International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 7 Issue 2|| February 2018 || PP. 28-37

Survey Of Routing Protocols In Wireless Sensor Networks:-

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ABSTRACT:- *wireless sensor network (WSN) technology is having capability of sensing, transmitting/receiving physical parameters which results in varied application areas. The characteristics of wireless network require cost effective method of processing and forwarding the data. The sensor nodes have limited transmission range low processing rate less storage capability and scarcest energy resources. Hence Routing Protocols for wireless sensor network responsible for maintaining the routes in network are to be designed to ensure reliable communication with limited energy, less bandwidth and less buffer space. This paper presents survey of routing protocols of wireless sensor networks with comparison of their strength and weakness.*

KEYWORDS: *Wireless Sensor Networks, Routing Protocols, energy constraints*

Date of Submission: 21-01-2018 *Date of acceptance: 05-02-2018*

I. Introduction

A WSN consists of randomly deployed low cost, low power and multifunctional nodes with sensing, communicating and computation capabilities [1,2]. These sensor nodes collaborate, communicate through wireless medium to accomplish wide range of application like environment monitoring, military surveillance, and industrial process control [3]. The basic philosophy behind WSNs is that, the capability of each individual sensor node is limited but the aggregate power of the network is enough for the required application .In WSN applications, the deployment of sensor nodes is performed in random fashion. Once deployed, the sensor nodes autonomously setup and organized them self's into a wireless communication network. Sensor nodes are battery-operated and worked unattended for a relatively long period of time. In most cases it is very difficult and even impossible to change or recharge batteries for the sensor nodes. WSNs are characterized with denser levelsof sensor node deployment, sever power, computation, and memory constraints.

Thus, the nique characteristics and constraints present new challenges for the design and development of new routing protocols to implement various network control and management functions such as synchronization, node localization, and network security. The conventional routing protocols have several drawbacks when applied to WSNs, which are mainly due to the energy-constrained nature of such networks [3]. For example, flooding is a technique in which a given node broadcasts data and control packets that it has received to the rest of the nodes in the network. This process repeats until the destination node is reached. Note that this technique does not take into account the energy constraint imposed by WSNs. As a result, when used for data routing in WSNs, it leads to the problems such as implosion and overlap [4,5]. In flooding duplicated packets may keep circulate in the network, and hence sensors will receive those duplicated packets ,causing an implosion problem. To overcome the shortcomings of flooding, another technique known as gossiping can be applied [17]. In gossiping, upon receiving a packet, a sensor would select randomly one of its neighbors and send the packet to it. The same process repeats until all sensors receive this packet. Using gossiping, a given sensor would receive only one copy of a packet being sent. A large number of research activities have been carried out to explore and overcome the constraints of WSNs and solve design and application issues. This paper presents various routing protocols of wireless sensor network for comparison of advantages and limitations. Section 2 of the paper discusses the network characteristics and design objectives. Sections 3, presents network design challenges and routing issues. Section 4 discuses different routing protocols and compared. Finally, Section 5 concludes the survey.

II. Network Characteristics and Design Challenges

The characteristics of sensor networks and application requirements have a decisive impact on the network design objectives in term of network capabilities and network performance

2.1 Network Characteristics

wireless sensor networks have the following unique characteristics and constraints:

Dense sensor node deployment: Sensor nodes are usually densely deployed .

Battery-powered sensor nodes*:* Sensor nodes are usually powered by battery and has.

Severe energy, computation, and storage constraints: Sensors nodes are having highly limited energy, computation, and storage capabilities.

Self-configurable: Sensor nodes are usually randomly deployed and autonomously configure themselves into a communication network.

Data redundancy: data sensed by multiple sensor nodes typically have a certain level of correlation or redundancy.

Application specific: A sensor network is usually designed and deployed for a specific application. The design requirements of a sensor network change with its application.

Many-to-one traffic pattern: In most sensor network applications, the data sensed by sensor nodes flow from multiple source sensor nodes to a particular sink, exhibiting a many-to-one traffic pattern. ***Frequent topology change:*** Network topology changes frequently due to the node failures, damage addition, energy depletion, or channel fading.

2.2 Network Design Objectives

Most sensor networks are application specific and have different application requirements. Thus, all or part of the following main design objectives is considered in the design of sensor networks:

Small node size: Since sensor nodes are usually deployed in a harsh or hostile environment in large numbers, reducing node size can facilitate node deployment. It will also reduce the power consumption and cost of sensor nodes.

Low node cost: Since sensor nodes are usually deployed in a harsh or hostile environment in large numbers and cannot be reused, reducing cost of sensor nodes is important and will result into the cost reduction of whole network.

Low power consumption: Since sensor nodes are powered by battery and it is often very difficult or even impossible to charge or recharge their batteries, it is crucial to reduce the power consumption of sensor nodes so that the lifetime of the sensor nodes, as well as the whole network is prolonged.

Scalability: Since the number sensor nodes in sensor networks are in the order of tens, hundreds, or thousands, network protocols designed for sensor networks should be scalable to different network sizes.

Reliability: Network protocols designed for sensor networks must provide error control and correction mechanisms to ensure reliable data delivery over noisy, error-prone, and time-varying wireless channels.

Self-configurability: In sensor networks, once deployed, sensor nodes should be able to autonomously organize themselves into a communication network and reconfigure their connectivity in the event of topology changes and node failures.

Adaptability: In sensor networks, a node may fail, join, or move, which would result in changes in node density and network topology. Thus, network protocols designed for sensor networks should be adaptive to such density and topology changes.

Channel utilization: Since sensor networks have limited bandwidth resources, communication protocols designed for sensor networks should efficiently make use of the bandwidth to improve channel utilization.

QoS support: In sensor networks, different applications may have different (QoS) requirements in terms of delivery latency and packet loss. Thus, network protocol design should consider the QoS requirements of specific applications.3. Network Design Challenges and Routing Issues

The design of routing protocols for WSNs is challenging because they suffer from the limitations of several network resources, like energy, bandwidth, processing , and storage [7.8]. The design challenges in sensor networks involve the following parameters [3,7 ,8] *Limited energy capacity:* The sensor nodes are battery powered and have limited energy capacity. which poses a big challenge for network designers in hostile environments, like a battlefield, where it is impossible to recharge their batteries. Hence, routing protocols designed for sensors should be energy efficient to extend their lifetime, while guaranteeing good performance overall.*Sensor locations:* Another challenge that faces the design of routing protocols is to manage the locations of the sensors. Most of the proposed protocols assume that the sensors either are equipped with global positioning system (GPS) receivers or use some localization technique [9] to learn about their locations.

Limited hardware resources: In addition to limited energy capacity, sensor nodes have also limited processing and storage capacities, and thus can only perform limited computational functionalities. These hardware constraints present many challenges in software development and network protocol design for sensor networks, which must consider not only the energy constraint in sensor nodes, but also the processing and storage capacities of sensor nodes.

Network characteristics and unreliable environment: A sensor network usually operates in a dynamic and unreliable environment. The topology of a network, which is defined by the sensors and the communication links between the sensors, changes frequently due to sensor addition, deletion, node failures, damages, or energy depletion. Also, the sensor nodes are linked by a wireless medium, which is noisy, error prone, and time varying. Therefore, routing paths should consider network topology dynamics due to limited energy and sensor mobility as well as increasing the size of the network to maintain specific application requirements in terms of coverage and connectivity.
Data Aggregation: Since sensor nodes may generate significant redundant data, similar packets from multiple nodes can be aggregated so that the number of transmissions is reduced. Data aggregation technique has been used to achieve energy efficiency and data transfer optimization in a number of routing protocols.
4. Routing Protocols in WSN Routing in wireless sensor networks differs from conventional routing in fixed networks in various ways. There is no infrastructure, wireless links are unreliable, sensor nodes may fail, and routing protocols have to meet strict energy saving requirements [10]. Many routing algorithms were developed for wireless networks in general. All major routing protocols proposed for WSNs may be divided into Three categories as shown in figure 1. We review sample routing protocols in each of the categories in preceding sub-sections.2q2q

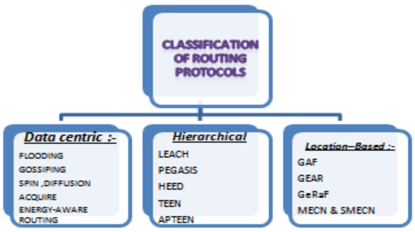
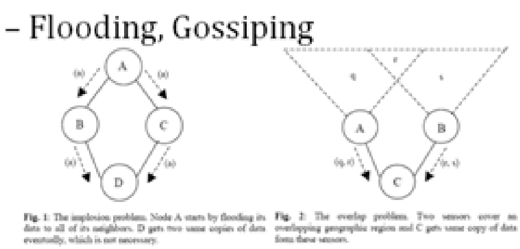
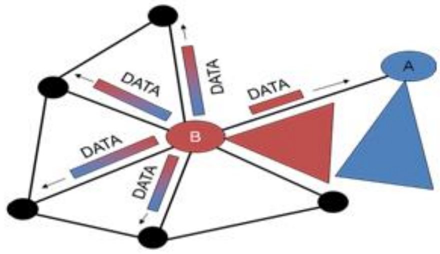


Figure 1: Routing Protocols for WSNs Category Representative Protocols

Data-centric Protocols Flooding ,Gossiping, SPIN, Directed Diffusion, Rumor Routing, COUGAR, ACQUIRE, EAD, Information-Directed Routing, GradientBased Routing, Energy-aware Routing, Information-Directed

Hierarchical Protocols LEACH, PEGASIS, HEED, TEEN, APTEEN Mobility-based Protocols SEAD, TTDD, Joint Mobility and Routing, Data MULES,
Location-based Protocols MECN, SMECN, GAF, GEAR, Span, TBF, BVGF, GeRaF
4.1 Data Centric Protocols Data-centric protocols differ from traditional address-centric protocols in the manner that the data is sent from source sensors to the sink. In *address-centric* protocols, each source sensor that has the appropriate data responds by sending its data to the sink independently of all other sensors. However, in *data-centric* protocols, when the source sensors send their data to the sink, intermediate sensors can perform some form of aggregation on the data originating from multiple source sensors and send the aggregated data toward the sink. This process can result in energy savings because of less transmission required to send the data from the sources to the sink. In this section, we review some of the data-centric routing protocols for WSNs.
In flooding duplicated packets may keep circulate in the network, and hence sensors will receive those duplicated packets ,causing an implosion problem. To overcome the shortcomings of flooding, another technique known as gossiping can be applied [6]. In gossiping, upon receiving a packet, a sensor would select randomly one of its neighbors and send the packet to it. The same process repeats until all sensors receive this packet. Using gossiping, a given sensor would receive only one copy of a packet being sent.

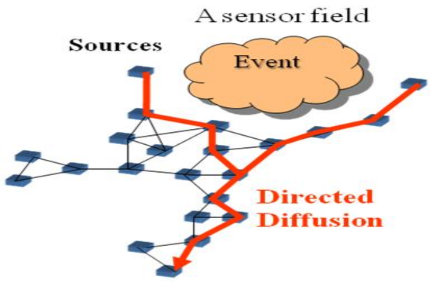




III. Data Dissemenation In Spi Afternegotiation

Sensor Protocols for Information via Negotiation (SPIN): SPIN [11,12] protocol was designed to improve classic flooding protocols and overcome the problems they may cause, for example, implosion and overlap. The SPIN protocols are resource aware and resource adaptive. The sensors running the SPIN protocols are able to compute the energy consumption required to compute, send, and receive data over the network. Thus, they can make informed decisions for efficient use of their own resources. The SPIN protocols are based on two key mechanisms namely *negotiation* and *resource adaptation.* SPINn

enables the sensors to negotiate with each other before any data dissemination can occur in order to avoid injecting non-useful and redundant information in the network. SPIN uses *meta-data* as the descriptors of the data that the sensors want to disseminate. The notion of meta-data avoids the occurrence of overlap given sensors can name the interesting portion of the data they want to get. It may be noted here that the size of the meta-data should definitely be less than that of the corresponding sensor data. Contrary to the flooding technique, each sensor is aware of its resource consumption with the help of its own *resource manager* that is probed by the application before any data processing or transmission. This helps the sensors to monitor and adapt to any change in their own resources.



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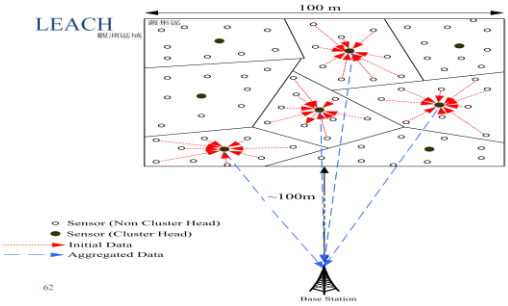
Directed Diffusion: Directed diffusion [13,14] is a data-centric routing protocol for sensor query dissemination and processing. It meets the main requirements of WSNs such as energy efficiency, scalability, and robustness. Directed diffusion has several key elements namely *data naming, interests and gradients, data propagation,* and *reinforcement.* A sensing task can be described by a list of attribute-value pairs. At the beginning of the directed diffusion process, the sink specifies a low data rate for incoming events. After that, the sink can *reinforce* one particular sensor to send events with a higher data rate by resending the original interest message with a smaller interval. Likewise, if a neighboring sensor receives this interest message and finds that the sender's interest has a higher data rate than before, and this data rate is higher than that of any existing gradient, it will *reinforce* one or more of mits neighbors.*Active Query Forwarding in Sensor Networks (ACQUIRE):* ACQUIRE [15]is another datacentric querying mechanism used for querying named data.. It provides superior query optimization to answer specific types of queries, called *one-shot complex queries for replicated data.* ACQUIRE query (i.e., interest for named data) consists of several sub queries for which several simple responses are provided by several relevant sensors. Each sub-query is answered based on the currently stored data at its relevant sensor. ACQUIRE allows a sensor to inject an active query in a network following either a random or a specified trajectory until the query gets answered by some sensors on the path using a localized update mechanism. Unlike other query techniques, ACQUIRE allows the querier to inject a complex query into the network to be forwarded stepwise through a sequence of sensors.*Energy-Aware Data-Centric Routing (EAD):* EAD is a novel distributed routing protocol, which builds a virtual backbone composed of active sensors that are responsible for in-network data processing and traffic relaying [16]. In this protocol, a network is represented by a broadcast tree spanning all sensors in the network and rooted at the gateway, in which all leaf nodes' radios are turned off while all other nodes correspond to active sensors forming the backbone and thus their radios are turned on.

Specifically, EAD attempts to construct a broadcast tree that approximates an optimal spanning tree with a minimum number of leaves, thus reducing the size of the backbone formed by active sensors. EAD approach is energy aware and helps extend the network lifetime. The gateway plays the role of a data sink or event sink, whereas each sensor acts as a data source or event source

4.2 Hierarchical Protocols

Many research projects in the last few years have explored hierarchical clustering in WSN from different perspectives [1]. Clustering is an energy-efficient communication protocol that can be used by the sensors to report their sensed data to the sink. In this section, we describe a sample of layered protocols in which a network is composed of several *clumps* (or *clusters)* of sensors. Each clump is managed by a special node, called *cluster head*, which is responsible for coordinating the data transmission activities of all sensors in its clump.

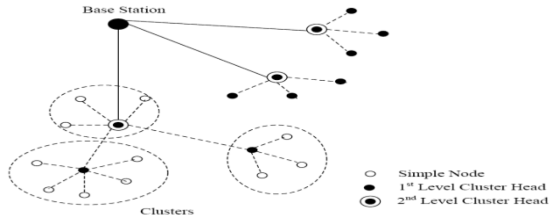
Figure 2 Cluster-based Hierarchical Model As shown in Figure 2, a hierarchical approach breaks the network into clustered layers [17]. Nodes are grouped into clusters with a cluster head that has the responsibility of routing from the cluster to the other cluster heads or base stations. Data travel from a lower clustered layer to a higher one. Although, it hops from one node to another, but as it hops from one layer to another it covers larger distances. This moves the data faster to the base station. Clustering provides inherent optimization capabilities at the cluster heads. In this section, we review a sample of hierarchical-based routing protocols for WSNs.



Low-energy adaptive clustering hierarchy (LEACH): LEACH [18,19] is the first and most popular energy-efficient hierarchical clustering algorithm for WSNs that was proposed for reducing power consumption. In LEACH, the clustering task is rotated among the nodes, based on duration. Direct communication is used by each cluster head (CH) to forward the data to the base station (BS). It uses clusters to prolong the life of the wireless sensor network. LEACH is based on an *aggregation* (or *fusion)* technique that combines or aggregates the original data into a smaller size of data that carry only meaningful information to all individual sensors. LEACH divides the a network into several cluster of sensors, which are constructed by using localized coordination and control not only to reduce the amount of data that are transmitted to the sink, but also to make routing and data dissemination more scalable and robust. LEACH uses a randomize rotation of high-energy CH position rather than selecting in static manner, to give a chance to all sensors to act as CHs and avoid the battery depletion of an individual sensor and dieing quickly.

The operation of LEACH is divided into rounds having two phases each namely (i) a setup phase to organize the network into clusters, CH advertisement, and transmission schedule creation and (ii) a steady-state phase for data aggregation, compression, and transmission to the sink. LEACH is completely distributed and requires no global knowledge of network. It reduces energy consumption by (a) minimizing the communication cost between sensors and their cluster heads and (b) turning off non-head nodes as much as possible [20]. LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. Therefore, it is not applicable to networks deployed in large regions. Furthermore, the idea of dynamic clustering brings extra overhead, e.g. head changes, advertisements etc., which may mdiminish the gain in energy consumption. While LEACH helps the sensors within their cluster dissipate their energy slowly, the CHs consume a larger amount of energy when they are located farther away from the sink. Also, LEACH clustering terminates in a finite number of iterations, but does not guarantee good CH distribution and assumes uniform energy consumption for CHs.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS): PEGASIS [21] is an
extension of the LEACH protocol, which forms chains from sensor nodes so that each node
CH-Level 1
CH-Level 2



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CH-Level 2 transmits and receives from a neighbor and only one node is selected from that chain to transmit to the base station (sink). The data is gathered and moves from node to node, aggregated and eventually sent to the base station. The chain construction is performed in a greedy way. Unlike LEACH, PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS (sink) instead of using multiple nodes. A sensor transmits to its local neighbors in the data fusion phase instead of sending directly to its CH as in the case of LEACH. In PEGASIS routing protocol, the construction phase assumes that all the sensors have global knowledge about the network, particularly, the positions of the sensors, and use a greedy approach. When a sensor fails or dies due to low battery power, the chain is constructed using the same greedy approach by passing the failed sensor. In each round, a randomly chosen sensor node from the chain will transmit the aggregated data to the BS, thus reducing the per round energy expenditure compared to LEACH.

Simulation results showed that PEGASIS is able to increase the lifetime of the network twice as much the lifetime of the network under the LEACH protocol. Such performance gain is achieved through the elimination of the overhead caused by dynamic cluster formation in LEACH and through decreasing the number of transmissions and reception by using data aggregation. Although the clustering overhead is avoided, PEGASIS still requires dynamic topology adjustment since a sensor node needs to know about energy status of its neighbors in order to know where to route its data. Such topology adjustment can introduce significant overhead especially for highly utilized networks. *Hybrid, Energy-Efficient Distributed Clustering (HEED):* HEED [21,22] extends the basic scheme of LEACH by using residual energy and node degree or density as a metric for cluster selection to achieve power balancing. It operates in multi-hop networks, using an adaptive transmission power in the inter-clustering communication. HEED was proposed with four primary goals namely (i) prolonging network lifetime by distributing energy consumption, (ii) terminating the clustering process within a constant number of iterations, (iii) minimizing control overhead, and (iv) producing well-distributed CHs and compact clusters. In HEED, the proposed algorithm periodically selects CHs according to a combination of two clustering parameters. The primary parameter is their residual energy of each sensor node (used in calculating probability of becoming a CH) and the secondary parameter is the intra-cluster communication cost as a function of cluster density or node degree (i.e. number of neighbors). The primary parameter is used to probabilistically select an initial set of CHs while the secondary parameter is used for breaking ties. The HEED clustering improves network lifetime over LEACH clustering because LEACH randomly selects CHs (and hence cluster size), which may result in faster death of some nodes. The final CHs selected in HEED are well distributed across the network and the communication cost is minimized. However, the cluster selection deals with only a subset of parameters, which can possibly impose constraints on the system. These methods are suitable for prolonging the network lifetime rather than for the entire needs of WSN.

Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN): TEEN [23,24] is a hierarchical clustering protocol, which groups sensors into clusters with each led by a CH. The sensors within a cluster report their sensed data to their CH. The CH sends aggregated data to higher level CH until the data reaches the sink. Thus, the sensor network architecture in TEEN is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until the BS (sink) is reached. TEEN is useful for applications where the users can control a trade-off between energy efficiency, data accuracy, and response time dynamically.

TEEN uses a data-centric method with hierarchical approach. Important features of TEEN include its suitability for time critical sensing applications. Also, since message transmission consumes more energy than data sensing, so the energy consumption in this scheme is less than the proactive networks. However, TEEN is not suitable for sensing applications where periodic reports are needed since the user may not get any data at all if the thresholds are not reached.

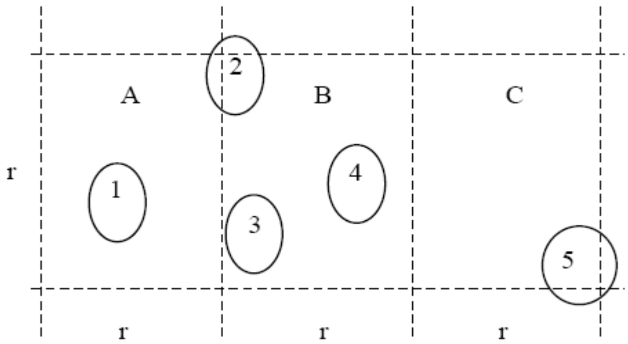
Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN): APTEEN [25] is an improvement to TEEN to overcome its shortcomings and aims at both capturing periodic data collections (LEACH) and reacting to time-critical events (TEEN). Thus, APTEEN is a hybrid clustering-based routing protocol that allows the sensor to send their sensed data periodically and react to any sudden change in the value of the sensed attribute by reporting the corresponding values to their CHs. The architecture of APTEEN is same as in TEEN, which uses the concept hierarchical clustering for energy efficient communication between source sensors and the sink. APTEEN supports three different query types namely (i) historical query, to analyze past data values, (ii) one-time query, to take a snapshot view of the network; and (iii) persistent queries, to monitor an event for a period of time. APTEEN guarantees lower energy dissipation and a larger number of sensors alive [25].

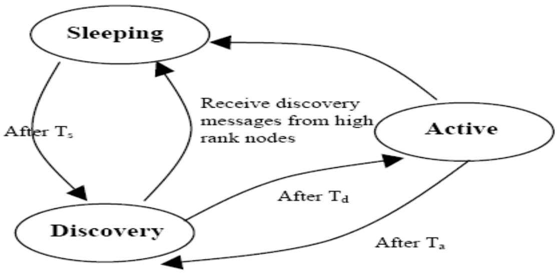
Energy Efficient Homogenous Clustering Algorithm for Wireless Sensor Networks: Singh et al. [2] proposed homogeneous clustering algorithm for wireless sensor network that saves power and prolongs network life. The life span of the network is increased by ensuring a homogeneous distribution of nodes in the clusters. A new cluster head is selected on the basis of the residual energy of existing cluster heads, holdback value, and nearest hop distance of the node. The homogeneous algorithm makes sure that every node is either a cluster head or a member of one of the clusters in the wireless sensor network. In the proposed clustering algorithm the cluster members are uniformly distributed, and thus, the life of the network is more extended. Further, in the proposed protocol, only cluster heads broadcast cluster formation message and not the every node. Hence, it prolongs the life of the sensor networks. The emphasis of this approach is to increase the life span of the network by ensuring a homogeneous distribution of nodes in the clusters so that there is not too much receiving and transmitting overhead on a Cluster Head.

4.3 Location-based Protocols

In location-based protocols, sensor nodes are addressed by means of their locations. Location information for sensor nodes is required for sensor networks by most of the routing protocols to calculate the distance between two particular nodes so that energy consumption can be estimated.

In this section, we present a sample of location-aware routing protocols proposed for WSNs. *Geographic Adaptive Fidelity (GAF):* GAF [17] is an energy-aware routing protocol primarily proposed for MANETs, but can also be used for WSNs because it favors energy conservation. The design of GAF is motivated based on an energy model [18,19] that considers energy consumption due to the reception and transmission of packets as well as idle (or listening) time when the radio of a sensor is on to detect the presence of incoming packets. GAF is based on mechanism of turning off unnecessary sensors while keeping a constant level of *routing fidelity* (or uninterrupted connectivity between communicating sensors). In GAF, sensor field is divided into grid squares and every sensor uses its location information, which can be provided by GPS or other location systems [18, 20, 21], to associate itself with a particular grid in which it resides. This kind of association is exploited by GAF to identify the sensors that are equivalent from the perspective of packet forwarding.Fig. 1 State transition diagram of GAFAs shown in Figure 1, the state transition diagram of GAF has three states, namely, *discovery,active,* and *sleeping.* When a sensor enters the *sleeping* state, it turns off its radio for energy savings. In the *discovery* state, a sensor exchanges discovery messages to learn about other sensors in the same grid. Even in the *active* state, a sensor periodically broadcasts its discovery message to inform equivalent sensors about its state. The time spent in each of these states can be tuned by the application depending on several factors, such as its needs and sensor mobility. GAF aims to maximize the network lifetime by reaching a state where each grid has only one active sensor based on sensor ranking rules. The ranking of sensors is based on their residual energy levels. Thus, a sensor with a higher rank will be able to handle routing within their corresponding rids. For example, a sensor in the *active* state has a higher rank than a sensor in the *discovery* state. A sensor with longer expected lifetime has a higher rank.



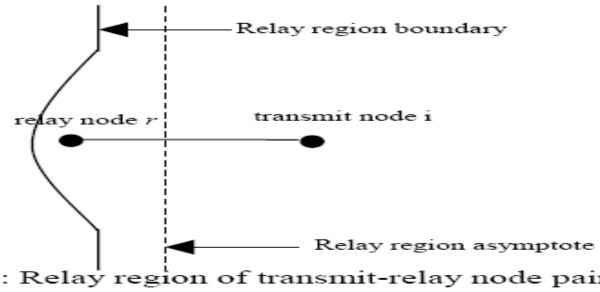


Geographic and Energy-Aware Routing (GEAR): GEAR [22] is an energy-efficient routing protocol proposed for routing queries to target regions in a sensor field, In GEAR, the sensors are supposed to have localization hardware equipped, for example, a GPS unit or a localization system [9] so that they know their current positions. Furthermore, the sensors are aware of their residual energy as well as the locations and residual energy of each of their neighbors. GEAR uses energy aware heuristics that are based on geographical information to select sensors to route a packet toward its destination region. Then, GEAR uses a recursive geographic forwarding algorithm to disseminate the packet inside the target region.

Geographic Random Forwarding (GeRaF): GeRaF was proposed by Zorzi and Rao [26], which uses geographic routing where a sensor acting as relay is not known *a priori* - When a source sensor has sensed data to send to the sink, it first checks whether the channel is free in order to avoid collisions. If the channel remains idle for some period of time, the source sensor broadcasts a request-to-send (RTS) message to all of its active (or listening) neighbors. This message includes the location of the source and that of the sink.

Note that the coverage area facing the sink, called *forwarding area,* is split into a set of *Np* regions of different priorities such that all points in a region with a higher priority are closer to the sink than any point in a region with a lower priority. When active neighboring sensors receive the RTS message, they assess their priorities based on their locations and that of the sink. The source sensor waits for a CTS message from one of the sensors located in the highest priority region. For GeRaF, the best relay sensor the one closest to the sink, thus making the largest advancement of the data packet toward the sink. In case that the source does not receive the CTS message, implies that the highest priority region is empty. Hence, it sends out another RTS polling sensors in the second highest priority region. This process continues till the source receives the CTS message, which means that a relay sensor has been found. Then, the source sends its data packet to the selected relay sensor, which in turn replies back with an ACK message. The relay sensor will act in the same way as the source sensor in order to find the second relay sensor. The same procedure repeats until the sink receives the sensed data packet originated from the source sensor. It may happen that the sending sensor does not receive any CTS message after sending *Np* RTS messages. This means that the neighbors of the sending sensor are not active. In this case, the sending sensor backs off for some time and retries later. After a certain number of attempts, the sending sensor either finds a relay sensor or discards the data packet if the maximum allowed number of attempts is reached.

Minimum Energy Communication Network (MECN): MECN [27] is a location-based protocol for achieving minimum energy for randomly deployed ad hoc networks, which attempts to set up and maintain a minimum energy network with mobile sensors. It is self-reconfiguring protocol that maintains network connectivity in spite of sensor mobility. It computes an optimal spanning tree rooted at the sink, called *minimum power topology*, which contains only the minimum power paths from ach sensor to the sink. It is based on the positions of sensors on the plane and consists of two main phases, namely, *enclosure graph construction* and *cost distribution.* For a stationary network, in the first phase (*enclosure graph construction*), MECN constructs a sparse graph, called an *enclosure graph,* based on the immediate locality of the sensors. An enclosure graph is a directed graph that includes all the sensors as its vertex set and whose edge set is the union of all edges between the sensors and the neighbors located in their enclosure regions. In other words, a sensor will not consider the sensors located in its relay regions as potential candidate forwarders of its sensed data to the sink. In the second phase (*cost distribution*), non-optimal links of the enclosure graph are simply eliminated and the resulting graph is a *minimum power topology.* This graph has a directed path from each sensor to the sink and consumes the least total power among all graphs having directed paths from each sensor to the sink. Each sensor broadcasts its cost to its neighbors, where the cost of a node is the minimum power required for this sensor to establish a rected path to the sink.While MECN is a self-reconfiguring protocol, and hence is fault tolerant (in the case of mobile networks), it suffers from a severe battery depletion problem when applied to static networks. MECN does not take into consideration the available energy at each sensor, and hence the optimal cost links are static. In other words, a sensor will always use the same neighbor to transmit or forward sensed data to the sink. For this reason, this neighbor would die very quickly and the network thus becomes disconnected. To address this problem, the enclosure graph and thus the minimum power topology should be dynamic based on the residual energy of the sensors



: Relay region of transmit-relay node pair (i, r) in MECN.

Small Minimum-Energy Communication Network (SMECN): SMECN [28] is a routing protocol proposed to improve MECN, in which a minimal graph is characterized with regard to the *minimum energy property*. This property implies that for any pair of sensors in a graph associated with a network, there is a minimum energy-efficient path between them; that is, a path that has the smallest cost in terms of energy consumption over all possible paths between this pair of sensors. Their characterization of a graph with respect to the minimum energy property is intuitive. In SMECN protocol, every sensor discovers its immediate neighbors by broadcasting a neighbor discovery message using some initial power that is updated incrementally. Specifically, the immediate neighbors of a given sensor are computed analytically. Then, a sensor starts broadcasting a neighbor discovery message with some initial power *p* and checks whether the theoretical set of immediate neighbors is a subset of the set of sensors that replied to that neighbor discovery message. If this is the case, the sensor will use the corresponding power *p* to communicate with its immediate neighbors. Otherwise, it increments *p* and rebroadcasts its neighbor discovery message. 5.

IV. Conclusion and Future Research

One of the main challenges in the design of routing protocols for WSNs is energy efficiency due to the scarce energy resources of sensors. The ultimate objective behind the routing protocol design is to keep the sensors operating for as long as possible, thus extending the network lifetime. The energy consumption of the sensors is dominated by data transmission and reception. Therefore, routing protocols designed for WSNs should be as energy efficient as possible to prolong the lifetime of individual sensors, and hence the network lifetime.

In this paper, we have surveyed a sample of routing protocols by taking into account several classification criteria, including location information, network layering and in-network processing, data centricity, path redundancy, network dynamics, . For each of these categories, we have discussed a few example protocols. Two important related research directions should receive attention from the researcher namely the design of routing protocols for duty-cycled WSNs, and three-dimensional (3D) sensor fields when designing such protocols. Although most of research work on WSNs, in particular, routing, considered two-dimensional (2D) settings, where sensors are deployed on a planar field, there are some situations where the 2D assumption is not reasonable and the use of a 3D design becomes a necessity. In fact, 3D settings reflect more accurate network design for real-world applications. For example, a network deployed on the trees of different heights in a forest, in a building with multiple floors, or underwater [29] requires design in 3D rather than 2D space. Although some efforts have been devoted to the design of routing and data dissemination protocols for 3D sensing applications, we believe that these first-step attempts are in their infancy, and more powerful and efficient protocols are required to satisfactorily address all problems that may occur.

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International Journal of Engineering Science Invention (IJESI) is UGC approved Journal with Sl. No. 3822, Journal no. 43302.

Patil Anil Kumar"Survey Of Routing Protocols In Wireless Sensor Networks:-" International Journal of Engineering Science Invention (IJESI), vol. 07, no. 01, 2018, pp. 28–37.