Jurnal
Teknologi

Full Paper

ROUTING PROTOCOLS FOR MOBILE AD-HOC NETWORK: A QUALITATIVE COMPARATIVE ANALYSIS

Article history
Received
30 October 2015
Received in revised form
16 February 2016
Accepted
15 July 2016

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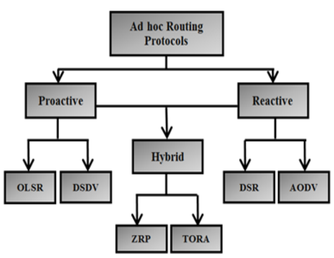
Graphical abstract



Abstract

Routing in MANET is a challenging task due to the dynamic nature of the participating nodes in MANET. This challenge has led to the development of many different routing protocols, with each originator claiming that his or her proposed protocol was more effective than its predecessors were. Nonetheless, the effectiveness of these protocols relies on the prevailing network scenarios, which differ in terms of node density and traffic. Against this challenging backdrop, the authors provide an overview of the different MANET protocols, such as OLSR, AODV, DSR, DSDV, ZRP and TORA, which are broadly classified based on three categories, namely Proactive (table-driven), Reactive (on-demand) and Hybrid routing protocol. The authors then provide a comparative analysis of the different protocols based on qualitative metrics. This paper concludes by highlighting the expected performance of each protocol for a particular network environment, which is deemed suitable based on the specific characteristics of the protocol.

Keywords: Wireless network, mobile ad hoc network, routing protocol

Abstrak

Penghalaan di dalam Manet merupakan satu tugas yang mencabar kerana sifat dinamik nod yang terlibat dengan Manet. Cabaran ini telah membawa kepada pembangunan banyak protokol penghalaan yang berbeza, dimana setiap penciptamengatakan protokol yang merekacadangkan adalah lebih berkesan daripada yang sedia ada. Namun begitu, keberkesanan protokol ini bergantung kepada keadaan semasa rangkaian, dimana ia berbeza dari segi kepadatan nod dan lalu lintas. Dengan latar belakang yang mencabar ini, penulis memberikan gambaran keseluruhan mengenai protokol Manet yang berbeza, seperti OLSR, AODV, DSR, DSDV, ZRP dan TORA, yang dikelaskan berdasarkan tiga kategori iaitu Proaktif (jadual yang didorong), reaktif (atas - permintaan) dan penghalaan protokol Hybrid. Penulis kemudian memberikan analisis perbandingan protokol yang berbeza berdasarkan metrik kualitatif. Kertas kerja ini memberi kesimpulan dengan menekankan prestasi yang diharapkan setiap protokol untuk persekitaran rangkaian yang tertentu, yang difikirkan sesuai berdasarkan ciri-ciri tertentu protokol.

Kata kunci: Rangkaian tanpa wayar, rangkaian mudah alih, protokol penghalaan

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1.0 INTRODUCTION

Mobile Ad hoc Network (MANET) can be defined as a self-organized, self-configured wireless network, which can be deployed without any support of infrastructure such as centralized base station (BS) or access point (AP) [1-6]. Essentially, MANET is a temporary short-lived network, which can be setup anytime, anywhere as a solution for the situation in which prevailing infrastructure is inadequate or infeasible. For example, MANET is considered as an appropriate network to be used in disastrous areas (which typically arise from floods, earthquakes, or fire breakout) in which an existing infrastructure may have been damaged, causing a serious communication breakdown. Basically, MANET consists of multiple nodes or devices, such as laptops, smart phones, personal digital assistants (PDAs), MP3 players, and digital cameras, which are connected to help them communicate with each other through wireless links. All the nodes in MANET may connect or leave a network at any time without any restrictions, and each node can be a sender, a receiver, or an intermediate node by acting as a router to forward data to other mobile nodes. In real life, these devices are highly mobile, moving freely from one location to another. Thus, the topology of a network may change rapidly and unpredictably [7]. These mobile nodes, which rely on batteries to operate, can be located in cars, ships, airplanes, or other electronics devices, depending on the types of MANET application. Table 1 shows a list of typical examples of possible applications of MANET.

Table 1 Possible MANET Applications [31]

Applications	Scenario/Services
Tactical networks	• Military communication and operations • Automated battlefield
Emergency services	• Search and rescue operations • Disaster recovery (i.e. flood, earthquake, fire and etc.) • Replacement of fixed infrastructure in case of environmental disasters • Policing and fire fighting • Supporting doctors and nurses in hospitals (i.e. patient monitoring)
Commercial and civilian environments	• E-commerce: electronic payments anytime and anywhere • Business: dynamic database access, mobile offices • Vehicular services: road or accident guidance, transmission of road and whether conditions, taxi cab network • Sports stadiums, trade fairs, shopping malls • Networks of visitors at airports
Home and enterprise networking	• Home/office wireless networking • Conferences, meeting rooms • Personal area networks (PAN), Personal networks (PN) • Networks at construction sites
Education	• Universities and campus settings • Virtual classrooms • Ad hoc communications during meetings or lectures
Entertainment	• Outdoor internet access • Theme parks

Routing protocols is one of the key issues in MANET. A routing protocol is required when the source node needs to transmit and deliver the packets to a destination node. In essence, routing protocols are used to find the valid routes between two or more communicating nodes in the network [8]. More specifically, these protocols help nodes or devices to decide the way to route packets in the network. In other words, routing protocols are used to establish and maintain multi-hop routes to allow data communication between nodes. Designing a routing protocol for MANET is challenging given the inherent nature of the participating nodes, which are mobile and battery-operated. Thus, routing protocols should be appropriately designed to cope with highly mobile and rapidly changing topologies. To address some of these challenges, several routing protocols have been proposed to be used in MANET environment by taking into consideration the dynamic nature of the network.

The proposed protocols can be classified into three categories, namely Proactive (or table-driven), Reactive (or on-demand), or Hybrid protocols. The choice of a particular category depends on whether a continuously updating of routes or reaction based on demand (routes updated only when they are needed) is entailed [7-16]. Figure 1 shows the classification of routing protocols for mobile ad hoc network, and Table 2 summarizes the advantages and disadvantages of these protocols.

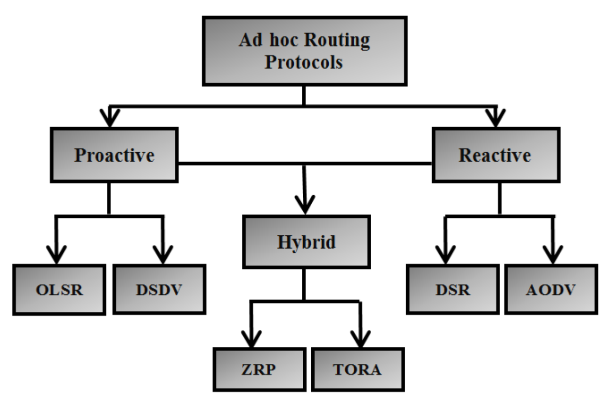

Figure 1 Classification of MANET's Routing Protocols

1.1 Proactive Protocols

Proactive protocols, which are also called table-driven protocols, involve the use of routing tables that maintain the route of every node in a network [9]. These types of protocols build their routing tables continuously by broadcasting periodic routing updates through the network. Routing information of every node in the network is continuously updated in the routing tables by sending control messages periodically [17]. Whenever a new node is entered into the network or removed from the network, control messages are sent to nearby nodes so that these nodes can update their routing tables accordingly. This category of routing protocols uses link-state routing algorithms, which frequently flood the link with information about its neighbors. Examples of proactive protocols are Optimized Link State Routing (OLSR) [17-20].

Table 2 MANET's Routing Protocols Comparison

Category	Advantages	Disadvantages
Proactive	Periodic updates of routing information ensure the routes are always available when needed. Small delay in discovering a new route.	Periodic updates of routing information produce high message overhead. Available routing information is not fully utilized. Waste a large amount of resource (i.e. bandwidth, power). Tendency of creating loops.
Reactive	On demand updates reduce the routing load and message overhead. Uses less resource for the route establishment. The use of sequence number ensures loop-free.	On demand updates of routing information causes the routes are not always available. Produce high latency in discovering a new route.
Hybrid	Combines the strength of both proactive and reactive protocol; reduce the overhead of proactive and reduce the delay of reactive.	Produces inter-zone routing latencies. Uses more resources for large size of zones.

1.2 Reactive Protocols

Reactive protocols, which are also called on-demand protocols, are protocols that build their routing tables on demand. As indicative of the term used, these routing protocols initiate route discovery to find a route between communicating nodes only when the source node has data packets. Having found the route, route maintenance will be initiated to maintain this route until it is no longer required or the destination node is reachable. To maintain a fresh route and to avoid looping, a sequence number is used. Some examples of the reactive routing protocols are Dynamic Source Routing (DSR) [6] and Ad Hoc On-demand Distance Vector (AODV) [17, 19-20].

1.3 Hybrid Protocols

Hybrid protocols, as the names suggest, are derived from the combination of proactive and reactive methods, which offers several advantages of both protocols by creating reactive routing zones interconnected with proactive routing links. Initially, hybrid protocols perform as proactive routing protocols as the starting nodes have tables. Then, whenever the nodes notice that they do not have a path to a destination, they start initiating route discovery and performing as reactive routing protocols. Temporally Ordered Routing Algorithm (TORA) [21] and Zone Routing Protocol (ZRP) [10] are two examples of the hybrid protocols.

2.0 ROUTING PROTOCOLS

2.1 Optimized Link State Routing Protocol (OLSR)

OLSR is a proactive routing protocol developed by IETF group [22-26]. It is an optimized version of the classical link state protocol, where every node broadcasts messages and generates heavy overhead traffic. For optimization, OLSR uses MPRs selection concept to reduce the overhead of packet transmission during flooding process. In OLSR, few nodes are selected as Multi Point Relays (MPRs) to broadcast the messages for link detection in the nework. Each node then selects its set of MPRs in the network. OLSR performs hop-by-hop routing, where each node uses its most recent routing information to route packets. MPRs covers all nodes that are two hops away (i.e., immediate neighbors). A node senses and selects its MPRs with control messages called HELLO messages. HELLO messages are used to ensure a bidirectional link with a neighbor, and these mesages are sent at a certain interval. Nodes broadcast Topology Control (TC) messages to determine their MPRs. In this case, only the control messages are passed between the MPRs, thus eliminating the need to pass entire information between nodes. Each node then keeps it own route table. By being proactive, OLSR updates and stores the information about all routes in the network. Therefore, the routes in the network are always immediately available when needed.

2.2 Destination-Sequenced Distance-Vector (DSDV)

The Destination-Sequenced Distance-Vector (DSDV) Routing Algorithm is a proactive protocol developed by C. Perkins and P. Bhagwat in 1994. It was developed based on the idea of the classical Bellman-Ford Routing Algorithm with certain improvements made [12, 21-22]. The improvements made included freedom from loops in routing tables by using sequence numbers. In DSDV, each node periodically transmits routing information to its immediate neighbors to maintain a routing table. The routes updates can be either time-driven or event-driven. Each entry in the table contains the destination address, number of hops to reach the destination, next hop address, and sequence number provided by the destination node. The destination node chooses the shortest path according to the hop count and sequence number in which the route with the highest sequence number is preferred. Once the routes are selected, the destination node then forwards the RREP controls messages for route establishment. The routing table updates can be sent in two ways: a full dump update or an incremental update (which is to reduce the large amount of network traffic created by the updating process). For the full dump update, full routing table is sent to the neighbors. In contrast, the incremental update involves only those entries that have changed since the last update, which must fit in a packet.

2.3 Ad-Hoc on Demand Distance-Vector (AODV)

The Ad Hoc On-demand Distance Vector (AODV) [7, 12, 21-22, 25, 27-28] is a pure on-demand routing protocol by adapting the destination sequence number technique used by DSDV. Compared to DSDV network, AODV is more efficient for any network where its size may increase depending on the number of nodes. Being a reactive protocol, AODV only needs to maintain the routing information about the active paths. In AODV, whenever a source node wants to send packets to a destination node, the former initiates a route discovery operation if no route is available. In the route discovery operation, the source broadcasts route request (RREQ) packets, which include the addresses of source and destination nodes, broadcast ID (which is used as its identifier), last seen sequence number of the destination as well as source node's sequence number. This sequence number ensures loop-free and up-to-date routes in AODV. In AODV, each node maintains a cache to keep track of the RREQs it has received. In addition, the cache also stores the path that trace search RREQ originator. When the destination, or a node that has a route to the destination, receives the RREQ, it checks the destination sequence numbers it currently knows with lower destination sequence number that will be dropped. If a link break occurs in an active route, the node broadcasts a route error (RRER) packet to the source node. Then, the affected source can re-initiate a route discovery operation to find another route to the desired destination.

2.4 Dynamic Source Routing (DSR)

DSR [15] is a reactive unicast protocol based on source routing algorithm. Essentially, DSR does not use periodic advertisements as it calculates the routes deemed essential and then maintains these routes accordingly. In the source routing technique, each data packet contains complete routing information to reach its destination. There are two important stages in DSR: Route Discovery and Route Maintenance. When a source node wants to send a packet, it first searches for an entry in its route cache. If the route is available, the source node will include the routing information in the data packet before sending it. Otherwise, the source node will initiate a route discovery operation by broadcasting route request RREQ packets. Each RREQ packet is uniquely identified by the source address and request id (i.e., a unique number). On receiving the RREQ packet, an intermediary node checks its route cache. If the node does not have routing information for the requested destination, the route record field of the route request packet is appended to the node's own address. Then, the request packet is forwarded to its neighbors. A node processes a route request packet only if it has not detected the packet before and its address is not presented in the route record field. If the route request packet reaches the destination or an intermediate node has routing information to the destination, a route reply packet will be generated. When the route reply packet has been generated by the destination, the addresses of nodes that have been traversed by the route request packet will then be stored. Otherwise, the addresses of nodes that the route request packet has traversed will be concatenated with the route in the intermediate node's route cache, are stored in the route reply packet.

2.5 Zone Routing Protocol (ZRP)

ZRP [16, 29] divides the topology into zones and uses different routing protocols within and between the zones based on their weaknesses and strengths. Each node in ZRP has a predefined zone centered on itself. ZRP maintains a zone around each node that consists of all nodes within 'k' hops away from that node. Proactive routing is used within the zones, whereas reactive routing is used among zones. For data delivery, a check on the destination node is made whether this node exists within the zone or not.

If this node does exist, data will be sent immediately; otherwise, RREQ packet will be sent to border nodes. Border nodes will be searched within their own zones for destinations. If these nodes are found, each border node will send RREP on the reverse path. Otherwise, the address of this border node will be added to the packet, and then this node will forward the packet to its own border nodes. This process will continue until the packet reaches the destination or a node is within its destination zone. Path in the RREP packet is used for sending data to destination.

2.6 Temporally Ordered Routing Algorithm (TORA)

The Temporally Ordered Routing Algorithm (TORA), which is also deemed as reactive [8, 22-23] and proactive protocol [12], is a highly adaptive, efficient, and scalable distributed routing algorithm based on the concept of link. Thus, TORA is deemed suitable for highly dynamic, mobile multi hop wireless networks. Essentially, TORA is a source-initiated routing protocol where it finds multiple routes from a source node to a destination node. The main feature of TORA is that the control messages are localized to a very small set of nodes near the occurrence of a topological change.

To achieve this localization, the nodes have to maintain routing information about adjacent nodes. The protocol of TORA has three basic functions, namely Route Creation, Route Maintenance and Route Erasure. TORA has a unique feature of maintaining multiple routes to the destination so that topological changes do not require any reaction at all. More precisely, the protocol will react only when all routes to the destination are lost. In the event of network partitions, the protocol is able to detect the partition and erase all invalid routes. On the downside, however, TORA can suffer from unbounded worst-case convergence time for very stressful scenarios.

3.0 PERFORMANCE METRIC FOR EVALUATION

According to the Internet Engineering Task Force (IETF) MANET working group as in RFC 2501[30], routing protocols should be compared and evaluated in terms of both qualitative and quantitative metrics. The descriptions of both metrics are described below:

3.1 Qualitative Metrics

The following are the qualitative metrics list that can be used to evaluate the performance of any MANET routing protocols:

- Loop freedom

  This property refers to a situation where the packet transmission in a network is free from ‘looping’. It is vital for routing protocol to prevent a packet transmission from ‘looping’ to avoid waste of resources (i.e. energy, bandwidth) and processing time.

- Sleep mode

  This property refers to a situation where some nodes switch to ‘sleep mode’ and stop transmitting or receiving packets to save the energy source. However, the protocol should be able to operate smoothly, even though some nodes are in ‘sleep mode’ periods.

- Reactive behavior

  This property refers to the protocols that maintain and up-to-date its routing table on demand (only when requested), making routing information of the network available when it is needed.

- Proactive behavior

  This property refers to the protocols that periodically maintain and up-to-date its routing table, making routing information for the entire network available at all time.

- Unidirectional link support

  This property refers to the communication between nodes operating in one direction. It is desirable that the routing protocol should be able to support both unidirectional and bidirectional links.

- Multicasting

  This property is very important for applications that involve the transmission of real-time data in many nodes simultaneously (i.e., multimedia data transmission).

- Security

  This property ensures routing protocols can efficiently support security mechanisms to address vulnerabilities in MANET.

3.2 Quantitative Metrics

The following are the quantitative metrics list that can be used to evaluate the performance of any MANET routing protocols:

- Packet Delivery Ratio (PDR)

  PDR refers to the ratio of the total number of received data packets at the destination node over the total number of packets sent by the source node, which is expressed as follows:

$$PDR = \frac{Total\ Data\ Packets\ Received}{Total\ Data\ Packets\ Sent}$$

- Average end-to-end-delay

  This metric refers to the average time taken by a source node to deliver data packets to a destination node. The end-to-end delay includes all possible delays in the network caused by buffering during route discovery latency, retransmission delay by the intermediate nodes, processing delay, queuing delay, and propagation delay. This metric is important in delay sensitive applications such as video and voice transmission. The equation to calculate average end-to-end delay is as follows:

$$Avg\ EndtoEnd\ Delay = \frac{\sum(Time\ Received - Time\ Sent)}{Total\ Data\ Packets\ Received}$$

- Packet Loss Ratio

  Packet loss occurs when one or more packets being transmitted across the network fail to arrive at a destination. This loss may be due to path breaks or node failure. The equation to calculate Packet Loss Ratio is as follows:

$$Packet\ Loss\ Ratio = \frac{Number\ of\ packets\ not\ received}{Number\ of\ packets\ transmitted}$$

- Normalized routing

The normalized routing load is defined as the fraction of all routing control packets sent by all nodes over the number of received data packets at destination nodes, which indicates the efficiency of a routing protocol. Thus, a larger ratio indicates that a particular protocol is less efficient. In general, proactive protocols have a higher normalized routing load than reactive ones. The equation to calculate Normalized routing is as follows:

$$Normalized\ Routing\ Load = \frac{Total\ Routing\ Packets\ Sent}{Total\ Data\ Paackets\ Received}$$

- Normalized MAC Load

The normalized MAC load is defined as the fraction of all control packets (routing control packets, Clear-to-send, Request-to-send, Address resolution Protocol request and replies, and MAC ACKs) over the total number of received data packets. This is the metric for evaluating the effective utilization of a wireless medium for data traffic. The ratio of Normalized MAC Load is shown below:

$$Normalized\ MAC\ Load = \frac{Total\ Control\ Packets\ Sent}{Total\ Data\ Paackets\ Received}$$

4.0 COMPARATIVE ANALYSIS

The comparative analysis provided in this section is based on qualitative metrics. As indicated in Table 3, both OLSR and DSDV are from the same category – proactive protocol (table-driven protocol). These two protocols must maintain an up-to-date routing table at all time, making routing information for the entire network readily available. However, unlike OLSR, the routes updates of DSDV can be sent in two ways: full dump update (by sending a full routing table to neighbors) or incremental update (by sending only those entries that have changed since the last update, thus reducing the large amount of network traffic created by the updating process). Between the two protocols, OLSR has the unidirectional link support and sleep mode features. With ‘sleep mode’ feature, some nodes are able to operate even though other nodes are in ‘sleep mode’. However, both protocols do not have multicasting capability, which is important especially for the transmission of real-time data in many nodes at the same time.

For AODV and DSR, both fall under the reactive (on-demand) category. These protocols do not use periodic updates but only maintain the information about a network as needed. However, there is a marked distinction between the two protocols: AODV maintains routes in the route table, whereas DSR in the route cache. Unlike DSR and proactive protocols, multicast capability is available in AODV. Nonetheless, compared to DSR, AODV does not support unidirectional link. In contrast, hybrid protocols were designed to combine the advantages of both reactive and proactive protocols, depending on the prevailing situation of a current network. For example, ZRP works as a proactive protocol and a reactive protocol when handling communication within the same zones and between different zones, respectively. Despite the many variations of features, all protocols share some common attributes that guarantee loop-free paths, but not security in data transmission. The lack of security support in data transmission introduces many security vulnerabilities in MANET given that each node in a network is required to participate actively in a routing process. Table 3 summarizes the comparative analysis of OLSR, DSDV, AODV, DSR, ZRP and TORA. Clearly, each protocol has its own unique capabilities and drawbacks arising from its particular design as summarized in Table 4.

OLSR: OLSR is a flat routing protocol, which does not need a central administrative system to handle its routing process. The link is reliable for control messages as delivery of messages is periodic and non-sequential. This protocol is suitable for high-density network as long delay in the transmission of packets is not allowed. However, the inherent limitation of this protocol is that each node has to send updated topology information periodically throughout the entire network, thus increasing the bandwidth usage of the protocols. To minimize this flooding, MPRs are allowed to forward topological messages. Another downside of OLSR is that it must maintain information about unused routes, hence wasting possibly scarce resources. Given that OLSR must maintain a routing table for the entire network at all time, the demand for storage capacity increases, hence further depleting the battery power.

DSDV: The main advantage of DSDV is the use of the sequence number in DSDV to ensure the freshness of routing information available in a routing table. This protocol maintains only the best path or shortest path to every destination, hence reducing the amount of space in the routing table. It also avoids extra traffic by using incremental updates instead of full dump updates. The limitation of DSDV is that it produces a large amount of overhead resulting from periodic update messages, making this protocol ineffective in large networks. This ineffectiveness is due to needless advertising (as a requirement for periodic update messages) of a network topology that does not change, causing severe wastage of bandwidth. Furthermore, this protocol does not support multipath routing.

AODV: The main advantage of AODV protocol is that routes are established on demand and destination sequence numbers are used to find the latest route to a destination. In addition, AODV supports both unicast and multicast packet transmissions even for nodes in constant movements. Characteristically, AODV responds quickly to topological changes in a network and updates only the nodes that may be affected by the changes using RRER message. The Hello messages, which are responsible for the route maintenance, are also limited so that they do not create unnecessary overhead in the network. However, one of the limitations of AODV protocol is that all nodes in a broadcast medium can detect each other's broadcast. Moreover, it is also possible that a valid route may have expired and finding a reasonable expiry time is difficult. The reason for this constraint is that the nodes, being highly mobile, will have different sending rates. In addition, with increasing network size, other performances will decrease correspondingly. Thus, a route discovered by AODV may no longer be the optimal route over certain duration. This uncertainty can arise because of network congestion or fluctuating characteristics of wireless links.

DSR: The main advantage of DSR is the use of route cache, which reduces route discovery overheads. Essentially, DSR does not require any periodic beaconing or hello message exchanges. Furthermore, this protocol supports multipath routing and provides quick path recovery. Nonetheless, similar to AODV, DSR suffers from high route discovery latency, resulting in large packet header and long response time. These problems render DSR less effective in large networks as the amount of overhead carried in a packet will grow with increasing network diameter.

ZRP: The aim of this protocol is to combine the advantages of reactive and proactive routing protocols. With a properly configured zone radius, ZRP may outperform both proactive routing protocols and reactive routing protocols. However, the potential disadvantage of this protocol is that the path to a destination may be suboptimal when hierarchical routing is used. Furthermore, memory requirement of this protocol will be greater because each node has higher level topological information.

TORA: TORA brings in several advantages to the running and maintenance of MANETs. For examples, this protocol supports multiple routes between source and destination nodes. Therefore, failure or removal of any nodes is quickly resolved without a source intervention by switching to an alternate route to improve congestion. Another advantage is that it does not require a periodic update, thus minimizing communication overhead and bandwidth utilization. Other additional advantage is that it supports link status sensing and neighbor delivery, reliable in-order control packet delivery, and security authentication. On the downside, TORA has some limitations such as its dependence on synchronized clocks among nodes in an ad hoc network. The dependence of this protocol on intermediate lower layers of certain functionalities presumes that the link status sensing, neighbor discovery, in order packet delivery, and address resolution are all readily available. A solution to this problem involves running the Internet MANET Encapsulation Protocol at a layer immediately below TORA. Thus, the overhead of this protocol will be difficult to separate from that imposed by the lower layer.

From the above discussion, clearly, no single protocol can offer MANET the best solution – each protocol has its own merits. In other words, each protocol with its own unique features will perform effectively and efficiently under a particular network environment. As reviewed, OLSR is suitable for large, high-density networks in which long delays in the transmission of packets is not permitted. In contrast, DSDV is suitable for smaller, less dense networks. A large, dense network refers to a communication network that has a large number of nodes; whereas, a smaller, less dense network refers to a communication network that has a small number of nodes. On the one hand, OLSR is beneficial for traffic pattern involving communication of a large subset of nodes and constantly changing source-destination pairs. Meanwhile, AODV is a protocol that is appropriate for highly dynamic environments, and DSR is a preferred protocol for network environments having up to 200 communication nodes. Nonetheless, DSR is not very effective in large networks, as the amount of overhead carried in packets will continue to grow with increasing network diameter. Thus, for highly dynamic versatile network environments, ZRP and TORA are protocols that can provide reliable network services with greater efficiency.

Table 3 Summarization of Characteristic of Various MANET's Routing Protocols

Property	OLSR	DSDV	AODV	DSR	TORA	ZRP
Routing Category	Proactive	Proactive	Reactive	Reactive	Hybrid	Hybrid
Protocol Type	Link State	Distance Vector	Distance Vector	Source routing	Link Reversal	Link Reversal
Routes Maintained	Route Table	Route Table	Route Table	Route Cache	Route Table	Route Table
Routes updates	Periodically update	Periodically update	On demand update	On demand update	Both	Both
Loop-free	Yes	Yes	Yes	Yes	Yes	Yes
Multiple routes	No	No	No	Yes	Yes	Yes
Multicast routes	Yes	No	Yes	Yes	No	No
Multicast capability	No	No	Yes	No	No	No
Sleep mode	Yes	No	No	No	No	Partly
Security support	No	No	No	No	No	No
Unidirectional link support	Yes	No	No	Yes	No	Yes

Table 4 Advantages and Limitations of Different MANET's Routing Protocols

Protocols	Advantages	Limitations
OLSR	o Does not need central administrative system to handle its routing process o The link is reliable for the control messages, since the messages are sent periodically and the delivery does not have to be sequential o Suitable for high density network o Does not allow long delays in the transmission of the packets	o Require greater demand for storage capacity of nodes due to information about the entire network need to be maintained at all time o The control overhead adds to the necessary processing in each node, hence increasing the battery depletion o Must maintain information about routes that may never be used, hence wasting possibly scarce resources
DSDV	o Sequence number ensures the freshness of routing information available in the routing table o Avoids extra traffic by using incremental updates instead of full dump updates o Maintains only the best path or shortest path to every destination. Hence, amount of space in routing table is reduced	o Large amount of overhead due to the requirement of periodic update messages o It doesn't support multipath routing o Wastage of bandwidth due to needless advertising of routing information even if there is no change in the network topology
AODV	o Require less amount of storage space as compared to other reactive routing protocols since routing information which is not in used expires after a pre-specified expiration time o Can handle highly dynamic MANETs o Only information about active routes are stored at a node, hence reduces energy consumption o Support multicasting o Small routing table o Quick recovery	o Lacks an efficient route maintenance technique. The routing information is always obtained on demand. o AODV also suffers from high route discovery latency o More number of control overheads due to many route reply messages for single route request and long response time o Aggregate routing is not possible at intermediate nodes
DSR	o Reduction of route discovery overheads with the use of route cache o Supports multipath routing o Does not require any periodic beaconing or hello message exchanges o Quick path recovery	o Similar to AODV, DSR suffers from high route discovery latency o Not very effective in large networks, as the amount of overhead carried in the packet will continue to increase as the network diameter increases o Long response time and large packet header
TORA	o Failure or removal of any of the nodes is quickly resolved without source intervention o Not require a periodic update, hence communication overhead and bandwidth utilization is minimized o Reliable in-order control packet delivery and security authentication	o Depends on synchronized clocks among nodes in network o The dependence on intermediate lower layers for certain functionality produce overhead

Protocols	Advantages	Limitations
ZRP	o May outperform both proactive and reactive routing protocols.	o Path to a destination may be suboptimal o Require greater memory requirement

5.0 CONCLUSION

This paper provides a critical review based on a qualitative comparative analysis of several MANET routing protocols, which are broadly classified into proactive, reactive or hybrid protocols. Clearly, these protocols, such as OLSR, DSDV, AODV, DSR, ZRP and TORA, possess a diverse range of characteristics or capabilities that work best under a particular network environment. In essence, each protocol will be able to perform efficiently and effectively under a particular environment – a specific protocol provides an optimal solution for a particular network scenario. However, the same protocol may not be effective or efficient when applied in other network environments given the different requirements imposed by prevailing settings. In view of the wide spectrum of network characteristic (e.g., size, mobility, and configuration), none of the available protocols (i.e., table-driven, on-demand, and the mixture of the two protocols), can provide the best solution to all kind of networks. In other words, there is no "one-size-fits-all" solution to handle the diverse network environments.

Thus, deciding on which type of protocol to apply is not that straightforward as each protocol has its own advantages and disadvantages. For example, reactive protocols minimize control overheads and power consumption as routes will only be established when they are needed. Thus, AODV and DSR are suitable for highly dynamic network environment; whereas, DSR is a preferred protocol for network environments that can contain up to 200 communication nodes. However, the downside of these protocols is that a source node has to wait for a route to be discovered before communication can take place. Furthermore, the latency in route discovery might be intolerable for real time communications.

In contrast, proactive protocols incur unnecessary routing overheads because periodic route updates, which are necessary to keep information current and consistent, will include redundant routes. Hence, these protocols are not very effective in large networks due to high overhead. Despite this constraint, proactive routing protocols provide quality service as routing information is constantly updated to ensure a particular destination is always made available, and these protocols can minimize end-to-end delay. For this reason, proactive protocols, such as OLSR and DSDV, are suitable for congested networks, which typically involve heavy traffic. Between the two, OLSR performs better than DSDV for large scale networks. In contrast, hybrid protocols, such as ZRP and TORA, work exceptionally well for highly dynamic, versatile network environments as this type of protocols synergize the inherent capabilities of both reactive and proactive routing protocols. This synergy of capabilities makes hybrid protocols a better solution for network environments that entail reduced overhead and fast updating of network information.

Future work will involve an experimental study to compare and evaluate the performances of these protocols. Notably, the comparative evaluation will be carried out based on quantitative metrics, such as throughput, delay, and packet delivery ratio (PDR). In addition, the energy consumption and number of nodes alive will also be analyzed. The findings from the proposed experiment will provide greater insights of the impact of different characteristics of each protocol on the overall performance of an entire network. Moreover, the effects of contributing factors (e.g., the number of nodes, network size, mobility speed, and data transmission rate) on network performance will help practitioners and researchers to formulate better solutions for increasingly complex networks.

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