease the amount of traffic to the base station. FTEAP protocol uses this observation to increase the efficiency of the network. To develop the FTEAP protocol, some assumptions are made about sensor nodes and the underlying network model. For sensor nodes, it is assumed that all nodes are able to transmit information with enough power to reach the base station by adjusting the amount of transmitted power, and each node can support different Medium Access Control (MAC) protocols and perform signal processing functions. These assumptions are reasonable due to the technological advances in radio hardware and low-power computing [11]. For the network, it is assumed that nodes have often data for sending to the base station and close nodes to each other have correlated data.

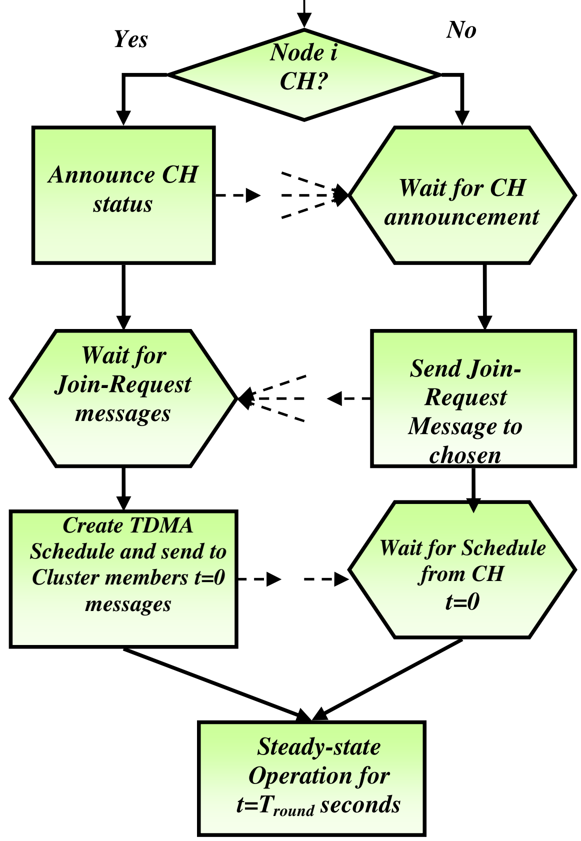

Figure 1. distribution of cluster information in LEACH algorithm [11].

Like LEACH, in the first phase, FTEAP protocol chooses a node stochastically, the principal explained in the coming: every sensor nodes generate a random number between 0 and 1, if the random number is lower than threshold, then it will be chosen as cluster-head, otherwise it cannot be cluster-head threshold calculate by (1). After first phase and using randomization for selecting the cluster-heads, algorithm compares selected cluster-head residual energy with other cluster member's residual energy. If there is any node with more energy than selected cluster-head, other nodes reselect this node as main cluster-head and this node undertakes cluster-head role. In fact, after cluster formation phase, FTEAP protocol replaces cluster-heads based on the threshold value of residual energy on the sensor nodes.

With this method strongest node in any cluster will be selected as cluster-head and previous node as reserved one. After establishing the clusters, the steady-state phase begins and the network starts to work. But if cluster-head was damaged or corrupted, cluster members know what the cluster-head is, so they communicate with new cluster-head until the end of current round. In the next round cluster-head selection phase starts again.

In the Fig. 2 we assume, CH A is elected in cluster-head selection phase and since CH B has more energy than CH A, cluster-head is replaced.

Regarding to reselecting cluster-head based on residue energy of cluster member nodes. We are sure strongest node will be selected as cluster-head and the reserved cluster-head is available. This algorithm increases network lifetime and achieves fault tolerant by having double cluster-heads in each round. If the initial selected cluster-head is strongest node or its residue energy is equal to other nodes, this algorithm works like LEACH.

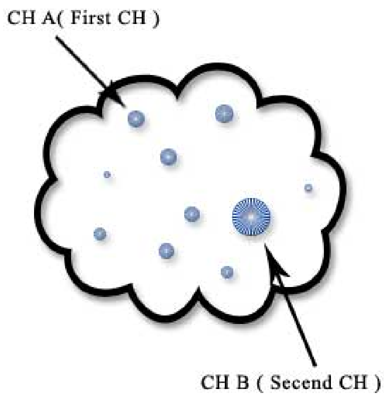

Figure 2. Strongest node (CH B) as main CH and previous node (CH A) as reserved CH.

Like LEACH, in order to reduce the probability of collision among joint-REQ messages during the setup phase, Carrier Sense Multiple Access (CSMA) protocol is utilized in the data link layer. Cluster-head is required to listen to the medium; this is called carrier sensing. If the medium is found to be idle, the cluster-head starts transmission. If the medium is found busy, the node defers its transmission for an amount of time determined by one of several possible algorithms.

Note that if the cluster-head fails to work for any reason, the algorithm replaces cluster-head on the basis of the reserved cluster-head. The cluster-head also chooses a new organizer providing that the old one is annihilated.

SIMULATION RESULT

In order to evaluate the performance of the FTEAP protocol, the simulator, specific to the needs of our model, was coded in PHP with Apache HTTP server version 2.2 and uses PHP/SWF Charts for its graphical needs.

We assume a simple model for the radio hardware energy dissipation. For the experiments described here, both the free space (d^2 power loss) and the multi path fading (d^4 power loss) channel models were used, depending on the distance between the transmitter and receiver. Power control can be used to invert this loss by appropriately setting the power amplifier. If the distance is less than the threshold d_o, the free space (fs) model is used; otherwise, the multi path (mp) model is used. Thus, to transmit l-bit message a distance, the consumed energy of radio for sender is:

$$E_{Tx}(l,d)=E_{Tx\text{-}elec}(l)+E_{Tx\text{-}amp}(l,d)=\begin{cases} lE_{elec}+l_{\varepsilon fs}d^2, \\ lE_{elec}+l_{\varepsilon mp}d^4, \end{cases} \qquad (2)$$

And to receive this message, the consumed energy in receiver is:

$$E_{Rx}(l)=E_{Rx\text{-}elec}(l)=lE_{elec} \qquad (3)$$

The electronics energy, E_{elec}, depends on factors such as the digital coding, modulation, filtering, and spreading of the signal, whereas the amplifier energy, $_{\varepsilon fs}d^2$ or $_{\varepsilon mp}d^4$, depends on the distance to the receiver and the acceptable Bit Error Rate (BER).

We consider the wireless sensor network with N=100, N=200 nodes randomly distributed in a 300 * 300 m^2 environment. We assume that the base station fix and is located at the origin (0, 0) of the coordinated system. The used radio parameters in our simulations are shown in Table I.

Table 1. Parameters used in simulations.

Parameter	***Value***
Transmitter/Receiver Electronics	E_{elec} = 50 nJ/bit
Transmit Amplifier if dmaxtoBS ≤ d0	$\varepsilon £_s$ =10 pJ/ bit/m^2
Transmit Amplifier if dmaxtoBS ≥ d0	ε_{mp}=0.0013 pJ/bit/m^4
Nodes first energy	3 J
Data Aggregation	E_{DA}=5nJ/bit/message
Message size	8192 bits

Fig. 3 and Fig. 4 present the energy consumption of the clustering protocols when the amount of nodes spread in network is 100 respectively. The x-axis indicates the number of rounds while y-axis indicates the mean residual energy of each node. The results demonstrate that the energy consumption of FTEAP protocol is generally smaller than LEACH-E and LEACH protocols.

Fig. 5 presents the number of dead nodes in the three clustering protocols. This result is closely related with the network lifetime of the wireless sensor networks. . Fig. 6 presents the number of live nodes in the three clustering protocols.

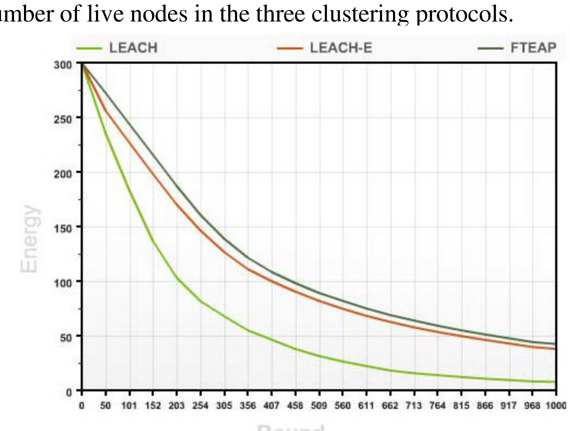

Figure 3. Total network energy with N=100 nodes

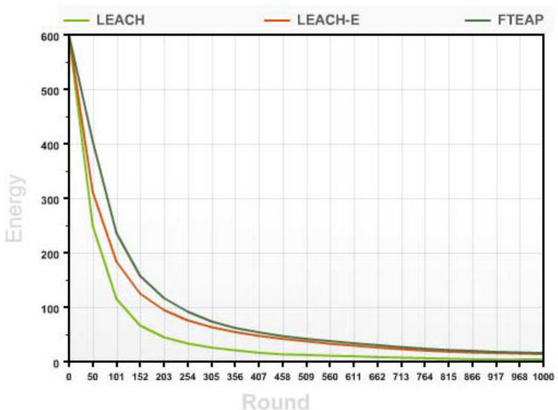

Figure 4. Total network energy with N=200 nodes

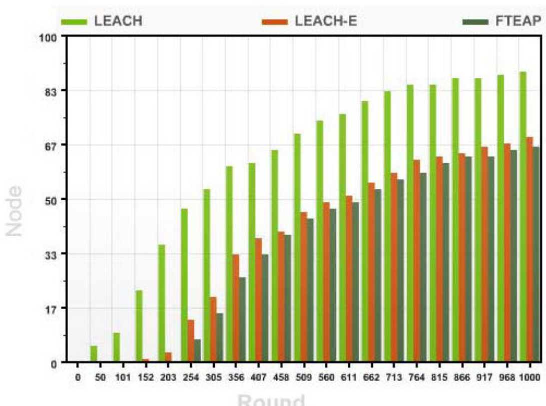

Figure 5. Total dead nodes with $N=100$ nodes.

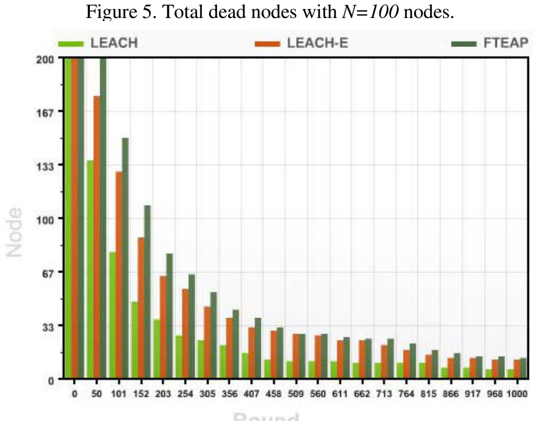

Figure 6. Total transmiting nodes with $N=200$ nodes.

CONCLUSIONS

In wireless sensor networks, the energy consumption and the network lifetime are important issues for the research of the routing protocol. This paper introduces FTEAP protocol that distributes loads among more powerful nodes. Ease of deployment, energy conservation, fault tolerant operation, and extension of network lifetime make FTEAP protocol a desirable and strong protocol for wireless sensor networks. Simulation results show that FTEAP protocol has a better performance than LEACH and LEACH-E protocols.

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