International Journal of Engineering & Technology, 7 (4) (2018) 5494-5500

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v7i4.28111
Research paper

A survey on power and load-aware multipath node-disjoint routing protocol for MANET

Sathish Kumar. S [1] *, Ravi.G [2]

[1] *Assistant Professor, Department of Electronics & Communication Engineering, Jayalakshmi Institute of Technology, Dharmapuri, Tamilnadu*
[2] *Associate Professor, Department of Electronics & Communication Engineering, Sona College of Technology, Salem, Tamilnadu*
**Corresponding author E-mail: sathishkumarphd2018@gmail.com*

Abstract

In Mobile Ad-hoc Network (MANET), the most challenging task is communication through multipath routing. Generally, each node in the network may have limited power resources to communicate with the other nodes without any backbone structures. So, an unbalanced traffic allocation among nodes may cause power dissipation in overloaded nodes. Due to this, path failure has occurred that degrades the network lifetime and its performance. As a result, power and load-aware multipath routing protocols have been proposed to reduce the energy consumption and link failure in the network. Hence, a multipath routing scheme is the most crucial in MANET to transmit the data packets efficiently. This paper presents a detailed review of power and load-aware based multipath routing for MANET. Primarily, different power and load-aware multipath routing protocols designed by previous researchers for MANET are briefly studied. Then, a comparative analysis is conducted to understand the drawbacks in those protocols and suggest the new solution to improve the multipath routing in MANET with high network performance.

Keywords: *MANET; Power-Aware Routing; Load-Aware Routing; Link Failure; Energy Consumption; Network Lifetime.*

1. Introduction

Generally, MANET is a kind of Wireless Sensor Network (WSN) in which several mobile nodes are deployed for data communication through wireless links. The mobile nodes use peer-to-peer data transmission via multihop routes and functioning based on any wireless backbone infrastructures. Each node in this network can function as a router by discovering and maintaining paths to the other nodes. The main characteristics of this network are bandwidth and energy constraints, collaboration and dynamic topology. Thus, this type of decentralized networks can support a different kind of applications such as tactical communication, survival, search and disaster rescue operation, defense, etc.

To transmit the data packets using different routing protocols, each node should rely on each other node. Typically, the major advantage of this network is that they are more robust than the centralized networks since it relays the data packets based on the multihop manner. Though it has different advantages and applications, still those networks are more susceptible to many attacks because of its open nature. Also, the mobility pattern of nodes within the network can degrade the overall network performance. Moreover, it has to deal with a number of challenges due to its major characteristics.

Usually, nodes are bounded in their energy resources that are consumed by the communication between each other nodes. The energy of intermediate nodes is also consumed during transmission and reception of data and control packets for other nodes due to multihop communication. Several ad-hoc routing protocols have been designed whereas the routing is referred as the process for selecting the path with the minimum number of hops i.e., the shortest path from a particular source node to its destination as the optimal solution. Therefore, the set of nodes that forms this optimal route can involve for various source-destination pairs. The major design principles for the routing protocols are the following:

- Consistency and Scalability.
- Simplest implementation.
- Distributed and lightweight.
- Error tolerance.
- Dynamic topology control.

Each node in an ad-hoc network is linked dynamically in an arbitrary manner to create more than one path between the source and the destination node. This process is generally known as multipath routing. In several cases, a backup path is made through the multiple paths from the source to destination while the primary route is failed during packet transmission. This achieves a better fault tolerance and route recovery. Moreover, this may provide a load balancing by disseminating the traffics among a set of disjoint routes. The node-disjoint paths have specific advantages over non-disjoint paths. Node-disjoint paths may have lower aggregate resources than disjoint paths since it distributes links or nodes. Normally, node-disjoint paths provide the most aggregate resources since neither links nor nodes are shared between the routes. Also, it offers the highest degree of fault tolerance. Likewise, multipath achieves better performance than a unipath. As a result, it may be crucial for using a self-adaptive method to determine the path selection based on the real-time circumstances of the nodes and paths. Since multipath routing uses number of path to transmit the data whereas unipath routing uses only one path for data transmission.

Generally, routing protocols in MANET classified into three primary categories such as proactive, reactive and hybrid. Proactive protocols are utilized for learning the network topology regularly

based on the topological information among the nodes. Therefore, this route information is available immediately when there is a requirement for a path to the destination. If the network topology is modified frequently, then the network maintenance cost will be very high. If the network activity is low, then the information about the normal topology can even not be used.

Reactive routing protocols are designed according to the few sorts of query-reply dialog. They are used to establish the paths to the destination only when the requirement arises. They do not require the periodic transmission of topological information of the network. Moreover, both proactive and reactive routing protocols are combined to design a novel hybrid routing protocols. Nowadays, different hybrid protocols are also designed. Eventually, the battery of theses overloaded nodes will decrease to low and this will cause node failure or route failure. Such failure may reduce the network lifetime and lead to a network partition. As a result, many power and load-aware routing protocols were proposed in past few types of research with the objective of maintaining the link or path between nodes and maximizing the network lifetime. Also, these protocols can improve the network routing efficiency by locally analyzing the discovered paths and neglecting node-disjoint paths. However, some challenges are still addressed in multipath routing for MANET. Consequently, an overview of previous researches regarding power and load-aware multipath routing in MANET is presented in this article. The main aim of this article is to study the detailed information on different power and load-aware based multipath routing protocols in MANET. As well, their performance efficiency and limitations are also illustrated to further enhance the multipath routing based data packets transmission for MANET.

The remaining part of the paper is organized as follows: Section II provides the previous researches related to power and load-aware based multipath routing for MANET. Section III compares the performance efficiency of those algorithms and Section IV concludes an entire discussion.

2. Survey on power and load-aware multipath node disjoint routing protocols

A novel Device-Energy-Load Aware Routing (DELAR) protocol [1] was proposed for heterogeneous MANET. In this protocol, a hybrid transmission scheduling scheme was proposed by combining reservation-based and contention-based medium access control schemes for coordinating the transmissions. Moreover, a novel notion of mini-routing was introduced into the data link layer and an Asymmetric MAC (A-MAC) scheme was proposed for supporting the MAC-layer acknowledgments over unidirectional links caused by asymmetric transmission power levels between powerful nodes and normal nodes. In addition, a multi-packet transmission scheme was presented for improving the end-to-end delay.

A new intrusion-fault tolerant routing scheme [2] was proposed to provide a high reliability through the secure and efficient disjoint multipath routing construction. Initially, Sub-branch Multipath Routing Protocol (SMRP) was proposed to enhance the network lifetime. This method requires only one message per node for establishing a reliable routing topology. Based on this protocol, a Secure and Efficient Intrusion-Fault tolerant (SEIF) protocol was proposed to tackle the security issues in the network.

MultiPath OLSR (MP-OLSR) protocol [3] was proposed for MANET. In this protocol, a new multipath Dijkstra algorithm was proposed for discovering the multiple paths between the source and destination by adjusting the distinct cost functions. The two cost functions were used for generating multiple disjoint or non-disjoint paths. Moreover, additional functionalities were used for adapting the topology changes. The additional functions were route recovery and loop detection for ensuring QoS and feasible backward compatibility according to the IP-source routing.

A node-disjoint multipath routing method [4] was proposed based on Ad-hoc On-Demand Distance Vector (AODV) protocol (NDMP-AODV) for MANET for discovering all available node-disjoint paths from the source to destination. The main aim of this protocol was minimizing the effects of link failures. In this protocol, an initial path was determined to start the data transmission. Then, all the other backup paths were determined simultaneously by using the initial path to minimize the initial delay. Moreover, three different path maintenance methods were proposed to maintain the route discovery process.

QoS Enhanced Hybrid Multipath Routing (QEHMR) protocol [5] was proposed MANET. In this protocol, topology and path discovery processes were proposed in a proactive and reactive manner, respectively. In proactive topology discovery process, different information of each node like battery power, queue length and residual energy was collected by every other node and stored in the topology information table. Then, the topology was discovered by exchanging the topology information table. After that, the source node uses the reactive discovery mechanism to establish the multiple paths using a multipath Dijkstra algorithm and transmit the data packet to the destination.

A novel approach named Maximum Multipath AODV (MM-AODV) [6] was proposed for discovering the multiple node-disjoint routing paths in MANET. The main objective of this protocol was finding the maximum number of node-disjoint routes between a source and the destination based on the number of neighbors of a source node. This protocol was based on the extended AODV to balance the energy and traffic load on the entire network for improving the network lifetime.

Multipath routing and forwarding scheme [7] was proposed in non-cooperative wireless networks. In this scheme, a hybrid protocol was designed that incorporates GSP and FORBID in a unified framework. Based on this protocol, malicious behavior during packet transmission was detected and GSP was triggered for updating the least cost paths to remove Byzantine nodes from the network. Here, the GSP auction mechanism was enhanced with the traffic allocation policies for nodes cooperation.

Fibonacci Multipath Load Balancing (FMLB) protocol [8] was proposed for MANET. The main task of this protocol was balancing the packets transmitted over the selected routes and ordering them based on the hop count. Initially, multiple paths between the source and destination were discovered. Then, these were sorted in an increasing order based on their lengths and paths with a small number of hops were selected. For each selected paths, a Fibonacci weight depends on the number of hops was assigned. After that, the packets were distributed over multiple paths by the source node according to their Fibonacci weights.

Node Disjoint (NDj) multipath routing protocol based on AODV [9] was proposed in MANET. In this technique, multiple node-disjoint paths were discovered towards the destination by AODV routing protocol. Here, a sequence number was used for ensuring freshness of paths and avoiding routing loops. Moreover, the path discovery and maintenance processes of AODV were entirely updated to discover the multiple node-disjoint paths to the destination with the minimum routing overhead and latency. Also, the energy consumption was reduced by selecting optimum energy expending routes.

Node-Disjoint Multipath routing Protocol (NDMP) was proposed [10] based on AODV protocol. Initially, the primary route from source to the destination was discovered to initiate the data transmission. By using such a primary route, all the other backup routes were determined simultaneously during transmission to minimize the initial delay caused by the time taken for finding an initial path. When the path was broken, the data at the intermediate nodes was removed before selecting the backup paths to prevent any malicious activities in the network.

Energy Aware Load Balancing Multipath (EALBM) routing protocol was proposed [11] based on AODV protocol. In this protocol, three phases were performed namely neighbor discovery, multipath discovery and data transmission. The multipath discovery was initiated by the source node for determining all disjoint multipaths from source to destination. Then, a weight was assigned by each disjoint path according to the energy level of nodes along

that path. The path with the maximum energy of nodes was selected for data transmission with reduced delay and packet loss.

A Dual Node-Disjoint paths Routing (DNDR) protocol [12] was proposed in MANET for improving the network reliability and robustness. In this protocol, the characteristics of Reversing AODV (R-AODV) strategy and on-demand node-disjoint multipath routing protocol were combined to find available node-disjoint paths with the minimum routing control overhead. In addition, the backup routing strategy was included for providing the process of data salvation more efficient when link failure has occurred.

An Adaptive Transmission Power (ATP) aware multipath routing protocol [13] was proposed for MANET. This protocol was based on the modification of Adhoc On-demand Multipath Distance Vector (AOMDV) routing protocol to find node-disjoint paths. In this protocol, an adaptive selection of sufficient transmission power was used for an individual packet that avoids high interference and excessive traffic generated by the control packets. It has the ability to change the transmission power of control packets used for discovering the routes in the network dynamically. Moreover, the path errors were also efficiently handled by this protocol.

Residual Energy based Reliable Multicast Routing (RERMR) protocol was proposed [14] for data transmission in MANET by achieving more network lifetime and packet delivery ratio. In this protocol, a multicast backbone was built for obtaining more stability according to the node familiarity and trustable loop. Reliable route criterion was estimated for selecting the best reliable path among all available paths. After that, the data packets were transmitted through the selected reliable path. In addition, energy consumption was also minimized based on the residual energy of the node during transmission.

Energy Aware On-demand Multipath Routing (EAOMR) protocol was proposed [15] in MANET based on AOMDV protocol. In this protocol, an optimal energy aware node-disjoint multipath was selected between the source and destination pairs to improve the network lifetime by utilizing two new power metrics namely minimize the maximum node cost and minimize the cost per packet. This protocol consists of three major processes such as path selection, path discovery and path maintenance. Initially, all available paths were selected by using the primary cost and then an optimal path was selected based on the minimization of secondary cost.

A novel load balancing scheme [16] was proposed for a multipath routing protocol in MANET. In this scheme, the Path Efficient AOMDV (PE-AOMDV) protocol was proposed to improve the routing performance. A novel threshold value and a counter variable were applied to limit the number of communication routes passing over the node in the path discovery process. For each new request, the counter variable was incremented by one and the threshold value was compared to know whether the maximum number of connections has been reached or not. Based on this protocol, both congestion and energy consumption were reduced.

Energy Efficient Load-Aware Routing (EELAR) technique [17] was proposed for MANET. The main aim of this technique was to improve both load balancing and energy efficiency in parallel. In this technique, two major processes were performed in parallel such as link estimation was proposed to improve the energy efficiency and learning of network load balancing was performed to improve the QoS performance. An Energy Efficient Node-Disjoint Multipath Routing Protocol (E2NDjMRP) [18] with dynamic transmission rate adjustment was proposed for MANET. In this protocol, the shortest hop count was used with dynamic transmission range adjustment for determining the primary route and secondary routes. Such obtained primary routes were used for data transmission and the next optimal backup path was directly obtained in the worst case to avoid retransmission of data packets. Moreover, the distance was computed between the transmitting and receiving nodes to adjust the transmission power in a certain transmitting node for reducing the energy consumption in the network.

Power-aware Node-Disjoint Multipath Source Routing (PNDMSR) protocol [19] was proposed and analyzed in MANET. The major aim of this protocol was to select energy-aware node-disjoint multipath between a source and destination by controlling the overhead. In this protocol, a new power-aware metric such as minimum node cost was used for discovering the optimal routes. In addition, power consumption and bandwidth were also optimized to support reliability in the network. Moreover, the network lifetime was maximized by maintaining the minimum energy level to each node.

Power-Aware Load Balancing Multipath Routing Protocol (PALBMRP) was proposed [20] for MANET. This protocol was based on the combination of energy efficient path selection and effective load distribution protocols. In this protocol, an optimal energy efficient path was selected according to the multiple parameters such as residual energy, delay, congestion and hop count. Moreover, load balancing was also performed by considering the nodes with minimal residual energy for transmitting the data packets according to its capacity.

Multipath Battery and Mobility-Aware (MBMA) routing scheme [21] were proposed based on the Optimized Link State Routing (OLSR) protocol. The main intention of this scheme was to rank the link stability by using a link assessment function and select the most efficient and stable routes from source to the destination. To achieve this, a Multi-Criteria Node Rank (MCNR) metric was utilized. In addition, an Energy and Mobility-Aware Multi-Point Relay (EMA-MPR) selection mechanism was proposed to identify the node's willingness to contribute as MPR for flooding topological information.

An on-demand Power and Load-Aware (PLA) multipath node-disjoint source routing scheme [22] was proposed based on Dynamic Source Routing (DSR) protocol to improve the network lifetime. In this approach, a new cost function was measured that permits source nodes to find a multiple node-disjoint power and a load-aware optimal path to their destinations. In addition, over-dissipation of nodes in the optimal paths was avoided and the number of path discovery processes was reduced. Moreover, a threshold was set for preventing nodes with low residual energy from participating in path discovery processes.

2.1. Comparison of existing protocols

A comparative analysis of the merits and demerits of different power and load-aware node-disjoint multipath routing protocols whose functional information is discussed in the above section is presented. Through the review of those protocols, the following limitations are addressed:

- The route failure due to an energy reduction of nodes and asymmetric links was not detected using NDj-AODV protocol.
- Many protocols such as NDMP-AODV, QEHMR, PNDMSR and PLA-DSR have high control/routing overhead.
- EALBM, PE-AOMDV and EAOMR protocols have high packet loss.
- Average end-to-end delay of DELAR, ATP-AOMDV, MM-AODV and PLA-DSR was high.
- Few protocols like RERMR require the symmetric cryptographic scheme to improve network security and lifetime.
- The energy consumption of E2NDjMRP with dynamic transmission rate adjustment was not reduced.
- MP-OLSR and MBMA have a high number of packets dropped that degrades the QoS performance.
- FMLB does not reduce congestion through the network.
- Performance efficiency of EELAR protocol was less while the number of nodes was increased.
- The number of node-disjoint paths in SMRP with SEIF was low since path disjointness was possible only in dense networks.
- Some protocols like NDMP-AODV require route selection process to satisfy the user requirements.

- Computation complexity of FORBID protocol was high and also it does not consider the energy consumption and load-balancing issues.
- DNDR protocol has a high normalized routing load when compared to the AODV with increased node mobility.

From the following Table 1, the most challenging issues in power and load-aware node-disjoint multipath routing protocols are observed and an ideal solution is suggested to overcome those limitations in node-disjoint multipath routing protocols in MANET.

Table 1: Comparison of Different Power and Load-Aware Node-Disjoint Multipath Routing Protocols for MANET

Ref. No.	Methods	Merits	Demerits	Performance Metrics
[1]	DELAR	Increased PDR.	An average end-to-end delay was high.	Node speed=2m/s: Average energy consumption=19mJ, PDR=0.968, Average end-to-end delay=0.14sec
[2]	SMRP and SEIF	Improved scalability by requiring only one message per node.	The number of node-disjoint paths was low since path disjointness was possible only in dense networks.	Network size=100: Average energy consumption=789900μJ, Mean time to failure=50sec, Average CPU consumption=214800μJ
[3]	MP-OLSR protocol	Improved scalability and network lifetime.	Link quality was not considered that degrades the QoS performance.	Speed=5m/s: PDR=90%, Average end-to-end delay=0.039sec, Average time in queue=0.001sec
[4]	NDMP-AODV protocol	Continuous data transmission was achieved by using multiple backup paths.	The route selection process was required to satisfy the user requirements.	Pause time=100sec: Routing control overhead=45%, Average end-to-end delay=0.125sec, Average PDR=93.5%
[5]	QEHMR protocol	Better QoS.	Overhead was high.	Number of nodes=70: PDR=0.62, Delay=7sec, Overhead=11000 Speed=40m/s: PDR=0.5, Delay=7sec, Overhead=14000
[6]	MM-AODV	Better performance.	An average end-to-end delay was high.	Node speed=20m/s: PDR=85%, Routing overhead=1, Throughput=146Kbps, Average end-to-end delay=250msec Number of nodes=50: PDR=89%, Routing overhead=1.22, Throughput=143Kbps, Average end-to-end delay=180msec
[7]	FORBID	Byzantine nodes are quickly detected and isolated from the forwarding paths.	Computational complexity was high. Also, energy consumption and load-balancing were not considered.	Number of nodes=200: Packet loss rate=0.11
[8]	FMLB protocol	Increased PDR.	Congestion was not reduced.	Transmission rate=5packets/sec: PDR=60%, End-to-end delay=0.01sec Node speed=75m/s: PDR=40%, End-to-end delay=0.22sec
[9]	NDj-AODV based multipath routing protocol	Reduced routing overhead and latency.	Route failure due to energy depletion of nodes and asymmetric links was not efficiently detected.	Mobility=25m/sec: Packet Delivery Ratio (PDR)=45%, Average end-to-end delay=2.41sec, Normalized routing load=3.5
[10]	NDMP-AODV	Better scalability and security.	Routing overhead was high.	Pause time=500sec: PDR=58%, Average end-to-end delay=2.6sec, Normalized routing load=2.1 Number of nodes=100: PDR=99%, Routing overhead=130
[11]	EALBM routing protocol	Reduced delay and load in the network.	The packet loss was high.	Interface queue length=30 (Dynamic different energy of nodes): Throughput=33kbps, PDR=6%, End-to-end delay=18sec, Packet loss=12750, Residual energy=97.8, Normalized load=7.5
[12]	DNDR protocol	Enhanced network reliability and robustness.	Normalized routing load was higher than AODV when node mobility was increased.	Node mobility=50m/s: PDR=91.9%, Average latency delay=0.275sec, Normalized routing load=4
[13]	ATP-AOMDV based multipath routing proto-	Increased average residual energy of the nodes in the	High average end-to-end delay.	Pause time=100sec: PDR=68%,

	col	network.		Average end-to-end delay=1500sec, Throughput=400kbps, Average residual energy of nodes at end of simulation=5800watts
[14]	RERMR protocol	Improved reliability of multipath routing.	It requires a symmetric cryptographic scheme for improving network security.	End-to-end delay (Speed:100mbps)=7ms, Path reliability rate (Number of paths:20)=89%, Network stability rate (Pause time:5sec)=89%, Communication overhead (Time:40sec)=2packets,
[15]	EAOMR protocol	High scalability, robustness and energy-efficient.	When the node's speed was increased, the packet loss rate was high.	Node speed=40m/s: Overhead=370packets, Energy consumption=390J, Throughput=72kbps, PDR=72%, Packet loss=92%
[16]	PE-AOMDV based multipath routing protocol	Reduced normalized routing overhead and increased PDR.	Packet loss ratio was high.	Number of nodes=75: Packet loss ratio=181packets, PDR=95.9013%, Normalized routing overhead=0.0401sec, Routing overhead=170packets, Throughput=173.02kbps,
[17]	EELAR protocol	Computational complexity was less.	Performance efficiency was less when the number of nodes was increased.	Mobility speed=50m/s: Throughput=35Kbps, Delay=0.052sec, PDR=92%, Number of nodes=20: Throughput=50Kbps, Delay=2sec, PDR=5%
[18]	E2NDjMRP with dynamic transmission rate adjustment	High PDR and throughput.	Energy consumption was high.	Number of nodes=100: Throughput=400kbps, PDR=99.8%, End-to-end delay=120ms, Energy consumption=1300mJ,
[19]	PNDMSR protocol	Better performance.	Overhead was high. So, many bandwidth and power were exhausted and also the delay was increased.	Time=20sec: Energy consumption=1500J, Residual energy=2500J, Number of nodes expired=4, Throughput (Mobility=10sec)=0.94
[20]	PALBMRP	Increased PDR and reduced average energy consumption.	Routing overhead was not analyzed.	Number of nodes=50: Average energy consumption=0.05, PDR=95%, End-to-end delay=0.18sec
[21]	MBMA and EMA-MPR	High energy efficiency.	The number of packets dropped was still high.	Node's speed=10m/s: Throughput=49Kbps, Average end-to-end delay=0.85sec, Total packets dropped=330packets, Average residual energy=1mAhr, Average energy consumption=50.45mWh, Energy Cost per Packet (ECP)=11.5μWh, Number of dead nodes=30nodes
[22]	PLA-DSR based multipath node-disjoint source routing protocol	Reduced energy consumption.	Average end-to-end delay and control overhead and were high.	Packet rate=20packets/sec: Network lifetime=62sec, Average end-to-end delay=1.36sec

3. Results and discussions

In this section, the performance efficiency of the above-surveyed protocols is evaluated and compared. The experiments are conducted by using the Network Simulator version 2.35 (NS2.35). NS2 simulator is open source software that supports many routing protocols written in C++ with object Tool Command Language (TCL) interpreter as the front-end. In this experiment, the performance of the power and load-aware node-disjoint multipath routing protocols is evaluated and compared in terms of end-to-end delay, PDR and throughput. The simulation parameters are given in Table 2.

Table 2: Simulation Parameters

Simulator tool	NS2.35
Network size	1400×1400sqm
Number of nodes	100
Network topology	Flat-grid
MAC layer	IEEE 802.11
IFQ type	DropTail
IFQ length	50
Antenna type	Omni-directional
Propagation model	Two Ray Ground
Physical type	Phy/WirelessPhy
Channel type	Channel/WirelessChannel
Routing protocol	DSR/OLSR/AODV/PLA-DSR
Transmitted signal power	0.2818W
Transmission range	250m
Initial energy	100J
Transmitting power	1.4W
Receiving power	1W
Mobility model	Random waypoint
Node Speed	0-10m/s
Pause time	0-100s
Traffic type	Constant Bit Rate (CBR)
Packet size	512bytes

3.1. Simulation parameters

- End-to-end delay: It refers to the time taken to transmit the data packets from source to destination. It is considered as one of the performance metrics which indicates that the network can efficiently transmit the data packets from

source to destination through the selected path within a given time.

$$\text{End} - \text{to} - \text{end delay} = \frac{\text{Total time for packets received by the destination}}{\text{Total Number of packets received by the destination}} \quad (1)$$

- PDR: It is the fraction of the total amount of data packets received at the destination to the total amount of forwarded packets from the source. It gives the amount of packets transmitted through the selected routing path without any information loss.

$$\text{PDR} = \frac{\text{Total number of packets received by destination}}{\text{Total number of packets sent by source}} \quad (2)$$

- Throughput: The amount of forwarded data packets over a time period is known as throughput and its unit is kilobits per second (kbps). Based on the highest throughput, the stability of the nodes is improved.

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

3.2. Performance analysis

The performance analysis of end-to-end delay, PDR and throughput are shown for node speed is considered as 10m/s.

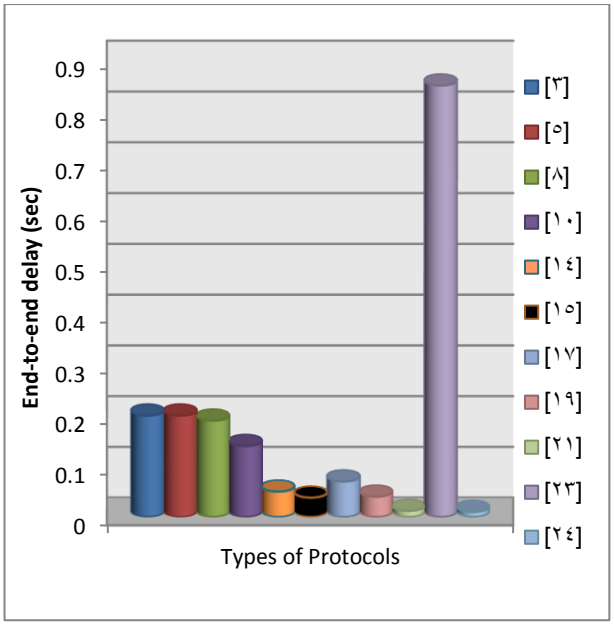

Fig. 1: Comparison of End-to-End Delay (Node Speed=10m/S).

Fig. 1 shows that the end-to-end delay of different protocols such as DELAR [3], MP-OLSR [5], MM-AODV [8], FMLB [10], DNDR [14], ATP-AOMDV [15], EAOMR [17], EELAR [19], PNDMSR [21], EMA-MPR [23] and PLA-DSR [24] based multipath node-disjoint source routing protocols. From the analysis, it is observed that the PLA-DSR protocol has a better end-to-end delay than the other protocols.

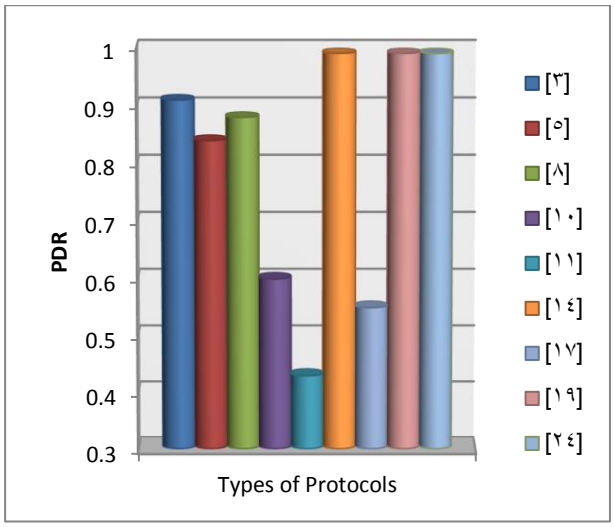

Fig. 2: Comparison of PDR (Node Speed=10m/S).

Fig. 2 shows that the PDR of different protocols such as DELAR [3], MP-OLSR [5], MM-AODV [8], FMLB [10], NDj-AODV [11], DNDR [14], EAOMR [17], EELAR [19] and PLA-DSR [24] based multipath node-disjoint source routing protocols. From the analysis, it is observed that the PLA-DSR protocol has better PDR than the other protocols.

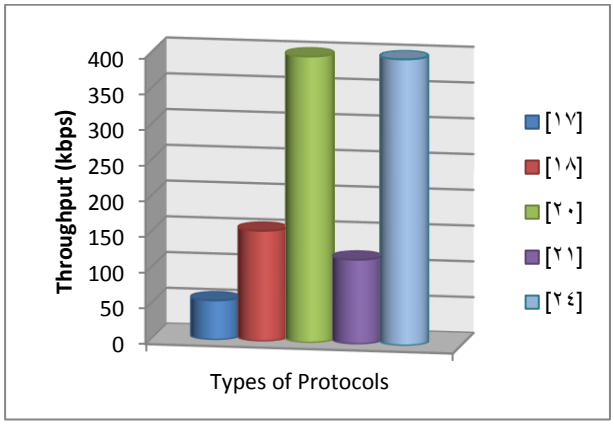

Fig. 3: Comparison of Throughput (Node Speed=10m/s).

Fig. 3 shows that the throughput of different protocols such as EAOMR [17], PE-AOMDV [18], E2NDjMRP [20], PNDMSR [21] and PLA-DSR [24] based multipath node-disjoint source routing protocols. From the analysis, it is observed that the PLA-DSR protocol has better throughput than the other protocols.

4. Conclusion

In this paper, a detailed comparative study on power and load-aware node-disjoint multipath routing protocols in MANET is presented. From this comparative analysis, it is clearly noticed that all researchers have practiced in power, load-aware and node-disjoint multipath routing protocols to transmit the data packets from source to destination in MANET with reduced energy consumption, end-to-end delay and increased packet delivery ratio. Among those protocols, PLA-DSR based multipath node-disjoint routing protocol has better network performance than all other protocols. It chooses DSR protocol rather than other routing protocols since it establishes a path only when it is required. Even, some limitations are addressed in PLA-DSR protocol. Therefore, the future extension of this study could be focussed on further improvement on PLA-DSR protocol by using hybrid opportunistic routing algorithm, improved multi-channel cooperative neighbor discovery algorithm and QoS-aware routing protocol.

Normally, opportunistic routing protocols are a novel paradigm that selects the node nearest to the target node for transmitting the

data. The main function of this protocol is its ability to overhear the transmitted packet and coordinate among relaying nodes. Each node in this routing protocol can utilize different paths for transmitting the packets from the source to the destination node. Thus, the QoS performance of the network would be increased with the reduced number of node failure by using this enhanced PLA-hybrid opportunistic routing protocol.

References

[1] Liu W, Zhang C, Yao G, & Fang Y (2011), "DELAR: A device-energy-load aware relaying framework for heterogeneous mobile ad hoc networks", *IEEE journal on selected areas in communications*, *29*(8), 1572-1584. https://doi.org/10.1109/MILCOM.2004.1495132.

[2] Challal Y, Ouadjaout A, Lasla N, Bagaa M, & Hadjidj A (2011), "Secure and efficient disjoint multipath construction for fault tolerant routing in wireless sensor networks", *Journal of network and computer applications*, *34*(4), 1380-1397. https://doi.org/10.1016/j.jnca.2011.03.022.

[3] Yi J, Adnane A, David S, & Parrein B (2011), "Multipath optimized link state routing for mobile ad hoc networks", *Ad hoc networks*, *9*(1), 28-47. https://doi.org/10.1016/j.adhoc.2010.04.007.

[4] Lal C, Laxmi V, & Gaur MS (2012), "A node-disjoint multipath routing method based on AODV protocol for MANETs", In *2012 IEEE 26th International Conference on Advanced Information Networking and Applications*, pp. 399-405. https://doi.org/10.1109/AINA.2012.49.

[5] Devi PR, & Rao DS (2012), "QOS enhanced hybrid multipath routing protocol for mobile adhoc networks", *International Journal of Distributed and Parallel Systems*, *3*(6), 89. https://doi.org/10.5121/ijdps.2012.3608.

[6] Chowdhury T, & Mukta RBM (2014), "A novel approach to find the complete node-disjoint multipath in AODV", In *2014 IEEE International Conference on Informatics, Electronics & Vision (ICIEV)*, pp. 1-6. https://doi.org/10.1109/ICIEV.2014.6850858.

[7] Su X, Peng G, & Chan S (2014), "Multi-path routing and forwarding in non-cooperative wireless networks", *IEEE Transactions on Parallel and Distributed Systems*, *25*(10), 2638-2647. https://doi.org/10.1109/TPDS.2013.200.

[8] Tashtoush Y, Darwish O, & Hayajneh M (2014), "Fibonacci sequence based multipath load balancing approach for mobile ad hoc networks", *Ad Hoc Networks*, *16*, 237-246. https://doi.org/10.1016/j.adhoc.2013.12.015.

[9] Arya V, & Gandhi C (2014), "NDj-AODV: Node disjoint multipath routing in Mobile Ad Hoc Networks based on AODV protocol", In *2014 IEEE Seventh International Conference on Contemporary Computing (IC3)*, pp. 601-606. https://doi.org/10.1109/IC3.2014.6897241.

[10] Barbudhe VK, Kumar A, Sisat SN, Bhopale P, Chalse RR, Talmale R, ... & Bapat AV (2014), "Node-disjoint Multipath Routing Method Based on AODV Protocol", *International Journal of Research in Advent Technology*, *2*(2). https://doi.org/10.1109/AINA.2012.49.

[11] Deshmukh SR, & Raisinghani VT (2014), "EALBM: Energy aware load balancing multipath routing protocol for MANETs", In *2014 IEEE Eleventh International Conference on Wireless and Optical Communications Networks (WOCN)*, pp. 1-7. https://doi.org/10.1109/WOCN.2014.6923061.

[12] Yu Y, & Liang M (2015), "A Node-Disjoint Multipath Routing Protocol in MANETs", In *2015 IEEE International Conference on Computer Science and Mechanical Automation (CSMA)*, pp. 108-112. IEEE. https://doi.org/10.1109/CSMA.2015.28.

[13] Arora B (2015), "An adaptive transmission power aware multipath routing protocol for mobile ad hoc networks", *Procedia Computer Science*, *57*, 1242-1248. https://doi.org/10.1016/j.procs.2015.07.424.

[14] Gopinath S, & Nagarajan N (2015), "Energy based reliable multicast routing protocol for packet forwarding in MANET", *Journal of Applied Research and Technology*, *13*(3), 374-381. https://doi.org/10.1016/j.jart.2015.07.003.

[15] Bheemalingaiah M, Naidu MM, Rao DS, Vishvapath P, & Uniersity JNT (2016), "Energy Aware On-Demand Multipath Routing Protocol in Mobile Ad Hoc Networks", *International Journal of Computer Networks and Wireless Communications*, *6*(5), 14-33.

[16] Mounagurusamy K, & Eswaramurthy K (2016), "A Novel Load Balancing Scheme for Multipath Routing Protocol in MANET", *Journal of computing and information technology*, *24*(3), 209-220. https://doi.org/10.20532/cit.2016.1002497.

[17] Salem MA, & Yadav R (2016), "Efficient load balancing routing technique for mobile ad hoc networks", *International Journal of Advanced Computer Science and Applications*, *7*(5), 249-254. https://doi.org/10.14569/IJACSA.2016.070535.

[18] Benakappa SM, & Kiran M (2017), "An energy-aware node disjoint multipath routing protocol for MANETs with dynamictransmission range adjustment", In *2017 IEEE International Conference on Electrical, Electronics, Communication, Computer, and Optimization Techniques (ICEECCOT)*, pp. 335-341. https://doi.org/10.1109/ICEECCOT.2017.8284523.

[19] Bheemalingaiah M, Naidu MM, Rao DS, & Vishvapathi P (2017), "Performance Analysis of Power-Aware Node-Disjoint Multipath Source Routing in Mobile Ad Hoc Networks", In *2017 IEEE 7th International Advance Computing Conference (IACC)*, pp. 361-371. https://doi.org/10.1109/IACC.2017.0084.

[20] Shinde M, & Jain S (2017), "PALBMRP: Power Aware Load Balancing Multipath Routing Protocol for MANET", *International Journal of Advanced Networking and Applications*, *9*(1), 3329-3334.

[21] Jabbar WA, Ismail M, & Nordin R (2017), "Energy and mobility conscious multipath routing scheme for route stability and load balancing in MANETs", *Simulation Modelling Practice and Theory*, *77*, 245-271. https://doi.org/10.1016/j.simpat.2017.07.001.

[22] Ali HA, Areed MF, & Elewely DI (2018), "An on-demand power and load-aware multi-path node-disjoint source routing scheme implementation using NS-2 for mobile ad-hoc networks", *Simulation Modelling Practice and Theory*, *80*, 50-65. https://doi.org/10.1016/j.simpat.2017.09.005.