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A Review of Routing Mechanisms in Wireless Sensor Networks

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***Abstract*— Research on Sensors is one of the major topics in computer and electronic fields. They used to monitor and control the physical environment such as buildings, forests and battlefields. According to these applications, sensors are expected to be functional for a long period of time. Since the sensor networks include many low cost and low power sensor nodes, a great effort is devoted to develop new protocols that use these limited resources efficiently. In this way, routing protocols play the key role to enhance the network parameters. In this paper, we classify the routing mechanisms into four categories. This classification consists of flat, hierarchical, QoS and geographic routing protocols. Moreover, each class can employ multi-path technique to decrease end-to-end delay and increase network lifetime. We categorize different multi-path strategies into link-disjoint and node-disjoint mechanisms and discuss them in details. This paper covers a variety of famous protocols, which motivate potential ideas for future works. We finally present a comprehensive comparison among various routing protocols.**

***Index Terms*— Wireless sensor networks (WSNs), Routing protocols, Energy-Efficiency and Multi-path**

I. INTRODUCTION

WIRELESS sensor network (WSN) is a kind of network, which includes many smart devices, called sensor nodes plus one or several sinks, randomly deployed in a wide area. These nodes are spatially distributed in order to perform an application-oriented global task [1]. The basic component of the network is the sensor. It is necessary for measuring real world physical conditions or variables such as humidity, pressure, temperature, vibration, pollutants, sound, motion, and intensity. These tiny devices within the network are smart and inexpensive. Such properties make them to cover large areas of any geometry [2] [3] [4].

One of the most important design and implementation requirements of a typical sensor network is energy efficiency.

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For instance, some environmental monitoring networks must do their duty in a long period of time (several months even a few years). On the other hand, some applications request multimedia information transmission which leads to new real-time and delay-constrained routing mechanisms. To address these issues, routing protocols in network layer has received a lot attention and is considered a great challenge for WSNs [5]. Thus most of researchers focus on the design of a new protocol for network layer in WSNs in order to improve network parameters such as lifetime and latency.

This paper firstly proceeds to categorize energy-efficient routing protocols from the network structure point of view. This taxonomy includes flat, hierarchical, QoS, and location-based routings. Due to the large number of nodes in sensor network, flat protocols employ data centric method that helps in omitting a large amount of redundant data transmissions. Hierarchical protocols try to save energy through clustering the sensors. In this way, data gathering and reduction will be done by cluster heads. Some network metrics should be guarantee in QoS routing mechanisms. Geographic protocols use the location information to forward the data towards the desired zones rather than the whole sensor field [6].

Multi-path method is an effective technique utilized to avoid network partitioning phenomenon and data transmission latency caused by packet loss. Therefore, a main part of this research discusses some multi-path routing mechanisms used to enhance network lifetime and end-to-end delay.

This paper is organized as follows. In section 2, a high level classification for routing protocol in WSNs is presented. Section 3 discusses different multi-path strategies in details and section 4 shows a comparison among various routing protocols. Finally a conclusion is made in section 5.

A. Routing Challenges and Issues

Routing in wireless sensor networks is very challenging. Firstly, it is impossible to use a kind of global addressing method like classical IP for this kind of networks. Secondly, all applications require the flow of sensed data from multiple source nodes to a particular sink. Thirdly, a significant redundancy generated by multiple sensors should be exploited by the routing mechanisms to enhance bandwidth and energy utilization. Finally, sensor nodes are extremely energy constrained and thus require careful resource management.

Therefore, many new mechanisms are proposed for the issue of data routing in WSNs due to such differences [6].

II. Routing Protocols for WSNs

A. Flat Protocols

Multi-hop flat routing protocols basically are the first category of routing protocols. In these networks all the sensor nodes do the same task and collaborate with each other to sense and forward data to the sink node. SPIN and Directed Diffusion [6] are two special types of data centric routing which have designed to eliminate redundant data and save energy through data negotiation. So many other protocols have been motivated by these two protocols that follow the same concept.

SPIN (Sensor Protocols for Information via Negotiation) is a series of resource adaptive protocols. SPIN uses three kinds of messages in separate phases, ADV, REQ, and DATA. New data will advertised by ADV message to all neighbors of a source node and those who interested in data will reply by REQ. so DATA is the real message itself. ADV message only consists of metadata that describes a node collected data. So it conserves energy by sending and receiving small advertisement messages. A user also can easily send query to each node and immediately get the required information. On the other hand, this protocol saves energy by sending no redundant data through the network in time driven manner. SPIN-2 and SPIN-PP are two energy efficient family of SPIN-1. In SPIN-2 a node participates in protocol if and only if it has enough energy to complete all three steps of protocol. So it prevents packet loss and save energy. An energy heuristic model has been attached to SPIN-EC which designed for P2P communications. The main drawback of SPIN family is that they cannot guarantee the message delivery by their data advertisement scheme but from the point of energy it acts better than flooding and gossiping [6].

Directed diffusion is one of the famous data centric protocols. In this algorithm, some attributes should be attached to sensed data by sensor nodes. Sink nodes used to propagate interests to receive relevant data based on these attributes. Gradients to the sink node could be implemented while the relay nodes forward interests to their neighbors in order to find a source node that satisfies the interest. Directed diffusion employs multi-path method for multiple queries. If the sink node recognizes that one or several paths have better link quality, it starts to reinforce them while negative reinforce the others. This algorithm can conserve a large amount of energy due to flooding interest if essential. However, using attribute-based naming mechanism is extremely application dependant and it is the main drawback of this kind of protocols [6].

Rumor routing [7] uses the same idea as directed diffusion. In this algorithm a Long-lived packet, called agent, carry new events through the network. A node generates an agent as soon as detects an event. Then it adds the event to its events table and sends the agent into the network. It propagates information about local events by meeting intermediate nodes until its TTL will be expired. However it reduces energy consumption by preventing the network from query flooding but the cost of maintaining a large number of agents and huge event table will be prohibitive.

MCFA (Minimum Cost Forwarding Algorithm) that proposed by Ye et al. [8] is a kind of data centric routing which maintains the least cost estimated from each node to the sink. The idea is that a node which sensed a new event broadcasts a message to its neighbors. After that neighboring nodes check if they are on the least cost path between the source and the sink. If this criterion is correct, it rebroadcasts the message to its neighbors again. This procedure repeats until the sink node is reached. Though this protocol cannot support mobility but reduce energy consumption by using energy factor such as residual energy in cost formula.

GBR (Gradient-based routing) which proposed by Schurgers and Srivastava [9] is a member of directed diffusion family. Each node calculates a cost based on the number of hops when the interest is diffused through the network. Thus the minimum number of hops to the sink will be assumed as node height. Meanwhile, the gradient on the link is the different between a node's height and its neighbors so that packet forwarding performs on a link with the biggest gradient. This protocol uses three different techniques to spread traffic over the network and prolong its lifetime. One of them is "energy-based scheme" where a sensor node increases its height when its power falls off below a certain threshold. As a result, in terms of total communication energy this algorithm is more successful than directed diffusion.

COUGAR [10] is another data centric protocol which assumes the network as a large distributed database system. It separates the query procedure from network layer functions and put it between network and application layers as the query layer. In order to obtain more energy efficiency, COUGAR exploits in-network data aggregation. Nevertheless, extra query layer may ends to higher overhead and more energy consumption.

EAR (Energy-Aware Routing) which designed by Shah and Rabaey [11] is the last flat protocol, has been addressed here. The main goal of this protocol is to prolong the network lifetime. However Energy-Aware Routing protocol is the same as directed diffusion, it is different from the point of route maintenance. It doesn't reinforce the path with higher rate or negative reinforce the other ones so that it tries to maintain a multi-path between the source node and the sink. It manages these paths according to certain probability and the amount of energy consumption in each path affects on the value of this probability. The protocol chooses a path at different times, Thereby; the energy consumption spreads on all nodes in the network uniformly. It prevents energy depletion on the single path, hence, prolong network lifetime. Experiments show that Energy-Aware Routing protocol provides 21.5 percent improvement in energy saving and 44 percent in network lifetime rather than directed diffusion. However, it requires addressing mechanism for each node, which makes hard route setup in this protocol.

B. Hierarchical Protocols

In a hierarchical architecture, nodes with higher energy introduce themselves as cluster heads and aggregate the data from sensor nodes with lower energy that called cluster members. This scheme accompany with data aggregation and fusion in cluster heads used to perform energy-efficient routing in WSNs [6].

PEGASIS (Power-Efficient Gathering in Sensor Information Systems) is a different kind of hierarchical protocols in this group. In this chain-based protocol, nodes only communicate with nearest neighbors. Therefore, they form a chain and select a sensor node as a chain header per round which is responsible to send aggregated data among the chain members to the sink node. By using collaborative techniques and local coordination between nodes, PEGASIS could improve the network lifetime significantly. However, it has many drawbacks like extravagant delay for nodes which are far away from chain leader and a single header that may become a bottleneck in the network [12].

TEEN (Threshold-Sensitive Energy Efficient Protocols) is designed for time-critical applications. It forms a multilevel hierarchical clustering in which, sensor nodes continuously sense the interested area but turns the radio on and transmit the data only if the sensed value changes excessively. So there is no periodic transmission. In addition CH sends a hard and a soft threshold to its members. According to hard threshold, a member sends the data to the CH only if the data value is in the range of interest. Meanwhile, soft threshold specifies the amount of changes in data value. Thus, it prevents transmitting data to the CH whenever there is nothing or a little change in data value. It results in a huge amount of energy saving. However, the main drawback of this algorithm is that the node cannot send any data to the user until receive threshold messages [6].

There is another version of TEEN protocol that introduced by Manjeshwar and Agarwal [13]. They named it *APTEEN* (Adaptive Periodic TEEN) and tried to eliminate TEEN's problem by addition parameters applied to sensor nodes in each cluster. By defining a specific time that periodically forces the nodes to send their reports to CH and using a TDMA-based scheduling between cluster members to perform this communication, APTEEN can omit the ambiguity between packet loss and unimportant sensed data which indicates no significant changes. In this way they obtain a drastic improvement in energy conservation and network lifetime. Nevertheless both of mentioned protocols suffer from high overhead and the difficulty of forming multilevel hierarchical clustering.

C. QoS-Based Protocols

The network should balance between data quality and energy consumption in this kind of protocols. Moreover, the network has to satisfy certain QoS parameters such as bandwidth, delay, energy at the time of data delivery to the sink [14].

One of the first routing algorithms for WSNs that applies the notion of QoS in the routing decisions is named *SAR* (Sequential Assignment Routing). This protocol aims to achieve energy efficiency and fault tolerance by the help of table-driven multi-path mechanism. Energy resources, the priority level of each packet and, QoS on each path are three factors used for routing decision in this protocol. Furthermore, a multi-path and localized path restoration schemes are utilized to avoid single route failure. Sensor nodes can send data to a set of sinks based on a tree mechanism rooted at the source node. Sensors with low energy are avoided to become elements of the paths of the tree. A path re-computation is needed if topology changes due to node failures. In addition, SAR uses the additive QoS metric accompany with the priority level of the packet to calculate a weighted QoS metric. So, the algorithm tries to minimize this metric during the whole of the network lifetime. Since, it's a table-driven protocol; maintaining the tables and states at each sensor node especially in fully dense networks imposes a large amount of overhead on the routes [6].

Power Aware Smart Routing is another protocol in the venue of QoS based schemes in Wireless Sensor Networks. Network lifetime and Quality of information are two QoS parameters which provided to the sink. However, there is a number of ways to define Quality of information; but sending a general definition of relevant data to the sink in a timely manner is a usual approach. So, the aim of the tiny CPN WSN routing protocol is achieving these goals while minimizing the power used. Utilizing smart packets to find a reliable low-power route between source and destination pairs in packet switched networks is the main objective of smart routing scheme. There is an attempt to maximize the quality of service by forwarding the smart packets in a way that minimize some metrics such as packet loss, round trip delay, or a combination of them. Finally, these routes will be used by dumb packets which carrying data payloads [14].

D. Location-Based Protocols

Location-based routing, also named geographic, directional, position-based, or geometric routing, is another approach in which every node is aware about its own and its neighbor's positions. In addition, the source of data should know the position of the destination that is mainly the sink node in WSNs [14]. The location information can easily obtain from a low power GPS that communicate with a satellite [15]. Nevertheless, some solutions can be used to limit the GPS usage in order to save energy significantly. In [16], only a few nodes are equipped by GPS devices and other sensor nodes can calculate their position according to incoming radio signal strength at the deployment phase. GPS-free approach which proposed by Savvides et al. [17] and Capkun et al. [18] is another way to energy conservation. In the subsets of this section, some of the single-path and multi-path location-based routing protocols are described.

E. Greedy Forwarding Scheme

Upon this algorithm, forwarding decisions will be limited to information about the position of the current forwarding sensor node, its one hop neighbors and final destination which is sink node. In this way, a source node compares the location of the sink to itself and also to its neighbors. Then, it chooses the neighbor which is closest to the sink in order to propagate the message (Fig. 1). Each relay node repeats this greedy scheme until the sink node is reached eventually [19]. However, the access to the sink is not deterministic in some cases which described in the holes problem section. There are some metrics which have been proposed for the concept of closeness. Nevertheless, the projected line and the Euclidean distance are the most popular ones joining the source node and the sink. Thus, the network can resist against the topology changes by restricting the flooding processes to one-hop in this strategy.

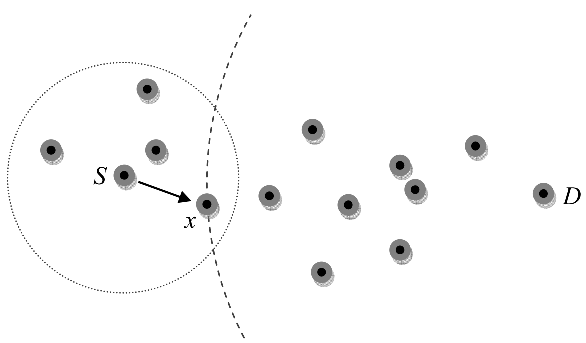

Fig. 1. y in greedy forwarding is x's nearest neighbor to D [24]

Different policies may be fined in literatures for the selection of the next-hop node in geographic routing. In order to express these policies, Medjiah et al. [20] takes *d* as the destination node, *u* the current forwarding node and *v* the next relay node in the network. In the following such policies have been described.

- Compass routing (DIR): In this approach, if the angle $\angle vud$ is the smallest among all neighbors of *u*, then the next relay node is *v*.
- Random compass routing: Assume *v1* and *v2* are two nodes above and below the line *ud* that minimize the angles $\angle v1ud$ and $\angle v2ud$ among all such neighbors of *u*. Then the authors showed that *u* can choose one of the *v1* or *v2* nodes randomly to relay the message.
- Greedy routing *(GEDIR)*: if the distance $\| vd \|$ is the shortest among all neighbors of *u*, then the protocol can select *v* as the next forwarding node.
- Most forwarding routing *(MFR)*: In this approach, it assumes that *v'* is the projection of *v* on the line *ud*. So, the node *u* can select *v* as the next relay node if $\| v'd \|$ is the shortest segment among all neighbors of *u*.
- Nearest neighbor routing: in this state, the protocol initially defines angle α and then, the node *u* looks for the nearest node *v* as relay node among other neighboring nodes of *u* so that $\angle vud \leq \alpha$.
- Farthest neighbor routing: in this state, the protocol initially defines angle α and then, the node u looks for the farthest node v as relay node among other neighboring nodes of *u* so that $\angle vud \leq \alpha$.
- Greedy compass: This method use a technique in which The packet is relayed to the node of {*v1, v2*} with minimum distance to *d* so that *v1* is one of the *u*'s neighbors that makes the smallest counterclockwise angle $\angle duv1$ and *v2* is another one that makes the smallest clockwise angle $\angle duv2$ among all other neighboring nodes of *u* with the line *ud*.

F. The Holes Problem

Greedy forwarding, generally regards nodes in forward direction according to distance or progress factor. Since, there is a concern about routing loop, it is impossible to choose a node in backward direction as the packet get closer to destination. On the other hand, the existence of a path between source and destination cannot guarantee packet delivery in greedy routing manner. This state has been shown in fig. 2 where the packet sent by source node S to destination D is rejected at node *x*, since all of its neighbors (*S* and *y*) are in the backward direction. In fact, node *x* in which, greedy algorithm is stopped is called a concave node and such a condition is termed local minimum [21].

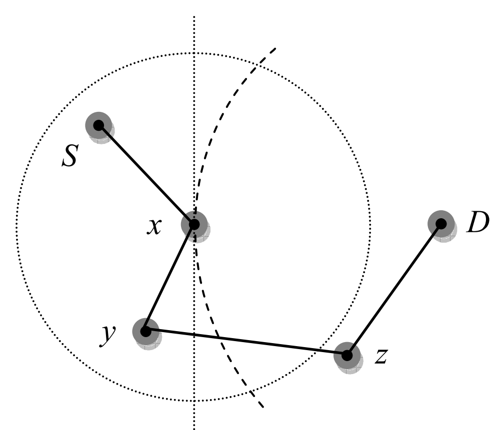

Fig. 2. Void area between nodes *x* and *D* in greedy mechanism

G. The Right Hand Rule

As it has been said before, the phenomenon in this there are not any neighbors closer to the sink than the current holder of packet is the main drawback of the greedy algorithms, lead to transmission failure. The existence of an obstacle may cause a void area between the source and the destination and cut out the stream of data even when there is a possible path between them [22]. In order to overcome the mentioned drawback, some approaches have suggested the "right hand" rule [23].

GPSR is the first algorithm which uses the right hand mechanism in order to handle a packet around a void area. According to this protocol, a packet should be forwarded hop by hop based on greedy forwarding scheme and available local information until it meet a void area. In this way, each node that receives the message, pass it to the first neighbor counterclockwise about itself [24]. However, GPSR is a suitable candidate to apply for large scale network but it couldn't been take into account as an energy efficient algorithm for WSNs since, multi-path routing or any other kind of load balancing methods cannot used in it [20]. Fig. 3 shows the state where the interior of the triangle performs a void area so that y forwards the packet to x and this node finds the first neighbor z, counterclockwise about itself in order to pass it on. Finally, y receives the packet from z in this manner.

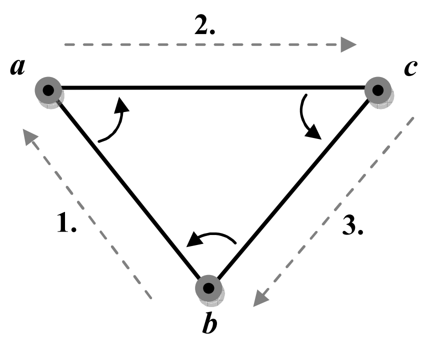

Fig. 3. Right hand mechanism for a void area bounded in triangle [24]

GAF (Geographic Adaptive Fidelity), for example, is an energy-efficient location-based protocol that assumes a virtual grid is applied on the network so that all of the sensor nodes in a cell are considered to be equivalent. It is necessary to have location information of all nodes in order to exchange discovery messages between the nodes of one group in a cell periodically. In this way, sensors of the same group can identify equivalent nodes. Thus, one of them is going to support the communications and the others will go to sleep mode [6].

GEAR (Geographic and Energy Aware Routing) is another type of single-path energy-efficient algorithm which uses geographic information in order to disseminate queries to destination region. Instead of sending the interests to the whole network, it only considers a certain region to restrict the number of interests in directed diffusion. So it can save more energy than directed diffusion [6]. The key idea is to keep a learning cost and an estimated cost of reaching the destination through its neighbors. This cost consists of two factors, "distance-to-destination" and residual energy while the learned cost is an improved version of the estimated cost that is suitable for routing around void areas in the network. If there are no void areas, both of the factors are equal.

III. MULTI-PATH ROUTINGS IN AD HOC AND SENSOR WIRELESS NETWORKS

Applying multi-path routing in WSNs results in traffic load and energy balancing over the network. On the other hand, by distributing traffic load through the network, the energy consumption will be balance on all nodes equally. In addition, it is not necessary to update the route information periodically that wastes a remarkable amount of nodes energy. Consequently, it is possible to prolong the network lifetime significantly [25].

Traditional on-demand single-path routing schemes are the pattern of the most popular multi-path routing protocols in wireless ad-hoc and sensor networks. For instance, AODV (Ad hoc On-demand Distance Vector) and DSR (Dynamic Source Routing) [26] are two samples of on-demand protocols designed for ad hoc networks. According to the on-demand method, the route should be built only when a node decides to send data to a destination in contrast with the table driven technique in which, all of the nodes should exchange route messages periodically to keep permanent route table all over the network. Therefore, only the active path, in which a link failure has taken place, should be updated. As a result, energy consumption, control overhead, congestion and collision will be minimized in the network. At the rest some geographic multi-path routings have been described.

In the next subsections, the multi-path routing algorithms are divided into two categories, link-disjoint and node-disjoint multi-path protocols that come with some examples. Then, a number of flooding-restricted and collision-aware node-disjoint routings will be explored in order to design a new efficient multi-path protocol according to the advantages of predecessors.

A. Link-disjoint Multi-path Protocols

These kind of multi-path routings are the first attempt to distribute the traffic load through the network uniformly. However, they can improve the load balancing and the network lifetime in the form of making several paths between the source and the destination but there is still a serious problem, explained here. In some cases, an intermediate node may be chosen by several routes that make it as a bottleneck in the network. On the other hand, this node should relay the data packets from all of the routes that end in congestion of data on this node. The state, in which several routes converge on a specific node, may deplete its energy faster than usual. So network partitioning phenomena occurs in that place which lessens the lifetime of the network.

AOMDV (Ad-hoc On-demand Multi-path Distance Vector) and *SMR* (Split Multi-path routing) are two samples of this type of protocol. AOMDV has derived from original single-path AODV but from the aspect of fault tolerance, it can achieve a better result than its predecessor so that the routes can be recovered so fast in dynamic networks. In this protocol, multiple loop-free and link-disjoint paths are computed. A notion of "advertised hop count" should be used to guarantee the loop-freedom. Meanwhile, a specific characteristic of flooding will be implemented to achieve link-disjointness of multiple paths. It can improve the end-to-end delay about twice than AODV and also can lessen the route overhead at least 30% [26].

SMR is also another on-demand multi-path protocol that implement multiple routes of maximally disjoin path in order to minimize control message overhead and route recovery stage. This algorithm distributes data packets through active multiple paths, using a per-packet allocation basis. It can prevent the network from the congestion situation in heavily loaded traffic [27].

Some approaches pay attention to node energy at multi-path construction phase. For example, MPSR (Multi-path Power Sensitive Routing Protocol) is a kind of on-demand algorithm based on DSR that makes the source node cache multiple route replies in order to switch between them in data packet transmission based on the network behavior. It assumes a weight for each node based on remaining power and then, according to this factor, it establishes the routing table properly. A heuristic model helps the forwarding system to select the routes in an energy efficient manner [28]. L. He [29] proposed another multi-path protocol with three phases: firstly, double routing trees construction stage in which, the algorithm establishes two trees rooted on the source and the sink with some shared nodes. Secondly, it presents route discovery phase for determining multiple high energy level paths and finally, data transmission step on selected multiple routes.

B. Node-disjoint Multi-path Protocols

In contrast with previous category, node-disjoint multi-path algorithms avoid to share any node between the multiple paths. It means, this kind of protocols try to forward the data simultaneously on multiple independent routes. It can prevent any overload and congestion on specific node along the paths. It is worth noting that many protocols in this area try to restrict the route request flooding by geographic information and also try to reduce interference between parallel paths by different tools and manners. In the following some technique to implement flooding-restricted and collision-aware multi-path protocols will be discussed.

C. Flooding-restricted Multi-path Routing

Using flooding makes some challenges for wireless sensor networks due to competitive bandwidth and restricted resources like energy. Thus, utilizing geographic information can limit the flooding usage in such networks. The authors of [30] proposed a variety of multiple path protocols which formed from the combination of the basic location-based schemes such as GEDIR, DIR and MFR. These protocols are named *c-GEDIR*, *c-DIR* and *c-MFR*, in which the messages are sent to c best neighbors based on corresponding factor. Hereafter, the intermediate nodes should forward them to only the best neighbor. This approach introduces three kinds of c-path technique called original, alternate and disjoint c-path method among them disjoint multiple path styles provides a better result than the others. In this way, upon receiving the message in an intermediate node, it will be forwarded to the best neighbor among those who never received the message before in order to perform c disjoint paths.

There is another multi-path method in which the source node forwards the message to *c* best neighbors base on distance from destination (GEDIR). Hereafter, each of c neighbors can make a copy of message and follows the disjoint method.

All of the above mentioned protocols which implemented on greedy methods try to restrict flooding and enhance delivery rate.

D. Collision-aware Multi-path Routing

Pearlman et al. [31] shows that node-disjointness of multiple paths is not sufficient to have a high performance transmission because there is still the probability of collision due to interference between the paths that ends in high packet loss rate specially when they transmit data packets simultaneously. To address this problem, many efforts have been done recently; some of them are as follows: The method proposed by [32] uses the directional antenna to propagate radio beams towards an interested zoon in the form of restricted angle (α). As it is shown in fig. 4, using this manner significantly can reduce radio interference between two paths due to limited area covered by each radio beam.

Coupling factor used in [31] is a powerful metric in order to define the corresponding degree of independence along a series of paths. The performance of multi-path routing algorithms will be affected by route coupling caused by contention or radio interference between the paths, even if they are disjoint topologically. In [31], they have measured the coupling between two paths as the average numbers of blocked nodes that cannot communicate with each other along one of the paths when a node is transmitting data through the other one. Therefore, it is important to select the paths with low coupling factor in order to have an efficient multi-path routing.

Correlation metric, defined by [33] is another factor used to measure the degree of independence between the multiple paths in wireless networks. In this approach, the total number

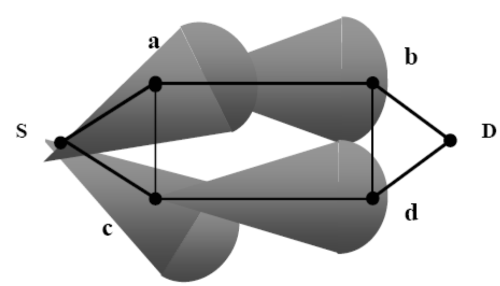

Fig. 4. Using directional antenna in multi-path communication between S and D [32]

of shared links between two node-disjoint paths is defined as correlation metric. Just like coupling factor, selecting the paths with low correlation can enhance the performance of multi-path routing [25].

The authors of the *ECCA* (collision-constrained minimum energy node-disjoint multi-path routing algorithm) have shown that collision avoidance and Energy minimum aren't compatible. So, collision avoidance will be affected negatively by limited battery capacity. The scheme described in this paper is an effort to find a tradeoff between them by calculating the same correlation factor as said before to weigh the collision probability between node-disjoint multiple paths.

Meanwhile, an upper limit for correlation factor based on service requirement is calculated. Eventually, the algorithm can find a proper node-disjoint multi-path routing with minimum energy in order to satisfy that limit [34].

Hwang et al. [35] proposed *EASR* (Energy Aware Source Routing) as a multi-path geographic protocol in which multiple paths should be selected probability but only one path will be utilized for data packet transmission along a period of time through multiple paths. This approach tries to find routing paths without any overlap. So, the nodes in one path cannot easily overhear the others on second path while transmitting the data. In order to lessen the overhearing energy waste through each selected path, they define a factor, named overhearing ratio. Then, the energy efficient multiple paths will be established based on this factor. However, this technique can improve network lifetime and remain packet delay at acceptable level but it requires a sophisticated algorithm.

IV. ALGORITHM COMPARISON

The routing mechanisms as discussed in Sections 2 and 3 are compared in Table I based on the following criteria:

- Classification: Due to the large number of nodes in sensor network, flat protocols employ data centric method that helps in omitting a large amount of redundant data transmissions. Hierarchical protocols try to save energy through clustering the sensors. In this way, data gathering and reduction will be done by cluster heads.
- QoS algorithms should guarantee some network metrics such as lifetime and latency. Geographic protocols use the location information to forward the data to the desired regions rather than the whole sensor field.
- Multi-path: By using multiple paths from the source to the destination, traffic load could be distributed through the network uniformly. It can prevent network partitioning and prolong network lifetime. Moreover, at the time of link failure another route will be used by the source node. In this manner, the end-to-end delay could be reduced for each packet.
- Route Disjointness: An important property for multi-path mechanisms is disjointness. Link or node disjoint algorithms try avoiding interference between multiple routes and prevent packet retransmission caused by collision. Node-disjoint strategies have much better performance than link-disjoint multi-path schemes. The reason is that they are congestion avoided. Meshed protocols cannot guarantee the Link or node disjointness among the multiple paths.

TABLE I
COMPARISON OF ROUTING PROTOCOLS IN WSNS

Protocol	Classification	Multi-path	Route Disjointness	Data Routing Method	Mobility	Location Info.	Data Aggregation	Localization
SPIN	Flat	Yes	Meshed	Query-Driven	Poss.	No	Yes	No
Directed Diffusion	Flat	Yes	Meshed	Query- Driven	Ltd.	No	Yes	Yes
Rumor Routing	Flat	No	N/A	Query- Driven	Very Ltd.	No	Yes	No
MCFA	Flat	No	N/A	Event- Driven	No	No	No	No
GBR	Flat	No	N/A	Query- Driven	Ltd.	No	Yes	No
COUGAR	Flat	No	N/A	Query- Driven	No	No	Yes	No
EAR	Flat	No	N/A	Query- Driven	Ltd.	No	No	No
PEGASIS	Hierarchical	No	N/A	Time-Driven	Fixed BS	No	No	Yes
TEEN	Hierarchical	No	N/A	Time-Driven	Fixed BS	No	Yes	Yes
APTEEN	Hierarchical	No	N/A	Time-Driven	Fixed BS	No	Yes	Yes
SAR	OoS	No	N/A	Query- Driven	No	No	Yes	No
PASR [14]	QoS	No	N/A	Time-Driven	No	No	N/S	No
MFR, GEDIR	Geographic	No	N/A	Event- Driven	No	No	No	No
GPSR	Geographic	No	N/A	Event- Driven	No	Yes	No	No
GAF	Geographic	No	N/A	Event- Driven	Ltd.	Yes	No	No
GEAR	Geographic	No	N/A	Query- Driven	Ltd.	No	No	No
AOMDV	N/A	Yes	Link-Disjoint	Event- Driven	Yes	No	N/A	No
SMR	N/A	Yes	Link-Disjoint	Event- Driven	Yes	No	N/A	No
MPSR	N/A	Yes	Link-Disjoint	Event- Driven	Yes	No	N/A	No
[29]	Flat	Yes	Link-Disjoint	Query- Driven	No	No	Poss.	No
MPR-E [32]	N/A	Yes	Node-Disjoint	Event- Driven	Yes	No	No	No
EECA	Geographic	Yes	Node-Disjoint	Event- Driven	No	Yes	No	No

- Data Routing Method: A protocol can employ different mechanisms to send data to the sink. In time-driven method, the nodes sense the environment and send the data to the sink periodically. In event-driven application, only the data about a certain event will be relayed to the sink node. On the other hand, in the query-based schemes, the sensor nodes send the data to the sink based on a pre-request.
- Mobility: In real-time applications, a mobile sink can go towards the source node in order to decrease the number of hops between the source and itself. It can decrease the end-to-end delay significantly. Furthermore, a mobile sink can migrate across the network time by time to balance energy consumption all over the sensor field. It can prevent network partitioning and sink isolation caused by fast energy exhaustion around the sink. In this state, the sensor nodes can also be mobile and move autonomously.
- Location Information: In some algorithms, the sensor nodes should know their location. By running a location computation mechanism or using GPS, a sensor node can determine its location. This information can be used by a sink node to determine its next position or might be utilized in clustering phase in hierarchical protocols.
- Localization: Since the sensor nodes are distributed at the field randomly, finding the coordinates of the sensor is called localization. The researchers who work on sensor networks try not to use GPS widely [16]. Instead, they apply GPS-free approaches [17-18] which might not provide enough accuracy in this field.
- Data Aggregation: In order to decrease the number of data packets transmitted among the sensor field and increase the network lifetime, some approaches use data aggregation mechanism in their proposed methods. This technique is mostly applied in hierarchical protocols where the cluster heads employ data collection through cluster members. Then they proceed to send the data to the sink themselves.

V. CONCLUSION

This paper firstly proceeds to categorize routing protocols in wireless sensor networks. This taxonomy includes flat, hierarchical, QoS, and location-based routings. After that, it discusses several multi-path routing mechanisms used to enhance network metrics such as lifetime and latency. These mechanisms are mainly divided into link-disjoint and node-disjoint strategy. Using multi-path method is an effective strategy to avoid network partitioning phenomenon and prolong sensors' lifetime. An overview and comparison of various routing protocols in WSNs are also presented.

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