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RESEARCH ARTICLE

Exploration of Energy Efficient Location Based Routing Protocols for Wireless Sensor Networks

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ABSTRACT

Few routing protocols designed for wireless sensor networks (WSN) have been adopted for commercial use in today's technology. This is because when designing the protocols, there is a need to trade-off some features to improve others, but for some designs, these compromises are deemed adamant especially when resources are constrained. An Ideal sensor node is expected to have a small code size capable of coordinating communication activities with the least energy possible. This survey studies some energy-efficient location-based routing protocols that were proposed over the years, with a key interest in factors influencing energy utilization, as it is the most important challenging feature in wireless sensor networks. Other features looked at include the routing process, scalability, strengths, and limitations of the protocols. The inferences on each protocol's energy efficiency and scalability were based on some of the features inherent to the protocol's design. Furthermore, a classification based on path selection strategy for the surveyed location-based routing protocols was presented. This study aims to help researchers make better suggestions when deciding which location-based routing protocol to use, as they are the most explored and forecasted protocols of the future due to their ability to adapt to changing topologies. The study also highlighted open research directions for new protocol designs.

Keywords: Energy efficiency, Location based routing, Protocols, Wireless sensor network and Path Selection Strategy

1. Introduction

Recent advances in micro-electro-mechanical systems, low-power designs, and highly integrated digital electronics have led to the development of micro sensors that are equipped with data processing and communication capabilities [1]. Ad-hoc network, made up of a large number of these sensor nodes formed the Wireless Sensor Network (WSN) which is regarded as an emerging technology that combines the concept of wireless network with sensor technology to enable great distributed efficient measurement methods across vast physical system and environments [2] and [3]. This unique feature of measurement across physical systems and environments has made the swift amalgamation of WSN technology into Cyber Physical Systems (CPS). WSN has been designed majorly for communicating and sensing related data, CPS on the other hand utilizes a broader definition and dimension of sensing data over multiple networks with specific link to the internet with the aim of providing elevated controlled intelligence [4]. An Ideal WSN should operate with the least possible energy required to increase the lifetime of the sensor nodes, at the same time ensuring network connectivity and availability [5] and [6], however, sensor nodes are constrained in energy and bandwidth [1, 7–11]. These constraints have posed a lot of challenges to the design and application of the sensor node and the network as a whole. Applications of WSN entail Military and civil applications; such as target field imaging, intrusion detection, weather monitoring, security, and tactical surveillance. Distributed computing, detecting

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ambient conditions such as temperature, movement, sound, light, or presence of certain objects, inventory control, and disaster management. Agricultural and Lifesaving applications such as precision agriculture, rescue operations, medical operations, and underwater exploration [1, 7, 8].

The main contribution of this paper is to provide a survey that focuses on energy-efficient issues associated with location-based routing protocols. This is because of their capabilities to scale well, work in infrastructure and infrastructureless environment, their increasing evolution over the years, and their ability to grow futuristically into the flourishing CPS technology. The rest of the paper this paper is organized as follows. Section 2 describes the energy conservation mechanisms in WSNs, Section 3 introduces and explains the proposed classification on path selection, Section 4. explains the routing protocols and classifies them based on a classification selected in this paper, Section 5. highlight some open research directions for future work, the study is concluded in Section 6.

2. Energy conservation mechanism in wireless sensor networks

Energy is the most important and challenging feature of WSN. Node's lifetime is dependent on the life of its battery, which in most cases cannot be replenished due to the nature of the deployed perimeter [1, 5, 12, 13] and [14]. Sensor nodes have limited communication and computational capabilities [15]. The energy sustained in the battery is used for its communication, sensing, and data processing for which some of these processes can be overly exhaustive on the nodes' energy. A good WSN is expected to operate with the least possible energy required to prolong the lifetime of the sensor nodes while at the same time ensuring connectivity and availability [5, 13]. Fig. 1 [16] shows the sources of energy consumption in a node. When these sensor nodes make a WSN, the effect of this energy consumption emanates all through the network. The routing protocols that coordinate these communication and computation processes when properly designed can limit the energy consumption in the network and prolong the lifetime of the network.

The two most adopted power conservation mechanisms that are used for wireless communications designs are described in [17]. These mechanisms are:

2.1. Passive power conservation mechanism

This approach involves turning off the node's radio interface (transceiver) when not partaking in any communication activity (periodic hibernation) [13, 17]. The approach is further classified into:

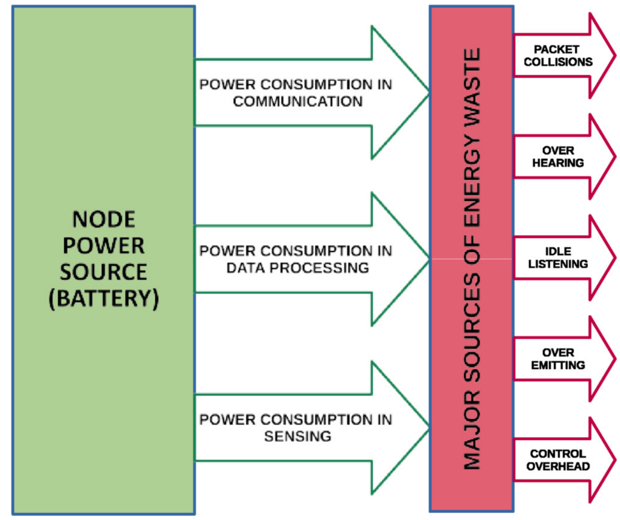

Fig. 1. Sources of energy consumption [16].

- *Physical layer power conservation:* Implies the application of the turn-off technique (hibernation) at the physical layer to reduce substantial energy consumed by components such as the Processing Unit.
- *Fine Grained Power Conservation:* Here the Media Access Control layer (MAC) is set to take charge of the switching process, it basically turns off the radio interface module for a period of one transmission frame which leads to a small or no delay to incoming traffic, thereby minimizing energy spared for unnecessary overhearing [17].
- *Coarse Grain Power Conservation:* Higher layer application information (other than MAC and PHY) is used in deciding when to turn off the transceiver module. Thus hibernation period may be longer than a MAC frame, which may lead to a longer delay for incoming traffic addressed to a node in the hibernation period. A substantial amount of energy is saved but at the expense of increased delay [13].

2.2. Active power conservation mechanism

These are the concepts and methods applied to various layers in a sensor node that contribute towards a successful communication process in an energy-efficient manner. For instance, the PHY layer could determine links that are less congested and reliable enough to ensure delivery, MAC layer can adjust its transmission signal to a level, just enough to reach the destined or next hop node. In the network Layer, algorithms can be used to select the route

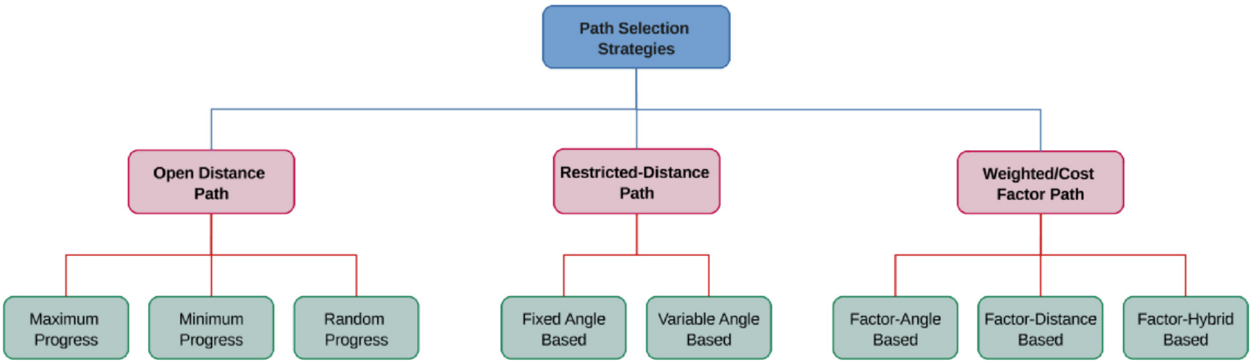

Fig. 2. Path selection strategy.

that will consume the least energy possible in propagation or an algorithm that manages energy in a fair manner amongst nodes in a network. Transport layer algorithms could try to eliminate or reduce the energy-consuming process of retransmission in a network [13, 17].

3. Path selection strategy

Path selection strategy employed at the network layer tends to select forwarding routes based on criteria specified by the protocol designers to coordinate the communication processes, based on a desired goal. Such specified criteria are usually based on parameters such as distance, energy, number of hops, etc. Algorithms such as Dijkstra's shortest path algorithm - based on distance parameter, minimum spanning tree MST - based on weighted parameters (a combination of more than one parameter).

The classification in this paper was based on network layer algorithms that are employed in location-based protocol designs to establish energy-efficient communication and in some instances, to establish a compromise between WSN con- straints such as energy, security, bandwidths, etc. Fig. 2 shows the classifications in path selection strategies employed at the network layer to coordinate the routing processes in order to minimize energy consumption.

The classification attempts to group these algorithms used in location-based routing protocols for path selection into various categories as observed in Table 1 for the listed protocols in Section 4. Each category is further explained below:

- *Open Distance Path:* In this approach, the distance alone is used as a metric for determining the next relay node which in turn paves the path, thus variations in this approach are measured based on the progressive distance chosen for propagation. A relay node chosen, based on having the highest progressive distance towards the destination is considered a maximum within a given transmission range. Thus such a strategy is considered as the maximum progress or maximum open distance path selection. Minimum progress is a safe distance established after careful consideration of the range, energy, and other constraints associated with the network. A relay node chosen is said to have made a minimum progress that is progressive enough to minimize say energy consumption or any QoS metric of interest. Random progress is made when the relay node is chosen randomly from a set of nodes within its range. This is mostly employed in protocols designed for secure routing, the random selection of path makes spatial analysis of the nodes' traffic difficult for the malicious observer.

Path selection based on open distance (distance metric alone) is simple and easy to implement in protocols, designers have only one parameter to adjust, in order to enhance or balance the performance of their network. However, since the selection is open, nodes tend to experience path dilation as they tend to deviate from the path leading to the destination in the shortest possible time.

- *Restricted-Distance Path:* In this approach, the distance parameter is used but a restriction is placed on the distance in the form angle for which the propagation range is confined, this helps to minimize node deviation from the path leading to the destined node. When the angle is fixed for the propagation range, only relay nodes within the boundaries of the angle are selected thus a Fixed Angle Based Path. In some instances the angle is made to vary so as to accommodate more nodes within its boundary or a threshold value for the boundary is set to limit the path deviation, in such instances, it is considered a Variable Angle Based Path. Fixed angle and variable angle path

Table 1. Classification using path selection.

	Restricted Distance Path		Open Distance Path			Weighted/Cost Fact Fixed or Path		
Protocols	Fixed Angle	Variable Angle	Maximum Progress	Minimum Progress	Random Progress	Factor-Angle Based	Factor-Distance Based	Factor-Hybrid Based
DREAM	X							
GPSR			X					
GEAR							X	
GEM			X					
IGF	X							
GPER				X				
SELAR						X		
GPVFR			X					
GDSTR			X					
PFR		X						
OGF			X					
MACRO							X	
IMRAFRA								X
SGF							X	
HGR		X						
LACAR							X	
CPR							X	
EAGR							X	
STBPR		X						
LBRP							X	
MGEAR							X	
RCER								X
DEELM				X				X
GB-FERMA				X			X	

selection approaches can further be classified as maximum, minimum, and random based on the progressive distances for which a packet is propagated within an angle-based boundary.

This path selection strategy is an enhancement of the open distance path selection to minimize path dilatation and to reduce energy consumed as nodes deviate from the intended destination due to dilatation. The angle restriction could serve as an advantage in a dense network and a disadvantage in a sparse network where the bounded angle has very limited relay nodes or no relay nodes at all.

- *Weighted/Cost Factor Path:* Here, the criteria for path selection is based on other parameters for instance energy, number of retransmissions, node occupancy period, signal to noise and interference ratio, etc. are selected, and related to either node to node distance, angle (restriction) or both. All parameters are synchronized into a function to produce a weighted/cost factor, this factor is used to determine the forwarding node that paves the path to the destination. When the factor is related to the distance alone, it is considered a factor-distance based selection, and if the factor is related only to the angle, it is considered a factor-angle based selection finally factor-hybrid based selection, when the obtained factor is related to both distance and angle.

This path selection strategy combines the advantages of the two previous selection strategies, it is robust, and reliable as in most cases designers use optimization strategies to obtain the best factor to suit the network's performance. It however very complex and difficult to implement and careful design can lead to improved performance, otherwise the worst should be expected.

The energy efficiency of a routing protocol is not deduced from a single layer's effectiveness in minimizing energy consumption, but rather from the effectiveness of each layer and inter-layer mechanisms utilized to achieve energy saving in the network.

4. The routing protocols

Routing is one of the critical functions required in WSN, it implies the ability to move information collected from one part of the network to another, and this is made possible using network layer routing protocols that have been designed to carry out such important tasks. Due to WSN constraint, when designing a routing protocol, researchers are tasked with a lot of considerations which include but are not limited to:

- *Resource management*
- *Tailored design towards applications (application specific)*

- *Location/navigation capability*
- *Capable of exhibiting Fairness, fault tolerance, reliability, and scalability*
- *Security*

Location information provides numerous advantages in terms of energy conservation and their increasing demands in applications designed for today's technology are simply overwhelming [18, 19]. Location for different data generating and terminating points serve as first-class knowledge for many applications [2]. In CPS design, observability is a critical issue that can only be achieved if sensors and actuators provide the information either through GPS or other forms of triangulation algorithms to extract the location of the observed event of interest [20]. The sensed information together with position information (source and destination) can allow flexibility and energy utilization in the delivery of information, since no time is wasted and the route can be as short as possible when delivering to a known destination (location-wise).

4.1. Location based routing in WSN

Location-based routing (also called position-based routing or geo-routing) is a routing principle that relies on geo- graphic position information, sensor nodes are addressed by means of their location, not IP address. The location of nodes may be available via satellite using GPS or other triangulation mechanisms to provide the location [7]. Location-based routing is centered on two principle assumptions [5, 19]:

- *Every node knows its own network neighbor position.*
- *The source of a message is assumed to be informed about the position of the destination.*

Some location-based routing protocols are table-driven, while others operate without routing tables. Location-based routing is known to have high throughputs, low latencies, and are energy efficient as compared to other routing protocols, and in some instances, allowing nodes not partaking in the routing process to go to sleep. In this regard, this paper reviewed some of the location-based routing protocols that were proposed over the years. The reviewed location-based routing protocols are categories based on path selection strategy as observed in Table 1.

1. *DREAM:* Motivated by the shortcomings presented by most proactive and reactive protocols for mobile ad-hoc networks such as long delay in message delivery, increased overhead in maintaining routes, and unusable address due to mobility of targeted destination, [21] proposed a Distance Routing Effect Algorithm for Mobility (DREAM). DREAM is a loop-free, robust, and adaptive (mobility) protocol that was designed based on Distance Effect and Mobility Rate. The Routing Protocol utilizes a location table (LT) in which nodes gather information about other nodes' coordinates and eliminate the use of a routing table. It was observed that the greater the distance between two nodes (Sending-S and Receiver-R), the less often their entries will be updated in the LT as they will always appear to be moving slowly (position) as opposed to nodes that are nearer to each other whose entries are frequently updated. This is referred to as the distance effect, while the mobility rate stems from the fact that when S forwards a message to R, it first checks the LT to determine R's coordinate, but as R moves the LT is updated thus coordinates keep changing and propagated at a frequency with respect to the mobility of R.

DREAM is bandwidth efficient since it has no need for routing tables but rather LT and route discovery mechanism which incurs a lot of overhead as a result of increased control messages. It has a high delivery rate and low latency as a result of short transmission time instigated by short control messages that carry only location information. However, it utilizes a broadcast propagation mechanism, thus nodes that do not fall amidst the coordinate of S to R are affected since they will have to continuously listen and decline thus consuming energy in the process.

2. *GPSR:* Motivated by the observation made on the rate of topological changes in wireless networks and the need to traverse multiple hops despite limited radio range, [18] proposed a Greedy Perimeter Stateless Routing protocol (GPSR) for wireless networks. GPSR aims to increase scalability and packet delivery with an increasing mobility rate. It utilizes greedy forwarding when propagating the message to its destination, by selecting a next hop node to be a node that minimizes the distance towards the destination. This method of message propagation is advantageous as it only requires the next hop node's information and a dense topology. However, this propagation technique has its peaks as there are instances where a suitable forwarding node is not found as a result of obstacles on the path (dead ends or holes). In such a situation, [22] employed the use of a face routing technique to help recover from dead-end or hole problems experienced. This recovery routing technique routes around the perimeter of the region until a suitable forwarding node or destination is found, thus ensuring message delivery.

GPSR reduces the number of states a node should keep since the node never forwards a packet beyond a single hop, this reduces the control message overhead, which if allowed to luxuriate, may choke the bandwidth and consume energy [1, 7], its recovery mechanism which ensures message delivery provides reliability to the routing process. However, message delivery comes at an increased latency especially when faced with a communication hole problem since the message has to be re-routed around the perimeter of the region until it finds a suitable forwarding or destination node.

3. *GEAR:* Yu et al., in [23] proposed a protocol that considers the fact that sensor network queries may often be geographical in nature, the protocol Geographic Energy Aware Routing (GEAR) propagates a query to the appro- priate geographical region in an energy-efficient manner. It utilizes a geographically informed neighbor selection heuristics to route a packet towards the target region and a recursive geographic forwarding technique to ensure packet delivery within the region [1, 5, 7]. The residual energy and the distance are leveraged in an energy- efficient manner to determine neighbor selection such that the learned cost and estimated cost functions are used to determine the forwarding action within the network. GEAR neighbor selection heuristic considers that:

- When a closer neighbor to a destination exists, it reverts to greedy forwarding in its next hop selection while minimizing the learned cost value (minimizing energy and maximizing distance).
- When all neighbors are far away, thus creating a hole. GEAR picks a next hop node that minimizes some cost value by combining the learned cost and its update rule to provide a substitute route that circumvents the hole.

GEAR is energy efficient as it avoids the use of flooding in packet propagation which is known to be energy- consuming. It also tries to balance energy consumption and increase network lifetime by using the cost functions to efficiently determine routes and make forwarding decisions. However, a low-density network leading to the creation of an empty space can affect the performance of GEAR since a packet continues to search an empty spaced region barring it from the destination node, leading to energy depletion and eventually death of the node surrounding the region since the destination cannot be reached.

4. *GEM:* Newsome and Song in [24] argued the fact that the current method for determining the geographic location of a node is not energy efficient and may be difficult to realize. He proposed Graph EMbeddding for sensor networks (GEM). In GEM, graph embedding takes a known network topology (Guest Graph) and maps it to the actual sensor network topology (Host Graph), mapping consists of a node assignment function and edge routing function used to establish a path that connects nodes in both graphs on a one-to-one basis. The protocol labels sensor nodes in a distributed and efficient manner, like other geographic routing protocols, a node needs its next neighbor label to route a message to its destination. In essence, a label can be considered as that which defines a virtual location.

GEM leverages Virtual Polar Coordinate Space (VPCS) which is closely aligned to the sensor network topology to establish virtual locations (angles) and Virtual Polar Coordinate Routing (VCPR) which is a routing algorithm for the VPCS that ensures reachability to any point within the sensor network topology. When routing a message, VPCR checks to see the availability of a neighbor node that is closer to the destination node, if found, the message is greedily forwarded closer to the destination's angle range coordinate. If however, a neighbor seems to exist (missing link/void) VPCR uses the tree structure to find a path around the missing link by routing to the parent node and then downwards past the missing link to the destined location, since all parent have a link to their child node, after which VPCR returns to its greedy forwarding routing. GEM is a loop-free, route-efficient protocol that ensures delivery even in the face of obstacles and scales well with network size and density [5]. It however overloads the parent node anytime an obstacle or a change in network topology is encountered.

5. *IGF:* In an attempt to combat the excessive delay, message loss, and expensive upkeep of tables in state-based routing protocols, [11] proposed an Implicit Geographic Forwarding protocol (IGF). It is a State-Free protocol that works without the knowledge of the existing neighboring nodes or the network topology [5, 25]. It makes non-deterministic routing decisions, implicitly allowing any opportune receiving node to be the next hop node. The non-deterministic implicit decision-making is based upon Increasing Distance Towards the destination (IDTD) and Energy Remaining (ER) as metrics for the route selection process. Built as a cross-layer/ MAC protocol IGF leverages broadcast within a confined forwarding area when forwarding a message, nodes receiving the broadcast contend for candidacy within a fixed time interval, and the opportune receiving nodes that emerged as the forwarding node further repeat the process until the message reaches the final destination. IGF provides robust message delivery, increasing system stability as all nodes are given an equal chance to contend for the next hop node position, this fair forwarding node election process and rotating communication responsibilities ensure balanced traffic dispersion and a prolonged lifetime of the network. However, the protocol involves a broadcast and contentious mode for next-hop selection these features are known to consume more energy

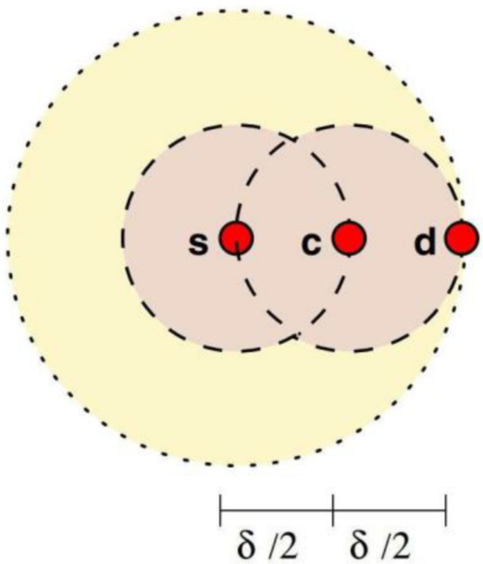

Fig. 3. Effect of using relay node [26].

as nodes not partaking in the communication process are exposed to overhearing.

6. *GPER:* Wu and Candan in [26] tried to mitigate energy consumption by using smaller ranged transmission in the proposed Geographic Power Efficient Routing Protocol (GPER). In the protocol, the location of a node is presumed to be its ID and its network address. Given a final destination *d*, the sending node *s* first routes a packet to a sub- destination *c* within its maximum radio range as shown in Fig. 3. [26] stated that routing a message *m* from sender *s* to a destination *d* (within *s* radio range) via a relay node *c* reduces power consumption than routing directly to *d*.

Where δ is the distance between the nodes. GPER permits each relay node the capability to change the route direction as long as the node that it intends to reach has a smaller distance to the destination and will save energy. It also introduced a forced routing mechanism that guarantees that the routing path generated by GPER is free of infinite loops since there may be cases where the sub-destination may not find a suitable intermediary node to forward to. Like GPSR, face routing using a planar graph is utilized as a preventive measure against routing holes or empty spaces that may exist when routing outside the range of a node. The protocol performs well in a uniform or close-to-uniform distribution, energy consumption of the resulting routes is close to optimal and incurs very low overhead since only local information is utilized for routing. However, it suffers from increased latency since intermediary nodes are always utilized when routing, thus creating more hops before a destination is reached.

7. *SELAR:* Lukachan and Labrador [27] argued that location-based routing decisions need not be only based on location information but rather the amount of energy left in nodes, they also emphasized that energy dissipation must be done in a uniform manner so as to avoid network partition or island of nodes [28]. These arguments led to the development of a Scalable Energy-Efficient Location Aided Routing Protocol (SELAR). The proposed protocol design consideration includes making it scalable, minimum computational overhead, location-aware, and increased lifetime.

Communication using SELAR involves two phases; Control packet dissemination (CPD) and Data packet dissem- ination (DPD). Nodes begin communication in the first phase (CPD) by broadcasting their location and energy level to all neighbors. Subsequent broadcast carries only the node's energy level. When a node needs to send a data packet to the base station, the DPD phase is engaged, it considers all nodes that lie along the forwarding area within the transmission range of the sending node. The sensor node then forwards the data packet to the node with the maximum energy in the forwarding area. In this manner, the data is subsequently propagated until it reaches the base station.

SELAR is also considered a moving base station so as to prevent nodes from energy depletion and to create a sense of fairness and balance in data propagation amongst nodes. The protocol performs well in terms of packet delivery, scalability, and in prolonging the lifetime of the sensor nodes. It, however, uses broadcast in CPD phase, and the continuous table update required for the node's energy level contributes to an increase in energy consumption.

8. *GPVFR:* Routing performance issues led to the development of the Geographic Path Vector Face Routing (GPVFR). The protocol, proposed by [25] utilizes information about planar graphs leveraged through a distributed algorithm "Path Vector Exchange" (PVEX) that propagates and maintains local face information efficiently. Nodes utilizing this protocol will have to maintain extra storage to maintain local face information gained through periodic broadcasts to inform neighboring nodes of their position and face information. The face information stored enables them to make good decisions on the forwarding direction. Also, [29] in-cooperated a tri-modal algorithm that exhibited.

- Greedy forwarding using neighbor information.
- Greedy forwarding using face information.
- Perimeter traversal.

These three modes combined with PVEX yielded GPVFR routing protocol. GPVFR does not require participating nodes to have complete face information to proceed with the routing process. When communication is initiated, the greedy mode of forwarding using neighbor information is employed first. When it fails, packets switch to greedy forwarding using face information with the assumption that it knows of a next hop node along its planar face close to the destination node. A common peculiar problem faced by both modes is that a node may end up not knowing its next hop node or nodes along its planar face other than itself. In such circumstances, the algorithm switches to the third mode known as perimeter traversal or face routing, using a known set of path vectors, the node forwards that packet along the edges of the planar face that contains an imaginary line from node to destination [29].

The protocol can guarantee packet delivery due to the robust path-finding algorithms embedded in it, routing performance is also improved in terms of path stretch and hop stretch. However, the improvement came at the cost of increased storage memory and bandwidth utilization.

9. *GDSTR:* Leong et al., in [30] still attempted to improve the performance in geographic routing by proposing the Greedy Distributed Spanning Tree Routing (GDSTR). The protocol leverages Greedy forwarding and hull tree in packet propagation around the network. A hull tree is a spanning tree where each node has an associate convex hull that contains within it locations of all descendant nodes in the tree. Hull trees provide a way of aggregating location information and they are built by aggregating convex hull information up the tree [30]. In GDSTR each node maintains a summary of the network by broadcasting a keep-alive message periodically to inform its neighbors of its location, view of the root of each tree, and distance in both hop and path distance from each root. These periodic updates enable good decision-making in routing when a packet is propagated. The greedy forwarding is the major routing mechanism for this protocol, hull tree is initiated in the advent of void thus packets undergo only a small fraction of hops before finding their way around the void, hence, switching back to greedy forwarding.

The advantage of combining the two mechanisms is that greedy forwarding yields good stretch and shorter path while the hull tree performs well in mitigating the route void problem, thus improving overall performance, however, the continuous keep-alive messages generated contribute to energy depletion in nodes thus shortening the networks lifetime.

10. *PFR:* Influenced by the distributed cooperativeness of nodes in large sensing tasks and problems associated with local detection and propagation of events, [31] proposed a Probabilistic Forwarding Routing Protocol (PFR). The idea in routing using PFR was to probabilistically favor packet propagation towards the sink within a thin zone of nodes around the line connecting the nodes sensing the event and the sink. The protocol studied under a two- dimensional plane lattice topology made some interesting assumptions about the lattice grain particles otherwise known as the nodes:

- It can estimate the direction of the received transmission.
- It can estimate the distance from a nearby particle that did the transmission.
- It knows the direction towards the sink.
- All particles or nodes have a common coordinate system.

This is achieved in two phases “front phase creation” and “probabilistic forwarding phase”. During the first phase, a thin zone is built using a limited flooding round from the event-detecting node to the sink node to ensure a robust propagation route. In the second phase, nodes propagating the data broadcast its information to all its neighbors towards the sink. The information includes calculated angle Φ and distances of the destination from the propagating node. This broadcast information allows a node to determine the probability of a packet reaching the sink thus number of forwarding phases of the protocol depends on the $\Phi_{threshold}$. Increasing this past the threshold makes the route more robust but at the expense of increased zone and increased energy consumption since energy is minimized by probabilistically favoring certain paths of the network (thin zone) instead of the entire network. The protocol is robust and minimizes energy consumption using a thin zone route for data propagation. However, the continuous propagation along the zone can lead to energy depletion in nodes found within the thin zone.

11. *SIGF:* Wood et al., in [25] pushed the limits in routing protocols for WSN despite their limited resources, they proposed resource-bound security solutions to routing in adversarial environments. The protocol is an enhancement of IGF protocol discussed earlier. Their aim was to provide minimal active security protection while maintaining performance and minimal resource consumption (energy) when no attacks were inflicted on the network. Secured Implicit Geographic Forwarding (SIGF) describes three levels of resource-bound security for which each higher criteria is an improvement of the lower level.

- SIGF-0 uses its non-deterministic property in making forwarding decisions and unlike IGF which operates on a first-come first-serve basis when selecting a forwarding node, SIGF-0 uses both prioritized and randomized methods of selecting forwarding nodes.

- SIGF-1 built on SIGF-0, and also uses location reputation, where a node had to be weighted based on some criteria before selected as the forwarding candidate.
- SIGF-2 employed cryptography to secure communication in nodes.

The protocols (SIGF family) are robust, immune to most security attacks known in WSN, and still maintain performance to a certain extent (especially in the absence of an attacker) while maintaining balance across the network. It, however, requires a high-density network and suffers from increased overhead due to control messages propagated. Other resources such as memory and processing units are strained mostly when cryptography (as a security measure) is applied.

12. *OGF:* Chen and Varshney in [32] proposed an On-demand Geographic Forwarding (OGF) protocol for data delivery in large-scale and resource-constrained static wireless sensor networks with unreliable sensors. OGF like IGF, is a cross-layer routing protocol that combines the tasks of forwarding and explicit contention-based MAC to minimize the complexity of the protocol stack and to improve network performance. OGF uses forwarding tables of small size to maintain route for forwarding subsequent data packets, its communication is based "on-demand", thus if there is no data traffic, no overhead is incurred and it also leverages partial source routing to combat voids or holes found in the network.

When initiating a communication process, a sender S first checks the forwarding table to see if there exists an entry to the targeted destination D. When found, it unicast the packet to the next hop relay node in the entry. The process continues until it reaches D. Otherwise, it resorts to initiating a contention-based scheme to establish and acquire the next–hop nodes succeeding until the destination D is met. If however in both cases no next-hop entry is available (due to void), the sender switches partial source routing which is the void handling mode.

OGF is robust and capable of ensuring delivery even when faced with voids along the routes. It does leverage broadcast during its contention phase only to acquire path and update table for subsequent transmissions, this minimizes the energy consumption in the network. However, its continuous dependence on the table hinders its ability to cope with the changing network topology, also the partial source routing used to remedy the void problem consumes a reasonable amount of energy while it incurs increased delay which affects the performance of the network.

13. *MACRO:* Galluccio et al, in [33] proposed an idea to improve energy consumption in WSN, by tuning the trans- mission power to allow communication range to be varied according to node density and connectivity constraints, this led to the development of MACRO. The proposed protocol is a cross-layer routing protocol that exploits the capability of nodes to use different transmission power levels for data propagation and reliable delivery of packets. Unlike other geographic routing protocols, it does not require an exchange of location information but rather a node should know its own position and that of the destination. It also uses a power-saving scheme that allows nodes to cyclically turn off their wireless interface to minimize energy consumption. A competition is initiated when selecting the next-hop node for which the opportune node is selected based on its progress towards the destination per unit of transmission power.

To initiate communication. A wake-up phase is entered where nodes evaluate their progress factor (distance towards the destination/ transmission power), and the sending node S sends a short WAKE-UP signal for a fixed period, after which the Competing-Phase is initiated. Here S tries to identify the best relay node R from a set of nodes by transmitting a broadcast GO-AHEAD message which in turn triggers competition amongst the set of relay nodes. S selects the node with the best progress factor and relays the message to it. However, if a collision occurs while competing retransmission is triggered by the back-off timer in the same way a CSMA/CA protocol [33]. Nodes not selected automatically switch their wireless interface off to minimize energy.

The protocol performs well in minimizing energy consumption and maintaining balance (fairness) in the network due to its ability to turn off the wireless interface and select nodes based on their progress factor respectively. It however while routing incurs more hops which could result in increased delay.

14. IMRAFRA: The combined idea of hierarchical and geographical routing in a single protocol was put in place by [34] to improve the energy efficiency of WSN. They proposed an Intra-cluster Multi-hop Routing Algorithm based on the Forwarding Restriction Angle (IMRAFRA) and categorized the transmission process into two modes; the one- hop communication mode where the ordinary clusters transmit directly to the cluster head greedily (also used in inter-cluster communication), and the Intra-cluster chain transmission mode where the collected data is forwarded to the cluster head through a pre-constructed chain of nodes. However, in this mode, Yin et al. stated that

the collected data can only pass through intermediate nodes that tend to reduce energy consumption in the angle-limited area.

Intra-cluster communication uses flooding within its cluster to propagate data along the network when the intra- cluster nodes are less than a predetermined threshold (in size), otherwise recursive geographic forwarding approach is used.

IMRAFRA's method of communication by determining low energy communication path with angle limited area to route data minimizes energy consumption and also uses a shorter chain and greedy forwarding strategy to improve latency. However, in a sparse network, finding such paths may pose a serious challenge, and forwarding greedily could be affected by interference, thus hindering performance in the network.

15. *SGF:* Huang et al., in [35] proposed a State-Free Gradient-Based Forwarding protocol (SGF) to mitigate the problem associated with node/link failure in a multiple-hop communication pattern. SGF is a stateless gradient-based routing protocol that selects forwarding nodes opportunistically among multiple candidates using a distributed contention process. The protocol maintains a cost field based on minimum energy consumption called gradient, which provides nodes with an energy-efficient path to forward collected data toward the sink.

When routing using SGF, the contentious forwarding node selection is performed by making checks on the channel condition (link cost), thus the opportune forwarding node is selected based on its channel gain and its minimum cost, defined as the minimum total energy consumed (transmission power) to reach the next hop node. This methodof next hop node selection considers the total amount of energy consumed in transmitting a packet along a path as a better routing metric than hop count.

Unlike other protocols that continuously update their schematics due to a change in the topography or route, SGF changes are tracked by data transmission and do not require updates or refreshing. It is robust, and scalable and ensures data delivery in an energy-efficient manner since it eliminates the use of tables and constant updates in maintaining routes toward the sink nodes. However, path selection by minimum cost in an unconfined direction could lead to path dilation and even looping.

16. *HGR:* Finding a balance between energy efficiency and delay performance to satisfy constraints on specific appli- cations was the motivating factor towards the design of the Hybrid Geographic Routing protocol (HGR). The novel idea of combining two selection criteria; distance and direction when selecting a forwarding node within a network was suggested, such that the node selected made the most progress towards the destination yet had a very small deviation angle [36].

The distance-based scheme is known for making the most progress towards the destination thus fewer number of hops, low end-to-end delay but increased energy consumption, while the direction-based scheme yielded more hops and increased delay but consumed less energy compared to distance based scheme. Committed with the task of determining the eligibility (Qi) of a forwarding node, rules were established such that; the greater the distance, the larger the value of Qi, so also the smaller the direction (deviation angle) the larger the value of Qi. Different forms of Qi can be defined to combine both criteria in order to improve the performance of a specific application [5, 36]. In the situation whereby an application considers varied weights of distance and direction, an adjustment factor a is defined to weigh the impact of both selection criteria on the QoS achieved when communicating, for instance by adjusting delay to minimize energy or vice versa. HGR achieves flexibility in trading off delay for energy consumption and vice-versa thus enabling applications to choose the configuration which works best for their routing task in achieving better performance. However, the tuning and balancing of the hybrid criterion may result in increased computational overhead which may inevitably affect the performance of the network in terms of throughput and the delay itself.

17. *DWSIGF:* Motivated by the shortcomings of SIGF-0 of the SIGF family earlier discussed, [37] proposed a Dynamic- Window Secured Geographic Implicit Forwarding (DWSIGF) routing protocol. This protocol inherits the robust- ness, security, and good performance of the SIGF family and improves on the SIGF-0 (both priority and random) protocol by incorporating dynamic timing into the forwarding node selection process to improve the security- bound property of the protocol. The idea was to confuse the attacker in the network with regard to uncertainty in determining the duration of the collection window used in collecting forwarding nodes. This provided an attacker (malicious node) a slim chance of being chosen as the forwarding node especially when dealing with the blackhole attack.

The protocol outperforms SIGF-0 of the SIGF family in terms of packet delivery in the presence of an attacker and makes it impossible for a malicious observer to perform a temporal correlation analysis for traffic monitoring. It however experiences increased end-to-end delay and incurs a lot of overhead due to the dynamism in timing which causes retransmission when it fails to collect the forwarding nodes needed for the process.

18. *LACAR:* Due to the inherent correlation between congestion and data success rate (delivery) in a sensor network Bhuiyan et al, in [38] deemed it fit to propose Location Aided Congestion Aware Routing (LACAR) protocol. Unlike other reactive congestion control protocols, LACAR tries to proactively prevent congestion from occurring in a network. It leverages information collected from MAC layer feedback (congestion parameters) in making routing decisions in a given network. Information used includes:

- MAC's layer Buffer Occupancy (BO): it determines node congestion level, in other words, the amount of data that is currently queued for transmission.
- Average Number of Transmission Attempts per Successful Transmission (ANAST): determines the link congestion level or its reliability in ensuring delivery.

They suggested a utility function f which is a function of the three parameters used for node selection.

$$f(n_{node}) = a \times \frac{Dn_{node}}{D_{max}} + \beta \times 1 - \frac{BOn_{node}}{Buff_{size}} + \theta \times 1 - \frac{ANASTn_{node}}{Max_{ANAST}} \quad (1)$$

where Dn_{node}, BOn_{node}, $ANASTn_{node}$ are distance of next node *nnode* towards the base station, buffer occupancy of the next node, average number of the transmission attempts by *nnode* per successful transmissions receptively and $a + \beta + \theta = 1$. The node that poses the highest f (n_{node}) value is chosen as the forwarding node.

LACAR next node selection ensures that the shortest but lightly loaded routes are selected and nodes on the route have a sufficient amount of energy to complete the transmission process, this way higher packet delivery rate and minimum congestion cases are recorded. It however consumes energy as a trade-off to good performance in data delivery and as a result of computational overhead incurred in information collection and utilization.

19. CPR: In routing, nodes inevitably drop packets as a result of the cumulative load mounted on them due to transmitting, receiving, and overhearing transmission from neighbors, thus hindering packet flow along routes and network performance. In an attempt to mitigate this problem, Li et al., in [39] proposed a Cost-to-Progress Ratio (CPR) routing protocol. The protocol combines the concept of Cost-to-progress and greedy forwarding to achieve a load- aware geographic routing process in a network, Cost in this context is measured as the load a node possesses while progress is a measure of the advancement made (distance) in its effort to reach its destination [39]. The idea behind this routing protocol is to use both distance and load as a metric in deciding the next hop node such that the risk of selecting nodes that are strained in capacity can be limited.

In CPR, nodes can monitor their load by keeping count of their computation and communication activities such as sending, receiving, and processing, these information are propagated to neighboring nodes by periodic hello messages. Establishing a route from node S (source) to D (destination) through node A is based on A's ratio of cost-to-progress compared to other forwarding nodes within the propagation of range of S, if A possesses the least value determined by the function:

$$f_{CPR}(A) = \frac{Cost(SA)}{|AD| - |SD|} \quad (2)$$

where $Cost(SA)$ is the cost of node A from S, $|AD| - |SD|$ is the progressive distance of A towards the destination D.

20. *EAGR:* Energy-aware geographic routing (EAGR) introduces the use of forwarding node selection criteria based on geographic information, characteristics of energy consumption, and the metric of advanced energy cost to make forwarding decisions [40]. Message forwarding in EAGR involves dynamic adjustment of the transmission power such that it is just enough to reach the selected node. The protocol aims to produce a routing scheme that utilizes optimal energy for routing and data delivery processes.

The protocol includes four main aspects namely:

- *Visible Neighbor information exchange and collection:* position information of nodes within the network is announced periodically via a beacon broadcast message to use their maximum transmission power.
- *Anchor list obtaining:* The anchor list provides the routing path from source to destination, both propagation modes (greedy and detouring) and routes are included in the list. In other words, the list for the routing path is obtained as the union of all detouring mode paths and greedy route paths. When the source node first routes a burst packet to the destination node, the destination on receiving the burst packets generates and feeds the anchor list back to the source nodes before commencing actual transmission.
- *Forwarding node selection:* Based on geographic information, characteristics of energy consumption, and the metric of advanced energy cost, an intermediate or anchor node is chosen. These criteria are all related to the projected distance of a node

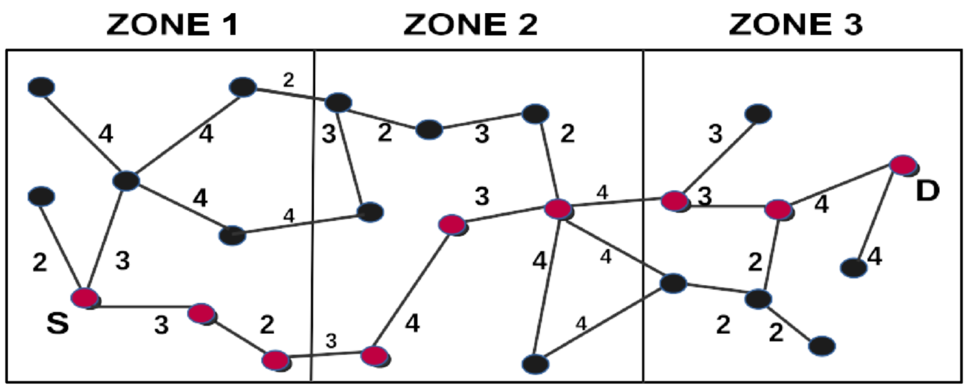

Fig. 4. STBPR routing process [41].

and the distance chosen usually results in optimal energy.

- *Transmission power adjusting and packet forwarding:* Each node adjusts its transmission power such that the power is just enough to reach the intermediate or next-hop node. Dynamic adjustment of the power minimizes the energy consumed and prolongs the node lifetime.

EAGR outperforms GPSR in terms of packet delivery, energy consumption, and average end-to-end delay. However, incurs a lot of overhead as a result of anchor list generation and maintenance which could affect energy consumption.

21. *STBPR:* Vipin and Kumar in [41] proposed the Spanning-Tree-Based Position-Based Routing protocol (STBPR). The protocol uses a minimum number of control packets in creating a route and employs the Maximum Spanning Tree (MST) optimization technique with a greedy approach (DIR) to find the best path from source to destination as packets traverse across zones in the network [41]. As seen in Fig. 4, Each node in a zone uses the DIR to select a forwarding node to propagate packets to (from node to node and zone to zone). The DIR approach which is a greedy approach to selection and propagation utilizes the angle between the next hop, current node, and destination node in limiting deviation from the line connecting the sender and destination.

When a packet is sent, on reaching the receiving node, prompts the receiver to send back an acknowledgment (ACK) signal, this signal allows the sending node to dispose copy of the sent packet that was stored for redundancy purposes in case of a loss. In the case of a failed route, an ALT message (seeking an alternate path) is repeatedly transmitted till a route is discovered [41].

The protocol's use of the maximum spanning tree optimization technique to prevent loop formation, also avoids flooding as a propagation mechanism, to limit the transmission of unnecessary control packets and guarantees packet delivery using the best forwarding path across the zones. However, it does not scale well as it shows an increase in end-to-end delay as the number of nodes increases in the network. Limitations in sensor memory could prevent another packet from being accommodated in the network as a result of a failed Acknowledgment (ACK) packet, this prevents disposing of the previous packets sent.

22. *LBRP:* The Location-Based Routing Algorithm for Wireless Sensor Networks (LBRP) [43] uses a greedy forward- ing approach where nodes forward packets to the neighbor node closest to the destination. The Location Service Module (LSM) tracks network node locations using a beacon-based technique, and the source node adds destina- tion location to packets. Intermediate nodes extract the destination location and trigger the LSM to determine the next hop. If a more recent destination location is known, the intermediate node updates the packet and routes it towards the new location. The introduction of intermediate nodes reduces the beaconing frequency, resulting in better resource utilization.

LBRP shows better performance in terms of energy consumption, end-to-end delay, and delivery rates as compared to other routing protocols. However, LBRP was never tested in real life scenario.

23. *MGEAR:* In [44], the authors proposed a modified energy-efficient geographical routing protocol (MGEAR) using a gateway node. The whole network is divided into four logical regions; in which two regions use direct communi- cation and the rest two regions use clustering hierarchy. The gateway node is deployed at the center of the sensing region in order to reduce the transmission distance of each node and then lead to reduced energy consumption and increased network lifetime. By the use of GPS, the distance between the nodes is determined prior to data transmission.

In the MGEAR protocol, at the first round, the cluster heads are earmarked in each region. Then, in the subsequent rounds, the cluster heads are determined based on the distance between the nodes and the probability of residual energy within the nodes. This process curtails the energy consumption of the nodes which is manifested in terms of their lifetime. However, MGEAR protocol did not consider the link quality metrics which may lead to reduced packet delivery ratio and throughput.

24. *RCER:* Haseeb et al. [45] introduced a reliable cluster-based energy-aware routing (RCER) approach in WSN for maximizing network lifetime along with decreased routing cost. To achieve energy efficiency, the network is partitioned into geographical clusters. Based on the residual energy factor, hop count, and weighted value of Round Trip Time (RTT) factors, the next hop is selected to achieve optimal routing. (RCER) approach increased the performance of data delivery but failed to evaluate the performance of mobile sensors. Furthermore, nodes with lower energy levels have a lesser chance of being selected in path selection. Moreover, RCER increases the integrity of the transmission process due to multi-criteria next-hop selection.

25. *DEELM:* Karthick et al. [46] proposed a routing protocol based on Energy Efficient for improving network lifetime in WSNs. The researchers is explored a Dynamic Energy Efficient Localization model that able to decrease the total amount of energy consumption by constraint on the geographical location of all selected nodes. In order to achieve a great outcome, a cluster region is designed with a Cluster Head (CH), and server nodes are selected that focus on significant parameters, i.e. the delay between nodes, node energy, and the total distance between nodes. Network topology is considered very important for their research in association with the deployment of the node with correct accuracy outcomes. Furthermore, there are a number of paths are revealed to route the packets with the selection of the least route metric, and reliable path. In this scenario, the proposed method using the network simulator tool with various parameters was taken that showed robust improvement and obtained high accuracy and performance.

26. *GB-FERMA:* Wang et al [47] propose an efficient grid-based geocasting scheme for WSNs. GB-FERMA uses the Fermat point theorem to search for the specific nodes as Fermat points in a grid-based WSN, and it selects the optimal relay nodes (gateways) in the grid structure to realize energy-aware forwarding. The proposed scheme overcomes the compared protocols in terms of energy consumption and network lifetime. However, the authors have not evaluated the proposed work in terms of transmission delay which may be increased in large-scale networks.

4.2. Analysis of the protocols

The analysis begins with the matching of the location-based protocols to the proposed path selection strategy as seen in Table 1. It can be observed that the path selection strategy employed in a protocol design does affect the energy consumption and scalability of routing protocols. For instance, when a protocol uses the variable angle (restricted distance) path-based selection process, it tends to control the number of neighboring nodes exposed to its broadcast signal since the more nodes within the range of broadcast, the higher the energy consumed in both the broadcasting node and the nodes receiving the broadcast. HGR [36] and STBPR [41] have a variable-restricted path-based selection and are capable of limiting the nodes exposed to their broadcast signals. These together with other features have enabled the protocols to exhibit good scalability and medium energy consumption level as shown in Table 2. While GPSR classified as maximum open distance based suffers rapid energy loss (Table 2) and has a poor chance of scaling (limited). Other features influencing the energy consumption and scalability features of the network include:

4.2.1. The Dissemination/Forwarding process

These are the methods employed to propagate or forward packets of information within a given network. It should be noted that these processes are not responsible for node selection as node selection is completely based on the path selection strategy discussed earlier. These processes include:

- *Flooding:* This is a process where information is communicated to every node in the network except the node sending the information. This implies that in a network with n node size, a flood will require that all n-1 nodes in the network capture the same information the single node has [5], [42]. Flooding is extremely robust, ensures reachability, and does not require a recovery mechanism. It however consumes a lot of resources (energy, memory, processing power) and when sensing an event nodes within the same station end up duplicating messages which also adds to energy consumption as all n-1 nodes will capture duplicate messages [5].
- *Recursive Geographical Forwarding:* In this approach a target region is selected and packet dissemination takes place by splitting the sensed

Table 2. Summary of routing protocol.

Protocol	Objective	Topology Build up Process	Forwarding and Path Selection Strategy	Scalability	Energy Efficiency
DREAM [21]	Ensure reliable Packet delivery, while minimizing overhead to improve energy	Periodic Message (Broadcast) to build location table (LT)	Restricted directional forwarding to any node found in its LT within a given range towards the destination	Limited	Low
GPSR [22]	Improve protocols adaptability to increasing scalability and mobility while ensuring reliable packet delivery.	Ranged periodic message (broadcast) of nodes position	Ranged greedy packet forwarding and perimeter face routing in hop nodes	Limited	Low
GEAR [23]	To reduce and balance energy consumption by avoiding the use flooding dissemination technique.	Uses a simple HELLO messaging to determine location, and remaining energy level	Restricted directional flooding for less dense topology/region while Recursive geographic forwarding for dense region.	Limited	Low
GEM [24]	To provide efficient routing in an imprecise topological setting while making proper use of energy	Virtual space (VCPS) construction using broadcast and advertisements messages to establish locations (label) which are more of angle coordinates.	VCPR leveraging greedy forwarding to propagate packet to reachable nodes and parent node reroute procedure to reach unreachable destination	Good	Medium
IGF [11]	To improve on weakness observed in state-based protocol parameters such as delay, delivery, energy consumption.	Assumes nodes have knowledge of their locations and uses contentious buildup	Restricted broadcast with distance based forwarding for path selection and packet propagation.	Limited	Medium
GPER [26]	To reduce total energy consumption in a network by using relays (intermediary nodes) and smaller transmission range	Assumes nodes have knowledge of their location thus a Neighborhood graph is built indicating distances, range which transmitting nodes periodically learn (periodic update)	smaller range broadcast using distance based minimum path algorithm for minimum energy consumption path and perimeter routing to bypass voids in the network	Limited	Medium
SELAR [27]	To improve on energy depletion problem, scalability, robustness and to reduce protocol complexity	Nodes send broadcast to build a routing table with information on location , energy , time and identification (ID)	Variable zone (range) is used in path selection and weighted/cost factor based on maximum energy forwarding scheme is used for packet propagation.	Limited	Medium
GPVFR [29]	Improve routing performance in terms of reduced path and hop stretch	Path Vector Exchange Protocol (PVEX) used to maintain local face information by sending periodic beacon broadcast to provide nodes position and face information.	Uses greedy forwarding using neighbor information, uses greedy forwarding using face information and perimeter traversal	Good	Low
GDSTR [30]	Improve routing performance in terms of reduced path and hop stretch and to ensure hitch free routing in the face of void.	Convex hulls aggregate location information of nodes through periodic broadcast of keep alive messages	Greedy forwarding used for packet propagation to destination route and tree routing when a void is encountered.	Limited	Low
PFR [31]	Minimize energy consumption in local detection and propagation of events	Other assumption about position were made and the buildup process involved flooding a thin zone to define a route source to destination	Restricted broadcast based on direction and distance of nodes. a threshold is also set to limit route within the thin zone	Limited	Medium

(*continued on next page*)

Table 2. Continued.

Protocol	Objective	Topology Build up Process	Forwarding and Path Selection Strategy	Scalability	Energy Efficiency
SIGF [25]	To enable resource bound security in WSN routing while maintaining performance and fairness in the network	Assumes node have knowledge of their locations and uses a contentious build up process	All family members broadcast within ted in a fixed angle with differences as per; SIGF-0 and SIGF-2 using the restriction with distance based forwarding, SIGF-1 employs weighing factor considered as reputation.	Limited	Medium
OGF [32]	To improve routing performance by improving energy, delay and delivery of packet in a large scale, resource constrained static network.	Nodes have knowledge of their location and uses table and contention based scheme to build up a table	Table is used to unicast packet if forwarding location is found in the table, otherwise a distance based broadcast in the destination's direction is used for propagation.	Good	Medium
MACRO [33]	Reduce energy consumption to prolong network lifetime by tuning transmission power in accordance with node density and connectivity constrain	Assumes node has knowledge of its position and the position of its destination node.	Distance based broadcast used in a contentious mode to determine a weighted/cost progress factor that is used to select a forwarder.	Limited	Medium
IMRAFRA [34]	To reduce the on energy consumption and delay involved in data transmission in a network.	Neighbor list is built up containing neighbors location and energy value	Inter-cluster uses a greedy forwarding while Intra-cluster queries are disseminated using a simple flooding or recursive geographic forwarding and	Good	Medium
SGF [35]	To address the issue of node/link failure in multi-hop network.	Assumes nodes have knowledge of their position and gradient thus state-less and update of these gradients are based	Broadcast based on minimum cost value depending on distance is used to the decide forwarder along the path.	Limited	Medium
HGR [36]	To achieve an efficient tradeoff between energy efficiency and delay performance in a network.	Nodes have knowledge of their location and use contention based scheme to build up a table	Weighted factor agreed for both distance and direction thus the name hybrid. It can otherwise resorts to the use of either direction or distance only.	Good	Medium
DWSIGF [37]	To improve security in routing by minimizing the chances of choosing an attacker while maintaining performance efficiency.	Assumes node have knowledge of their locations and uses the contentious buildup process.	Restricted broadcast with distance based forwarding using a contention-based approach are utilized for path selection and packet propagation	Limited	Medium
LACAR [38]	To reduce congestion and improve reliability.	Assumes each node knows its location, energy information, buffer list and transmission attempt list. Thus uses contentious build up based on defined function for node selection.	Ranged broadcast with distance values are used to deduce path. And forwarding is based on highest weighted value (f) to suggest path that is shortest and lightly loaded.	Limited	Low
CPR [39]	To improve on routing performance by reducing the number of packets dropped as a result of node overload.	Periodic HELLO messages communicate location information and load	Weighing/cost factor is used to propagate packet towards the destination. Weighing factor is inversely proportional to distance value.	Limited	Medium
EAGR [40]	To minimize energy consumption for end-to-end delivery.	Periodic beacon broadcast containing node location information	Anchor list formation which outlines the routing path to be followed. Path is formed by collecting advance energy cost of each node as their weighing/cost factor.	Good	Medium

(*continued on next page*)

Table 2. Continued.

Protocol	Objective	Topology Build up Process	Forwarding and Path Selection Strategy	Scalability	Energy Efficiency
STBPR [41]	To find the shortest path to the destination while avoiding unnecessary transmissions	Assumes nodes have global knowledge of their position and that of neighboring nodes	Uses directional routing (DIR) greedy routing approach that restricts flooding	Good	Medium
LBRP [43]	To find the neighbor node with shortest path to the destination node	Assumes nodes have global knowledge of their position and that of neighboring nodes	use LMS to provide the location of the next hop, the destination location and keeping track of the network nodes' position	Medium	Good
MGEAR [44]	To reduce energy consumption and enhance the network's throughput	Network divided into four logical regions, two of which communicate directly while other two regions use clustering hierarchy	Nodes in first region communicate directly to sink node, whereas nodes in second regions communicate with gateway node while nodes in other regions use clustering hierarchy to transmit data to the gateway node.	Limited	Good
RECR [45]	Ensure reliable Cluster-based Energy-aware routing to increase network lifetime	Assumes nodes have knowledge of their locations and uses contentious buildup	Use of fitness function to determine Forwarder Point (FP) node based on hop-count, residual energy and Weighted Round Trip Time	Limited	Good
DEELM [46]	To improve packet delivery ratio, least packet loss percentage, least delay, more throughput	Network topology is derived to locate sensor nodes in the cluster region and the route cost and packet forwarding capability of routes decides the selection of reliable routes in the cluster region	path selection between cluster members is chosen based on energy level, distance and delay	Good	Meduim
GB-FERMA [47]	To reduce energy consumption, minimize delay and improve network lifetime	For each cell,a node *v* broadcasts the head query message to all neighbor nodes for cell head election	Grid-based shared tree path Greedy routing with optimal relay nodes	Meduim	Good

information and continuously forwarding it to four (4) sub-regions within the target region until the stop condition has been satisfied [23, 42]. It is energy efficient and the stop conditions are made in such a way as to minimize the utilization of node's resources. It however does not work well in a low density network and fails to terminate the recursive process, thus causing energy depletion in nodes.

- *Greedy Forwarding:* This forwarding approach is used to push information from source to destination, its decision is made based on optimization criteria and does not ensure the reachability of information from the source to the destination [38]. Communication using greedy forwarding is energy efficient as it only requires the metrics agreed upon for optimization. Metrics such as distance, power, cost, delay, etc, or their combinations are used. However, the forwarding approach may lead to holes or voids which might further require recovery mechanisms that are quite energy-demanding [42].

4.2.2. The topological build-up process

The topology build-up process is the way nodes build up connections among themselves and they cope with changes as a result of incoming nodes (new) or outgoing nodes (depleted nodes) during the routing process. Some of the processes in this study include:

- *Periodic Messages and Table list:* In these messages (hello messages, advertisements, keep-alive messages, etc) nodes provide their personal information to their neighboring nodes over a fixed period of time, information such as energy, location, delay, utilization, etc. is shared, and sometimes, the information gossiped over the network. Nodes still post updates of such information to their neighboring nodes even after a routing process or event is completed.

Similarly, in a table list topology build-up, nodes in some instances need to keep track of a particular information within a network while maintaining other information. For instance, in a static network, the node location is important despite its static nature but its residual energy might be needed after an event occurrence thus the need to update the information. Nodes build up a table list of all information required and make future plans based on the table list.

Both approaches (periodic messages and table list) are robust, and reliable but also suffer from update issues which consume energy. Scalability issues as in most cases, are associated with limitations in memory, a node cannot accommodate huge table lists or information updates of increasing number of nodes in the network.

- *Contentious buildup: Topology based on a contentious medium forces the nodes to compete for a position in the network after receiving a broadcast signal requesting a relay node. The process ensures balance in the network since each node is given a fair chance to compete. However, the buildup is not reliable as a collision in the contending nodes could result in zero node selection and retransmission of the broadcast signal which can eventually lead to unnecessary energy consumption in the network.*
- *Assumed Cases: Protocol designers in some cases make assumptions as to node information and topologies based on location service devices such as GPS. For instance, assumptions made as nodes having general knowledge of their network, assumptions make relaxed judgments on constrained resources in wireless sensors and ad-hoc networks. The approach is quite robust and allows different results to be achieved but at the cost of reliability.*

These features, together with the proposed path selection strategy classification lead to the inferences on energy efficiency and scalability of the studied protocols as seen in Table 2. Hence, other routing protocols not mentioned in this study can also be categorized using the proposed strategy to obtain information regarding energy and scalability.

5. Open research issues

Although the above-reviewed routing techniques look promising and have achieved notable performance in terms of energy consumption and network lifetime, there are remaining open issues that have to be considered when designing an efficient routing protocol in WSNs. These remaining open issues could be future work for new research. Some of these future directions are highlighted and pinpointed as follows:

1. *Packet delay:* The time of sending a packet from a sender node to the destination needs to be taken into account when designing an efficient routing protocol. In some WSNs applications, the time of packet delivery is a very important factor especially when an action needs to be decided on time.
2. *Quality of service (QoS):* It is important to consider the QoS when designing an energy-efficient routing protocol in real-time WSN applications. Real-time applications require guaranteed bandwidth throughout WSNs.
3. *Data security:* With increasing demand and usage of WSNs in varied fields, the security of data collected has been a main challenging issue recently. Besides energy efficiency and QoS, routing in WSNs needs to be secure.

6. Conclusion

Location-based routing is one of the most explored and forecasted protocols of the future due to their ability to adapt to changing topology and minimize energy consumption in their routing process, location awareness, and ability to work in infrastructure and infrastructure-less environments. These abilities have led to the swift amalgamation of the WSN technology with the rising CPS technology. In this paper, the study showed that most of the proposed routing protocols aimed to enhance energy consumption and improve network lifetime while other performance metrics were left behind such as packet delay, QoS, and data security. Moreover, the proposed classification on path selection can enable researchers to narrow down their choices when deciding how a node should be selected during the routing process to achieve their desired goal of the design. It was inferred that path selection, information dissemination, and topology build-up process also influence energy consumption and scalability in a network and it is believed that through proper selection of the features, researchers can achieve more in the design of scalable, robust, energy-efficient protocols for the WSN.

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