A Survey and Analysis of various Multipath and Multisink Routing Protocols for Wireless Sensor Networks

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Abstract- Wireless Sensor Network (WSNs) consist of numerous small, battery powered sensor nodes deployed in targeted environments to monitor physical or environmental conditions. These nodes integrated sensing, communication, and limited processing capabilities to transmit data wireless to a centralized base station or sink. Efficient and reliable routing is crucial in WSNs due to inherent constraints such as limited energy, memory and computational power. Traditionally, single path protocols are used to send data along one stablished route and single sink architecture rely on a centralized sink node to collect all data from sensor nodes. However, the single path routing may result in path failure during data transmission and re-establishment of alternate path might take more duration. Also, using a single sink architecture can lead to uneven energy dissipation and poor channel condition near the sink. To overcome these limitation, recent research has focused on multipath routing protocols in a multi sink network that aims to enhance fault tolerance, improve energy efficiency and extend network lifetime. These protocols discover multiple energy efficient paths and distribute data across multiple sinks to reduce traffic load and energy depletion in hotspot areas. This paper presents a detailed review of multi sink and multipath routing protocols for WSNs. First, the various protocols proposed in the literature are briefly discussed. Then, a comparative analysis is performed to evaluate their performance, identify limitations and suggest future directions for improving routing in WSNs.

Keywords: Wireless Sensor Network, Sensor nodes, Single path, Multi path routing and Fault tolerance.

I. INTRODUCTION

WSN is a network of many tiny batteries powered sensor nodes deployed in area of interest for monitoring physical environments. Nodes integrate sensing units, transceiver and actuators with limited on-board processing and radio capabilities. Radio is implemented on nodes of wireless communication to transfer the sensed data from node to base station which can be an access point to fixed infrastructure computing device like laptops etc[1]. The data accumulated at the base station provides dense sensing close to physical phenomena of the environment to be used by the user. There are certain constraints in the field of WSN namely low memory of the sensors, limited energy availability and reduced processing power. Still WSN application has spread into various multi-disciplinary fields [2]. These fields can be categorized into environment monitoring in marine, soil and atmospheric context, seismic and flood detection, meteorological or geophysical research, battlefield surveillance, vehicle and object tracking. In health applications WSN provides integrated patient monitoring, diagnostics and drug administration in hospital. Smart environment and automation of home, office buildings environmental control, Vehicle tracking and detection, natural disaster relief and agriculture.

Routing of sensed data from the environmental to base station under the constraints of WSN is the primary channel. Routing in sensor networks is different from contemporary communication and wireless ad-hoc networks. Numbers of sensor nodes are deployed in the area to be sensed and data collected from these nodes is forwarded to sink node by inter-node wireless multihop communication. Performance of routing protocols depends upon the architecture model of the network i.e. sensor nodes, sink and events to be sensed from the environment. The data sensed by sensor node from environment are to be routed to the sink in energy efficient mode in order to increase the lifetime of the network [3].

Traditionally, WSN routing protocols are designed to communicate sensed data to single sink in energy efficient way to maximize life time. For example, in habitat monitoring sensed environment data from multiple sensor nodes is collected in a single sink [4]. However, recent research has explored the use of multiple sink to reduce energy consumption and extend network longevity. In scenarios like fire detection, sensor nodes may simultaneously send emergency signal alerts and active water sprinkler systems, necessitating more flexible and resilient routing schemes[5]. While Single path routing is simple and scalable, it is increasingly considered inefficient due to the resource constraints and dynamic conditions of modern sensor networks.

Single path routing, where each data packet follows one fixed path through the network, offers simplicity and lower energy usage. However, it has several drawbacks. A single point of failure can interrupt data delivery entirely. This method lacks flexibility in adapting to node or link failures may significantly reduce the network performance in critical situations. The probability of successful delivery is lower and if the active path becomes unusable due to power depletion, link stability or physical damage, establishing a new path introduces additional overhead and delays. Due to these limitations, single path routing is often unsuitable for applications requiring high reliability and fault tolerance[6].

The single sink network refers to a design where all sensor nodes transmit their data to a centralized sink node, which act as a gateway to control or data processing system. This architecture is simple to implement, cost effective and facilitates centralized data aggregation and network management. However, Sensor nodes are typically connected via multi hop wireless links to a central sink, which then forwards the data to a control system . This model often considers only the number of hops and energy consumption from the source nodes to the sink. Furthermore, the sink becomes a bottleneck and a point of vulnerability, particularly in the presences of poor channel conditions near it [7]. Nodes located closer to the sink tend to consume more energy than distant ones, as they must forward a larger volume of data, leading to uneven energy depletion and network fragmentation.

Cipollone et al. [8] presented an adaptive energy saving and reliable routing protocol (AESRR) for WSN. In AESRR, sensor node reduces its maximum transmission range in order to reach the extreme neighbor for saving energy before sending the first packet. The route discovery process of AESRR is on-demand. In the route discovery process, a combined link weight is determined based on the parameters transmission success ratio and node's residual energy. The best route is selected based on this link weight value. The sensor node must readjust the transmission range when remaining energy reaches bellow a threshold link weight value. This protocol saves energy, and prolongs the lifetime of node while enhancing the reliability.

To address these issues, Multi path routing protocol in multi sink network have been proposed. Multipath routing is adopted to provide alternative paths for data to be delivered in order to increase the probability of successful delivery. To minimize the chances of the multiple paths approaching one another and contending for the shared wireless channel, the paths diverge like a starburst towards multiple sinks deployed along the edges of the sensor network [9]. In a multi-sink network, the sinks act as gateways forwarding sensed data towards the storage systems network. Each sink collects the data generated only by a subset of devices and the overall monitored phenomenon is reconstructed at the data storage system. Multi-sink networks can remarkably reduce the mean distance between nodes and sink, resulting in energy saving and longer lifetime[10]. An example of Multipath Routing in a Multi-Sink network is shown in figure 1.

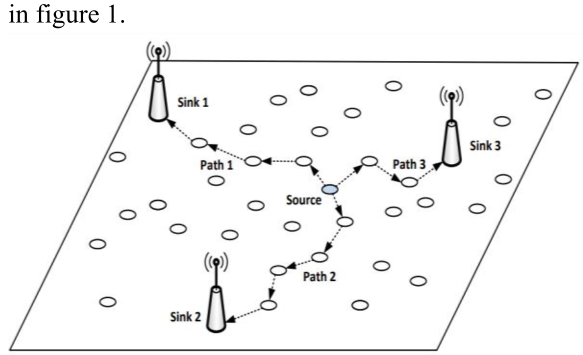

Figure 1: Example of Multipath Routing in a Multi-Sink WSN

Therefore, this paper presents the detailed survey on multi-sink and multipath routing protocols in multi sink in WSN. It also includes a comparative analysis to evaluate the benefits and drawbacks of these approaches, aiming to identify potential improvements in routing strategies. The remaining parts of this paper are structured as: Section II discusses various multi-sink and multipath routing protocols designedfor WSN. Section III presents the comparative study of these protocols. Section IV concludes this study and outlines the future research directions.

II. LITERATURE SURVEY

2.1 Survey on Multipath Based Routing Algorithms in WSN

Liping et al. [11] introduced an energy aware multipath routing algorithm aimed at improving energy efficiency and network reliability in WSNs. This algorithm selects data transmission paths by avoiding nodes with low residual energy, thereby reducing the risk of early node failures. It incorporates both the remaining energy of nodes and the number of hops as key metrics for path selection. By considering these parameters, the algorithm effectively minimizes energy consumption during data transmission and significantly extends the overall network lifetime. Comparative analysis with traditional methods demonstrated that this approach offers higher reliability and energy efficiency.

Fu et al. [12]developed the Environment-Fusion Multipath Routing Protocol (EFMRP) to support reliable data transmission in harsh environments. EFMRP makes routing decisions based on a mixed potential field that incorporates node depth, residual energy and environment factors. By leveraging the sensing capabilities of WSNs, the protocol dynamically avoids hazardous areas, improving routing safety. It also balances latency, energy consumption and survivability to optimize overall network performance. EFMRP includes specialized mechanism for route maintenance, traffic allocation and retreat mechanisms. Comparative evaluations with existing protocols show that EFMRP significantly improves PDR and extends network lifetime in challenging conditions.

Deepa&Suguna [13] proposed Optimized QoS-based Clustering with Multipath Routing Protocol (OQoS-CMRP) for WSNs aimed at reducing energy consumption in sink coverage area. Initially, a Modified Particle Swarm Optimization(PSO)-based clustering algorithm was employed to form clusters and select cluster heads, addressing the energy hole problem. Then, the SingleSink-AllDestination algorithm was used to establish near optimal multi-hop communication paths followed by Round-robin Paths Selection for data transmission. Simulation results demonstrated that OQoS-CMRP achieved efficient data communication with reduced energy consumption, transmission delay and communication overhead compared to existing protocols.

Wang. [14]introduced a multipath routing method based on a genetic algorithm to enhance fault tolerance and reduce energy consumption in WSN. First, they developed an effective fitness function that incorporates key distance parameters, including the distance between the sending and receiving nodes, the next hop's distance to the base station, and the number of hops. Then, the genetic algorithm was utilized to determine optimal multipath routes. Finally, simulation analysis verifies the method's effectiveness in improving energy efficiency and network reliability.

Guo et al. [15] proposed a multi-path routing algorithm for a WSN based on the real time evaluation approach. Initially, a real-time evaluation algorithm based on semi-supervised learning (RESL) was designed and implemented to enhance evaluation time and accuracy. Comparative experiments demonstrated the superiority of RESL in both evaluation speed and accuracy. Building upon RESL, a Multi-path routing algorithm based on semi-supervised learning (MRSSL) was developed to improve routing decisions. Experimental results showed that MRSSL effectively enhances the accuracy of multi-path routing schemescompared to existing methods.

Darshan&Prashanth[16] proposed Dynamic Multipath Trust Secure Routing Protocol (DMTSR) with Advanced Ad hoc On-Demand Distance Vector (AAODV) protocol and Advanced Encryption Algorithms (AES) encryption for secure data transmission. First, the protocol identified the fastest path based on neighboring node's energy level and consumption, integrating AES for encryption and decryption at each hop. Then, source node's initiated path discovery and update intermediated nodes using primary and secondary encryption keys to ensure packet delivery. Finally, the simulation outcomes of the DMTSR protocol achieved a PDR, Throughput, and a delay in the network.

Patil et al. [17] presented an Optimum Cluster-based Congestion - Aware Multipath Routing protocol (OCC-MP) to enhance routing efficiency in WSNs. Initially, Improved Atom Search Optimization (IASO) was used to efficient clusters. Then, the HSIPO method was employed for decision making by calculating each node’s trust degree and selecting the CH accordingly. Next, a Deep Recurrent Neural Network (DRNN) was utilized to monitor congestion and enable congestion aware routing. Finally, simulations under various node densities and simulation rounds demonstrated that OCC-MP outperformed existing approaches in terms of energy consumption, throughput, traffic load overflow, delivery ratio and number of nodes alive.

Dan et al. [18] proposed EMRAR, an Energy-efficient Multipath Routing scheme that balances data Accuracy and transfer Reliability. First, they formulated the multipath routing as a multi-objective problem to optimize reliability and energy utilization while satisfying data accuracy necessities. Then, an adaptive artificial immune algorithm was employed for multipath routing. However, failures caused by node mobility were not mitigated, leading to increased delays.

Pujitha et al. [19] proposed an Efficient Cryptography-Based Multipath Routing policy (ECBMR) designed for WSNs in IoT environments. This approach integrates cryptographic techniques into the multipath routing process to enhance both the performance and reliability of data transmission. The ECBMR strategy aims to improve the PDR and extend the overall network lifetime by securing data routes and minimizing transmission failures. ECBMR was evaluated against existing protocols, and the results demonstrated superior performance in terms of PDR and network lifetime.

Prakash et al. [20] introduced a Multi-Route Clustering Protocol Using Timeslot Transmission (MRCP-TTDPS) with dynamic path selection to improve energy efficiency and path quality in WSNs. First, multipath routing was configured using Multipath Optimized Routing (MPRS) to assess and utilize high-quality path data. Then, Cluster-Based Optimal Path Selection (CORS) was applied to identify energy efficient routes. Finally, energy consumption models were developed, where cluster heads were selected based on nodes with the highest residual energy and regular nodes joined nearby cluster heads. Sensor nodes transmitted data to their cluster heads, which then forwarded the information to the base station. Simulation results demonstrated superior performance in terms of path identification energy consumption and overall path quality compared to traditional routing models.

Kamathamet al. [21] developed NGFMR, a Node Grade Factor (NGF) centered node-disjoint multi-path routing protocol aimed at enhancing Cognitive sensor networks (CSN) performance through improved energy efficiency and reliability. The protocol incorporates multiple QoS metrics in route selection, including sink distance, spectrum availability, communication costs, and node latency. This integration allows the protocol to adapt to changing network circumstances for efficient intelligent device-to-device (D2D) communication. Finally, simulations demonstrated that NGFMR outperforms traditional routing protocols in network throughput, energy consumption, packet delivery, and delay. Table 1 shows that the comparison of Multipath Routing for WSN.

Table 1. Comparison of Various Multipath based Routing Protocol in WSN

Author name & Ref no.	Protocol	Merits	Demerits	Performance Evaluation
Liping et al. [11]	Energy aware multipath routing algorithm	Avoids low energy, increases network lifetime and reliability	May not scale well in highly dynamic networks	Surviving node percentage = 98%,Average delivery ratio = 97%

Fu et al. [12]	EFMRP	Adapts to hazardous environments and balances latency and energy	Complex due to integration of environmental sensing	PDR = 99%, E2D = 1000ms Network lifetime = 6000s
Deepa&Suguna [13]	OQoS-CMRP	Reduces energy in sink area, solves energy holes issue	Limited evaluations in heterogeneous network conditions	PDR = 96%, Normalized overhead = 7%, Average Residual Energy = 2.94J, Throughput = 64kbps, E2D = 0.02ms
Wang. [14]	Genetic algorithm based Multipath Routing	Enhances fault tolerance, energy efficient path selection	May face scalability issues with large WSNs.	For 50 relay nodes Energy consumption = 6J
Guo et al. [15]	MRESL	Improves routing accuracy using RESL	Due to the limited training data and time-consuming acquisition, the proposed method can only be a semi-supervised algorithm with lower evaluation accuracy	Accuracy = 98%, Time = 180ms,
Darshan&Prashanth [16]	DMTSR	Secure routing with high PDR and low delay	Overhead due to encryption or decryption	Throughput = 975kbps, E2D = 278ms, PDR = 83% Energy consumption = 10J
Patil et al. [17]	OCC-MP	Incorporates DRNN to proactively monitor and mitigate congestion, improving network adaptability under varying traffic loads	Complex due to multiple algorithms	PDR = 85%, Throughput = 420kbps, Energy consumption = 30J, Overhead ratio = 10%
Dan et al. [18]	EMRAR	Uses adaptive artificial immune algorithm for improved multipath routing.	May not perform well in extremely dynamic environments.	For different data transmission rates Average accuracy loss = 3%, PDR = 84%, Network residual energy = 60%
Pujitha et al. [19]	ECBMR	High PDR improves reliable data transmission	Lack of mobility support in dynamic environments	PDR = 92.1%, Network lifetime = 550s
Prakash et al. [20]	MRCP-TTDPS	Improves energy efficiency through dynamic path selection	Increase complexity due to multi stage routing process	For no. of packets is 500 Delay = 23s, Network lifetime = 39s, Energy consumption = 60ms
Kamatham et al. [21]	NGFMR	Balances network load across multiple paths	Scalability challenges in dense cognitive networks	Throughput = 580kbps, Energy consumption = 4J, Delay = 14ms

2.2 Survey on Multi - Sink Based Routing Algorithms in WSN

Mukherjee et al. [22]proposed an efficient multi sink routing protocol for WSNs using sensor nodes equipped with three sector antennas. Nodes discover neighbor and sink locations with minimal control overhead and forward data either directly within two hops or via multi hop routing using sector based transmission. OMNeT++ simulations demonstrated effective data delivery and network performance. However, the fixed sector based forwarding limits adaptability in dynamic topologies and may cause inefficiencies in uneven node distributions.

Hussienet al. [23] proposed the Multi-Sinks Cluster-Based Location Privacy Protection (MSCLP) scheme for WSNs. First, the network area was divided into equal distance clusters, with four sink nodes positioned at the corners of the region. When a packet reaches a cluster, the cluster head generates a fake packet and circulates it within the cluster to mislead potential adversaries, preventing traceback to the source. The actual packet is then forwarded to the neighboring cluster head, continuing the path toward the designated sink. Compared to the CPSLP scheme, MSCLP demonstrated the performance in terms of reducing energy consumption and delay. However, further experimentation is required to evaluate its impact on overall network lifetime and utilization efficiency.

Daas et al. [24] proposed a Dynamic Multi-Sink Routing Protocol (DMS-RP) designed for self-organizing multi-hop WSNs, iMANETs and IoT environments. The protocol utilizes sink-based auto-clustering of the network without using a dedicated clustering algorithm and supports multipoint-to-multipoint communication for local areas as well as for distant separated areas. Three multi-hop forwarding techniques were evaluated: $BASIC$, $MULTI - PARENT$ and $MULTI - PARENT + SNR$. The protocol was implemented as a new module for NS-3 simulator. Simulation results demonstrated that DMS –RP significantly outperformed the AODV protocol in terms of packet delivery, network delay, communication overhead, energy and network lifetime.

Onwuegbuzie et al. [25] proposed a MultiSink Load Balancing Mechanism (MSLBM) for WSN that adaptively distributes network traffic to sinks with fewer active tasks. First, they designed a dynamic load allocation strategy to prevent sink overload, thereby enhancing energy efficiency and prolonging network lifetime. Then, the mechanism was evaluated against related schemes, demonstrating superior performance in terms of reliability, latency and energy consumption. However, mobility induced topological changes were not addressed, potentially limiting its effectiveness in dynamic or large scale network environments.

Rehan et al. [26] proposed QCM2R, a QoS-aware multichannel multisink routing protocol that establishes reliable communication paths between source nodes and sinks upon event detection in the region of interest. The protocol selects the best QoS-aware path at a particular epoch for end-to-end data delivery and dynamically shifts the path during communication sessions to ensure load balancing. Additionally, QCM2R performs distributed channel assignment jointly with routing, enabling two-hop channel orthogonality for interference mitigation. A channel refresh mechanism is also incorporated to reassign wireless channels on links experiencing degradation. However, the integration of routing, channel assignment and refresh mechanism may introduce overhead and complexity, potentially affecting scalability in dense or large scale WSN deployments.

Fouly et al. [27] proposed an energy efficient and environmentally aware routing protocol for WSNs with multiple sinks. The protocol selects routes based on multiple criteria, including energy consumption, latency, hop count, sink load and environmental risk factors. By modeling environmental hazards, the routing algorithm avoid dangerous regions while maintaining load balancing across the network. The approach was evaluated against SMRP and EERP and improved routing performance integrating realistic and dynamic routing metrics. However, the increased number of routing parameters and environmental modeling led to higher computational complexity, making the protocol less suitable for time constrained or resource limited WSN scenarios.

Liu &Guo [28] proposed Multiple Mobile Sinks Coverage Maximization based hierarchical routing protocol for mobile WSN (MMSCM) that organize the network into three layers: data gathering, routing and aggregation to reduce traffic and packet loss. CH selection is optimized using a bacterial coupling operator genetic algorithm, considering energy density, mobility and coverage. CH re-election occurs only when residual energy drops below a threshold. Robust routing is achieved by selecting next hop CHs based on distance, energy and mobility. Mobile sinks move uniformly within regions to avoid energy holes and reduce latency. However, the multi-layer design and algorithmic complexity may introduce significant computational overhead and delay affecting scalability in large networks.

Ding et al. [29]proposed a multisink-oriented cascading model for WSNs to accurately characterize the cascading failure process based on load distribution and routing behavior. The model incorporates two common routing schemes and introduces five topological parameters to quantify the impact of sink placement on network robustness. An extensive experimental analysis was conducted on two real life inspired network topologies to examine the correlation between sink locations and network stability. To further enhance resilience, a simulated annealing algorithm was developed to optimize sink placement with pre and post optimization comparisons validating the improvement. However, the approach focuses on static analysis a may not adapt effectively to dynamic network conditions or real time failures.

Uvegeset al. [30] proposed a Multi-sink Reliable Resilient Multipath Routing Protocol (MsR2MRP) for WSNs to enhance resilience by delivering information to multiple sinks and constructing multiple paths to avoid danger zones and mitigate failures. The protocol also supports constrained locomotion, enabling WSN nodes employ to evade damage by hostile events and to prolong the network's lifetime. MsR2MRP utilizes sensor, energy, communication, and mobility information to maintain WSN-level monitoring during mobility and hostile events. Additionally, a heuristic model for constrained locomotion in WSNs was introduced. Finally, the proposed protocol was evaluated against a state-of-the-art routing protocol from existing literature, with simulation results demonstrating superior monitoring performance and extended network lifetime. Table 2shows that Multi-Sink based routing protocolfor WSN.

Table 2. Comparison of Various Multi-Sink based Routing Protocol in WSN

Author name & Ref. No.	Protocols	Merits	Demerits	Performance Evaluation
Mukherjee et al. [22]	Multi-sink based sensor network	Low power consumption of sensor nodes, greater scalability, reduction of hotspot problems, and low transmission delay.	Less effective in sparse or low density networks	Average node load = 0.75J Throughput = 118kbps, Energy = 0.9J
Hussien et al. [23]	MSCLP	Reduces risk of node tracing with randomized paths	However, need to do more experiments to test network lifetime and network utilization efficiency.	Delay = 33 hops, Total energy consumption = 7.5J
Daas et al. [24]	DMS-RP	Scalable and efficient in both static and mobile environments	Performance may vary with extremely high node mobility	Network lifetime = 130s, Energy consumption = 13J, Normalized routing overhead = 1.5s
Onwuegbuzie et al. [25]	MSLBM	Enhances network lifetime by avoiding early sink battery drain	It may increase control overhead to coordinate among multiple sinks	PDR = 98%, Latency = 21.7ms, Power Consumption = 1.6mW
Rehan et al. [26]	QCM2R	Multi sink reduces congestion and balances load	Multichannel systems can increase system complexity and power usage	Network lifetime = 300s, Network reliability = 94% Network E2D = 60Ms Throughput = 60kbps
Fouly et al. [27]	Swarm Intelligence based Heuristic algorithm	Balances energy among sinks and nodes	There is a trade-off between performance and temporal complexity	Processing time = 0.08s, Energy Imbalance Factor (EIF) = 0.25s, Average E2D = 0.58s
Liu &Guo[28]	MMSCM	It is suitable for time-sensitive and high mobility application scenarios.	Cluster formation overhead may affect performance	Average E2D = 700ms, Average Expenditure = 0.009J,

Ding et al. [29]	Multi-Sink oriented cascading model	It considers actual load distribution characteristics	The topology structure designed is robust to cascading failures and can also meet other network performance requirements, such as delivery latency and energy efficiency.	For before optimization for SFN-LR Scenarios Average Degree of Sinks (ADS) = 3.67 Average Betweenness of Sinks (ABS) = 88.42 Average Efficiency of Sinks (AES) = 274.67
Uveges et al. [30]	MsR2MRP	Handles spatial destruction with resilient routing	However, with minimal additional messaging and careful protocol extension, nodes following mobility could also accept and send data from neighboring nodes	E2D = 250ms, PDR = 32%

III. RESULTS AND DISCUSSION

The performance efficiency of the above-studied protocols is evaluated by the Network Simulator version 2.35 (NS2.35) to compare in terms of E2D, throughput, and PDR. The considered performance metrics are described below:

- E2D: It is the time taken to transmit the data between origin and target nodes.

$$E2D = \frac{Total\ time\ for\ packets\ received\ by\ the\ target}{Total\ Number\ of\ packets\ received\ by\ the\ target} \quad (1)$$

- PDR: It is the fraction of the total amount of data packets received at the targetto the total amount of forwarded packets from the origin.

$$PDR = \frac{Total\ number\ of\ packets\ received\ by\ target}{Total\ number\ of\ packets\ sent\ by\ origin} \quad (2)$$

- Throughput: The amount of forwarded data packets over a time period is known as throughput.

$$Throughput = \frac{Number\ of\ transmitted\ packets}{Time\ taken} \quad (3)$$

Figure 2 shows that the E2D of different protocols such as EFMRP [12], OQoS-CMRP [13], DMTSR [16], MRCP-TTDPS [20], NGFMR [21], MSLBM [25], QCM2R [26], MMSCM [28] and MsR2MRP [30]. From the analysis, it is observed that the EFMRP routing protocol has the maximum E2D than the other protocols.

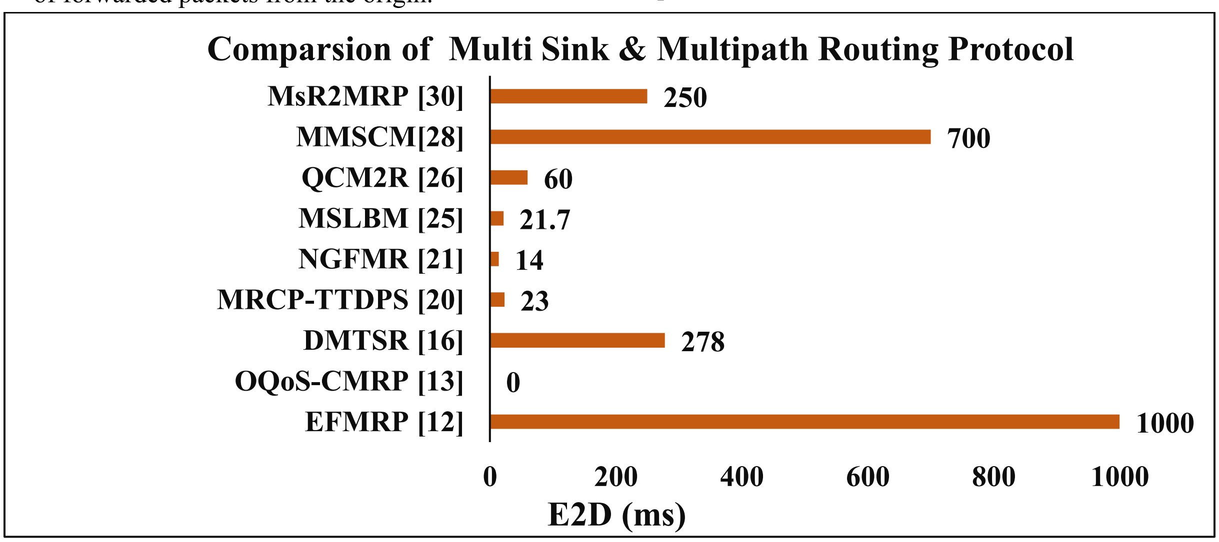

Figure 2: Comparison of End-to-end delay

Figure 3 shows that the PDR of different protocols such as EFMRP [12], OQoS-CMRP [13], DMTSR [16], OCC-MP [17], EMRAR [18], ECBMR [19], MSLBM [25] and MsR2MRP [30] routing protocols. From the analysis, it is observed that theEFMRP attains highest PDR whereas MsR2MRP attains slightly less PDR than the other protocols.

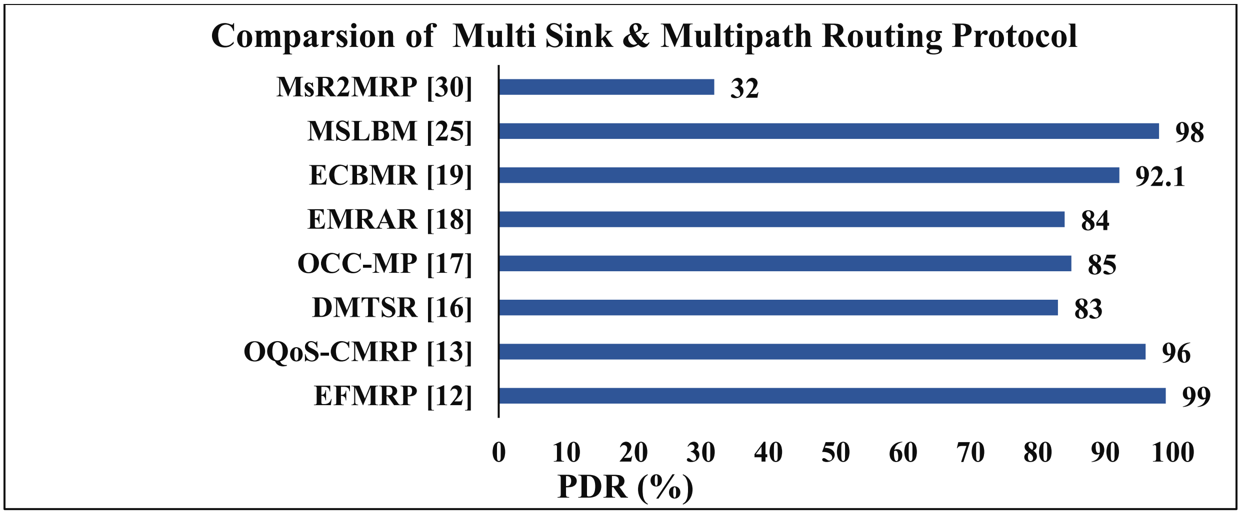

Figure 3: Comparison of PDR

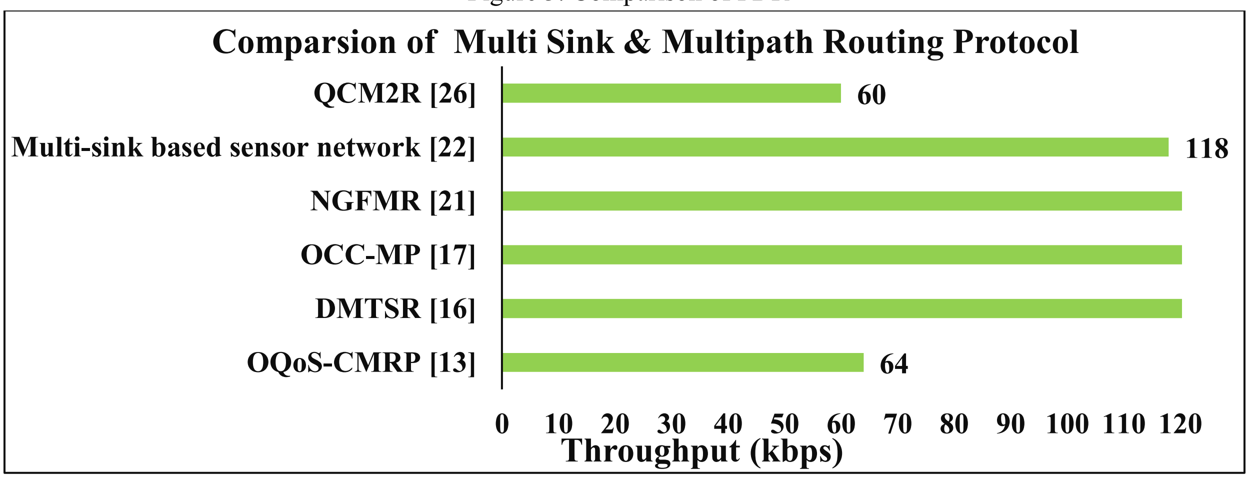

Figure 4: Comparison of Throughput

Figure 4 shows that the throughput of different protocols such as OQoS-CMRP [13], DMTSR [16], OCC-MP [17], NGFMR [21], Multi-sink based sensor network [22] and QCM2R [26] routing protocols. From the analysis, it is observed that the DMTSR attains higher throughput whereas QCM2R attains slightly less throughput than the other protocols.

IV. CONCLUSION

In this paper, a detailed comparative study on multipath protocols in WSNs was presented. From this comparative analysis, it is evident that many researchers have explored various multi sink and multipath routing protocols to improve fault tolerance, energy efficiency and network lifetime in WSNs. Among these protocols analyzed, EFMRPdemonstrated the maximum E2D, indicating efficient data transmission. However, MsR2MRP shows a comparatively lower PDR, affecting reliable data delivery. The DMTSRachieves higher throughput then others, while QCM2R attains slightly lower throughput. Although these protocols improve network performance in specific area, challenges remain in balancing energy consumption, ensuring data reliability and maintaining resilience under varying network conditions. Future research will focus on addressing these challenges to enhance the overall efficiency and reliability of multi path routing in multi sink WSN architectures.

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