An Energy-Aware and Intelligent Cluster-based Event Detection Scheme in Wireless Sensor Networks

Sunil Kumar*
Department of Electrical and Computer Engineering,
San Diego State University, San Diego, CA 92182
E-mail: skumar@mail.sdsu.edu

Kashyap K. R. Kambhatla
Computational Sciences Research Center
San Diego State University, San Diego, CA 92182
E-mail: kashayp3881@gmail.com

Bin Zan
Rutgers University, North Brunswick, NJ 08902-3390
E-mail: zanb@winlab.rutgers.edu

Fei Hu
Department of Computer Engineering,
Rochester Institute of Technology, Rochester, NY14623-5603
E-mail: fxheec@rit.edu
*Corresponding author

Yang Xiao
Department of Computer Science
The University of Alabama, Tuscaloosa, AL 35487-0290 USA
E-mail: yangxiao@ieee.org

Abstract: In this paper, a wireless sensor network relies on a combined effort of several micro-sensor nodes for detecting spontaneous and persistent events on the fly in various parts of a spanning network. It is important to consider fast and reliable detections of these events occurring in various parts of the network. Grouping sensor nodes in clusters to detect events is carried out for prolonged network lifetime, load balancing, and scalability. We propose a cluster based, energy-aware event-detection scheme where events are reliably relayed to a sink in the form of aggregated data packets. The clustering scheme provides faster and better event detection and reliability control capabilities to the areas of the network where an event is occurring. It also reduces network overhead, latency, and loss of even information due to cluster rotation. The proposed scheme has the following new features: a new concept of energy-level based cluster head selection, event packet(s) being capable of transmitting from the cluster heads to the sink while the cluster(s) are being formed, the sink's assigning a dynamically adaptable reliability factor to clusters, a mechanism used to control the transmission rate of the sensors according to the assigned cluster reliability, etc. Simulations are done in ns-2 to show that advantages of the proposed scheme in terms of system lifetime, reliability in event detection, and energy consumption.

Keywords: sensor networks; wireless; energy consumption; clustering; event detection

1 INTRODUCTION

In recent years, Wireless Sensor Networks (WSNs) are being applied in a wide variety of applications and systems with vastly varying requirements and characteristics (Romer et al. 2005). The lifetime of WSN is application dependent ranging from a few hours to several years. This lifetime can be significantly enhanced if the system software, including the operating system (OS), application layer, and network protocols, are all designed to be energy aware (Raghunathan et al. 2002). Some important principles for designing WSN protocols are: (1) providing data-centric mechanisms for data processing and querying within the network, (2) using application knowledge to tailor the software design and implementation, (3) using localized algorithms to collectively achieve a global objective while providing scalability and robustness, (4) lightweight middleware in terms of computation complexity and communication requirements, and (5) smartly trading quality of service (QoS) of various applications with each other (Yu et al. 2004).

A cluster-based mechanism provides simplicity, flexibility, and robustness to the implementation of network protocols (Cougar (website); Heinzelman et al., 2006; Singh et al., 2003; Younis et al., 2002). The challenges and tradeoffs for cluster based architecture design have been discussed in (Yu et al. 2004). A cluster is formed based on a combination of several metrics of sensor nodes, including data accessibility, node capacity, and network connectivity. To maintain the cluster information at the cluster head (CH) and exchange cluster and data information with other clusters or the sink, efficient transport and routing mechanisms are required. Directed diffusion (Intanagonwiwat et al., 2000) scheme is applicable for such kind of information source exchange. Due to dynamic nature of the phenomena being monitored and the need for collaborative signal processing, it is necessary to use on-the-fly self-configuring distributed clustering schemes in WSNs (Melodia et al., 2005).

The clustering scheme have been previously investigated as either stand-alone protocols for ad-hoc networks, e.g., (Basagni et al., 1999; Banerjee et al., 2001; Bandyopadhyay et al., 2003; Amis et al.,2000), or in the context of routing protocols, e.g., (Kawadia et al., 2003; Lin et al., 1997; Gerla et al. 2000; Heinzelman et al., 2002; McDonald et al., 2001)**.** Several clustering algorithms have been proposed for the purpose of reducing energy consumption and extending lifetime of a sensor network. Low Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman et al., 2002) is a distributed algorithm for sensor networks in which the sensors elect themselves as CHs with some probabilities and broadcast their decisions. It assumes that all nodes can hear each other and this assumption is not a realistic for randomly distributed sensor nodes. LEACH also assumes a large difference between the CH and normal node power requirement. A small difference would cause LEACH to become less effective. Power Information Gathering in Sensor Information Systems (PEGASIS) scheme (Lindsey et al., 2002) is an improvement of LEACH, in which the key idea is to form a chain among the sensor nodes so that each node will receive from and transmit to its close neighbors. The gathered data moves from node to node, gets aggregated and eventually a leader node transmits it to the sink. The leader node will rotate in each round to have energy load evenly distributed among the sensor nodes. Its disadvantage is large time delay and faster energy depletion. The nodes far away from the sink will require more energy to transmit data to the sink**.** A Hybrid, Energy-Efficient, Distributed Clustering approach for ad-hoc sensor networks (HEED) (Younis et al., 2004) periodically selects CHs according to a hybrid of their node residual energy and a secondary parameter, average minimum reachability power (AMRP). In Adaptive Self-Configuring Sensor Networks Topologies (ASCENT) scheme (Cerpa et al., 2001), each node assesses its connectivity and adapts its participation in the multi-hop network topology based on the measured operating region. Therefore each node signals when it detects high message loss, requesting additional nodes in the region to join the network in order to relay messages to it, reduces its duty cycle if it detects high message losses due to collisions, probes the local communication environment and does not join the multi-hop routing infrastructure until it is "helpful" to do so. A Fast Local Clustering Service (FLOC) scheme for WSNs produces non-overlapping and approximately equal-sized clusters (Demirbas et al., 2004). By restricting the number of hops, it tries to achieve locality and contain the effects of cluster formation and faults/changes in any part of the network within the fixed number of hops. It also tries to exploit the double-band nature of wireless radio-model and achieves clustering in constant time regardless of the network size.

The above-mentioned clustering schemes cannot send the event packets to the sink as fast as possible without vital information loss and salvaging precious energy resources. They also may have considerable latency involved in the set up of the clusters and overhead messages in the schemes due to random rotation of the cluster heads. Most of the schemes do not take into account the message losses due to collisions and congestion at the sensor nodes. The cluster rotation involves a complete change over of the entire topology, which requires synchronized control and consumes lot of sensor energy. There is no reliability control in these schemes for proper event detection at the sink, which could also help in efficiently utilizing the scarce energy resource of the sensor nodes.

The event-driven WSNs have been extensively studied in recent years. The Event to Sink Reliable Transport (ESRT) (Sankarasubramaniam et al., 2003) scheme addresses the event to sink transport problem in WSNs. The primary objective of ESRT is to achieve and maintain the sensor nodes in the optimal operating region (OOR). For this, it tries to configure a reporting frequency (f) to achieve the desired event detection accuracy with minimum energy expenditure. It assigns the same value of *f* to all sensors. However, it may be more reasonable to use different reporting frequency for each sensor depending on its contribution to congestion. The ESRT transmits the control message from sink to the sensors by using a channel (one-hop) with high power that may interfere with the on-going data transmission. The sink often receives new event packets from some of the sensor nodes with the old frequency even though it has sent a control message asking all the sensor nodes to vary their rate of transmission. Congestion Detection and Avoidance (CODA) scheme (Wan et al., 2003) comprises of the following three mechanisms to address the congestion problem in WSNs: (i) receiver-based congestion detection, (ii) open-loop hop-by-hop backpressure, and (iii) closed-loop multi-source regulation. Congestion Control and Fairness for Many-to-One Routing (CFMR) scheme (Cheng et al., 2004) eliminates congestion within WSN and ensures the fair delivery of packets to a sink by distributing different frequencies to each sensor node based on its sub tree size.

The proposed scheme mainly focuses on fast, reliable and efficient event detection in WSN. It is influenced by a variety of above mentioned event-detection and cluster formation schemes. We also consider the energy efficient clustering mechanism to meet our event detection objective. The proposed scheme also ensures that no valuable event information is lost while forming and regrouping the clusters. The proposed scheme has the following novel features: (*i*) a new concept of energy-level based CH selection is used which is different from the existing schemes; (*ii*) event packet(s) can be transmitted from the CHs to the sink while the cluster(s) are being formed; (*iii*) the sink assigns a dynamically adaptable reliability factor to clusters, according to their size and event proximity such that the clusters closer to the event send packets to the sink more frequently; (*iv*) a mechanism is used to control the transmission rate of the sensors by their CH according to the assigned cluster reliability; (*v*) the CH rotation is done such that higher energy nodes remain as cluster heads for longer time; and (*vi*) selective cluster dismissal is employed which incurs less overhead compared to altering the entire cluster topology.

The rest of the paper is organized as follows. The proposed scheme is described in Section 2 followed by the simulation results in Section 3. The conclusion and future work are discussed in Section 4.

2. THE PROPOSED SCHEME

The proposed scheme detects the event(s) on the fly that occur for a period of time in any part of the WSN or move to other various parts and then subside. Fig. 1 shows clusters formed when an event occurs in the network where each sensor (including sensors in overlapping cluster regions) reports to one cluster head (CH) only. The sink and the sensor nodes do not know their absolute locations in the geographic area. However the sink and the sensor nodes know their neighboring nodes with which they can directly communicate. Every sensor node is identified through its node ID. We discuss below the energy level determination of sensor nodes, event-triggered and energy-aware cluster formation, dynamic adaptation of reliability based on the cluster member density and event proximity, transmission rate control of the sensors by their CH according to the assigned cluster reliability to provide reliable detection of events at the sink, and cluster dismissal mechanism.

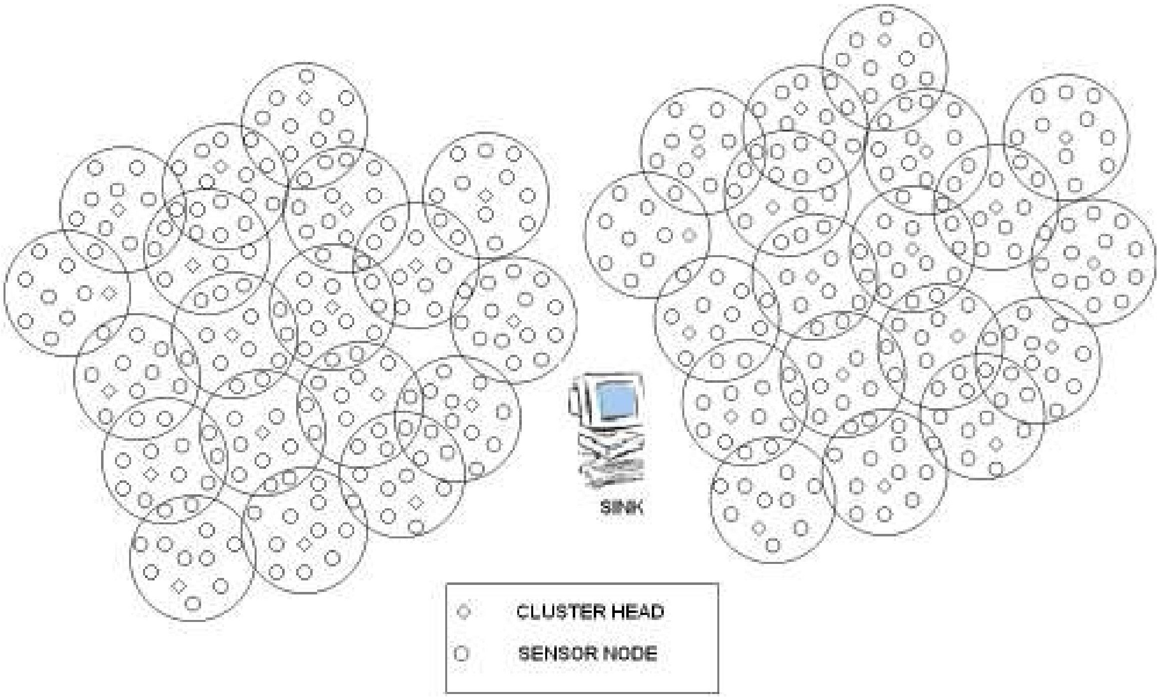


Fig. 1: Clusters formed for event detection in WSN.

2.1 Determining Energy-Level of Sensor Nodes

We assume that the sensor nodes know their maximum energy (E_{max}), residual energy (E_R) and threshold energy (E_{th}), where E_{th} is the minimum energy required by the sensor nodes to identify themselves in one of the '*n*' energy levels. A sensor node with $E_R \leq E_{th}$ belongs to the energy level '0'. Initially the energy of a sensor node is divided into *n* levels as shown below:

$$n = \left\lceil \log_x \frac{E_{max}}{E_{th}} \right\rceil \qquad (1),$$

where, the energy range of a level L is defined as the difference between the upper and lower energy values and 'x' is the ratio between the maximum and minimum values of a level. The value of 'x' depends on the requirement of the application. The energy level (L) of a sensor node is determined as: if ($E_R<E_{th}$) L=0; else $L = n - \lfloor E_{max}/E_R \rfloor$.

The energy level values of a sensor node are shown in Table 1 for x=2, E_{max} = 8J and E_{th} = 1J.

Table 1: Energy level values of the sensor nodes

Level	Upper limit	Lower limit
3	8J	4J
2	<4J	2J
1	<2J	1J
0	<1J	0J

It can be observed from Table 1 that higher energy levels have larger energy ranges which helps in maintaining the candidate sensor nodes as CH for longer duration with lesser rotation as explained in the next subsection.

2.2. Event-triggered, Energy-Aware Cluster Formation

A sensor node decides to participate in the cluster formation process if amplitude of the event parameter that it detects crosses a predetermined threshold 'Δ'. Here the value of 'Δ' depends on the measured event parameter.

While forming clusters the sensors with the highest energy level (L) are given opportunity to become the CHs, to ensure longer cluster lifetime. In areas lacking high energy sensor nodes the lower energy sensor nodes take initiative to form CHs. This is mainly to ensure that the primary purpose of reliable event detection at the sink is achieved. The sensor nodes then elect their cluster heads based on the energy level and AMRP value, where AMRP is defined as the average minimum power level required by the 'r' neighboring nodes to reach the sensor node claiming to become the CH as shown below (Younis et al., 2004):

$$AMRP = \frac{\sum_{i=1}^{r} Min\mathrm{PWR_i}}{r} \qquad (2),$$

where, $\mathrm{MinPWR_i}$ denotes the minimum power level required by a node $v_i, 1 \leq i \leq r$, to communicate with the CH and 'r' is the number of neighbor nodes. The sensor nodes advertise themselves as CH based on their energy level. The sensor node claiming to be a CH broadcasts the advertisement message to its neighbors using maximum power (MaxPWR). The normalized AMRP is defined as the ratio of AMRP to that of the MaxPWR.

The other sensor nodes on receiving the advertisements decide to join a CH based on a function of CH energy level and communication power. Every sensor node waits for a random time before advertising itself to other sensor nodes to become a CH. This delay time for sending the advertisement message is based on a function of the energy level (L) of the sensor node and normalized average minimum reachability power (nAMRP).

The delay time of a node for sensing the advertisement message is computed as:

$$Delay\_time = (time\_slot)* \{(k)*(n-L)+(rand)*(nAMRP)\} \qquad (3),$$

where, the time_slot is defined as the minimum amount of time difference required between two sensors advertising themselves as cluster heads (e.g., time_slot =1 msec), 'k' is a multiplication factor and 'rand' is random number required to vary the delay_time for various sensor nodes. The time_slot can be fixed at the time of deployment of the sensor nodes or programmed by sink.

The nodes with higher energy level L in equation (3) wait for a lesser period of time than the nodes with lower L. Furthermore, the nodes with equal L and different nAMRP values wait for different time intervals due to 'rand' number. Upon receiving a CH advertisement from its neighboring node(s), a sensor node defers its own CH advertisement. Instead, it joins a cluster by selecting a CH from the various CH advertisements it has received based on a function of the power (MinPWR) required to communicate with selected CH and the CH energy level (L). Here, the CH energy is the residual energy E_R of the selected CH node. For example, if the energy of various sensor nodes is divided into 8 levels (i.e., L = 0 to 7), a sensor node (with L>=4) will accept only a candidate node (with L>=4) as its CH depending on the value of MinPWR. This is because the energy of the sensor nodes in these levels does not deteriorate as fast as the energy of the sensor nodes in the lower levels. Similarly a sensor node with L_i energy level will not accept another sensor node with energy level lower than L_i as its CH, where L_i = 1 to 3. Furthermore, a sensor node (L=0 to 3) selects a candidate node as its CH, giving more importance to CH's energy level and simultaneously caring for MinPWR. But when there are two nodes advertising with the same energy level then the one with MinPWR is chosen as cluster head.

During the process of CH selection, the event packets received from the neighboring sensor nodes are simultaneously sent by the CH candidate nodes to the sink in a unicast manner through multi hop. The sensor node does not send separate messages to join the cluster. Initially when it has not yet chosen its CH it sends a data packet to one of the CH candidate with a flag set to 0 in its packet header stating that it's not yet a member. After it has chosen its CH it sends a unicast data packet to that CH with the flag set to 1 to indicate that it is a member of that cluster. This process has two advantages: 1) it avoids overhead messages sent for joining the clusters, and 2) the event information is timely reported to the sink.

2.3. Dynamic Reliability Control

The sink assigns a reliability value 'REL' for an event in terms of the total number of packets of the event required to be reported in a time 'T' at the sink. This reliability factor is distributed among the clusters formed in the event area based on (i) the number of sensor nodes in the cluster, and (ii) the cluster-event proximity. Every CH of the event area transmits the number of its cluster members in the aggregated data packet header to the sink through multi-hop. Analyzing the values of the measured event parameters in the aggregated data packets the sink knows which of the CHs are closest to the event. The sink assigns a reliability value to each cluster shown below:

$$CRi = \frac{REL * (J_i)(m_i)}{\sum_{i=1}^{z} J_i \; m_i} \qquad (4),$$

where, CR_i is reliability assigned to ith cluster, z is the number of clusters, J_i is the event proximity for its cluster, and m_i is the number of sensor nodes in the cluster. If $J_i = 1$ then the reliability is distributed among all the clusters based on their member density. By assigning higher value of J_i, the sink can acquire more number of packets from the clusters closer to the event. The event proximity parameter J_i varies from cluster to cluster from a minimum value of 0 to a maximum value of 1.

The sink will vary the reliability values for the clusters if the event propagates to other areas. If the event propagates to other areas of the network, their sensors will also form clusters based on the values of the measured event parameters. This idea of 'Dynamic Reliability Adaptation' at the sink is helpful obtaining maximum information of the event.

2.4. Two Levels Transmission Rate Control

Transmission rate control includes two levels: one is event-packets reporting frequency control and the other is aggregate data packet transmission frequency control.

The event-packets reporting frequency control is carried out by the CH on its members every time period 'τ' to avoid congestion in the network and conserve energy. The sink sends a control message in a unicast manner to the CHs apprising them of their new reliability values (CR) after every time period T. Each CH then computes the reporting frequency (f) of its cluster members as shown below, and broadcasts it to them though a control message.

$$f = \frac{CR}{m \times \tau} \qquad (5),$$

where, m is the number of sensors in the cluster. The normalized reliability (λ) of the CH is defined as $\lambda = r/CR$, where r is the number of event packets received at the CH in time interval 'τ'. To enhance the accurate of event detecting, the reporting frequency (*f*) finally broadcast to the sensor nodes, can be multiplied by a fact "*r*" (for example $r=1.2$) based on the observation of network situation from the cluster head side.

For aggregate data packet transmission frequency control, an algorithm similar to the rate control algorithm used in ESRT (Bandyopadhyay et al., 2003) is implemented to control the change in the transmission rates due to congestion and link failure. The proposed scheme tries to operate in the optimal operating range (OOR) through the process of rate control, where the normalized reliability λ lies in the range of 1-ε to 1+ε (Sankarasubramaniam et al., 2003). Here ε is a protocol parameter which could be defined as the tolerance allowed for the normalized reliability λ in the OOR. The value of ε used in proposed scheme is 0.05. Therefore for the network to operate in the OOR, the normalized reliability could vary from 0.95 to 1.05.

```
If (No_Congestion)
    If (λ < 1- ε)   /* reliability is low */
        $f = \frac{f}{\lambda}$;  /* Increase the reporting frequency aggressively */
    else if (λ > 1+ ε)  /* reliability is high; may lead to congestion */
        /* Decrease reporting frequency cautiously to avoid congestion and conserve energy */
        $f = \frac{f}{2}(1+\frac{1}{\lambda})$;
Else if (Congestion)
    If (λ>=1) /* reliability is high */
        /* Decrease reporting frequency to relieve congestion; no compromise on reliability*/
        $f = \frac{f}{\lambda}$;
    else if(λ<1)
        /* Decrease reporting frequency to relieve congestion; no compromise on reliability*/
        if(f>1)
            $k = k + 1; f = f^{\frac{\lambda}{k}}$;
        else if(f<=1)
            $f = \frac{f}{2}$;
```

Fig. 2: The two-level transmission rate control algorithm.

2.5. Cluster Dismissal and CH Rotation

Cluster dismissal occurs in the following three cases: (i) when the CH energy has dropped to a lower energy level L, (ii) the sink sends a cluster dismissal message selectively to a cluster, or (iii) the sink sends a total cluster topology dismissal message. These cases are discussed below.

(i) We assume that the clusters closer to the event are maintained for a longer time by the sink. The control message sent by the sink contains information about the energy value of the CH up to which the cluster has to be maintained before it dismisses itself. This enables the sink to extract as much information as possible about the event but at the expense of the energy depletion of that CH. Other clusters dismiss themselves when the energy of the CH has dropped to a lower energy level (L) [(1-1/x) of its start energy)]. The CH broadcasts a group dismiss message to its cluster members and inform the sink. The sensor nodes could either regroup by selecting a different CH with higher energy level or join other clusters. The selection of new CH(s) depends on the factors explained in Section 2.1.

(ii) The sink regularly analyzes the aggregated data information from the CHs. If the information received from a cluster is not found useful, the sink selectively sends a unicast dismiss messages to it. The sensor nodes of the dismissed cluster abstain from joining other clusters or forming new clusters.

(iii) The sink broadcasts a total cluster dismissal message if it feels that the event has totally subsided or further information on that event is not useful. This helps in preserving the energy of sensor nodes in the network and increases the network lifetime.

The cluster rotation process in the proposed scheme is selective. All the clusters are not rotated which different from HEED (Younis et al., 2004) or LEACH (Heinzelman et al., 2002) schemes. This provides efficiency in terms of reliable transmission of aggregated data packets from the CHs to the sink. There will be fewer packet losses due to collisions with overhead messages involved in the process of cluster rotation. The energy of the sensor nodes is preserved by avoiding periodic rotation of clusters in the network.

3 SIMULAION AND DISCUSSION

In order to evaluate the performance of the proposed scheme, we shall study the following performance metrics using ns-2 (UCB/LBNL/VINT, website): (i) first aggregated packet delay, (ii) rotational packet loss, (iii) rotational energy cost, (iv) number of dead nodes, (v) rate control performance, and (vi) energy cost comparison with and without rate control.

3.1. Network Scenario

We developed an evaluation environment, which consists of 300 nodes, randomly distributed in a 200m X 200m flat grid as shown in Fig. 3. We assume that the event occurs at point (30, 40) with an event radius of 100m. The event area consists of 130 sensor nodes that participate in cluster formation and event detection. We evaluate the proposed scheme considering three different energy situations in the sensor nodes: (i) when the residual energy (E_R) level of the sensor nodes varies from 2J to 4J, (ii) when the E_R of the all the sensor nodes is 4J, and (iii) when the E_R of the sensor nodes varies from 4J to 8J.

Here the maximum energy (E_{max}) of the sensor nodes is 8J. We also implemented HEED scheme (Younis et al., 2004) for the above cases with three different cluster rotation periods of 20, 50 and 100 seconds. We compare our scheme with HEED which is an efficiency scheme addressing the issues of energy utilization and optimal cluster head selection during event detection. The sink in the network is shown in the upper right corner of the network. We use IEEE 802.11 (IEEE, 1999) as the medium access control (MAC) layer with 11mbps channel bandwidth and DSR protocol (Johnson et al., 2003) for the routing layer. We set all packets size as 50 bytes, and assume aggregate data packet can combine different number of event packets into one packet which is also the assumption used in LEACH (Heinzelman et al., 2002). We have a modified MAC layer where the CH broadcasts control packets to its cluster members without RTS, CTS and ACK messages. It uses RTS, CTS and ACK messages to send the aggregated data packets to the sink in a unicast manner. The sensor nodes in a cluster send the event packets to the CH in a unicast manner without RTS, CTS and ACK messages. Since we consider 'on the fly' scenario, we assume the event to exist for a period of 250 seconds in a given network area.

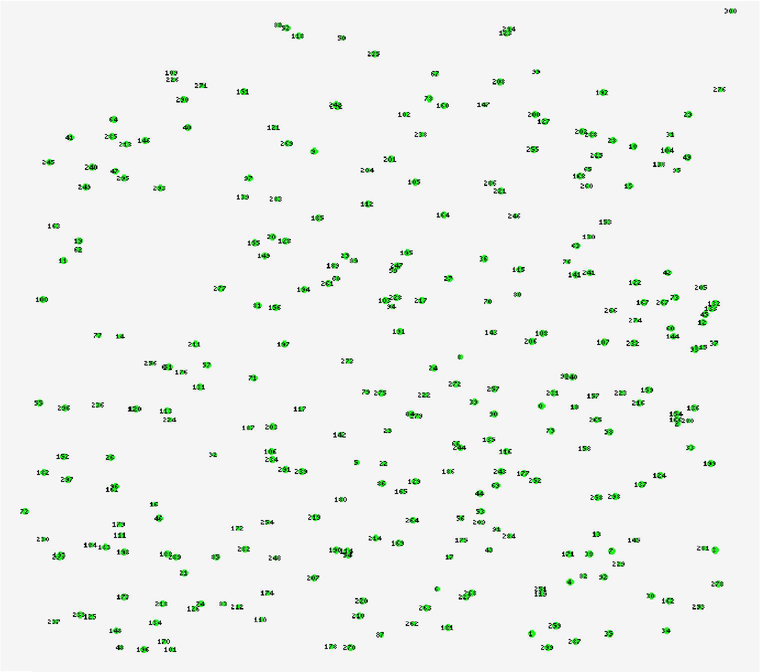


Fig. 3: Randomly distributed 300 sensor nodes in a 200mX200m flat grid.

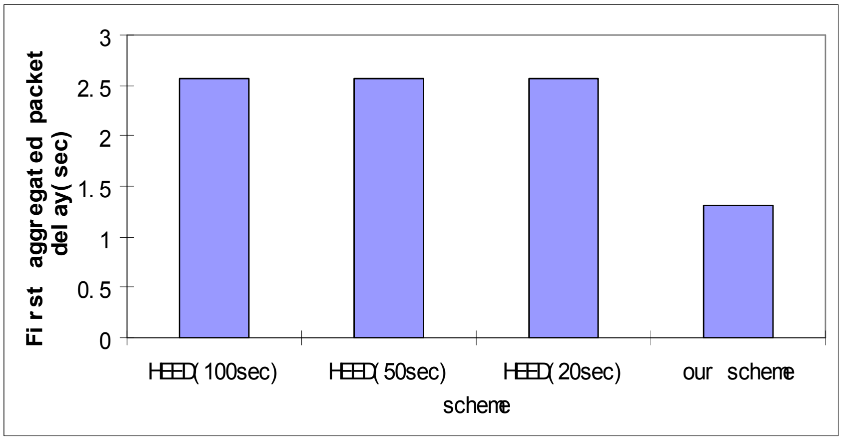


Fig. 4: The first aggregated packet delay from the cluster head to the sink.

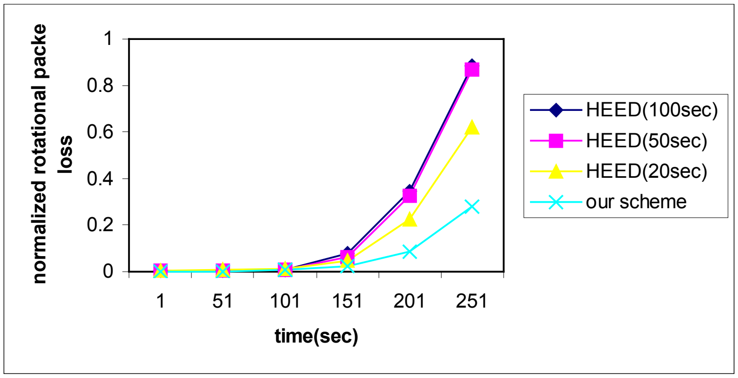


Fig. 5: Normalized rotational packet loss during cluster rotation.

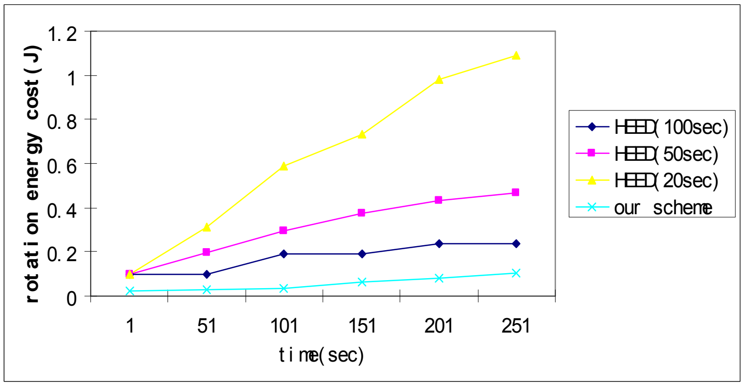


Fig. 6: Energy spent during cluster rotation.

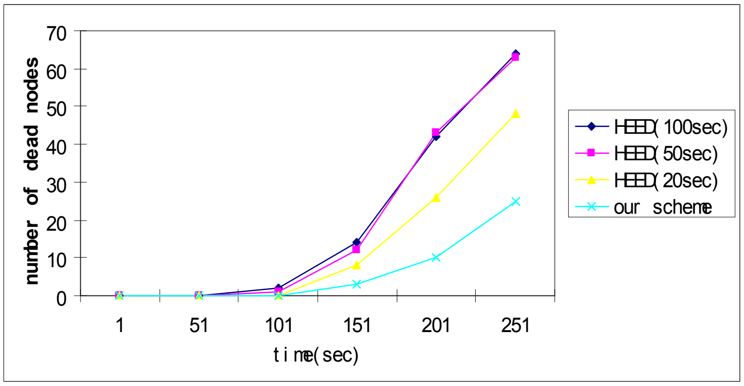
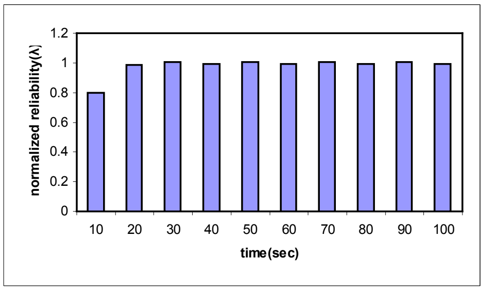
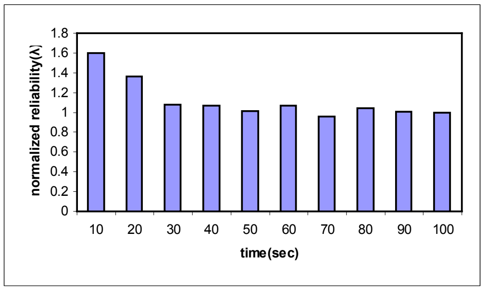


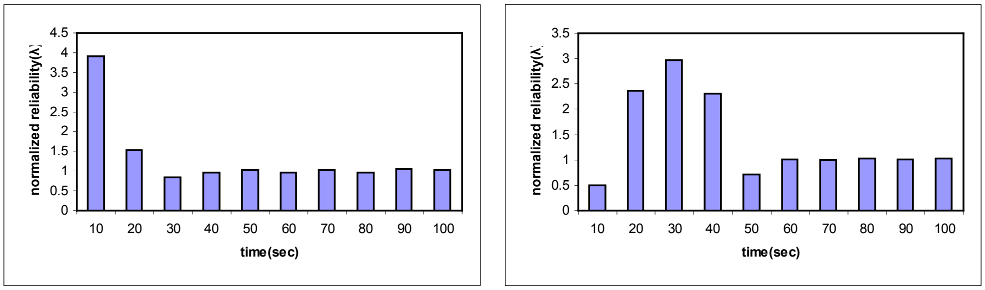
Fig. 7: Number of dead nodes.



Case 1: Low Reliability, No Congestion



Case 2: High Reliability, No Congestion



Case 3: High Reliability, Congestion

Case 4: Low Reliability, Congestion

Fig. 8: Rate control performance of the proposed scheme (energy value from 128J).

3. 2 Performance Evaluation

(i) **First aggregated packet delay** is the time taken for the first aggregated event packet to reach the sink from the time an event is detected by the sensor nodes. This parameter represents the speed of reaction of the network to the event occurrence. In the proposed as well as HEED (Younis et al., 2004) schemes, we consider that clusters are formed 'on the fly' when the event occurs. As shown in Fig. 4, HEED scheme consumes more time for the first aggregate data packet to reach the sink due to the set up phase. In this phase no packets are reported to the sink and clusters are formed with the help of overhead messages. In the proposed scheme the event packets are transmitted to the sink even as the clusters are being formed.

(ii) **Rotational packet loss** is defined as the number of event packets dropped during cluster rotation, due to collisions with the overhead packets generated during cluster regrouping. The normalized (all data divided by a fixed large number) rotational packet loss is shown in Fig. 5. The proposed scheme involves lesser packet loss during cluster regrouping since fewer cluster rotations take place. As discussed in Section 2 (2.1 and 2.2), the higher energy nodes are given more opportunity to serve as CH in the proposed scheme, which decreases the amount of CH rotation. The proposed scheme tries to achieve a tradeoff between the energy utilized by the sensor node to maintain itself as the CH and the number of event packets lost from being reported to the sink. On the other hand, a sensor node can be selected as a CH in HEED even when it does not have highest energy level among the cluster members. This can cause more cluster rotations in HEED thereby increasing the number of overhead messages and rotational packet loss. Moreover each time a cluster is dismissed in HEED, all the other clusters are also dismissed and regrouped. This further magnifies the rotational packet loss.

(iii) **Cluster rotation energy cost** is defined as the amount of energy used during cluster rotation. HEED needs more overhead messages for cluster rotation and this process is carried out more frequently (every 20, 50 or 100sec). Moreover HEED performs cluster rotation all over the network. This consumes more energy from the sensor nodes for rotation when compared to the proposed scheme, as shown in Fig. 6. However, in the case where energy varies from 2J-4J, the rotational energy consumption is low for 100 seconds in HEED. From the observation of the number of dead nodes, we noticed that is due to HEED with rotation period of 100 seconds die much faster than in other cases of 20 seconds, 50 seconds and proposed scheme. It is clearly, when most nodes died, total rotation energy cost will reduce.

(iv) **Number of dead nodes** gives an indication of the number of nodes dead after the event occurrence is over. The number of nodes dead in case of HEED (Younis et al., 2004) is more than that in the proposed scheme at the end of the event. This could be attributed to the facts that the proposed scheme involves almost no overhead for rotation and fewer rotations take place in the event period, shown in Fig. 7. For the other two cases where energy varies from 2-4J and all 4J, the difference is as the start energy of the sensor nodes decreases the number of sensor nodes dead in the event duration increases.

From the observation, we also found in HEED (Younis et al., 2004), the first node dies at a later time as the rotation time increases, but if the rotation time is too long then the CH is depleted of its energy and dies fast. The proposed scheme is intelligent in performing rotation at the optimal time based on (i) the drop in energy of the CH, (ii) proximity of the cluster to the event and (iii) finally the presence of the event itself (i.e. if the event is present or it has subsided).

(v) **Rate control performance** is evaluated in two parts: (i) aggregate data packets transmission frequency control by the sink, and (ii) the performance comparison between with two levels rate control and without two levels rate control.

(i) We study aggregate packets transmission frequency control performance of our proposed scheme in terms of the normalized reliability (λ) for the very high energy value (i.e., 128J) of sensor nodes. The desired reliability value is 150 packets per 10 seconds. The starting aggregate data packet transmission frequency is 1, 2, and 5 packets per seconds, which covers three different situations (LR, NC), (HR, NC), and (HR, C). To observe (LR, C), we make desired reliability value to 300 packets per 10 seconds and starting frequency to 1000 packets per seconds. As shown in Fig. 8, the proposed scheme reaches the Optimal Operating Range (OOR) (Sankarasubramaniam et al., 2003) where λ ranges from 0.95 to 1.05 in 30 seconds in case 1, 2, in 40 seconds in case 3, and in 60 seconds in case 4. Thereafter, the scheme continues to operate in OOR.

(ii) Fig. 9 shows the two levels rate control performance for the clusters in the event area with target reliability value of 1600 event-packets and 100 aggregate data packets per 10 seconds, where the maximum (E_{max}) and threshold (E_{th}) energy of the sensors are 8J and 31.25mJ, respectively. The energy value of sensor nodes is from 4 to 8J. The normalized reliability of the sensor nodes without the two levels rate control decreases with time because they are depleted of their energy in trying to keep up with reliability requirement of the sink without any knowledge of real reliability requirement from the sink. However, with two levels rate control they not only salvage their precious energy resource (which can be observed in Fig. 10) but also keep up with the target reliability.

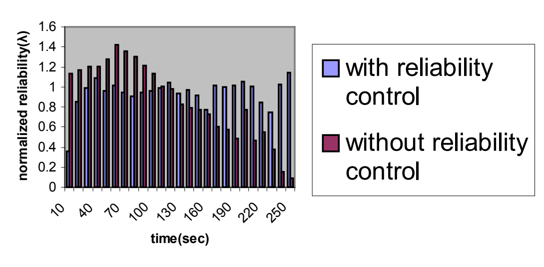


Fig. 9: Rate control performance.

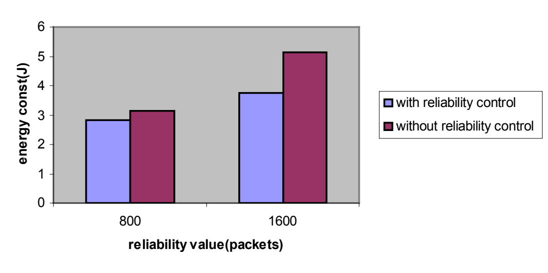


Fig 10: Energy cost with and without rate control.

(vi) **Average energy cost** with and without rate control is computed as,

$$\text{Average energy cost} = \frac{\sum SRE - \sum RE}{S} \qquad (6),$$

where the SRE, RE and S represent the starting residual energy, residual energy after a time period of 100 seconds, and total number of sensor nodes, in that order. The results for the proposed scheme are illustrated in Fig 10. The maximum (E_{max}) and threshold (E_{th}) energy of the sensors are 8J and 31.25mJ, respectively. The average energy cost without rate control is higher since the sensor nodes either transmit at a rate much higher or lower than what is actually required. The efficient rate control ensures proper utilization of the energy to maintain reliability. For higher values of reliability, the rate control mechanism makes the energy utilization more efficient.

4 CONCLUSION AND FUTURE WORK

In this paper, we presented a novel scheme for a very fast, reliable event to sink transfer. The proposed scheme is simple without any dependence on the topology of the network or making any assumptions about the underlying transport infrastructure. We hope the proposed scheme will help researchers to look at the event detection with a new direction. The proposed scheme will be very useful to be implemented in scenarios of monitoring disaster prone areas or monitoring wildlife environment and so on. We plan to focus on this area further and make enhancements to this scheme. We plan to consider the case of multiple event detection in the same area where clusters are already set up to detect another event occurrence. We also consider the case where the frequencies of the sensors are pre-programmed for detecting different events so the CH needs to handle the frequencies of its members individually based on the events they are detecting. We also plan to develop an optimal cluster size formula for restricting the size of the clusters formed in the event area. This obviously makes the scheme even more challenging than before. Results from this phase of our work will be the subject of a future publication.

References

Romer, K., Mattern F. and Zurich E. (2004), "The design space of wireless sensor wireless sensor networks," Proc. IEEE Wireless Communications, Dec. 2004.

Raghunathan, V., Schurgers, C., Park S. and Srivastava, M. B. (2002) "Energy-aware wireless microsensor networks," Proc. IEEE Signal Processing Magazine, pp. 40-50, March, 2002.

Yu, Y., Krishnamachari, B. and Prasanna, V. K. (2004) "Issues in designing middleware for wireless sensor networks," Proc. IEEE Network Magazine, vol. 18, no. 1, Jan. 2004, pp. 15-21.

Cougar Project. [Online]. Available: http://www.cs.cornell.edu/database/cougar

Heinzelman, W., Chandrakasan, A. P. and Balakrishnan, H. (2006) "An application specific protocol architecture for wireless microsensor networks," Proc. IEEE Trans. on Wireless Comm., vol. 1, no. 4, Oct. 2002, pp. 660-670.

Singh, M. and Prasanna, V. K. (2003) "A hierarchical model for distributed collaborative computation in wireless sensor networks," Proc. 5th Workshop on Advances in Parallel and Distributed Computational Models, 2003.

Younis, M., Youssef, M. and Arisha, K. (2002) "Energy-aware routing in cluster-based sensor networks," Proc. 10th IEEE International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunications Systems (MASCOTS), Oct 2002.

Intanagonwiwat, C., Govindan, R. and Estrin, D. (2000) "Directed diffusion: a scalable and robust communication paradigm for sensor networks," Proc. ACM MobiCom 2000 Boston, MA, 2000, pp. 56-67.

Melodia, T., Pompili, D., Gungor, V. C. and Akyildiz, I. F. (2005) "A distributed coordination framework for wireless sensor and actor networks," Proc. MobiHoc'05, May 25-27,2005, Urbana-Champaign, Illinois, USA

Basagni, S., (1999) "Distributed clustering algorithm for ad-hoc networks," Proc. International Symposium on Parallel Architectures, Algorithms, and Networks (I-SPAN), 1999.

Banerjee, S. and Khuller, S. (2001) "A clustering scheme for hierarchical control in multi-hop wireless networks," Proc. IEEE INFOCOM, April 2001.

Bandyopadhyay, S. and Coyle, E. (2003) "An energy efficient hierarchical clustering algorithm for wireless sensor networks," Proc. IEEE INFOCOM 2003, vol. 3, pp. 1713-1723.

Amis, A. D., Prakash, R., Vuong, T. H. P. and Huynh, D. T. (2000) "Max-min d-cluster formation in wireless ad hoc networks," Proc. IEEE INFOCOM, Conference on Computer Communications, March 2000.

Kawadia, V. and Kumar, P. R. (2003) "Power control and clustering in ad hoc networks," Proc. IEEE INFOCOM, San Francisco, California, Apr. 2003.

Lin, C. R. and Gerla, M. (1997) "Adaptive clustering for mobile wireless networks", Proc. IEEE J. Select. Areas Comm., vol. 15, no. 7, pp. 1265-1275, Sept. 1997.

Gerla, M., Kwon T. J. and Pei, G. (2000) "On demand routing in large ad hoc wireless networks with passive clustering," Proc. IEEE WCNC, 2000.

Heinzelman, W. R., Chandrakasan, A. and Balakrishnan, H. (2002) "An application-specific protocol architecture for wireless microsensor networks," Proc. IEEE Transactions on Wireless Communications, vol. 1, no. 4, pp. 660–670, October 2002.

McDonald, A.B. and Znati, T. (2001) "Design and performance of a distributed dynamic clustering algorithm for ad hoc Networks." Proc. 34th Annual IEEE/ACM Simulation Symposium (ANSS), Seattle WA, April 2001, pp. 27-35.

Lindsey, S. and Raghavendra, C. S. (2002) "PEGASIS: power efficient gathering in sensor information systems", Proc. 2002 IEEE Aerospace Conference, March 2002, pp. 1-6.

Younis, O. and Fahmy, S. (2004) "Distributed clustering in ad-hoc sensor networks: a hybrid, energy-efficient approach," Proc. IEEE INFOCOM, March 2004.

Cerpa, A. and Estrin, D. (2001) "Ascent: adaptive self-configuring sensor network topologies," Proc. UCLA Computer Science Department Technical Report UCLA/CSD-TR-01-0009, May 2001.

Demirbas, M., Arora, A. and Mittal, V. (2004) "FLOC: A fast local clustering service for wireless sensor networks," Proc. Dependability Issues in Wireless Ad Hoc Networks and Sensor Networks DIWANS'04, June 29, 2004, Florence, Italy.

Sankarasubramaniam, Y., Akan, O. and Akyildiz, I. (2003) "ESRT: event-to-sink reliable transport in wireless sensor networks," Proc. ACM MobiHoc'03 Conf. pp. 177-189, June 2003, Annapolis, MD.

Wan, C.-Y., Eisenman, S. and Campbell, A. (2003) "CODA: congestion detection and avoidance in sensor networks," Proc. ACM SenSys'03, Conf., pp. 266-279, Nov. 2003, Los Angeles, CA.

Cheng, E. T. and Bajcsy, R. (2004) "Congestion control and fairness for many-to-one routing in sensor networks," Proc. ACM SenSysn'04, Nov. 3-5, 2004, Baltimore, Maryland, USA.

UCB/LBNL/VINT Network Simulator – ns (2000). [Online]. Available: http://www.isi.edu/vint/nsnam.

IEEE (1999) "IEEE standard for wireless LAN medium access control (MAC) and physical layer (PHY) specifications," ISO/IEC 8802-11: 1999(E), Aug. 1999

Johnson, D. B., Maltz, D. A. and Hu, Y. (2003)"The dynamic source routing protocol for mobile ad hoc network," Internet-Draft, draft-ietf-manet-dsr-09.txt, April 2003.