Routing Protocols In Large Scale Wireless Sensor Networks – A Survey

Alaa Alzoubi  
Department of Computer Science  
Amman Arab University  
Amman, P.O. Box: 2234, 11953, Jordan  
alzo3bi.alaa@gmail.com

Tarek Kanan  
line 1 Department of Software Engineering  
line 2: AlZaytoannah University of jordan  
line 3: Amman, P.O. P.O.Box 130, Jordan  
Trek.kanan@zuj.edu.jo

Ghassan Kanaan  
Department of Computer Science  
Amman Arab University  
Amman, P.O. Box: 2234, 11953, Jordan  
Gkanaan@aau.edu.jo

Riyadh Alshalabi  
Department of Computer Science  
Amman Arab University  
Amman, P.O. Box: 2234, 11953, Jordan  
shalabi@aau.edu.jo

Abstract—Various enhancements have been provided for wireless sensor network (WSN) to increase the capability and availability of the small and cheap nodes in WSN. One of the most important features of WSN is the ability of sending and receiving the data effectively. There are several limitations of WSN like, transmission range, storage, lifetime, and energy resources. Routing in WSN came to ensure reliable transmission of data and maintain the routes in the network. In this paper, we produce a survey of routing techniques in WSN and compare their strengths and weaknesses.

Keywords: Wireless sensor network; Routing techniques; data transmission in WSN.

I. INTRODUCTION

One of the most significant technologies in 20th century is the wireless sensor network (WSN) [1]. The basic element of the WSN structure is the nodes, which communicate with each others with different computation and sensing capabilities [2], [3]. Over short-distance areas, the sensor nodes communicate and collaborate to achieve some task and purpose, such as: control of industrial process, military surveillance, and network security [4].

Various WSN application deployments have been operated based on ad-hoc style without engineering and planning for this style. As the nodes autonomously manage and organize themselves in WSN. Sensor nodes aren’t expected to work for relatively lone period because of its battery-power life time. Furthermore, charging and changing the nodes batteries are so complex. Due to the energy constraints, the nodes management and control functions are required like, node localization, synchronization, and network security. By using the traditional routing techniques, there are several weaknesses when applied to WSN, due mainly to the energy-constrained limitation [4]. For instance, one technique for broadcast a control and data packets between the network nodes is the flooding technique. This process has to be repeated until the destination node has been reached. Thus may not take the energy constraints into its account. As a result, overlap and implosion problems have been appeared [9], [12]. The flooding is sightless technique, as several duplicated packets have to be circulated in the network, thus may lead to receiving several copies form the same packet in one node, thus cause implosion problem. In addition, broadcasting the data at the same time over the same region occur by two or more sensors to their neighbors when they sense the same region, at this situation, those neighbors will receive duplicated packets. To handle flooding shortcomings, gossiping techniques has been used [10].

A lot of researches have been produced to investigate and handle the WSN constraints, application, and design issues.

In this paper several routing techniques for wireless sensor network are investigated and compared. Section 2 of this research explains the network features and design objectives. In Sections 3, challenges of the WSN routing are been described. In Section 4, routing techniques are discussed and in section 5 they are compared. At the end, Section 6 concludes the survey.

II. WSN FEATURES AND DESIGN OBJECTIVES

The sensor networks and application requirements characteristics have a significant impact on the network
design objectives in term of network performance and capabilities [4].

A. WSN features

Wireless sensor networks have the following unique features and constraints, compared with the traditional sensor network:

- Data redundancy: In most sensor network application, sensor nodes are violently collaborated and deployed in a region to accomplish a common sensing task. Thus, multiple sensor nodes sensed the data by specific level of correlation or redundancy.
- Severe energy, storage constraints, and computation: highly limited computation, energy, and storage capabilities.
- Deployment of dense sensor node: WSN nodes are usually violently deployed and can order of magnitude higher than that in a MANET.
- Frequent topology change: changing network topology frequently due to the channel fading, addition, damage, energy depletion, or node failures.
- Sensor nodes battery-powered: Sensor nodes depend usually on battery power and are deployed in a severe environment where it is very difficult to recharge or change the batteries.
- Application specific: A WSN is usually deployed and designed for a specific application. The design requirements of a WSN change with its application.
- Many-to-one traffic pattern: In most WSN applications, many-to-one traffic pattern produced due to the sensing the data by sensor nodes from multiple source nodes to a specific sink.
- Self-configurability: the random and autonomous WSN deployment by the WSN node to configure themselves and reconfigure their connectivity in the network topology failure and changes.
- Unreliable nodes: As WSN nodes are prone to physical failures or damages because of its deployment in severe environment.

B. Design objectives

Most WSN are application specific with different application requirements. Thus, the following design objectives have to be considered in design objectives:

- Data redundancy: In most sensor network application, sensor nodes are violently collaborated and deployed in a region to accomplish a common sensing task. Thus, multiple sensor nodes sensed the data by specific level of correlation or redundancy.
- Security: Introducing effective security mechanisms to promote authentication, integrity, and prevent unauthorized users from accessing the information or physical resources.
- Low power consumption: As WSN nodes are powered by battery also the difficulty of recharging or changing the nodes batteries, it is significant to decrease the power consumption of WSN nodes so that the lifetime of the WSN nodes is prolonged
- Small node size: As WSN nodes are usually deployed in a severe environment with large numbers of nodes, reducing node size can facilitate and improve node deployment.
- Adaptability: When a node joins, fail, or move from the network, thus may change a node density and topology, WSN protocols must be designed to be adaptive to such topology and density changes.
- Scalability: As the number WSN nodes are in the order of different sizes with (tens, hundreds, or thousands node), WSN must be scalable to different network sizes.
- Reliability: The WSN must be able to reduce the number of failure over operation time frame as much as possible to guarantee higher availability.
- Channel utilization: As WSN node has limited bandwidth, communication techniques designed for WSN should efficiently and effectively make use of the bandwidth to enhance channel utilization.
- Fault tolerance: the WSN must be reliable, so it can continue running even with erroneous situation.

III. Network Design Challenges and Routing Issues

Because of various network constraints, the routing techniques of WSN are challenging. WSNs tolerate from the limitations of several WSN resources, for instance, bandwidth, energy, storage, CPU [11], [13]. The following aspects are the main design challenges in WSN networks [4], [11]:

- Limited hardware resources: WSN nodes have also limited storage and processing capacities, and thus can only achieve limited computational functionalities. These hardware limitations produce many constraints in the architecture and design for WSN.
- Limited energy capacity: As WSN nodes have limited capacity of the power as they are battery powered. Energy and the node power sources are a big challenge for WSN designers in severe environments.
• Random and massive node deployment: WSN node deployment depends (fully) on the application itself and can be either random or manual which actually affects the performance of the routing technique.

• Sensor locations: Another critical challenge that faces the design of routing in WSN is how to manage the node locations? Various of the proposed techniques assume that the nodes either are organized with localization technique [14] or GPS receivers.

• Diverse sensing requirements: WSN have a very wide range of varied applications. No network technique can meet all applications requirements at once. Therefore, the routing technique should guarantee a reliable data.

• Data Aggregation: As WSN nodes may generate a lot redundant data, multiple nodes with similar packets. A data aggregation protocol has been used to guarantee data transfer optimization and energy efficiency in a number of routing techniques.

IV. WSN ROUTING TECHNIQUES
Routing in WSN is completely different from traditional routing in stable networks in various ways. With no infrastructure, unreliable wireless links, WSN nodes may fail, and routing protocols have to meet stringent energy and power requirements [5]. Many routing techniques were produced for WSN such as: coherent-based routing protocols, quality of service (QoS-based) routing protocols, negotiation-based routing protocols, multipath routing protocols, etc.

Routing protocols are required to sending data between sensors and the base station for communications. Different routing protocols are proposed in wireless sensor network with optimized features to deal with application requirement, each protocol provide a predefined techniques to ensure reliable transmission, high quality services, decisions about the best path to forward on, and others. However, routing protocols can be classified according to various parameters:

• Routing protocols can be classified according to the network structure (the participation style of the node) as:
  – Direct Communications Protocols
  – Hierarchical (Clustering) Protocols
  – Flat Protocols
  – Local-Based Protocols

• Routing protocols can be classified according to the Network Operations as:
  – Multipath Protocols
  – Query-based Protocols
  – Negotiation-based Protocols
  – Quality of service (QoS-based) Protocols
  – Coherent-based Protocols

Each routing category has a several representative protocols that have been applied according to this category, as the hierarchical category has (PEGASIS, LEACH, APTEEN, HEED, TEEN) protocols, Mobility-based category has (SEAD, TTDD) protocols, QoS-based category has (SAR, SPEED) protocols, Location-based category has (GAF, SMECN) protocols, and Data-centric category has (Energy-aware Routing, EAD, SPIN) protocols. We summarize the protocols for enhancing the efficiency by reducing overhead control; mitigate energy consumption and balance the energy .the classification is shown in figure 1

![Figure 1. large scale WSN routing](image-url)
A. Reducing overhead control

1) DECROP: Distributed and Effective Cluster Routing Protocol (DECROP) is simple and efficient technique proposed in [17] in order to decrease the number of control messages, decreasing the end-to-end delay and achieving other requirements for example data aggregation etc. DECROP contains three processes: initialization process, data transmission and maintenance (route maintenance).

In the initialization stage, a cluster is formed jointly to aggregate data chunks from cluster members and to decrease transmission energy to deliver it to the base station (BS). The initialization strives to produce confirmation from each sensor to its neighbors. Initially an initialization message has to be sent by the base station. The node which received the message for the first time moves the transmitter, and updates the Transmitting ID in the broadcasted message with its own ID and resends the message. Then the receiver will deny the following messages. Finally, all the sensor nodes build the forwarding line (path) as following figure 2 shows.

![Figure 2. DECROP mechanism [17].](image)

2) L-OFFIS: In order to expand the network lifetime, Jamalipour et al. [18] produced a 2-layer OFFIS (2L-OFFIS) and used fuzzy inference system (FIS) to optimize the forwarding process. The cluster structure in 2L-OFFIS, inherited from LEACH, but with either inter-cluster or intra-cluster or multi-hop routing while data transmission. A FIS is produced to reflect a collection of metrics such as link usage, power, distance, in deriving the optimal line (path) from the source to the destination. 2L-OFFIS contains 2 parts, which are formation part and data forwarding part. In the first stage, it inherits the feature from LEACH while chunking sensor nodes. The nodes have to choose themselves as the cluster heads (depending on a pre-defined probability) then the sensor nodes pick up a cluster head to join the cluster (depending on the signal strength which received from the cluster head). TDMA “Time division-multiple access” has to be used in each cluster while transmitting sensed data packets in order to power off the transceiver.

The main difference between LEACH and 2L-OFFIS, is that in 2L-OFFIS the more remote nodes will receive earlier slots and the nearer nodes will receive later slots. In the second phase, the sensed data will be first delivered to the corresponding CH and then transmitted to the sink node [18]. While the delivery, either intra or inter cluster OFFIS has to be applied in order to choose the next hop from all of its neighbors. It works as following procedure: the forwarding node captures its neighbors’ location to calculate the distance between those neighbors and that node, also to compute the distance between its neighbors themselves, and the distance between the source and the target (destination) is also computed. As shown in Figure 3, yellow nodes are discarded, while blue nodes are the forwarding path candidate. In this technique, a localization algorithms or GPS are assumed to be available. Thus the routing protocol is more. During transmission the next hop is chosen independently without request flooding from the route in the whole network (no need to change the ID of each sensor node). As, each sensor node just needs to preserve the neighbor information. That means, the energy consumption will be reduced according to these feature and the network lifespan will be expanded.

![Figure 3. Election process in OFFIS [18].](image)

B. Mitigate energy consumption

1) DMSTRP: Is a short of “Dynamic Minimal Spanning-Tree Routing Protocol” which is routing protocol proposed by Huang et al. [19]. This protocol work well with the large scale networks in terms of delay and lifespan by using the term of MST minimal spanning tree. It uses MST's to replace clubs in 2 layers of the network: inter-cluster and intra-cluster. That’s why DMSTRP is a stellar solution in larger network areas, as shown in Figure 4(a) LEACH uses a clubs to connect the network nodes, while in DMSTRP, MST has been used to connect and alleviate the collisions among various transmitting nodes. By using these
structure, multiple network nodes can transmit various messages simultaneously, thus lead to increase the throughput of the network. The transmitting algorithm is as follows: if a branch transmitter can be used to transmit the data if it does not need to receive any data. However, if a number of child-nodes want to send data to the same parent-node at simultaneously, only the first level node can transmit the data to the parent-node, and the others child-nodes have to wait for the next round. If the transmitting and receiving happening simultaneously, receiving has priority.

![LEACH structure by using clubs](image1)

From figure 4, we can see the difference between the LEACH and DMSTRP structure where the queue is \{3, 5\} of the first round transmission, which means the nodes 3 and 5 can send their data at the same time. The transmitting queue is \{1, 4 and 6\}.

![DMSTRP structure by using MST](image2)

2) **JCOCR**: Ge, W.; Zhang, J.; Xue, G. in [20] proposed a new idea by using MANET "mobile ad hoc network" to produce cooperative communication for wireless sensor network in order to energy reduction. In first phase during packet transmission, the coalition head sends data packets to all of the other nodes within its coalition; where coalition head cooperatively send the packet to the next hop destination in the second phase. This process proceeds until the packet reaches the destination. Thus reduce the cooperative cost, but more multicast energy is needed to reach the far destinations. The optimal coalition can be derived during the 1-hop delivery by [20]:

\[
C_{ab} = \min_{k_a} \left[ P_{k_a}^M + P_{k_a}^C \right]
\]

\[
P_{k_a}^M = \max \left\{ P_{a1\_direct}, P_{a2\_direct}, \ldots, P_{ak\_direct} \right\}
\]

\[
\min P_{k_a}^C = P_a + \sum_j k_j P_j
\]

\[
s.t. \ P \leq \ P_{\text{max}}
\]

\[
\frac{1}{N} \left( \sum_{j=1}^{k_j} \sqrt{P_j / d_{ab}^\beta} + \sqrt{P_a / d_{ab}^\beta} \right)^2 \geq \gamma
\]

The original network could be considered as a directed graph and edge-weighted after the size of optimal coalition has been found, as shown Figure 5. The key factor is the number of neighbor nodes, because the node with fewer neighbors could transmit with higher cost.

![JCOCR routing graph](image3)

C. **Energy balance**

1) **MELEACH-L**: is a routing protocol, which has been proposed by Chen et al. in [21], it short for "More Energy-efficient LEACH ". MELEACH-L is more comfortable with the large-scale wireless sensor networks. It control the size of each chunk and partition the CH " cluster head" from the backbone nodes, the problems that produced during the collaboration among CHs during data gathering and the channel assignment among neighbor groups have been solved by using MELEACH-L . The MELEACH-L procedure is divided into steps "rounds". Each one consists of sequential phases: while the CH Selection, the Tree Backbone Construction, the STC "Spanning Tree Construction" and the Data Gathering "Collection". The
time and the order-line of the MELEACH-L procedure is shown in Figure 6.

![Figure 6. MELEACH-L time-line [21].](image)

In MELEACH-L, the network sensor node transceiver is assumed to switch its channel among a set of twenty channels, from 0 to 19 channel range. Channel 0 captures the common channel.

MELEACH detailed procedure is shown in the following steps [21]:

- **CH Selection.** The network sensor nodes set up a timer \(T_i\) and initialize the channel set, where \(C_i = \{1, 2 \ldots 19\}\). Sensor node \(i\) becomes a cluster head and it must send an Advertisement Message (ADVi), which consists of the node ID, serial number of inter and intra-cluster channel which is used in the cluster, and it contains the geographical coordinate, thus happening when \(T_i\) expires. Eventually, if a node \(j\) receive ADVi & the distance between \(j\) and \(i\) is > than \(R/2\), \(j\) has not to join the cluster and the channel I from \(c_j\) has to be deleted else, \(j\) empty \(T_j\) and becomes a non-CH node. * \(R\) is the maximum transmission radius.
- **Backbone Tree Construction.** Based on the EVBT algorithm (Energy-aware Virtual Backbone Tree), the EVBT construction is based on some of non CH nodes. As, the sink node initiates ECR (EVBT Construction Request) at the beginning of the process. The EVBT expands the entire sensor network when it grows from the sink node. Building an energy efficient tree is the main purpose of the EVBT.
- **Spanning Tree Construction.** It comes after the construction of the backbone tree, each cluster head selects the nearest EVBT node and according to the geographical coordinate information it also selects its upstream node.
- **Data Collection.** By using TDMA schedule, each chunk member carries out transmission and collection of messages with specific time frame. In the schedule, the time frame (slot) when a sensor node \(i\) send the aggregated data to its parent node thus will come only after child of \(i\) send data to \(i\). In MELEACH-L, the massively redundant nodes are used to deliver the data, and that can reduce cluster heads energy consumption

2) MuMHR: Hammoudeh et al. in [22] proposed a Multi-path Multi-hop Hierarchical Routing (MuMHR) which is robust and efficient routing protocol. This protocol is superior to LEACH in terms of reliability and load balance. In order to control energy depletion this is result from using the same path for transmission constantly or some nodes being CHs for a long while. Two stages of MuMHR process: set-up (with data transmission during the set-up), election of CHs and the clusters creation. Stochastically, 5% of all the nodes selected as CHs by sink node and send this information by a discovery message. Where each node which received this message has to change its status from “waiting” to “discovered”, and it has to check if it’s elected as cluster head or not. If it isn’t, it should forward the same message to its neighbors.

Otherwise, it sends an advertisement message for forming a new chuck (cluster). The node must ignore any other advertisement message when it has joined the cluster. During the data transmission phase, the non-cluster head nodes send the sensed messages to their cluster heads by TDMA schedule. The cluster heads aggregate the received data, and then send those aggregated packet to the sink.

V. THE ROUTING PROTOCOLS COMPARISON AND ISSUES

Each routing protocol has its own strengths and weaknesses; the protocol design depends mainly on different factors. We summarize results of the discussed routing protocols in large-scale wireless sensor network in Table 1. This table shows in which category the routing protocols and it compare between those protocols by using different metrics. The following metrics have been used to compare the routing protocols:

- **Message Complexity:** It represents the number of the messages that needed for route discovery, plays an important role in the assessment of the of routing protocols scalability
- **Memory requirement:** It depends on whether each node has to save some routing information, for instance the route information, cluster information,
data packets that are waiting to be forwarded, or neighbor information.

- Data aggregation: the main advantage of hierarchical is the former data aggregation in the network that conducted at CH nodes. These nodes work to gather the sensed messages, and remove the redundant part, therefore, reducing the total number of the messages towards the sink nodes. Thus may lead to increase the network efficiency.
- Clustering manner: is the network reactive or proactive cluster? As the proactive cluster means that the network clustering has to be operated before the network operates. On the other hand, reactive clustering triggered on the demand.
- Cluster head election: there are different ways that are used to elect the CH, such as: randomly, source based, energy based, the # of CH required, information quantity, node's degree.
- Multiple path routing: it means the traffic can be delivered to the destination along several paths which is used to balance the consumption of sensors energy along the single path.
- Localization: Position information is used to improve the efficiency and the accuracy of routing protocols, and this information can be generally acquired by GPS.

<table>
<thead>
<tr>
<th>Data Aggregation</th>
<th>Clustering manner</th>
<th>Cluster head election</th>
<th>Multiple Path routing</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECROP</td>
<td>Yes</td>
<td>Proactive</td>
<td>No</td>
</tr>
<tr>
<td>2L-OFFIS</td>
<td>Yes</td>
<td>Proactive</td>
<td>Randomly</td>
</tr>
<tr>
<td>DMSTRP</td>
<td>Yes</td>
<td>Proactive</td>
<td>Randomly</td>
</tr>
<tr>
<td>JCOCR</td>
<td>No</td>
<td>Reactive</td>
<td></td>
</tr>
<tr>
<td>MELEACH-L</td>
<td>Yes</td>
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<td>Yes</td>
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<td>Randomly</td>
</tr>
</tbody>
</table>

n = number of network nodes; g = number of the clusters; m = number of the edges.

According to section 4 routing protocols for large-scale wireless sensor network, the route discovery, and topology update, and route maintenance. This flooding causes message collisions, which reduce network efficiency in large scale WSNs. However, the flooding has numerous advantages over the location-based in economic cost and complexity without additional equipment. Hence, research on flooding technique is so important and necessary.

VI. CONCLUSION

At large-scale WSNs routing is a hot research topic, with a limited but faster growing set of efforts being created and published. In this research, we have produced a survey of the different large-scale WSNs routing protocols. The routing protocols has been classified as reducing overhead control, mitigate energy consumption and energy balance. We presented an effective comparison between the discussed routing protocols in terms of message memory requirement, multi-path routing, localization, clustering manner, and data aggregation, CH selection and complexity. By using those metrics, the protocols strengths and weaknesses has been shown. Some issues remains to be considered regardless of improving scalability and increasing the performances of large-scale wireless sensor networks. As the number of sensors node increased in the large scale wireless sensor network, the intensity of the network is increased. Hence, more redundant and duplicated information is created which leads to more serious congestion in the network.

On the other hand, in some unstable and harsh environments, some degree of redundancy may be desirable in order to increase the network reliability and availability. There is a trade-off between the redundancy utilization and the redundancy reduction. Furthermore, delays in data transmission are an unavoidable and unacceptable problem when time-sensitive and strict tasks such as fire alarms are deployed to an entire network. In this situation, the routing protocol has to be produced in advance and constantly maintained. Furthermore, the communication links in a
large-scale wireless sensor network become longer with denser deployment of the network nodes. More researches should consider other performance criteria of network such as node mobility and the quality of service (QoS). Nonetheless, increasing wireless sensor node functionalities, more complicated tasks involved with more network overhead and energy consumption, so how to increase the network scalability and energy efficiency remains a challenging research area.

REFERENCES