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OPTIMAL PRECISION ALLOCATION THROUGH PA ALGORITHM IN WIRELESS SENSOR NETWORK APPLICATIONS

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ABSTRACT

Wireless sensor networks(WSN) comprises a hundreds to thousands of small nodes employed in wide range of data gathering applications such as military, health care monitoring and many other fields. Due to limited energy there is a difficultly in recharging a large number of sensor nodes, so energy efficiency and maximizing the network lifetime are the most important goals of sensor network. WSN requires robust and energy efficient communication protocols to minimize the energy consumption as much as possible. However, the lifetime of multi-hop WSN is reduced by radio irregularity and fading. A cluster-based scheme is proposed as a solution. The proposed scheme extends High Energy First (HEF) clustering algorithm and enables multi-hop transmissions among the clusters by incorporating the selection of supportive sending and receiving nodes. The performance is evaluated in terms of energy efficiency and reliability. The planned obliging algorithm HEF broadens the network era with 75% of nodes remaining alive when compared to Low Energy Adaptive Clustering Hierarchy (LEACH) protocol.

Key Words : Cluster head selection, network lifetime, timing constraint, wireless sensor network.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) comprise a great number of nodes with sensing, computing, and wireless communication capabilities. Sensor networks become more and more popular as cost of sensor gets cheaper and cheaper. The sensor network is a wireless network formed by a group of sensors deployed in same region, which can be used to measure air pressure, temperature, acceleration, etc. Sensors transmit signals via radio signal. Since sensors are now small and cheap, they can be deployed in large scale. They become more and more important for applications like security, traffic monitoring, agriculture, war field, etc.

Inexpensive sensor nodes are deployed to the sensing area with little mobility and high density. The sensor nodes have very limited battery power and computing capability. Hence, the sensor networks should be well organized to meet the task. The objective of the clustering algorithm is to partition the network into several clusters. WSNs are used in safety-critical or highly reliable applications, two timing constraints are considered .Real time constraints and network lifetime constraints (as shown in Fig. 1).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.

For these systems, research advances such as Rate-

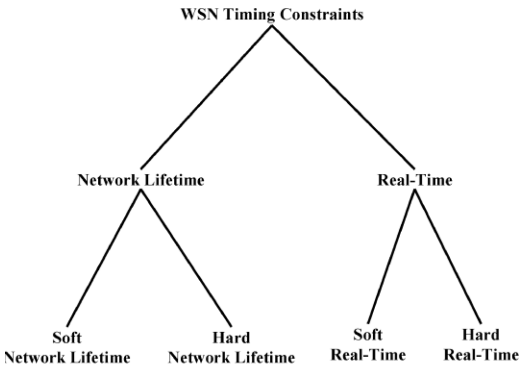

Fig. 1. Two time constraints on WSN based safety critical system

Monotonic Scheduling (RMS) and Earliest-Deadline First (EDF) scheduling algorithms have facilitated efforts by the real-time research community to minimize the risk of harm to all involved with good success. With respect to WSNs, 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 WSN is characterized as a hard lifetime WSN in which every node must continue to function until the obligatory dead- line. 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 3) the time taken from the deployment of the net- work to when the network is not able to fulfill designed requirements (such as coverage, packet loss, and connectivity).

A hard network lifetime requirement for a WSN means that the system must guarantee that at least K nodes are active at each round during the period from the start of operation to the end of the designated lifetime. Conversely, a soft network lifetime WSN makes a best effort, and has a certain level of acceptance of lifetime misses (as shown in Fig. 1). Time-critical WSN systems are ubiquitous in many practical applications. In the literature, researchers have applied them in applications such as target tracking systems, pollution monitoring, and health care. They are briefly discussed below.

In target tracking systems, such as wildlife monitoring systems or border security surveillance systems, sensor nodes may be required to detect and classify a fast moving target within one second before it moves out of the sensing range.

In an oil pollution monitoring system application, it is a requirement to process collected data over waters, and provide relevant oil-spill location information to the pollution control authority within one hour.

In the health care application arena, a wearable sensor is required to meet the real-time specifications for collecting and transferring patient data (e.g., electrocardiography) to the monitoring server with a signal sampling rate of 150 times per second.

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.

II. HC-WSN CHS Algorithms

There are 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 have gathered significant interest is the issue of prolonging network lifetime under energy constraints. Several solutions to maximize network lifetime are available, and each approach provides different magnitudes of energy savings and levels of efficiency.

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. However, the CHS phase plays the most dominant role with respect to the optimality and predictability of the entire network operation. A smart cluster head selection strategy can significantly reduce energy consumption, which in turn prolongs the network lifetime. Furthermore, a rule-based cluster head selection strategy can make the network lifetime more predictable. The CHS phase has been researched more actively than the other two phases.

In Table I, we have classified the cluster head algorithms based on a priori energy information, and summarized their network lifetime properties.

A. 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 life- time, and hot-spot cluster head sensors die quickly. Some of the CHS algorithms are given in Table I.

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.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.

B. 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 at- tempt to find the optimal tradeoff between the energy consumptions on communication overhead and the energy savings by appropriately forming the clusters.

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. Some of the energy awareness CHS algorithms are given in Table I.

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). The secondary index will be considered if two nodes have the same residual energy. There are also some algorithms that try to get as much information as possible to compute the best clustering, and to maximize the overall net- work lifetime. These algorithms are mostly centralized. In these algorithms, in addition to only collecting data from sensors, the base station or a centralized center will also determine the working status of the sensors. For instance, a centralized base station using the LEACH-Centralized (LEACH-C) algorithm chooses a cluster head based on a hybrid of location in- formation and energy levels. LEACH-C maintains enough separation distance to keep cluster head nodes separate from each other.

Nevertheless, none of the above cluster head selection algorithms addresses the predictability analysis issue in their pro- posed 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 predictability analysis of the WSN cluster head selection algorithm in hard network lifetime environments.

III. HEF CLUSTERING ALGORITHM

Without a priori knowledge (such as network lifetime, residue. energy level, and the energy consumption for clusters), it is impossible for any cluster head selection algorithm to obtain

TABLE I: COMPARISION OF CLUSTER HEAD SELECTION ALGORITHM

	Cluster Head Selection Algorithm	Selection Rule	Network Lifetime		
			Prolongation	Optimality	Predictability
Without apriori energy information	Lowest-ID [22]	Lowest Node ID			
	Associativity-based clustering [29]	Highest spatial-associativity, minimum distance			
	LEACH[20]	Probability Function	√		
	Trust-based [23]	Vote, quantitative measure of trust	√		
	Adaptive Contention Window (ACW)-based [25]	Minimum backoff value	√		
	CIPRA[33]	mod (Node ID * Current round number, total number of sensors)	√		
Energy Awareness	Maximum Residual Energy [18]	Maximum Residual Energy	√		
	LEACH2[27]	Probability Function	√		
	Probabilistic Clustering(extended probabilistic algorithm for HEED)[28]	Probabilistic and priority(such as residual energy and Node ID)	√		
	HEED[31]	A hybrid of residual energy and a secondary parameter with Probability Function	√		
	LEACH-C[32]	Location and energy level	√	√	
	Chen[30]	Hop number calculation	√	√	
	Our Paper	Residual energy	√	√	√

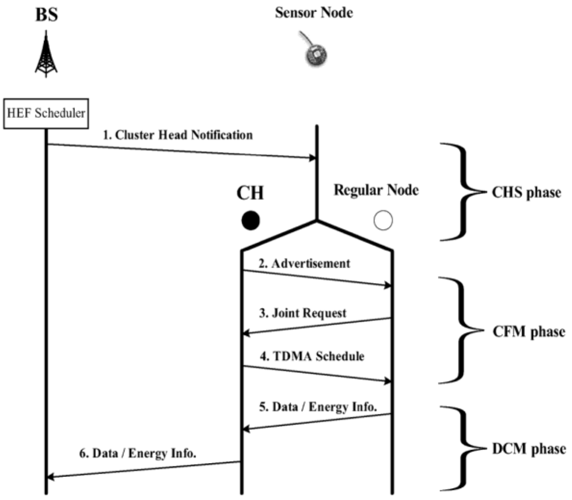

Fig. 2. Information flow of the centralized HEF system

good results for prolonging the network lifetime. 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 Algorithm: HEF selects set of M highest-ranking energy residue sensors for cluster at round where denotes the required cluster numbers at round.

Some researchers have claimed that HEF is an efficient cluster selection algorithm that prolong network lifetime based on simulations. However, their measurements and simulation results are stochastic processes. A theoretical proof to demonstrate the optimality of HEF under certain conditions is provided in this paper.

HEF is designed to select the cluster head based on the energy residue of each sensor to create a network-centric energy view. Intuitively, HEF is a centralized cluster selection algorithm; but it also can be implemented in a distributed fashion with the synchronization approach. Fig. 2 depicts the information flow of the centralized HEF system.

Each round comprises the following three phases: CHS Phase, CFM Phase, and DCM Phase. 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.

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3) After receiving the “setup” message at the 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) 6) Upon collecting cluster members' information at a given period, the cluster head sends the summative.

A. 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. Let us denote V as the set of sensor nodes deployed, and let N represent the total count of the sensor nodes.

B. 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 of and are constant during the entire operation.

In the working-conserving mode, sensor nodes must consume energy at any time while they operate. In the WSN, sensor nodes must serve as either a cluster head, or a regular node. The amount of energy a sensor consumes depends on the role it serves, as well as the workload it handles. Here, regular sensor nodes can operate in either the sleep state, or active state. In the active state, a sensor node functions completely (i.e. transmit, receive or idle), while in the sleep state, the sensor operates at a low-power operating condition, and is awake for a short period of time to hear emergency messages. Nevertheless, though the sleeping sensors do not receive and forward the control messages, they still consume energy to participate in the clustering operation, and to listen to the idle channel. Conversely, a cluster head must operate at the active state to collect data from associated regular nodes, and to forward data to the base station.

From the performances of energy consumption models reported in the literature, it can be observed that the energy consumption for the cluster head is more than that for a regular node. In particular, for time critical systems, the worst case scenario is also a crucial consideration in which it is assumed that the energy consumption of and are constant during the entire operation.

IV. 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 condition.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)(shown fig.3).

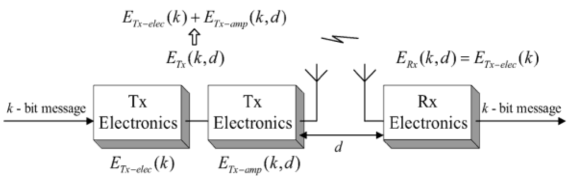

Fig 3. Transmitting and receiving

Transmission in WSNs is more energy consuming compared to sensing, therefore the cluster heads which performs the function of transmitting the data to the base station consume more energy compared to the rest of the nodes. Clustering schemes should ensure that energy dissipation across the network should be balanced and the cluster head should be rotated in order to balance the network energy consumption. The communication model that wireless sensor network uses is either single hop or multi hop.

Since energy consumption in wireless systems is directly proportional to the square of the distance, single hop communication is expensive in terms of energy consumption.

Under the ICOH condition, we assume that the energy consumption of and are constant during the entire operation. However, in actual environments, and 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 predictability, the worst-case energy consumption (WCEC) analysis is used. Let , , , and denote the maximum, and the minimum energy consumed for a cluster head, and a regular node in a round respectively.

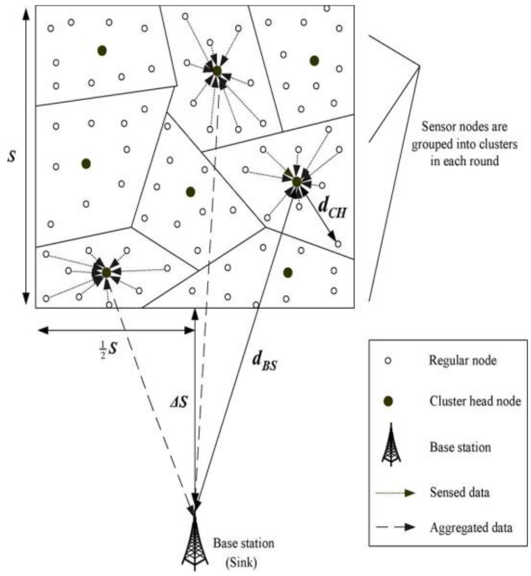

Fig. 4. Environment of the hierarchical clustering WSNs (HC-WSN)

V.PREDICTABILITY ANALYSIS OF HEF

The most important property of the WSN network life - time is not longevity, but predictability. Schedule ability 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.

Predictability tests allow engineers to assess what actions (e.g. changing energy budget or lifetime, etc.) should be taken to improve the dependability and reliability of the systems. The schedulability test flow chart consists of three major stages: Deployment Planning, Energy Estimation and Schedulability Analysis. In the Deployment Planning stage, efforts are made to plan the shape of the network topology, the initial energy level of sensor nodes, and the necessary configurations to perform. 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 predictability Analysis stage, schedulability test results pro- vide the necessary information to all running scenarios.

VI. SIMULATION

In this section, we demonstrate that the derived results above are consistent with simulation results. We use NS2 to conduct a performance study to compare the performance 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). The simulation parameters are listed in Table III.

TABLE III: SIMULATION PARAMETERS

Parameters	Value
Number of Nodes	100
Number of cluster	5
Network size	$100\ m \times 100\ m$
Base Station location	$(50, 180)$
Radio speed	$1\ Mbps$
Header size	$25\ bytes$
Packet size	$500\ bytes$
Radio electronics energy (E_{elec})	$50\ nJ/bit$
Radio amplifier energy (ε_{fs})	$10\ pJ/bit/m^2$
Radio amplifier energy (ε_{mp})	$0.0013\ pJ/bit/m^4$
Cross-over distance for friss and two-ray ground attenuation models	$87\ m$
Data aggregation energy (E_{DA})	$5\ nJ/bit$
Compression ratio (α)	0.5

The comparison results between HEF and LEACH are presented in Fig. 7, where the Y-axis represents the minimum residue energy level of sensors, and the X-axis denotes the running time for individual rounds.

In this study, the network lifetime performance is evaluated for both the HEF and LEACH models under various initial energy ranging Fig. 7 shows that the lifetime in- creases 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

b1. 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.

b2. 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.

b3. The HEF algorithm performs better out of all LEACH schemes under high initial energy level.

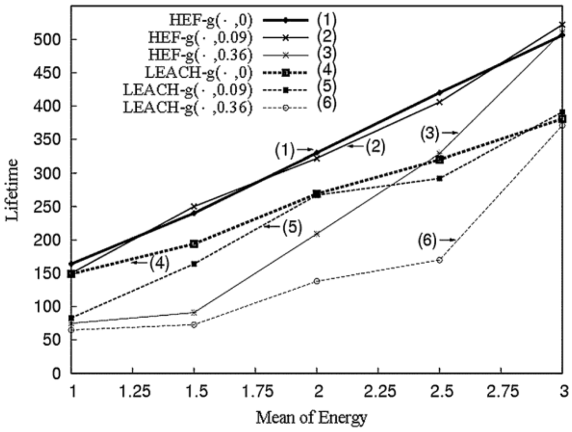

Fig. 7. Network lifetime vs. initial energy

In this experiment, HEF surpasses LEACH by taking into ac- count network lifetime when they have the same initial energy level.

In simulation results, is compared with nodes and its energy level shown in TABLE IV. Let us consider, in cluster 1 node 0 has maximum energy so its selected as cluster head, in cluster 2 node 5 is selected as cluster head.

TABLE IV: COMPARISION OF NODES WITH ITS ENERGY

Cluster	Node numbers	Energy level%
Cluster1	0	90
	2	80
	1	75
	3	70
	4	60
Cluster 2	5	70
	8	60
	6	55
	7	50

	9	53

VII. CONCLUSION & FUTURE WORK

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. 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 life- time for the HEF algorithm

In future multi-hop transmission can be implemented and to avoid the inefficiency, AOMDV protocol can be used.

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