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An Energy*Delay Efficient Multi-Hop Routing Scheme for Wireless Sensor Networks*

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SUMMARY Sensors have very scarce resources in terms of memory, energy and computational capacities. Wireless sensor network is composed of a large number of such sensor nodes densely deployed in inhospitable physical environments. Energy efficient information dissemination throughout such a network is still a challenge. Though dissemination of information with minimum energy consumption is a key concern in wireless sensor networks, it often introduces additional delay. In this work, we first propose an energy and delay efficient multi-hop routing scheme called C^2E^2S (Cluster and Chain based Energy*Delay Efficient Routing Scheme) for wireless sensor networks. This scheme is a combination of cluster-based and chain-based approaches and the way to form clusters and chains in this work is center-based approach. To reduce a large number of communication overheads due to this approach, we propose a modified-center-based approach called passive-BS-based approach. Next, we propose (1) an energy and delay aware routing algorithm for sensors within each k-hop cluster, and (2) an Energy-efficient chain construction algorithm for cluster heads. To evaluate the appropriateness of our approach, we analyze the evaluated performance against existing protocols in terms of communication overhead, the number of communication rounds (network lifetime), total amount of energy dissipated in the system over time, network delay and Energy*Delay metric using SENSE simulator. The simulation results show that C^2E^2S consumes less energy, balances the energy and delay metrics, and extends the network lifetime as compared to other approaches.
key words: *sensor network, intra-cluster routing, inter-clusterheads routing, Energy*Delay, network lifetime*

1. Introduction

Wireless sensor nodes are combining the wireless communication infrastructure with the sensing technology. Instead of transmitting the perceived data to the control center through wired links, ad hoc communication methods are utilized, and the data packets are transmitted using multi-hop connections [13]. Sensor nodes have a short transmission range due to their limited radio capabilities. Therefore, the data must be relayed using intermediate nodes towards the base station (BS). In addition, it may be more advantageous to use a multi-hop path to the BS consisting of shorter links rather than using a single long connection. In many cases, scalability of the network becomes a very important design issue. In order to obtain a scalable network, the sensor nodes should be divided into clusters. Each cluster has a cluster head that aggregates all data sent to it by all its mem-

bers. Then, cluster heads cooperate to disseminate data to the BS. In a wireless sensor network, data aggregation of related data (or from many of correlative data) will reduce a large amount of data traffic on network, avoid information overload, produce a more accurate signal and require less energy than sending all the unprocessed data throughout the network. In various literatures, clustering approach is addressed as a potential routing method supporting the data aggregation feature. Works in [9], [11] involved the multi-hop approach into clusters for a larger set of sensors covering a wider area of interest. Many clustering algorithms have also been proposed together with those literatures, however, most of those algorithms are heuristic in nature and their collective aim is to generate the minimum number of clusters such that a node in any cluster is at the most k hops away from cluster head. In our context, generating the minimum number of clusters might not ensure minimum energy usage. Energy consumption in a sensor node can be due to many factors such as sensing event, transmitting or receiving data, processing data, listening to the media, communication overhead, etc. Considering the sensor's energy dissipation model in [1], the energy used to send q bits a distance d from one node to another node is given by $E_{tx} = (\alpha_1 + \alpha_2 d^n)*q$. Where α_1 is energy dissipated in transmitter electronics per bit, α_2 is energy dissipated in transmitter amplifier. For relatively short distances, the propagation loss can be modelled as inversely proportional to d^2, whereas for long distances, the propagation loss can be modelled as inversely proportional to d^4. Obviously, energy consumption in a sensor will be significant if it transmits data to a node that is at a long distance. This is one of the reasons that we suggest the k-hop cluster approach rather than single-hop cluster approach. Another reason is that the single-hop cluster approach is suitable only for networks with a small number of nodes. It is not scalable for a larger set of sensors covering a wider area of interest since the sensors are typically not capable of long-haul communication. Moreover, the energy dissipation is not even in the single-hop cluster approach. Although energy efficiency is a key concern in wireless sensor networks, it often introduces additional delay. In this paper, we mainly focus on energy efficient routing for wireless sensor networks with minimum delay by proposing a new multi-hop routing scheme called C^2E^2S. This scheme provides an Energy*Delay efficient multi-hop routing approach to tackle with resource constrains of sensor nodes as well as meet time-constrained applications of sensor networks.

Technically, this work investigates a new multi-hop

routing scheme to balance the efficiency on energy and network delay. C^2E^2S is a mixed scheme of cluster-based and chain-based approaches for wireless sensor networks. Doing this not only reduces energy consumption but also provides a low latency. Besides, we propose a passive approach called passive-BS-based approach to reduce the high communication overhead compared with general-BS-based approach. We also propose two algorithms in order to balance the energy and delay metrics for all sensor nodes and extend network lifetime. Energy*Delay routing algorithm is applied within 3-hop cluster in order to balance energy and delay metrics for sensors within each cluster while Energy-efficient chain construction algorithm is applied for cluster heads to construct energy-efficient chains from cluster heads to the BS. Logically, if we use more than 3-hop clustering, relaying nodes will need much more energy to forward data in the network, the computation complexity at each node is also higher. It brings about the higher latency. Besides, our goal is to balance the energy and delay metrics. And the more hops are used, the higher delay is required. This is really not an expected concern in WSNs.

The remainder of the paper is organized as follows. Section 2 mentions about related work studied together with our research. In Sect. 3, an Energy*Delay efficient multi-hop routing scheme, C^2E^2S, is introduced along with a passive-BS-based approach. Section 4 addresses routing issues including intra-cluster and inter-clusterheads routing algorithms. In Sect. 5, we analyze the performance of C^2E^2S evaluated against existing protocols. Finally, Sect. 6 gives concluding remarks and future directions.

2. Related Work

In recent years, many sensor network protocols have been proposed to increase the energy efficiency. A clustering architecture (LEACH) based on the distributed algorithm for wireless sensor networks has been proposed in [1], where sensor nodes elect themselves as cluster heads with some probability based on residual energy of sensors for each round. Although this approach has advantages by using the distributed cluster formation algorithm, it may form poor clusters throughout the network. In addition, this approach allows only 1-hop clusters to be formed. This limits the capability of the protocol. Later, the authors improved clustering algorithm by using a center cluster algorithm. In this approach, the BS controls almost all operations in the network including computing and determining optimal clusters. In general, the clusters formed by BS are better than those formed using the distributed algorithm. However, this kind of approach suffers a large number of communication overheads between sensors and BS.

Clustering architecture introduced in [4] provides two threshold parameters (hard, soft) in order to reduce number of transmission in the network. The main drawbacks of the two approaches are the overhead and complexity of forming clusters in multi-levels and implementing threshold-based functions. Younis et al., have proposed a hierarchical rout-

ing architecture in [10] based on 3-layer model. Clusters are formed by a lot of factors such as communication range, number and type of sensor nodes and geographical location, that can base on GPS [8] or other techniques. However, communication from cluster heads to the BS is still direct communication. Besides, authors only focused on the issue of network management within the cluster, particularly energy-aware routing. In [2], authors have provided a protocol called HEED. This approach selects well-distributed cluster heads using information about residual energy and a second parameter such as node proximity to its neighbors or node degree. Authors have presented simulation results in order to compare the energy efficiency with other protocols. However, the clustering algorithm in HEED is still heuristic. Besides, this clustering algorithm suffers a high network delay due to the complexity of clusterhead selection algorithm. This is a disadvantage in time-constrained applications of sensor networks, especially in large networks. In [7], authors have proposed a distributed, randomized clustering algorithm to organize the sensors in clusters energy efficiently. They consider the network in which the sensors are distributed as per a homogeneous spatial Poisson process. We use the results of their paper to support our scheme.

The approach proposed in [3] to improve the energy efficiency is chain-based approach. In this approach, each node communicates only with a close neighbor and takes turns transmitting to the BS, thus reducing the amount of energy spent per round. However, while chain-based protocols are more energy efficient than cluster-based protocols, they suffer the high delay and poor data fusion capacity. An Energy-Latency tradeoff approach in wireless sensor networks has been proposed in [6]. Authors studied the problem of scheduling packet transmission for data gathering in wireless sensor networks. They focus on the energy and latency tradeoffs using techniques such as modulation scaling. Although optimal algorithms based on dynamic programming have been proposed, they suffer an exponential complexity.

In [14], we have proposed a clustering approach called PLIR for prolonging network lifetime and distributing data evenly by improving BS-based clustering algorithm of LEACH-C [1] and providing 3-hop routing algorithm within clusters. In addition, in [15], we have proposed a novel hierarchical routing protocol for a large sensor network where sensors are arranged into a multi-layer architecture with the nodes at each layer interconnected as de Bruijn graph. In this work, a new hierarchical routing algorithm has also been proposed. Using our approach, every sensor obtains a unique node identifier addressed by binary addressing fashion. We have shown that our approach has reasonable fault-tolerance, admits simple and decentralized routing, and offers easy extensibility.

3. Energy*Delay Efficient Multi-Hop Routing Scheme - C^2E^2S

In this section, an Energy*Delay efficient multi-hop rout-

ing scheme called C^2E^2S along with a passive-BS-based approach is presented.

3.1 The Network Scheme

A proposed network scheme (C^2E^2S) for the wireless sensor networks is shown in Fig. 1. In this scheme, sensors in the WSN are distributed as a homogeneous spatial Poisson process of rate α in a square area of side a. The computation of the optimal probability p to become a cluster head and the maximum number of hops k allowed from a sensor to its cluster head is beyond the scope of this paper. We use the results in [7] to obtain the optimal parameters for our scheme. According to [7], we determine the maximum number of hops k as follows:

$$k = \left\lceil \frac{1}{r} \sqrt{\frac{-0.917 \ln(\alpha/7)}{p\lambda}} \right\rceil \tag{1}$$

Where:

p : optimal probability of becoming a clusterhead

r : transmission range.

α : a very small value, ($\alpha = 0.001$ used in simulation), which implies that the probability of all sensors being within k hops from at least one cluster head is very high.

Sensors are distributed into m k-hop clusters using these parameters. Each cluster has a cluster head that aggregates all data sent to it by all its members. Then, m cluster heads form l binary chains. Each chain divides each communication round into several levels. Each node transmits data to the closest neighbor in a given level. Only those nodes that receive data can rise to the next level. Finally, leader for each chain sends data to the BS. Have one transmission round completes. In this approach, each intermediate node performs data aggregation.

In this scheme, cluster-chain formation can be either computed in a centralized manner by the BS and broadcasted to all nodes or accomplished by the sensor nodes themselves. To produce better clusters and chains as well as to remove the strong assumption that all sensors have global knowledge of the network, we use the BS-based approach. However, the centralized approach suffers from high communication overhead. To deal with this, we propose a passive approach (called passive-BS-based approach)
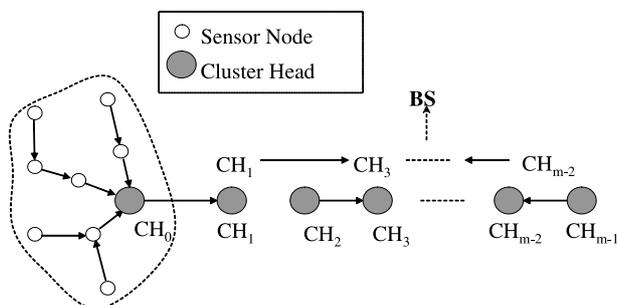
in which each sensor node, upon sending a data packet, piggybacks related information. Upon a data packet reception, the BS extracts this information in order to apply for cluster and chain formation. The data packet format is depicted in Fig. 2. The INFO part is a trio (*Node ID*, *Node Energy*, *Number of bits*). The BS bases on this trio in order to compute the residual energy for each node. For example, the trio (100, 1.5, 2500) describes that node 100 has 1.5 joules residual energy and has sent 2500 bits data to the BS.

In this scheme, we rely on the assumptions that the sensors are quasi-stationary. Each tiny sensor has a sensing module, a computing module, memory and wireless communication module. The BS is assumed to have adequate energy to communicate with all sensor nodes in the network. Sensors are left unattended after deployment. In addition, they can use power control to vary the amount of transmission power to reduce the possibility of interference with nearby clusters and its own energy dissipation.

3.2 C^2E^2S Operation

In C^2E^2S, network lifetime is divided into number of rounds. Each round begins with cluster-chain formation phase followed by data transmission phase. In each frame of data transmission phase, each sensor node is assigned its own time slot to transmit data to cluster head. By turn, each cluster head is also assigned its own slots to communicate with the nearest cluster head based on chain construction. A detail description is depicted in the Fig. 3. This figure shows the time-line for C^2E^2S operation, from the time clusters and chains are formed during the cluster-chain formation phase, through the data transmission phase when data are transferred from the sensor nodes to cluster heads and forwarded to the BS.

The operation of C^2E^2S is compacted in Fig. 4. Using passive-BS-based approach, C^2E^2S distinguishes between the first round and the remaining rounds. In the first round, all sensors must send information about their location and
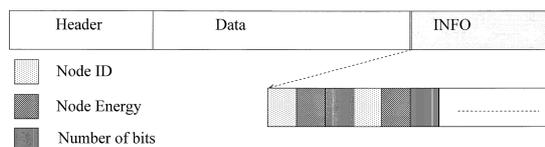
Fig. 2 Data packet format. The INFO includes information about *ID*, *Energy*, *Number of bits* of nodes that packet passed.

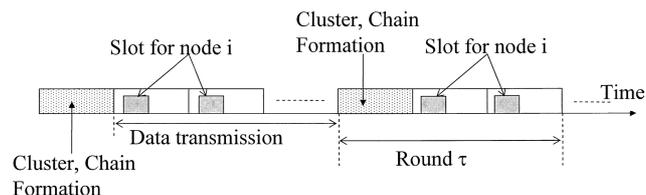**Fig. 1** A combination scheme of cluster and chain based approaches for the WSNs.

Fig. 3 Time-line showing C^2E^2S operation. Data transmissions are explicitly scheduled to avoid collisions and increase the amount of time each sensor nodes can remain in the sleep mode to save energy.
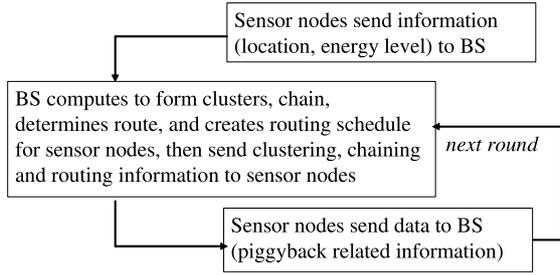
Fig. 4 Flowchart of C^2E^2S operation.

Table 1 Maximum number of hops within each cluster for different network size ($r = 1$).

Network size (number of sensors)	Intensity (λ)	Maximum number of hops (k)
1000	10	4
1500	15	3
2000	20	3
2500	25	3
3000	30	3
3500	35	3
4000	40	3

current energy level to the BS directly. The BS uses this information and the cluster and chain formation algorithms to choose cluster heads, to distribute the remaining sensor nodes into associated clusters, and to construct l binary chains among cluster heads. In subsequent rounds, to form clusters and chain, the sensor nodes do not need to resend the information about location and residual energy to the BS. Instead, information will be extracted from the INFO part (see Fig. 2) in the data packets received from cluster heads in the previous round. The last packet from each node at the end of each round is the only one that carries information about residual energy level and number of transmitted bits of that node. The other packets carry data normally. Cluster heads receive data packets from other sensor nodes, perform data integration then send data packet to the BS following binary chains.

4. Routing Algorithms for C^2E^2S

In this section, two routing algorithms, the intra-cluster and inter-cluster heads routing algorithms are presented.

4.1 Intra-Cluster Routing Algorithm

The experiments were conducted for sensor networks of the different intensities, λ. For each of network intensities, we use Eq. (1) to calculate the maximum number of hops, k, allowed from a sensor to its cluster head. Results are given in Table 1.

From results calculated in Table 1, obviously, the 3-hop (at most) cluster is the best choice for the large sensor networks. Plus, if more hops are used, the higher latency is required. Hence, in this section, we propose an Energy*Delay-aware routing algorithm for sensors within each 3-hop cluster instead of k-hop cluster. This reduces the complexity of algorithm significantly as compared to other approaches [10], [11].

The 3-hop routing algorithm within each cluster consists of two steps as follows:

1. Sensors within each cluster (except the cluster head) are partitioned into three sets: I, J, K. The detailed algorithm is described in Fig. 5.
2. Using the Shortest Path Algorithm to determine the best route from these sets of node to cluster head.

```
# E_i :energy of node i;
# d(i,CH_j) : distance from sensor i to clusterhead within cluster j
# C_j : Cluster j    # m : the number of clusters
#z : the number of sensors within each cluster
#I_1 ← {} : set of nodes that sense data, relay data from J_1, J_2 to clusterhead;
#J_1 ← {} : set of nodes that sense data, relay data from K to I_1;
#I_2 ← {}; J_2 ← {}; K ← {} : sets of sensing nodes;
#J : union of J_1 with J_2.        #I : union of I_1 with I_2.
```

1. $CAD = \dfrac{\sum_{i=1}^{z} d(i,CH_j)}{z}$ $\forall i \in C_j, 0 \le j \le m-1$ /*average distance from sensors to associated clusterhead*/

2. $CAE = \dfrac{\sum_{i=1}^{z} E_i}{z}$ $\forall i \in C_j, 0 \le j \le m-1$ //average energy for each cluster;

3. If ($d(i,CH_j) < CAD$) then
If ($E_i \ge CAE$) then $I_1 \leftarrow I_1 \cup i$;
Else $I_2 \leftarrow I_2 \cup i$;
4. Else If ($d(i,CH_j) \ge CAD$ and $d(i,CH_j) < 2*CAD$) then
    If ($E_i \ge CAE$) then $J_1 \leftarrow J_1 \cup i$;
    Else $J_2 \leftarrow J_2 \cup i$;
5. Else $K \leftarrow K \cup i$;
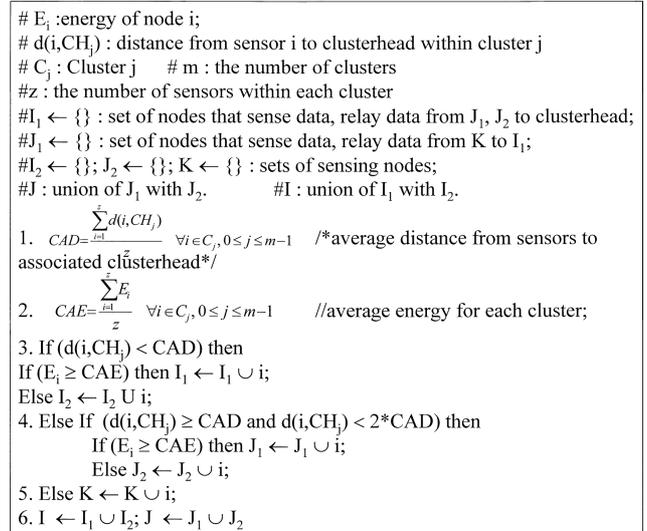6. $I \leftarrow I_1 \cup I_2$; $J \leftarrow J_1 \cup J_2$

Fig. 5 Algorithm - partition sensors into 3 sets of nodes I, J, K.
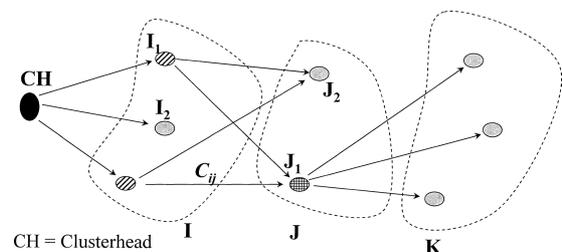

Fig. 6 An example of the intra-cluster routing.

In step 2, we apply the Shortest Path Algorithm to determine the best route from cluster head to J (union of J_1 with J_2), K using the set nodes I_1, J_1 respectively. An example of network within each cluster is depicted in the Fig. 6.

Our intra-cluster routing problem can be considered as determining the shortest route (least cost) from one node to a set of nodes. We apply Dijkstra's algorithm [5] to disseminate data from sensors to cluster head with the link cost C_{ij} for the link between the nodes i and j defined as follows:

$$C_{ij} = \sum C_k \quad (k = 1, \dots, 4) \tag{2}$$

Where:

$C_1 = c_1*d^2(i, j)$: data communication cost (energy) from node i to node j where c_1 is a weighting constant. This parameter reflects the cost of the wireless transmission power. Where $d(i, j)$ is distance between the nodes i and j.

$C_2 = c_2*d(i, j)$: delay cost because of propagation between the nodes i and j where c_2 is a constant which describes the speed of wireless transmission.

$C_3 = c_3*E(j)$. This parameter reflects cost of energy, c_3 is a constant. Where $E(j)$ is residual energy of node j.

$C_4 = c_4*Z(j)$. Where c_4 is a constant, $Z(j)$: number of connections to node j.

4.2 Inter-Clusterheads Routing Algorithm

In this section, we propose an Energy-efficient chain construction algorithm for cluster heads. The operation starts with one cluster head, the farthest cluster head from the BS. This node works as the head of the chain. Then, the *non-chain* node, the one that is closest to the head of the chain, will be appended into the chain. The BS also takes part in chain construction procedure in order to decide when a chain should be ended (using EndOfChain variable). This procedure repeats until all cluster heads are in the chains. The detailed algorithm is described in Fig. 7.

This algorithm ensures that cluster heads will communicate with the closest neighbor. Based on the radio energy dissipation model in [1], the receiving cost only depends on packet size, while the transmission energy depends on the distance between two nodes along a chain. As a result, that communication with the closest node is synonymous with consuming the least energy. Besides, this algorithm avoids the situation where a node may have a local neighbor very far away while the BS is closer than that neighbor. This not only reduces the energy consumption for sensors but also lower the network delay.

```
# CHAIN: chain
# HEAD: the head node in the chain
# d(i,j): distance from node i to node j
1. N: set of cluster heads;
2. HEAD ← The farthest cluster head from BS;
        ∀ all nodes ∈ N;
3. N' ← N − {HEAD};
   CHAIN ← {HEAD};    EndOfChain ← False;
4. While (N' ≠ ∅)
   key[i] ← min[d(HEAD,i)];   ∀ i ∈ N';  /* select a cluster head i
                              that is closest to the HEAD*/
   If key[i] < d(HEAD,BS);    //BS: base station
        HEAD ← i;
   Else {
        HEAD ← BS;
        EndOfChain ← True;
        }
   Append(CHAIN, HEAD);        // append HEAD at the end of CHAIN
   N'' ← N' − HEAD;
   If (EndOfChain ← True) Exit(); /* end of While(N' ≠ ∅);
                              a chain is constructed */
5. N ← N' − ⌉N'';
6. If (N≠ ∅)    Goto 2;      // construct another chain
7. Else    Stop;            // chains are constructed.
```

Fig. 7 Chain construction algorithm for cluster heads.

5. Performance Evaluation

In this section, we analyze the performance evaluated against LEACH-C, H-PEGASIS (Hierarchical PEGASIS), and HEED protocols in terms of communication overhead, the number of communication rounds (network lifetime), total amount of energy dissipated in the system over time, network delay and Energy*Delay using a simulator named SENSE [12].

5.1 Simulation Setup

Our sensor field spans an area of $100 \times 100\,\mathrm{m}^2$ wherein 2000 sensors are scattered randomly with the BS location at $(75, 125)$. A node is considered "dead" if it consumes more than 95% of its initial energy level. For a node in the sensing state, packets are generated at a constant rate of 1 packet/sec. For the purpose of our simulation experiments, the values for the parameters c_k in the link cost C_{ij} (given by Eq. (2)) are initially selected based on sub-optimal heuristics for best possible performance. In our simulation, c_1, c_2, c_3 and c_4 are 5, 4000, 20 and 125 respectively. The communication environment is contention and error free; hence, sensors do not have to retransmit any data.

To compute energy consumption for each transaction of sending and receiving, we use the radio energy dissipation model in [1]. The energy used to transmit q-bit data a distance d for each sensor node is: $E_{Tx}(q, d) = qE_{elec} + q\varepsilon_{fs}d^2$. The energy used to receive data for each node is: $E_{Rx}(q) = qE_{elec}$. Where E_{elec} is the electronics energy, ε_{fs} is power loss of free space. In these experiments, each node begins with 2 *joule* of energy and an unlimited amount of data to be sent to the BS. Table 2 summarizes parameters used in our simulation.

5.2 Simulation Results

For the first experiment, comparing the efficiency of network lifetime between the existing protocols and C^2E^2S, we studied the number of communication rounds as number

Table 2 Simulation parameters.

Parameter	Value
Network size	100x100
Number of sensors	2000
Base station location	(75,125)
Packet generating rate	1 packet/sec
E_{elec}	50nJ/bit
ε_{fs}	10pJ/bit/m^2
Initial energy (for each node)	2 Joule
Data packet size	500 bytes
Header size	25 bytes
Info packet size	25 bytes
Cluster Info packet size	50 bytes
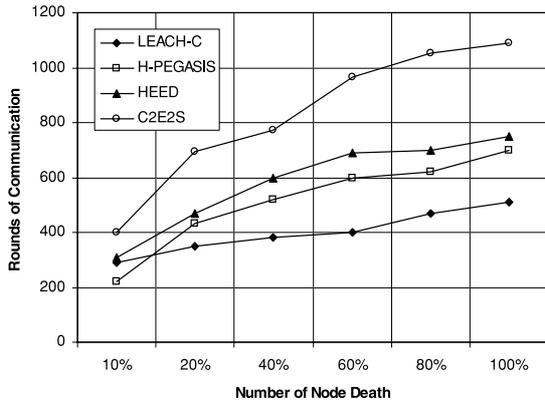
(a) Number of communication rounds upon percentage of dead nodes.
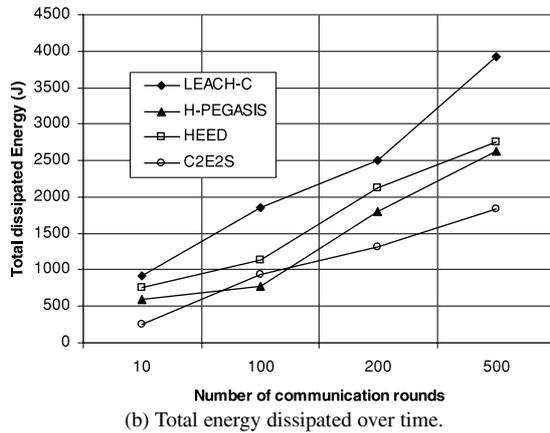
(b) Total energy dissipated over time.

Fig. 8 Comparing the efficiency of network lifetime among protocols.

Fig. 9 Delay upon percentage of dead nodes.

(a) Energy*Delay upon percentage of dead nodes.

(b) Energy*Delay upon network size.

Fig. 10 Comparing the efficiency of Energy*Delay metric among protocols.

of dead nodes increases and the total energy dissipated upon number of communication rounds.

The graph in Fig. 8 (a) compares the network lifetime among LEACH-C, H-PEGASIS, HEED and C^2E^2S. In C^2E^2S, sensor nodes consume energy more evenly than other approaches. Although k-hop cluster approach in C^2E^2S suffers slightly higher delay, it balances energy dissipation between sensor nodes. Thus, number of communication rounds increases significantly. Compared with LEACH-C and HEED, C^2E^2S balances energy consumption between cluster heads. Compared with H-PEGASIS, C^2E^2S reduces a large number of identical data bits between sensors in the same cluster. Figure 8 (b) shows the amount of energy dissipated after a number of communication rounds. C^2E^2S is able to keep its energy to be dissipated gradually thus prolonging network lifetime.

For the second experiment, we first evaluate network delay metric. Next, to calculate the Energy*Delay, we multiply the total delay with total dissipated energy over time for each protocol. The graph in Fig. 9 shows that the network delay in LEACH-C is the highest while C^2E^2S offers the lowest delay. However, when a great number of dead nodes increases, the network delay in C^2E^2S is slightly higher as compared to H-PEGASIS. Regardless of this, C^2E^2S saves much more energy than H-PEGASIS. Thus, Energy*Delay metric in C^2E^2S is always lower than H-PEGASIS. As
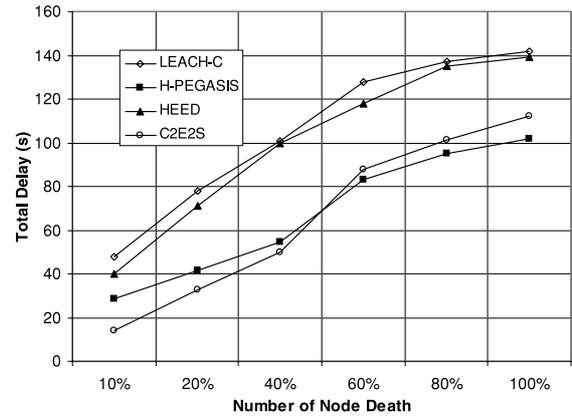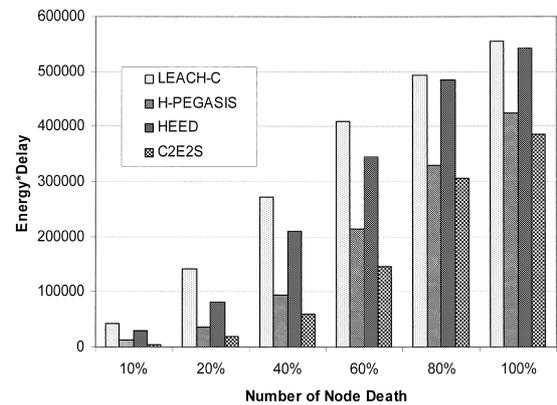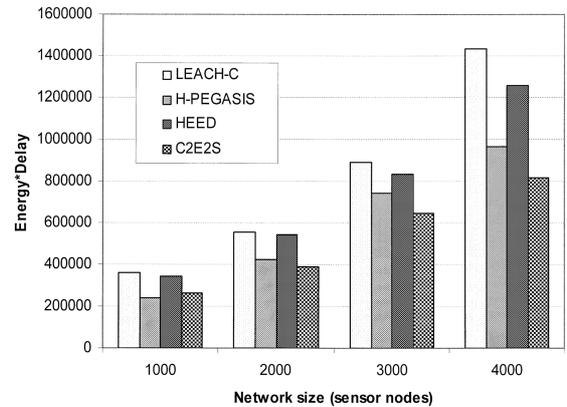
shown in Fig. 10 (a), this metric is also lower than in both LEACH-C and HEED (cluster-based approaches).

To indicate the effectiveness of our scheme in terms of Energy*Delay metric for large sensor networks, we ran several simulations with different network sizes (from 1000 to 4000 sensors). Figure 10 (b) shows that when network size increase, the effectiveness of Energy*Delay metric in our scheme also increases significantly. For 1000 sensor nodes, C^2E^2S is slight higher than H-PEGASIS. However, for

more than 2000 sensor networks, Energy*Delay in C^2E^2S is lower than other protocols. Hence, we can say that, C^2E^2S is an Energy*Delay efficient scheme for large wireless sensor networks.

In the last experiment, we studied the communication overhead as total number of header bits transferred from sensors to the BS. In our approach, node's information is piggy-backed by data packets. Thus, it reduces a large number of communication overheads broadcasting through the network using general BS-based approaches (called Gen-BS-based approach). Figure 11 (a) shows that the communication overhead is the same in the first round for both the approaches. However, from the second round, the number of communication overheads increases gradually in C^2E^2S, while Gen-BS-based approach (LEACH-C, HEED) increases very fast. The effectiveness of C^2E^2S is seen more clearly as there are several simulations run for a large number of sensor nodes. Yet again, we compare two approaches for different network sizes (from 2000 to 4000 sensors). Result in Fig. 11 (b) shows that the communication overhead increases rapidly in Gen-BS-based approach, while it increases gradually in our approach (Passive-BS-based approach) as number of senor nodes increases.

The performance of the protocol depends on the size of the networks and distribution of nodes. For small size net-

(a) Communication overhead over time.

(b) Communication overhead upon network size.

Fig. 11 Communication overhead for Gen-BS-based and Passive-BS-based approaches.

works some existing protocol may perform better than the proposed scheme but as the size of the network increases the protocol will outperform all the existing hierarchical protocols.

6. Conclusions and Future Work

Routing in wireless sensor networks has attracted a lot of attention in the recent years and introduced unique challenges as compared to traditional data routing in wired networks. Due to limitations of sensor nodes in terms of memory, energy and computational capacities, the most important issues for designing sensor network protocols is energy efficiency and long-life network. Although energy efficiency is a major concern in wireless sensor networks, it often suffers from the additional delay. Thus, to reduce the energy consumption while meeting other design goals such as short latency in a large sensor network is the main contribution in our research. We investigate a new multi-hop routing scheme to balance the efficiency on energy and latency for wireless sensor networks.

In this paper, we have proposed an Energy*Delay multi-hop routing scheme, C^2E^2S, along with a passive approach called passive-BS-based approach. We have also proposed two algorithms in order to balance the energy and delay metrics for all sensors in the network and extend the network lifetime. The Energy*Delay routing algorithm is applied within the 3-hop cluster in order to balance energy delay metric for sensors within each cluster while the chain construction algorithm is applied for cluster heads to construct energy-efficient chains from cluster heads to the BS. By simulation, we have shown appropriateness of our scheme evaluated against LEACH-C, H-PEGASIS, and HEED protocols in terms of communication overhead, network lifetime, total amount of energy dissipated in the system over time, network delay and Energy*Delay.

The proposed routing protocol provides optimal performance for large sensor networks. In this work we consider a particular distribution of nodes. There may be other applications where distribution will differ. As a future work we will study of an optimal scheme for different distribution of nodes and its performance.

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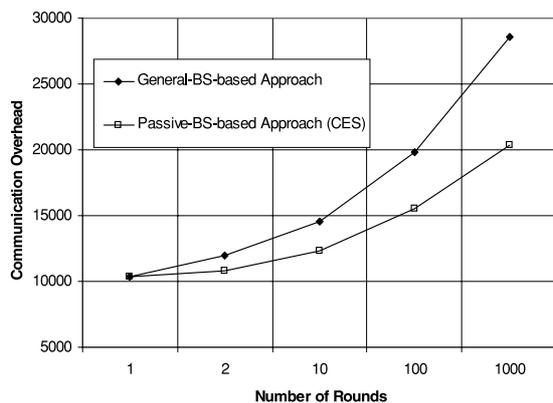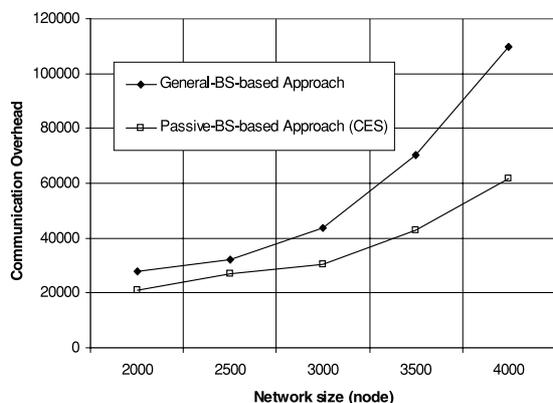
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