

A Survey on Energy Efficient Routing Techniques in Wireless Sensor Network

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Abstract— Energy conservation in Wireless Sensor Network (WSN) has always been the most crucial issue, for the sensor nodes are all powered by limited capacity battery sources which are difficult, if not impossible, to replace or recharge due to the inherent nature and types of applications WSN is used for. Therefore, energy efficient design of WSN has drawn considerable attention from many researchers resulting in quite a good number of approaches for saving the precious and limited energy of the sensor nodes. However, designing energy efficient routing protocol for WSN is the area that has received the most of the attention giving rise to many Energy Efficient Routing (EER) protocols. In this paper, a comprehensive list of these EER protocols have been studied having classified them into proper categories. The relative advantages and disadvantages of the protocols are also discussed while the protocols are evaluated based on certain performance metrics at the end of the paper.

Keywords— Wireless Sensor Network, Energy Efficient Routing, Routing Protocol, EER

I. INTRODUCTION

A Wireless Sensor Network (WSN) consists of a collection of some sensing stuffs usually called sensors which observes an event or gathers some physical data from its area of interest, processes the observed or gathered data by a tiny processor embedded in it and sends processed data via a short range radio transmitter to a central data collector usually called sink either directly or through intermediate sensor nodes. All these activities in a sensor node are carried out by limited energy battery sources which drain out in course of time as these activities are carried out. Therefore, energy conservation has always been a vital factor and a major challenge in the design of WSN.

Although WSN is a class of ad hoc network, routing techniques for WSN widely differ from that of the traditional ad hoc networks mainly for its energy constrained nature. WSN routing approaches are compelled to find out routes that ultimately result in prolonged network life time, rather than focusing on routes with shortest distance, minimum delay or maximum bandwidth. Therefore, considerable research has been conducted on routing data in WSN where the main focus has been on reducing energy consumption giving rise to a new class of routing called Energy Efficient Routing (EER). In this

paper, the dominant EER protocols for WSN are explored with proper classification. To finish the paper, a comparative study of the EER protocols is also carried out.

II. ENERGY DISSIPATION AND ENERGY WASTE IN WSN

In WSN, sensors dissipate energy mainly for transmitting and receiving data as compared to data sensing and processing, while a significant amount of energy is wasted with regard to data communications as described in [1] which is mentioned below.

- **Data Collision:** Data packets collide when a node receives more than one at the same time resulting in all the packets that caused this collision being discarded which will in turn necessitate retransmission of the discarded packets causing significant energy waste.
- **Data Overhearing:** Although a node is not transmitting, it will eventually listen to transmissions destined for other nodes causing continuous energy waste.
- **Idle Listening:** This phenomenon occurs when a node keeps listening to an idle channel in search of a data packet destined for it, thus wasting a good amount of energy.
- **Interference:** Energy is wasted as each node within the transmission and interference range receives a packet but cannot decode it.
- **Control Packet Overhead:** Control packets usually synchronize the whole data transmission phase but don't carry any user data. Therefore, it is always a design goal that minimal number of control packets be generated to reduce the energy consumption by these non-data packets.

III. ENERGY EFFICIENT ROUTING PROTOCOLS IN WSN

The main goal of any Energy Efficient Routing (EER) protocol for WSN is to maximize network lifetime by minimizing energy consumption in end-to-end transmission. WSNs are largely application-specific which implies that routing protocols are also dependent on applications. Generalizing the classification given in [2], the EER protocols for WSN are categorized in this paper as follows:

- Data Relaying Protocols
- Data Centric Protocols

- Hierarchical or Clustering-based Protocols
- Location-based or Geographical Protocols
- Mobility-based Protocols
- Heterogeneous Protocols

In the following subsections, these routing approaches along with their representative protocols are discussed.

A. Data Relaying Protocols

Data relaying protocols are very simple in nature and easy to implement as they don't require any routing table nor do they require maintaining topology information about the network. Gossiping [3], Flossiping [4], and LGossiping [5] are some popular protocols of this family.

1) Gossiping: A Gossiping [3] was proposed as an improvement over the straight forward flooding mechanism with a view to overcoming the implosion problem with flooding. Implosion is a phenomenon where a node broadcasts a packet to all of its neighbours which in turn continue with broadcasting the packet creating multiple copies of the same packet in the network. On the other hand, Gossiping doesn't broadcast a packet to all the neighbours, rather only to a single one chosen randomly which in turn forward the packet randomly to one of its neighbours including the one from which it received the packet. This process continues until the ultimate destination is reached. Gossiping reduces energy consumption over flooding to a great extent, but it heavily suffers from long propagation delay.

2) Flossiping: Y. Zhang and L. Cheng proposed Flossiping [4] which is a balance between flooding and Gossiping. When a node has a packet to send, it decides a threshold value and then forwards the packet in Gossiping mode by saving the threshold in the packet header. Receiving the packet, a neighbour node generates a random number and chooses flooding if the random number is smaller than the threshold, otherwise; Gossiping is used.

3) LGossiping: LGossiping [5] proposed by S. Kheiri et. al. requires the nodes to have their location information available through GPS. Actually, it improves over Gossiping by choosing a known neighbour that is closer to the source based on GPS location information. Thus, it reduces the long latency problem of Gossiping, but introduces some extra cost for GPS device per node.

B. Data Centric Protocols

Because of the sheer number of nodes, in a WSN global addressing technique is not feasible. As a result, every sensor node has to transmit data to the sink which results in huge redundancy in the transmitted data causing significant energy waste. Therefore, routing techniques have been developed that are able to select a set of sensor nodes based on a query driven model and are also able to aggregate data while relying to the sink leading to a new class of routing called Data Centric Routing. SPIN [6] is considered to be the first of this kind of protocols, but the most influential one is Directed Diffusion (DD) [7]. An overview of the dominant and recent data centric protocols is given below.

1) SPIN: Adaptive Protocols for Information Dissemination in Wireless Sensor Networks (SPIN) [6] overcame the limitations of Implosion, Overlapping, and Resource Blindness of the traditional data flooding protocols by negotiating meta-data among the nodes before transmitting real data. Whenever a node has some new data to share, it sends an ADV message to its neighbours who then place a request to get the new data if they haven't already availed it via a REQ message in response to the ADV message. Eventually, the originator of the ADV message sends the real data to all REQ message issuers via DATA message to complete the whole process. Figure 1, which is redrawn from [6], shows the phases of SPIN. While SPIN achieves a reduction in energy consumption by a factor of 3.5 less than that of flooding [6], it can't guarantee the delivery of data in case the potential neighbours are far away from the ADV message generator (i.e. source node) and the nodes in between the source and destination are not interested in the new data.

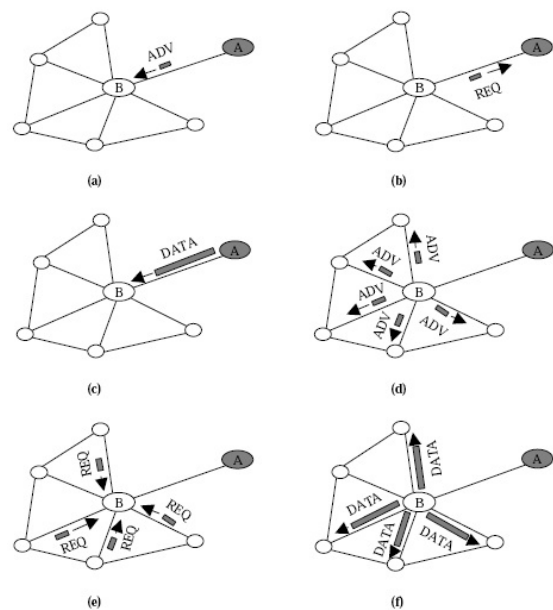


Figure 1. SPIN protocol. (a) Node A starts by advertising its data to node B. (b) Node B responds by sending a request to node A. (c) After receiving the requested data. (d) node B then sends out advertisements to its neighbours, (e-f) who in turn send requests back to B.

2) Modified SPIN (MSPIN): MSPIN [8] transmits information only to sink node instead of the whole network thereby making the response to the sink faster than SPIN. Here, total number of packet transmissions is less than SPIN. Therefore a significant amount of total energy can be saved. But, MSPIN is not free from the typical drawbacks of SPIN.

3) Directed Diffusion: Directed Diffusion (DD) described in [7] consists of 3 steps: interest propagation, gradient setup, and path reinforcements. An interest is a message that describes the sensing task the sensor network is meant for with a view to acquiring data. DD names each data by an attribute-value pair. Thus, a sensing task is disseminated with the help of interest messages throughout the network for named data. This dissemination of interest also sets up a

gradient in each node that receives an interest event. The gradient which is characterized by data rate, duration and expiration time is a reply link to the neighbouring node from which the interest is received. Events start flowing toward the originators of interests along multiple gradient paths out of which only one or a few are reinforced by the network. Figure 2, which is redrawn from [7], illustrates these steps. DD brings many advantages such as, no global addressing, less energy consumption due to on-demand nature and less delay. But in its downside, DD suffers from limited scope of applications due to its dependence on a query-driven data delivery model which may not be feasible for all WSNs specially networks that require continuous data delivery to the sink [2].

C. Hierarchical or Clustering-based Protocols

A single-tier flat sensor network cannot scale well when the number of sensor nodes increases to larger amount, simply because it will cause the single gateway to overload with huge amount of data. Therefore, the whole WSN is broken into some clusters having multiple gateways where nodes within a cluster communicate in multi-hop fashion consuming energy efficiently. Every cluster has a cluster head that performs data aggregation and/or data fusion before forwarding them to the sink and the selection of cluster head is dominated by the energy reserve of the nodes within a cluster. Among many hierarchical protocols, LEACH [9] is the pioneering one with its different versions like E-LEACH [10], M-LEACH [11], LEACH-C [12], V-LEACH [13] etc. Other remarkable hierarchical protocols include PEGASIS [14], TEEN [15] and APTEEN [16]. These protocols are briefly discussed below.

1) LEACH: LEACH [9] divides the whole WSN into some clusters each containing some cluster members and a cluster head which regulates channel access among the cluster members using TDMA. The cluster members wake up from sleep state during their respective TDMA slot during which they transmit data to the cluster head which then aggregates, fuses and finally transmits the data directly to the sink. So that the cluster head doesn't die out quickly, at a fixed interval a new cluster head is dynamically elected from the not-yet-chosen cluster members based on their residual energy. LEACH reduces energy consumption by a factor of 7 compared to direct communication and a factor of 4-8 compared to minimum energy transmission routing protocols by limiting the data transmission to long distance sink to only

a few cluster heads [9]. Moreover, each cluster head also performs local computation on the gathered data to reduce its volume. But, due to broadcast required during the cluster head selection process, good amount of energy is wasted.

2) E-LEACH: Energy-LEACH (E-LEACH) [10] improves over LEACH by considering the residual energy of each node during the second round of the cluster head selection process thereby making it more energy-efficient over LEACH.

3) M-LEACH: Multi-hop-LEACH [M-LEACH] [11] improves on LEACH by relaying cluster head data to the sink through multiple intermediate cluster heads which act as relay stations. This effectively solves the problem of LEACH or other earlier versions of LEACH where a cluster head is located far away from the sink in which case huge energy is consumed for direct or single-hop transmission between cluster head and the sink.

4) LEACH-C: Centralized LEACH [12] runs a centralized cluster formation algorithm so that the cluster heads can be distributed uniformly throughout the network. Though it reduces energy consumption over its LEACH siblings by balancing the distribution of cluster heads throughout the whole network, LEACH-C requires location information of the nodes usually provided by GPS devices which makes the protocol less robust and introduces some extra cost per node.

5) V-LEACH: The new Version LEACH (V-LEACH) protocol proposed in [13] keeps the provision of a vice-cluster head that takes over the role of the cluster head in case the cluster head dies.

6) PEGASIS: Instead of forming any cluster, Power-efficient GATHERing in Sensor Information Systems (PEGASIS) [14] forms a chain of nodes where each node transmits and receives data from a neighbour and at a time only one node can send data to the sink. Data are aggregated at the nodes when they move from node to node. It is shown that PEGASIS can outperform LEACH by about 100-300% for different network sizes and topologies. But, it causes long latency for nodes located at a distance on the chain. It is also subject to single point of failure in case the single leader on the chain fails which is also the reason for performance bottleneck of the system.

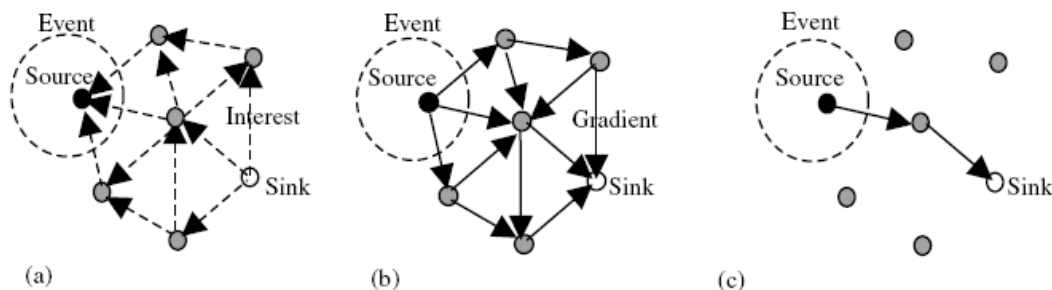


Figure 2. Simplified schematic for directed diffusion. (a) Interest propagation. (b) Initial gradients setup. (c) Data delivery along reinforced path.

7) TEEN: Threshold Sensitive Energy Efficient Network Protocol (TEEN) [15] combines both data-centric and hierarchical approach. Instead of having a flat clustering of nodes like LEACH or PEGASIS, TEEN creates multi-level hierarchy of nodes by grouping closer nodes into clusters on the first level, then on the second level and so on until the sink node is reached. Figure 3, which is redrawn from [15], depicts this concept of clustering. TEEN tries to reduce energy consumption by reducing the number of transmissions with the help of two thresholds as broadcast by the cluster heads after the clusters are formed – hard and soft thresholds. Hard threshold refers to the minimum possible attribute value that causes a sensor node to switch on its transmitter and transmit the sensed data to the cluster head, whereas a node sensing an attribute value at or beyond the hard threshold will transmit the sensed data only when the attribute value changes by an amount equal to or greater than the soft threshold. Although TEEN is quite energy-efficient, it is not useful for applications that require periodic reporting of the sensed data. Most importantly, the forming of multi-level hierarchy, implementing different thresholds and attribute-based naming impose huge overhead and complexity to this approach.

8) APTEEN: An extension to TEEN was proposed in [16] called Adaptive Threshold Sensitive Energy Efficient Network Protocol (APTEEN) which overcomes the limitation of TEEN by incorporating the periodic reporting of sensed data along with the reactive response. Figure 3 shows the architecture of APTEEN which remains the same as TEEN as a result of which APTEEN inherits the drawbacks of TEEN as well.

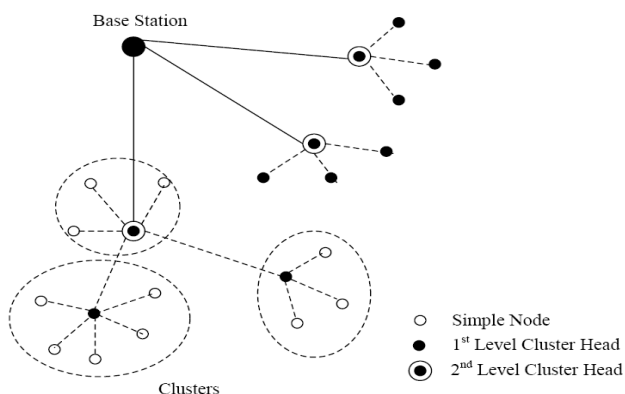


Figure 3. Hierarchical Clustering in TEEN and APTEEN

D. Location-based or Geographical Protocols

Location based or geographical protocols rely on the location information of the sensor nodes to find out the most energy efficient path between a source node and the sink or the cluster head. Location information is usually made available to the nodes by the use of GPS devices as it gives very accurate location information but imposes an extra cost per node. Sometimes, some localization algorithms such as the one described in [17] are also used to find out the position of a node which is very cost effective. But this approach suffers from inaccuracy or approximation in estimating the position of a node. Some of the popular and representative

geographical routing protocols for WSN include GAF [18], GEAR [19] and LEAR [20] which are discussed below.

1) GAF: Geographic Adaptive Fidelity (GAF) [18] proposed by Y. Xu et. al. forms a virtual grid where each node is associated with a point on the virtual grid by exploiting its GPS-indicated position information. GAF tries to reduce energy consumption by switching some nodes to their sleeping states provided that some equivalent nodes are kept active. Figure 4, which is redrawn from [18], depicts the idea. Here, node 2, 3 and 4 are considered to be equivalent as node 1 can reach all of them which all can reach node 5.

2) GEAR: Geographical and Energy Aware Routing (GEAR) [19] complements the Directed Diffusion (DD) protocol by restricting the dissemination of interest messages to only a certain region rather than to the whole network as is the case with DD. This is possible in GEAR since it enables each node to possess the location information and remaining energy level of itself and its neighbours.

3) LEAR: Location Based Energy-Efficient Reliable Routing Protocol (LEAR) [20] proposed by Alasem et al. is based on the geographical positioning and clustering of the nodes. In LEAR, each node constructs a routing table based on the distances to its neighbours where distance is computed from the location information which is made available by GPS devices and published by each node to its neighbours. The core of the LEAR protocol is Enhanced Greedy Forwarding (EGF) algorithm which, unlike the greedy approach used by most other geographic routing protocols, selects the nearest node to the active node based on its distance which is a good attempt to minimize energy consumption. EGF is implemented by selecting only and only the forward nodes in the routing path on the way to the destination while pruning all the nodes in the backward routing path which ultimately minimizes the number of hops to reach the sink thereby, significantly reducing energy consumption. Simulation result shows that LEAR significantly improves network lifetime and throughput over other reference protocols like LEACH or EGF [20]. But it bears the common drawbacks of geographical routing; i.e. extra cost for GPS devices.

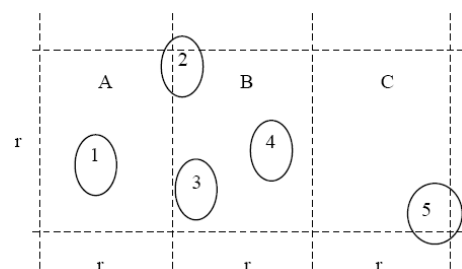


Figure 4. Virtual Grid in GAF

E. Mobility-based Protocols

WSN, in most applications, consists of sensor nodes that are static. But in some cases, in order to have better connectivity, wider coverage or to support multiple missions, it is beneficial to equip the nodes with mobility feature having restricted movement within a few meters which in turn, causes

the topology of the network to change frequently. Nevertheless, the sink in a WSN may also be mobile putting much more challenges to the problem of data routing. Therefore, the mobility-based protocols should be designed taking into consideration the mobility characteristic of the nodes as well as the sink. Popular mobility-based protocols like EAGRP [21] and LBDD [22] are discussed below.

1) EAGRP: Energy Aware Geographic Routing Protocol [21] first calculates the average distance between the source node and all its neighbours based on the location information of the nodes and then checks their energy levels. Finally, it selects the neighbour having energy level above a set threshold, having the maximum energy plus whose distance is equal to or less than the calculated average distance among its entire neighbours.

2) LBDD: Line-based Data Dissemination (LBDD) protocol [22] addresses the fact that in a WSN there may be multiple sink moving randomly in the sensor field. LBDD, like other geographical protocols, assumes that each node has its own location information available to it either through the use of GPS devices or by some virtual coordinate system. Then it defines a virtual vertical line of a certain width w intersecting the sensor field at the middle thereby, dividing the whole sensor field into two parts. The line itself is divided into g groups. The nodes lying closer to the boundary of the line are termed as in-line nodes while the other nodes are referred to as ordinary nodes. LBDD forwards data towards sink in two phases [22]. When an ordinary sensor node generates some new data, it forwards the data to the nearest inline node. Whenever a sink wishes to retrieve a specific data, it sends a query towards the line in a perpendicular fashion. The first inline node receiving the query propagates it in both directions along the perpendicular line until the inline node that owns the data is reached. The owner of the data forwards the data directly to the sink only when it owns a new copy of the data.

F. Heterogeneous Protocols

In most WSNs, the participant sensor nodes have an equal initial energy reserve and all the nodes consume energy at the same rate thus forming a homogeneous network. But, a WSN may consist of heterogeneous sensor nodes that have different hardware characteristics to perform different tasks and have different initial energy reserve thereby forming a heterogeneous network. Therefore, routing protocols for homogeneous WSNs will not suit for a heterogeneous network. Two popular heterogeneous protocols namely LEACH-HPR [23] and SEP [24] are discussed below.

1) LEACH-HPR: LEACH-HPR [23] categorizes all nodes into three categories – category A, B and C based on the energy reserve of the nodes from lowest to highest. Just like LEACH, it also selects a cluster head for each cluster, but it takes into account the current energy reserve of the nodes while deciding on the next cluster head. Each node sets up an internal timer initialized to the value equal to the reciprocal of its current energy reserve and starts counting down its timer at a predefined rate. Then each node listens to the wireless

channel for any message from its neighbours. The node that hasn't yet received any message but have its timer reached to zero, will declare itself as the new cluster head for the next round by broadcasting an announcement message. When a neighbour receives an announcement message, it joins the new cluster by sending a join request message to the new cluster head. If a node receives multiple announcement messages, it responds to the one that came from the closest cluster head as determined by the received signal strength of the announcement messages. Moreover, each cluster also elects an assistant cluster head in order to manage the tasks like data aggregation and fusion. Provision for having such a node reduces energy consumption and prolongs network lifetime.

2) SEP: A Stable Election Protocol for clustered heterogeneous wireless sensor networks (SEP) proposed in [24] takes into account the heterogeneity of the sensor nodes in their initial energy reserve and tries to prolong the time interval before the first node of the network expires (usually called stability period) which is particularly crucial for applications that have a stringent requirement of reliability of the data gathered from a WSN. SEP is based on the assumption that the sink node isn't energy restricted; at least in comparison with the other sensor nodes in the network and that the nodes of the network are static. A cluster head for each cluster is elected in a distributed fashion in a WSN that is organized into two-level hierarchy. While electing a cluster head, SEP exhibits heterogeneous-awareness in the sense that the probability of a node to become a cluster head is weighted by the initial energy reserve of the node relative to that of the other competitor nodes. This in turn maximizes the stability period of the WSN.

IV. ANALYSIS OF THE EER PROTOCOLS

Now that a comprehensive study of the representative routing protocols from each of the EER categories is conducted, a relative comparison among the different categories taking one protocol from each can be drawn. For comparison, we consider different metrics such as class, scalability, lifetime, energy efficiency, data aggregation, latency, hop communications and extra overhead. To be more precise, Gossiping, Directed Diffusion (DD), LEACH, LEAR, EAGRP and SEP are compared in table 1.

V. CONCLUSION

WSN, by nature, is extremely energy constrained thereby forcing the routing protocol designers to go for energy-efficient design. In this paper, a comprehensive list of the EER protocols for WSN has been studied. Through this discussion, it is obvious that still there are plenty of issues the EER protocols are left with to address such as QoS, bandwidth utilization, exact but cost effective localization etc. Therefore, it is expected that researchers will of course go for these open areas of research to put things into shape so that the yet-to-be standardized EER protocols could be standardized.

TABLE 1. RELATIVE COMPARISON AMONG DIFFERENT EER PROTOCOLS FOR WSN

Font Size	Gossiping	DD	LEACH	LEAR	EAGRP	SEP
Class	Data Relaying	Data Centric	Hierarchical	Geographical	Mobility-based	Heterogeneous
Scalability	Low	Medium	High	High	High	Medium
Lifetime	Medium	Medium	High	Very High	High	Medium
Energy Efficiency	Low	High	High	Very High	High	High
Data Aggregation	No	Yes	Yes	No	No	No
Latency	Very High	High	Low	Medium	Medium	Medium
Hop Communications	Multi-hop	Multi-hop	Single-hop	Multi-hop	Multi-hop	Multi-hop
Extra Overhead	No	Local Caching of Interests	Cluster Formation	Location Tracking Devices (e.g. GPS)	Location Tracking Devices (e.g. GPS) or Localization Algorithms	No
Resource Awareness	No	Yes	Yes	Yes	Yes	Yes

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