Improvement of LEACH for fault tolerance in sensor networks

Mohamed Lehsaini, Hervé Guyennet

Improvement of LEACH for fault tolerance in sensor networks

Mohamed LEHSAINI[1], Herve GUYENNET[2]

[1]STIC Laboratory, Faculty of Technology, University of Tlemcen, 13000Tlemcen Algeria
[1]m_lehsaini@mail.univ-tlemcen.dz
[2] LIFC Laboratory, University of Franche-Comte, 25030 Besancon, France
[2]herve.guyennet@femto-st.fr

Abstract. In wireless sensor networks, failures occur due to energy depletion, environmental hazards, hardware failure, communication link errors, etc. These failures could prevent them to accomplish their tasks. Moreover, most routing protocols are designed for ideal environment such as LEACH. Hence, if nodes fail the performance of these protocols degrade. In this context, we propose two improved versions of LEACH so that it becomes a fault-tolerant protocol. In the first version, we propose a clustered architecture for LEACH in which there are two cluster-heads in each cluster: one is primary (CHp) and the other is secondary (CHs). In the second version, we propose to use the checkpoint technique. Finally, we conducted several simulations to illustrate the performance our contribution and compared obtained results to LEACH protocol in a realistic environment.

Keywords: LEACH, FT1-LEACH, FT2-LEACH, Fault-tolerance, Checkpoint, WSN.

1 Introduction

Wireless sensor networks (WSN) consist of a large number of low-cost and low-powered sensor devices, communicating with each other through wireless links and collaborating to accomplish a common task. Sensors can be deployed over a geographical area for monitoring physical phenomena like temperature, humidity, vibrations, seismic events, and so on [1]. Now, WSN are permeating a variety of application domains such as avionics, environmental monitoring, structural sensing, telemedicine, space exploration, and command and control.

WSN should have a long lifetime to accomplish the application requirements. However, In addition to resource constraints in WSN, the failure of sensor nodes is almost unavoidable due to energy depletion since they have been usually deployed in hostile environments and their batteries cannot be recharged or replaced, hardware failure, communication link errors, and so on [2,3,4]. Therefore, in WSN, fault tolerance has become as important as other performance metrics such as energy efficiency, latency and accuracy.

In general, the consequence of these failures is that a node becomes unreachable, violates certain conditions that are essential for providing a service or returns false readings which could cause a disaster especially in critical applications. Furthermore, the above fault scenarios are worsened by the multihop communication nature of WSN. It often takes several hops to deliver data from a source node to the remote base station; therefore, failure of a single node or link may lead to missing reports from the entire region of WSN.

Therefore, since sensors are prone to failure, fault tolerance should be seriously considered in many sensing applications which are generally required to be fault-tolerant, where any pair of sensors is usually connected by multiple communication paths. Recently, several studies have dealt with fault tolerance in WSN, particularly in the routing process. Moreover, these works focus on the detection and recovery of failures in WSN.

We evaluate LEACH in a realistic environment in which sensor nodes can fail and links may be lost. Then, we propose two improved versions FT1-LEACH and FT2-LEACH of LEACH so it is fault tolerant. FT1-LEACH involves two cluster-heads in each cluster one is primary and the other secondary and FT2-LEACH use the check-point technique. Moreover, cluster-heads are elected based on their capabilities. Furthermore, in clusters, main cluster-heads and their vice cooperate with each other to reduce extra costs by sending only one copy of sensed data to the sink.

FT1-LEACH and FT2-LEACH could tolerate links failures and therefore guarantee routing reliability in WSN while dissipating less extra energy and time. Finally, we conducted several simulations to demonstrate the performance of our contribution and we compared obtained results with those of LEACH [5] in a realist environment.

The rest of this paper is organized as follows: Section 2 presents briefly the protocol LEACH; in Section 3, we propose two improved versions of LEACH; Section 4 illustrates performance analysis of LEACH and the proposed schemes in a realistic environment. Finally, we conclude our paper and discuss future research work in Section 5.

2 Presentation of LEACH

LEACH (Low Energy Adaptive Clustering Hierarchy) is a hierarchical cluster-based routing protocol for wireless sensor networks which partitions the nodes into clusters. In each cluster a dedicated node called Cluster-head (CH) and other nodes are cluster members. CH is responsible for creating and manipulating a TDMA schedule and sending aggregated data from nodes to the base station using CDMA technique. Moreover, this protocol is divided into rounds and each round consists of two phases:

2.1 Setup Phase

During this phase, cluster formation takes place. In which, each sensor node decides independently of other nodes if it will become a CH or not. This decision takes into account when the node served as a CH for the last time i.e. the node that has not been a CH for long time is more likely to elect itself as a CH.

Once CHs are elected, they inform their neighborhood with an advertisement packet that they become CHs. Each non-CH node picks the advertisement packet with the strongest received signal strength and it sends the message "Join Packet" to request to join its corresponding CH.

After this process, the CH knows the number of member nodes and their IDs. Based on all messages received within the cluster, the CH creates a TDMA schedule and broadcast it to its cluster members. Then, it picks a CSMA code randomly to avoid interference when transmitting data to the base station.

2.2 Steady-state phase

During this phase, data transmission begins. Sensor nodes send their data collected during their allocated TDMA slot to their respective CHs. The radio of each non-CH node can be turned off until the nodes allocated TDMA slot, thus minimizing energy dissipation in these nodes. When all the data has been received, the corresponding CH aggregates these data and sends them to the remote base station as presented by Fig. 1.

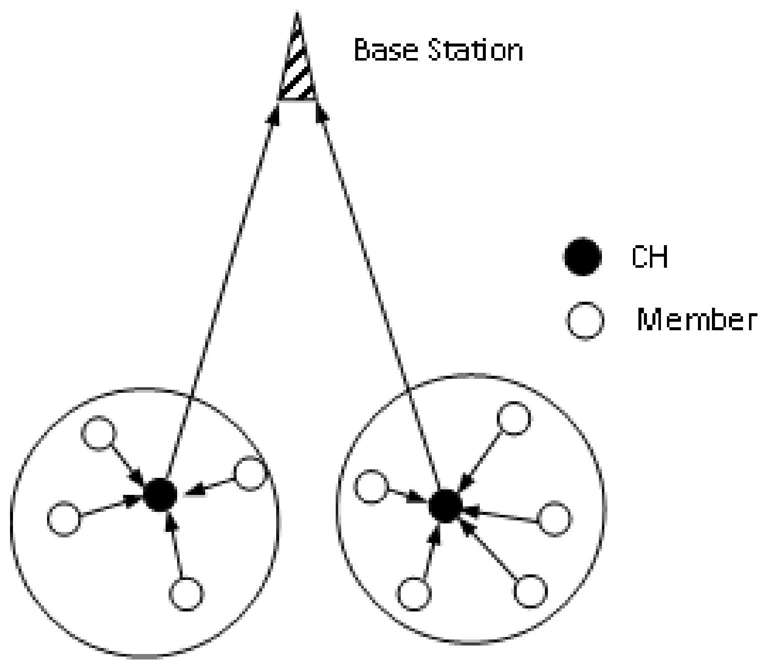

Fig. 1. Cluster formation in LEACH

LEACH is able to perform local aggregation of data in each cluster to reduce the amount of data that transmitted to the base station. Although LEACH protocol acts in a good manner, it suffers from many drawbacks such like;

- CH selection is randomly, that does not take into account energy consumption and CHs can quickly deplete their batteries and hence they stop working and cause holes in the target area.
- It cannot cover a large area when some sensor nodes fail.

Since LEACH has many drawbacks, many works have been done to make this protocol performs better but to the best our knowledge there is no work dealing with fault-tolerance in LEACH.

3 Contribution

In most routing protocols, fault-tolerance was not considered particularly in LEACH. In this context, we propose two improved versions of LEACH protocol so that it becomes a fault-tolerant protocol. In the first version called FT1-LEACH, we propose a clustered architecture for LEACH in which there are two cluster-heads in each cluster: one is primary (CHp) and the other is secondary (CHs). In the second version, we propose to use the checkpoint technique to make LEACH as a fault-tolerant protocol.

3.1 Contribution 1: FT1-LEACH

FT1-LEACH is performed in three consecutive phases:

Cluster formation.
This phase is performed in two steps:

Election of primary cluster-heads (CHp).
The election of primary cluster-heads is made in the same way as in LEACH based on the probability of being cluster-heads during this period.

Election of secondary cluster-heads (CHs).
After the election of CHp, this step begins wherein each sensor calculates its weight which is a combination of 2-density $(\rho_2(u))$and residual energy $(E(u))$ as presented in Eq. (1) We involve 2-density factor in the purpose to generate clusters whose members are linked with cluster-heads and remaining energy parameter to select the nodes with more energy in their 2-neighborhood. Then, each cluster member generates a 'Hello' message including two extra fields addition to other regular contents: Weight and CHp and broadcast it as well as it eavesdrops its neighbor's 'Hello' message. The node with the largest weight in each cluster is elected as secondary cluster-head (CHs).

$$Weight(u) = \alpha * \rho_2(u) + \beta * E(u) \quad \wedge \quad \alpha + \beta = 1 \qquad (1)$$

The values of α and β are chosen depending on the application. For example if we want to favor the node that has more energy as cluster-head we would attribute great value to β.

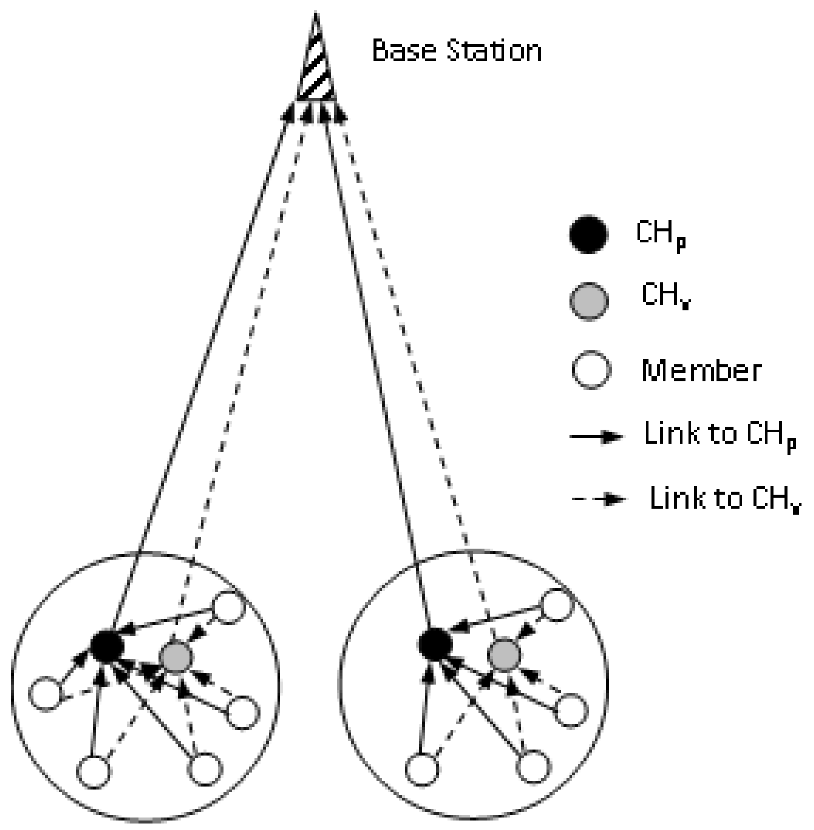

Fig. 2. Cluster formation in FT1-LEACH

Routing paths.

When a node detects a relevant event, it sends it to its corresponding cluster-heads (CHp and CHs). If the primary cluster-head does not send to the remote base station within a threshold time interval, the secondary cluster-head considers it that is down and it sends data to the base station.

There are two kinds of routing:

Intra-cluster.

Cluster members do not transmit data collected directly to the base station but they send them to their respective Cluster-heads (CHp and CHv).

CH-to-BS .

In each cluster, primary cluster-head is responsible to transmit the aggregated data to the remote base station and if they do not perform this task within a defined time interval the secondary cluster-head considers that the primary cluster-head is down and it sends information to the base station.

3.2 Contribution 2: FT2-LEACH

Our second contribution is based on the checkpoint technique which is considered the most typical approach to tolerate failures in parallel and distributed systems. By writing checkpoints into stable storage periodically, the checkpoint approach is able to tolerate the failure of the whole network. The advantage of this approach is that it is very general and is able to tolerate the failure of the whole network. However, the limitations of checkpoint approach are that it generally needs stable storage to save a global consistent state periodically and that it aborts all survival processes even if only one of many processes failed.

In this context, we use the base station to store availability information about cluster-heads. Each cluster-head sends periodically a message to the base station. If during a period, the base station does not receive a message from a cluster-head, it is considered as defective. As a result, the base station transmits a message to the cluster concerned to elect a cluster-head among its members. The member which has the greatest weight based on its remaining energy and its density parameter as presented in Equation (2), becomes cluster-head.

$$Weight(s) = \frac{1}{2}\, Energy(s) + \frac{1}{2}\, density(s) \qquad (2)$$

4 Evaluation and simulation results

In our experiments, we conducted extensive simulations to evaluate FT1-LEACH and FT2-LEACH performance and compare them with LEACH in terms respectively of the ratio of successful reception at the base station during the network's lifetime and energy consumption. To achieve these goals, the simulations have been performed in NS-2[6] using the MIT_uAMPS [7]. We have carried out these simulations with the same scenario presented in LEACH in order to illustrate the performance of our contribution. Hence, we considered a network topology with 100 non-mobile sensor nodes with a sensing range of 25 meters. Sensor nodes are placed randomly in a 100 m×100 m square area by using an uniform distribution function, and the remote base station is located at position x = 50, y = 125, i.e. the base station was placed 75 meters outside the area where the sensor nodes were deployed. At the beginning of the simulation, all the sensor nodes had an equal amount of energy i.e. the sensor nodes started with 2 Joules of energy. We note that system lifetime is defined as the time when last sensor dies in the sensor network.

The simulations were performed until all the sensors in the network consumed their energy and the average values were calculated after each round whose duration is 20 seconds. This duration represents the cluster timeout. It is used to prolong network lifetime and balance energy deviation among all its sensors. On expiry of this period, FT-LEACH1 and FT-LEACH2 triggered the cluster-head's election process again. Moreover, we used the same energy parameters and radio model as discussed in [8], wherein energy consumption is mainly divided into two parts: receiving and transmitting messages. The transmission energy consumption requires additional energy to amplify the signal according to the distance from the destination. Thus, to transmit a k-bit message to a distance d, the radio expends energy (E_{Tx}) as described by the formula (3), where ε_{elec} is the energy consumed for radio electronics, $\varepsilon_{friss\text{-}amp}$ and $\varepsilon_{two\text{-}ray\text{-}amp}$ for an amplifier. The reception energy consumption is $E_{Rx} = \varepsilon_{elec} \times k$.

$$E_{Tx} = \begin{cases} \varepsilon_{elec} * k + \varepsilon_{friss-amp} * k * d^2 & if\ d < d_{Crossover} \\ \varepsilon_{elec} * k + \varepsilon_{two-ray-amp} * k * d^4 & if\ d \geq d_{Crossover} \end{cases} \quad (3)$$

Simulated model parameters are set as shown in Table 2. The data size were 500 bytes/message plus a header of 25 bytes. The message size to be transmitted was:

$$k = (500\ bytes + 25\ bytes) \times 8 = 4\ 200\ bits$$

Table 1. Model Parameters

Parameter	Value
Network grid	(0,0) x (100,100)
Base Station	(50,125)
ε_{elec}	50 nJ/bit
$\varepsilon_{friss-amp}$	10 pJ/bit
$\varepsilon_{two-ray-amp}$	0.0013 pJ/bit
$d_{Crossover}$	87 m
Data packet size	500 bytes
Packet Header size	25 bytes
Intial energy per node	2 J
Number of nodes (N)	100

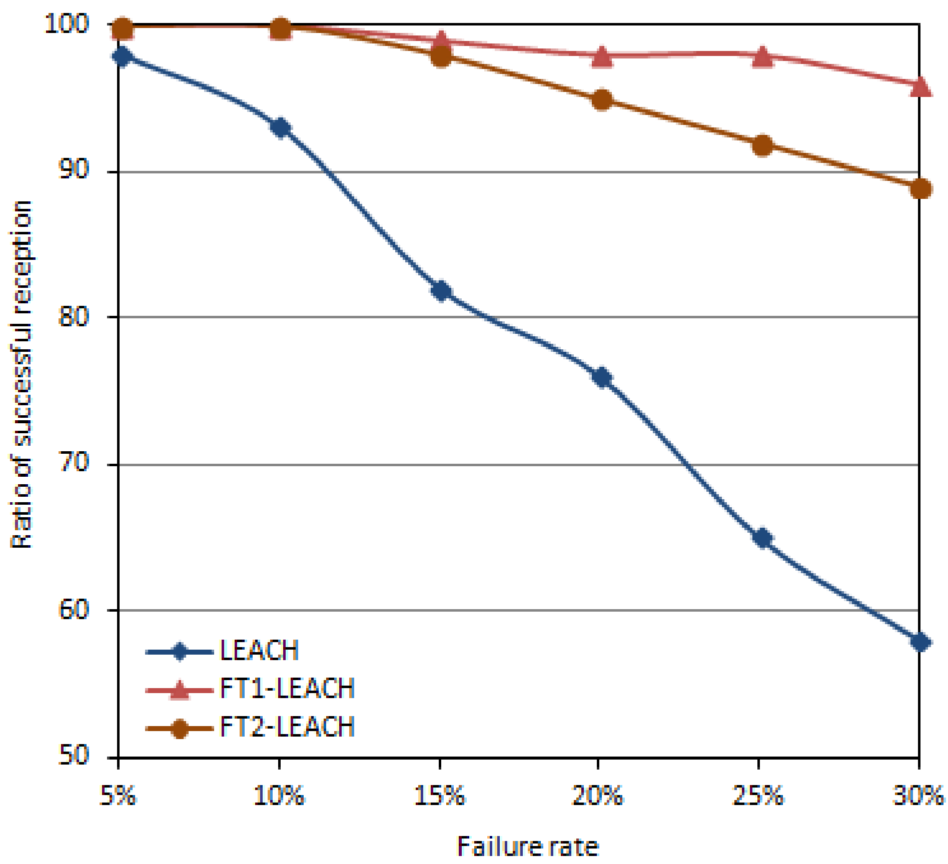

Fig. 3. Ratio of successful reception with different failure rates

Fig.3 shows that the ratio of successfully received packets to the base station is higher than in LEACH because in LEACH, if a cluster-head stops working information will not be forwarded to the base station while in LEACH-FT1 if the main cluster-head is down its vice transmits the information to the base station. However, in LEACH-FT2, a cluster-head may fail before the end of the warning period the base station.

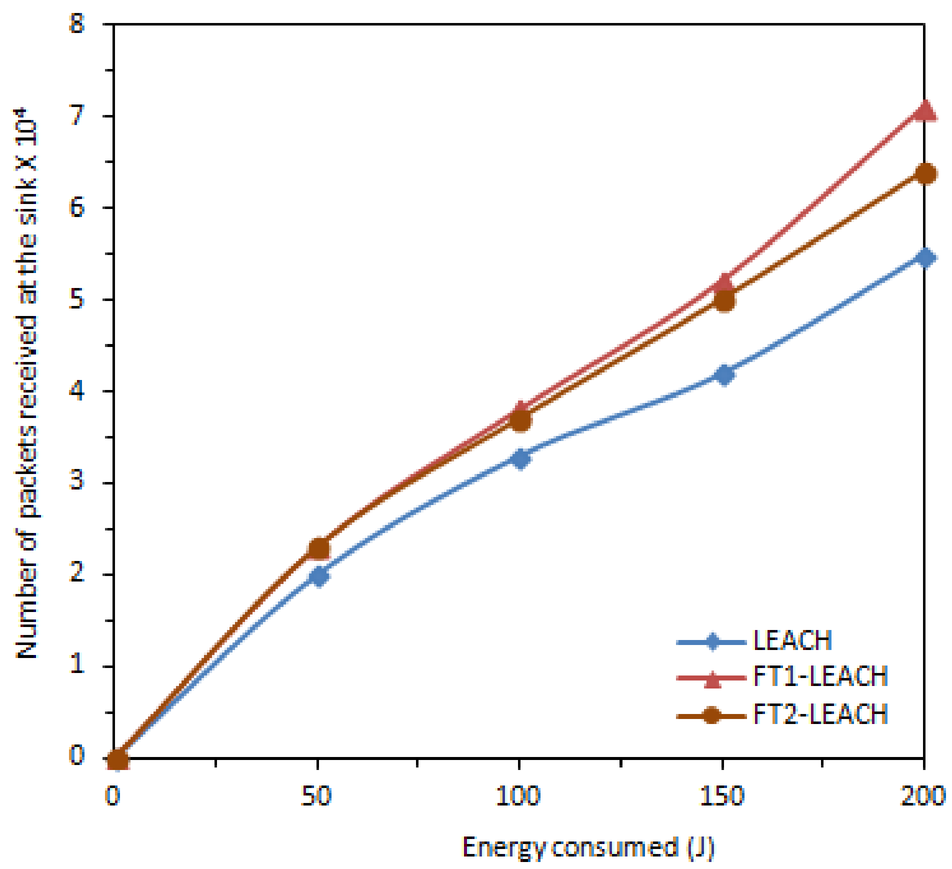

Fig. 4. Amount of packets received at the sink during network lifetime

Fig.4 illustrates that in FT1-LEACH and FT2-LEACH, the amount of packets received at the base station during network lifetime is higher than in LEACH because in LEACH, if a cluster-head stops working information will not be forwarded to the base station and hence the energy will be lost without sending information. Furthermore, in FT1-LEACH and FT2-LEACH if the main cluster-head is down its vice transmits the information to the base station and hence the energy consumed reflects a transmission.

5 Conclusion

The evaluation of LEACH in a realistic environment showed that LEACH loses performance when some nodes fail. In this context, we have proposed two improved versions of LEACH so it becomes a fault-tolerant protocol.

Simulation results showed that our contributions have improved the performance of LEACH in terms of number of packets successfully received at the base station and the energy to send these packets to the base station.

Reference

1. Akyildiz I.F., Su W., Sankarasubramaniam Y., Cayirci E.,“Wireless sensor networks: a survey”. Computer Networks (Elsevier). Vol.38, No.4, pp 393-422, March 2002.
2. A. Woo, T. Tong, and D. Culler,"Taming the underlying challenges of reliable multihop routing in sensor networks". Proceedings of the 1st International Conference on Embedded Networked Sensor Systems, pp.14-27, November 2003.
3. L. Paradis and Q. Han, "A Survey of Fault Management inWireless Sensor Networks", Journal of Network and Systems Managemen, Vol.15, No.2, pp.171-190, 2007.
4. H.M. Ammari and S.K; Das, "Fault tolerance measures for large-scale wireless sensor networks", Journal ACM Transactions on Autonomous and Adaptive Systems (TAAS), Vol. 4, No. 1, pp.1-28, 2009.
5. Heinzelman and al. ‘Energy-efficient communication protocol for wireless microsensor networks’, IEEE Proceedings of 33rd Annual Hawaii International Conference on System Sciences (HICSS '00), Vol. 2, Maui, Hawaii, USA, January 2000.
6. NS-2, Network Simulator, World Wide Web, www.isi.edu/nsnam/ns/ns-build.html
MIT_uAMPS LEACH NS2 Extensions, World Wide Web,
7. www.ece.rochester.edu/research/wcng/code/index.html.
8. Heinzelman and al. ‘An application-specific protocol architecture for wireless microsensor networks’, IEEE Transactions Wireless Communications, Vol. 1, No. 4, pp.660–670, October 2002.

.