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Energy Efficient Routing in Wireless Sensor Network

S. A. Ahsan Rajon, *Member, IACSIT* *and* Md. Mahbubur Rahman, *Member, IACSIT*

***Abstract*—Wireless sensor networks (WSN) have achieved tremendous research interest in recent times because of their multidimensional applications in both civilian and military purposes. But, providing flexible service using wireless sensor network is challenging because they usually contain a large number of resource constraint sensing nodes with small memory, lower processing capability and extremely limited battery life. In this paper, we present an extensive survey on existing routing schemes and propose an effective approach for data communication for such resource constrained sensor network. The main contribution of our paper is, it proposes an enhanced routing scheme which is power efficient and also robust to node failures. It is also a mentionable feature of our research that, our proposed schemes takes the resource constraints of individual sensor nodes into concern and provides a communication scheme which focuses on the balanced work load distribution in sensor network. Our proposed scheme introduces cluster coordinators and focuses on adopting computationally simple approach and consequently minimizes the power consumption for routing phases as well as data transmission steps.**

***Index Terms*— Wireless Sensor Networks, Resource Constraints, Power Consumptions, Data Communication, Routing, Cluster Coordinators.**

I. Introduction

Wireless Sensor Networks (WSN) usually consist of a large number of ultra small low-cost battery-powered devices that have limited energy resources, small computational capability, limited memory, and shorter communication capacities [1],[13]. According to different applications such as battlefield reconnaissance and homeland security monitoring, agricultural field monitoring, fire detection WSNs are often deployed in a vast terrain to detect events of interest and deliver data reports over multi-hop wireless paths to the sink. Data engineering and management is essential for these mission-critical applications to work in unattended and even hostile environments. WSNs can be used for data collection purposes in situations such that environmental monitoring, habitat monitoring, surveillance, structural monitoring, equipment diagnostics, disaster management, and emergency response [1],[2],[5],[13].

Manuscript received May 30, 2012

S. A. Ahsan Rajon is with the Computer Science and Engineering Discipline, Khulna University, Khulna-9208, Bangladesh. (e-mail: ahsan.rajon@gmail.com).

Prof. Dr. Md. Mahbubur Rahman is with Computer Science and Engineering Discipline, Khulna University, Khulna-9208, Bangladesh.

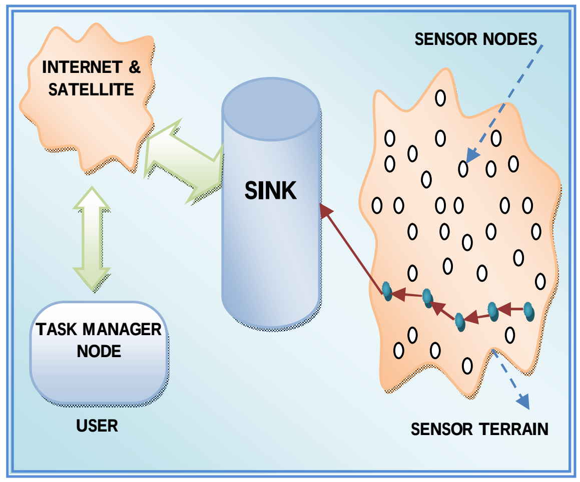

Fig. 1. Generic view of Sensor Network.

As the main use of wireless sensor network is to use in data collection and event monitoring, it is extremely important for the sensor networks to communicate data effectively and efficiently using the minimum resources including energy consumptions i.e. battery power, bandwidth, internal memory and above all processing speed. Consequently, any sensor network data routing scheme will must focus on the issues including computational simplicity, low communication overhead, minimized memory consumption and hence ensure reduced energy consumption.

The main contributions of this paper are: firstly, it proposes an effective routing scheme where the data communication is distributed as well as the workload distribution is more or less balanced and consequently, in spite of using the energy of any specific sensor especially the event reporting source sensor at a greater level, we propose to achieve the total communication at a hop by hop basis, which essentially ensures robust data delivery. Moreover, this paper employs the cluster coordinator which is the prime point of achieving energy efficient routing.

This paper is organized into six sections. In the related literature section, we provide elementary concepts of sensor network and data routing. Recent researches regarding data communication in wireless sensor networks are presented in section three. A detailed overview of our proposed scheme has been illustrated in section four. Section five is devoted to present an extensive analysis of the energy consumption for proposed scheme. This paper concludes with section six

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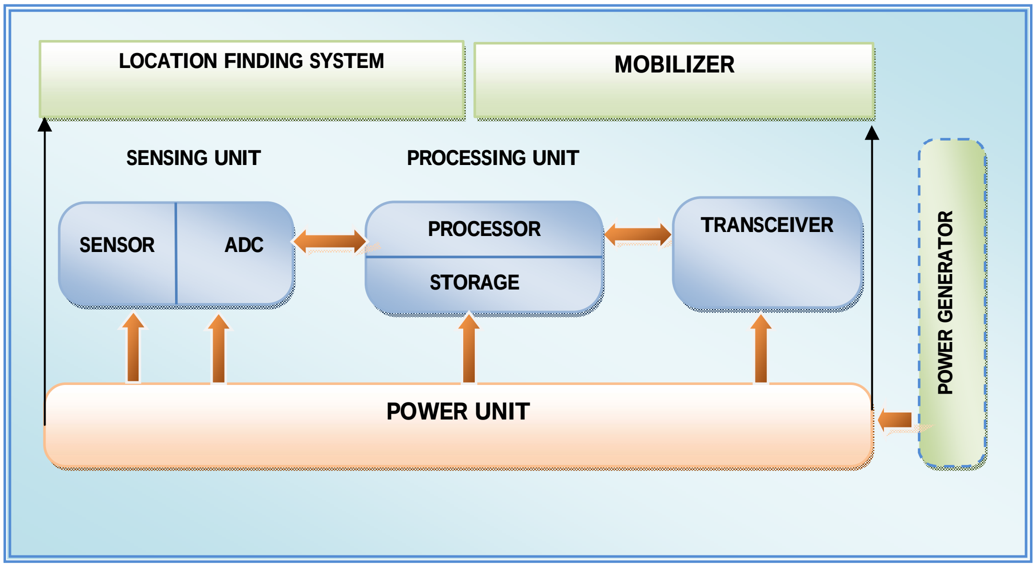

Fig. 2. Components of a Sensor Network

specifying future directions regarding proposed scheme.

II. Related Literature

This section provides a glimpse on the basic concepts of wireless sensor network and data compression with investigation of the necessity of data compression for wireless sensor networks. An overview of the existing data compression schemes are also incorporated

A. Sensor Networks

Wireless Sensor Networks are usually composed of hundreds and thousands of individual tiny sensor nodes which are often densely deployed in a vast terrain. These nodes have the capability to collect data and to send the data to other neighboring nodes or components participating to serve the mutual goal of the system. Individual sensor node consists of four basic generic components: sensing unit, processing unit, transceiver unit, and power unit. Sensing units comprise of two subunits: sensors and analog-to-digital converters (ADCs). The analog signals are produced by the sensors based on the sensing objects and sensing pattern and are converted into digital signals by the ADC. These digital signals are then fed into the processing unit which is generally associated with a small storage unit serving computational aspects. The processing unit also manages the applications and procedures which make the sensor node collaborate with the other nodes to carry out the assigned sensing tasks. A transceiver unit connects the node to the network. One of the most important components of a sensor node is the power unit that may be supported by power scavenging units such as solar cells. There are also other units that are Location tracking system and Power generator systems are also often integrated with the sensor nodes in order to achieve sophisticated functionalities and services.

Sensor Networks are mostly application specific and the adopted routing strategy is also considered as a design criteria. That is, each routing algorithm considers the intended observational subjects and also at the same time, the internal architecture of Sensor. However each routing technique considers several common and essential features like ensuring maximum lifetime of the sensors by minimizing energy consumption through reducing redundant data transmission or data exchange. The task of finding and maintaining routes in WSNs is nontrivial since energy restrictions and sudden changes in node status cause frequent and unpredictable topological changes [1].

B. Sensor Networks and Ad-Hoc Networks

Though Sensor network applications require wireless ad hoc networking techniques, there are several differences between sensor network and ad-hoc networks. In generally, a large number of tiny sensor nodes which are limited in power, computational capacities, and memory are densely deployed into the field of interest whereas in case of ad-hoc network normally the numbers of nodes are normally not so huge. The topology of sensor network changes very frequently and the nodes are prone to failures which make the sensor network comparable with ad-hoc network. Moreover, in case Sensor nodes the communication paradigm is mainly broadcast or semi-broadcast communication, whereas in case of ad hoc networks point-to-point communication is most likely.

C. Advantages and Disadvantages of Wireless Sensor Networks

There are numerous advantages which make the sensor network a tremendous field of interest. Firstly, sensors are extremely small in size, which makes it usable to various places for various applications. Since the network setups can be done without fixed infrastructure, it is considered an ideal solution for the hard-to-reachable places such as across the deserts, mountains, deep forests, sea, rural areas and so forth.

Moreover, WSNs are not only flexible in nodes additions, removal but also cheap to implement. However, there are several challenges in WSNs including security, power consumptions, speed and configurations. Since, the network may be formed independently, it is extremely vulnerable to attackers. Since the power consumption is the most important issue for wireless sensor networks, processing capability and speed are often compromised.

III. Routing in Wireless Sensor Networks

A sensor network design is influenced by many factors, which include fault tolerance; scalability; production costs; operating environment; sensor network topology; hardware constraints; transmission media; and power consumption [2]. There are several routing techniques for wireless sensor networks. Most of the recent routing approaches proposed energy aware routing. These routing techniques can be classified according to various points of view. However, most of the literature differentiates the routing algorithms into three main categories including Data Centric Approaches, Hierarchical Cluster based Routing Techniques and Location based routing.

To relay data in sensor networks, flooding and gossiping are two fundamental mechanisms. In case of flooding, each sensor node receiving a data packet broadcasts it to all of its neighbors which is continued until the packet arrives at the destination or the maximum number of hops for the packet is reached. On the other hand, gossiping is a slightly enhanced version of flooding where the receiving node sends the packet to a randomly selected neighbor rather than entire nodes, which picks another random neighbor to forward the packet to and so on [1].

A. Flat Based Data Centric Routing Protocols

In data centric routing approaches, normally, the WSN is considered as flat network since all nodes play the same role in data gathering and communication. Hierarchical protocols aim at forming clusters and selecting appropriate cluster heads on the basis of some criteria so that cluster heads can do some aggregation and reduction of data in order to save energy and also maintain data integrity. In case of location-based protocols, the relative position information is taken into consideration for communicating data to the desired regions rather than the whole network and thus maximizing the lifetime of the sensors [1].

In data centric routing protocols, SPIN (Sensor Protocol for Information via Negotiation) and Directed Diffusion are two widely adopted schemes.

The main advantage of flat based i.e. data centric routing is that, the total approach is very simpler and doesn't focus on specific nodes and also tends towards energy consumption minimization. However, the problem with a data centric approach is that it works well for static nodes, but these approaches are not designed to handle the mobility of neither the nodes nor the sink. Flat based routing schemes cannot handle complex queries. Scalability and data aggregation is also a point of limitation for data centric approaches.

A.1. SPIN (Sensor Protocol for Information via Negotiation)

The concept of SPIN (Sensor Protocols for Information via Negotiation) is mainly based on naming the data using high level descriptors or meta-data. Prior to transmission, meta-data are exchanged among sensors using some direct data advertisement mechanism. When any node receives any new data, it advertises ADV (advertise) message that to its neighbors and interested neighbors. Here interested neighbors are defined as those nodes that do not have the data. Interested nodes send a request message to retrieve the data.

The main advantage of SPIN is, it facilitates a lot in achieving energy efficiency because, the meta-data negotiation proposed in SPIN solves the classic problems of flooding such as redundant information passing, overlapping of sensing areas and resource blindness. Second feature of SPIN is that, topological changes are localized since each node needs to know only its single-hop neighbors.

The main criticism is, SPIN's data advertisement mechanism cannot guarantee the delivery of data. As the data dissemination is based on neighbors and interested neighbors, if the actual nodes that are interested in the data are far away from the source node and the nodes between source and destination are not interested in that data, such data will not be delivered to the destination at all.

A.2. DD (Directed Diffusion)

Directed Diffusion is basically an improvement of SPIN. In case of Directed Diffusion, the sink node requests interested data by broadcasting a request message to the nodes. This request message is circulated from node to node in a multi-hop fashion and each node is informed of the query of the sink. Each node also maintains a gradient to the node from which it received the interest. When the data reaches to the intended sensor(s), and the sensing in particular is done, data is sent back towards the sink. When there are multiple paths towards the sink, some performance metric is used to decide on the optimal path. This decision made by the intermediate nodes performing some in-network data processing tasks like aggregating the data based on name and attributes value aids some energy saving. Though this is a point of advantage, it also raises the problem of some energy consumption during data aggregation.

A.3. ACtive Query forwarding in sensor networks (ACQUIRE)

ACtive Query forwarding in sensor networks (ACQUIRE) is a flooding based query technique which maintains a clear distinction between the query dissemination and response gathering stages which is to some extent assimilated in previous schemes. The main idea behind ACQUIRE lies in viewing the sensor network as a distributed database and thus broadens the scope to work with complex queries which may consist of several sub queries.

For any query raised by the sink each node first tries to respond using their pre-cached information and then sends it to other neighbor sensor nodes. For nodes which doesn't have up-to-date data, the node themselves gather data from their neighbors within a look-ahead of d loops. Here d may range from network size to any lower value. The query is to travel more hops for any lower value of d. When the query is resolved completely, it is sent back towards the sink through either on the reverse path or through shortest-path from node to the sink. The underlying impetus for ACQUIRE is dealing with one-shot queries proficiently where the response can be constituted by many nodes. Though setting up d as the maximum (i.e. equal to network size) makes ACQUIRE behave similar to generic flooding approaches, varying parameter d makes the scheme much more energy efficient by restricting flooding for one-shot query processing.

4. Rumour Routing

Rumour Routing protocol is an energy-efficient protocol based on directed diffusion scheme. This technique is used for network comprise of densely distributed sensors of fixed infrastructure and there exists bidirectional links. When geographic information is not available, Rumor Routing is also a candidate choice.

Rumour routing algorithm employs long-lived packets, called agents to flood events through the network. After detecting an event, it adds such event to its local table known as events table, and generates an agent. The network is traveled by the agent on a random path with related event information. These visited nodes form a gradient towards the event. Rumour routing only maintains one path between source and destination. The main advantage of Rumor Routing is, it works fine when the number of events is lower

Table 1: Comparison of Routing Protocols for Wireless Sensor Networks

Protocols / Feature	*SPIN*	*Directed Diffusion*	*ACQUIRE*	*Rumour Routing*	*LEACH*	*TEEN*
Type	Flat	Flat	Flat	Flat	Hierarchical	Hierarchical
Scalability	Low	Low	Low	Good	Good	Good
Data Delivery	Event driven	Demand driven	Demand driven	Demand driven	Cluster based	Threshold
Data Delivery Confirmation	No	Yes	No	Yes	No	No
Efficient Power Usage	Low	Low	Low	Low	Good	Good
Network Lifetime	Good	Good	Good	Very good	Very good	Very Good
Overhead	Low	Low	Low	Low	High	High
Mobility Support	Good	Limited	Limited	Limited	Limited	Limited
Optimal Route	No	Yes	No	No	No	No
Hop Communication	Single-Hop	Multi-Hop	Multi-Hop	Multi-Hop	Single-Hop	Single Hop
Main Advantage	Meta-data negotiation proposed in SPIN solves the classic problems of flooding and topological changes are also localized since each node needs to know only its single-hop neighbors	More than one sink can make queries and receive data at the same time; hence, simultaneous queries could be handled inside a single network	Energy efficiency may be controlled by varying a parameter and thus limiting the number of hops to include in query processing.	Since, Rumour Routing maintains only one path between source and destination, the data delivery model is low energy consuming.	limits most of the communication inside the clusters, and hence provides scalability in the network along with Distributiveness, where it distributes the role of CH to the other nodes	Best suited to time-critical data sensing applications. The energy consumption in this scheme can potentially be must less than in the proactive network, because data transmission is done less frequently
Main Disadvantage	If the actual nodes that are interested in the data are far away from the source node and the nodes between source and destination are not interested in that data, such data will not be delivered to the destination.	Since Directed Diffusion is a query-based protocol, it may be not work well in applications where continuous data transfers are required	Revealing the shortest path is often more energy consuming. Moreover, for setting the parameter d as maximum directed diffusion behaves like flooding.	For a large number of events, the cost of maintaining agents and event-tables becomes infeasible	CHs directly communicate with sink—there is no inter cluster communication, and this needs high trans-mission power	If the thresholds are not reached, the nodes will never communicate the user will not get any data from the network even if the network dies.

whereas, for large number of events, the cost of maintaining agents and event-tables becomes infeasible.

B. Cluster based Hierarchical routing protocols

The main idea of Hierarchical routing protocols (also known as cluster based routing protocols) resides in grouping the sensor nodes on the basis of some suitable criteria. Cluster based protocols normally also chooses node(s) with the highest residual energy as cluster head(s) which eases efficient energy distribution. Mentionable cluster based protocols include Low Energy Adaptive Clustering Hierarchy (LEACH), Power-Efficient Gathering in Sensor Information Systems (PEGASIS), Threshold sensitive Energy Efficient sensor Network protocol (TEEN).

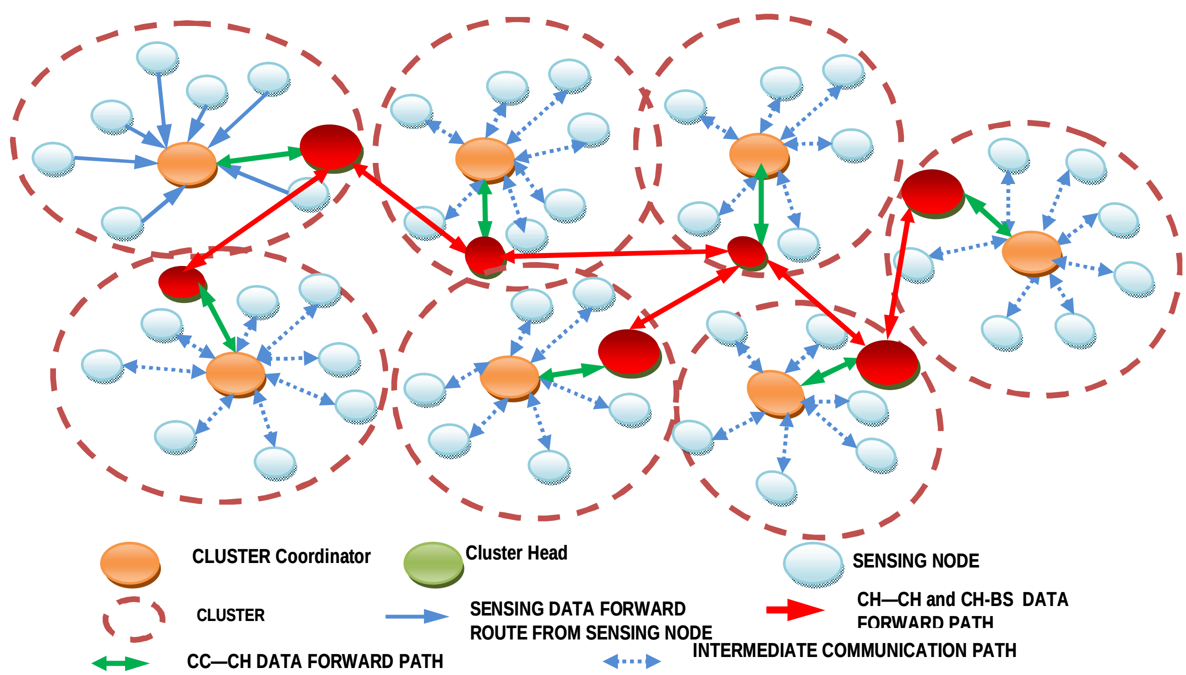

Fig. 3. proposed scheme

by those clusters alone rather than sensor nodes. It is also estimated that 5% of total nodes will be the optimal amount for cluster nodes [5]. One of the interesting features of LEACH has the flexibility of randomly changing the cluster heads. Balancing the dissipation of energy from nodes with respect to time through this scheme also makes LEACH an important approach. The sensor nodes elect themselves to be Cluster Heads at any given time with a certain probability. At each interval the decision whether a node elevates to cluster head is made dynamically and solely by each node independent of other nodes to minimize overhead in cluster head establishment. This decision on Cluster Head selection is a function of the percentage of optimal cluster heads in a

B.1. Low Energy Adaptive Clustering Hierarchy (LEACH)

LEACH is one of the first hierarchical self-organizing clustering protocols which apply randomization for distributing the energy load among the sensor nodes in the concerned network.

LEACH protocol assumes that, all the nodes are homogeneous and they can transmit with enough power to reach the base station and also each node possesses enough computational power. It is also assumed that, the base station is fixed and the nodes observation is correlated.

The main idea of LEACH resides in forming clusters of sensor nodes based on incoming signal strength and then local cluster heads are used as routers to the sink. The energy saving phenomenon is achieved by employing transmissions

network (determined a priori on application) in combination with how often and the last time a given node has been a cluster head in the past. Expression for threshold function is mentioned below [5].

$$T(n) = \begin{cases} \dfrac{p}{1 - p\left(r \bmod \dfrac{1}{p}\right)} & \text{if } \; n \in G \\ 0 & \text{otherwise} \end{cases}$$

Where n is the given node, P is the a priori probability of a node being elected as a cluster head, r is the current round number and set of nodes which haven't been chosen as cluster heads in the recent 1/P rounds is G. Each node during cluster head selection will generate a random number between 0 and 1. If the number is less than the threshold (T(n)) the node will become a cluster head [5].

B.2. TEEN (Threshold sensitive Energy Efficient sensor Network)

TEEN is a cluster based routing protocol based on LEACH which improves it at the same time by transferring the data less frequently. The network is considered as collection of simple nodes, first-level cluster heads and second-level cluster heads. LEACH strategy used in this protocol for cluster formation. After forming the clusters, the cluster head broadcasts two thresholds namely hard and soft thresholds to all the nodes; which are the key feature of TEEN. Hard threshold is the minimum threshold used to trigger a sensor node to switch on its transmitter and therefore transmit to the cluster head. Thus, the hard threshold will ask the sensor node to perform transmission only when the sensed attribute is in the required range and reduces the number of transmissions significantly. Once a node senses a value at or beyond the hard threshold, the data is transmitted only when the attribute changes by an amount greater than or equal to the soft threshold. That is, soft threshold reduces the number of frequent transmissions even after the hard threshold is crossed if there is no change or little change in the value of sensed attribute compared to soft threshold.

A brief comparison on the basis of various performance parameters of the above schemes has been presented in Table 1 [1], [2], [5], [18].

IV. Energy Efficient Routing In Wireless Sensor Networks

In this paper, we provide an improved routing algorithm on the basis of clustering approach proposed in LEACH. We also propose an effective solution for overcoming the limitations of non-guaranteed data communication in TEEN. Moreover this paper proposes an effective energy balancing algorithm which makes the overall procedure feasible to power consumption.

The proposed approach makes the following assumptions on the network. Firstly, the nodes are considered as static nodes and each cluster head possesses the capability to communicate with the base station or sink.

At the network initialization step, it is assumed that, a broadcasting scheme is adopted by each node which informs each node about its residual energy. Also neighbors are also identified by each node. Neighbors are defined as those nodes which is reachable at the radio range of each node. This neighbor detection is particularly important for cluster formation. Whenever the detection is done, it builds an information table with its residual energy, neighbor nodes and corresponding residual energy. There exists other parameter regarding number of rounds it is acting as cluster head (initially zero), number of rounds it is acting as cluster coordinator (initially zero), current cluster head id, current cluster coordinator id. There are threshold values including Hard and Soft Threshold (as in TEEN) and

Cluster coordinator is aimed to minimize the energy dissipation of nodes of each cluster. Cluster coordinator is selected as the node which has the maximum residual energy in that cluster other than cluster head. The main motivation of incorporating cluster coordinator is to balance the load distribution between inter cluster communication and intra cluster communication. Based on the distance threshold and percentage of coordinator threshold, there may be more than one cluster coordinator.

Cluster Heads perform the inter-cluster communication whereas cluster coordinators perform the intra cluster tasks. Since, inter cluster communication and cluster head to base station communication requires greater power than that of inner cluster communication, we are interested in proposing two level of cluster leaders namely cluster coordinators and cluster heads. The selection mechanism of cluster head is the same as proposed in LEACH. For cluster head selection, it also imposed that, any node currently engaged as cluster coordinator may not become cluster head for that round because this would lead to redundant exchange of the entire cluster information to the next cluster assistant. However, interchange between the cluster head and the cluster coordinator is supported. Cluster coordinators also perform as sensing node at the same time. Thus, the task of cluster heads is simply relaying the information received from the cluster coordinators to other cluster heads or to the sink or base station. All types of queries are also communicated through the cluster heads, however the actual processing and data gathering is done by the cluster coordinators. Cluster heads may gather and decide on data received only from another cluster head or cluster coordinator. We employ the TEEN approach for minimizing the communication of sensed information. Another threshold echo threshold is also employed for overcoming the limitation of TEEN. That is we use the hard threshold and echo to trigger a sensor node to switch on its transmitter and therefore transmit to the cluster coordinator. Once a node senses a value at or beyond the hard threshold, the data is transmitted only when the attribute changes by an amount greater than or equal to the soft threshold. Moreover, for every echo threshold value, the sensed information is sent to the cluster coordinators and the same for cluster coordinators to cluster heads.

V. Analysis of Proposed Approach

This section analyzes the power consumption of proposed scheme which has been greatly benefitted from [3]. Let us consider that there are total of n nodes into the network. The number of clusters be c. The parameters are: Hard Threshold t_h, soft threshold t_s. Echo threshold t_e. If r_i be the rotating epoch i.e. number of rounds for the subject node s_i to be a cluster head, in homogeneous network there are average pin cluster heads in each round. Each node s_i, $i=1,2,\ldots,n$ become cluster head once every $n_i=1/p$ rounds. The probability threshold each node s_i uses to determine to become a cluster head or not in each round, is given as [3]-

$$T(s_i) = \frac{2p_i}{1-p_i(r \bmod \frac{1}{p_i})}\frac{E_{res}}{E_{init}}; s_i \in G$$

Here G is the set of nodes that are eligible to become cluster heads at round r. if node s_i has not been a cluster head during most recent n_i rounds, then $s_i \in G$. In each round r, when node

s_i finds that, it is eligible to be cluster head, it will choose a random number between *0* and *1*. If the number is less than the threshold $T(s_i)$, the node s_i becomes a cluster head during that current round.

According to radio energy dissipation model [4] the energy expended to achieve signal to noise ratio in transmitting *k*-bit message over a distance *d* is given as

$$E_{Tx(k,d)} = E_{elec} * k_{bit} + E_{fs} * k_{bit} * d^2$$

Here, E_{elec} is energy dissipated per bit to run transmitter or receiver circuit; k_{bit} is the control packet length for every time; E_{fs} depends on the transmitter amplifier model and *d* is the distance between the sender and receiver.

To receive *kbit* message the radio expends energy indicated as

$$E_{Rx(k,d)} = E_{elec} * k_{bit}$$

Consider that, over the deployment field, n nodes are uniformly distributed and the sink is located at any place in the field, and the distance of any node to the sink less than d0 be:

$$d_0 = \sqrt{\frac{E_{fs}}{E_{ms}}}$$

Data aggregation is the processing cost of a bit per report to the sink. The energy for data transmission for non sensing nodes in sending k_{bit} data to the cluster coordinator assuming d_{cs} be the distance between the sensor nodes and the cluster coordinator is obtained by

$$E = E_{elec} * k_{bit} + E_{fs} * k_{bit} * d_{cs}^{\ 2}$$

That is, total energy consumption in sending data by the nodes comprising the network is $n*E$.

For LEACH and TEEN and similar schemes, the same may be computed as

$$E_1 = E_{elec} * k_{bit} + E_{fs} * k_{bit} * d^2$$

Where, *d* is the distance between the sensor nodes and the cluster head.

Since, each node is to send data to the cluster coordinators and there may be more than one cluster coordinator in the single cluster, it is evident that, the average distance between the nodes and the cluster head is lower than the average distance between the cluster head and sensing nodes. That is, $d_{cs} \leq d$. Consequently it may be easily remarked that, $E \leq E_1$

Again, for sending k'_{bit} data from cluster coordinator to cluster head deployed at a distance d_{ch}, the energy required may be computed as

$$E' = E_{elec} * k'_{bit} + E_{fs} * k'_{bit} * d_{ch}^{\ 2}$$

For receiving data, power consumption for cluster coordinators is: $E_r = E_{elec} * k_{bit} * n_c$ where n_c is the total number of sensor comprising that cluster.

For receiving data, power consumption for cluster head is given by: $E'_r = E_{elec} * k'_{bit}$. As cluster coordinators are designated to send aggregated and summarized data to the cluster heads, it may never be greater than the preliminary data sent by the sensing nodes to the cluster coordinators. That is, $k'_{bit} \leq k_{bit} * n_c$. This leads towards $E'_r \leq E_r$.

In case of LEACH and TEEN, for receiving data, power consumption for cluster head is given by: $E'_r = E_{elec} * k''_{bit}$ where $k''_{bit} \geq k$

That is, average power consumption for cluster coordinator is equal to the summation of power consumption for receiving data from sensor nodes, receiving data from cluster heads, transmitting data to cluster heads. For cluster heads, the power consumption is in transmitting data to cluster coordinators and receiving data from cluster coordinators and transmitting data to cluster heads or base stations.

Again, the proposed scheme intends towards sending data between the cluster heads (at distance d_{hh}) rather than between cluster heads and base stations (d_{hb}), and usually, $d_{hh} \leq d_{hb}$ thus, for transmission of same amount of data, our proposed approach consumes less energy than traditional LEACH and TEEN.

Thus, from the above discussion, it is clear that, for each case, the power consumption of proposed scheme is less than the existing schemes.

VI. Conclusion

In this paper, we have presented an overview of the existing researches on Sensor Network data communication i.e. routing approaches. This paper also proposes an energy efficient data routing technique which is also computationally simple and effective. We employ cluster coordinators in order to reduce the overhead imposed on cluster head. Since, cluster coordinators performs entire intra-cluster computation and management whereas cluster heads perform inter-cluster computation, management and transmissions, it ensures a balanced energy consumption and thus enhances the network lifetime. Future works may be dedicated to implement this scheme for sensor networks with mobile infrastructure. Specific measures may also be taken to optimize the inter-cluster communication paradigms.

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Md. Mahbubur Rahman is a currently serving as a professor and head of Computer Science and Engineering Discipline, Khulna University, Khulna-9208, Bangladesh. He completed PhD. From Japan Advanced Institute of Science and Technology, (JAIST) Japan and M. Engg. from Asian Institute of Technology, (AIT), Thailand. He completed B. Sc Engg. in CSE from Bangladesh University of Engineering and Technology, BUET, Dhaka.
Dr. Mahbub served as a faculty of University of Tohoku, Japan. He has made a number of publications in international conferences and journals. He received best paper award for his outstanding research contribution through the paper "An Unsupervised Natural Image Segmentation Algorithm Using Mean Histogram Features" in 14th International Conference on Computer and Information Technology (ICCIT' 2011), held on December 22-24, 2011. Dr. Mahbub is a member of Institution of Engineers, Bangladesh (IEB). His research interests include Image processing, Pattern Recognition and Optical Networks.

S. A. Ahsan Rajon is a research student and adjunct faculty of Computer Science and Engineering Discipline, Khulna University, Bangladesh. He is also serving as a Senior Lecturer of Department of Computer Science of Khulna Public College, Khulna. Engr. Rajon is the author of seventeen papers including seven journal and ten conference papers.
Engr. Rajon is a member of Institution of Engineers, Bangladesh (IEB). He is also a member of International Association of Computer Science and Information Technology (IACSIT), International Association of Engineers and Scientists (IAEST) and Internet Society (ISOC). Rajon is also a member of International Board of Reviewers and Editorial Review Board of Journal of Information Technology Education of Informing Science Institute and member of Technical Review Committee of International Journal of Computer Science and Information Security. In 2011, he received the best paper award for his paper titled "An Enhanced Scheme for Lossless Compression of Short Text for Resource Constrained Devices" in 14th International Conference on Computer and Information Technology (ICCIT' 2011), held on December 22-24, 2011. His area of interest includes data engineering and management, information systems and ubiquitous computing.