Chapter 2
Multi-hop Energy Efficient Routing

Abstract The very challenging requirement of WSN is energy efficiency, which depends upon the distributed design and dynamic topology of the network. This requirement can be fulfilled by the multi-hop energy efficient routing protocols. The objective of all the energy efficient protocols is to extend the network's lifetime. Sensor nodes are battery operated, so generally concern of all routing protocols is to conserve energy. In this chapter, energy efficient protocols are categorized into two types (i) heterogeneity based energy efficient routing protocols and (ii) chain based energy efficient routing protocols. Comparisons of various energy efficient routing protocols are specified here with open issues. A systematic and comprehensive taxonomy of various energy aware schemes are discussed in depth. This chapter is focused on various energy conservation schemes and hence, discussion of various routing protocols gives the readers a new insight.

Keywords WSN · Multi-hop routing · Energy efficiency · Classification · Comparison · Future trend

2.1 Introduction

A lot of work has been carried out in recent past for wide development of applications in WSN and to support these applications many energy efficient routing protocols have developed to deal with limited energy issue of WSN. Sensors may be used in the area monitoring to locate the object, to measure the humidity, to measure the air pollution, to measure the water density etc. WSN is comprised of many tiny sensor nodes. A tiny sensor node is consisted of three subsystems, a communication unit for data transmission, a sensing unit to capture the data from physical environment and a processing unit to process the gathered data. Power source of sensor nodes is battery operated and it is inconvenient to recharge it when SNs are once deployed in unattended atmosphere. A long network lifetime is required from sensor networks by most of the applications, as few months or

S. Rani and S.H. Ahmed, *Multi-hop Routing in Wireless Sensor Networks*,
SpringerBriefs in Electrical and Computer Engineering,
DOI 10.1007/978-981-287-730-7_2

several years. But how to prolong the network lifetime of the WSN with battery operated nodes is the major issue. Energy conservation is the key concern for WSNs. In this chapter, we have explored various multi hop routing protocols which are energy efficient. The energy of the routing protocols is affected by the many factors and some are discussed as below:

(a) Energy Expenditure in One round: One round is defined as the execution of the protocol for one time in which data of all the sensor nodes is transmitted to the BS. This is the total count of the energy expenditure of all the nodes in one round.
(b) Energy Consumption in Data aggregation: It is defined as the depletion of the energy in aggregating data. Some routing protocols are multi-hop and they transmit their data through the CHs and data is aggregated at the CHs by the nodes. So CHs consume energy in this task and it depends upon the condition whether the data was already processed or still have to be processed by the CH.
(c) Residual Energy Threshold: It is the term which makes aware of the remaining energy of the nodes so that it could become easier to know how much load can be handled by the sensor node. Some Routing protocols do not elect the sensor nodes as the CHs when their energy level is less than the threshold.
(d) Lifetime of the Network: It is defined as the time till the death of the last node of the network. Routing protocols use this factor to predict the total time of the execution of the network.
(e) Energy and the Length of the data: length of the packet to be transmitted is the factor, which should be considered while computing the energy consumption as lengthy packets will consume more energy of the nodes than the short packets.
(f) Enhancement of the Reliability at Cost of Energy: Requirement of the applications decide whether the redundancy of the data is required or not. As some applications require that data must be reachable to the BS at any cost the redundancy of data is preferred and same data packets are sent via the multiple paths. In contrast to these applications some require that energy should be conserved and where it is the common tendency to reduce the redundancy.
(g) Sleep and the Wake-up Schedule: In some routing protocols if the data communication is not on the continuous basis then only few nodes are active and other nodes turned off their antennas to save energy. After some time interval they wake up to receive the data buffered or intended for them.
(h) Idle listening or overhearing: Idle listening is the mode when sensor nodes do not send or receive any data but just listen to the channel and overhearing is the process when data is transmitted to some neighbor nodes and other nodes are in the range on their neighbor and overhear the messages which are not intended for them. Both the factors should be decreases by controlling the radio antennas and the range of the nodes.
(i) Total Energy Consumption by the Node: Mainly energy of the node is depleted in the sensing, transmitting, processing and aggregation of the data. So energy cost of the nodes is computed in these terms.

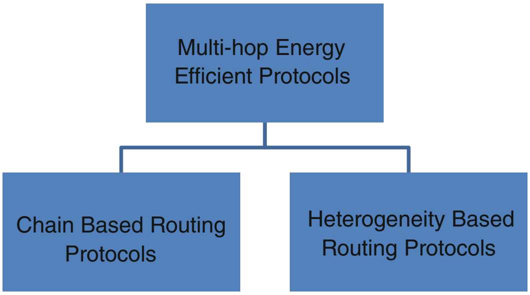

Fig. 2.1 Classification of multi-hop energy efficient protocols

(j) Energy Consumption in Informatics Messages: Time to time some messages are transmitted by base station to the nodes to know their status and sensor nodes acknowledge back to the BS. These messages should be kept as minimum as possible to conserve energy.
(k) Travelling Distance of the Data: More energy of the sensor node is consumed if the packet has to be transmitted at the long distance that is why some protocols use the clustering scheme to reduce the communication distance among the nodes.

Factors discussed above account for the computation of the energy metric of the network. Energy based data routing protocols are as follows. Energy efficient protocols can be classified into two categories [1] as shown in Fig. 2.1.

2.2 Multi-hop Energy Efficient Routing Protocols

Development of energy efficient protocols is the need of the hour. WSN is the energy constrained network due to the limited power, low memory, low processing battery operated sensor nodes [2]. Routing protocols mainly considers the try to maximize the life of the WSN by developing the optimal shortest routing paths and by minimizing the data travelling distance among the nodes. To make the WSN work for several years, other issues are also considered like switching off the radio components of the nodes whenever they are not in use and nodes have to self organize to maximize the energy efficiency. The environmental conditions also affect these nodes where it becomes more essential to take necessary to develop the new routing algorithms. The main objective of routing is not only to transmit the data from the source station to destination but to perform this function in energy efficient way. Architecture and design of the network also affects the energy of the sensor nodes. To cater the need of the today's WSN, the research in the hardware also lead some companies (Crossbow, WorldSense, Ember Cooperation etc.) to develop the ready to use energy efficient sensors which can be deployed directly. The present research is going on energy efficient routing protocols to optimize the energy conservation techniques for extending the lifetime of WSN. How to reduce

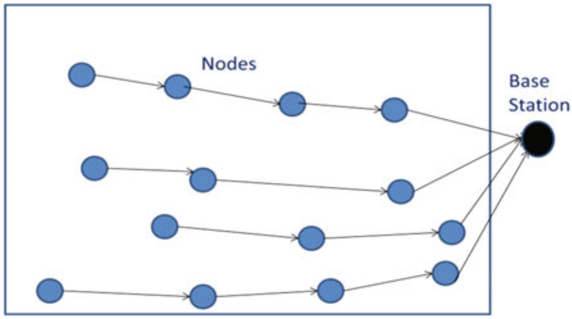

Fig. 2.2 Multi-hop communication

the load of the nodes and processing task; how to reduce the redundant transmissions are the essential factors to be considered and the routing algorithms which will support these, will be preferred in future. The communication cost in terms of energy expenditure sometime increases too much that it lead to the division or the partition of the network.

Factors discussed above account for the computation of the energy metric of the network. Energy based data routing protocols are as follows. Energy efficient protocols can be classified into two categories [1] as shown in Fig. 2.1:

Reduction in delay and distance can be achieved by multi hop transmission (Fig. 2.2), which will increase the reliability of the data transmission and network lifetime. Travelling distance directly affects the energy of nodes so by reducing the distance travelled by the nodes, enhance the energy efficiency of the nodes. Several routing multi hop protocols have been proposed in literature.

In this section, focus is on discussion of chain based data transmission protocols (Fig. 2.3). Main benefit of this scheme is energy conservation by forming the chain between the nodes so that travelling distance of the nodes could be reduced. But problem with chain-based protocols is delay. Few algorithms are working on this metric called energy delay metric.

2.2.1 Chain Based Data Transmission

An Energy-Efficient Unequal Clustering Mechanism for Wireless Sensor Networks (EEUC) is the energy efficient homogeneous multi-hop routing protocol. To compute the energy expenditure, multipath and free space models are used for the periodic data gathering. Clusters near the BS are smaller than the clusters, which are away from the BS. This strategy is used to avoid the problem of hot spot near the BS due to data forwarding. Node's competition radius should be less when its distance from the BS is less. The maximum competition radius is predefined. Each CH maintains the list of adjacent tentative CHs. After the selection of CHs, each node joins the closest cluster with largest received signal strength. Intra cluster routing is same as used in LEACH [3] that is with the help of election of optimal

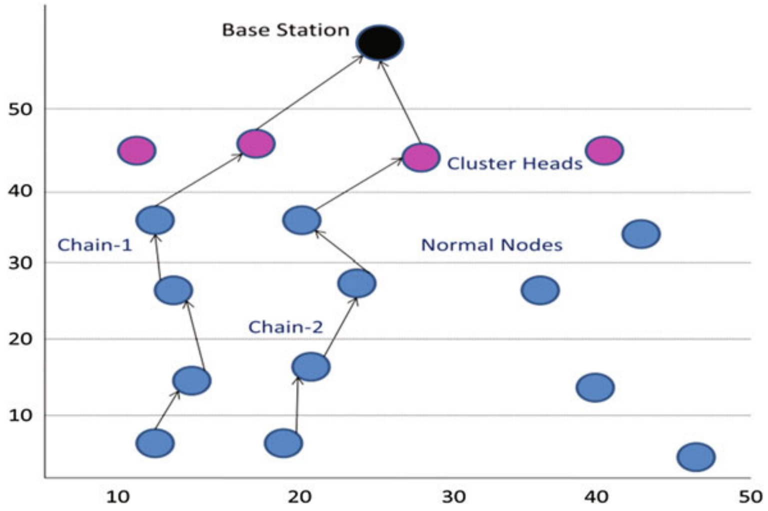

Fig. 2.3 Chain based communication

number of clusters and then role of the CH is rotated among the nodes. For inter cluster communication the distance of the nodes from the BS is calculated, if the distance is less than the predefined threshold distance then the data is transmitted directly, otherwise a forwarding node is find out to forward the data. It is the node from the list of the CHs maintained by the CH, which wants to transmit the data for node. Node with high residual energy is elected as the forwarding node. It has shown its validity over LEACH and HEED but as it has assumed that it does not require the use of GPS then the location of nodes is not known exactly and distance calculation will generate the error which may cause the loss of the packets.

A Hybrid Adaptive Routing Protocol for Mobile Ad Hoc Networks (SHARP) [4] is proposed by Ramasubramanian et al. (2003) to extend the network lifetime. Number of hops, link quality and battery availability; metrics were used in it. To balance the load over the nodes the traffic is distributed on the different possible routes. Topology is also maintained in it to ensure the reliable data transmission. The nodes with received signal strength (RSS) below the threshold values are not included in the routing table. To select the best routes SHARP uses link quality indicator and RSSI. It validated its performance in terms of energy consumption and network lifetime. The routing strategy used in SHARP is complex and it is not easy to compute the hybrid of reactive and proactive which makes it less reliable. A review paper on clustering and routing techniques is proposed in [5]. In this survey, some protocols are described which use multi-hop communication like LEACH-Ensuring the Reliable Data Delivery (LEACH-ER) and it is based on the scheme in which packets exchanged between the nodes are decreased and hence results in the increase of the network lifetime. LEACH-Trust Transmission Mechanism (LEACH-TM) was proposed in 2009 [6]. It considers the residual energy and hop count to make it reliable for data transmission. The distance of the

CH from BS is finding out by RSS (Received signal strength). It has optimized the lifetime of the WSN.

Gateway-Based Energy-Aware Multi-Hop Routing Protocol for WSNs (M-GEAR) was proposed by Nadeem et al. in 2013 [7] in which network has been divided into four regions for energy conservation. Different communication hierarchies are used for communication. Nodes in one region communicate directly to the BS and in the second region they communicate with gateway node. In the third region, clustering hierarchy is used to communicate and in the fourth region, data is passed to the gateway node by the CHs. The number of cluster heads is based on the formula as devised in LEACH. A gateway node is the node located in the centre of the area and its main aim is to forward to the BS which is far away from the area. Nodes near to the gateway transmit data to it and nodes near to the BS, transmit data to the BS directly and other nodes transmit the data to the gateway node via CHs and use multi-hop communication. It has shown its improvement over LEACH in terms of network lifetime.

Hybrid DEEC-Towards Efficient Energy Utilization in Wireless Sensor Networks [8] shows the improvement over DEEC [9], hybrid DEEC has been proposed in which nodes are divided into two categories where 90 % nodes are the normal nodes and 10 % nodes act as the beta nodes (nodes with high residual energy) which collect data from the CHs. Chain of nodes is formed like PEGASIS [10] and the node at the end with less distance to the BS is elected as the beta node. Multi Edged DEEC has shown improvement over H-DEEC. The multipath model computes distance parameter by using the distance of CH to the BS and the average distance of the nodes to the BS. The node with minimum weight will be elected as the leader of the nodes. Localization and interference problems are left to resolve in this protocol. MODLEACH-A Variant of LEACH for WSNs was proposed by Mahmood et al. [11]. It also proposes that for the intra-cluster communication the power level of the nodes should be 10 times less than the power levels used in the inter-cluster communication. Dual power transmission level and modification in election of the CHs improved the network lifetime and throughput.

Dynamic Cluster-based Routing for Wireless Sensor Networks (DCBR) [12] is based on the division of the area into clusters according to *K*-medoids method. f the value of *K i*s 1 then it behaves like LEACH. Its algorithm divides the area into sub-square areas. Each sub-square has some fixed length and centre C(i, j) where 1 <= i and j <= k. Role of CH is exchanged with the node with high residual energy according to its distance from the BS. It has shown its improvement over LEACH. But by forwarding the data to the one subarea by other subareas will cause that subarea to lose all its nodes fast and in future further information from that subarea will not be available.

Trust-Aware and Low Energy Consumption Security Topology Protocol of Wireless Sensor Network (TLES) [13]: It takes into account the node's residual energy, node's degrees and its distance from the BS to elect the forwarding node in routing. It is divided into two parts, in the first part the trust value is calculated and in the second part the forwarding node is elected. Evaluating node *i* monitors the quantity sending of the evaluated node *j*. If the number is lower than the lower limit threshold T_L, the node can be considered as a selfish node. If the number is more than the upper limit threshold T_H, the node may have performed attack as behavior of denial of service. To prevent the forget packets, consistency factor is evaluated which is called analysis of spatial coherence. The receiving node compares the data of the other node with its own data and if the received data is co-related then the data is consistent. The credibility of the node is checked when data is transmitted via relay node. If the computed value is 0 then it is the abnormal node and if its value is close to 1 then this node is reliable node. This computed value if direct trust value but indirect trust value must be considered in multi-hop communication. It is not suitable for the real time applications as it takes long time in searching the path.

Chen et al. proposed an energy efficient Chain Based Hierarchical Routing Protocol, named as CHIRON in 2009 [14]. The main objective of CHIRON was to split the sensing field into a number of smaller areas, so that it can create multiple shorter chains to reduce the data transmission delay and redundant path, and in this way gained the energy conservation per node and hence resulted in prolonging the network lifetime. It shows about 15 and 168 % improvements on average data propagation delay, 30 and 65 % improvements on redundant transmission path, respectively over enhanced PEGASIS [15] and PEGASIS protocols respectively. Similarly, an improved energy-efficient PEGASIS-based protocol (IEEPB) was proposed in 2011 by Sen et al. [16]. It shows better performance than EEPB in terms of balancing energy consumption and prolonging lifetime of Wireless Sensor Networks (WSN). MIEEPB was proposed in 2013 by Jafri et al. to improve the delay factor [17]. Sink mobility is fixed in particular location and sink stays in that location. Nodes search location for some time, which is known as sojourn time and gathers the data of all the chain leaders from that region (sojourn region). It has shown its improvement over IEEPB.

The hybrid of LEACH and PEGASIS is Chain Based Mixed Routing (CCM) [18] but limitation of this work is that energy consumption increases with the increase in the network size. The main objective of this protocol is to achieve energy efficiency and it tries to find out the chains, which consume less energy and take less time. Selection of the chain leader can be optimized to enhance the present algorithm. In the same year another protocol, Chain routing with even energy consumption (CREEC) was proposed [19], which outperforms in terms of energy savings and load balancing, as compared to LEACH, PEGASIS and power efficient data gathering and aggregation protocol (PEDAP) [20]. It performs very well for all the WSN sizes and base station distances. EBRAMS [21] has shown better performance than LEACH and PEGASIS in delay parameter. Mahajan et al. proposed chain-based protocol in 2013 to form the chain on the basis of the selection value (SV) [22]. But, this protocol does not suit the high dense network as it will lead to more comparisons and will consume more energy of the node. It can affect both the network lifetime and the delay factor.

2.2.2 Heterogeneity-Based Protocols

Many routing protocols assume that sensors have the same capabilities in communication, power, processing, storage and sensing. These protocols are known as

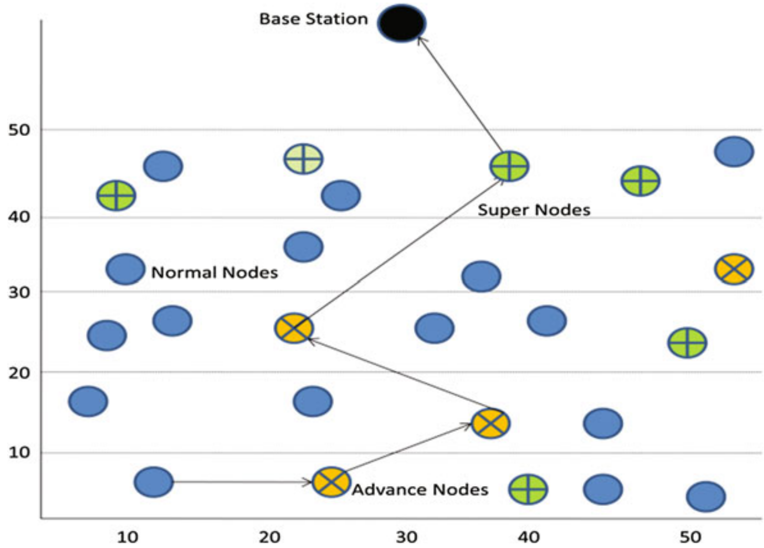

Fig. 2.4 Heterogeneity based communication

homogeneous where links between any two nodes are symmetric. However, in some application sensors with different capabilities are required which are known as heterogeneous. Sensors with same physical properties and using the same platform models are not feasible. For the specific requirements of the sensing applications, heterogeneous nodes are used as shown in Fig. 2.4. iPAQ and CrossBow Mica motes can be used together in the same network as iPAQ motes use more power but can compute the data quickly, so they can be used for the data fusion and CrossBow motes can be used for the sensing as they use very little power and can perform the complex processing. This type of deployment was proposed by the authors of [23]. Using some powerful nodes in the network can extend network lifetime. Inexpensive nodes can be used sensing and powerful nodes can be used for in-network processing. Three layers architecture was proposed in 2005 for heterogeneous network. This architecture is based on the rationale that more energy is consumed in forwarding the data of many nodes by one node. But there should be the optimal number of the powerful nodes at the second layer. With the use of line powered sensor nodes the network lifetime of WSN can be increased. Some sensors are required to provide high quality links to the sink (Highly reliable links at long distance); as provided in 802.11 type connectivity. These links reduces the number of hops in data transmission to the sink. These links are also known as back haul links, which helps in reducing the end-to-end delay. But advantage of this type of heterogeneity depends upon backhaul sensors and their locations. If each sensor is one hop away from the sink or from backhaul sensor then end-to-end success rate is approximately is same as link success rate. Maximum benefit of heterogeneity either link heterogeneity or energy heterogeneity depends upon the size, architecture and density of the network. The length of the shortest path from location (i, j) to the sink that is adjacent to the midpoint of the edge is computed. If backhaul sensor *k*, is consider one hop away then the distance from that node is calculated. Link heterogeneity can help in maintaining the lifetime of the network.

Gathering Algorithms in Sensor Networks Using Energy Metrics [24]: Main problem in heterogeneous networks is to minimize the detection latency and energy consumption and maximize the information gain for target tracking and localization with dynamic data routing and querying. There are certain events in the network, which should be reported in time so only some sensors required to be active to conserve energy. But election of the active sensors depends upon the important information they have which is balanced by their communication cost. Useful information is defined by the time and space of the events. If X represents the target position of estimation then representation of the current posteriori distribution (belief) with given set of measurements Z1, Z2…Zn is calculated. Belief is based on the measurements of the sensor nodes and so it is required to minimize the communication to select the best belief. Chu et al. proposed routing protocol for heterogeneous sensor network in 2002 [25]. Two novel techniques, constrained anisotropic diffusion routing (CADR) and information-driven sensor querying (IDSQ) were used for energy-efficient routing and data querying in ad hoc sensor networks. It proved its optimized results in detection latency and node failures. To derive the sensor measurement to belief state information driven sensor querying protocol (IDSQ) aims at optimizing the sensor selection. A sensor *l* is elected as the leader from the N set of sensors which will be responsible for electing the optimal sensors based on some information like geometric measure given as the Mahalanobis distance from the destination to the sensor node under consideration queries for data. The leader must have the knowledge of certain features as locations. Each sensor will wait for the query from the leader and after queried, each sensor sends the information back to the sender. When the target is in the range of the cluster nodes then leader is activated and computes the belief using its own dimension. Based on, its quality the leader may stop processing or may continue with sensor selection. If belief is not good then it runs its own algorithm for sensor selection then it updates it belief state by incorporating new sensors. It runs again if the selection is again not good. In this way, it helps in conservation of the energy of the nodes if they do not have useful information but at the cost of less reliability. RSVP [23] is based on notion of the heterogeneous receivers [26]. This protocol is not scalable and resources reservation scheme is static. Resources should be assigned dynamically so that few resources could cater the need of all the nodes. Supporting Hierarchy and Heterogeneous Interfaces in Multi-Hop Wireless Ad Hoc Networks [27] has the same problem of addressing which arises when two nodes handled by different administrators want to communicate [28]. Delay and energy problems are encountered in the heterogeneous protocol [26] developed for dense network because nodes have to broadcast the message again and again to claim itself as the CH and it has no support for recovery from fault [29]. In SEP [30] routing protocol sink is assumed in centre but it does not present the good idea for the applications where BS is located at corner and it is not scalable. For scalability purpose [31], a routing scheme with heterogeneous sensor nodes was proposed. It shows its improvement over Directed diffusion (DD) and Granted delivery (SWR) protocols. In it data is forwarded to the BS by the relay nodes. Forwarding data by relay nodes will cause the relay nodes to lose their energy faster than other nodes that can make network obsolete and for high dense applications it is not practicable.

Energy efficient heterogeneous clustered scheme [32] uses three types of heterogeneity that are energy heterogeneity, computational heterogeneity and link heterogeneity. Without energy heterogeneity the link and computational can't bring the positive results in terms of QoS metrics of WSN. This represents the same structure as used in SEP but with minor difference that in SEP only one level of energy heterogeneity but it uses tow levels of heterogeneity. But it has not explained two concepts (1) the reliability and (2) how the network will cope- up with the nodes after the failure of some nodes. Chan et al. proposed the other protocol, WSN, in the same year, which is named as a geography-based heterogeneous hierarchy routing (GBHHR) protocol [33]. A dormancy system is adopted in this protocol for heterogeneous nodes to solve the problem of election of CH to conserve energy in better way than traditional protocols. In 2014, a routing protocol based on topologies for heterogeneous wireless sensor networks (ROUT) was proposed [34]. It follows the idea of division of nodes into H-sensors (nodes with higher hardware capabilities) and L-sensors (nodes with lower hardware capabilities). How to maintain heterogeneity in the WSN to optimize the QoS metric is the main concern of all the protocols.

2.3 Comparative Analysis

In Table 2.1, we can clearly observe difference in the parametric values of all the energy efficient protocols. All protocols have different measures. As EEUC, LEACH-ER, LEACH-TM, M-GEAR, Hybrid DEEC etc. are less scalable as compared to SHARP, IDSQ/CADR, CHR, GBHHR etc. protocols. Due to load balancing few protocols are more energy efficient than other protocols. Focusing the energy parameter develops these protocols. In this chapter, we have surveyed the many approaches to energy conservation techniques in wireless sensor networks. Main objective is to discuss the comprehensive and systematic categorization of the solutions proposed in the literature.

Table 2.1 Comparative analytical table for multi-hop energy efficient protocols

Protocol	Classification	Scalability	Data aggregation	Energy efficient	Failure recovery	Network type	Load balancing	Latency	Reliability	Mobility	Location awareness
EEUC(2005)	Multi-hop	Low	Yes	Good	No	Homogeneous	Less	Average	Less	Stationery	No
SHARP(2009)	Multi-hop	Good	Yes	Average	Yes	Homogeneous	Yes	High	Yes	Mobile	No
LEACH-ER (2010)	Multi-hop	Low	Yes	Good	No	Homogeneous	No	High	Yes	Stationery	No
LEACH-TM (2009)	Multi-hop	Low	Yes	Good	No	Homogeneous	No	High	Yes	Stationery	No
M-GEAR (2013)	Multi-hop	Low	Yes	Good	No	Homogeneous	No	Average	less	Stationery	No
Hybrid DEEC (2013)	Multi-hop	Low	Yes	Good	No	heterogeneous	No	Average	Average	Average	No
MOD-LEACH (2013)	Multi-hop	Low	Yes	Good	No	Homogeneous	No	Average	Less	Stationery	No
DCBR(2014)	Multi-hop	Low	yes	Average	No	Homogeneous	No	Average	Less	Stationery	Yes
TLES(2014)	Multi-hop	Average	Yes	Good	No	Homogeneous	No	Average	Yes	Stationery	Yes
HEED(2004)	Multi-hop	Low	Yes	Average	Less	heterogeneous	Yes	Average	Less	Stationery	No
CCRP(2008)	Chain- Based	Low	Yes	Very Good	No	Homogeneous	No	Very High	Less	Stationery	Yes
CHIRON (2009)	Chain- Based	Average	Yes	Good	No	heterogeneous	No	Low	Less	Stationery	No
IEEPB(2011)	Chain- Based	Low	Yes	Average	No	Homogeneous	No	Average	Less	Sink Mobile	No
MIEEPB (2013)	Chain- Based	Low	Yes	Average	No	Homogeneous	No	Average	Less	Sink Mobility in Particular Locations	No

(continued)

Table 2.1 (continued)

Protocol	Classification	Scalability	Data aggregation	Energy efficient	Failure recovery	Network type	Load balancing	Latency	Reliability	Mobility	Location awareness
IECBSN (2013)	Chain-Based	Very Low	Yes	Low	No	Homogeneous	No	Very High	Very Less	Stationery	No
IDSQ/CADR (2002)	Heterogeneous	High	Less	Good	No	Heterogeneous	No	Low	Average	Nodes are Mobile	Yes
AODV-DSDV (2002)	Heterogeneous	High	Less	Good	No	Heterogeneous	No	Low	Average	Nodes are Mobile	No
CHR(2005)	Heterogeneous	Average	Yes	Good	No	Heterogeneous	No	Low	Less	Stationery	Yes
GBHHR (2008)	Heterogeneous	High	Yes	Good	No	Heterogeneous	No	Average	Average	Stationery	Yes
LayHet(2012)	Heterogeneous	Average	Less	Very Good	No	Heterogeneous	No	Low	Average	Stationery	No
ROUT(2014)	Heterogeneous	High	Yes	Depends upon the topology used	No	Heterogeneous	No	Depends upon the topology used	Average	–	Yes

2.4 Summary and Future Trends

A large number of energy efficient protocols have been proposed in recent past. Still there is lot of work to be done and research is continued. We have stressed on many approaches, like data driven and mobility based ideas. Final observations can be drawn on the basis of different techniques of energy management. An increasing interest towards sparse network architecture can be noticed but such network can be useful only if the advantages of mobility are exploited. The dependence and complexity upon the collaborative efforts of WSN require use of energy efficient protocols through which connectivity of the network can be maintained. New protocols are required to improve network lifetime, delay and network connectivity.

References

1. Pantazis N, Nikolidakis SA, Vergados DD (2013) Energy-efficient routing protocols in wireless sensor networks: a survey. IEEE Commun Surv Tutorials 15(2):551–591
2. Li C, Ye M, Chen G (2005) An energy-efficient unequal clustering mechanism for wireless sensor networks. IEEE Int Conf Mobile Adhoc Sens Syst Conf. doi:10.1109/MAHSS.2005.1542849
3. Heinzelman WB, Chandrakasan AP, Balakrishnan H (2002) Application specific protocol architecture for wireless micro sensor networks. IEEE Trans Wirel Netw 660–670. doi:10.1109/TWC.2002.804190
4. Ramasubramanian V, Haas ZJ, Sirer EG (2003) SHARP: a hybrid adaptive routing protocol for mobile ad hoc networks. In: Proceedings of the 4th ACM international symposium on mobile ad hoc networking and computing (MobiHoc '03). ACM, New York, NY, USA, pp 303–314. doi:10.1145/778415.778450
5. Tyagi S, Kumar N (2013) A systematic review on clustering and routing techniques based upon LEACH protocol for wireless sensor networks. J Comput Netw Appl 623–645. doi:10.1016/j.jnca.2012.12.001
6. Weichao W, Fei D, Qijian X (2009) An improvement of LEACH routing protocol based on trust for wireless sensor networks. In: 5th international conference on wireless communications, networking and mobile computing, 2009. WiCom'09. IEEE
7. Nadeem Q et al. (2013) M-GEAR: gateway-based energy-aware multi-hop routing protocol for WSNs. In: 2013 8th international conference on broadband and wireless computing, communication and applications (BWCCA). IEEE. doi:10.1109/BWCCA.2013.35
8. Qing L, Qingxin Z, Mingwen W (2006) Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks. Comput Commun 29(12):2230–2237
9. Khan MY et al (2013) Hybrid DEEC: towards efficient energy utilization in wireless sensor networks. arXiv preprint arXiv:1303.4679
10. Lindsey S, Raghavendra CS (2002) PEGASIS: power-efficient gathering in sensor information systems. In: Aerospace conference proceedings, 2002. IEEE, vol 3. IEEE
11. Mahmood D et al (2013) MODLEACH: a variant of LEACH for WSNs. In: 2013 8th international conference on broadband and wireless computing, communication and applications (BWCCA). IEEE. doi:10.1109/BWCCA.2013.34
12. Zhao L, Chen Z, Sun G (2014) Dynamic cluster-based routing for wireless sensor networks. J Netw 9(11):2951–2956. doi:10.4304/jnw.9.11.2951-2956
13. Chen Z, He M, Liang W, Chen K. Trust-Aware and low energy consumption security topology protocol of wireless sensor network. J Sens, Article ID 716468 (in press)

14. Chen KH, Huang JM, Hsiao CC (2009) CHIRON: an energy-efficient chain-based hierarchical routing protocol in wireless sensor networks. In: Wireless telecommunications symposium, 2009. WTS 2009. IEEE
15. Yueyang L, Hong J, Guangxin Y (2006) An energy-efficient PEGASIS-based enhanced algorithm in wireless sensor networks. China Commun 91–97
16. Sen F, Bing Q, Liangrui T (2011) An improved energy-efficient pegasis-based protocol in wireless sensor networks. In: IEEE 8th international conference On fuzzy systems and knowledge discovery (FSKD), vol 4. IEEE, pp 2230–2233
17. Jafri MR et al (2013) Maximizing the lifetime of multi-chain pegasis using sink mobility. arXiv preprint arXiv:1303.4347
18. Tang F, You I, Guo S, Guo M, Ma Y (2012) A chain-cluster based routing algorithm for wireless sensor networks. J Intell Manuf 23(4):1305–1313
19. Shin J, Sun C (2011) CREEC: chain routing with even energy consumption. J Commun Netw 13(1):17–25
20. Tan HÖ, Körpeoğlu I (2003) Power efficient data gathering and aggregation in wireless sensor networks. ACM Sigmod Record 32(4):66–71
21. Yarvis M, Kushalnagar N, Singh H, Rangarajan A, Liu Y, Singh S (2005) Exploiting heterogeneity in sensor networks. In: Proceedings IEEE INFOCOM'05, vol 2, Miami, FL, pp 878–890
22. Mahajan S, Malhotra J, Sharma S (2013) Improved enhanced chain based energy efficient wireless sensor network. Wirel Sens Netw 5(4):84–89. doi:10.4236/wsn.2013.54011
23. Zhang L et al (1993) RSVP: a new resource reservation protocol. Netw IEEE 7(5):8–18
24. Lindsey S, Raghavendra C, Sivalingam KM (2002) Data gathering algorithms in sensor networks using energy metrics. IEEE Trans Parallel Distrib Syst 13(9):924–935
25. Chu M, Haussecker H, Zhao F (2002) Scalable information-driven sensor querying and routing for ad hoc heterogeneous sensor networks. Int J High Perform Comput Appl 16(3):293–313
26. Xu K, Gerla M (2002) A heterogeneous routing protocol based on a new stable clustering scheme. MILCOM 2002. Proceedings, vol 2. IEEE
27. Broch J, Maltz DA, Johnson DB (1999) Supporting hierarchy and heterogeneous interfaces in multi-hop wireless ad hoc networks. In: 4th international symposium on parallel architectures, algorithms, and networks, 1999. (I-SPAN'99) Proceedings. IEEE
28. Smaragdakis G, Matta I, Bestavros A (2004) SEP: a stable election protocol for clustered heterogeneous wireless sensor networks. Boston University Computer Science Department
29. Du X, Lin F (2005) Improving routing in sensor networks with heterogeneous sensor nodes. In: Vehicular technology conference, 2005. VTC 2005-Spring. 2005 IEEE 61st, vol 4. IEEE
30. Qing L, Zhu Q, Wang M (2006) Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks. Comput Commun 29(12):2230–2237
31. Kumar D, Aseri TC, Patel RB (2009) EEHC: energy efficient heterogeneous clustered scheme for wireless sensor networks. Comput Commun 32(4):662–667
32. Kumar S, Prateek M, Bhushan B (2014) Energy efficient (EECP) clustered protocol for heterogeneous wireless sensor network. arXiv preprint arXiv:1408.3202
33. Chen X et al (2008) A geography—based heterogeneous hierarchy routing protocol for wireless sensor networks. In: 10th IEEE international conference on high performance computing and communications, 2008. HPCC'08. IEEE
34. Ludovico Guidoni, Daniel et al (2014) RouT: a routing protocol based on topologies for heterogeneous wireless sensor networks. Latin Am Trans IEEE (Revista IEEE America Latina) 12(4):812–817

http://www.springer.com/978-981-287-729-1

Multi-hop Routing in Wireless Sensor Networks
An Overview, Taxonomy, and Research Challenges
Rani, S.; Ahmed, S.H.
2016, X, 69 p. 14 illus., Softcover
ISBN: 978-981-287-729-1