Energy Efficient Wireless Sensor Networks:
A Survey on Energy-Based Routing Techniques

Soumya Dath G

GSSS Institute of Engineering and Technology for Women
Mysore, Karnataka, India

ABSTRACT

Wireless sensor network (WSN) is composed of sensing and detecting nodes distributed in the wireless communication region to access and sense the surrounding information of the particular deployed area. The distributed nature of WSN provides accessibility to tiny detecting nodes to sense the information statistics as well as various environmental and physical states. Efficient energy utilization is a considerable issue to maintain, expand and increase the lifetime of the wireless sensor network, as network contains battery-operated devices (nodes). Due to its sensing capability effect of nodes, WSN has a wide area of applications, such as environmental sensing, industrial process sensing, and health monitoring. These applications demand for the maintenance of network lifetime, energy efficiency, and QoS communication. These issues can be overcome with the energy efficient routing protocols. In literature, a number of routing protocols designed to address the energy efficiency, network lifetime and network capacity. To give complete understand of energy based routing mechanisms designed for WSN and cover the path for forthcoming research; this article deals with detailed information about various energy efficient routing techniques designed for WSN.

KEYWORDS: *Wireless Sensor Networks, Routing Protocol, Network Lifetime, Energy Efficient, Energy-aware.*

I. INTRODUCTION

The wireless sensor network is one of the greatest technology which gains high attention towards the researcher from the last few decades. WSN composed of the number of wireless sensor nodes distributed in wireless communication region to sense and detect the surrounding environment. Characteristics of WSN include less cost, Power efficiency, scalability, responsiveness, Reliability, and Mobility. From the last few decades, it received broad attention in academia as well as industry. Furthermore, these nodes communicate over the short distance to fulfill the given task like industrial process control [3, 4, and 5], IoT Technology and 5G Communication. However, these nodes have constrained resources such as battery power, memory capacity, highly sensitive, processing capability and sensing range. Available energy of the network must be utilized in such a way that the given mission should be accomplished, as restrictions in the energy for each single sensor node. Moreover, Power consumed by each sensor node is directly proportional to the whole networks lifetime so that for maximizing the network lifetime the node should consume less power [1, 2].

Practically these nodes are totally dependent on battery supply and the expectations are they should run up to a long period. But for several applications which are directly or indirectly related to human beings, it is extremely inconvenient or can say not possible to recharge or change charging cells for the particular sensor node. These types of network acquire thousands of nodes with sufficient sensing capabilities. In some previous protocols like Flooding, each node broadcast its control packet and data packets that it has received from other nearest nodes, and until and unless the destination reach repeating of this process is done several times[27]. Network protocol design should be scalable to different sized networks. Because of which the general problems like, Overlap and Implosion [2, 4] occurs. Due to the small or tiny size of the node, it can easily minimize the required power for getting energy efficiency and it automatically reduces the value of sensor nodes. In network protocol designing when density and topology changes, sensor node should be adaptive to such changes immediately. Furthermore, WSN is comprised of several nodes; by reducing each node cost it can easily reduce the whole networks cost [27].

In WSN, delivery of data packets over any channels, like noisy, error-prone, should be reliable. Furthermore, for maintaining connectivity in structure, the nodes should possess the capability of reconfiguration and organization themselves. Sensors node should efficiently posse's different talent like self-recovering, self- testing, self-calibrating, and it should be self-repairing. It should keep the data information packets from malicious assaults, for that purpose the sensor networks, should examine the QoS needs for the particular applications. Many researchers raise the issue of energy efficiency in WSN by designing different routing protocols to elaborate the lifetime. This survey paper deals in a detailed manner with different routing techniques by considering several parameters of the sensor nodes like mobility, heterogeneity, hierarchical nature, location, data-centric, QoS and multi-path based techniques. Also, it deals with the limitations of these above-talked routing techniques and shows some analysis of well-known energy efficient routing protocols. Furthermore, it gives some routing methodologies for achieving energy efficiency in different routing techniques [1, 2]. Finally, it shows that the Hierarchical routing technology schemes are more energy efficient as compare to location-based routing techniques.

This survey will discuss various energy efficient as well as non-energy routing protocols in WSN. 2nd Section will talk about the routing techniques in WSN, 3rd Section will describe Energy based routing techniques in WSN, 4th Section will discuss non-energy based routing techniques in WSN, 5th Section will talk about key elements in conservation of energy

and new trends of WSN and finally, 6th Section will give the conclusion of our survey and future scopes in WSN.

II. Routing Techniques In Wsn

The main mechanism of the WSN is the routing protocols, which are developed for individually dependent on the particular independent application. Hence different routing protocols were developed for wireless sensor networks [27].

Anyhow these Wireless Sensor Networks are differs from the conventional routing in several ways because WSN's are infrastructure less, unreliable. If talking about the energy efficient routing protocol then it may divide different routing protocols into some very important categories as shown in the figure below.
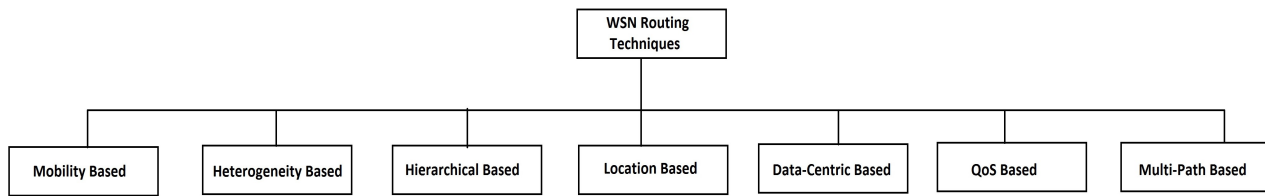

Fig. 1. Different Routing Schemes in WSN

These protocols are further categorized on the basis of energy-based and non-energy based routing techniques in the next section.

III. Energy Based Routing Techniques

Energy based routing techniques are the routing techniques which considers energy as a main constraint in the routing protocol designing. They are further divided based on different sub-parameters like energy-aware protocol, energy efficient protocol, and reliable type protocols.

A. Mobility-based Protocols

The application-distinct nature of WSN needs that the nodes should have several capabilities. Design, development, and deployment are the main research areas in WSN because it is fact that mobility in the sensor nodes leads to several new design mechanisms for different routing techniques. Based on the movement ability of the sensor nodes some routing technologies which are related to mobility type of scheme are discussed below.

JMRP: The JMRP routing technique is a mobility based routing technique in which heavily doped sensors drain their battery energy abnormally very quick, consequently disconnecting the sensor network. This problem occurs even if the constant destination node is used and located at its principal location as the heart of the sensor field [6]. The mobile sink is adopted to overcome this problem with a load balancing technique.

SEAD: SEAD [7] routing technique is mobility based routing approach which falls under energy efficient routing protocol. Furthermore, it minimizes the delay to a mobile sink when it is related to forward transmission and also utilization of energy. It deals with data information flow where the source has to report its data sensed to several movable destination nodes. The main application of SEAD protocol is it works on three main elements, like maintaining linkages to mobile sinks, construction of circulation tree (d-tree), and information circulation.

Dynamic Proxy Tree-Based Data Dissemination: This routing technique is mobility based routing technique which is energy aware type of routing protocol. Basically, it was proposed for the maintenance of the connection between source sensor nodes and destination nodes [8]. The main application is it minimizes the evaluated value of squeeze information and enquiring information from reference node and sink agent.

B. Heterogeneity-based Protocols

The Heterogeneity-based routing protocols are depends on the diversity of the routing technique which is used in WSN. Also, it can divide the nodes into two categories, namely like line-powered sensor nodes and battery-powered sensor nodes. Some of its types are discussed below,

IDSQ: The IDSQ [9] routing technique is heterogeneity based routing technique which lies under energy efficient type routing protocol. Its main application is to reduce detection latency and to increase tracking accuracy. Due to the relay between the sensors notable energy can be necessarily consumed.

CHR: This is heterogeneity type of routing technique which shows energy-aware protocol property. It has two different types of nodes Low-end (L) sensors and high-end (H) sensors while both types of sensor nodes deal with same single destination node in the network to make a diverse network [10]. It divides the work between L an H sensor nodes that High sensor nodes will be done the long distance data information transmission while Low sensor will do the same work for short range in the particular clusters only.

C. Hierarchical Protocols

For achieving energy efficiency, stability, and scalability a network structure is imposed in the Hierarchical type of protocols. The main application of this type of routing mechanisms are each sensor node from the structure reports its sensed information to destination node [1, 2, 4], CLUSTERING is one of them. The advantage of this protocol is, it can minimize the utilization of energy and automatically it can enhance the lifetime of the network. Some Hierarchical type of protocols are discussed below.

LEACH: This Hierarchical type of routing technique comes under efficient energy protocol. It is a much-known mechanism which minimizes the power utilization of a particular network. Its working principle is split into two stages which are Setup and aggregation of data [11]. The main aim behind clustering is, in this, the given function is normally spin in between all the sensor nodes which are related to that particular cluster, and the cluster heads follow direct communication technique to transmit the data information to the destination.

PEGASIS: One more Hierarchical routing technique is PEGASIS [12], which falls under energy aware routing

protocol. It is a chain-based mechanism which forms a series of chain between the nodes due to which each and every node can forward and collect the information through the nearest relay nodes. PEGASIS works on the assumption that each and every node in the chain knows regarding the whole network, especially about the position of the other nodes in the chain.

HEED: The valuable improvements in the LEACH protocol is given as HEED, which is in a Hierarchical routing approach. It works on flexible power transmission for maintaining the communication in between the active sensor nodes in the cluster for multi-hop type of networks. Its working principle is subdivided into four stages, elaborating the lifetime of the network [13], it works on by proper use of power splitting technique, after some continuous rotation it concludes the particular clustering process, minimization of dominance exertion, and the main stage of HEED which differs it from other protocols is that it can build dense clusters which are small in size and well-distributed head nodes.

TEEN: The Main objective of this technique is it can work easily in the network while unexpected changes have occurred, as a change in temperature. In TEEN neighbor sensor nodes form a group for making cluster [14], also select the head node of the cluster and this activity to pursue unless and up to the destination node reached. Its drawback is it consumes more power even though the hierarchy is small due to long distance transmission.

APTEEN: The improvement in the TEEN protocol is designed and named APTEEN routing technique which is a Hierarchical type of routing [15]. Also, efficient energy mechanism collects data from the head nodes and transmits the information within the time slot allotted to it. The APTEEN protocol comprises of both qualities of TEEN and LEACH protocol that's why it is called as a hybrid protocol.

D. Location-based Routing Protocols:
The aim behind this routing mechanism is it can calculate the energy consumption easily by calculating the distance between the particular nodes. Also, this mechanism works on that a node must know the proper location of the other nodes with which it shares or transfers the data packets. If the nodes are mobile then, in that case, they have limited scalability. Some location-based types of routing protocols are discussed below.

GAF: GAF is a location-based routing technique, which comes under energy aware type of routing protocol, stimulate depends on a power model [16]. Furthermore, it considers power utilization in between receiving and transmission of packets as well as identifies the present position of the incoming data packets. This principle works on making off unused sensors nodes while maintaining the fidelity between the sensors.

SPAN: Span [17] is a routing protocol used to reduce energy utilization of the particular node. In an idle time of the particular node, it makes the radio in off condition because the WSN is the largest consumer of power. In SPAN, protocol selection procedure for the node needs that the sensor node must add its status, as well as its neighbors, and its coordinators status.

GEAR: GEAR is a location-based routing technique which comes under energy-efficient routing protocol. It forwards the data information packets to the destination or sinks

without using Greedy Algorithm [18]. It is mainly proposed for routing queries in which sensors have a global positioning system unit or a localization system. One important feature of GEAR routing protocol is each and every sensor node used in it is aware of their residual energy and present location.

TBF: TBF is a location-based routing technique, in which coordinator system, like the global positioning system, is used. By using GPS, like in GEAR, the sensor nodes can easily locate themselves and can calculate the distance from their very close or neighbor nodes. The applications of TBF are flooding [19], discovery, and network management. Furthermore, this routing mechanism is commonly used as security measures of the network.

MECN: One more location-based routing technique is MECN with self-reconfiguring property. Basically it is developed for randomly deployed ad-hoc networks for achieving minimum power, furthermore, this mechanism deals with less power layout. Cost distribution and enclosure graph construction are the two main stages, depends on the present location of the sensor nodes. In this protocol each and every sensor broadcast their cost to its nearest node, for the establishment of a well-controlled path to the destination [28].

SMECN: For discriminating minimal plot, SMECN is introduced, which is an improvement in MECN routing technique. It gives the idea, for any combination of sensor nodes in a network; there is the smallest cost in terms of energy consumption between the source and destination. In SMECN protocol, by transmitting a next node discovery message every sensor discovers its instant next node and it can be computed analytically [28].

GeRaF: GeRaF technique is a location-based routing technology, which comes under energy-aware routing protocol. It assumes that all the sensor nodes are aware of their present location as well as that of sink or final destination [20]. If the channel remains idle the source node broadcast RTS (request-to-send). The basic aim of the GeRaF routing technique is, it says the best transmitter sensor node is the one which is very close to the sink, thus largest development of the information packet made towards the destination.

E. QoS-based Routing Technique
QoS routing strategies are very important routing techniques nowadays. This type of routing techniques maintains the stability and alignment between transmitted data quality as well as to minimize the energy consumption within the network. For achieving the quality of service we have to make concentration on some constraints like data transmission rate, fault finding, and the path should be reliable for the transmission. Some QoS-based protocols are discussed below.

SAR: The notion of QoS is primarily introduced by SAR routing protocol which is a pro-active approach whose routing decisions are based on some important elements mainly: the priority level of each packet, energy resources, and QoS. The main aim of SAR protocol is for any reshape in the geometry a repeated re-computation of the route is initiated by the source sensor node. Furthermore, it minimizes the throughput of QoS and enhance the network lifetime [29].

QoS Routing Energy-Aware Protocol: This routing technique is a QoS based technique which comes under energy-aware routing protocol [21]; there is a generation of real-time traffic by representing the sensors. This routing technique is also deals with the source to destination delay by maintaining or finding a minimum value route and enhance the lifetime of the system. Least value link is a function of stored energy, energy used for transmission, processing energy, and transmission factors influenced.

F. Data-Centric Protocols

Data-centric protocols correspond with the fashion that information data sent through the origin to the destination are with the aggregation process. It means in data-centric protocols, mediator sensor nodes can perform some aggregation of the information starting through multiple nodes and send aggregated information data towards destination/sink. Through this mechanism, power can be saved due to fewer communication nodes involved in forwarding particular information data through the source to destination. Some of the data-centric routing protocols are discussed below.

COUGAR: COUGAR [22] belongs to Wildcat family member which comes under data-centric routing techniques. It is a database type of approach used to task the sensor network. Furthermore, it utilizes an in-network collection of information for obtaining energy savings. Being a database approach, it faces some challenges. The Cougar architecture provides computation within the network ability which can provide proper energy utilization when a huge data is produced, that is the main advantage of COUGAR.

SPIN: Negotiation based routing protocol SPIN is from the prior performance which comes under centric data routing mechanism. It improves flooding and also overcome the implosion and overlaps problems. It has three stages, namely Advertise, Request, and Data [1, 2]. The main aim of this protocol is all the sensor nodes have the skill to evaluate the energy essential to receive, compute, and then send the information data packets.

DD: DD routing technique is a data-centric type of routing protocols. It has several main portions, like, calling of data (data naming), the increment in data information (interests and gradients), propagation of data, and augmentation. In this routing technique initially, the sink node frames a minimum rate of information for the series of successive occurrence of the events in the network [30].

RR: RR routing technique comes under the data-centric routing protocols. Eventually, it is a natural agreement between flooding enquiries and flooding occurrence information. Furthermore, the main aim of Rumor routing is it can deliver enquiries to the occurrence of the information packets in the system in which the quantity of the nodes is very extensive as per wide range orders [31].

EAD: EAD routing technique is a data-centric routing technique, which comes under energy-aware routing protocols. It is also called as distributed rout location protocol, with growing effective spine aggregation of working sensor nodes which are accountable for processing of the information data within the network and traffic transmission from origin to sink/destination [32].

ACQUIRE: ACQUIRE [23] routing technique is a centric data type of routing mechanism, which is similar to COUGAR querying mechanism. The main advantage of ACQUIR is it can enquire the information data which is pre-identified. The broad application of ACQUIRE is it is used for continuous and aggregate queries, where other protocols are not useful due to complex queries.

G. Multi-path Based Protocols

When talking about the data information transmission between source sensor nodes and destination sensor nodes then it can be divided the routing techniques into two different models as single path technique and multipath technique. Each and every sensor node which works as a source sends its information to the destination through low cost (shortest) route, in single path technique [2]. Some multi-path based protocols are discussed below,

Disjoint Paths: The DP [9] routing is a multipath routing technique which comes under efficient energy routing mechanism. Main design objective in this protocol is it finds alternate routes in the network that doesn't have any similarity in between sensor node. It makes a differentiation between all the paths (primary or secondary), thus, failures are not affecting any of those other or alternate paths.

Braided Paths: In this routing technique for the construction of braided multipath [9], computation of the primary path is done as a basic requirement for each and every sensor nodes. After that best suitable route is selected and computed which should not attain the nodes which are used in the primary path. Now for some extent, this path is a disjoint path after modifying brokenness limitations from source nodes to the destination node.

N-to-1 Multipath Discovery: The N-to-1 multipath routing technique [24] is a Multipath routing mechanism which comes under energy aware routing protocol. This technique locates on two stages namely, stage 1 and stage 2, stage 1 deals with branch awareness with flooding technique and stage 2 is also related to flooding technique with some extension with multipath. Furthermore, it minimizes the energy utilization as well as it can enhance the networks lifetime.

IV. Non-Energy Based Routing Techniques

These types of routing techniques are the routing techniques which are not considering the energy conservation as the main metric [1, 2, and 3], because some protocols works on QoS entirely some works on data reduction and some believes that data information transmission is the main theme in routing strategy as compared to energy conservation. These type of routing protocols are listed below

BVGF: BVGF is a location-based routing technique which comes under the non-energy based protocol which deals with the concept of Voronoi diagram. In this type of routing, the sensor nodes should be aware of their physical positions. The main application of this protocol is it chooses the succeeding hop neighbor which has the shortest route by using Postulates of Euclidean distance to the sink among all other nearest nodes [33].

SPEED: SPEED routing technique is a QoS based type of routing technique which deals with the source to destination real-time scheme. The basic need in this regard is each sensor node have to keep its neighbors information, furthermore, it

utilizes geographic transmission procedure to discover the best rout in the network. It suffers from some major drawbacks like when congestion is there it consumes more power because it does not consider energy consumption as the main constraint in its protocol designing [2].

Data MULES: Data MULES routing technique is a mobility based type of protocol, which works with a different layer structure, the bottom layer will sense the environment and the central layer collects the information data from sensor nodes which also has mobile entities that are called as Data MULES. These protocols were proposed for getting cost-effective connectivity [25] within an infrequent network.

V. Key Elements in Conservation of Energy and New Trends in WSN

Energy wastage in WSN occurs due to different operations like idle listening of a node, collision overhearing, control packet overhead. Furthermore, transmission of one data packet takes energy which is sufficient to process thousands of data packets. Hence, an argument for conservation of energy in WSN is, it has to maintain three parameters duty cycle, reduction of data, and sink mobility. The duty cycle can be maintained by topology control and power management schemes like Traffic Adaptive Medium Access (**TRAMA**), Brooke Army Medical Center (BAMC), and new hybrid MAC scheme (ZMAC). Secondarily, by providing a mobile sink, attach mobilize to the sink node or attach it to the moving element like animal. Finally, reduce the data when it is going to transmit towards the sink by doing the aggregation process. Due to which repeated information can be easily removed and then transmit the data through a specific node to the sink.

With the development in the technology of Micro-Electromechanically System (MEMS), new trends in wireless transmission and WSN have also made an appearance. Furthermore, it has become one of the nearly all attracting areas of research in the past few years. Here, if look into the recent advances and future trends in WSN it got maturity in its conventional form but the new trend is the Internet of Things [1, 2, 26]. WSN is the collection of thousands of sensor nodes connected wirelessly to gather the information data; no doubt it is a vast area for aggregating important data. The advantage of IoT is the data packets are transmitted in one hop only to the internet and WSN is like a single node in IoT topology. Due to which the speed of IoT operation is extremely fast as compare to WSN technique.

VI. Conclusion and Future scope

The key challenges of designing energy based routing protocols are discussed in a detailed manner for increasing efficiency and enhancement of network lifetime which suffers from the limitation of resources like less power and the drain of battery. It insists that designing of routing mechanism should be in such a manner that the sensor nodes (especially head nodes) operates for a long time and hence automatically it will enhance the networks lifetime. The study says that nowadays mobile agent based WSN is coming into the picture, and has some handsome applications also. Furthermore, routing is the faultless process and hence careful consideration should be taken under ensuring the conditions in the continuity of connection, transmission of data and should minimize the conservation of power. So, appealing for routing technique will ensure proper information delivery, interconnection between sensor nodes

as well as enhancement of systems lifetime. On the other hand, the data information should be securely reaching the destination.

Above routing technique mentioned has their own features, but they are suffering from some limitations. Therefore, further investigation should be done for developing a particular routing mechanism that elaborates networks lifetime by minimizing energy consumption. Further, it can improve the WSN by using some techniques primarily by doing Battery-less sensing in which by dealing with energy harvesting, supplying unpredictable power and designing new operating systems & Network Simulators like NS2 and NS3. Secondarily, it can go with nano-scale wireless nodes due to which it can elaborate the networks lifetime and minimize the power consumption in broadways. Furthermore, energy can be harvested from the environment also not as a source but means of conservation of energy.

References

[1] Yetgin, Halil, Kent Tsz Kan Cheung, Mohammed El-Hajjar, and Lajos Hanzo Hanzo. "A survey of network lifetime maximization techniques in wireless sensor networks." IEEE Communications Surveys & Tutorials 19, no. 2 (2017): 828-854.

[2] Pantazis, Nikolaos A., Stefanos A. Nikolidakis, and Dimitrios D. Vergados. "Energy-efficient routing protocols in wireless sensor networks: A survey." IEEE Communications surveys & tutorials 15, no. 2 (2013): 551-591.

[3] Kaur, Lovepreet, and Gndu Reg Jalandhar. "Energy-Efficient Routing Protocols in Wireless Sensor Networks: A Survey." International Journal of Computer Applications (0975–8887) Volume (2014).

[4] M.P. Singh, S.K. Singh, and D.K. Singh, "A Survey of Energy-Efficient Hierarchical Cluster-Based Routing in WSN's", International Journal of Advanced Networking and Application (IJANA), Sept.-Oct.2010, vol.02, issue 02,pp. 570I-580.

[5] Abbas Jamalipour and Jun Zheng, "Wireless Sensor Networks: A Networking Perspective", A book published by A John and Sons, Inc, and IEEE, 2009.

[6] J. Luo and J. P. Hubaux, "Joint mobility and routing for lifetime elongation in wireless sensor networks", Proceedings IEEE INFOCOM'05, vol. 3, Miami, FL, Mar. 2005, pp. 1735-1746.

[7] B. Karp and H. T. Kung, "GPSR: Greedy perimeter stateless routing for wireless networks", Proceedings ACM MobiCom'00, Boston, MA, Aug. 2000, pp. 243-254.

[8] W. Chang, G. Cao, and T. La Porta, "Dynamic proxy tree-based data dissemination schemes for wireless sensor networks", Proceedings IEEE MASS'04, Fort Lauderdale, FL, Oct. 2004, pp. 21-30.

[9] S. Lindsey, C. S. Raghavendra, and K. M. Sivalingam, "Data gathering algorithms in sensor networks using energy metrics", IEEE Transactions on Parallel and Distributed Systems, vol. 13, no. 9, Sept. 2002, pp. 924-935.

[10] X. Du and F. Lin, "Improving routing in sensor networks with heterogeneous sensor nodes",

Proceedings IEEE VTC'05, Dallas, TX, Sept. 2005, pp. 2528-2532.

[11] W.R. Heinzelman, A. Chandrakasan and H. Balakrishnan, "An Application-Specific Protocol Architecture for Wireless Microsensor Networks" in IEEE Transactions on Wireless Communications (October 2002), vol. 1(4), pp. 660-670.

[12] S. Lindsey and C.S. Raghavendra, "PEGASIS: Power-efficient Gathering in Sensor Information System", Proceedings IEEE Aerospace Conference, vol. 3, Big Sky, MT, Mar. 2002, pp. 1125-1130.

[13] Ossama Younis and Sonia Fahmy, " Heed: A hybrid, Energy-efficient, Distributed Clustering Approach for Ad-hoc Networks", IEEE Transactions on Mobile Computing, vol. 3, no. 4, Oct.-Dec. 2004, pp.366-369.

[14] A. Manjeshwar and D. P. Agrawal, "TEEN: A Protocol for Enhanced Efficiency in Wireless Sensor Networks", in the Proceedings of the 1st International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing, San Francisco, CA, April 2001.

[15] A.Manjeshwar and D. P. Agrawal, "APTEEN: A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks", Proceedings of the II International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing, San Francisco CA, April 2001, pp. 2009-1015.

[16] Y. Xiu, J. Heidemann, and D. Estrin, "Geography-informed energy conservation for ad-hoc routing",

Proceedings ACM/IEEE MobiCom'01, Rome, Italy, July 2001, pp. 70-84.

[17] B. Chen, K. Jamieson, H. Balakrishnan, and R. Morris, "Span: An energy-efficient coordination algorithm for topology maintenance in ad hoc wireless networks", Wireless Networks, vol. 8, no.5, Sept. 2002, pp. 481-494.

[18] Y. Yu, R. Govindan, and D. Estrin, "Geographical and energy aware routing: A recursive data dissemination protocol for wireless sensor networks", Technical Report UCLA/CSD-TR-01-0023, UCLA Computer Science Department, May 2001.

[19] B. Nath and D. Niculescu, "Routing on a curve", ACM SIGCOMM Computer Communication Review, vol. 33, no.1, Jan. 2003, pp. 155-160.

[20] M. Zorzi and R. R. Rao, "Geographic random forwarding (GeRaF) for ad hoc and sensor networks: Multihop performance", IEEE Transactions on Mobile Computing, vol. 2, no. 4, Oct.-Dec. 2003, pp. 337-348.

[21] K. Akkaya and M. Younis, "An Energy-Aware QoS Routing Protocol for Wireless Sensor Networks," in the Proceedings of IEEE Workshop on Mobile and Wireless Networks(MWN'03), Providence, Rhode Island, May'03.

[22] Y. Yao and J. Gehrke, "The Cougar approach to in-network query processing in sensor networks", SGIMOD Record, vol. 31, no. 3, Sept. 2002, pp. 9-18.