A SURVEY OF CONSERVING ENERGY FOR WIRELESS SENSOR NETWORK MOBILE NODES

Saurabh Singh*

Abstract

In Wireless sensor networks the major concern is how to conserve the nodes' energy so that network lifetime can be extended significantly. Employing one static sink can rapidly exhaust the energy of sink neighbors. Furthermore, using a non-optimal single path together with a maximum transmission power level may quickly deplete the energy of individual nodes on the route. This all results in unbalanced energy consumption through the sensor field, and hence a negative effect on the network lifetime. In this paper, we present a comprehensive taxonomy of the various mechanisms applied for increasing the network lifetime. These techniques, whether in the routing or cross-layer area, fall within the following types: multi-sink, mobile sink, multi-path, power control and bio-inspired algorithms, depending on the protocol operation. In this taxonomy, special attention has been devoted to the multi-sink, power control and bio-inspired algorithms, which have not yet received much consideration in the literature. Moreover, each class covers a variety of the state-of-the-art protocols, which should provide ideas for potential future works. Finally, we compare these mechanisms and discuss open research issues.

Keywords: wireless sensor networks (WSNs), network lifetime, energy-efficiency, multi-path, multi-sink, mobile sink, power control, bio-inspired protocols

* **Guide Name: Prof. Sapna Chaudhary**

Collage : Shri Ram Group of Institutions Jabalpur

1. Introduction

Wireless sensor networks (WSNs) are composed of a lot of small, low cost sensor nodes that work together to measure various parameters of the environment

and send the data to a unique or several sinks where they will be processed [1]. WSNs have a wide range of uses in military, medical, metropolitan and industrial venues. They are employed in many applications such as security surveillance, battlefield and habitat monitoring, intrusion detection, and target tracking purposes. Although reducing the size of sensors could make them cheaper, this also requires that all hardware equipment, specially the batteries, be extremely small. Since the sensor nodes should be functional for a long period of time and battery replacement in harsh environments like battlefields is usually impossible, nodes may lose their energy very fast, thus becoming nonfunctional in a short time. This situation can negatively affect the whole network connectivity, fault tolerance and lifetime. Therefore, optimization for energy consumption is an important issue, especially to prolong network lifetime in WSNs [2]. To address this problem, a variety of approaches are implemented in the area of routing strategies, which play a key role in network functionality and performance [3].

Routing in wireless sensor networks is very challenging. One of the problems that affect the network lifetime refers to nodes in the vicinity of the sink, whose activity imposes a high traffic on this series of sensor nodes. In this state, the nodes that are closer to the sink lose their energy very fast. These nodes are the neighbors located at one hop away from a single static sink. Not only do they utilize energy to relay the data from any other nodes through the network to the sink, but also for sending their own data. This problem is known as the “sink neighborhood problem” [4], which can lead to premature network disconnection. When most of the sink's neighbors' energy is fully depleted, this isolates the sink from the rest of the network, while there is still a huge potential for most of the sensor nodes to continue to perform their tasks and functionalities normally.

One of the basic solutions for the sink neighborhood problem is to employ more than one static sink in the network. Using multiple sinks [5–7] that are statically distributed across the sensor field, it is possible to spread traffic load uniformly among sensor nodes. This can enhance the network lifetime and decrease the end-to-end delays significantly. Another solution for the sink neighborhood problem is to provide some of the network elements with mobile capability [4]. A good strategy to balance energy consumption for data transmission across the network could be replacing the neighbors of the sink. Since nodes' power is limited, a mobilizer unit in mobile nodes consumes the remaining energy faster than under static conditions. The key idea is to maintain the sensors stationary while moving the sink periodically to the parts of the network with sufficient energy. This can prevent network partitioning and consequently prolong the network lifetime. Many protocols [8–11] are proposed for sink mobility, but they differ from each other in the aspect of mobility itself [4]. For instance, in some applications where the sink goes through the network to collect data by itself, an uncontrolled sink movement pattern is applied to the approaches. This means the network may be unable to control the sink movement by applying a specific trajectory based on the nodes' remaining energy or the amount of traffic at each sensor [4]. On the other hand, controlled sink mobility [10,11] can efficiently improve the network lifetime without any negative effects on end-to-end delay.

Although the sink neighborhood problem is one of the most important reasons for network partitioning, there is another problem that can affect the network lifetime. In fact, using a single optimal path [12,13] for every communication may gradually drain the energy of nodes which are located on the route. This causes some problems such as node and link failure due to unbalanced depletion of nodes' batteries across the network. Applying multi-path routing [14,15] in WSNs could result in traffic and energy load balancing over the network. Furthermore, it is not necessary to update the route information periodically, which wastes a remarkable amount of the nodes' power [16].

The sensor nodes are used to forward the data and control packets to the next hop at a maximum power level, which results in fast energy exhaustion. In this state, by employing a power control scheme [17–19] in routing protocols in which the nodes are able to adjust the transmission power level based on the distance from the next hop, the relay nodes can conserve much more energy.

Finally, bio-inspired algorithms [20] have recently been added to the above category as an important class since they can optimize the route construction phase. Bio-inspired protocols which are designed based on insect sensory systems try to construct the shortest path between the source and the destination so that it can conserve much more energy.

Our aim in this paper is to help readers better understand the fundamental energy-aware mechanisms applicable to routing algorithms in wireless sensor networks and point out the potential for improving network lifetime making use of these techniques. We present a comprehensive classification for these mechanisms and discuss a variety of the state-of-the-art energy-efficient routing and cross-layer protocols under this taxonomy. As mentioned before, multi-path methods can avoid network partitioning by distributing traffic loads on most of the sensor nodes while multiple sink and mobile sink methodologies overcome this problem by changing the sink's neighbors periodically and balancing the energy consumption in the sink vicinity. Power control schemes can save nodes' energy by decreasing the power needed to transmit data packets to the next hop in the routing protocols while bio-inspired algorithms can optimize the route construction phase by finding the shortest path for data routing. We categorize the protocols using power control techniques as cross-layer schemes, while the rest are classified as simultaneous mechanisms in the network layer. To the best of our knowledge, our work is the first effort to categorize lifetime improvement strategies applied in routing for WSNs.

2. Related Work

The growing interest in wireless sensor networks on the one hand, and the continual emergence of new architectural techniques in the other hand have inspired some previous efforts for surveying the characteristics, applications and communication protocols for such a technical area [21,22]. In this subsection we point out the features that distinguish our paper and highlight the differences in scope.

The authors in [23] presented full categories of routing protocols for WSNs, as did the authors in [21,24]. However, none of them include the recent energy-efficient mechanisms (such as mobile sink, multi-sink, *etc.*) which could be combined with routing algorithms to increase the network lifetime. Moreover, all of the mentioned approaches only consider the routing algorithms in WSNs from the network structure and the protocol operation point of view. In our paper, we classify not only the routing schemes based on protocol operation, but also from the viewpoint of energy-efficiency.

A taxonomy of different energy-saving strategies applicable in wireless sensor networks is developed in [1] and [25]. According to these surveys, the energy-aware routing protocols in sensor networks are classified by considering several factors such as data cycling, mobility, topology control and data-driven techniques. However, the authors do not focus sufficiently on the network layer and these papers do not include bio-inspired and multi-sink mechanisms for routing protocols. Our survey can serve those who seek deeper insight into energy-efficient routing issues and schemes in wireless sensor networks.

A comprehensive study of mobile techniques for increasing network lifetime is presented in [2]. The authors explained the protocols proposed in all aspects of mobility such as mobile sinks, mobile sensors redeployment, and mobile relays. Although the paper covers a number of routing protocols that support mobility, it does not provide a classification for other energy-efficient techniques applied in routing algorithms. As the best of our knowledge, our paper is the first one that presents a taxonomy of energy-efficient mechanisms, including mobile sink, multi-sink, multi-path, power control and specially bio-inspired schemes, in order to prolong the WSNs' lifetime.

3. Background and Preliminaries

3.1. Wireless Sensor Network Architecture

Before describing the high-level taxonomy of energy saving protocols, it is better to have an understanding of the node-level and network architecture for future reference.

The structure of a typical wireless sensor node [1].

A node consists of four main elements with two optional subsystems as follows:

- A sensing unit, including one or several sensors equipped with analog-to-digital converters for data collection.
- A processing unit, including a microprocessor and memory which cooperate to process the sensed data locally.
- A radio unit used as a transmitter/receiver.
- A power supply unit, including one or more batteries.
- A global positioning system to find the sensors' locations (*optional*).
- A mobilizer unit to change their position (*optional*).

It is worth mentioning that as indicated, the last two components are optional and may be used based on application requirements [1].

3.2. Sources of Energy Consumption in WSNs

Power failure in WSNs depends on the nodes' characteristics. For example, Raghunathan *et al.* [26] have shown that the power properties of a Stargate sensor node are different from those called motes. However, they do share the following common points:

- The energy consumption of communication unit is much higher than that of the processing unit. For instance, the energy needed for executing 3,000 instructions in a

CPU is equal to the energy needed for transmitting just 1 bit of data [27], so a tradeoff between computation and communication is necessary.

- The radio unit consumes energy at the same level in reception mode, transmission mode and idle state. In order to save energy, it is better to turn off radio whenever it is not in used.
- The sensing unit can be a main source of power consumption depending on the application in use, so an appropriate policy should reduce the energy utilization in this unit significantly [1].

According to the above architecture and power failure issues, the routing protocols are classified into three main categories based on the network structure, namely *flat*, *hierarchical*, and *geographic algorithms*. At the next subsection, this general classification will be discussed.

3.3. General Classification of Routing Protocols in WSNs

Is mentioned, according to the network structure, routing protocols in WSNs can be divided into three categories [21]: data-centric (flat), hierarchical, and geographic (location-based). They are described as follows:

- *Data-Centric protocols:* Multi-hop data-centric routing protocols are basically the first class to be introduced in WSNs. Considering a large number of nodes in sensor networks, flat algorithms employ *query-based* mechanisms in which the sink node only requests the desired data in order to prevent continuous data transmissions and thus save power. In this group, Sensor Protocols for Information via Negotiation (*SPIN*) [28], Directed Diffusion [29], Energy-Aware Routing (*EAR*) , Rumor Routing_and Minimum Cost Forwarding Algorithm (*MCFA*) are some of the most famous flat algorithm paradigms.
- *Hierarchical protocols:* Different from the flat category, in hierarchical protocols that utilize a clustering scheme, nodes are assigned different roles or functionality. In fact, energy conservation can be achieved in these protocols by some aggregation and reduction of data in so-called cluster heads (CHs). In this class, Two Tier Data Dissemination (*TTDD*), Low-Energy Adaptive Clustering Hierarchy (*LEACH*), Threshold-Sensitive Energy-Efficient Sensor Network Protocol (*TEEN*), Adaptive Periodic Threshold-Sensitive Energy-Efficient Sensor Network Protocol (*APTEEN*) and Power-Efficient Gathering in Sensor Information Systems (*PEGASIS*) [37] are some inspiring protocols.

- *Location-Based protocols*: The possibility to apply position information in routing schemes will be used in location-based algorithms to route data towards the desired regions in the sensor field. This can save energy by limiting the flooding through the network [22]. *GPSR* , *GAF* [12], and *GEAR* [13] fall in this class.

4. Lifetime Improvement Mechanisms in Routing

In the next subsections, the main categories of energy-aware mechanisms applied to routing protocols in WSNs will be discussed in detail. Figure 2 shows the taxonomy of the methods covered in this paper.

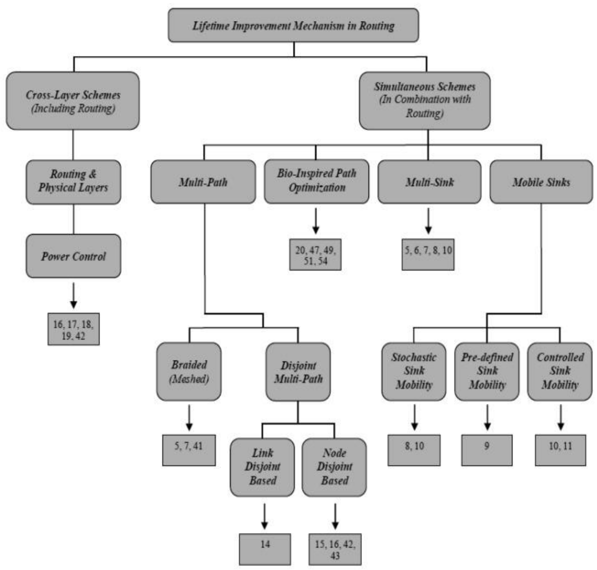

Figure 2.

Classification of fundamental lifetime improvement mechanisms in routing protocols for WSNs.

In this figure, the numbers represent the corresponding references. However, some protocols [5,7,8,10,16] fall in more than one category. Lifetime improvement mechanisms in routing protocols for WSNs are basically divided into two main categories: *simultaneous schemes* and *cross-layer schemes*. Simultaneous schemes [21] usually refer to the mechanisms which could be combined with routing algorithms in order to achieve a specific goal like energy-efficiency. In WSNs, these mechanisms are classified based on the protocol operation. However, cross-layer schemes [1] investigate different layers simultaneously to make the protocol more energy-efficient. In the following, we discuss the various classes under these two categories.

4.1. Multi-Sink Mechanisms

As mentioned before, network partitioning caused by energy depletion around the sink (the sink neighborhood problem) is one of the main issues that affect the network lifetime. Therefore, many techniques have been used in previous works to overcome this problem. One possible method is to employ multiple sink nodes throughout the network. Researchers who work on multi-sink mechanisms believe that by increasing the number of static sink nodes one can distribute the traffic load all over the network and consequently balance energy consumption around the sink. Finding an optimal location for the sink nodes and looking for low cost paths from each source node to one or several sinks [5] are the main concerns in this research area.

Multi-Sink Directed Diffusion (MSDD), which was proposed in [5], is a kind of multi-sink approach that employs the basic idea of a Directed Diffusion (DD) routing protocol to construct routes from each source node to the nearest sink node. Network lifetime could be increased in this protocol by switching the data flow to the next nearest sink when the power level of relay nodes on the primary path falls below a certain threshold. Just like the DD algorithm, the sinks propagate interest messages through the network to find the sources which contain the data of interest. When a source node receives such messages from multiple sinks, it responds by broadcasting an exploratory data (ED) message through the network. Then bi-directional paths are constructed towards the source node and the sinks start to send positive reinforcement messages to the source. In this state, if the source node accepts all reinforcement messages from multiple sinks, the data packets should be forwarded to all of them, which imposes a large overhead caused by the redundant data. Therefore, it registers the neighbor node that sends the positive reinforcement with smallest *Hop_Count* value into the *Path_List* table. It also retains the information about other paths to use them as backup routes when the residual energy of the primary path falls below a certain threshold.

In some situations, as shown in Figure 3, a single neighbor of the source may be shared among several paths from different sinks. Thus, by choosing this node, data packets will be relayed towards all the paths including this neighbor. In order to avoid this problem, each sink node assigns a random number as *Path_Id* to the positive reinforcement messages. These path identifiers that distinguish the paths from each other are also registered in Path_List table. As illustrated in Figure 3, D represents the sink node (destination) and S indicates the source. There is also a source neighbor that is common between the paths with Path_Ids 1 and 2. In MSDD, a negative reinforcement message is employed to inform the source node of a path failure. In this state, it then removes this path from its Path_List

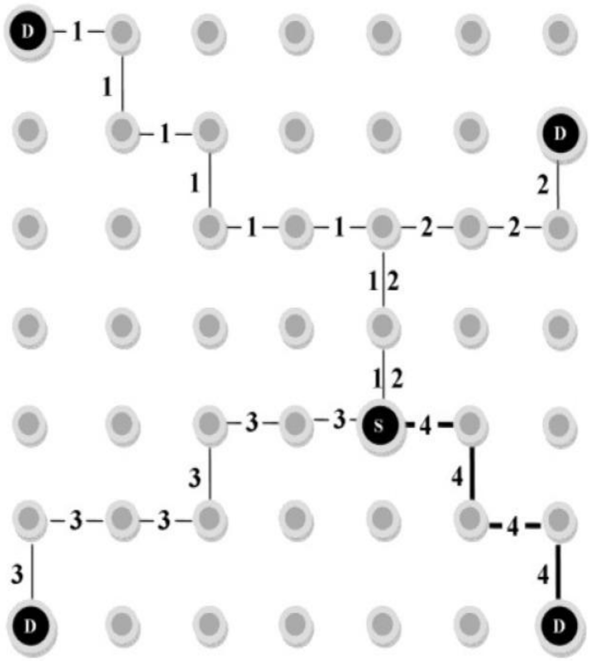

table.

Figure 3.

Path selection with minimum hop count [5].

Simulation results [5] show that MSDD could enhance the average energy of network nodes and the energy of nodes with the minimum energy by increasing the number of sink nodes. The authors also proved that connection lifetimes up to three times longer could be achieved using a multi-path routing algorithm. The routing overhead of Directed Diffusion is decreased in MSDD, which results in up to two times higher network lifetime. Nevertheless, the algorithm could only be used in query-driven applications according to the main operation of Directed Diffusion family protocols.

Gradient-Based Routing Protocol for Load Balancing (GLOBAL) [6] is another multi-sink protocol that maximizes network lifetime with the help of a new gradient model. This algorithm selects the least-loaded path for data forwarding that also excludes the most overloaded sensor nodes. By applying this method, network lifetime is not limited by the short lifetime of such overloaded nodes. Each sensor node in this protocol computes its residual energy depletion rate (*REDR*) that will be used later in gradient field construction phase. Equation (1) shows the *REDR* for node *i* where: *α* is the weighting factor, $REDR_{old}$ indicates the previous *REDR*'s value for this node and $REDR_{sample}$represents *REDR* during past *T* seconds:

$$REDR_i = \alpha \times REDR_{old} + (1 - \alpha) \times REDR_{sample}$$

(1)

$REDR_{sample}$ is calculated by the Equation (2) as follows:

$$REDRsample = \left(1 - \frac{Current\ Residual\ Energy}{Current\ Residual\ Energy - T}\right)/T$$

(2)

The protocol consists of two phases as follows: (1) *Gradient field construction and data forwarding phase:* in this stage, an advertisement (ADV) message is flooded by each sink but not at the same interval to ensure that there is no interference between two consecutive floodings. It contains the three following fields: (a) *hcnt:* the number of hops from the sink, (b) *sum-redr*: the sum of nodes' *REDR* on the path and (c) *max-redr*: the maximum *REDR* value of nodes on the path. When the source node *i*receives an ADV message for the first time, it assumes that the acquired path is the shortest one and uses it for data transmission. Then it computes its gradient G_i according to Equation (3), saves it in memory, updates ADV message and finally rebroadcasts it through the network:

$$Gi = \beta \times sum{-}redrL + (1 - \beta) \times max\ {-}redrL$$

(3)

In this equation, $sum\text{-}redr_L$ = the path's *REDR* + node *i*'s *REDR*, $max\text{-}redr_L$ = the maximum *REDR* on the path including node *i* and *β* is a weighting factor of these parameters. If node *i* experiences a lower loaded path than the first one so that its length does not exceed a specific number of hops and its gradient is lower than G_i, it replaces this newly discovered path with the previous one. (2) *Gradient field maintenance:* during the network functionality, the gradient field should be refreshed. Instead of flooding, GLOBAL updates this field during data transmission by exploring overhearing packets from other neighbors. This can reduce overhead throughout the network.

Simulation results [6] indicate that GLOBAL improves the network lifetime by 50% and 18% more than shortest path routing (SPR) and CPL, which is a gradient-based routing using the cumulative path load only, respectively. The philosophy behind this improvement is that in

GLOBAL, the traffic load of the most overloaded sensor over the path and a weighted average of the cumulative path load are used by an independent node to determine its gradient. The main drawback of GLOBAL is the high control overhead caused by sinks' advertisement flooding in the gradient field construction phase.

5. Protocol Comparison

A common objective of all mechanisms surveyed in this paper is to prolong the network lifetime. In all approaches, it is assumed that sinks have unlimited energy resources while sensor nodes are energy constrained. Multiple and mobile sink strategies, multi-path strategy, power control schemes and bio-inspired mechanisms are examples of methods that can be employed in routing algorithms to increase network lifetime. The multi-sink and mobile sink mechanisms as discussed in Sections 4.1 and 4.2 respectively are compared in . based on the following criteria:

- *Multi-sink*: As mentioned before, the network lifetime could be improved by preventing network partitioning caused by fast energy depletion around the sink. Increasing the number of sinks is one of the methods to distribute the traffic load through the sensor field and balance energy consumption around the sinks. The algorithms presented in [5–7], are samples of multi-sink mechanisms for lifetime enhancement. Although some other protocols [8–10] are originally designed for mobile sink strategy, they can also support multi-sink mechanisms as well as previous approaches. Therefore, the researchers can use these two techniques simultaneously to get better results.
- *Mobile sink*: It is another solution for "sink neighborhood problem" caused by network partitioning around the sink. A mobile sink can replace its neighbors with low residual energy by relocating to fresh part of the network periodically. Some of the protocols [8–11] in . use this mechanism to prolong the network lifetime.
- *Multi-path*: Since employing a single path for data transmission between a source and the sink can decrease the energy level of sensor nodes on the path quickly and cause network partitioning along the route, making use of the multi-path mechanism results in traffic load and energy balancing over the sensor field. In MSDD [5] and MSLBR [7], for instance, each source node can implement multiple paths towards the multiple sinks to increase reliability and fault tolerance as far as possible. It is worth mentioning that there is no protocol listed in . using mobile sink and multi-path mechanisms simultaneously.

- *Power control*: according to this mechanism, each sensor node tries to compute the energy needed to send a packet to the next hop in multi-hop routing protocols. In this way, the node is capable to adjust the transmission power level based on the distance to the next hop and avoid using maximum power level. As a result, the network lifetime will be improved by saving nodes' energy individually on the path. Only one protocol [11] in this table can employ a power control scheme.
- *Sensor mobility*: As mentioned before, the ability to change the position of sensor nodes helps to maintain connectivity by avoiding network partitioning and sink neighborhood problems.
- *Sink movement pattern*: There are three methods used by the sink node to identify the next position during the movement. In stochastic mobility pattern [8,10], a random path is followed by the sink node while the path is predefined in a fixed [9] strategy. In controlled mobility pattern [10,11], the sink is able to define the next position autonomously based on variations of the energy factors in the sensor field. The algorithm proposed in [11] uses a fixed sink mobility method for the first round. However, it switches to controlled sink mobility in subsequent rounds.
- *Location awareness*: Location information is a powerful tool to find the best next hop in routing mechanisms. It can also be used for determining the next location of mobile nodes in the network. This information can be acquired from GPS directly or calculated on other localization methods. None of the multi-sink approaches in . are location aware. Although the sink node in all mobile sink mechanisms knows its position, there is only one [9] algorithm in which all nodes are location aware.
- *Number of sinks*: The network lifetime can be improved by increasing the number of sinks up to a specific point. When the number of sinks exceeds that point, the network lifetime is constant. The reason behind this phenomenon is that each sink becomes at most 1-hop away from a sensor node. *Network structure*: Routing algorithms in WSNs are usually classified into three group as follows: Flat (data-centric), hierarchical and geographic (location-based).
- *Data aggregation*: This technique can enhance the network lifetime by reducing the number of data packets transmitted in the network. Data aggregation mostly is employed

in hierarchical protocols [11] where the cluster heads proceed to gather data from cluster members before they act to send them to the sink node.

- *Application Type*: This factor shows that which kind of mechanisms will be employed to send data to the sink. In time-driven method, the data are sent to the sink continuously by all or special groups of sensor nodes that caused fast energy depletion through the network. In event-driven strategy [6], on the other hand, only the data about an interested event will be forwarded to the sink while in the query-based method [5], the data should be transmitted according to the sink's request. Most of the algorithms [8–10] that support sink mobility are used for time-driven applications.
- *Sink speed*: In mobile WSNs, the sink speed is an important factor. A sink can move from one place to another by using a constant speed [8]. Some approaches [9] use a move/stop mechanism in which, the sink node moves to a new place and stops in that position for a specific period of time in order to collect data from k-hop neighbors and after that moves to another place, and so on. Sometimes the sink speed is adaptive [11] based on the number of congested areas that should be visited for data gathering.

Comparison of multi-sink and mobile sink mechanisms.

These algorithms are mainly aimed at distributing traffic load through the network and enhancing the network lifetime by avoiding network partitioning. These protocols are compared together according to the following criteria:

- *Lifetime improvement mechanism*: This field shows that which kind of mechanism for lifetime improvement is used in each protocol. As shown in ., all protocols only use multi-path mechanism except MSMRP [42] that employs both multi-path and power control schemes simultaneously.
- *Node or link disjoint*: Disjointness is an important property for multi-path protocols. Node or link disjoint protocols try to prevent interference between multiple paths and avoid packet retransmission caused by collision. Those algorithms in which the node-disjoint scheme is used are congestion avoided and thus, having much better performance than link-disjoint multi-path strategies [14]. Braided protocols cannot guarantee the disjointness among the multiple paths.
- *Number of paths*: This factor indicates the rate of traffic distribution through the network. Whenever this metric is increased, the possibility of network partitioning will be

decreased. The number of paths in some approaches is specified, however in other approaches [15] the number of parallel routes are increased as far as possible to improve the network lifetime.

- *Network structure:* Routing algorithms in WSNs are usually classified into three groups as follows: Flat (data-centric), hierarchical and geographic (location-based). Flat networks [15] employ a query-based strategy in order to decrease redundant data transmission through the network and conserve a huge amount of energy. In a hierarchical architecture, nodes with higher energy are chosen as cluster heads and aggregate data from other nodes (*i.e.*, cluster member). Both position information and the greedy forwarding techniques are used by geographic routings [14] to establish one or more energy-efficient paths from the source nodes to the sink.
- *Application Type*: This factor shows that which kind of mechanisms will be employed to send data to the sink. In time-driven method, the data are sent to the sink continuously by all or special groups of sensor nodes that caused fast energy depletion through the network. In event-driven strategy [14], on the other hand, only the data about an interested event will be forwarded to the sink while in the query-based method [15], the data should be transmitted according to the sink's request.
- *QoS*: The routing protocols [14] that apply quality of service criteria (QoS) to the network have to balance data quality and energy consumption. So, the network has to satisfy certain QoS factors such as energy, bandwidth, and delay when delivering data to the sink.
- *Network connectivity*: The algorithms proposed in [15] assume that the sensor nodes in the network should have a connected topology while in some others this assumption is not considered. AGEM [14] is an example that makes use of mobile sensors to transmit data packets between disconnected network areas.
- *Mobility*: In a static sensor network, the sensors which located at the sink vicinity may die quickly due to transmitting a large number of data packets from the nodes which are far away from the sink. The fast energy depletion around the sink causes the network partitioning and consequently sink isolation phenomenon. Thus, changing the position of neighbors [14] or sink itself is a smart choice to keep connectivity and enhance the network lifetime.

- *Location awareness*: Location information is a powerful tool to find the best next hop in routing mechanisms or can be used for determining the next location of mobile nodes in the network. This information can be acquired from GPS directly or calculated on other localization methods. In AGEM protocol [14], for example, each node checks the location information of its neighboring nodes in route construction phase to find the best neighbor for greedy forwarding mechanism. According to greedy method, a neighboring node having maximum progress on the virtual line between the source and the sink is the best candidate to be chosen as the next hop.

5. Conclusions

In wireless sensor networks, the nodes which are located on a non-optimal single path and forward data packets with maximum transmission power level may run out of energy quickly. This causes network partitioning along the paths through the sensor field. Furthermore, the sink neighbors tend to lose their energy much faster than the nodes which are far away from the sink due to the fact they are carrying heavier traffic loads. This also results in network partitioning around the sink and consequently causes sink isolation phenomena. All these problems can decrease the network lifetime significantly. In recent years, many approaches were proposed to address these problems. Nevertheless, there is a need to discuss and classify these methods as well as investigate their advantages and weakness points. In this paper, we present a new classification of the fundamental mechanisms that are applied in routing protocols to prolong the network lifetime. Figure 2 showed this taxonomy in detail. These mechanisms are categorized into five groups: multi-sink, mobile sink, multi-path, power control and bio-inspired schemes. Among them, power control is definitely a cross-layer technique including routing and physical features while the rest are simultaneous schemes which are applied in routing protocols. We discuss all mechanisms in detail, with an emphasis on their advantages and disadvantages as well as their significance. Comprehensive comparisons of these methodologies are based on their inherent characteristics. Although these energy-efficient mechanisms look promising, there are still many challenges that need to be resolved in order to improve sensor network lifetime. We note those challenges and have highlighted future research trends in this regard.

References

1. Anastasi G., Conti M., Francesco M.D., Passarella A. Energy conservation in wireless sensor networks: a Survey. Ad Hoc Netw. 2009;7:537–568.

2. Yang Y., Fonoage M.I., Cardei M. Improving network lifetime with mobile wireless sensor networks.Comput. Commun. 2010;33:409–419.

3. Yick J., Mukherjee B., Ghosal D. Wireless sensor network survey. Comput. Netw. 2008;52:2292–2330.

4. Basagni S., Carosi A., Melachrinoudis E., Petrioli C., Wang Z.M. Controlled sink mobility for prolonging wireless sensor networks lifetime. Wirel. Netw. 2008;14:831–858.

5. Eghbali A.N., Javan N.T., Dareshoorzadeh A., Dehghan M. An Energy Efficient Load-Balanced Multi-Sink Routing Protocol for Wireless Sensor Networks. Proceedings of the 10th International Conference on Telecommunications (ConTEL '09); Zagreb, Croatia. 8–10 June 2009; pp. 229–234.

6. Yoo H., Shim M., Kim D., Kim K.H. GLOBAL: A Gradient-Based Routing Protocol for Load-Balancing in Large-Scale Wireless Sensor Networks with Multiple Sinks. Proceedings of the 2010 IEEE Symposium on Computers and Communications (ISCC '10); Riccione, Italy. 22–25 June 2010; pp. 556–562.

7. Wang C., Wu W. A Load-balance Routing Algorithm for Multi-Sink Wireless Sensor Networks. Proceedings of the 2009 International Conference on Communication Software and Networks (ICCSN '09); Macau, China. 27–28 February 2009; pp. 380–384.

8. Chatzigiannakis I., Kinalis A., Nikoletseas S. Sink Mobility Protocols for Data Collection in Wireless Sensor Networks. Proceedings of the international Workshop on Mobility Management and Wireless Access (MobiWac '06); Torremolinos, Spain. 2–6 October 2006; pp. 52–59.

9. Luo J., Hubaux J.P. Joint Mobility and Routing for Lifetime Elongation in Wireless Sensor Networks. Proceedings of the 24th Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM '05); Miami, FL, USA. 13– 17 March 2005; pp. 1735–1746.

10. Basagni S., Carosi A., Petrioli C., Phillips C.A. Heuristics for Lifetime Maximization in Wireless Sensor Networks with Multiple Mobile Sinks. Proceedings of the IEEE International Conference on Communications (ICC '09); Dresden, Germany. 14– 18 June 2009; pp. 1–6.

11. Nazir B., Hasbullah H. Mobile Sink Based Routing Protocol (MSRP) for Prolonging Network Lifetime in Clustered Wireless Sensor Network. Proceedings of the 2010 International Conference on Computer Applications and Industrial Electronics (ICCAIE 2010); Kuala Lumpur, Malaysia. 5–8 December 2010; pp. 624–629.

12. Xu Y., Heidemann J., Estrin D. Geography-Informed Energy Conservation for Ad-Hoc Routing. Proceedings of the 7th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom '01); Rome, Italy. 16– 21 July 2001; pp. 70–84.

13. Yu Y., Govindan R., Estrin D. Geographical and Energy Aware Routing: A Recursive Data Dissemination Protocol for Wireless Sensor Networks. Citeseer; University Park, PA, USA: 2001. Technical Report UCLA/CSD-TR.

14. Medjiah S., Ahmed T., Krief F. AGEM: Adaptive Greedy-Compass Energy-aware Multipath Routing Protocol for WMSNs. Proceedings of the 7th IEEE Consumer Communications and Networking Conference (CCNC ′10); Las Vegas, NV, USA. 9– 12 January 2010; pp. 1–6.

15. Yahya B., Ben-Othman J. REER: Robust and Energy Efficient Multipath Routing Protocol for Wireless Sensor Networks. Proceedings of the IEEE Global Telecommunications Conference (GLOBECOM ′09); Honolulu, HI, USA. 30 November– 4 December 2009; pp. 1–7.

16. Wang Z., Bulut E., Szymanski B.K. Energy Efficient Collision Aware Multipath Routing for Wireless Sensor Networks. Proceedings of the 2009 IEEE International Conference on Communications (ICC'09); Dresden, Germany. 14– 18 June 2009; pp. 91–95.

17. Zhou Y.F., Lyuon M.R., Liu J. On Setting up Energy-Efficient Paths with Transmitter Power Control in Wireless Sensor Networks. Proceedings of the 2nd IEEE International Conference on Mobile Ad-Hoc and Sensor Systems (MASS '05); Washington, DC, USA. 7 November 2005; pp. 440–448.

18. Lin S., Zhang J., Zhou G., Gu L., He T., Stankovic J.A. ATPC: Adaptive Transmission Power Control for Wireless Sensor Networks. Proceedings of the 4th International Conference on Embedded Networked Sensor Systems (SenSys '06); Boulder, CO, USA. 31 October–3 November 2006; pp. 223–236.

19. Kim J., Chang S., Kwon Y. ODTPC: On-Demand Transmission Power Control for Wireless Sensor Networks. Proceedings of the 2008 International Conference on Information Networking, (ICOIN); Busan, Korea. 23–25 January 2008; pp. 1–5.

20. Song X., Wang C., Wang J., Zhang B. A Hierarchical Routing Protocol Based on AFSO algorithm for WSN. Proceedings of the International Conference on Computer Design and Applications (ICCDA '10); Qinhuangdao, China. 25–27 June 2010; pp. 635–639.

21. Akkaya K., Younis M. A survey on routing protocols for wireless sensor networks. Ad Hoc Netw.2005;3:325–349.

22. Pavai K., Sivagami A., Sridharan D. Study of Routing Protocols in Wireless Sensor Networks. Proceedings of the 2009 International Conference on Advances in Computing, Control, and Telecommunication Technologies (ACT '09); Trivandrum, Kerala, India. 28–29 December 2009; pp. 522–525.

23. Eslaminejad M.R., Sookhak M., Razak S.A., Haghparast M. A review of routing mechanisms in wireless sensor networks. Int. J. Comput. Sci. Telecommun. 2011;2:1–9.

24. Al-Karaki J.N., Kamal A.E. Routing techniques in wireless sensor networks: A survey. IEEE Wirel. Commun. 2004;11:6–27.

25. Mahfoudh S., Minet P. Survey of energy efficient strategies in wireless ad hoc and sensor networks. Proceedings of the Seventh International Conference on Networking (ICN '08); Cancún, Quintana Roo, Mexico. 13–18 April 2008; pp. 1–7.

26. Raghunathan V., Schurghers C., Park S., Srivastava M. Energy-aware wireless microsensor networks. IEEE Signal Process. Mag. 2002;19:40–50.