Hard network lifetime wireless sensor networks with high energy first clustering

G.JAYASEELAN
Department of Electronics and Communication
AVC College of Engineering,Mannampandal,Mayiladuthurai.609305,Tamilnadu,India.
jacobgjayaseelan@gmail.com

S.K.RAJALAKSHMI
Department of Electronics and Communication
AVC College of Engineering,Mannampandal,Mayiladuthurai.609305,Tamilnadu,India.
raji.paramu@gmail.com

Abstract—Wireless sensor network (WSN) requires robust and energy efficient communication protocols to minimize the energy consumption as much as possible. However, the lifetime of sensor network reduces due to the adverse impacts caused by radio irregularity and fading in multi-hop WSN. A cluster-based scheme is proposed as a solution for this problem. The proposed scheme extends High Energy First (HEF) clustering algorithm and enables multi-hop transmissions among the clusters by incorporating the selection of cooperative sending and receiving nodes. The performance of the proposed system is evaluated in terms of energy efficiency and reliability. Simulation results show that tremendous energy savings can be achieved by adopting hard network lifetime scheme among the clusters. The proposed cooperative MIMO scheme prolongs the network lifetime with 75% of nodes remaining alive when compared to LEACH protocol. HEF algorithm proved that the network lifetime can be efficiently prolonged by using fuzzy variables (concentration, energy and density). Providing a trustworthy system behavior with a guaranteed hard network lifetime is a challenging task to safety-critical and highly-reliable WSN applications.

Index Terms—Cluster head selection, network lifetime, Schedulability, timing constraint, wireless sensor network

ACRONYM

CFM - Cluster Formation

CHS - Cluster Head Selection

DCM - Data Communication

EDF- Earliest-Deadline First

HC WSN- Hierarchical Clustering WSN

HEF- High Energy First

LEACH Low-Energy Adaptive Clustering Hierarchy

1. Introduction:

Wireless Sensor Networks (WSNs) comprise a great number of nodes with sensing, computing, and wireless communication capabilities. WSNs are used in safety-critical or highly-reliable applications, two timing constraints are considered.

1. Real-time computing
2. Network lifetime

There are two types of real-time systems: hard real-time systems that do not allow any task to miss its deadline, and soft real-time systems that strive to satisfy deadline requirements statistically. Real-time computing has been mostly applied in the areas of sensing, data processing, aggregation, and communication with deadline constraint requirements. The network lifetime is another form of deadline, where we need to investigate new solutions in the context and property of the network lifetime. Depending on the mission requirements, network lifetime is most widely defined as: 1) The time span from the deployment of the network to when the first node runs out of energy 2) The time duration from the deployment of the network to when a certain percentage of the nodes die due to energy resource exhaustion (or) the time taken from the deployment of the network to when the network is not able to fulfill designed requirements (such as coverage, packet loss, and connectivity). When time-critical constraints (either hard real-time or hard network lifetime) are considered in WSN applications, predictability, rather than speed or energy efficiency, is of greater importance. Systems must be predictable (or deterministic),but not necessarily fast nor sufficiently long lasting to adapt to evolving situations. In a predictable WSN, we should have the confidence to determine in advance whether the specific critical tasks can be performed completely under current energy budgets, as well as within the time constraints. To provide predictability to time critical WSN applications, it is important to understand how the system behaves. Through the worst case energy consumption analysis, we develop the predictability of collective timeliness for hard network lifetime environments in this paper. The rest of the paper is organized as follows. Section II reviews the past research related to this work. We address the cluster head selection algorithms in particular, as it has a great influence on energy savings, as well as the network lifetime for hierarchical clustering WSNs. Section III describes the HEF algorithm, and presents the HEF optimality under certain ideal conditions. Section IV describes an energy model with several adjustable parameters to analyze the worst case for energy consumptions. The predictability of HEF is discussed in Section V. Section VI presents the simulation results that demonstrate the superiority and predictability of HEF. Finally, concluding remarks are made in Section VII.

2. Related works:

Researchers and practitioners have addressed various technical challenges that are due to WSN system limitations such as limited battery capacity, and primitive computing capabilities. Among all design goals for WSNs, network lifetime is considered to be the most important. One of the research topics that has gathered significant interest is the issue of prolonging network lifetime under energy constraints. In this paper, we focus on the study of the optimality and predictability of the network lifetime for the *Hierarchical Clustering WSN* (HC-WSN).A typical HC-WSN is comprised of a base station, several cluster head nodes, and regular sensor nodes. For administrative purposes, the operation of a HC-WSN is divided into rounds in which sensor nodes are grouped into clusters. Each round consists of three phases: cluster head selection (CHS), cluster formation (CFM), and data communication (DCM). The deterministic behaviors of a HC-WSN are typically characterized by the above three phases.

2.1.HC-WSN CHS Algorithms without Energy Awareness:

The cluster head selection processes for this type of clustering do not require sensors to be aware of any a priori energy information. However, without awareness of the energy information, cluster heads cannot be rotated, and traffic loads cannot be shared. As a result, it is difficult for sensors to choose the most appropriate cluster heads to maximize their network lifetime, and hot-spot cluster head sensors die quickly. In the literature, one example of CHS algorithms without energy awareness is the Lower ID heuristic, which uses the static node ID scheme to choose the node with the minimum node ID as a cluster head. Crosby *et al.* Proposed an election process by secret ballot votes to identify a node that receives the majority vote of those seated in a cluster as a new cluster head, and a node with the second highest number of votes as the vice cluster head. After the election process, the current cluster head multicasts the results to all the members of the cluster, informing the nodes of the cluster head, and vice cluster head. The back off mechanisms in the contention window to guarantee a sensor node be elected as a cluster head at least a certain number of times so that all nodes have an opportunity to work as a cluster head at each round. In their short-term fairness based approach, a cluster head node will not take part in the contention of cluster head election until all sensor nodes have already been a cluster head exactly.

2.2. HC-WSN CHS Algorithms with Energy Awareness:

The cluster head selection processes for this type of clustering require partial knowledge on system energy levels and environment conditions. To maximize the network lifetime, some schemes pursue short-term fairness in time by sharing the energy consumption loading, while some others try to form clusters according to the geographical position of sensors. They attempt to find the optimal tradeoff between the energy consumptions on communication overhead and the energy savings by appropriately forming the clusters. Nevertheless, none of the above cluster head selection algorithms addresses the Schedulability analysis issue in their proposed algorithms. Although some of their approaches are optimal, the predictability of optimality is stochastic (non-deterministic).In other words, the above algorithms do not guarantee that the hard network lifetime constraints could be met. To the best of our knowledge, this paper is the first paper that discusses the Schedulability analysis of the WSN cluster head selection algorithm in hard network lifetime environments.

3.HEF Clustering Algorithm:

The core idea of the HEF clustering algorithm is to choose the highest-ranking energy residue sensor as a cluster head. The HEF clustering algorithm is defined as follows. HEF is designed to select the cluster head based on the energy residue of each sensor to create a network-centric energy view. Each round comprises the following three phases: CHS Phase, CFM Phase, and DCM Phase

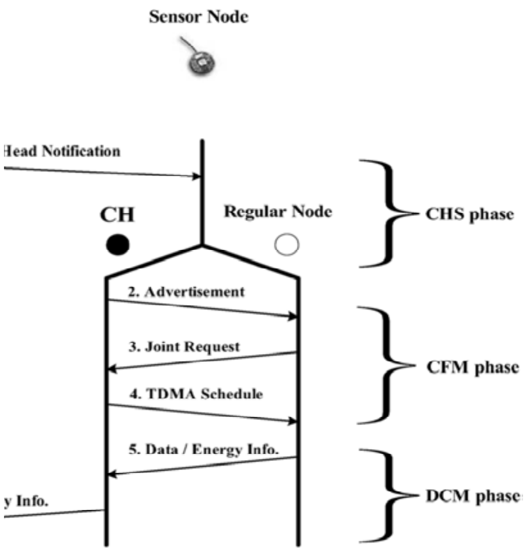

Fig. 1 Information flow of the centralized HEF system

The interactions and detailed operations between components are discussed as follows.

1) HEF selects cluster heads according to the energy remaining for each sensor node, and then the "setup" message (indicating cluster members, and the cluster head ID for each participated group) is sent to the cluster head of each cluster.

2) The cluster head of each group broadcasts the "setup" message inviting the neighbor sensor nodes to join its group.

3) After receiving the "setup" message at this round, the regular sensors send the "join" message to its corresponding cluster head to commit to associate with the group.

4) Each cluster head acknowledges the commitment, and sends TDMA schedule to its cluster members.

5) All sensors perform its sensing and processing and communication tasks cooperatively at this clock cycle (round).Each sensor sends its energy information to its cluster head at the end of this clock cycle.

6) Upon collecting cluster members' information at a given period, the cluster head sends the summative report to the base station.

3.1 Optimal Condition for HEF:

The HEF clustering algorithm and its variants are not new, but this paper is the first work to formulate the HEF algorithm analytically to characterize its optimality property. Before characterizing the optimality of HEF, we first define some notations used in this study. Let us denote V as the set of sensor nodes deployed, and let N represent the total count of the sensor nodes (N=|V). Furthermore, we define as the residue energy level of the sensor node in -th round. Moreover, , and denote the energy consumption for a cluster head, and a regular node in a round. Suppose that a sensor node has residue energy, and at the beginning of round and immediate round respectively

3.2 Ideal Conditions for Optimality of HEF (ICOH):

1) All nodes must operate in a working-conserving mode. In other words, each node works as a clutter head, or a regular sensor in a round.

2) The energy consumptions are constant during the entire operation.

4. Energy Consumption Model:

At this point, we have shown that, If we can get the initial energy information of all sensors, HEF provides optimal cluster head selection with respect to network lifetime under the ICOH. Under the ICOH condition, we assume that the energy consumption of ω_c and ω_r are constant during the entire operation. However, in actual environment ω_c and ω_r are not constant the amount of energy consumed by a sensor node depends on the role it serves, as well as the workload it handles. To analyze hard network lifetime for guaranteed schedulability, the worst-case energy consumption (WCEC) analysis is used. Let ω_c^*, ωc_+, ω_r^*, ω_{r+} denote the maximum, and the minimum energy consumed for a cluster head, and a regular node in a round respectively. For a given ω_c^*, ωc_+, ω_r^*, ω_{r+} fixed network topology, we can assume that

$$\omega_c^* \geq \omega c_+ \quad (1)$$

$$\omega_c^* \geq \omega_r^*,\ \omega c_+ \geq \omega_{r+},\ \omega_r^* \geq \omega_{r+} \quad (2)$$

Furthermore, the energy consumption model does not consider energy consumed on the initialization tasks and the failure routines. The energy consumption model provides the ability to control the number of cluster heads used in each round, which makes the energy consumption analysis more accurate, and allows a tighter bound for the network lifetime to be found. In each round, each sensor node sends the sensed data to its corresponding cluster, which forwards the information to the base station. WSN nodes are primarily equipped with three types of tasks namely sensing, processing, and communicating data to other nodes and ultimately to the sink (base station). To avoid non-uniform distribution of cluster heads, cluster heads are selected according to their residual energy, and a predefined energy level difference is used to enforce the cluster head rotation inside the cluster. proposed that all nodes contain a cluster head probability that is recomputed based on each round, and node priority (such as residual energy and node ID) will take effect in case of a tie. Proposed a cluster head node located at the center of the cluster where each node associated with hop number information to any other nodes. HEED (Hybrid Energy-Efficient Distributed clustering) periodically selects cluster heads based on a hybrid of residual energy, and a secondary index (such as node proximity to its neighbors or node degree).

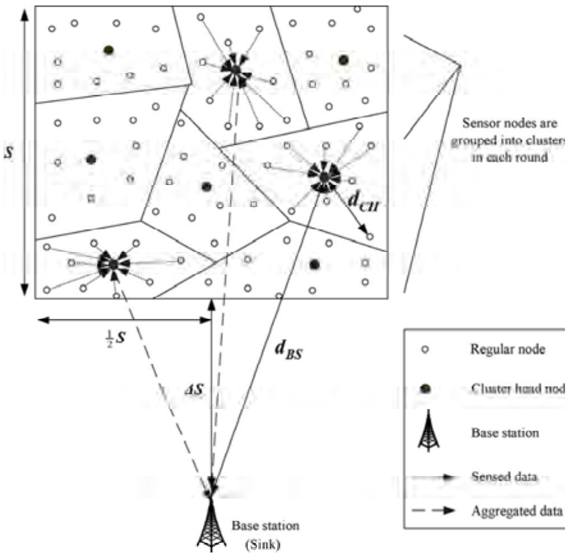

Fig. 2 Energy Consumption model

5. Schedulability Analysis Of HEF:

The most important property of the WSN network lifetime is not longevity, but predictability. Schedulability tests are essential for the time-critical system because it provides predictability to complement online scheduling. Cluster head selection algorithms produced by empirical techniques often result in highly unpredictable network lifetimes. Although an algorithm can work very well to prolong the network lifetime for a period of time, a possible failure can be catastrophic, resulting in the failure of a mission, or the loss of human life. A reliable guarantee of the system behaviors is hence a requirement for systems to be safe and reliable. However, there are currently no known analytical studies on the network lifetime predictability for cluster head selection algorithms. Thus, we apply the worst-case energy consumption analysis to derive the predictability of HEF. Activities and measures for the minimum and maximum energy consumption of the cluster head and the regular node are conducted in the Energy Estimation stage. In the Schedulability Analysis stage, schedulability test results provide the necessary information to all running scenarios. If the running case is not schedulable, the feedback process can be used to alternate the WSN deployment plan or other configuration parameters (such as coverage range), which can be used to re-design the system. The problem, however, is that no such formal network lifetime analysis methods currently exist. Thus, we approach this problem by first formally introducing the problem of hard network lifetime constraint. Then, we present a simple closed-form test for determining whether a sensor-set is schedulable or not (guaranteeing all nodes to meet network lifetime constraints) in terms of the N-of-N lifetime for the HEF cluster head selection algorithm.

6. Simulation:

In this section, we demonstrate that the derived results above are consistent with simulation results. We use NS2 to conduct of HEF with that of LEACH, and investigate the feasibility of HEF. There are 100 sensor nodes, organized in a random topology, and randomly deployed in a square region 100* 100 meters in size. The base station is located at the position (50, 180).

Table 1 The simulation parameters

PARAMETERS	VALUE
Number of nodes	100
Number of cluster	5
Base station location	50,180
Ratio speed	1Mbps
Header size	25bytes
Compression ratio(α)	0.5

6.1 Smooth Consumption at the Minimum Energy Level:

When considering the N-of-N lifetime problem (i.e., the time span from the deployment of the network to the instant the first node runs out of energy), we should recognize that the length of the N-of-N lifetime depends on the minimum energy level out of all sensors. There are two energy distribution types which define the initial power level. They are Leach and HEF. The comparison results between HEF and LEACH are presented in Fig. 3 where the Y-axis represents the minimum residue energy level of sensors, and the X-axis denotes the lifetime for individual rounds. Each point in the figure represents the result of the worst case in 100 experiments. From Fig. 3, the following observations are made.

a. With the same energy distributions, HEF has more minimum residual energy than LEACH during the running time. Both HEF and LEACH have the same residual energy in the beginning, but HEF gradually has more minimum residual energy than LEACH after a certain period of time (either 10 rounds for variance 0.09 and 0.36, or 20 rounds for variance 0). The results show that HEF further prolongs the network lifetime when compared with LEACH.

b. Given a fixed mean value of energy for a WSN, the larger the variance of the energy distribution, the lower the minimum energy level. The results show that cluster selection algorithms with the variance 0 has the longest network lifetime compared to that with a variance of 0.09 or 0.36.

c. When the variance of the energy is 0.09, there is a significant performance gap between HEF and LEACH algorithms. The performance gap becomes smaller in either a small or a large range of variances.

The simulation results show that HEF is able to smooth out the peaks and valleys that show on the minimum residual energy. As such, HEF outperforms the well-known LEACH algorithm on prolonging life span. In addition, the variance of mean energy distributions makes it more appealing to HEF than LEACH at certain values of the variance.

6.2. Initial Energy on Network Lifetime

In this study, the network lifetime performance is evaluated for both the HEF and LEACH models under various initial energy ranging .Fig. 4 shows that the lifetime increases with the initial energy increase. Their performances are also compared under the same mean values of energy, but with different variances. Each point in the figure represents the result of the worst case in 100 experiments. We make the following observations.

a. With the increase in initial energy, the lifetime for all schemes increases, but HEF prolongs the network lifetime as compared to LEACH when the initial energy becomes large enough. This result is because LEACH is unable to balance the energy consumption among the sensor nodes to avoid early energy depletion of the network.

b. When the initial energy level is low, there is no significant performance difference between HEF and LEACH. However, HEF has better performance at a small variance.

c. The HEF algorithm performs better out of all LEACH schemes under high initial energy level.

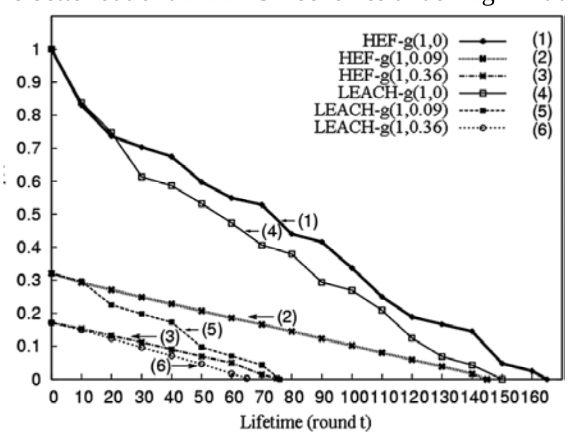

Fig. 3 Minimum remaining energy in each round

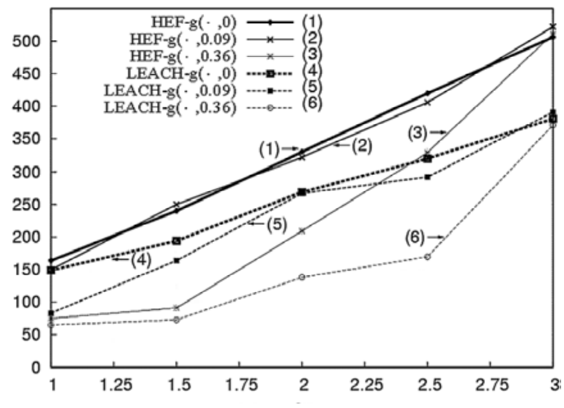

Fig. 4 Mean of energy in each round

The initial energy (for the 100 sensor nodes) follows a Gaussian distribution with mean 1J and variance 0.04. The experiments are conducted 100 times. The simulation results are aligned with the results obtained from the lower and upper bounds described in the previous section. In other words, all the values of the experiment results are between the upper bounds (L*, and L**) and the lower bounds (L_*, and L_{**})

7. Conclusion:

Providing a trustworthy system behavior with a guaranteed hard network lifetime is a challenging task to safety-critical and highly-reliable WSN applications. For mission critical WSN applications, it is important to be aware of whether all sensors can meet their mandatory network lifetime requirements. In this paper, we have addressed the issue of the predictability of collective timeliness for WSNs of interests. First, the High Energy First (HEF) algorithm is proven to be an optimal cluster head selection algorithm that maximizes a hard N-of-N lifetime for HC-WSNs under the ICOH condition. Then, we provide theoretical bounds on the feasibility test for the hard network lifetime for the HEF algorithm. Our experiment results show that the HEF algorithm achieves significant performance improvement over LEACH, and HEF's lifetime can be bounded. We have also developed formulas to derive the upper and lower bounds of the network lifetime quickly and easily (including both loose, and sharp bounds). In particular, the feasibility test analysis performed in this paper presented a solution that would guide the system administrator to ensure that the system lifetime is predictable.

References

[1] B. Kim, Y. Kim, I. S. Lee, and I. You, "Design and Implementation of a Ubiquitous ECG Monitoring System Using SIP and the Zigbee Network,"in Future Generation Communication and Networking(FGCN2007), 2007, pp. 599–604

[2] B.-C. Cheng, A. Stoyenko, T. Marlowe, and S. Baruah, "LSTF: A new scheduling policy for complex real-time tasks in multiple processor systems," Automatica, vol. 33, no. 5, pp. 921–926, May 1997.

[3] C. L. Liu and J. W. Layland, "Scheduling algorithms for multiprogramming in a hard-real time environment," Journal of the Association for Computing Machinery, vol. 20, no. 1, pp. 46–61, January 1973.

[4] J. A. Stankovic and K. Ramamrithan, Eds., Tutorial on Hard Real-Time Systems. : IEEE Computer Society Press, 1988.

[5] J. H. Chang and L. Tassiulas, "Routing for maximum system lifetime in wireless ad-hoc networks," in Proc. 37. th. Annual Allerton Conf. on Communication, Control, and Computing, Monticello, IL, Sep. 1999

[6] J. Lichtenegger, G. Calabresi, and A. Petrocchi, "A near-real time oil slick monitoring demonstrator for the Mediterranean," in XIX ISPRSCongress, Amsterdam, The Netherlands, 2000, pp. 193–200, XXXIII.

[7] M. Qin and R. Zimmermann, "Studying upper bounds on sensor network lifetime by genetic clustering," in IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS 2005), Marina del Rey, California, June 30-July, 1, 2005.

[8] M.Sirivianos, D.Westhoff, F. Armknecht, and J. Girao, "Non-manipulable aggregator node election protocols for wireless sensor networks,"in ICST WiOpt, 2007

[9] R. Cristescu and M. Vetterli, "On the optimal density for real-time data gathering of spatio-temporal processes in sensor networks," in Fourth International Conference on Information Processing in Sensor Networks (IPSN '05), April 2005

[10] R. L. Nord and B. C. Cheng, "Using RMA for evaluating design decisions,"in Second IEEE Workshop on Real-Time Applications,Washington,DC, July 1994.

[11] T. He, P. A. Vicaire, T. Yan, L. Luo, L. Gu, G. Zhou, R. Stoleru,Q.Cao, J. A. Stankovic, and T. Abdelzaher, "Achieving real-time

[12] Target tracking using wireless sensor networks," in ACMTransactions on Embedded Computing Systems (TECS), 2007.

[13] T. He, J. A. Stankovic, C. Lu, and T. Abdelzaher, "SPEED: A stateless protocol for real-time communication in sensor networks," in Proceedings of the 23rd International Conference on Distributed Computing Systems (ICDCS'03), May 2003.