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ABSTRACT
Routing in WSN is very challenging task due to lack of resources. For efficient communication and increase in lifetime of WSN there is a great need of optimal path selection. Data forwarding in optimal routes saves a lot of transmission energy of sensor nodes. This will result in increment in lifetime of the network. Many routing protocols have been proposed by researchers in recent years to save the energy and other resources like memory for WSN. Routing protocols mostly depend on applications and architecture of WSN. This paper presents the classification and analysis of routing protocols for WSN and concludes with open research issues in routing strategies in WSN.

Keywords
Routing, Routing protocol, Sensor, WSN, Opportunistic Routing, Communication.

1. INTRODUCTION
Wireless sensor networks can be seen as networks having small size sensor nodes which are able to collect the information from the surroundings (figure 1). The data collected by each sensor in the network is sent towards base station (sink, high power node) for further processing. Wireless sensor networks can operate in both single-hop and multi-hop communication operation. In a single-hop operation the data can be easily transmitted because sensor nodes directly communicate data to base station. But, in case of multi-hop communication the data packets must be transmitted to the neighbors. Hence the intermediate nodes between source and destination (base station) will have to work as relay nodes.

The operations of routing protocols are highly dependent on the applications of WSN. According to general application requirements the routing protocols for WSN must provide a high probability of data delivery. Also the protocol should be reliable and robust. Routing protocols should consider almost every characteristic of WSN.

The sensor nodes in WSN can be deployed in any traditional topology for the purpose of efficient and reliable communication. The sensor nodes in a wireless sensor network are deployed randomly and this random deployment of sensor nodes have taken traditional network topologies in new directions. Sensor applications in today's world require the networking protocols which can reduce the complexity of the networking and also reduce the cost of routing, but it should increase the reliability of the network. Some of the common topologies for WSN are single-hop star, Multi-hop mesh and grid, and Two-tier Hierarchical Cluster.

The routing protocols can operate in different topologies of the networks. Hence depending on the application the routing protocols should be simple, energy aware, adaptive and scalable. Also a good routing protocol should require a minimum processing and communication energy and less storage space.

Hence, the design and development of routing protocols come across the following challenges: Node deployment, Network variations, Energy conservation, Fault tolerance, Scalability, Node capabilities, Data delivery model and Data aggregation or fusion.

The organization of paper is as follows. In Section 2, classification of routing protocols for WSN will be presented. This section also summarizes all types of routing protocols available under different classifications like Data centric, hierarchical, location based, Network flow and QoS, and opportunistic routing. Section 3 give a brief review of the previous survey papers and also differentiate our work. Section 4 presents a comparative analysis of routing protocols and concludes the paper with comparison tables of the studied routing algorithms and points out the good approach for routing in WSN.

2. CLASSIFICATION OF ROUTING PROTOCOLS
Routing Protocols has been classified by many authors in different ways. Figure 2 shows the classification which is based on the network structure or organization, the process of route discovery, and the operation of routing protocol. The protocols are classified on the basis of different routing protocols studied in literature. Here, opportunistic routing is the new classification and in trend nowadays. A comparative analysis will be presented after discussing various types of classifications.
2.1 Network Organization

Network Organization classifies the routing protocols for WSN into three classes. 1) Flat-based routing protocols assume that all sensor nodes are having equal functionality or role. 2) Hierarchical-based routing protocols assume that different sensor nodes may perform different tasks in the routing process, that is, some nodes may act as only forwarders of data received from other nodes, while other sensor nodes generate and propagate the sensed data on their own and 3) In Location-based routing protocols the routing decisions rely on the location information from sensor nodes.

2.1.1 Data Centric Routing

The data centric routing algorithms focus on data retrieval, data aggregation and the data fusion of a particular type of data type described by some attributes, as opposed to collecting the data from particular type of sensors. The protocols which follow the data centric approach are: Sensor Protocols for Information via Negotiation (SPIN) [17], Directed Diffusion [18] [19], Energy-aware Routing [20], Rumor Routing [21], Gradient-based routing [22]. Constrained Anisotropic Data Routing protocol (CADR) [23], COUGAR [24], ACtiveQUery forwarding InsensoRnEtworks (ACQUIRE) [25] and Reliable Reactive Routing Enhancement for WSN (R3E) [53].

2.1.2 Hierarchical Routing Protocols

Hierarchical routing protocols have been designed for managing energy efficiently by using multi-hop communication. The multi-hop communication can save a lot of energy by involving all the sensor nodes in the network. Some protocols in this category also form clusters providing cluster head which can perform data processing task also. Some of the hierarchical routing approaches are: Low-energy adaptive clustering hierarchy (LEACH) [12], Multi-hop LEACH [62], LEACH-C (Centralized LEACH) [63], LEACH-F (Fixed number of clusters LEACH) [64], LEACH-E (Energy Efficient LEACH) [64], LEACH-B (Balanced LEACH) [64], LEACH-A (Advanced LEACH) [65], Q-LEACH (Quadrature LEACH) [66], LEACH-SM (LEACH with Spare Management) [67], Power Efficient GAthering in sensor Information Systems (PEGASIS) and Hierarchical-PEGASIS [26]. Threshold sensitive Energy Efficient sensor Network protocol (TEEN) and Adaptive TEEN (APTEEN) [14], Energy-aware routing for cluster-based sensor networks [13] and Self-organizing protocol (SOP) [9].

2.1.3 Location Based Routing Protocols

In some of the applications the location information is needed by the routing protocol. This location is the geographic position of the sensor node. The principle of routing protocols in such applications is to send a query towards a particular region only, from where the base station needs data. Examples of Location based protocols are: Minimum energy communication network (MECN) and Small MECN [29], Geographic adaptive fidelity (GAF) [28], Geographic and energy-aware routing (GEAR) [30].

2.2 Route Discovery process

The responsibility of the routing protocols is to identify or discover the routes from a source or sender to specified receiver. The route discovery process may be different for different routing protocols, and hence used to differentiate between routing protocols. First are the reactive protocols which establish the routes only when a source node tries to send data towards a receiver. In other words it is called as on-demand route discovery. Hence, the working of these protocols causes delays in transmission. On the other hand the second type of protocols that is, proactive routing protocols finds and store the routes before they needed. These types of routing protocols are table-driven, because the routing information is stored in the routing table, which is local to each sensor. The routing table on each sensor node contains a list of destinations addresses in combination with one or more next-hop neighbor sensor nodes that further lead towards the destinations. The proactive routing protocols solve the problem of route discovery delays but they may introduce overhead by storing such routes which may never be used in the routing process ever.

2.3 Protocol operation based routing protocols

The operations of routing protocols are also different. Hence one can classify the routing protocols based on their operation, like, some routing protocols reduce redundant data transmissions by exchanging messages between neighboring sensor nodes before actual data transfers occur. Some other protocols use multiple paths simultaneously for better fault tolerance and better performance. There are some other routing protocols which are receiver-initiated, that is, the destination node (base station) when in the need of some data it throws a query towards the sensor nodes and the sensor nodes in response provide the data.

There are QoS-based routing protocols also in which certain parameters need to be satisfied which are QoS metrics, like low latency, low energy consumption, or low packet loss etc. Finally some protocols are also differing in the way they support in-network data processing. Like the Coherent-based protocols supports only a minimum amount of data processing before sending the data. On the other hand, the non-coherent-based protocols allow the sensor nodes to perform significant local processing of the raw data before it to other nodes for further processing. The network flow and QoS protocols studied in literature are: Maximum Lifetime Routing in Wireless Sensor Networks [36], Sequential assignment routing (SAR) [2], Energy-aware QoS routing protocol [31], SPEED [32] and Dynamic Routing for Data Integrity and Delay Differentiated services in WSN (IDDR) [54].

2.4 Opportunistic Routing

Opportunistic Routing differ from traditional routing protocols in the sense that it selects the route at transmission time only. These types of algorithms utilize the broadcast nature of the wireless networks that is, instead of selecting a predetermined path for transmission, Opportunistic routing broadcasts a data packet to a set of neighboring nodes. Then, neighbor nodes, which are receiving the data packet, successfully, run a coordination algorithm to select the best relay node to forward the data packet. In other words, the opportunistic routing protocols work in following three steps:

a. Broadcast a data packet to neighbor nodes
b. Select the best neighbor as relay node by using a coordination algorithm

c. Forward the data packet from that relay node towards destination

Opportunistic Routing algorithms can transmit data packet through any possible route rather than a fixed path. It reduces the failure in transmission as well as the transmission delays. A simulation in [8] has also proven that Opportunistic Routing protocols outperform the conventional routing protocols when loss rates of routes are high. Hence it increases the reliability of the network.

Opportunistic Routing increases the transmission range by considering all possible routes, which include good quality routes (short-range) and poor quality routes (long-range), within a single transmission; hence, a data packet may directly jump to the farthest relay node which receives the data packet successfully. As a result, the performance improved. The theoretical analysis was presented in [1, 2]. The experimental analysis was presented in [3, 4, 5]. These analyses have shown that opportunistic routing has the ability to increase the performance of the network by using the log-range transmissions also. The following opportunistic routing protocols have been studied in literature: Energy Efficient Opportunistic Routing (EEOR) [39], Ex-OR: Opportunistic Multi-hop Routing for Wireless Networks [8], Opportunistic Real Time Routing (ORTR) [55], Opportunistic Routing for WSN (ORW) [40], EFFORT (On enhancing Network lifetime using opportunistic routing in WSN) [41], Opportunistic Distance Enabled Unicast Routing (ODEUR) [56], On End-to-end throughput of Opportunistic routing in Multi rate and multi hop Wireless networks [33], Fair Opportunistic Routing with Linear (FORLC) [34], EAOR: Energy Aware Opportunistic Routing [44], Efficient QoS-aware Geographic Opportunistic Routing (EQGOR) [58], Stop-On-First Acknowledgement (SOFA) [57], Multi-hop Optimal Position based Opportunistic Routing (MOOR) [59] and Energy Efficient Opportunistic Routing Protocol (EOMR) [60].

3. RELATED WORK

The increasing set of applications of WSN and also the new architectures proposed by researchers brought attention of researchers to survey the characteristics of WSN and communication protocols available for WSNs [1][11][6]. In this section we highlight some of the previous work in this area and differences between our survey and others are also discussed.

The survey paper [1] presented a brief review of the design issues and techniques for wireless sensor networks. The paper explained the resource constraints on sensor nodes in the network and the different protocols proposed in network stack’s layers. The paper also gives various applications of the wireless sensor networks. This survey paper contains a lot of introductory material for the beginners in wireless sensor network area. The paper had presented routing protocols in context of network layer protocols. The paper does not make a classification of routing protocols. Also the paper is more concerned about the introduction to WSN and its architecture. Our survey paper presents a classification and comparative analysis of routing protocols for WSN. The paper will give a deeper look at the characteristics of routing protocols in WSN.

The research paper [11] presents architectural attributes for WSN. The paper gives a detailed study of WSN architectures and its components. A classification of sensor networks has also been presented by considering the architectural factors like network dynamics and the data delivery models. The paper is very helpful for the researchers who are the designers of WSN architectures for given applications. The paper do not describe and classify the routing protocols. Our survey is more focused on network layer and routing protocols. it will give a brief review of different routing classifications.

The survey paper [6] gives a detailed study of network layer protocols and has presented a classification of routing protocols for WSN. The paper discusses the classification on the bases of network organization mainly. The paper also gives the open research issues in network layer for WSN. Although, the authors have tried to categorize all the protocols, but it do not gives the new categories of routing protocols like opportunistic routing. Since, the WSN are the opportunistic type of networks, opportunistic routing can be a big factor of performance increment in WSN. Our paper gives all the categories for routing protocols available till date for WSN. Also the paper finishes with open research issues in routing protocols.

4. COMPARATIVE ANALYSIS AND CONCLUSION

Routing in WSN is very crucial task and has attracted attention of researchers in the recent years. In WSN routing challenges are different to that of traditional networks. This paper presented classifications of routing protocols for WSN. Table 1 shows the categorization and characteristics of routing protocols in WSN.

The protocols which are mostly dependent on the network structure of WSN have been categorized as under network organization protocols. This category is further divided into three sub-categories. Firstly, the protocols which are based on the name of data and query are classified as data centric routing protocols. The protocols under this sub-category have very less computational overhead, but as the protocols are query and continuous data flow driven the communication cost (cost of transmission of data) is very high. The protocols do not optimize the route setup. Among all the protocols rumor routing and CADR are very good in reducing the overhead of communication. ACCQUIRE and R3E also perform well in low density WSN.

Second subcategory under network organization is the cluster based routing protocols, also called as hierarchical routing protocols. The protocols under this category are based on the grouping of sensor nodes in the network. The sensor nodes in the network relay the data towards the base station through cluster heads. The overhead in these types of protocols is the cluster formation and the cluster head selection. Cluster heads are the nodes which are less energy constrained. Cluster heads performs data aggregation of received sensed data and sends it towards the base station. The most interesting research issue in such protocols is the process of formation of clusters and the selection of cluster heads among different sensor nodes. The cluster formation should be in such a way so that it will increase the energy efficiency and reliability of the routing protocol. The process of data aggregation and fusion is also is also a very interesting issue in this category. The cluster based protocols proposed by researcher till date do not optimize the cluster head selection and do not provide the Quality-of-service.

The third subcategory protocols under network organization make use of location of sensor nodes and are categorized under location based routing protocols. The protocols in this category make use of sensor node location to find out the
optimal routes. But these protocols are not energy efficient, mainly in mobile sensor networks. The energy aware approaches based on location of sensor nodes are used only for small networks, like the WSN which contain 50 to 100 sensors only. The open research issue in this area is how efficiently and cleverly the protocols utilize the location information about sensor nodes.

The protocols under network flow and QoS based routing tried to provide a quality of service in data delivery in WSN. Although all the previous category protocols try to reduce the communication cost of the network, but does not guarantee the reliable delivery of data. Quality-of-service is highly needed in case of video and imaging sensor networks in real time applications. In current literature a few protocols are proposed which try to provide the QoS in energy constrained WSN. Also the protocols in this category can be applied only in the applications of small WSN.

The other category discussed in this paper is opportunistic routing. The WSN are opportunistic type of networks. Hence, the use of opportunistic routing in WSN is a very good idea. In this paper we have presented the fourth classification of routing protocols as opportunistic routing protocols. Opportunistic routing is the recent research area in WSN and has attracted many researchers. There are some protocols presented in the table below which are recently proposed for WSN. Most of the opportunistic routing protocols provide energy efficiency, scalability and reliability. But quality of service is still a big research issue in this category. Also the opportunistic routing has not been yet applied to real life applications of WSN.

From the comparative analysis table it can be seen that the opportunistic routing protocols have very good performance. Also, if we have to work with thousands of sensor nodes in WSN, than we have to develop such routing protocols that can cope with the challenges in such large networks. From the literature we can see that most of the routing protocols work only with static WSN, but there is a requirement of mobile sensor networks in today’s scenario of applications. Hence, there is a need of routing protocols which can be operational in both static and mobile WSN. From the working of opportunistic based routing protocols it can be concluded that opportunistic routing is capable to cope with both static and mobile WSN.

Another future research issues in routing protocols is the integration of wireless and wired networks. Since the routing requirements of applications of WSN are different, so the research is necessary for handling each application with best route selection.

Table 1 summarize the properties and classification of the routing protocols discussed in the previous sections. The table also incorporates the theoretical comparison based on the study of various routing protocols.

<table>
<thead>
<tr>
<th>Routing Protocol</th>
<th>Classification</th>
<th>Power Usage</th>
<th>Data Aggregation</th>
<th>Scalability</th>
<th>Query based</th>
<th>Over head</th>
<th>Data delivery model</th>
<th>QoS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding and Gossiping</td>
<td>Data Centric</td>
<td>High</td>
<td>Nil</td>
<td>Ltd.</td>
<td>No</td>
<td>Low</td>
<td>Continuous</td>
<td>No</td>
</tr>
<tr>
<td>SPIN</td>
<td>Data-centric</td>
<td>Ltd.</td>
<td>Yes</td>
<td>Ltd</td>
<td>Yes</td>
<td>Low</td>
<td>Event driven</td>
<td>No</td>
</tr>
<tr>
<td>DD</td>
<td>Data-centric</td>
<td>Ltd</td>
<td>Yes</td>
<td>Ltd</td>
<td>Yes</td>
<td>Low</td>
<td>Demand driven</td>
<td>No</td>
</tr>
<tr>
<td>EAR</td>
<td>Data-centric</td>
<td>Low</td>
<td>Nil</td>
<td>Ltd</td>
<td>No</td>
<td>High</td>
<td>Event Driven</td>
<td>No</td>
</tr>
<tr>
<td>RR</td>
<td>Data-centric</td>
<td>Low</td>
<td>Yes</td>
<td>Good</td>
<td>Yes</td>
<td>Low</td>
<td>Demand driven</td>
<td>No</td>
</tr>
<tr>
<td>CDR</td>
<td>Data-centric</td>
<td>Ltd</td>
<td>Yes</td>
<td>Ltd</td>
<td>Yes</td>
<td>Low</td>
<td>Continuous</td>
<td>No</td>
</tr>
<tr>
<td>COUGAR</td>
<td>Data-centric</td>
<td>Ltd</td>
<td>Yes</td>
<td>Ltd</td>
<td>Yes</td>
<td>High</td>
<td>Query driven</td>
<td>No</td>
</tr>
<tr>
<td>ACQUIRE</td>
<td>Data-centric</td>
<td>Low</td>
<td>Yes</td>
<td>Ltd</td>
<td>Yes</td>
<td>Low</td>
<td>Complex query</td>
<td>No</td>
</tr>
<tr>
<td>R3E</td>
<td>Data Centric</td>
<td>Low</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Low</td>
<td>Continuous</td>
<td>No</td>
</tr>
<tr>
<td>LEACH</td>
<td>Hierarchical</td>
<td>High</td>
<td>Yes</td>
<td>Good</td>
<td>No</td>
<td>High</td>
<td>Cluster-head</td>
<td>No</td>
</tr>
<tr>
<td>PEGASIS</td>
<td>Hierarchical</td>
<td>Ltd</td>
<td>No</td>
<td>Good</td>
<td>No</td>
<td>Low</td>
<td>Chains based</td>
<td>No</td>
</tr>
<tr>
<td>TEEN &amp; APTEEN</td>
<td>Hierarchical</td>
<td>High</td>
<td>Yes</td>
<td>Good</td>
<td>No</td>
<td>High</td>
<td>Active threshold</td>
<td>No</td>
</tr>
<tr>
<td>Younis et al.</td>
<td>Hierarchical</td>
<td>Ltd</td>
<td>No</td>
<td>Ltd</td>
<td>Yes</td>
<td>Low</td>
<td>Cluster Based</td>
<td>No</td>
</tr>
<tr>
<td>SOP</td>
<td>Hierarchical</td>
<td>Low</td>
<td>No</td>
<td>Good</td>
<td>No</td>
<td>High</td>
<td>Continuous</td>
<td>No</td>
</tr>
<tr>
<td>MECN and SMECN</td>
<td>Location Based</td>
<td>Low</td>
<td>No</td>
<td>Good</td>
<td>Yes</td>
<td>High</td>
<td>Query Driven</td>
<td>No</td>
</tr>
<tr>
<td>GAF</td>
<td>Location</td>
<td>Ltd</td>
<td>No</td>
<td>Good</td>
<td>No</td>
<td>Mod</td>
<td>Virtual grid</td>
<td>No</td>
</tr>
<tr>
<td>GEAR</td>
<td>Location</td>
<td>Ltd</td>
<td>No</td>
<td>Ltd</td>
<td>No</td>
<td>Mod</td>
<td>Demand driven</td>
<td>No</td>
</tr>
<tr>
<td>Chang and Tassiulas</td>
<td>Network Flow and QoS Aware</td>
<td>Low</td>
<td>No</td>
<td>Ltd</td>
<td>No</td>
<td>Mod</td>
<td>Continuous</td>
<td>No</td>
</tr>
<tr>
<td>Kalpakiset al.</td>
<td>Network Flow and QoS Aware</td>
<td>Low</td>
<td>Yes</td>
<td>Ltd</td>
<td>Yes</td>
<td>Mod</td>
<td>Continuous</td>
<td>No</td>
</tr>
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</table>
Table 2. Routing Protocols in various Applications

<table>
<thead>
<tr>
<th>Application Type</th>
<th>Project</th>
<th>Node Deployment</th>
<th>Topology</th>
<th>Size</th>
<th>Routing Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat monitoring</td>
<td>Great Duck[45]</td>
<td>Manual one time</td>
<td>Cluster Head</td>
<td>10-100</td>
<td>SPAN, GAF</td>
</tr>
<tr>
<td>Environment monitoring</td>
<td>PODS Hawaii[46]</td>
<td>Manual one time</td>
<td>Multi-hop Multi-path</td>
<td>30-50</td>
<td>DD</td>
</tr>
<tr>
<td>Health</td>
<td>Artificial Retina[48]</td>
<td>Manual one time</td>
<td>Cluster Head</td>
<td>100</td>
<td>LEACH</td>
</tr>
<tr>
<td>Military</td>
<td>Object Tracking[50]</td>
<td>Random</td>
<td>Multi-hop</td>
<td>200</td>
<td>GAF</td>
</tr>
<tr>
<td>Production/ Commercial</td>
<td>Cold Chain[52]</td>
<td>Manual Iterative</td>
<td>Three Tiered</td>
<td>55</td>
<td>SAR</td>
</tr>
</tbody>
</table>

5. REFERENCES


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