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A REVIEW ON WIRELESS SENSOR NETWORKS ROUTING PROTOCOL: CHALLENGES IN MULTIPATH TECHNIQUES

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ABSTRACT

A sensor network basically comprises of low cost sensor nodes which gather data from the environment and transmit them to sink, where they will be afterward processed. Owing to the high density of sensor nodes and restricted communication range, packet forwarding in sensor networks is regularly achieved throughout the multi-hop data transmission. Consequently, routing in wireless sensor networks has been counted a significant field of research over the past decade. Thus, we present an inclusive review and present classification on the current routing sensor protocols, which are particularly designed for wireless sensor networks. We emphasize the main motivation behind the development of each routing protocol category and clarify the operation of different protocols in detail related to energy issues, with emphasis on their advantages and disadvantages. Moreover, the current multipath routing approach is broadly used in wireless sensor networks in order to improve network performance such as load balancing, reliability, fault tolerance, bandwidth aggregation and QoS Improvement. Therefore, in this paper we highlight the notion of the multipath routing approach and its essential challenges, additionally the basic motivations for utilizing this technique in wireless sensor networks. In addition, we contrast and review the state-of-the-art multipath routing protocols that based on energy aware method, fault tolerance and QoS multipath routing. At the end of this paper, a characterized comparison has been forwarded on these methods based on the analysis outcome.

Keywords: *Wireless Sensor Networks, Routing Protocols, Energy Efficiency, Fault Tolerance, Qos, Multipath Routing.*

1. INTRODUCTION

The current progresses in wireless communication technologies and the manufacture of low-cost wireless devices have contributed to the introduction of low-power wireless sensor networks. Owing to their simplicity of deployment and the multi-functionality of the sensor nodes, wireless sensor networks have been exploiting for a diversity of applications such as environment monitoring, target tracking and healthcare [1].The major responsibility of the sensor nodes in every application is to sense the target area and broadcast their collected information toward the sink node for additional processing. Resource restrictions of the sensor nodes and unreliability of low-power wireless links [2],in addition with, diverse performance demands of different applications entail many challenges in designing efficient communication protocols for wireless sensor networks [3]. In the meantime, designing appropriate routing protocols to perform different performance demands of various applications is deemed as a significant problem in wireless sensor networking. Thus, researchers have suggested several routing protocols to develop performance demands of different applications throughout the routing layer of sensor networks protocol stack [4]. Almost all of the routing protocols can be classified based on the structure such as data-centric, hierarchical and location- based. Data-centric protocols are query-based and depend on the naming of desired data, which helps in eliminating many redundant transmissions. Hierarchical protocols aim at clustering the nodes so that cluster-heads can do some aggregation and reduction of data in order to save energy. Location-based protocols utilize the position information to relay the data to the desired regions rather than the whole network. Also, the routing protocols can also classify based on operation such as multipath-based, query-based, QoS-based negotiation based, and coherent-based Protocols [5]. Furthermore, the majority of the present routing protocols in wireless

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sensor networks have designed based on the single-path routing tactic without deeming the consequences of a variety of traffic load density. In this tactic, every source node chooses a single path that can assure performance requirements of the intended application for transmitting its traffic to the sink node. While route discovery throughout single-path routing tactic can be executed with minimum computational complexity and resource exploitation, the limited capacity of a single path highly decrease the achievable network throughput [6]. In addition, the low flexibility of this tactic besides node or link breakdown may extensively decrease the network performance in critical situations. For example, when the active path fails to convey data packets due to restricted power supply of the sensor nodes, high dynamics of wireless links and physical harms, discovering an alternative path to carry on data transmission process may cause further delay and overhead in data delivery. Thus, owing to resource restriction of sensor nodes and the unreliability of wireless links, the single-path routing tactics cannot be deemed effective techniques to meet the performance demands of various applications. In order to handle the restrictions of single-path routing techniques, another type of routing scheme, known as multipath routing approach has become as a promising technique in wireless sensor and ad hoc networks. Intense deployment of the sensor nodes permits a multipath routing approach to make several paths from individual sensor nodes to the target [7]. Finding paths can be exploiting concurrently to present sufficient network resources in rigorous traffic conditions. On the other hand, every source node can employ only one path for data transmission and change to another path when node or link failures. The multipath routing approach is primarily used for fault-tolerance purposes, and this is known as an alternative path routing [8]. Previously multipath routing approach have been broad been exploiting for diverse network management purposes such as improving energy efficiently, providing fault-tolerant routing, Quality of Service (QoS) [9] and congestion control support in traditional wired and wireless networks. On the other hand, the distinctive features of wireless sensor networks such as constrained power supply, low-memory capacity, higher rate of node deployment that are subjected to frequent breakdowns, QoS constraint and limited computational, as well as the characteristics of short-range radio communications namely, fading and interference Introduce new challenges that should be tackled during in the design of multipath routing protocols [10, 11]. Therefore, the current multipath routing protocols which have proposed for traditional wireless networks such as ad hoc networks cannot be used directly in low-power sensor networks [12]. Over the past years, this problem has motivated the research community of wireless sensor networks to develop multipath routing protocols which are important for sensor networks. There are numerous research papers surveying proposed routing protocols for wireless sensor networks. These surveys illustrate and analyze the general routing tactics proposed for sensor networks. On the other hand, none of these literatures has presented a comprehensive classification on the presented multipath routing protocols for wireless sensor networks based on energy aware, fault tolerance and QoS based multipath routing. The authors in [4] have presented routing challenges and design issues in wireless sensor networks. They categorize all the presented routing tactics based on the network structure and protocol operation. In addition, the authors [13] have also presented a short overview on the existing fault-tolerant routing protocols in wireless sensor networks and grouped these protocols into retransmission-based and replication-based protocols. Furthermore, [14, 15] categorize the presented multipath routing protocols in ad hoc networks based on the main criterion used in their design. Moreover, [16] have surveyed multipath based Infrastructure, non-Infrastructure and coding multipath routing. Thus, the primary stimulus of accomplishing this research was the lack of a comprehensive survey on the proposed multipath routing protocols for wireless sensor networks based on energy aware, fault tolerance and QoS aware multipath routing. To the best of our knowledge, this paper is the first attempts to categorize and investigate the operation of routing sensor network and also it provides a comprehensive review of multipath routing protocols with highlighting on their advantages and disadvantages of the presented multipath routing protocols in sensor networks.

2. GENESIS OF WIRELESS SENSOR NETWORK

Wireless sensor network is made of single nodes which have the capability to interact within a specific geographical area through the sensing of or by controlling the physical boundaries through the collaboration of sensor nodes and wireless connection to enable transmission of information from nodes to the base station [17]. However Smart

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Dust at DARPA (Defense Advanced Research Projects Agency of USA) defined WSN as: "A wireless sensor network is a deployment of huge numbers of small, low-cost, self- powered devices that can sense, compute, interact and communicate with other devices in order to gather local information to make global decisions about the physical environment" [18, 19]. The evolution of WSN development begun with the United States of America (USA) during the period of the Second World War with the then Soviet Union which is now Russia. The USA positioned acoustic sensor network at a tactical spot at the bottom of the sea floor with the intention of tracking Soviet Union submarines. The acoustic sensor network application at that time were known as Sound Surveillance System (SOSUS), and it was wired network instead of the current wireless sensor network so the challenges of energy and bandwidth limitations are less minimal [20]. Major research into innovative and advanced sensor networks was initiated by DARPA by USA with the introduction Distributed Sensor Networks (DSN) project in 1980. The acoustic sensor network comprises of transmission, processing schemes, algorithms, routing and distributed software systems. Modernization has also led to rapid advancement of sensor networks recently with the building of small and inexpensive micro-electro-mechanical systems (MEMS). Therefore, the project developed by DARPA contributed dynamic ad hoc network environments and wireless sensor networks in recent times.

3. MODEL OF WIRELESS SENSOR NETWORK

Wireless sensor network has known operational constraints such as resource limitations, node or link prone to failures, nodes densely deployed and the numbers of sensor nodes are so numerous when compared to ad hoc networks. The topology of sensor network has changed over the years, and new technology evolves. The following illustrate the key components of sensor networks: [19, 21]
Sensor Field: A sensor field is vicinity where the nodes can be positioned.
Sensor Nodes: Sensors nodes are the heart of the network. It is the responsibility of the sensor nodes to gather information and transmit to the sink or base station; it is engineered for the network.
Sink: Sink receives data from various nodes, and then process and stored all the data collected from the nodes. Message correspondences between nodes are diminished because of the sink thereby decreasing energy conditions of the entire network.
Task Manager: The tasks Manger acts as a gateway to other networks. The base station also called the centralized control room for data extraction, spread information back and forth to the networks, data processing and storage center with user access controls. See the figure 1 below for a description; [17].

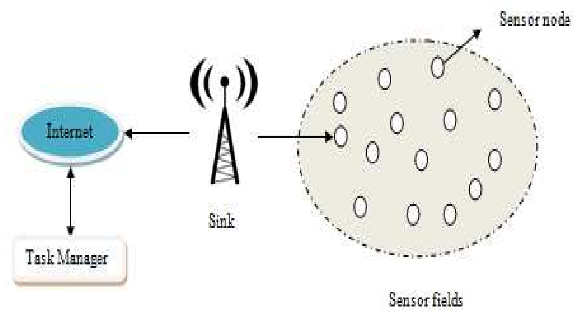

Figure 1: Wireless Sensor Networks Model And Architecture

Data is streamed to these workstations either via the internet, wireless channels, satellite etc. Sensor networks deployed in a specific geographical area does construct a wireless multi-hop network, and the sensor nodes apply wireless medium for transmission namely infrared, radio, Bluetooth during communication. The figure 1 above is the general view of sensor network made by task manager, internet, base station and sensor fields (geographical area deployed).

4. CLASSIFICATIONS OF SENSOR NETWORKS COMMUNICATION

From the figure 1, the few categories of sensor networks derived are highlighted below;

4.1 Static and Mobile Network

Sensor nodes are classified under two subdivisions namely mobile or static, so sensor networks might either mobile or static networks. For mobile sensor networks consist of the dynamic movement of sensors, that is, movement from one location to another that allows areas which are not initially covered locations to be possibly covered as wider sensor movements continue to expand. Static sensor networks are composed of sensor nodes that are stationary at a specific location which does not involve any form movement that is normally the basis for numerous sensor applications. But mobile sensor nodes are needed by certain sensor application in order to achieve a sensing task. For instance, wireless road network using self-

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governing road surfacing monitoring is a classic example of mobile sensor networks. Additionally static sensor networks are much easier to manage and applied, which is different from mobile sensor network because the mobility causes and frequent movements that lead to implementation difficulties.

4.2 Static Sink and Mobile Sink Network

The sink can either be static or mobile and positioned at various places in the wireless sensor network. While the static sink network is stationary having a constant point sit either inside or nearer to the sensing areas. The sensed data are transmitted to the sinks by the sensor nodes. The nodes positioned in the neighborhood of the sink drain their energy and die much quickly in comparison with nodes that are far off from the sink because of increasing packet relaying load contributing to network partition interruption of the network procedures. The mobile sink network involves the processes of the sink movements in the neighborhood sensing areas with the intention of gathering data from the sensor nodes used for equitable distribution of sensor nodes traffic load.

4.3 Single Sink and Multisink Network

There are two classifications of sinks in a sensor network namely single sink network and multiple sink networks. The single sink network is composed of a single sink positioned either inside or nearer of the sensing area. The sink is responsible for receiving the transmitted sensed data from every sensor node. In the case of multiple sink networks, many sinks are positioned at various areas which are either nearer or inside the sensing area. The tree-based routing joined together with multi-sink partitioning to create several routing trees founded at various sinks, and every sensor node is linked to a single sink only.

4.4 Single hop and Multi-hop network.

Single hope and Multi-hop sensor nodes are also one of the numerous components of wireless sensor network. In a single hop network whenever data are transferred to the next router, leading to hop appearance. The subsequent hop relays the packet between one hop the other, thereby single-hop defining as a means of which only one hop transmission takes place from the source to target destination. Wireless station can be linked to wireless access points (WAPs) that are connected to the router through wired network, for instance, wireless access points like Wi-Fi, WiMAX, cellular being connected to a bigger network, the Internet. On the other hand, multi-hop wireless sensor networks applied more than two or more hops in transmitting data from source to destination. And this is achieved by the sensor nodes transmitting of the sensed data to the sink by means of wireless exchange of information through one or more intermediate nodes. Every intermediate node is supposed to perform routing before relaying the data through the multi-hop path. The two different applications that can be used for multi-hop communications are MANET and Multi-hop cellular [22]. In wireless sensor networks, single hop communication can be measured not always as distribution of node scattered between the selected areas. A single hop communication is a direct communication between the transceiver of the source node and sink node. The transceiver of the single node is limited by the limitation of distance by the covering signal, "as a result", some features restrict the implementation of single hop communication when the distance has obstacles in between the source and sink [19, 23]. In the figure 2 below shows simple type of single hop wireless sensor networks.

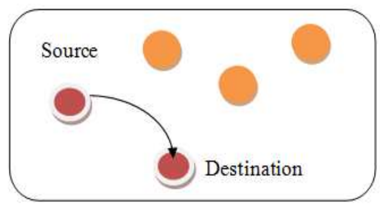

Figure 2: Single Hop Communication

Multi-hop communication has the ability to assist in overcoming the problem experience with a single hop communication. In multi-hop, relay techniques being used which transmit data packets from the source node toward the direction of the sink. Relay techniques are used nodes as a temporary medium to transmit the packet from one node to the others [24]. The nodes can be called as an intermediate node since the nodes located between the sources and destination. Figure 3 shows an example of multi-hop communication with an obstacle between source and sink.

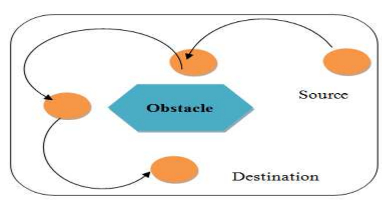

Figure 3: Multi-Hop Communication

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Although multi-hop can improve communication between source and sinks in wireless sensor networks, the guarantee of multi-hop routes existence is not permanent or that the route particular paths exist for a short period of time. While multi-hop can solve the problem in large communication area, it has the capacity to improve energy efficiency in sensor nodes because multi-hop techniques requires transmission on neighboring nodes which are very close with each other thus decreasing the transmitter functionality. As mentioned earlier, energy conservation is commonly issues in wireless sensor network environment where the sensor node energy needs to be preserved [19]. In comparison, single-hop network has easier network infrastructure and less trouble to manage because the coverage area for sensing data is not big, and nodes sparsely deployed unlike multi-hop that have bigger coverage and broad degree of application, so management is much difficult.

4.5 Self reconfigurable and Non self configurable network

Configurable networks are important in wireless sensor network because of their flexibility. In sensor networks, this can be self reconfigurable network or non-self configurable network. For non-self configurable, there is a limitation on the capability of the sensor nodes to effectively self-manage itself to become a network. They depend on centralized devices to manage every sensor node before extracting data from each of the nodes. A network of this nature is only applicable for operating in smaller network environments. A self reconfigurable network, on the other hand, is self-autonomous and self-governed can quickly auto-configured itself into becoming a network without the assistance of a remote connection control. The network can be implemented on a much broader levels and does carry out difficult sensing data schedules [25].

4.6 Homogeneous and Heterogeneous network.

Sensor nodes are either grouped into homogenous network or heterogeneous network. Homogeneous network is composed of computer network where all the sensor nodes used similar features such as same protocols, the same configuration and same devices. Their operations are harmonized so can share resources seamlessly. An example of a homogeneous network is a sensor network that uses Microsoft Windows over TCP/IP. In the case of heterogeneous network is a computer network that includes the sensor nodes that are made up different and varying degree of devices, operating systems and computers. The computational power and data processing tend to be much higher because of combinations of different devices, so sensor nodes can perform complicated tasks to prolong the lifetime of the network and as well as efficient data transmission [26].

5. HARDWARE COMPONENTS OF SENSOR NODE

In wireless sensor network every node can autonomously carry out processing and sensing schedules as well as communicate with each other and transferring of sense data to the central processing unit (CPU). Some of the commonly used sensor node platforms are Mica2 Mote. Sensor nodes are a small device that has a micro-sensor technology, low power signal processing, low power computation and a short-range communications capability. The hardware components for sensor node consist of Radio Transceiver, Embedded Processor, Memory, Power source and Sensor(s) [17, 27]. The sensor mainly comprises of four constituents and described in the figure 4 below:

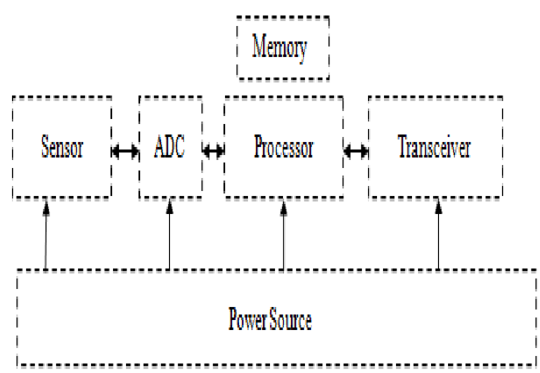

Figure 4: Architecture Of Sensor Node

5.1 Embedded Processor

The operations of an embedded processor are for programming tasks, process data and manage various areas of hardware components. Various kinds of embedded processors can be applied in sensor nodes, and these are Digital Signal Processor (DSP), Microcontroller, Application Specific Integrated Circuit (ASIC) and Field Programmable Gate Array (FPGA) [28]. In recent years, Microcontroller is the most commonly used embedded processor for sensor nodes because of its scalability and compatibility to several devices and cost. The CC2531 Processor, for instance, used

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8051 microcontroller, and while Mote platform used ATMega128Lmicrocontroller.

5.2 Transceiver

The wireless communication of sensor nodes is the function of the transceiver, and some widely used names of transceivers are Radio Frequency (RF), Laser and Infrared. For wireless sensor applications, RF is the most suitable choice. The operational states of a transceiver are Transmit, Receive, Idle and Sleep. The radio transceiver in sensor node architecture operates at different levels namely; Transmit, Receive, Idle and Sleep. **Transmit:** refers to the sending of data among nodes and to the base station. **Receive:** collecting transmitted packets from various sections of the sensor networks. **Idle:** available to receive incoming packets, but not ready to start. Some techniques are used to switch off the functions of the hardware in order to diminish the consumption of energy to lesser levels. **Sleep:** the process entails switching off considerable sections of the transceiver so limiting its ability to receive any forms of data or information. It is essential to program recovery time and startup energy so as to awake from sleep state. Moreover, the transmissions are through electromagnet radio frequencies which enables the transceivers to broadcast in a bit or byte stream similar to the format of radio waves [17, 28, 29].

5.3 Memory

Sensor node has in-built memories that include chip flash memory, a RAM of a microcontroller and external flash memory. Different types of sensor application might require a unique set of memory requirements, in other words, there is an application dependent. These two types are mainly for storage; in-built memories such as RAM and chips for program storage and external for storing private data. Data can also be discovered by the program memory. For instance, the ATMega128L microcontroller running on Mica2 Mote has 128-Kbyte flash program memory and 4-Kbyte static RAM [28].

5.4 Power Source

The consumption of energy in sensor nodes is through sensing data, processing of data and communication. Power is more likely to be consumed by communication of data than when compared with data processing and also sensing data. Battery and capacitors act as storage facilities for power and then supply the power for the sensor nodes. For instance, Mica2 Mote can run on 2 AA batteries [29]. The battery lifetime is very limited in WSN, so it is a bigger challenge; new ways of trying to improve power supply are by energy-harvesting methods that transform ambient energy such as solar, wind into electrical energy.

5.5 Sensors

Sensors are hardware which generates measurable reaction signal due to changes in environments like weather conditions, pressure, humidity and temperature. Analog signal sensed data are digitized by an analog-to-digital converter (ACD) and transferred to the embedded processor for additional processing. A sensor node can consist of numerous sensors integrated in or connected to the node. The primary objective for providing power supply for sensor nodes is to ensure that enough energy is made available to the nodes at the least cost, volume, weight, recharge time and longer lifespan. Recharging energy supplies might be or may not be an option depending on the environmental friendliness. For instance, primary battery for sensor such Lithium might have 2880Joule per cubic centimeter (J/cm3), whilst Alkaline battery is 1200Joule per cubic centimeter (J/cm3) [29]. The processor and the memory normally control the processes of the sensor node to ensure the node operations are accomplished while the transceiver link the sensor node in the network so becomes the means of communication for the node. The battery (AA size battery or quartz) supplies power not only to all the nodes and also determine the lifetime of the network [17]. To represent energy consumption, a typical sensor node burns up to around 4.8mA when receiving a message; 12mA is used to broadcast a packet and 5µA sleeping duration. Furthermore, the CPU disburses a typical 5.5mA during active mode.

6. WSN And Ad Hoc Networks

Ad hoc networks normally refer to certain types of wireless network where the buildings of network infrastructure or centralized accessibility points are unnecessary. These networks are so specialized to the extent that they are self autonomous in areas of operations such as auto-configurations, self-assembly, self-recovery so the uses of centralized computing systems are absent. In specific terms, ad hoc network is made of mobile devices like vehicles, PDAs, laptops, or sensor devices which produce dynamic transmission paths to ensure forwarding of data through one node and the next subsequent node. Fundamentally this type of network are grouped into two key classifications,

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such as Mobile Ad hoc Network (MANET) and Vehicular Ad hoc Networks (VANETs) [17, 23]. The topology for these types of networks is dynamic and changes rapidly in order to meet environments and infrastructure needs. But the only distinctions identified for VANET that distinguish it from other ad hoc networks are links disconnection are regular, network topology are much higher; energy and storage are much sufficient and geographical area for communication.

6.1 Mobile Ad Hoc Network

Mobile Ad Hoc Network (MANET) belongs to ad hoc category of network that is more dynamic in nature and can quickly adjust to change environmental conditions, auto-configure, self-organized itself instantly without the assistance of centralized workstations. Because there are mobile, the mode of connections are wireless which is the standard Wi-Fi connection or cellular or satellite transmission or mobile nodes communicating with each other by means of Radio frequencies [30]. Due to its efficient characteristic of rapid deployment and self-organization, MANET can be used for several applications such as communication between soldiers and vehicles. The geographical area for local wireless devices is confined to a specific locality because of the wireless connection range, for instance, laptop computers, PDA group together at a certain area, and some might be connected through the internet. MANET is more prone to changes mainly due to node mobility and failures, though changes are lower when compared to other type ad hoc network like VANET; however, security is a bigger concern, so care must be taken when transmitting data over MANET [31].

6.2 Vehicular Ad hoc Network

Vehicular Ad hoc Network (VANET) is another classification of MANET, which features include dynamic network topology changes in a mobile vehicular setup. It is similar to MANET because the building of static network infrastructures is not required. However for communication to take place, wireless devices are placed at vantage locations along the highway as stagnant network nodes. Those devices placed along the roads are then used to connect to a broad range of Intelligent Transportation System (ITS) for vehicular networks. Distribution of messages is by operating within a specific environment or from geographical information, or the internet being the gateway. Compared to MANET, VANET speed controls patterns are much higher because it comprises of rapid mobility nodes that are not constant and bigger physical limitation which can impede its performances, for instance, tall buildings along highway roads. The two states of affairs for speeding vehicles are; firstly, the vehicles can be discovered within the communication range when the vehicle is heading towards the same route, and secondly, if the vehicles are travelling towards the opposite path, network changes are very pronounced and is a difficult task when vehicles heading towards the opposite paths are so tough to manage the vehicular network [17, 19].

6.3 WSN Vs Ad hoc Networks

Routing in WSNs is very demanding due to inherent characteristics that differentiate these networks of other wireless networks like mobile ad hoc networks or cellular networks. Due to the relatively large number of sensor nodes, it is not possible to build a global addressing scheme for the deployment of a large number of sensor nodes as the overhead of ID maintenance is high. As a result, traditional IP-based protocols may not be applied to WSNs. In addition, sensor nodes that are deployed in an ad hoc manner need to be self-organizing as the ad hoc deployment of these nodes involve the system to form connections and cope with the resultant nodal distribution especially that the operation of the sensor networks is unattended. In WSNs, sometimes getting the data is more significant than knowing the IDs of which nodes sent the data. In contrast to typical communication networks, almost all applications of sensor networks entail the flow of sensed data from multiple sources to a particular Base Station. This, however, does not prevent the flow of data to be in other forms. Furthermore, sensor nodes are tightly constrained in terms of energy, processing, and storage capacities. Therefore, they require careful resource management [4, 27]. Additionally, in most application scenarios, nodes in WSNs are generally fixed after deployment except for, maybe, a few mobile nodes. Nodes in other traditional wireless networks are free to move, which results in random and frequent topology changes. However, in some applications, sensor nodes may be allowed to move and change their location although with very low mobility. Fifth, sensor networks are application specific i.e., Design requirements of a sensor network changes frequently with any type of application. For example, the challenging problem of low-latency accuracy tactical surveillance is different from that required for a periodic weather-monitoring task. In addition, position awareness of

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sensor nodes is important and significant since data collection is normally based on the location. Currently, it is not feasible to use Global Positioning System (GPS) hardware for this purpose [30]. Though WSN and MANET shared some common problems, however, there are primary variations among the two networks and such distinctions are essential because MANET are set up for a specific reason in order to assemble a rapidly emerging communication needs, unlike WSN. Below describes differences between WSN and MANET:

Tables 1 tabulate the differences between wireless sensor network and MANET. The differences as shows in the table can be seen in the area of the several mechanisms used to measure and evaluate each of them. They include environment through which each of them is to be deployed, deployment of nodes, node population, rate of failure, communication, that is, through broadcast or point to point, measurement metrics of each, such as efficiency, latency, scalability, speed, redundancy, robustness, rate of receiving. Another key issue is energy differentiation, while WSN is faced with a big challenge of limited energy constraints, MANET is not confronted by energy issue, bandwidth is a lesser problem in WSN when compared to MANET, identification of fault tolerance in WSN happens whenever nodes are move or existing ones runs out, for MANET it is only happens only when it is not stationed at one place. Both of them have dynamic topology networks can be quickly adjusted to meet changing trends, however, WSN can cover broader covered area, while MANET covered area is very small.

7. OSI OF WIRELESS SENSOR NETWORK

The standard structural design for WSN follows the OSI layer model which consists of five sub-sections namely the application, transport, network, data link and psychical layers. The following figure 5 describes the structure design OSI of WSN;

Table 1: Difference between WSN and MANET

Feature	WSN	MANET
Environment interaction	Focus on Environment	Support for web, voice laptops, tablets, workstations
Nodes deployment	numerous	few
Nodes Population	heavily populated	thinly populated
Rate of failure	high	low
Communication	Broadcast	Point-to-Point
Metrics	Efficiency, Resolution, Latency, Scalability, Robustness	Receipt rate, Dissemination speed Redundancy
Energy	Limited	No issue
Bandwidth deficient	Once awhile	yes
Fault tolerance	when nodes drain out existing energy or moved	when mobility increases it's required
Routing Protocols	Flooding, Gossiping, Flat Routing, Hierarchical, Location based	Proactive, Reactive, Hybrid
Benchmarks	ZigBee, IEEE 802.15.4, IEEE 1451	IEEE 802.11
Topology	dynamic	dynamic
Application specific	very large area	small area

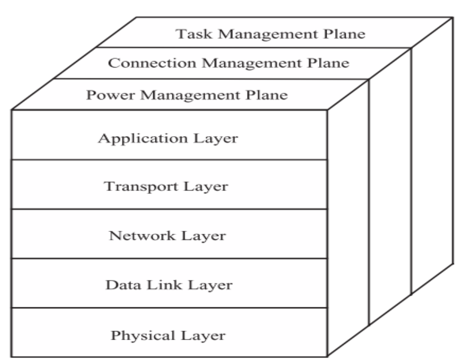

Figure 5: OSI Layers of WSN [32]

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The Application layer handles traffics and provides a platform for different kinds of applications to interpret the data into meaningful information or transmit further queries to obtain a specific data needed during a period of time. Sensor applications deployed in various areas in recent years such as environment, missions, medicals and, traffic. An additional layer call transport layer which ensures consistency and congestion avoidance, the protocols in this layer have been developed to be used for upstream -user to sink, for instance, ESRT, STCP and DSTN or downstream -sink to the user, for instance, PSFQ and GARUDA. The techniques apply various protocols to discover loss detection (ACK, NACK) and loss recovery [33]. Normally the transport layer protocol is partitioned into two sub-sections: Packet driven and Event driven. In Packet driven, the packet transmitted from the source should arrive at the target destination. In Event driven, any event which has taken place must be able to be detected and acknowledge as notification to reach the sink [19]. Furthermore, Network layer and the main function of this layer is for routing and the main resource constraints are energy supply, limited memory and buffers. The concept behind routing is to be able to discover reliable, efficient disused paths according to pre-determined techniques called metric, and it's quite unique from protocol to protocol [1, 5]. Some routing protocols for this layer are categorized into flat routing, for instance, direct diffusion, in addition other categorizes is hierarchal routing, for instance, LEACH. Finally, location routing such as GAF protocol. Data delivery models can be divided into time-continuous driven, query driven and event driven divisions.

The data link layer is accountable for multiplexing data streams, data frame detection, Medium Access Control (MAC), controlling of error, ensure consistency of packet delivery from the point to point or from point to multipoint. MAC for instance is essential for implementing channel access policies, scheduling, buffer management and controlling of errors and is important for the Sensor network because of its benefits of ensuring energy efficiency, consistency and delay reduction and throughput [32]. The physical layer allows the provision of an interface which is used to broadcast streams of bits across a physical medium. It also selects frequency, carrier frequency generation, signal detection, modulation and data encryption for transmission purposes. IEEE 802.15.4 is the recommended benchmark a lower geographical area for WSN because of its low cost, complexity, energy consumption, range of communication to ensure maximization of power supply [34]. The OSI protocol is further categorized under management plans diagonally to all the layers including power, connection, and task management.

Power Management Plane: The main goal for the power management plan is to take charge of managing the power supplies for all the different sections of the sensor such as sensing data, processing, broadcasting and responses that depend on a resourceful power management scheme at every phase of protocol layers. For instance, at the MAC layer, to conserve energy a sensor node might switch off the transceiver if there is not data to transmit and receive. At the network layer, a sensor node may select a neighbor node with the most residual energy as its next hop to the sink [32].

Connection Management Plane: The handling of configuration and re-configuration of the sensor nodes are through the connection management plan which ensure continuous connectivity and node maintenance of the network whenever changes to the topology due to break down of nodes, a mobile movement occurrence and node addition.

Task Management Plane: Allocation of tasks or schedule the sensing between the sensor nodes is the main duty of the task management plane. This procedure ensures energy efficiency improvement thereby network lifetime is increased. Deployment of sensor nodes is densely populated in the sensing sections so redundancy might occur since not every sensor node around the sensing area will the chance to perform similar sensing schedules. So that's why management techniques are applied to perform sharing of schedules for several sensors nodes [17].

8. ROUTING PROTOCOL CHALLENGES

Routing in wireless sensor network has always been a problematic issue of concern mainly due to several factors ranging from unfriendly deployment conditions, network topology that change repeatedly, network failures, resource constraints at every sensor node to designing of routing protocol issues. Therefore, the implementation of routing protocols is affected by several underlying features which must be taken into consideration before any attempt at designed routing are implemented, because these factors might prevent the successful design and implementation of routing protocol if these challenges are overlooked. The following explains some of the routing protocols challenges which hinder efficient routing procedures in wireless sensor networks [4, 16].

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8.1 Energy Consumption

The main goal of the routing protocols is efficient delivery of information between sensor nodes and the sink. Thus, energy consumption is a major concern in the design of routing protocol in WSNs. Due to the limited energy resources of sensor nodes, data need to be delivered in the most energy-efficient approach without compromising the accuracy of the information content. Hence, many conventional routing metrics such as the shortest path algorithm may not be appropriate. Instead, the reasons for energy consumption should be carefully investigated, and new novel energy-efficient routing metrics developed for WSNs [23, 35]. The major reasons of energy consumption for routing in WSNs can be classified as Neighborhood discovery and Communication vs. Computation:

Neighborhood discovery: Many routing protocols involves every node in order to exchange information between its neighbors. The information to be exchanged can differ according to the routing methods. While most geographical routing protocols involve knowledge of the locations of the neighbor nodes, a data-centric protocol may require the information content of the observed values of each sensor in its surrounding. In each case, nodes consume energy in exchanging this information during the wireless medium, which increases the overhead of the protocol. In order to improve the energy efficiency of the routing protocols, local information exchange should be minimized without hindering the routing accuracy [19].

*Communication vs. Computation***:** It is well known that computation is greatly cheaper than communication in terms of energy consumption. Moreover, in WSNs, the goal is to deliver information instead of individual packets. Consequently, in addition to the conventional packet switching techniques, computation should also be integrated with routing to improve energy consumption. An example, data from multiple nodes can be aggregated into a single packet to decrease the traffic capacity without hindering the information content. Similarly, computation at each relay node can be used to suppress redundant routing information [4, 23].

8.2 Robustness

WSNs rely on the nodes inside the network to deliver data in a multi-hop method. Hence, routing protocols operate on these sensor nodes instead of dedicated routers such as the Internet. The low- cost components used in sensor nodes, however, may result in unpredicted failures to such an extent that the sensor node may be non-operational. As a result, routing protocols should provide robustness to node failures and prevent single point-of-failure situations, where the information is lost if a sensor dies [19]. Furthermore, the wireless channel results in packets being lost during communication. As well as robustness against node failures, the routing protocol should guarantee that the effectiveness of the protocol does not rely on a single packet that can be lost. Even under very harsh conditions with numerous channel errors, the routing protocol should provide efficient delivery between the sensor and the sink. Fault identification, node or link failures, limited power, physical damage and weather instability are the common occurrence in WSN routing so care must be taken to ensure that a failure should not necessarily have a negative impact on the entire operations of the sensor network. When numerous nodes break down, the MAC and the routing protocols must be dynamic enough to facilitate construction of new communication links, paths through to the data compilation base stations. To achieve this, necessitate amending the broadcasting powers and signaling volumes on the current links to decrease energy utilization or rerouting packets to sections of the network having lot of energy [13].

8.3 Data Aggregation

In most sensor network applications, sensor nodes are closely deployed in the region of interest and work together to achieve a common sensing task. As a result, the data sensed by multiple sensor nodes naturally have a certain level of redundancy or correlation. The key points for data redundancy are the increased toughness to route failures by the protocol, the recovery of data that is being lost and to rebuild the primary message and the same time eliminating too much delay normally associated with when retransmission of data. Aggregation entails the procedure of merging data from diverse sources using operational methods, for instance, average, duplicate suppression technique, maxima [34, 36].

8.4 Node Deployment

The process by which nodes are deployed can have an impact on the performances of the routing protocol because nodes deployment is dependent on application. The nodes are deployed by two means, that is, deterministic or randomized. In the case of deterministic, there is manual setting of the sensor nodes before data is routed by way of pre-defined routes or paths. Random node deployment is the process of distributing randomly the sensor nodes to build an infrastructure that have a resemblance of

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ad hoc network. In deploying the nodes, if the allocation is not standardized, optimal clustering is enforce in order to permit connection and for managing network operations and energy effectively. When communications between sensors are inside a shorter range transmission, the probable route will include various wireless multi-hops [34].

8.5 Scalability

Sensor node deployments in sensing regions are so huge, running into hundreds or even thousands upon thousands of nodes. So any designed routing protocol technique should have the capability to function with enormous amount of sensor nodes. And additional must be flexible or dynamic enough to rapidly adjust to and response to changing environmental conditions or amendment to other sections of the network. Most sensor nodes can be allowed to be in sleep mode until when needed re-awake again, with only a few supplying hard quality works [32].

8.6 Quality of Service

Applications sensors are time sensitive and so data must be transmitted within a specific time frame at the exact moment. The data have sensed with the longer elapse of time, data might become irrelevant leading to latency issues. But in most sensor applications, preservation of energy that impact the lifetime of the network is regarded more significant when compared with the quality of data being transmitted. When the energy begins to drain, network quality performance is decreased so as to conserve energy dissipation in the nodes and prolong entire lifetime of the network, so energy-aware protocols are essential to analyze and produce the energy conditions for the network [37].

9. ROUTING TECHNIQUES IN WIRELESS SENSOR NETWORKS

The process through which paths are discovered between source and destination for transmitting packets are known as routing. For most networks, routing of incoming packets is normally concentrated in the network layer. In multi-hop networks the source node does not communicate directly to the sink, sensor nodes does the relaying of packets, so the protocols features a routing table which enables the touting algorithm to assist in the creation and maintenance of packet source and destination. Some networks that routing can be done includes telephone network (that is, circuit switching), electronic data networks (Internet), transportation and as usual WSN. Routing protocols comprise of various techniques and are categorized into distinct groups namely network structure based routing protocols and operation based routing protocols [23, 35]. For network structure routing promised is made of three classes, flat routing, hierarchical-based routing and location-based routing; in flat routing every node performs the similar roles; in hierarchical-based routing, where every node does not perform similar activities in the network; in location-based routing, it entails the process where every sensor nodes location is extracted in order to allow for routing of data on the network [38]. In addition, another classification based on protocol operations are grouped into Coherent based, negotiation based, Query based, QoS based and multi-path based. The negotiation based protocols have the objective to eliminate the redundant data by include high level data descriptors in the message exchange. In query based protocols, the sink node initiates the communication by broadcasting a query for data over the network. The QoS based protocols allow sensor nodes to make a tradeoff between the energy consumption and some QoS metrics before delivering the data to the sink node. Finally, multipath routing protocols use multiple paths rather than a single path and it has demonstrated its efficiency to improve wireless sensor and ad hoc networks' performance for load balancing, reliability, fault tolerance, bandwidth aggregation and QoS Improvement [16]. The figure 6 below shows the classification in routing wireless sensor network.

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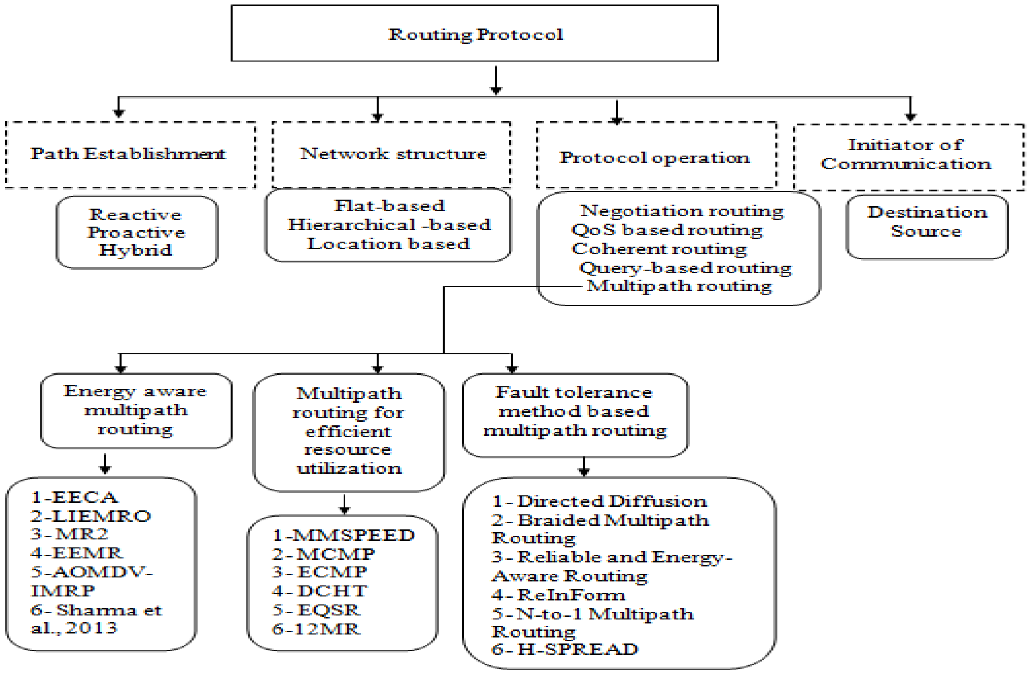

Figure 6: The classification of routing protocols

10. CATEGORIZATION BASED ON THE NETWORK STRUCTURE

The routing protocols designed for WSN can be classified based on path selection, as proactive; an approach where each router can build its own routing table based on the information that each router (or node) can learn by exchanging information among the network's routers reactive; routing is an approach where the routing process needs to discover a route whenever a packet arrives from a source and needs to be delivered to a destination and hybrid; which combine of proactive and reactive. Based on the network architecture, they can be further classified as Flat (flooding, data centric and forwarding) Hierarchical based routing and Geographical based routing.

10.1 Flat routing protocol

There are three types of flat routing schemes, namely, flooding, forwarding and data-centric based routing. Flooding is an old routing technique that can be used in sensor networks. In flooding, every node repeats the data once by broadcasting. It does not require costly topology maintenance and complex route discovery algorithms. Forwarding schemes utilize local information to forward messages. Unlike the traditional routing protocols, forwarding doesn't maintain end-to-end routing information. Instead, intermediate nodes maintain only neighbor information. One example is the gossiping protocol, a node only forwards data to one randomly chosen neighbor, so it doesn't maintain any routing information or we can say it uses randomness to forward data. In data-centric based routing, an interest message is disseminated to assign the sensing tasks to the sensor nodes and data aggregation is used to solve the implosion and overlap problems. There are two types of data-centric based routing based on either the sink broadcasts the attribute for data, e.g. Directed Diffusion, or the sensor nodes broadcast an advertisement for the available data and wait for a request, e.g. Sensor Protocols for Information via Negotiation (SPIN). In a flat network routing every single node normally plays similar function and nodes work collectively by performing assigned sensing tasks. Sensor nodes are so numerous, and assigning of global IDs to every single node is almost impossible, so data centric routing was proposed as an alternative that involves the base stations (BS) broadcasting queries to specific sections and wait for response a data from the sensor nodes. Some example of this class of routing protocols is Sensor Protocols for Information via Negotiation (SPIN), Minimum Cost Forwarding (MCF), Directed Diffusion (DD), Rumor Routing, SER (Stream Enable Routing), GBR (Gradient-Based Routing), CADR

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(Constrained Anisotropic Diffusion Routing), COUGAR and ACQUIRE (Active Query Forwarding in Sensor Networks) [5].

10.1.1 Flooding

In flooding mechanism the source node broadcast all events to each node in the network. Therefore when a sensor receives a data message, it holds a copy of the message and sends the message to every one of its neighboring sensors and the c
repeats as shown in the figure 7. The floodin
considered easy-to-implement routing scheme
it is appropriate for various network types, n
distributions and environments. The reliab
provided by flooding routing method is the m
advantage. Due to the message will be transmi
to at least once to every node. However the h
broadcasting the packets in the flooding sch
will cause the broadcast storm [39]. The flooc
routing protocol has three deficiencies as:

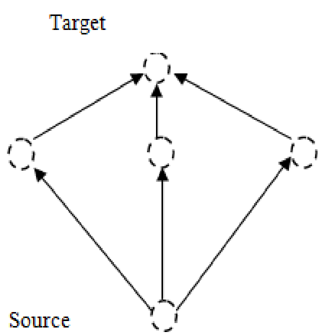

Figure 7: Flooding Routing

Implosion: as shown in figure 8 (a), the sensor nodes in flooding technique send data by broadcasting; hence similar data might attempt to reach similar sensor nodes through using different paths. When a sensor node receives a packet, it will not check the packet if it has received the packet before. Thus duplicated data are transmitted to similar locations. For instance Node A begins by flooding the packets to every area of its surrounding neighbors; D obtains double copies of the similar packets finally that is not needed.

Overlap: as shown in figure 8 (b), the procedure ensures that if two sensor nodes discover similar event, the nodes both attempts to transmit the packets of this event through the sink. By carrying out the process it ensures that the duplicate data of the event are transmitted to the sink. The boundaries of the region section (r) are enclosed by the two sensors and C receives similar copy of the packet from the two sensors.

Resource blindness: When a sensor node is not transmitting packets in flooding, it does not change their actives, even if the sensor nodes do not have much power to operation [4].

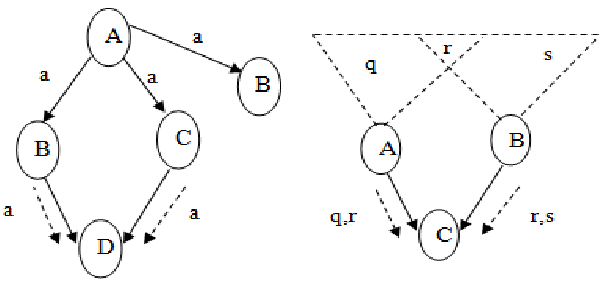

Figure 8: (A) The Implosion Problem, (B) The Overlap Problem

10.1.2 Gossiping

Gossiping is an enhanced version of flooding which avoids the problem of implosion. In gossiping [40], the sender node sends the data at random way to selected neighbor rather than broadcasting the packet blindly. Moreover every node that receives the packets randomly chooses a neighbour and sends the data to it. This procedure is repeated through all the nodes that receive the packets, until the data arrive at its destination. Since gossiping sends the data to only one neighbour, this is energy saving. However, the delay that a data experiences, on its way to the destination, may be too much due to the random nature of the protocol.

10.1.3 Sensor Protocols for Information via Negotiation

Sensor Protocols for Information via Negotiation (SPIN) [41] transmit data to sensor nodes and it is part of data-centric routing technique the principle behind SPIN was by choosing data through high-level meta-data or descriptors. The exchange of meta-data between sensor nodes through announcement of data scheme that are communicated prior to transmission, a vital feature of SPIN. Every node after receiving the new data will advertise to not only to nearer neighbors but also to all neighbors who are interested, that is, those who do not have the data, retrieve the data by

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sending request messages. A SPIN meta-data negotiation mechanism solves the problem of flooding like redundant information passing, overlapping of sensing areas and resource blindness. There are three messages defined in SPIN to exchange data between nodes. These are: ADV message to allow a sensor to advertise a particular meta-data, REQ message to request the specific data and DATA message that carry the actual data as shown in figure 9. The foremost important of SPIN indicates that of frequent topology changes because any changes are done undertaken locally, and every node will get to know about the changes at next neighboring single-hop. A broadcast technique from SPIN information does not ensure the possibility for data delivery. An example point to this, if the nodes that are interested in the data are far away from the source node and the nodes among source and destination are not interested in that data, such data will not be delivered to the destination at all. Therefore, making SPIN not suitable for application such as intrusion detection which requires the reliability of data delivery.

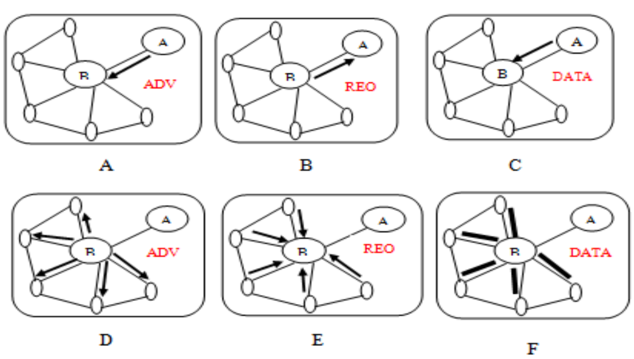

Figure 9: The process of SPIN Protocol

10.1.4 Rumor routing

Rumor routing comprises of two technique event flooding and query flooding [42]. The basic idea of rumor routing is to use agents to route the query to every section of the sensor nodes which are known to have connections to a specific event instead of attempting to flood the whole network to recover data about event currently happening. The agents in rumor routing are utilized as long-life packets to flood events throughout the network. Any event discovered by the sensor node, it adds that particular event to the routing table and produces an agent. The agents can travel through the network and spread messages about the neighboring events and nodes which are distant. In any situation where a node produces a query for any event, the sensor nodes connected to the route act in response to the query through references from the generated event table, thereby evading the extra overheads involving in flooding the entire network. One key point which distinguishes Rumor routing from Directed Diffusion (DD) is that, it keeps not more than one route between the source and the destination, as DD entails the transmission by multiple routes at cheaper levels. Moreover rumor routing tends to function much better if the amount of events being generated is small. If the amounts of events are too big, the cost of sustaining the agents and event tables for every sensor node is uncontrollable when sensor nodes have not attached a high significance of the events from the base station. Also the cost link with rumor routing is managed by various conditions applied through the techniques like time-to-live (TTL) pertain to the query and agents generations.

10.1.5 Active Query Forwarding in Sensor Networks

Active Query Forwarding in Sensor Networks (ACQUIRE) [43] is a scheme to query sensor networks. The technique has some likeness with COUGAR, but ACQUIRE analysis entire network to be a distributed database to which complicated queries categorized by numerous small sections of queries. The functions of ACQUIRE are; the base station node transmits and forward the query to every node. During this, each node receiving the query tries to respond to the query partially by using its pre-cached information and then forwards it to another sensor node. If the pre-cached information is not up-to-date, the nodes gather information from their neighbors within a look-ahead of d hops. Once the query is resolved completely, it is sent back through either the reverse or shortest-path to the sink. Hence, ACQUIRE can deal with complex queries by allowing many nodes to send responses.

10.1.6 Energy Aware Routing (EAR) Protocol

Energy Aware Routing protocol (EAR) was proposed by [44], it belongs to data-centric routing category and its operations are almost the same as Directed Diffusion (DD). However its difference over DD is simply through the preserving of a pair of routes rather than keeping single optimal routes at increased overheads. The usage of the routes is selected through probability function, which is related to energy consumption of every route. The scheme argues that when the lowest energy routes

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are utilizing frequently, it will lead to depletion of the energy of the node along that particular route, rather multiple routes should be used by assigning a algorithm or forecasting technique to ensure balance and increase approach of the network life. By employing load balancing technique that is more resourceful, it limits the rapid depletion of the energy on every single route. This scheme extends the lifetime of the network because energy dissolve equitably between every sensor node. One of the disadvantages of EAR where it does not provide any mechanism to recover from a node or path failure when compared to Directed Diffusion.

10.2 Hierarchical routing protocol

Hierarchical or cluster-based routing traditionally was meant for wireless sensor network because of its scalability and resourceful communication, so the model of hierarchical routing is also leveraging upon to execute efficient energy routine. In Hierarchical routing protocol the top most energy nodes processes and transmits the data, and lower level energy nodes carry out the sensing of target proximity. They enable an environment for constructing clusters and allocating assigned schedules to cluster heads contribute immensely to overall system performance in terms of energy efficiency, lifetime and scalability and it is the most effective means of reducing energy consumption within the cluster through the activation of data aggregation and fusion, thereby lessen the amount of transmitted messages to the base station Examples of this category are weight-clustering algorithm (EWC), TEEN (Threshold sensitive Energy Efficient sensor Network protocol), Self-organizing Protocol (SOP), LEACH (Low energy Adaptive Cluster Hierarchy) routing protocol and PEGASIS (Power Efficient Gathering in Sensor Information System) routing protocol belongs to this grouping. Some types of hierarchical based routing are explained briefly below;

10.2.1 Low Energy Adaptive Clustering Hierarchy (LEACH)

Low Energy Adaptive Clustering Hierarchy (LEACH) [45] is one of cluster-based protocol in sensor network. The operations of LEACH are the random selections of some nodes to form cluster-heads and rotate every role of the cluster-heads in order to equitably share the load energy between the sensors in the network. The cluster-head nodes also compress data being transmitted from the nodes that is in the same group of that particular cluster, and send aggregated packets to the Base Station (BS) thereby decreasing the number of information being sent to the BS. The operation of LEACH is separated into two phases, the setup phase and the steady state phase.

In the setup phase, the clusters are organized and CHs are selected. In the steady state phase, the actual data transfer to the base station takes place. The duration of the steady state phase is longer than the duration of the setup phase in order to minimize overhead. During the setup phase, a predetermined fraction of nodes, p, elect themselves as CHs as follows. A sensor node chooses a random number, r, between 0 and 1. If this random number is less than a threshold value, T (n), the node becomes a cluster-head for the current round. The threshold value is calculated based on an equation that incorporates the desired percentage to become a cluster-head, the current round, and the set of nodes that have not been selected as a cluster-head in the last (1/P) rounds, denoted by G. It is given by:

$$T(n) = \frac{p}{1 - p(r \bmod (1/p))} \quad \text{if} \quad n \in G, \qquad (1)$$

Where G is the set of nodes that are involved in the CH election. The application of TDMA/CDMA MAC being operated by LEACH normally leads to reduction in inter-cluster and intra-cluster collisions though the gathering of data is still operated at central locations and done once awhile. LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. Therefore, it is not applicable to networks deployed in large regions moreover, the notion of dynamic clustering brings extra overhead, e.g. head changes, advertisements etc., which may diminish the gain in energy consumption.

10.2.2 Power-Efficient Gathering in Sensor Information Systems

Power Efficient Gathering in Sensor Information Systems (PEGASIS) [46] is an improvement routing protocol over LEACH when both protocols are compared because PEGASIS is almost similar to a chain-based optimal routing protocol. Prolonging the network lifetime is the basic concern of the protocol because node communicates with each other through the nodes that are nearer to each, and also the nodes take their turns to communicate with the base station. A next round of communication will begin only when every node have communicated to the base stations, the end result is energy reduction per round of data being transmitted, because energy depletion is equitably distributed across every node. So the key importance is to increase the network lifetime of every node by applying collaborative schemes

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techniques, and secondly permit only local harmonization among the nodes that are nearer to each other, so bandwidth consumption during communications are reduced. Discovering of nearest neighbor nodes is through signal strength that each node applies to computing the distance of nodes closest to each other. PEGASIS introduces excessive delay for distant node on the chain. Hierarchical-PEGASIS is extended version of PEGASIS, with the only purpose of reducing the delays occurring for data whenever data is being transmitted to the base station. It also provides a scheme result for the packet collection constrains by taking notice by calculation energy x delay metric. Data reduction delays in PEGASIS can be achieved through concurrent data transmission of messages. For the issue of collision and interference coming from signaling between sensors, the two procedures have been recommended. The first technique allows for inclusion of signal coding, e.g. CDMA, while the second procedure entails spatially dividing nodes only are permitted to broadcast concurrently same time. In the second approach only spatially separated nodes are allowed to transmit at the equivalent times. CDMA, which is a chain-based routing protocol is made of reliable nodes, can build chains of nodes to form a tree structure hierarchy, where every chosen node a specific neighboring area send packets to the node that are at the top layer of the hierarchy. This technique enables parallel packets broadcasting thereby delays are immensely reduced. An advantage of PEGASIS is the prevention of clustering overhead usually associated with LEACH. One disadvantage of PEGASIS is the requirement for every single information inside the chain is combined as a single packet contributing to incorrect information transmitted to the sink.

10.2.3 Weight-clustering algorithm

Weight-clustering algorithm (EWC) [47] is energy efficient algorithm with the main reason being to join many special weight metrics such as residual energy, node degree and location, node degree, and the nodes with minimal combined weight become cluster heads which intend contributes to reduction of energy consumption through the improvement in cluster formation and selection processes. At selection phase for cluster head, various factors were taken notice because of the distribution of various weighted co-efficient to parameters like energy residual, location, scale of nodes, and also nodes which have added minimum weight are grouped together to become cluster heads. The algorithms additional permits adjustments to the co-efficient founded on network criteria. The authors also set various kinds of parameters which have diverse weight structures pertaining to precise system specifications. In selecting the cluster heads, extreme care must be considered as cluster heads can have significant impact on the operations of the entire network. Node suitability is measured through numerous factors such as residual energy, distance between the cluster heads, nodes degree and node and base station before being selected to be cluster heads. These are four procedures the authors recommended for the selection of cluster head; approximating distance among sensor node and base station; determine the neighboring areas of every sensor node. Sensor nodes transmit neighbor discovery messages, that is made by node ID, energy level and distance to the base station; Computation of the degree of diversity and Weight exchange, this is where after every node compute its weight, there are exchange of weight information with neighboring nodes, and which intend maintain the information in their tables.

10.2.4 Threshold-Sensitive Energy Efficient Protocols

Threshold-Sensitive Energy Efficient Sensor Network Protocol (TEEN) and Adaptive Periodic TEEN (APTEEN) are all designed for time-critical applications [48, 49]. In TEEN, the nodes being used have the ability to sense the medium continuously; however transmission of data is not always regular. The technique used includes, a cluster-head sensor transmitting to all its affiliates hard threshold, that are the sense attributes of the threshold rate and also soft threshold. It normally indicates the little change value of the sense attribute which enable the node to trigger and to determine when to switch the transmitter and to initiate a transmission. Consequently, the hard threshold attempts to decrease the amount of data being sent by enabling the nodes to send solely when the sense attribute is going to be beneficial or within a collection of interest. When the value is small of the soft threshold then that implies a more favorable view of the network over high consumption of energy. However, TEEN is not good for applications where periodic reports are needed since the user may not get any data at all if the thresholds are not reached. The major demerits of the technique is when the thresholds are not accepted or does not meet the requirements the nodes might not be allowed to exchange information with each other and the network will

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not generate any data from the network for the user to use.

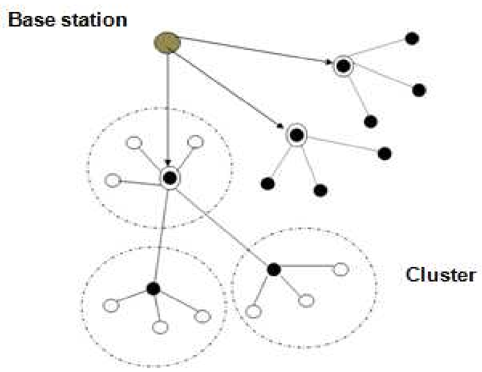

Figure 10: Hierarchical Clustering in TEEN and APTEEN

The Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN) [49] is upgraded version of TEEN, the main objectives are of two forms, first to take hold of periodic data compilation, and secondly respond to real-time event schedules. Its architecture is similar to TEEN, and the base station are founded on the clusters, and then the cluster top level heads transmits the properties, values of the threshold, and tasks of the broadcasting to every node. The operation of data aggregation is also done by the Cluster heads for preservation of energy. The APTEEN scheme can analyze three kinds of query such as historical, examination of past data values; one-time, quick and once overall view of the entire network; and persistent, observe schedules for specific time frame. Experiments conducted by the authors in TEEN and APTEEN which have proven that they perform much better when compared with LEACH. The APTEEN's performance is somewhere among LEACH and TEEN in terms of energy consumption and network lifetime. TEEN gives the best performance because it decreases the number of transmissions. The main disadvantages of the two methods are the overhead and complexity related with forming clusters at multiple levels, the method of implementing threshold-based functions, and how to deal with attribute-based naming of queries.

10.3 Location based routing

In terms of location based routing the nodes are recognized through their locations. The distance between the neighboring nodes are calculated on the base of arriving signal strengths. Medium of exchanging data among neighbors are acquired through relative coordinates of neighboring nodes. Moreover the discovery of sensor nodes is ascertained directly through communication satellite, applying Global Positioning System (GPS) when sensor nodes are fitted with a low power GPS receiver. Energy is saved by this routing scheme that allowed sleeping of the nodes when there is a lack of activity taken place [38]. Energy Aware Greedy Routing (EAGR), Geographic and Energy Aware Routing (GEAR), Geographical Adaptive Fidelity (GAF) are some examples which are discussed briefly below.

10.3.1 Geographic and Energy Aware Routing

Geographic and Energy Aware Routing [50] (GEAR) applies energy aware and heuristic neighbor selection to route packets in the direction of the destination area. One of the essential points is by limiting the amount of data interest in DD by considering only a specific sector instead of transmitting to the entire network. This makes GEAR preserve a lot of energy than directed diffusion. For GEAR, every node maintains the pre-determined estimated cost and learning cost about the network along the path of transmission by means of closest neighbors. The estimated cost is a combination of residual energy and distance to destination. The learned cost is a refinement of the estimated cost that accounts for routing around holes in the network. The incidents of holes happen if a node cannot have any nearer neighbors close enough to the targeted section apart from the node itself. In the case where holes are absent, then the estimated cost is equivalent to learned cost. The learned cost is spread one hop backwards whenever a data arrives at destination, so path setup for next data will be regulated to reflect the current situation of learned cost. The algorithm includes two stages. Firstly, Forwarding packets towards the target region: When a packet arrives, a node check the neighboring nodes to find out if there is any neighbor that is nearer to the estimated target section than the node itself. When more than one node are discovered, the closest neighbor node to the target section is chosen as the next hop for transmission. When every node is more distant away from the node itself, and the node exists, therefore one of the neighbor node is selected to relay the data according to learning cost function. The selection might be adjusted from time to time according to the conformity of the learned cost achieved throughout the packets delivery. Secondly, forwarding the packets within the region: When the data arrived in the region, the data will be spread to that region through two means, either by

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recursive geographic forwarding or restricted flooding. In restricted flooding, it is useful if the deployment of the sensors is not heavy. Recursive geographic flooding is more suitable and resourceful for high density network node deployment. From that situation, the region is separated into four sub-regions and four duplicate copies of the data are generated. The procedure of splitting and forwarding carry on till all the regions have one node remaining. GEAR comparison with GPSR protocol which has the same non-energy aware characteristics and was one earliest protocols developed to handle geographic routing which applied planar graphs in resolving the constraints of holes. GEAR shows perform better than GPSR and the advantage of GEAR is the reduction of energy consumption in the path setup time and delivery of packets.

10.3.2 Geographical Adaptive Fidelity

Geographic Adaptive Fidelity (GAF) is also energy-aware routing techniques [51]. The conservation of energy by GAF is conducted through the switching off redundant nodes in the network. GAF conserves energy by turning off unnecessary nodes in the network which does not affect routing efficacy. All the sensor nodes use GPS-assisted geographical based to connect their selves with a section in the virtual grid. When the nodes relate to the same section on the grid, and then there are classified as equal in terms of packet cost routing. The equitability of maintaining nodes in grid sections ensures the area to be designated as sleeping state thereby conserving and saving energy. Thus, GAF can substantially increase the network lifetime as the number of nodes increases. Nodes change states from sleeping to active in turn so that the load is balanced. There are three states defined in GAF, these states are discovery for determining the neighbors in the grid, active which reflecting participation in routing and sleep when the radio is turned off.

10.3.3 Energy Aware Greedy Routing

Energy Aware Greedy Routing (EAGR) [52] is a location-based protocol for providing geographical information on the sensor nodes, and at the same time preserving energy level accessibility in sensor nodes, considering the fact that every node which is available on the shortest path loose energy very fast, leaving a gap the section resulting in packets dropping. EAGR provides all nodes with the identical energy levels where a threshold energy rank is set if the nodes have lesser energy than the original level. The nodes which have a lower amount than the energy levels are measured as dead, allowing the algorithm to discover the positioning of every node. Every sensor node which have energy level higher than the threshold value obtains information about the neighboring nodes and build a table for the positions, and this positional table is used to compute the average distance of its neighboring nodes. In data relaying, the algorithm chooses the node which have distance equivalent to or lower to average distance value and at the same time having highest energy levels between its neighboring nodes. Through energy level indication, if needed, a fresh node is chosen, then each node depletion of energy is significantly reduced contributing to extended network lifetime. In EAGR, data dropped only if the target destination is not active or if there is lack of neighboring nodes which is alive to relay data. Research conducted by authors comparing the outcome of EAGR with shortest path greedy algorithm using OMNET++ simulator describes the immense difference between the two, with EAGR performing far superior in comparison with the simple greedy algorithm [53].

11. CATEGORIZATION BASED ON PROTOCOL OPERATION

The Classifications based on protocol operations are grouped into Query based, QoS based, negotiation based, Coherent based routing and multipath based. The negotiation based protocols have the objective to eliminate the redundant data by include high level data descriptors in the message exchange. In query based protocols, the sink node initiates the communication by broadcasting a query for data over the network. The QoS based protocols allow sensor nodes to make a tradeoff between the energy consumption and some QoS metrics before delivering the data to the sink node. Finally, multipath routing protocols use multiple paths rather than a single path and it has demonstrated its efficiency to improve wireless sensor and ad hoc networks' performance for load balancing, reliability, fault tolerance, bandwidth aggregation and QoS Improvement [54].

11.1 Negotiation-Based Routing

In negotiation-based routing, higher level packet descriptors are applied for eliminate redundant data by means of negotiation. The protocol makes decisions through communications and resources available to them within a certain period of time. The main motivation for using the protocol was that, they spread data by flooding techniques will

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generate implosion and overlap among the data being transmitted; therefore nodes will receive replica copies of same packets. Therefore this operation consumes a lot of energy and as well as more data processing through the transmissions of similar data by various sensor nodes. The rationale behind the designing of SPIN is the distribution of data of one sensor to every sensor node by predicting the sensor nodes are supposed to be base stations, thus preventing duplicate data and redundant data from being transmitted to next sensor or to the base stations by performing a sequences of negotiation messages before the real data transmission begins [55].

11.2 Query based routing

The protocol involves a technique where destination nodes propagate queries for data initiation from the node throughout the network, the node which had that specific data send the same data that matches the query to the node which started the query. Normally the queries are illustrated either in structured natural language or higher level query languages. For instance, a say client C2 could present inquiry to node N2 with the following question, Is there any movement of cars around the battle field section 2? Every node contains tables made of sense queries being received and transmits according the matches of tasks after receiving it. An example is Directed Diffusion, where the base station broadcast the interest message to every sensor node. While the interest is disseminated through the network, the gradients from the source to the base station are set up. If the source node has the data of interest, the source immediately transmits the data alongside the interested gradient path. Consumption of energy is decrease by means of data aggregation which is performed during routing. Other examples of Query base routing protocols are Rumor Routing, ACQUIRE and COUGAR [4].

11.3 QoS based routing

The standard criteria for the network has to be balancing of energy consumption between quality data through the fulfillment of distinct QoS metrics such as energy, delay, packet loss, throughput, bandwidth whenever sending data to the base station. An example is, SPEED (Stateless Protocol for Real-Time Communication in Sensor Networks) and SAR (Sequential Assignment Routing).

11.4 Non Coherent and Coherent Based Routing

Routing uses various kinds of data processing schemes, and normally in sensor networks, nodes might join forces among themselves in order to process diverse types of data being flooded into the network. There are two types of data processing techniques; namely coherent and non-coherent routing. In coherent routing, packets are relay to aggregators after minimum processing. The least amount of processing typically comprises of time stamps and replica suppression. Coherent based routing is the best choice to use carry out efficient energy routing. Moreover it allows the processing of raw data in the same domain area by the nodes before being transmitted to next available nodes for additional processing. Coherent routing bring about the realization of energy-efficient routing whenever energy issues arise because the process allow for the generations of longer data streams, so energy efficiency is obtained by maximization of the path. Multiple Winner Algorithm (MWE) is an example of coherent based data processing routing [25]. Non-coherent based routing operations include smaller packet traffic loading, while for instance, Coherent produces lengthy data streams, energy efficiency might be accomplished through optimal routes. While Non-coherent processing routing, data processing occurs in three stages: 1. Target discovery, data gathering, and pre-processing, 2. Relationship affirmation and lastly 3. Elections of central node. In stage 1, a target is discovered, data gathered and pre-processed. A node might make a decision to join in cooperative operations, before it enters stage 2, where declaration of intent are announced to all neighboring nodes. Because every sensor needed to have faster understanding of the local network topology, this process is quickly executed. In stage 3, is the election of central node. Because the central node is chosen to operate at higher delicate data and information processing, it requires high levels of energy reserves and high speed computational capability. Single Winner Algorithm (SWE) is a good example of non-coherent.

11.5 Multipath based Routing

This type of routing protocols uses multiple paths instead of a single path for the enhancement of network lifetime performance, in other words, the discovering of multiple successful paths from source to destination to send packets. If the failure occurs in the primary region between the source and the target destination, alternate paths are created to carry on the assigned scheduled sensing

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tasks, and the alternate paths are kept active by messages being sent frequently therefore leading to the high cost of energy consuming and traffic generation. Directed Diffusion is a good example of this type of multipath routing.

12. MOTIVATIONS FOR USING MULTIPATH ROUTING APPROACH

Multipath routing schemes does improve efficiency wireless sensor and ad hoc networks performance. The following are the motivational benefits to be derived when multipath routing techniques are used.

12.1 Reliability and Fault-Tolerance

In view of rapid time change characteristics of dynamic network topology, low-power wireless links and frequently wireless interference transmitting a reliable packet in a wireless network is a difficult task. As the primary inspiration of multipath routing in sensor networks were to give route resilience and the transmission of reliable data. Fault tolerance in sensor network simply means if a node cannot relay the packets in the direction of the sink, available alternative paths are used to prevent packets from failures coming from either the node or link. The scheme is such that so far as alternative paths are available from a target area to the sink node, packet transmitting can be continued without any interruption even in the case of path failure. Moreover multiple paths are also used concurrently to rise up the reliability of packet transmission. There are two ways of providing data transmission reliability simultaneously in multipath routing; the first technique is founded by sending numerous copies of the original data across various routes to allow recovery of data from several route failures. So the reliability of data transmission is assured when at least one route is able to forward data safely [11, 16]. The second technique is erasure coding which certain protocol used to extract reliability performance from several systems. For this approach, every source node inserts extra information to the original data before distributes the packets across different routes. So in case of routes failure to send packets to the sink, data transmission can still continue by reconstructing packets from previous good routes.

12.2 Load Balancing and Bandwidth Aggregation

Resource constrains in sensor nodes illustrates that, the rigorous traffic loads in high-data rate applications are subjected to congestion, leading to degradation of network performance. To handle this issue, data dissemination algorithms can profit from the high density of sensor network to raise the capability of network by employing several network resources. Multipath routing technique therefore produced the most convenient solution in supporting the bandwidth conditions of various applications to decrease the possibility of network congestion through separation of network traffic across several routes. Moreover, the dissemination of network traffic across numerous sensor nodes might contribute to equitable energy consumption between the nodes and extend the lifetime of the network. However in radio communication, the transmission character of the broadcast prevents attaining of such goals, the reason being that in single-channel wireless network, sensor nodes work with shared wireless channel to correspond with among nodes. So the simultaneous operations of neighboring routes contribute to immense inter-path interference that increases the possibility of packet collision at the nodes in the direction of active routes. This problem is known as route coupling effect, which relatively hinders the performance of multipath routing [56].

12.3 QoS Improvement

QoS is measured in the terms of throughput; end-to-end latency and lastly delivery data ration which are all essential goals in developing multipath routing protocols for various kinds of networks. Routes which have been discovered with several properties might be employed to spread network traffic on the conditions of QoS demands of the applications for which the multipath routing is intended for. For example, real-time critical data might be sent through high capacity routes having lesser delays, while the delay non-critical packets might be relay through non-optimal routes with high end-to-end delays. Additionally unlike single-path routing method, multipath routing technique sustains QoS demands of the designed application whenever routes failures happen by channeling network traffic to alternative active routes. But because of lack of link layer problems in single-channel wireless network, enhancing network throughput and delivery data ratio by concurrent multipath routing for sensor networks will be difficult when compared with wired networks [11]. The majority of the proposed routing protocols for WSN are focusing on efficiently using extremely constrained resources, in particular the energy. On the other hand, one significant factor of the routing protocols, the QoS routing has not been paid enough attention from researchers. In order to

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minimizing energy consumption, it is also significant to deem QoS requirements such as the delay, reliability, throughput in routing in WSNs. The authors in [57] have addresses the problem of QoS routing in order to improve energy consumption in WSNs through formulating a path-based energy minimization problem subject to QoS routing constraints expressed in terms of delay, geo-spatial energy consumption and the reliability. In addition the authors [58] have proposed a novel QoS-aware routing protocol to support high data rate for WMSNs. Being multichannel multipath, the routing decision is made according to the dynamic adjustment of the required bandwidth and path-length-based proportional delay differentiation for real-time data. In [59] author proposed a multipath method which employs the virtual grid, to meet the real-time requirements. In order to choose one of multi-paths depends on the service differentiation, the proposed method uses numerous information such as the size and transfer period of sensed data. Besides to an existing path, the algorithm dynamically chooses an alternative path according to multipath environments. Furthermore, it allocates the shortest path to the sensed data with most strict time. Authors [60], presented a Multiconstrained QoS multipath (MCMP) routing in WSN. Based on this model, an approximation of local multipath routing algorithm is explored to provide soft-QoS under multiple constraints, such as delay and reliability. This MCMP routing algorithm trades precise link information for sustainable computation, memory and overhead for resource limited sensor nodes.

12.4 Energy Efficient

One of the design challenges confronting wireless sensor network is the issue of limited power supply for sensor nodes. Resources for wireless sensor networks are vast; especially hundreds and thousands of sensor nodes which all need adequate supply of energy to perform effectively. So a usage of energy is a pre-requisite for maximization of the entire lifetime of the network. In single path routing, for example if the same optimal paths are used continuously all the time, some nodes might deplete their source of energy at a quicker rate therefore leading to network partition [16]. An Energy Efficient Multi-path Routing Protocol is proposed for WSN‘s [61]. The protocol argues that, when using the minimum energy, path will dissolve the nodes energy rapidly and the time taken to find out an alternate path will increase. The protocol employ multiple paths between the source and the sink which is intended to grant a reliable transmission environment with less energy consumption, by efficiently using the energy availability of the nodes to discover multiple routes to the destination. For the purpose of real-time transmission of multimedia data, authors [62] presented a new QoS protocol which called Real time Energy Aware (REAR) applies to WSNs. In this protocol the metadata is employing to establish multipath routing for decrease the energy consumption. In [63], the authors proposed an energy-efficient multipath routing protocol for WSNs and distribute the traffic through the multiple paths which have discovered based on their cost, which depends on the energy levels and the hop distances of nodes along each path.

12.5 Reduced Delay

When using the single path routing protocol in wireless sensor network, if a route or path in case of node failure, it implies that a fresh discovery of path procedures should be undertaken again to discover routes which are new contributing to delay of route discovery. Delays in multiple routing are diminished because of backup paths identifications during the period of route discovery. The main aim of multipath routing protocols is to enable utmost utilization of the network lifetime is operational and meet the intended observation schedules [64].

13. BASIC PRINCIPALS IN DESIGNING MULTIPATH ROUTING PROTOCOLS

There are diverse kinds of multipath routing protocol techniques and most of them are designed to meet certain specific application targets. However, the general consensuses were the estimated performance gains to be measured by the capability of the recommended protocol to create sufficient number of higher quality paths or routes. The protocols must entail embedded components that enable creation of multiple paths and the capability to allocate network traffic across paths explored. Although the multipath routing approach has been employed for different purposes, the achieved performance gain is highly affected by the ability of the proposed protocol to construct a sufficient number of high-quality paths [36]. Each multipath routing protocol includes several components to construct multiple paths and distribute network traffic over the discovered paths as well as the maintenance of the paths. Below are brief explanations the components for multipath routing.

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13.1 Path Discovery

In wireless sensor network, sending of data is traditionally undertaken by multi-hop data forwarding schemes, so the primary goal of the route discovery is the discovery of a pair of intermediate nodes to be chosen to create or build the numerous paths from the source to the sink nodes. There are several kinds of requirements used by the current multipath protocol to formulate informed routing decisions. Some of these parameters are; the number of path disjoint is one of the primary conditions, it allows every existing path disjoint to maximize its main path disjoint core conditions to give higher aggregated network resources. The random deployment of sensor nodes makes it almost impossible to find a bigger pair of node-disjoint path among sensor nodes and sink node. Numerous paths can be discovered in multipath routing and their classification are; non-disjoint paths and disjoint paths [11].

13.1.1 Non-disjoint paths

The Non-disjoint paths also called as joint multi-paths which can have links and nodes in common with any loop-free paths.

13.1.2 Disjoint paths

The Disjoint multipath process attempts to discover disjoint paths based on the degree of independence of each path. These paths can be grouped as below;

13.1.2.1 Link-disjoint multipath

The Link-disjoint paths refer to set of paths that have no common links however they may share some common intermediate nodes. In [65], the authors proposed a multipath routing scheme to distribute the traffic over the multiple link-disjoint paths based on the path deputies theory "one neighbor one deputy service, different neighbor different deputy service‖".

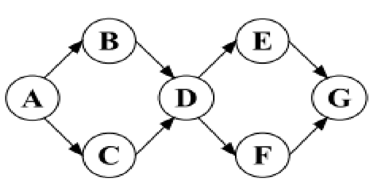

Figure 11: Link-Disjoint Paths

13.1.2.2 Node-disjoint multipath

The Node-Disjoint Multipath refers to the set of paths in which each path does not share any nodes other than the source and the destination nodes. Therefore they are not influenced by failure on the other path. Most existing routing protocols are not very practical for transmitting multimedia contents in resource constrained sensor networks. In [66], an optimized nod-disjoint multi-path routing method is presented which give a throughput enhancement moreover load balancing for transmitting multimedia content. In [67] the researchers presented TPGF is the first multi-path routing protocol in the WSNs field. It concentrate on exploring the maximum number of optimal node-disjoint routing paths in network layer in terms of minimizing the path length and the end to end transmission delay as well as taking the limited energy of WSNs into consideration.

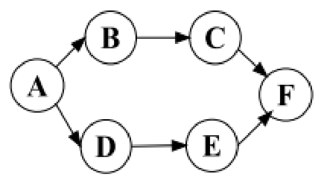

Figure 12: Node-Disjoint Paths

13.1.2.3 Totally disjoint multipath

In Totally disjoint multipath when concurrent data transmissions happen, the pair of optimal routes are linked together at the edge and so there is no interference. In [68] the case of totally disjoint multipath is a multi-hop which provides an estimation of throughput through multipath techniques by taken into consideration the effects of existing interferences within the network. Here the researcher's focuses on networks with fixed and non-energy constricted wireless backbone. The researcher also adopts an incremental approach to tackle the problem by first taking into account the interference between a single source-destination pair and next between multiple sources and destinations.

13.1.2.4 Maximally Disjoint Multipath

For Maximally disjoint multipath routing comprises with several pairs of node-disjoint routes which are used to efficiently optimize a disjoint features among the probable routes, and at the same time maintaining to the lowest frequent nodes. In WSN, the availability of fully disjoint routes are less common, so a substitute solution is through the application of partially disjoint routes, especially through the maximally link-disjoint routes. A set of routes coming through the source to target is formed to be known as the maximally link-disjoint whenever the amount of links shared between the routes are less. There are evidences to prove that fully disjoint routes are known to have null links, so

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multipath routing favors the routes with minimum joints in general.

13.1.2.5 Partially disjoint paths - braided multipath

Braided multipath or partially disjoint comprise of set of node-disjoint paths through relaxation of node-disjointness. For every node on the primary path, an optimal alternative path from a source toward a sink that does not include that node is computed. These alternate paths could potentially have much similar delay to that of the primary path and then extend more or less same amount of energy as that on the primary path.

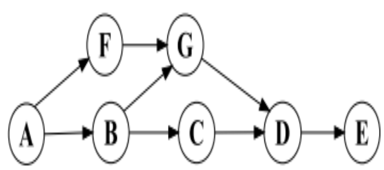

Figure 13: Partially Disjoint Paths

13.1.2.6 Zone–Disjoint Multipath

Zone-disjoint multipath consist a set of paths in which data communication on one path will not occur interferences with the data communication from another path. In combat missions, real time streaming in WSNs is needed to provide useful information for high quality data about the mission critical spots. Several progresses had been made in recent years that have enabled large-scale WSN to be deployed supported by high-bandwidth backbone network for that can ensure higher rate of streaming; the WSN remains the bottleneck because of the low-rate radios used and the effects of wireless interfering. Authors in [70] first presented a method to evaluate the quality of a path set for multipath load balancing, taking into account the effects of wireless interferences and that nodes may interference beyond communication ranges.

Secondly there is interference minimized multipath routing (I2MR) protocol which have the ability to increase throughput through finding out the several zone-disjoint routes to be used for balancing loads, Moreover, the researcher proposed another method, congestion control technique which enhance throughput through load balancing at the highest possible rate supportable. Lastly, validate the path-set evaluation method moreover evaluate and compare the I2MR protocol and congestion control scheme with AODV protocol and node-disjoint multipath routing (NDMR) protocol.

13.1.2.7 Radio disjoint multipath

Radio Disjoint Multipath (RDM) consist of pairs of routes either having a minimum interferences from radio, or several paths which are not interfering with each other and applied to decrease the impact of nodes interfering with other. According to the researchers, [61] that recommended Maximally Radio-Disjoint Multipath Routing (MR2), the focus was to resolve the challenges of routes interferences with each other with specific references to WSNs for intra- session as well as inter session interferences. To supply the requisite bandwidth to multimedia application, there is a step-by step techniques provided for a specific session and normally only a single route is develop at immediately is considered. Furthermore extra routes are built whenever needed, especially during congestion or during lack of bandwidth. In MANET ad hoc networks, Radio disjoint multi-path routing are discussed in [69] and it is a technique used for selecting multiple routes which are to be used simultaneously thereby reducing the impact of interferences among the nodes. In order to determine the interference level of a node, the authors deemed a method to evaluate the load of a node in terms of a given parameter to evaluate the packets transmitted or received by the node itself and to evaluate all the packets heard from the other nodes in the vicinity. The RDMs are classified into three groups as described below:

13.1.2.7.1 Full radio disjoint multiple paths (FRDM)

This is a shared interference among the full intermediate nodes of every active routes concurrently is deemed as zero. FRDM routes must be node disjoint.

13.1.2.7.2 Partial radio multiple disjoint paths (PRDM)

This type of disjoint routing some of the intermediate nodes with each selected routes are interfering with each other, while non-chosen nodes have no interference. PRDM paths are built by two ways, that is, through link disjoint or by node disjoint routes.

13.1.2.7.3 Non radio disjoint multiple paths (NRDM)

For Non Radio Disjoint Multiple Paths (NRDM), the whole intermediate nodes of every route chosen have interference issues among each are each. Sometimes, even node disjoint multipath routing might be regarded as NRDM especially there is a match or similarities in the nodes topology.

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13.2 Path Selection and Traffic Distribution

The path selection and traffic distribution is also multipath routing component which is plays equally significant job. When creation of multiple paths ends, next target is the choosing of the right amount of paths needed for transmissions reasons only. The multipath routing design objective is that, a specific number of paths must be chosen to equal the performance criteria of that particular application. That is why choosing the path selection technique to choose the approximate amount of paths is essential area in order to get the best design properties right to attain a higher performance multipath routing protocol. For examples, a certain protocol might attempt to use the most optimal favorable path to transmit data and keep the extra path to handle fault tolerance issue, while another routing protocol might use lots of wireless networks, but does not mean data transmission capacity will be higher. Whenever pair of paths is chosen between the discovered paths, the routing protocol must determine the sharing of network traffic across selected paths. Resource maximization can be realized across individual paths when the injected traffic is computed in terms of paths capacity on all paths [52].

13.2.1 One path at a time

One path at a time implies a pair of routes whereby traffic can be relay by applying only a path which have the most appropriate measuring metrics, while the rest of the paths found are maintained for backup purposes.

13.2.2 Simultaneous use of K- paths

It comprises of a pair of routes where traffic forwarding is accomplished above K distinctive routes concurrently. The researcher [71], emphasized on packet transmission having continuous consistency through the sense information generated by multipath routing scheme. Delivery of information is accomplished through fewer number of data transmission. There are restricted number of routes which are used among the source and the target destination established on the seriousness of the information which are to be transmitted rather than usage of the probably routes. The researchers also promulgated Multipath Data Transfer protocol which have the capability to offer continuous numerous routes for communication among random multiple nodes. The benefit of the algorithm is to spread the work load between the nodes evenly so network life is prolonged.

13.2.3 All paths at the same time

It is another technique of multipath routing, where a pair of routes where the traffic is relayed to all the available multiple routes at the same time, leading to decreases of delivery time, and delivery ratio is also increased.

13.3 Path Maintenance

Path maintenance is another component of multipath routing protocol. WSN is susceptible to resource constrained of nodes, wireless signals and node or link failures. In view of the listed problems, the path re-creation must have mechanisms to limit degradation of performance. The core operations and schedules for path maintenance tools in multipath routing protocols entails three points; First, activation of paths which have failed, Second; activation of all failed paths and Thirdly, activation of specific amount of paths which have failed to respond. The regularity of initiating route rediscovery process in the first approach is more that other approaches and that might hinder performance of the network and imposes high overhead, so normally the third method is a good one to use and might use as a trade-off between the other approaches [11].

14. ENERGY-AWARE MULTIPATH ROUTING PROTOCOLS

This type of multipath routing protocols are usually heuristic protocols which have the ability to CHOOSE the next hop destination based on the residual energy of the neighboring nodes. Normally sensor nodes having limited levels of energy, and to prolong the network lifetime, by using energy-aware techniques attempt to avoid choosing sensors which have lower energy during forwarding of data, and this approach lead to network partition, due to faster depletion of energy on some of the sensors. Therefore, the technique is the best heuristic applied for balancing routing protocols efficiently. Moreover, the technique for these types of routing protocols attempt to balance the load from communication channels centered on the residual energy of sensor nodes which can assist in balancing energy consumption and providing reliability of data through multiple routes method. Most of the routing protocols under this classification build the routes through broadcasting message to the whole network. The key standard for broadcasting the messages is enable collection of information from the neighboring nodes and also to create neighboring table (NT). Each node consist

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of a neighboring table that keeps the most essential information of the neighboring nodes like residual energy, distance of the hop and strength of the signal strength. Furthermore, the neighboring table supports the node by enabling them make the best choice for the next hop, applying the appropriate features kept in neighboring table. The use of the technique contributes to multiple route infrastructures being constructed by the nodes which are intended to meet particular conditions. Reactive routing are primarily used by Energy-aware protocols, this implies the route is constructed exclusively if it is needed, so it decreases many of the communication overheads. Another issue is Path maintenance, which is a key setback for all multipath routing protocols. To ensure maintaining of path performance or path failure, the destination node take charge of observing delays from inter-arrival delay from every packet. When the delay is recognized to be over a pre-defined threshold, the sink assumes that route is broken. In [72, 73], the researcher promulgated efficient algorithm EEMR to determine node-disjoint multiple routes among the source and destination nodes. Multiple routes can be created by taken into account a link cost functions, that have the properties of both energy level and hop distance. The researcher also proposed a load balancing algorithm, which assists in spreading network traffic equally over the entire network. This load balancing is attained through a definition

$$\Phi(\bar{r}) = \frac{\left(\sum_{J=1}^{N} r_j p_j\right)^2}{N \sum_{J=1}^{N} (r_j p_j)^2} \qquad (2)$$

Whereby N stands for number of disjoint routes among the source and the sink, while p_j stands for the product of the route cost that is the total of each link costs beside the route j, r stands for traffic distributed to every accessible routes and r_j implies traffic the apportioning to the path j. Every time the ratio of load balance attains 1, the assumption is that, there balance in traffic. Furthermore, every time a successful delivery occurs for each data packet, the sink node might retrieve the current condition of the multiple routes being used, in order to support the spreading the data across the routes. Through the application of the link quantity which is being used a benchmark for performance metric, the researchers in [74] recommended a multipath routing protocol, QoS and energy-aware multipath routing (QEMPR) to be used for real-time applications in WSNs. Every single node in the network is allocated a unique ID, and extra ability of estimating the packets received and packets sent probability applying the link quality information. The multiple paths are determined through dissemination of messages and every node keeps a record of neighboring table that maintains the information of neighboring nodes such as residual energy and transmission range. When the creating of the routes is completed, packets are sent according to the f the packet sequence number and the number of hops that is further from the sink. The explanation for this implies, the source attempt to initial send the packet having the lowest sequence number through the path with the lowest number of hops. After the sequence of the packet number and the hops linked to the route rise higher and higher, and so this process can lead to the sink being able to receive packets in sequence. The technique assist to spread the network traffic across the entire multiple routes, thereby the network lifetime rises. In [75], the researchers suggested EEAMR, a routing protocol with the capability to disseminate traffic based on each node residual energy and also signal strength obtained. In order to achieve constant resource consumption, more loads are allocated to under-utilized routes and less loads allocated to over-utilized route. Moreover in conserving extra energy, nodes that are not actively involved in transmitting of data transmission goes into sleep mode. In [76], the researchers suggested a multipath routing protocol known as Reliable and Energy Efficient multipath routing protocol (REEM), having the ability to create multiple routes from source to destination, taking into consideration the node reliability and energy level. The route is created through the base station by broadcasting of messages and every node receiving the information will store the neighboring information in a table. Additionally, the route reliability is estimated through the base station by a method such as weighted and oriented graph, found on the neighboring nodes information. In large scale WSNs, energy efficiency is indeed a difficult. So researchers in [77] promulgated an innovative protocol called Multipath Routing in large scale sensor networks having multiple sink nodes (MRMS) with the ability to conserve energy. The key aim of this routing protocol is by deploying multiple sink nodes and then applies path cost metric to choose the multiple routes. The path cost metric is founded according to the distance among multiple neighbors, hop count and energy available for every node. For certain situations, WSNs are set-up in a location which can enable the base station to query a specific area of the network to

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gather the sensing information of every node. the authors in [78] also recommended an energy balancing multipath routing protocol (EBMR) established on client-server architecture having a base station handling all the data obtained from the sensor nodes. To achieve path construction, this is implemented by applying broadcasting messages from the base station. Every node in the network consist of neighboring table, so any time the base station intends to query certain data in the network it transmits a Data Enquiry (DE) message. All the nodes having the requisite data will response through a Data Enquiry Reply (DER) message. When the DER message is received, the base station proceeds further to evaluate the shortest path to the source node by computing the total of energy utilization and then sending packet from source to base station. Though the protocol is known have to been successful in providing intelligent and adaptive energy aware multipath routing technique, but still confronted with certain major challenges arises. In the first place, broadcasting of message or flooding for the entire network contributes to huge communication overheads. Then transmitting the similar data packet from various determined routes consumes much energy at every data routing node and so network traffic is rises immensely. Lastly, routing protocols are usually susceptible to malicious attacks. For instance, broadcasting messages is the main source of communication in publicizes themselves to their nearby neighbors. So if node A receives a message from node B, but was certified as having more residual energy and more strength signal, this can contributes to node A choosing node B to be the next routing node for the next data; but node B might be the attacker broadcasting and, having the higher transmission power and might convince the nodes that it is their primary neighbor. This will lead the network traffic into confusions and affect network reliability and security as well. "HELLO flood attack" is the common feature of this kind of attack. The authors in [79] proposed EECA algorithm which is an energy efficient node disjoint multiple path routing algorithm, with the aid of node position information, it to discover two collision free routes with constrained and power adjusted flooding and then transmit the data with minimum power required through power control component of the protocol. In [80], the main objective was to provide necessary bandwidth to multimedia applications through non interfering paths. It is an incremental approach, only one path is built at a time and additional paths are built when required typically in case of network congestion or bandwidth shortage. Energy saving is done by putting the interfering nodes to passive state that is sleep state and after going to passive state they will not take part in any routing process.

14.1 Energy-Efficient Multipath Routing Protocol (EEMRP)

Energy-Efficient Multipath Routing Protocol [72] leverage on the path diversity given by the multipath routing technique to extend the lifetime of the network through broadcasting network traffic across several node disjoint routes. If a schedule happens in the network, a sensor node in the scheduled region is chosen as the source node to begin the route discovery procedures. Subsequently the chosen source node broadcast several route request messages to the neighboring nodes, and this route request message adds various IDs to create a several node disjoint routes from the chosen source in the direction of the sink node. At route discovery procedures, every transitional node chose one of the suitable next-hop neighboring nodes to the direction of the sink node that agrees with the equation module of the protocol and not belongs to any other paths**.** The main advantage of the protocol extends the lifetime of the network lifetime through the spreading of network traffic across multiple routes in agreement with the data transmission cost across these routes. The enduring battery rate of the sensor nodes and their distance to the sink node are regarded to be the main critical boundaries in the route discovery and load distribution algorithms. Node-disjoint multipath routing protocols construct paths with no common nodes/links and provide high resilience and fault tolerance since a node failure impacts only one path. However, they usually suffer from control message overhead and a lack of scalability.

14.2 Low-Interference Energy-Efficient Multipath Routing Protocol (LIEMRO)

LIEMRO protocol [81] improve the performance demands of event-driven sensor networks through disseminated network traffic over high-quality paths with less interference such as data delivery ratio delay, throughput and lifetime by construction of an sufficient number of interference-minimized paths. Moreover LIEMRO exploits an adaptive iterative method in order to build enough number of node-disjoint paths with less interference from every event area to the sink node. When an event happens in the sensor field and there is no active path for data transmission to the sink node, the elected source node starts to create the first path by sending a route-request message to the sink node.

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Through this stage, the source node and all the intermediate nodes choose one of their next-hop neighboring nodes. This protocol also employs a dynamic path maintenance procedure in order to check the quality of the active paths through network operation and adjusts the injected traffic rate of the paths according to the latest perceived paths quality. However, LIEMRO does not deem the consequence of buffer capacity as well as the service rate of the active nodes to estimate and adjust the traffic rate of the active paths.

14.3 AOMDV-Inspired Multipath Routing Protocol

The authors in [63] have updated the AODV protocol and it was promulgated based on AODV multipath routing version. The main aim is to accomplish energy efficiency and also low latency communication rate in sensor networks by using cross layer information. In the construction of path, it is almost similar to the technique found in AOMDV, but with little enhancements. For AOMDV attempts are made to determine every probability link-disjoint paths among every set of source, sink nodes, the AOMDV-Inspired multipath routing protocol, it applied a different routing table management tactics to build only hop count optimal paths toward the sink nodes. The sink node of the protocol have the capability to confirm an extra route only if the first hop is not the same as from the earlier discovered routes, and also if it gives the similar hop count to the direction of the sink node. Or else, when the sink node receives a Route-request message which shows that the lower hop count than the existing routes (found on the same node), it substitutes every earlier set up route through special determined path. AOMDV does not introduce load allocation schemes in order to separate network traffic across recognized paths. This protocol use flooding in order to spread the whole path information through the network during the route discovery phase. AOMDV-Inspired Multipath Routing Protocol employs the information given through MAC layer to decrease latency in data transmission.

The Table 2 below, explains the various energy aware multipath routing techniques like EECA, LIEMRO, MR2, EEMR, AOMDV-IMRP. This routing algorithms for multipath works through path disjointedness which can be node disjoint, example, MR2 or partially node, Route request messaging, that includes, 1.flooding,example, EEMR and EECA, 2 multicasting, example, LIEMRO, whether the algorithm is initiated from the source, that is, source initiated, almost all of them are initiated from the source such as EEMR, MR2, ECCA. Moreover, Collision avoidance of each routing protocol shows ECCA and MR2 attempts to avoid collisions, while the rest LIEMRO, EEMR and AOMDV-IMRP does not avoid collision. Finally balancing of load during routing processes illustrates LIRMRO, MR2, EEMR have load balancing capabilities and functions, and however the rest of the protocols do not have, for instance, EECA.

Table 2: Energy Aware Multipath Routing Methods

Algorithms	Path Disjointedness	Route request message	Source initiated	sink initiated	Collision avoidance	Load balancing
EECA	Node disjoint	Flooding	√	×	√	×
LIEMRO	Node disjoint	Multicasting	√	×	×	√
MR2	Node disjoint	Flooding	√	×	√	√
EEMR	Node disjoint	Flooding	√	×	×	√
AOMDV-IMRP	Node disjoint	Flooding	√	×	×	×
Sharma et al., 2013	Partially Node disjoint	Multicasting	×	√	√	√

AWARE MULTIPATH ROUTING

For alternative path routing, several of the current multipath routing protocols belonging to this category was suitably designed to give fault tolerance using the protocol stack for the network layer. The main motivation for employing multipath routing techniques for reliable data transmission across not unpredictable connections was because of the degree of fault tolerance, a lot of previous research by authors on multipath routing methods comes under this class. The issue being that link and node failures is the key areas for route failures; the key purpose therefore of the protocols was to certify specific performance indicators by means of conserving several alternative routes as backup paths to be used when needed.

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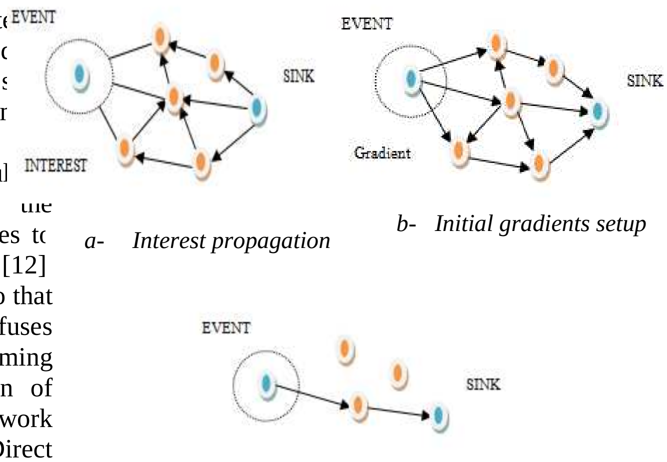
15.1 Directed Diffusion

The Directed diffusion [12] employs published communication model whereby a sink node requests data by transmitting an interests for a named data. When the interest is distributed and flooded through the network, every intermediate node creates a gradient with its neighbors. Th
Sensor nodes with data that matches the inte
will forward a data that is spreads by intermed
nodes through established gradients to the s
Moreover the sink transmits a reinforcem
message to the node that first forwarded the
data to it. Intermediate nodes use the same rul
reinforce their upstream neighbor. After the
reinforcement stage, the source node continues to
send data throughout the reinforced path [12]. Directed diffusion (DD) constructs gradients so that data can flow through source to sink. DD diffuses data by means sensor nodes and apply naming technique for data, with the main intention of eliminating unnecessary operations of the network layer routing thereby conserving energy. Direct Diffusion also makes it possible for attribute-value pairs for data and queries the sensors for on demand criteria. For creating queries, an interest is defined using a list of attribute-value pairs such as objects, distance, period, geographical neighborhood which are known as interests. These interests are transmitted with a sink via closest neighbors before every node does the caching for interest data received. Every node getting the interest implements the caching to be used at a later time as shown in figure 14. To make a better conclusion, the interests in the caches are used to compare the amount of data received with the values in interests received. Normally the interest is made up of numerous gradients sections. The gradient is a respond connection to a neighboring node from where interests were being received, and it is composed by data rate, period and ending of time originated emanating from the received interest sections. Thus through the employing interest and gradients, routes are connected among the sink and the source, numerous routes will therefore be set up in order to ensure a single of them is chosen by corroboration. The sink then re-transmits the original message through the chosen routes with lower time duration so enforce that the source node along the routes to transmit data more on a regular basis. However, directed diffusion is requires periodic interest broadcast and path reinforcement, which contributes to more energy consumption in handling such control traffic. Directed Diffusion (DD) does not apply to every sensor network application. So the application that needs continuous delivery of packets to the sink might not function very purposeful because the query-driven delivery format may not help in this regard. Therefore the Directed Diffusion is not a good selection as a routing protocol to be used for monitoring application like the atmosphere.



a- Interest propagation

b- Initial gradients setup

c- Data delivery along reinforced

Figure 14: Direct Diffusion Scheme

15.2 Braided Multipath Routing

There are partial disjoint path from the main primary path, that is, not completely node disjoint as shown in figure 15. Before braided multipath can be build, primary paths need to be calculated through the determination of every sensor node along the primary path; selection of the best path from source to sink is calculated. Energy consumption rate is a very good measure for braided routing especially when the density of the nodes is high and distance not very far [8]. The protocol employs two kinds of routes reinforcement messages to build partially disjoint routes. Route creation is started through broadcasting primary path reinforcement message from the sink node to the best sensor nodes around the neighboring region along the source node. The sink node transmits the primary path reinforcement message to a node. Then intermediate nodes accept the primary path reinforcement message, the message is then relay to the next best hop neighboring nodes along the source node. The procedure continues until the primary path is repeated reinforcement message is delivered to the source node. Apart from creating the primary route, the source node and every intermediate node, the primary route creates alternative routes in the neighborhood of their next-

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hop neighboring sensor nodes. The procedure finish upon being acknowledge for that specific message by any one of the sensor nodes in the direction of the primary routes. The outcome is, every intermediate node in the along the primary route create a backup route around the next-hop neighboring sensor nodes on the primary route through broadcasting an alternative path reinforcement message. Because connection of a pair of partial disjoint routes among the source and sink nodes, in case of primary route failure to relay the packets in the direction of the sink node, alternative route is employed to avoid data transmission breakdown. The simulation results have proven less overhead for braided multipath routing scheme than node-disjoint multipath routing, however they can be energy inefficient due to alternate node-disjoint path might be longer and thus expends significantly more energy than that expended on the primary path.

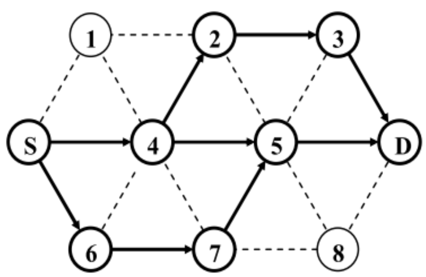

Figure 15: Braided Multipath routing

15.3 Disjoint Multipath Routing

Disjoint multipath routing attempts to build alternative paths that are not usually linked to disjoint node within the primary path and not link to another. Because of this processes any breakdown, node or link failure, are not directly affected due to several autonomous primary paths [16]. Though latency and expend energy might be higher in alternate paths, it can provide higher quality data because the sink can decide the neighboring nodes might have the lowest delay or packet loss especially when the network is flooded. The processes of the scheme entails smaller values of alternative routes from the sensor to the sink are created. These alternative routes does not have any sensor nodes created are different from the primary routes. The primary route regarded as the best available routes while alternate routes are less suitable because of delays. Whenever a failure happens in the primary routes, alternative routes are made available to transmit the packet. For sensor node disjoint routing protocol, every sink first discovers the best node available in the neighboring region having lower delay time and high rate quality in transmitting primary route reinforcement. The sensor node usually uses a similar scheme to identify the mainly the desired neighboring nodes. This reinforcement procedure replicates till the primary route is created. When this process is completed, the sink replicates similar procedure by broadcasting alternate path reinforcement to the next most suitable node. When the sensor node acknowledges only the initial reinforcement, the alternate routes are assured to be disjoint between each other and along with the primary route. By this means, sensor node does not much authority of all reinforcement that flows along with the initial node. However it is more certain, this process might discover similar alternate path which will be created by applying the global knowledge of network topology. The disadvantage being with the alternate routes being created that is taking much longer time when compared with the primary route so is less efficient in energy. But it has the advantage of discovering high fault tolerance by finding alternate disjoint paths [82].

15.4 Reliable and Energy-Aware Multipath Routing

This routing protocols was develop to reduce the energy efficiency conditions required in sensor networks, and at the same time providing reliable transmission of data by storing a backup routes at each source node in the direction of the sink node [83]. This protocol is also similar to others discussed earlier, because the initiation of the routing operation is through the sink nodes as well. That is, if the sink obtains an interest message from a source node and cannot find any active route to the direction of the source node, it begins service-path discovery procedures by flooding request information. When the corresponding nodes receives the service-path request message from the source, the receiver node broadcasts responds with reservation message in the directions of the sink node (that is, reverse path) in order to acknowledge the discovered route, and the service-path reservation message transports from the source node in the directions of the sink node. If a node besides the reverse route receives the message, it maintains a portion of the outstanding battery level to be used transmitting the data across the discovered route. The service-path creation procedures completes through receiving the

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service-path reservation message at the sink node. After, the source node broadcast its data packets in the direction of the sink node through the created route. When the service-path has been created, the sink node begins alternative route discovery procedures in order to find a backup route in the direction of the same source node, and this is achieved through flooding with a backup route discovery message. At this procedure, the intermediate nodes, that are not part of the discovered service-path, transmit the received backup route discovery messages to all surrounding nodes. So, a node-disjoint route is constructed to offer fault tolerance to the nodes in emergency cases where service-path experiences breakdowns. But though, the routing protocol is noted for energy-efficient and reliable of data transmission, the key constrains are that point-to-point capacity is restricted only to the single route capacity. And also another important constrain, is that, the protocol does not pay much attention to the impact of wireless interference and the unreliability of links for the necessary energy needed for transmitting data effectively.

15.5 Reliable Information Forwarding (ReInForm) Using Multiple Paths in Sensor Networks

The protocol applied the data replication mechanisms to provide the aspiration of reliability of data transmission for every application [84]. For this method, if a source node intends to relay own traffic to the directions of the sink node, it initially discovers the needed data transmission reliable founded on the importance of the data gathered. Then the source appends some information, for instance, lop count, rate channel error, as Dynamic Packet State (DPS) sections to the packets and broadcast several copies of the produced packets across multiple paths. Here the sources decide the criteria for the amount of routes to fulfill the reliability of demand of the gathered data in fulfillment to the DPS sections of the packets. In transmission of data, every intermediate nodes use the given information by the DPS sections in packets receive to find out the amount of copies that will be send to the next-hop neighbor nodes. The procedures keep on till every transmitted data arrive safely to the sink node. The foremost function of the ReInForm protocol, attempts to enhance transmission of data reliability by employing packet replication technique for every sensor nodes included in the transmission procedures. In addition the prominent reliability of the protocol is achieved by high energy consumption and bandwidth consumptions that is different from the major demands of resource limitation of nodes.

15.6 N-to-1 Multipath Discovery

The protocol is recommended for traffic pattern for wireless sensor networks. The key operations are for the concurrent detection of several node disjoint routes originating from every sensor node in the direction of a sole sink node [85]. In addition, in transmission of data stage, every intermediate node employs data recover mechanism for every hop to enhance reliability of data transmission. The whole routing function in N-to-1 multipath routing is carry out by easy flooding mechanism in two phases. In the first instance, the sink node begins the first phase of the path discovery procedures by transmitting to route update messages. This process is known as branch-aware flooding, applied the key advantage of flooding mechanism to build a spanning tree and determines multiple routes from the sensor node to the direction of a sink node. At this stage, every sensor node which received route update message, if it is the first time, the node chooses a sender of this message as own parent in direction to the sink node. So when a transitional node expect a route update message from another neighbor node that provides an alternative node disjoint route through a special branch of the spanning tree it will add this route to the routing table and the procedures keeps on till every sensor node determines their primary path in the direction to the sink node and a spanning tree is created throughout every node. The second phase is initiated in order to determine several routes from every sensor node in the direction to the sink node by applying multipath extension flooding mechanism. Every connection between the two separate nodes which belong to special branches of the created spanning tree might assist setting up extra routes from these nodes to the direction of the sink node. In agreement, the key feature for implementing multipath extension flooding mechanism for the second phase is corresponding information concerning the determined node disjoint paths in the initial phase among the nodes belonging to the various branches of the created spanning tree. Lastly the source nodes separate own traffic into multiple fragment and spread the data fragment across discovered routes. But, this protocol employs the single-path forwarding approach for transmitting every data segment, while all the intermediate nodes use an adaptive per-hop packet salvaging technique to provide fast data recovery from node or link failures along the active

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paths. Furthermore, N-to-1 multipath routing protocol employs the broadcast nature of radio communications to build a number of node-disjoint paths from sensor nodes to the sink node without using further control packets. This protocol also profits from the availability of numerous paths at the intermediate nodes to improve reliability of packet delivery by using a per-hop packet salvaging strategy. However, using such a simple flooding approach cannot result in constructing high-quality paths with minimum interference. According to the operation of this protocol, all the constructed paths are located in physical proximity of each other and concurrent data transmission over these paths may decrease the network performance.

15.7 H-SPREAD

The protocol integrates the path construction procedures in N-to-1 multipath routing with a hybrid transmission mechanism to enhance the reliability and security of data transmission in sensor network [86]. The H-SPEAD protocol guarantee of a threshold secret sharing technique and the path diversity of multipath forwarding to increase route resilient against node failures or route that have been tempered with. The security features of the threshold secret sharing technique, packets might be forwarding securely to the direction of the sink node even if a small number of nodes or routes have a breakdown or tempered through data transmission**.** The algorithm for the protocol is such that the source nodes split packet into several halves M1, M2, M3,…, Mn, by using the secret sharing tactics, before send the packets to the direction of the sink node by a different routes. Due to the unique properties of the threshold secret sharing scheme, even specific amount of routes breakdown because of link or node failures, the original message might be able to be retrieved back through another received shares at the destination node. Nevertheless, because the techniques employ the N-to-1 multipath routing algorithm to create several routes, the protocol might experience from the impact of wireless interference. So the issue of high packet loss ratio impact through interference might decrease the possibility of successful data retrieval at the sink node. It also enhances the reliability and security of delivery of data, but lack in the ability to improve security for every single node.

In Table 3 which is present below, focus on the several fault tolerance protocols such as Directed Diffusion (DD), Braided Multipath Routing, ReInForm, Reliable and Energy- Aware Routing, N-to-1 Multipath Routing, H-SPREAD. Several standard benchmarks are used to adjudge he operations of all the respective routing protocols, it includes, Path Disjointedness which consist of partially disjoint, or node disjoint or Link-disjoint, Route Maintenance made of new route discovery when all the active paths have failed, Traffic Distribution comprises of Multiple copies of each packet and Per-packet splitting, Number of Paths; that is not limited to DD and H-SPREAD, Two paths and Based on the desired reliability, Path Chooser consist of sink node, source and node intermediate nodes. Moreover, Performance Parameters, inclusive of data transmission, packet loss, network failure and reliability.

16. QoS- Aware multipath routing protocols

In addition to the resource constraints of sensor nodes, the main initiative at the back of designing strategy of this classification of the protocol is balancing of network traffic, and also resource utilization across the entire network. Under this section detailed explanation of the most recent recommended protocols for multipath routing will be shown.

16.1 Sequential Assignment Routing

Sequential Assignment Routing (SAR) [87] is a primary protocol in sensor network that begins to hold the idea of using QoS in routing processes. The SAR technique is a table event driven multipath that attempts to achieve efficient energy preservation and fault tolerance constrains issues. SAR protocol builds trees founded in the base of a single hop neighboring area of the sink through the application of QoS metrics, the level of energy resource on every route and the priority level of every data all taken into account and through the method of producing trees, multiple routes are established. With these established, a single route is chosen in accordance with QoS and energy resources requirements along the route. The reliability among upstream and downstream nodes for every route is undertaken by failure enforce routing recovery table. When a local failure occurs, it enables automatic route restoration processes within the network. SAR simulation experiments by authors that it offer lower energy consumption when compared with another algorithm known as the minimum energy metric, this algorithm has main purpose is to focus on energy consumption for every data instead of priority judgments. The protocol also keeps several routes beginning from the nodes to the sink, which manages fault tolerance and recovery, the extra cost overhead

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involved in sustaining the routing tables and each state of nodes in a case where the amount of sensors is very huge.

16.2 Stateless Protocol for Real-Time Communication

Stateless Protocol for Real-Time Communication (SPEED) [88] is another QoS multipath routing protocol used in sensor networks enabled real-time flexible end to end routing is assured. The protocol scheme is to enforce every node to retain information of its neighboring nodes and applies the geographic forwarding schemes to discover the intended route. Moreover SPEED attempts to quicken up the processing speed for every data from the network in order to ensure every application might estimate the end-to-end delay of data through division of the distance to the sink over the packet speed before making the admission decision. Additionally SPEED has the capability to assist overcome congestion by avoiding it anytime the network is heading towards congestion. SPEED has a routing component known as Stateless Geographic Non-Deterministic forwarding (SNFG) that operates with extra four components at the network layer level as shown in the figure 16. An estimation delay at every node is normally done by calculating the elapsed time when ACK acknowledged from neighboring node is received. Through the delays values, SNGF choose the node that meet with the speed requirement. When a situation arises where such a node is not discovered, the relay ratio of the node is verified, and the neighborhood feedback loop component act as the single provider for the relay ratio implemented by computing the miss neighboring node ratios, (that is nodes with less speed which does not meet estimated criteria) which is fed into SNGF component. Whenever the relay ratio is lower than randomly produced figures involving 0 and 1, the data is eliminated, and before back pressure re-routing component is enabled to check invalids, if a node does not discover the next hop node, and also to get rid of congestion through transmitting back messages to the source nodes, to allow them to pursue alternative paths. Compared to other routing protocols such as Dynamic Source Routing (DSR) and Ad-hoc on-demand vector routing (AODV) proves SPEED acts much better in the area of end-to-end delay and ratio miss. Also the overall total transmitted energy is low because of the ease of routing algorithm namely, low packet overhead and equitable dissemination of traffic.

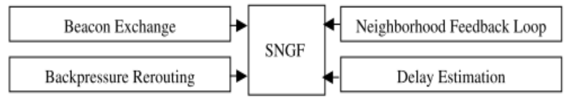

Figure 16: Routing components of SPEED

16.3 Multipath Multispeed Protocol (MMSPEED)

This protocol was developed based on cross-layer technique among the network and MAC layer to assist QoS criteria differences in terms of timeliness and reliability [9]. For timeliness viewpoint, MMSPEED is the extension of SPEED protocol by including in it several degree of speed to certify timeliness in data delivery. Additionally to meet delay conditions of different applications, MMSPEED additionally expands SPEED protocol to give various speed layers across a network. The protocol involves data being allocated to the correct speed layer to be positioned in the best queue in accordance to own speed classification. Then data are employed in the FCFS policy, to enable high priority packets are executed first before low priority packets takes their turn. But normally MAC protocols employ CSMA/CA mechanism to do channel accessibility, using local priority transmission technique at the level of network layer which usually cannot prioritize the transmission of data at level of the link layer. So MMSPEED takes advantage from the prioritized medium access mechanism through cross layer corresponding. If a source node intend to relay a data in the direction to the destination, it finds out the speed conditions first of the data based on their own distance to the destination, before set the standard for end-to-end duration and time to live (TTL). Then the classifier of the source node chooses the equivalent speed layers which meet the speed conditions of the data. The chosen speed layer component does every successive routing decision for the data relaying during the transmission process. The routing decision is founded on the number of speed progressions which can be accomplished through every intermediate node. Moreover when an intermediate node receive a packet and have doubt whether the packets can meet specific deadline through the chosen speed layer, the receiver node can set up other speed layers to meet the deadline conditions of the packet. For being measured in reliability perspective, MMSPEED take the advantage from multipath approach. However, this protocol cannot support long life time for sensor network.

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16.4 Multi-Constrained QoS Multipath Routing (MCMP)

It was purposely designed to give soft QoS guarantee in the areas of reliability and delay [60]. The end-to-end soft-QoS problem was created as a probabilistic programming problem, before being transformed into deterministic linear programming by applying approximation mechanism. So MCMP was designed in accordance with the linear programming technique that is a deterministic approximate of defined end-to-end soft-QoS problem. MCMP employ two kinds of approach to satisfy delay and reliability requirements of sensor applications. For the stage of the route discovery process, every intermediate node selects the neighbor node that meets the delay conditions of the specific application. To measure up to reliability, every node chooses at least one or a pair of its own neighboring nodes, which in addition gives the intended reliability to the direction of the sink node. So, at the end of the route discovery procedure, every source node might have discovered a pair of partial disjoint paths which might meet the delay and reliability requirements of the intended sensor application. The existence of data redundancy of MCMP is the main disadvantage of the protocol. Additionally because partially disjoint paths are normally positioned close, high data rate transmission contributes significant interference so the maximum data transmissions are impacted.

16.5 Energy Constrained Multipath Routing

Energy Constrained Multipath Routing (ECMP) [57] is extension to MCMP with the main objective is providing energy efficient communication, and at the same time meets the requirements of every sensor application. As explained in the MCMP protocol above, the intermediate node chooses a pair of neighbor nodes which meet the criteria of delay and reliability requirements of the data source, regardless of the energy consumption for data transmission across links. But in the case of ECMP protocol, it brings into focus an energy optimization concerns. The problem of the protocol is limited by delay, reliability and geo-spatial energy consumption in order to provide multi-constrained QoS routing in sensor networks the network. Moreover the central motivation for designing ECMP is for maintaining multi-constrained QoS routing with less energy consumption. However in MCMP, nodes randomly choose its next-hop neighboring sensor nodes without consider the amount of energy consumption across selected link. therefore when comparison are made between them, ECMP filter set of next-hop nodes to a smaller set by regarding the energy efficiency of the links towards neighboring sensor nodes.

16.6 Delay-Constrained High-Throughput Protocol for Multipath Transmission

Delay-Constrained High-Throughput (DCHT) [89] is a transformation adaptation of Directed Diffusion (DD) that spelt out the notion of applying multipath routing protocol to assist the high quality video streaming for low power wireless sensor network. DCHT announce an original path reinforcement technique and applied fresh routing cost function, that take into consideration the expected transmission cost (ETX) and delay metrics that can determine high-quality routes having the minimum end-to-end latency. It is same to DD routing functions, routing in this protocol is initialized through flooding of an interest message disseminated over the entire network. Also to achieve calculation of transmitting data latency across every route, the sink node adds a timestamp to the interest message. If a specific source node has the capability to supply the packets needed by the sink node, it broadcasts the explore data to the direction of the sink node by established gradients in the initial stage. After the receipt from the exploring data at intermediate node, the protocol applied Equations to calculate the cost of transmitting data across the sub-path where the packet originated from. Then, the receiver node transmits the lowest calculated cost to its next-hop neighboring nodes. On the other hand, because of the random topology of the wireless sensor networks, constructing an adequate number of node-disjoint paths to maintain high-rate multimedia streaming may not be feasible.

16.7 Interference-Minimized Multipath Routing Protocol

Maximally Radio-Disjoint Multipath Routing (12MR) [70] is another protocol aim to maintain high-rate streaming in low power wireless sensor network through considering high-bandwidth backbone network. 12MR attempts to build zone-disjoint paths and to disseminate network traffic across discovered routes by predicting a unique structure of network and the availability of particular hardware components. In 12MR, the source node employs two routes for transmission data and maintains only one backup path to the direction of the operational command center. In the route discovery three stages are identified; first stage, every source node chose one gateway node to

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be its primary gateway node and then build the shortest possible path to the direction of the gateway node. After that, in the interference-zone marking stage, one and two-hop neighboring nodes of every intermediate node among the first route are marked as the interference zone of the primary path. Finally, in the last stage, the primary gateway node decides the most suitable quadrants where the secondary and backup gateway nodes will be chosen, these quadrants are decided based on the location of the source node. Moreover, the most suitable gateway nodes can be positioned outside the interference range of the primary gateway node and the distance between them should be lesser when compared with other gateway nodes. Owing to the high complexity of the zone-marking algorithm, this method cannot effectively construct interference-minimized paths. Furthermore, source nodes construct the three shortest paths by minimum hop count toward the three separate gateway nodes to decrease the effects of wireless interference between the successive nodes along a path. On the other hand, in this protocol the data transmission over long hops increase packet loss ratio because of the time-varying properties of low-power wireless links.

16.8 Energy-Efficient and QoS-based Multipath Routing Protocol (EQSR)

Energy-Efficient and QoS-based Multipath Routing Protocol (EQSR) [90] is a currently recommended protocol designed to achieve reliability and delay requirements of real-time applications for sensor networks. EQSR enhance the reliability by applying lightweight XOR-based Forward Error Correction (FEC) schemes, that advances data redundancy in the transmission of data procedures. Besides that to facilitate accomplish the delay conditions of the different applications, the protocols employ a service differentiation method through the utilization of a queuing format to control real time and non-real time traffic. EQSR initiate operations by spreading the HELLO message to every sensor node. At this stage the sensor nodes gather information concerning the cost of transmitting data through neighboring nodes. The second stage involves the sink node beginning the route discovery procedures through broadcasting of route request message to intended neighbor node. Intermediate node request to choose the most intended next hop neighboring node to the direction of the source node. The procedures keep on until the source node receives a route-request message broadcasted through the sink node. While EQSR decrease transmission delay and improve reliability, on the other hand, the FEC method which is used to calculate ECCs and retrieval of the original messages will require high control overhead.

16.9 Energy-aware QoS routing protocol

A practically QoS aware protocol for sensor networks is presented by [91]. The Real-time traffic is created through imaging sensors. The presented scheme expands the routing approach in [92] and tries to discover a lowest cost and energy efficient path that meets certain end-to-end delay through the connection. Therefore, the link cost employed is a function that captures the nodes' energy preserve, transmission energy, error rate as well as other communication parameters. In order to support both optimal attempt and real time traffic simultaneously, a class that based queuing model is used. The queuing model permits the service sharing for real-time and non-real-time traffic. The bandwidth ratio is defined as primary value set throughout the gateway and represent the amount of bandwidth to be devoted to the real-time and non-real-time traffic on a particular outgoing link in case of a congestion. The protocol discovers a list of lowest cost routes by using an expanded version of Dijkstra's algorithm and picks a path from that list which meets the end-to-end delay requirement. In Table 4 which is present below, identified some QoS in multipath routing protocols namely MMSPEED, MCMP, ECMP, DCHT, EQSR, Energy- Efficient Multipath Routing and 12MR. The protocol standard benchmarks just like fault tolerance include several criteria to evaluate its processes. These are Path Disjointedness, Route Maintenance, Traffic distribution, Number of paths, Path chooser and improved performance parameters. To enable precise assessments and efficacy of each routing, these mechanisms were applied for every protocol, whether it is operations involves partially disjoint or node-disjoint, which first or second paths are active or non-active, or even some of the paths do not have any route maintenance paths, examples, DCHT and ECMP. Moreover Per-packet splitting and multiple copies of each packet being used by the protocols, Number of paths each protocols takes to transmit data from source to destination. The reliability and data delays, estimation of network lifetime and throughput.

17. OVERALL DISCUSSION:

Efficient energy, fault tolerance and QoS multipath routing protocols are some of the essentials components in wireless sensor networks because

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balanced routing decreases energy expenditure at sensor nodes. An efficient energy multi-path routing have the capability to discover multiple routes with high time-efficiency and energy-efficiency. The load balancing algorithm attempts to apportion traffic to every route optimally resulting in node energy efficiency, lower average delay and control overhead. Fault tolerant routing associated with sensor's fault owing to battery depletion or unreliable wireless links or nodes. To achieve this task, source nodes apply erasure coding, in order to code and transmit packets across multiple disjoint routes to the sink so as to distribute the load and prolong network lifetime. Quality of Service (QoS) multipath routing balances between the energy consumption and specific predefined metrics required by the various sensor applications. The fundamental key of these metrics is to ensure efficient and point to point reliability, average transmission delays, the optimal routes and selections to the sink.

18. CONCLUSIONS AND FUTURE DIRECTIONS

In the research paper we highlighted the different concepts of routing protocols with specific reference to energy efficient, fault-tolerance, QoS in multipath routing protocols and its implications of data transmissions on wireless sensor network. There was also a description of the various multipath routing protocols being used in sensor applications for data transmission. The benefits of applying such multipath routing protocols resulted in numerous kinds of multipath methods such as path disjointed, path chooser, traffic distribution, and path maintenance, performance indicators, route maintenance, and number of paths for efficient energy, fault-tolerance, QoS in multipath routing protocols. A brief summary of the protocols are illustrated presenting their distinct structures, processes and characteristics. Additionally the numerous types of routing techniques are categorized based on network infrastructure namely data-centric, hierarchical, location-based routing protocols and classification of sensor networks. Additionally further division include classification into multipath-based, query-based, negotiation-based and QoS-based routing procedures depend on the protocol operation. However a lot of research work have been undertaken for multipath routing protocols as discovered from the research, a lot more needed to be done as mobile devices and technology keeps evolving. In the future, another research will be attempted which key aim will be to investigate the possibility of discovering the various energy-aware protocols to maximize efficient energy conservations and to ensure efficient and reliable data transmission.

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Table 3: Fault Tolerance Multipath Routing Methods

Features / Protocols	Path Disjointedness	Route Maintenance	Traffic Distribution	Number of Paths	Path Chooser	Improved Performance Parameters
Directed Diffusion	Partially disjoint	New route discovery when all the active paths have failed Not	Not applicable	Not limited	Sink node	*Data transmission delay caused by path failure *Packet loss rate caused by path failure
Braided Multipath Routing	Partially disjoint	New route discovery when all the active paths have failed	Not applicable	Not limited	Sink node	*Data transmission delay caused by path failure *Packet loss rate caused by path failure *Route discovery and path maintenance overhead
Reliable and Energy- Aware Routing	Node-disjoint	New route discovery when the primary path has failed	Not applicable	Two paths	Source node intermediate nodes	*Packet loss rate caused by path failure *Network lifetime
ReInForm	Link-disjoint Not	Not mentioned	Multiple copies of each packet	Based on the desired reliability	Source node	*Reliability
N-to-1 Multipath Routing	Node-disjoint	Not mentioned	Per-packet splitting	Not limited	Source node intermediate nodes	*Reliability
H-SPREAD	Node-disjoint	Not mentioned	Per-packet splitting	Not limited	Source node intermediate nodes	*Reliability *Security

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Table 4: QOS Multipath Routing Methods

Features / Protocols	Path Disjointedness	Route Maintenance	Traffic Distribution	Number of Paths	Path Chooser	Improved Performance Parameters
MMSPEED	Node-disjoint	Not mentioned	Per-packet splitting	Not limited	Source node intermediate nodes	*Reliability *Delay
MCMP	Partially disjoint	Not mentioned	Multiple copies of each packet	Based on the desired reliability	Intermediate nodes	*Data delivery ratio *Delay
ECMP	Partially disjoint	Not mentioned	Two copies of each packet over two paths	Based on the desired Reliability and energy	intermediate nodes	*Network life time *Data delivery ratio *Delay
DCHT	Node-disjoint	Not mentioned	Two copies of each packet over two paths	Not limited	Source node intermediate nodes	*Data delivery ratio *Delay
EQSR	Node-disjoint	Not mentioned	Per-packet splitting	Based on the probability of successful data delivery over the active paths	Source node	*Data delivery ratio *Delay
12MR	Node-disjoint	When first and second paths have failed	Per-packet splitting	Three paths	Sink node Intermediate nodes	*Throughput