Taxonomy of Routing Protocols in Wireless Sensor Networks: A Survey

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***Abstract*— Recent advancements in wireless technology has led to tremendous growth in deployment of Wireless Sensor Networks (WSNs). WSNs are comprised of sensors and actuators nodes, densely deployed over some geographic location to sense, collect, process and send data wirelessly to central data collector. The communication among different wireless sensor nodes is administered by routing protocols; hence the performance of WSN highly depends on adopted routing technique. Many such energy efficient and quality routing protocols have been designed over the years in order to increase the performance of communication in WSNs. In this paper, an exhaustive review and taxonomy of routing protocols is discussed on the basis of network structures and data transmission techniques. This study will help WSN system designers to select appropriate routing protocol for particular application.**

Keywords- Wireless Sensor Network; Taxonomy of Routing Protocols; Flat Protocols; Hierarchical Protocols; Location Based Protocols.

I. INTRODUCTION

Recent technological advances in the area of wireless communications and micro-electro-mechanical systems have made it feasible to develop small sized and low cost sensors [1]. These Wireless sensor (WS) are small in size and performs important functions like data processing, sensing and communication [2, 3]. Based on their functionality, WS nodes are broadly categorized as:

- Sensor nodes
- Sink nodes

Sensor nodes are used for sensing the environment and may also transmit the data to other nodes. Sink node also known as base station (BS) receives data from sensor nodes and perform data aggregation. Main components of a WS node are micro sensor, microprocessor, battery, transceiver and memory [2]. A large number of WS nodes networked together for data gathering and processing has led to the idea of wireless sensor network (WSN) [1]. Figure 1 shows a simplified diagram of components of WS and Figure 2 shows general WSN architecture.

The concept of WSNs was initially motivated by military applications, but nowadays it is being implemented in various civilian applications like intrusion detection, security, weather monitoring, inventory control, disaster management, etc. [5, 6].

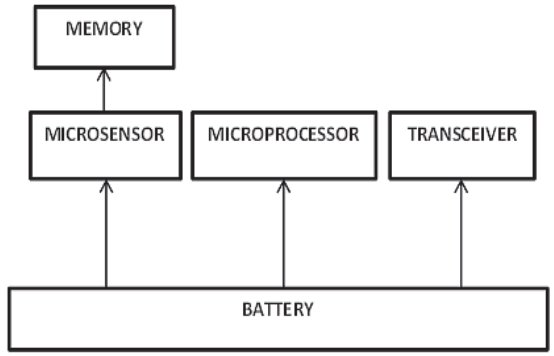

Fig. 1: Components of WS Node [4]

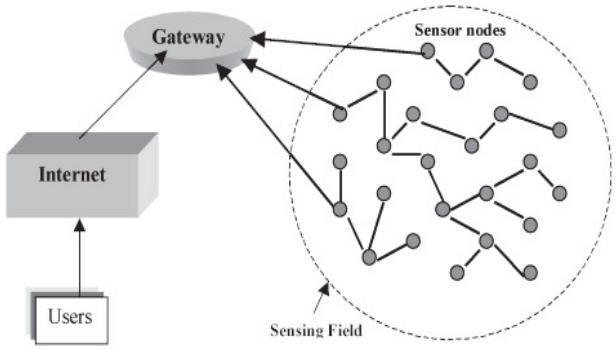

Fig. 2: Architecture of WSN [5]

For the realization of WSN based applications, many routing techniques have been proposed over the years like Low Energy Adaptive Clustering Hierarchy routing protocol (LEACH), Power Efficient Gathering in Sensor Information Systems (PEGASIS), Sensor Protocol for Information via Negotiation (SPIN), Hybrid Energy Efficient Distributed routing (HEED), Geographic Adaptive Fidelity routing protocol (GAF), etc.. Since, WS have limited power supply, energy efficient routing remains the major research issue in the proposed routing techniques. On the basis of structure of the network, WSNs routing protocols are broadly categorized into three classes: flat routing, hierarchical routing and

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location based routing protocols [5].There exist several review papers that presents the comparison of various routing protocols of WSNs from different perspectives [4-11]. But so far no work has been done to provide the full taxonomy of these protocols. In this paper, full taxonomy of the network based routing protocols is presented and their comprehensive review has been carried out.

The rest of the paper is structured as: design challenges of routing protocols in WSN are discussed in Section 2, Taxonomy and brief review of protocols with their advantages and disadvantages are discussed in section 3. In Section 4, the performance of the protocols is analyzed on the basis of performance metrics and section 5 concludes the paper.

II. Design Challenges of WSN

Despite being useful for numerous applications, WSNs suffer from several limitations like limited computing power, limited bandwidth and limited energy supply. The main aim of designing a routing protocol for WSN is to prolong the lifespan of WSN by keeping the WS nodes alive for as long as possible [12]. The design of WSN routing protocols is influenced by some challenging factors which must be dealt with for efficient communication. Some of the challenges and issues, affecting the routing in WSN are summarized below:

A. Deployment of nodes

Node deployment is application-dependent and can be implemented in two ways; manual deployment or randomized deployment. WS nodes are placed manually in manual deployment and paths are predefined for transmission of data, whereas, in random deployment, WS nodes are randomly scattered to create an ad hoc network infrastructure [13]. Manual deployment is usually done in small networks or when sensor nodes are few in number [13]. Random deployment is subjected to use in those environments where WS nodes need to move automatically to proper locations using optimization algorithms such as Virtual force algorithm, simulated annealing algorithm, genetic algorithm and particle swarm optimization algorithm.

B. Conservation of energy

The main aim of the routing protocols is to transmit data among WS nodes and to sink node efficiently. WS nodes consume energy while performing computations and data transmission. Energy must be conserved for the longer lifetime of the WS nodes and network. Energy conservation schemes are divided into data driven, duty cycling and mobility based approaches [14]. Data driven approaches are mainly concerned with WS nodes by restricting them to sense only necessary data. In duty cycling approaches, energy spent by transceiver is reduced using sleep/wake-up scheduling algorithms. To reduce energy consumed in movement of WS nodes, mobility based approaches for energy conservation are applied.

C. Fault tolerance

Lack of power, physical damages or environmental interference may result in a failure of WS nodes. Working of the WSN should not be affected by failure of one or more WS nodes [15]. Fault tolerance ensures the system that operations of WSN are not affected in presence of faults. Multipath routing is the most used technique to provide fault tolerance. It increases the system reliability, availability of services and dependability of the system.

D. Scalability

The number of WS nodes deployed may vary from order of hundreds to thousands. Scalability of the network means that the network is acceptable to any change in the increase in number of nodes or in size of the network [16]. So routing schemes must be able to handle the data transmission among large number of WS nodes effectively as well as routing protocols must respond to events effectively irrespective of the size of WSN.

E. Quality of service

In some applications, data become useless if not delivered in certain time period and in others; energy conservation is of more concern than quality of data. So, routing protocol must provide certain level of Quality of Service (QoS) as required by the application [17]. QoS is divided in two categories; application specific and traditional end to end. Application specific QoS is concerned with aggregation delay, fault tolerance, data accuracy, coverage and network lifetime etc., whereas in end to end approach, QoS is defined by certain parameters like packet loss, jitter, delay, bandwidth etc..

F. Topology maintenance

In WSN, WS nodes are deployed in number hundreds or thousands in the sensor field. Generally, the density of deploying the sensors is 10nodes/m^3. To handle such a large number of nodes and deploying those in an efficient manner require the topology maintenance [18]. WSN is required to work in harsh environments irrespective of changes in the topology of network. Another challenge is to maintain the connectivity of network during lifetime of WSN. Many solutions have been proposed for above stated challenges such as sparse topology and energy management (STEM), cluster based energy conservation (CEC), etc.

So to meet the wide diversity of WSN applications, these design challenges need to be followed but it is very difficult to deal with all design goals simultaneously. However, most applications have different priorities and requirements, therefore, designers can set the trade-offs among design goals to balance the performance of WSN.

III. Classification of Routing Protocols in WSN

In general, Routing Protocols in WSNs are broadly classified into three main categories on the basis of structure of network as shown in Fig. 3: Flat based routing protocols, hierarchical based routing protocols and location based routing protocols. Flat routing protocols assign equal functionality and roles to all the WS nodes. In hierarchical based routing, different roles and functionalities are assigned to different nodes whereas location of the WS nodes is used in location based routing for data transmission [4].

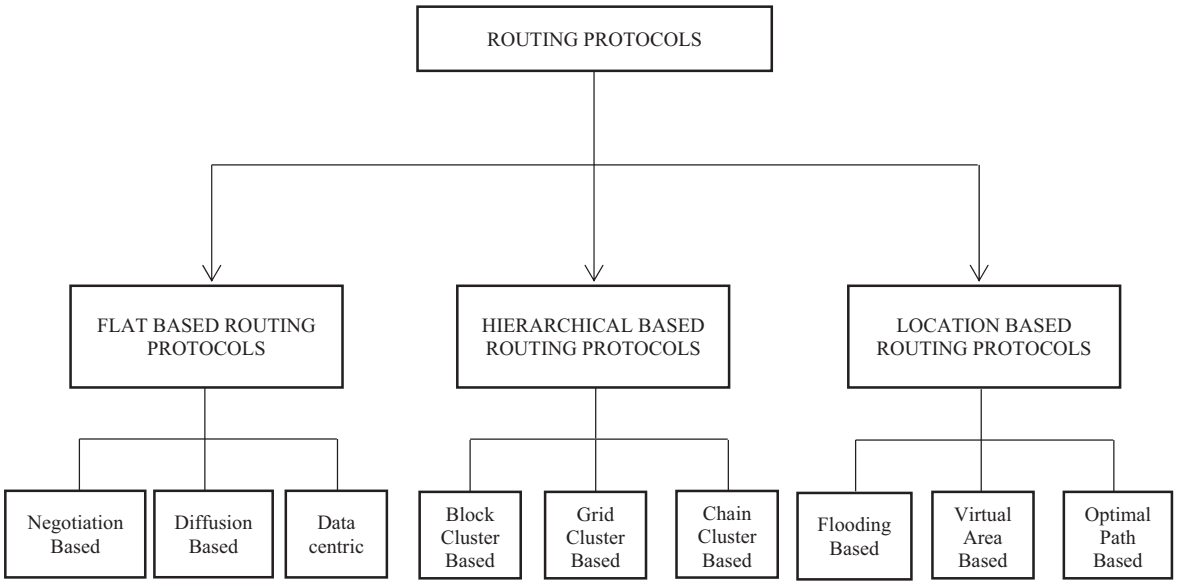

Fig. 3: Taxonomy of Routing Protocols

A. Flat Routing Protocols

In flat routing protocols (FRP) each node has same functionality and sensing task is performed by collaboration of the large number of WS nodes. Assignment of a global identifier to such a huge number of WS nodes is not achievable. This consideration has led to a routing concept, where data is requested through queries from certain regions by the Sink. FRP are broadly classified into three categories on the basis of data transmission method they follow: negotiation based, diffusion based and data centric based routing protocols.

1) Negotiation based routing protocols: These protocols follow the principle of data negotiation to avoid the unnecessary redundancy in data and to save energy. Earlier, there existed only two classical mechanisms for the transmission of data in WSN's: Flooding and Gossiping.

- Flooding and gossiping are simplest algorithms to transmit data among WS nodes without routing technique or topology maintenance. In Flooding [19], each node broadcasts data to neighbor nodes until the data reaches to destination node or data packet reaches its maximum number of hops. Whereas, Gossiping [20] is slightly different or advanced version of flooding in which data packet is broadcasted to randomly selected neighbors. Although, flooding and gossiping algorithms are easily implemented, they have their own drawbacks like implosion and overlap. These drawbacks results in wastage of large amount of energy due to resource blindness [20].
- Later, a family of adaptive protocols known as sensor protocol for information via negotiation (SPIN) was introduced by Heinzelman et al. [21]. In SPIN, before the transmission of data, high level data descriptors called metadata are exchanged among WS nodes to avoid the data redundancy. Each WS node, on receiving new data informs the neighbour nodes through an advertisement mechanism. The neighbouring nodes can send request message to retrieve the data. SPIN overcomes drawbacks of flooding like implosion and overlap, along with a great increase in the energy efficiency. The following three messages are used by SPIN protocols for data transmission as shown in Fig. 4: ADV- This message is sent by a node to inform other WS nodes about the data collected by it. REQ- The nodes in need of advertised data can receive it by sending REQ message. DATA- Then the data is transmitted to interested nodes with a meta-data header using DATA message.

SPIN protocol has the advantage of providing abstraction to the topological changes, as each node needs only to know its immediate neighbours. But delivery of data to the distant nodes is not guaranteed. Consider if distant located node wants some data but the neighbour nodes are not interested, then data cannot be delivered to the distant located node.

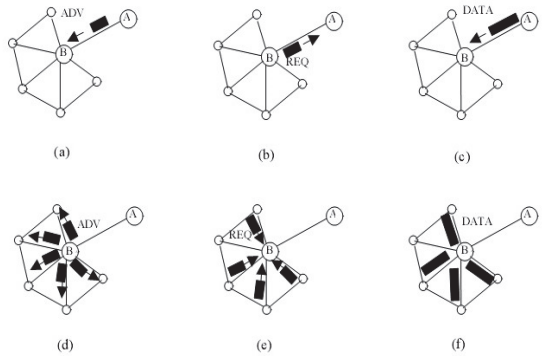

Fig. 4: SPIN protocol operations [23]

2) Diffusion based routing protocols: The diffusion based routing protocols uses the idea of naming scheme for data packets. The use of naming scheme results in energy conservation by reducing unnecessary routing operations at network layer. There exist number of protocols based on diffusion based routing scheme which are discussed below:

- Directed diffusion: Directed Diffusion (DD) uses the pairs of attribute-value for the data packets and queries are done on demand basis. Queries are created to define the interest which is broadcasted through its neighbours by a sink to source node. Each node which receives the interest can save it (caching) for later use. Data which is received by source node is compared with the stored cached to confirm its integrity. Gradient field is also included in the interest which is a reply link to sink node. Paths are established between sink and source nodes by using interests and gradients, from which one path is selected for data transmission [22]. DD is different from SPIN in terms of demand basis data querying mechanism it apply.
- Energy aware routing: In order to prolong the lifetime of a WSN, Shah and Rabaey [23] proposed an energy aware routing (EAR) protocol which applies a set of sub-optimal paths for communication. EAR protocol is based on the concept that using a single minimum energy path for transmission will result in complete usage of the energy of WS nodes of that path. Thus using multiple minimum energy paths can prolong the lifetime of network. In EAR protocol data is transmitted in following three phases: In Setup phase, Localized flooding is used to initialize a connection, which is used to create the routing tables by finding all routes and their respective cost. In Data communication phase, packets are forwarded by choosing target node randomly from routing table. Route maintenance phase keep all the paths alive by flooding a network from time to time. EAR is an extension to DD as multiple paths are chosen one by one for data transmission as compared to only one dedicated path chosen by DD. In comparison to DD, 21.5% more energy is saved and network lifetime is increased by 44% in EAR.
- Rumor routing: Rumor routing (RR) is diffusion based protocol applicable in those cases in which small amount of data is requested [24]. In RR, events are flooded when events are small in number and queries are large. RR is based on the idea that queries are only routed to those WS nodes which have sensed an event and not to flood the whole network. Event table and agents are used in RR for transmission of data. Event table is used to store the new events and agent is a long lived packet created in order to flood events throughout the network. When an event occurs, the respective node updates its event table and creates the corresponding agent. Agents propagate the information about the event throughout the network. So, when an event is queried by any node, the nodes knowing the route uses their event table to respond to the query. In this way the cost of flooding the whole network is minimized in comparison to DD. Also, it is more energy efficient and can handle nodes failure; however, RR is only useful when the number of events is few.

3) Data centric protocols: In data centric routing, data from all sources is transmitted to the sink by performing some aggregation operation. Data aggregation means that information is added from node to node until it reaches the sink. Some of the data centric protocols are discussed below:

- COUGAR: It is a data centric protocol proposed by Yao et al. [25] that classifies the sensor network as distributed database system. COUGAR routing protocol uses declarative queries for processing abstract queries from network layer functions. A query layer is added to support the abstraction. COUGAR uses an architecture in which a leader is selected from the deployed WS nodes to perform aggregation and is responsible for transmission of the data to sink. The sink is responsible for all the operations. COUGAR provides a network layer independent method for data query but it also have some drawbacks. Firstly, the insertion of query layer between network and application layer increases the overhead of energy consumption and storage. Secondly, nodes are required to synchronize for in-network data aggregation before transmitting data to the leader node. Thirdly and most important is that the maintenance of leader node must be done to prevent it from failure.
- Active Query Forwarding in Sensor Networks (ACQUIRE): A technique for querying sensor networks known as ACQUIRE was proposed by Sadagopan et al. [26]. In similar to working of COUGAR, queries are further divided into sub queries in ACQUIRE. A query is sent by the BS to all the neighbour WS nodes in network. Then response to the query is sent by each node using pre-cached information and is forwarded to another WS node. If the information is not up to date, then the information is acquired from the neighbours within a look ahead of predefined hops. The query is sent back to the BS using the reverse path or using the shortest path, when it is resolved.

B. Hierarchical Routing Protocols

Hierarchical routing protocols (HRP's) divide the WSN into number of clusters. Each cluster have one or more cluster heads (CHs) for transmitting and processing data and other nodes are used only for sensing and transmitting the information to the CHs. The WS nodes which have high energy level are chosen as CHs, while the other WS nodes are used for sensing the data [8, 9, 27]. There can be more than one layer of CHs as shown in Fig. 5.

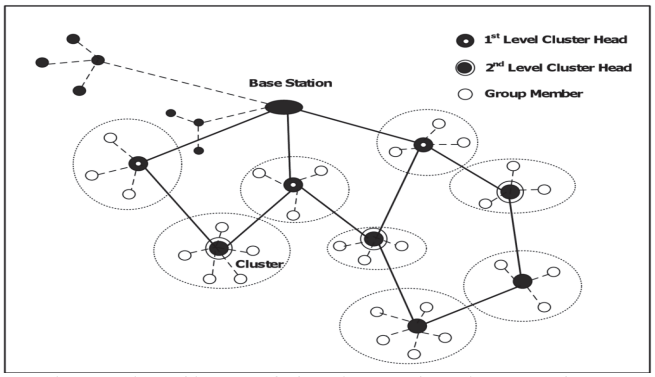

Fig. 5: Basic Architecture of Clustering Based Routing Protocols[28]

1) Block cluster based routing protocols: In block based topology, energy parameter is used to partition WS nodes into two layers [29]. The first layer is for selection of CH's randomly and the second layer is used for sensing the data. The lifetime of a WSN is increased by a factor of n in block based topology where n represents number CH. Following are some of the block cluster based protocols:

- Low Energy Adaptive Clustering Hierarchy (LEACH)**:** LEACH is a hierarchical clustering algorithm introduced by Heinzelman et al. [30]. The main idea behind LEACH protocol is to select cluster heads randomly from WS nodes and then uniformly rotate this role for equal energy consumption. Basic architecture of LEACH protocol is shown in Fig. 6. The LEACH operation is divided into two phases: Setup phase to form clusters and to select respective CHs; steady state phase to transfer data to the BS. Though, LEACH can increase the network lifetime, it also possesses few limitations. LEACH assumes that each node has enough power to transmit data to BS if needed and that each node can support MAC protocols. Another assumption of LEACH protocol is that there is always some data to transmit and the neighbour nodes have correlated data. Another limitation is that LEACH cannot be implemented in large networks as there is a chance of having no CHs in close vicinity. These limitations are overcome by an extended version of LEACH, called LEACH with negotiation, which is a mixture of LEACH and SPIN.

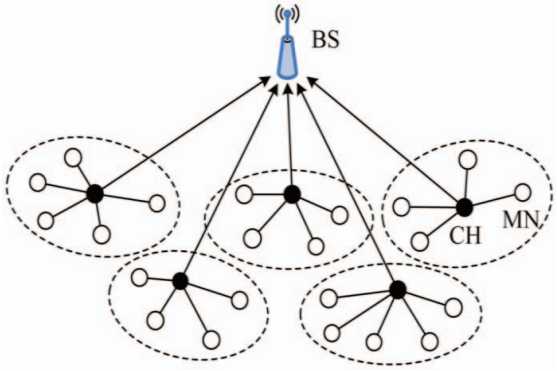

Fig. 6: Architecture of LEACH protocol [8]

- Manjeshwar et al. [31] designed a protocol specifically for sensing the sudden changes in the environment like temperature monitoring. There are two versions of this protocol: one is Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN) as shown in Fig. 7 and the other is Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN).

  In TEEN, the data is not transmitted very frequently to the BS but the sensing operation continues at all time. For the implementation of TEEN, two thresholds are maintained for the selection of CH: soft threshold and hard threshold. Hard threshold allows the sensor nodes to transmit data only if the sensed attributes are in the range of interest. After sensing hard threshold, the data is transmitted only if sensed attribute is equal to or larger than soft threshold. The limitation of TEEN is taken care by APTEEN, which can be used for applications requiring periodic updates.

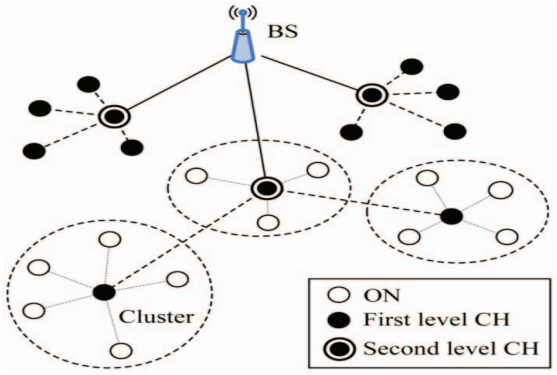

Fig. 7: Structure of TEEN protocol topology [8]

2) Grid cluster based routing protocols: In this topology, the clusters are formed by dividing the network into various geographical grids [29]. There is no need of routing tables, as there are no routing operations performed. It has the advantages of simple structure and efficient data delivery. There are mainly following two popular protocols based on this topology:

- Position based aggregator node election protocol (PANEL) proposed by Buttyan et al. [32] is a geographical position based algorithm which uses location of nodes for determining the nodes aggregators. The whole network is divided into number of geographical clusters and for each cluster; a reference point is calculated in reference to the bottom left corner of cluster. Then that node is selected as CH which is closest to the reference point. Transmission can be intra-cluster or inter-cluster. Most of the data aggregation algorithms are synchronous in nature, but PANEL has the advantage to support asynchronous applications also. However

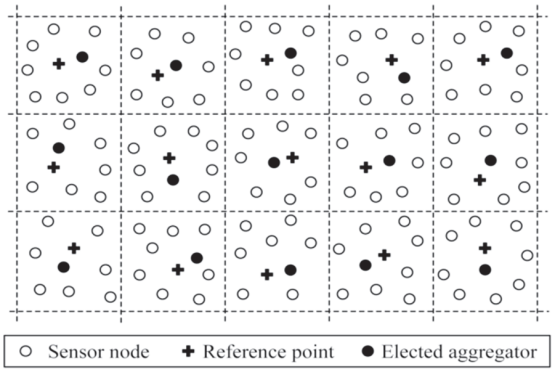

Figure 11:Architecture of PANEL routing protocol [8]

the infrastructure cost of this algorithm is high due to requirement of special hardware and software for implementation on the basis of geographical knowledge of nodes.

- Two tier data dissemination (TTDD) is another grid based protocol proposed by Luo et al. [33]. In TTDD, network is divided into a number of cells to establish a grid structure, each having several scattered nodes. The function of these scattered nodes is to relay query messages to proper sources. Whenever a data is required by sink, whole network is queried using flooding process until query message reaches the source node. Greedy geographical forwarding method is used by source to propagate the data to other dissemination nodes. The message ends, when it reaches the node which is closest to the reference point. The process continues until the boundary of WSN is reached. TTDD is best suitable for the applications which are event driven but not for applications requiring continuous information.

3) Chain based routing protocols: A chain is constructed to connect the nodes deployed over WSN in chain based routing (CBR) protocols. For each chain, a leader node is selected on the basis of closest distance to sink [29]. The advantage of chain based method is that they are simpler and energy efficient, on the other hand, they suffers from long delays, imbalance energy consumption and are less robust. Following are the popular protocols based on chain based topology:

- Power-Efficient Gathering in Sensor Information Systems (PEGASIS) is the most popular chain based hierarchical protocol proposed by Lindsey et al. [34]. The WS nodes are organized in the form of a chain for the transmission and aggregation of the data. The formation of chain can be centralized or distributed depending upon the application. Working of PEGASIS is based on the assumption that global knowledge of network is provided to all the nodes. The formation of chain starts from the farthest node from sink and its closest neighbour are selected as next node in the chain and so on. The end node must be the sink and the node before sink acts as a leader of the node. Operations like data processing and aggregation are done by leader node. However, PEGASIS is not suitable for the networks with dynamic or time varying topology [35]. Larger the size of network, longer is the delay in transmission, due to which PEGASIS suffers from scalability problem.
- Concentric Clustering Scheme (CCS) proposed by Jung et al. [36] is another chain based algorithm which is an extension of PEGASIS. The main goal of the CCS is to achieve a better energy efficiency then PEGASIS by choosing the BS effectively. In CCS, WSN is divided into number of concentric circles around the BS, each representing different cluster levels as shown in Fig. 8. Circular track which is closest to the BS is assigned level-1 and so on. Each cluster have one CH and CHs of different levels communicate with each other to transmit data from one level to another and ultimately to BS. In this way, the distance between the BS and CH is reduced [37]. Therefore the problem faced by PEGASIS of longer delays is overcome by CCS.

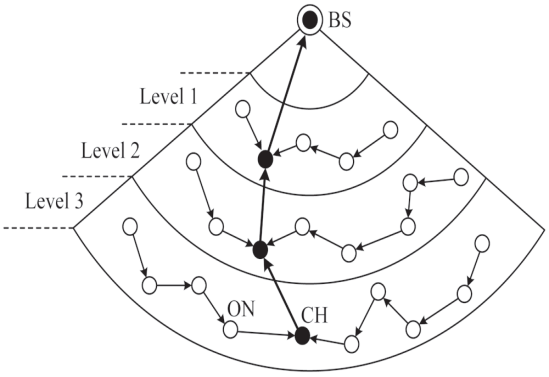

Fig. 8: Structure of CCS topology [8]

C. Location based routing protocols

Locations based routing (LBR) protocols use the location of WS nodes for the transmission of data and are not dependent on the addressing scheme used by WSN. In LBR, source sends the message to destination by using its geographical location, thus also known as geographical routing [38]. On the basis of the location of nodes, LBR protocols are classified as: Flooding restriction, Area partition and optimal path based routing.

1) *Flooding restriction based routing:* In this methodology, the traditional flooding based routing is restricted to predefined distance or position to increase the efficiency of network [39]. A particular node is restricted to some area for flooding the data. In case of unavailability of suitable path, traditional flooding approach is followed. In this way, the performance of the WSN is increased as compared to traditional flooding approach. The restrictions are employed in following ways:

- Distance based flooding restriction: Restriction on the basis of distance is used when location of target node is not available. The information packet is flooded to predefined distance in all directions and the packet is

flooded again by the receiving WS nodes in same manner. Flooding ends when the packet reaches the destination WS node. In this way, the data redundancy is reduced. On the other hand, when the target node's location is certain, a request zone is created with nodes which are closer than the target node region [39]. An example of routing protocol using this concept of creating request zones is the Location-Aided Routing (LAR) [40].

- Angle based flooding restriction: An angle from the source node is used to determine the restricted region when the direction of destination node is known to the source node. The nodes falling under the region covered by angle are subjected to relay the data by flooding. The direction of angle is chosen such that the target node must fall in that region. Data redundancy is further reduced in this method and guarantees the transmission of data [39].
- Rectangle based flooding restriction: In this restriction method, the flooding restriction is done in rectangular region. The rectangular region is created using locations of source and destination node as two of its opposite vertices. A circular region around these vertices is also added to increase the routing success rate. The radius of the circular region is small if the nodes are closely deployed and large if they are scattered [39].

2) *Virtual area partition:* The entire WSN is divided into number of sub networks and then routing scheme is designed keeping in mind the location information of the WS nodes in sub network. Each sub network has its own location information for routing data, which reduces the redundancy and resource blindness. As it provides mobile node processing and information fusion, it allows a better real time transmission. Further, tasks are divided and scheduled among WS nodes due to which nodes will go in sleeping state when not active thus resulting in energy conservation [39]. Following are some of the algorithms which employs virtual area partition approach:

- Geographic Adaptive Fidelity (GAF) proposed by Szewczyk et al. [41] is based on the idea of partition in which the whole WSN is subdivided into number of virtual partitions also called grids. The partition is done in such a way that any two nodes belonging to the adjacent grids can communicate with each other. At one time, only one node in each grid is in active state which performs all the data processing and transmissions. The active node is selected as that node which has the highest energy left. There are three transition states for the nodes in a grid: active, discovery and sleep state. In discovery state, the node with highest energy is discovered and is triggered to be in active state from sleep state.
- Grid Clustering Routing Protocol (GROUP) is a hybrid of clustering and location based routing protocol proposed by Yu et al. [42]. In GROUP, WSN is divided into clusters and one node from cluster is selected as CH. CH receives the queries from all nodes in its cluster and forwards them to the respective destination node using the location information. Each node has its own location information and also location information of all WS nodes in cluster is known to CH. GROUP has some limitations; it assumes that all WS nodes are stationary and are able to adjust the power consumption of transceiver.

3) *Optimal path choice:* This scheme uses the angle of a node or distance as a criterion for routing the data. For finding the location of the target node, a localization system or global information system can be used. The different versions of optimal path are as follows:

- Greedy Perimeter Stateless Routing (GPSR) proposed by Karp et al. [43] is an algorithm which follows the optimal path choice technique to route the information. GPSR adopts the greedy forwarding algorithm for routing the data packets. Data packet is send to the next closest neighbour node and if there is no node satisfying this condition, it uses perimeter forwarding algorithm. The unavailability of the next node is called as the route hole problem and this algorithm draws a planar graph to solve this problem of finding the next node.
- Geographic and Energy Aware Routing (GEAR) is a location based routing protocol proposed by Yu et al. [44] which selects the target region to route the data packet. For routing, each node has to keep the information of its location and energy left, and also the location and energy of the neighbour nodes. To select the next node, two costs are calculated: learned cost and estimated cost. The estimated cost is used to find the next node which is closest to the target region using two factors, residual energy and its distance to the destination. On the other hand, learned cost is used when no neighbour node is closer to destination. Learned cost is used to solve the hole problem. After reaching the target region, the information is transmitted using restricted flooding methods and recursive geographic forwarding. This approach is better suitable for the applications where the nodes are densely deployed.

IV. Comparison and Discussion

In this paper, an attempt has been made to present a comprehensive comparison of different routing algorithms based on performance metrics related to network structure and data transmission techniques which are tabulated in the following Table 1.

TABLE 1
COMPARISON OF ROUTING PROTOCOLS

Routing protocols	Classification	Mobility	Power usage	Data aggregation	Localization	Scalability	Query based
SPIN	Flat/ Negotiation based	Yes	Limited	Yes	No	Limited	Yes
DD	Flat/ Diffusion based	Limited	Limited	Yes	Yes	Limited	Yes
RR	Flat/ Diffusion based	No	N/A	Yes	No	Good	Yes
COUGAR	Flat/ Data Centric	No	Limited	Yes	No	Limited	Yes
ACQUIRE	Flat/ Data Centric	Limited	N/A	Yes	No	Limited	Yes
LEACH	Hierarchical/ Block based	Fixed BS	Maximum	Yes	Yes	Good	No
TEEN	Hierarchical/ Block based	Fixed BS	Maximum	Yes	Yes	Good	No
PANEL	Hierarchical/ Grid based	Yes	Limited	No	Yes	Low	No
TTDD	Hierarchical/ Grid based	Yes	Limited	No	No	Low	No
PEGASIS	Hierarchical/ Chain based	Fixed BS	Maximum	No	Yes	Good	No
CCS	Hierarchical/ Chain based	Fixed BS	Maximum	No	Yes	Good	No
GAF	Location based/ Area partition	Limited	Limited	No	No	Good	No
GRID	Location based/ Area partition	No	Limited	No	Yes	Good	Yes
GPSR	Location based/ Optimal Path	Limited	Limited	No	No	Limited	No
GEAR	Location based/ Optimal Path	Limited	Limited	No	No	Limited	No

The evolution of WSN has revolutionized the way of communication. The application areas of WSN are growing exponentially. The implementation of WSN and selection of routing protocols is application dependent. Consider an example of tornado monitoring; one way is to sense the tornado from sky using small airplanes. Another way is to deploy a sensor grid on ground and to report data when tornado passes through sensor grid. Also, one can think of deploying lightweight sensors inside the tornado. To implement WSN for tornado monitoring, any of these three methods can be followed but they all have their different topology constraints like mobility is not required when deploying on ground while it is must when sensing from sky. So, the primary motive of designing any routing protocol is to report the data within a desired accuracy level while maintaining all topology constraints. Comparison shown in this paper can be used by application developers to select a routing protocol which best suits the constraints of an application.

V. CONCLUSION

WSNs hold a promising future in various civil and military applications like environmental monitoring, security surveillance, border protection and healthcare. For appropriate implementation and working of these applications, a good architecture is required. Since the architecture of the network is application dependent so proper routing technique must be followed which should ensure the longer lifetime and energy efficiency. In this paper, network structure based routing protocols are discussed on the basis of their topology. Further, comparison of these protocols is done using important performance metrics. We hope that the taxonomy presented in this paper can help the researchers and designer for selecting an appropriate routing protocol for specific application.

REFERENCES

[1] F. Akyildiz, S. Weilian, Y. Sankarasubramaniam, E. Cayirci, "A survey on sensor networks", IEEE Commun. Mag. 40(8) (2002) 102-114 doi: 10.1109/MCOM.2002.1024422

[2] Frontmatter, in "*Wireless Sensor and Actuator Networks"*, ed: John Wiley & Sons Inc., 2010, pp. 1-15.

[3] W. Dargie, "Dynamic Power Management in Wireless Sensor Networks: State-of-the-Art", IEEE Sens. J. 12(5) (2012) 1518-1528 doi: 10.1109/JSEN.2011.2174149

[4] J. N. Al-Karaki, A. E. Kamal, "Routing techniques in wireless sensor networks: a survey", 11(6) (2004) 6-28 doi: 10.1109/MWC.2004.1368893

[5] S. Mishra, A. Raj, A. Kayal, V. Choudhary, P. Verma, L. Biswal, "Study of Cluster Based Routing Protocols in Wireless Sensor Networks", Int. J. Scient. Eng. res. 3(7) (2012)

[6] J. Yick, B. Mukherjee, D. Ghosal, "Wireless sensor network survey", Comput. Netw. 52(12) (2008) 2292-2330 doi: http://dx.doi.org/10.1016/j.comnet.2008.04.002

[7] K. Akkaya, M. Younis, "A survey on routing protocols for wireless sensor networks", Ad Hoc Networks 3(3) (2005) 325-349 doi: http://dx.doi.org/10.1016/j.adhoc.2003.09.010

[8] X. Liu, "A Survey on Clustering Routing Protocols in Wireless Sensor Networks", Sensors 12(8) (2012) 11113-11153

[9] S. Naeimi, H. Ghafghazi, C.-O. Chow, H. Ishii, "A Survey on the Taxonomy of Cluster-Based Routing Protocols for Homogeneous Wireless Sensor Networks", Sensors 12(6) (2012) 7350 doi: 10.3390/s120607350

[10] R. Sumathi, M. G. Srinivas, "A Survey of QoS Based Routing Protocols for Wireless Sensor Networks", J. Inform. Proc. Syst. 8(4) (2012) 589-602 doi: 10.3745/JIPS.2012.8.4.589

[11] S. Tilak, N. B. Abu-Ghazaleh, W. Heinzelman, "A taxonomy of wireless micro-sensor network models", ACM SIGMOBILE Mob. Comput. Commun. Rev. 6(2) (2002) 28-36 doi: 10.1145/565702.565708

[12] W. Feng, L. Jiangchuan, "Networked Wireless Sensor Data Collection: Issues, Challenges, and Approaches", Commun. Surveys Tuts. 13(4) (2011) 673-687 doi: 10.1109/SURV.2011.060710.00066

[13] W. Y. Poe, J. B. Schmitt, "Node deployment in large wireless sensor networks: coverage, energy consumption, and worst-case delay", Proceedings of the Asian Internet Engineering Conference, Bangkok, Thailand, 2009, pp. 77-84.

[14] G. Anastasi, M. Conti, M. Di Francesco, A. Passarella, "Energy conservation in wireless sensor networks: A survey", Ad hoc networks 7(3) (2009) 537-568 doi: http://dx.doi.org/10.1016/j.adhoc.2008.06.003

[15] G. Hoblos, M. Staroswiecki, A. Aitouche, "Optimal design of fault tolerant sensor networks", in Proceedings of the IEEE International Conference on Control Applications, 2000, pp. 467-472.

[16] L. K. Alazzawi, A. M. Elkateeb, A. Ramesh, "Scalability Analysis for Wireless Sensor Networks Routing Protocols", in Proceedings of 22nd International Conference on Advanced Information Networking and Applications - Workshops, AINAW, 2008, pp. 139-144.

[17] B. Bhuyan, H. K. D. Sarma, N. Sarma, A. Kar, R. Mall, "Quality of Service (QoS) Provisions in Wireless Sensor Networks and Related Challenges", Wireless Sensor Network 2(11) (2010) pp. 861 8 doi: 10.4236/wsn.2010.211104

[18] L. Frye, C. Liang, D. Shenfu, M. W. Bigrigg, "Topology Maintenance of Wireless Sensor Networks in Node Failure-prone Environments", in Proceedings of the IEEE International Conference on Networking, Sensing and Control, ICNSC '06, 2006, pp. 886-891.

[19] H. P. Keeler, P. G. Taylor, "A stochastic analysis of a greedy routing scheme in sensor networks", SIAM Journal on Applied Mathematics 70(7) (2010) 2214-2238

[20] S. M. Hedetniemi, S. T. Hedetniemi, A. L. Liestman, "A survey of gossiping and broadcasting in communication networks," Networks 18(4) (1988) 319-349

[21] W. R. Heinzelman, J. Kulik, H. Balakrishnan, "Adaptive protocols for information dissemination in wireless sensor networks", in Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking, Seattle, Washington, USA, 1999 pp. 174-185.

[22] C. Intanagonwiwat, R. Govindan, D. Estrin, "Directed diffusion: a scalable and robust communication paradigm for sensor networks", in Proceedings of the 6th annual international conference on Mobile computing and networking, Boston, Massachusetts, USA, 2000, pp. 56-67.

[23] R. C. Shah, J. M. Rabaey, "Energy aware routing for low energy ad hoc sensor networks", in Proceeding of the IEEE confernce on Wireless Communications and Networking, WCNC2002. 2002, pp. 350-355.

[24] D. Braginsky, D. Estrin, "Rumor routing algorthim for sensor networks", in Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications, 2002, pp. 22-31.

[25] Y. Yao, J. Gehrke, "The cougar approach to in-network query processing in sensor networks", ACM Sigmod Record 31(3) (2002) 9-18 doi: 10.1145/601858.601861

[26] N. Sadagopan, B. Krishnamachari, A. Helmy, "The ACQUIRE mechanism for efficient querying in sensor networks", in Proceedings of the First IEEE International Workshop on Sensor Network Protocols and Applications 2003, pp. 149-155.

[27] A. Abbasi, M. Younis, "A survey on clustering algorithms for wireless sensor networks", Computer Communications 30(14–15) (2007) 2826-2841 doi: http://dx.doi.org/10.1016/j.comcom.2007.05.024

[28] D. Bhattacharyya, T.-h. Kim, S. Pal, "A Comparative Study of Wireless Sensor Networks and their Routing Protocols", Sensors 10(12) (2010) 10506-10523.

[29] L. Xuxun, "Atypical Hierarchical Routing Protocols for Wireless Sensor Networks: A Review", IEEE Sensors Journal 15(10) (2015) 5372-5383 doi: 10.1109/JSEN.2015.2445796

[30] W. R. Heinzelman, A. Chandrakasan, H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks", in Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, 2000, vol.2 pp 10.

[31] Manjeshwar, D. P. Agrawal, "TEEN: A Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks", in IPDPS, 2001, p. 189.

[32] L. Buttyán, P. Schaffer, "Position-based aggregator node election in wireless sensor networks", International Journal of Distributed Sensor Networks 2010

[33] H. Luo, F. Ye, J. Cheng, S. Lu, L. Zhang, "TTDD: two-tier data dissemination in large-scale wireless sensor networks", Wireless Networks 11(1-2) (2005) 161-175 doi: 10.1007/s11276-004-4753-x

[34] S. Lindsey, C. S. Raghavendra, "PEGASIS: Power-efficient gathering in sensor information systems", in Proceedings of the Aerospace Conference, 2002, pp. 3-1125-3-1130 vol.3.

[35] E. Fasolo, M. Rossi, J. Widmer, M. Zorzi, "In-network aggregation techniques for wireless sensor networks: a survey", IEEE Wireless Communications 14(2) (2007) 70-87

[36] J. Sung-Min, H. Young-Ju, C. Tai-Myoung, "The Concentric Clustering Scheme for Efficient Energy Consumption in the PEGASIS", in Proceedings of the 9th International Conference on Advanced Communication Technology, 2007, pp. 260-265.

[37] N. Gautam, W.-I. Lee, J.-Y. Pyun, "Track-sector clustering for energy efficient routing in wireless sensor networks", in Proceedings ofNinth IEEE International Conference on Computer and Information Technology, CIT'09, 2009, pp. 116-121.

[38] J. Grover, Shikha, M. Sharma, "Location based protocols in Wireless Sensor Network: A review", in Proceedings of the International Conference on Computing, Communication and Networking Technologies (ICCCNT), 2014, pp. 1-5.

[39] Z. Kai, T. Libiao, L. Wenjun., "Location-Based Routing Algorithms for Wireless Sensor Network". *Emerging Technologies of Future Multimedia Coding, Analysis and Transmission*. Available: http://wwwen.zte.com.cn/endata/magazine/ztecommunications/2009year/no1/articles/200903/t20090319_170883.html

[40] Y. B. Ko, N. H. Vaidya, "Location Aided Routing (LAR) in mobile ad hoc networks", Wireless networks 6(4) (2000) 307-321

[41] R. Szewczyk, E. Osterweil, J. Polastre, M. Hamilton, A. Mainwaring, D. Estrin, "Habitat monitoring with sensor networks", Communications of the ACM 47(6) (2004) 34-40 doi: 10.1145/990680.990704

[42] Y. Liyang, W. Neng, Z. Wei, Z. Chunlei, "GROUP: A Grid-Clustering Routing Protocol for Wireless Sensor Networks", in Proceedings of the International Conference on Wireless Communications, Networking and Mobile Computing, 2006, pp. 1-5.

[43] Karp, H. T. Kung, "GPSR: greedy perimeter stateless routing for wireless networks", in Proceedings of the 6th annual international conference on Mobile computing and networking, Boston, Massachusetts, USA, 2000.

[44] Y. Yu, R. Govindan, D. Estrin, "Geographical and energy aware routing: A recursive data dissemination protocol for wireless sensor networks", Technical report ucla/csd-tr-01-0023, UCLA Computer Science Department 2001.