Behavioral Study of MANET Routing Protocols

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***Abstract*—Ad hoc wireless networks are characterized by multihop wireless connectivity, infrastructureless environment and frequently changing topology. As the wireless links are highly error prone and can go down frequently due to mobility of nodes, therefore, stable routing is a very critical task due to highly dynamic environment in adhoc wireless networks. In this paper, behavioral study of different MANET routing protocols viz. Optimized Link State Routing (OLSR), Destination Sequenced Distance vector (DSDV), Dynamic Source Routing (DSR), Adhoc On-demand Distance Vector (AODV) and Temporary Ordered Routing Protocol (TORA) protocols, have been carried out so as to identify which protocol is most suitable for efficient routing over Mobile Adhoc NETwork (MANET). The identification of stable and efficient routing protocol plays a very critical role in places where wired network are neither available nor economical to deploy. This paper provides an overview of these routing protocols by presenting their overview and then makes their comparative analysis so to analyze their performance. The study will be helpful in identifying which protocol is best suitable for MANET and how the performance of that protocol can be further improved. In future MANET's, denser mediums will be used with increasing number of applications, therefore, the study will be of great interest to researchers in getting an idea about which protocol to consider under sparse/denser medium environments for efficient and stable routing.**

***Index Terms*—Adhoc Network, AODV, DSDV, DSR, MANET, OLSR, TORA**

I. Introduction

Wireless network [1] is a network without connecting cables. It is generally implemented and administered using a transmission system called radio waves. It can be classified into two types: Infrastructured or Infrastructure less. In Infrastructured wireless networks, the mobile node can move while communicating, the base stations are fixed and as the node goes out of the range of a base station, it gets into the range of another base station. In Infrastructureless or Adhoc wireless network, the mobile node can move while communicating, there are no fixed base stations and all the nodes in the network act as routers. The mobile nodes in the Adhoc network dynamically establish routing among themselves to form their own network 'on the fly'.

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II. MANET and Protocol Stack

MANET [1] is a collection of wireless mobile nodes forming a temporary/short-lived network without any fixed infrastructure where all nodes are free to move about arbitrarily and where all the nodes configure themselves. In MANET each node acts both as a router and as a host & even the topology of network may also change rapidly. Some of the key challenges in MANET include:

1) Efficient and Stable routing
2) Dynamic topology
3) Network Scalability
4) Network overhead
5) Quality of Service
6) Power Management
7) Security

In this section, the protocol stack [7] for mobile ad hoc networks is shown with respect to TCP/IP and OSI Model. Table 1 shows the protocol stack for MANET which consists of five layers: physical layer, data link layer, network layer, transport layer and application layer. On the right, OSI model is shown. It is a layered framework for the design of network systems that allows for communication across all types of computer systems. In the middle, the TCP/IP model is illustrated. The lower four layers are the same but the fifth layer in the TCP/IP model i.e. the application layer is equivalent to the combined session, presentation and application layers of the OSI model. On the left, the MANET protocol stack is shown which is somewhat similar to the TCP/IP model. The main difference between these two protocols stacks lies in the network layer. Mobile nodes, which can be host or router in MANET, use an ad hoc routing protocol to route packets. The network layer in MANET is divided into two parts: Network and Adhoc Routing. The protocol used in the network part is Internet Protocol (IP) and the protocols which can be used in the adhoc routing part are OLSR [6, 10], DSDV [4, 7], DSR [5, 7], AODV [1, 3] or TORA [9, 10]. This paper focuses on adhoc routing protocols which is handled by the network layer.

III. Routing Protocols

A routing protocol is needed whenever a packet needs to be transmitted to a destination via number of nodes and numerous routing protocols have been proposed for such kind of adhoc networks. The behavioral study on various aspects of routing protocols has been an active area of research for many years. The routing protocols can be broadly classified into two categories:

1) Table driven routing protocols
2) On-demand routing protocols

TABLE 1: MODELS

MANET Model		TCP/IP Model	OSI Model
Application Layer		Application Layer	Application Layer
			Presentation Layer
			Session Layer
Transport Layer		Transport Layer	Transport Layer
Network Layer	Adhoc routing	Network Layer	Network Layer
Data Link Layer		Data Link Layer	Data Link Layer
Physical Layer		Physical Layer	Physical Layer

TABLE 2: COMPARISON OF TABLE DRIVEN ROUTING PROTOCOLS ON THE BASIS OF QUALITATIVE METRICS

Qualitative Metric	OLSR	DSDV
Loop free	Y	Y
Unidirectional/Bidirectional links	Y, support both links	Support only bidirectional links
Sleep mode	Y	N
Multicasting	N	N
Routing scheme	Flat	Flat
Nodes with special tasks	Y	N
Routing metric	Shortest distance	Shortest distance
Security	N	Y
Nature	Proactive	Proactive

TABLE 3: COMPARISON OF REACTIVE PROTOCOLS ON THE BASIS OF QUALITATIVE METRICS

Qualitative Metric	DSR	AODV	TORA
Loop free	Y	Y	Y
Unidirectional/Bidirectional links	Y, support both links	Support only bidirectional links	Support only bidirectional links
Sleep mode	N	N	N
Multicasting	N	Y	N
Routing scheme	Flat	Flat	Flat
Nodes with special tasks	N	N	N
Routing metric	Shortest path	Shortest path	Shortest path
Security	N	N	N
Multiple routes	Y	N	N
Type	Source Routing	Distance Vector	Link Reversal
Message Overhead	High	High	Low
Nature	Reactive	Reactive	Reactive

In Table Driven routing protocols each node maintains one or more tables containing routing information to every other node in the network. All nodes keep on updating these tables to maintain latest view of the network. Some of the existing table driven protocols are: OLSR [6, 10], DSDV [4, 7] etc.

In On-demand routing protocols, routes are created as and when required. When a transmission occurs from source to destination, it invokes the route discovery procedure. The route remains valid till destination is achieved or until the route is no longer needed. Some of the prominent on demand routing protocols are: DSR [5, 7], AODV [1, 3] and TORA [9, 10].

The emphasis in this paper is concentrated on the behavioral study of various aspects of OLSR, DSDV, DSR, AODV and TORA.

A. OLSR [6, 10]

It is a proactive link-state routing protocol optimized for mobile ad-hoc networks, which can also be used on other wireless ad-hoc networks. It uses Hello and Topology Control (TC) messages to discover and then disseminate link state information throughout the aforementioned network. Individual nodes use this information to compute next hop destinations for all nodes in the network. This is done using shortest hop forwarding paths. This protocol is basically based on the link state algorithm and it has been modified and optimized to efficient routing over mobile adhoc network. This protocol adapt according to the changes of the network without creating control messages overhead due to the protocol flooding nature. Link-state routing protocols such as OSPF and IS-IS elect a designated router on every link to perform flooding of topology information. In wireless ad-hoc networks, there is different notion of a link, packets can and do go out the same interface; hence, a different approach is needed in order to optimize the flooding process. Using Hello messages, the OLSR protocol at each node discovers 2-hop neighbor information and performs a distributed election of a set of multipoint relays (MPRs). Nodes select MPRs such that there is a path to each of its 2-hop neighbors via a node selected as an MPR. These MPR nodes then source and forward TC messages that contain the MPR selectors. This functioning of MPRs makes OLSR unique from other link state routing protocols in a few different ways: The forwarding path for TC messages is not shared among all nodes but varies depending on the source, only a subset of nodes source link state information, not all links of a node are advertised but only those that represent MPR selections. Since link-state routing requires the topology database to be synchronized across the network, OSPF and IS-IS perform topology flooding using a reliable algorithm. Such an algorithm is very difficult to design for ad-hoc wireless networks, so OLSR doesn't bother with reliability; it simply floods topology data often enough to make sure that the database does not remain unsynchronized for extended periods of time.

B. DSDV [4, 7]

It is a table-driven routing scheme for ad hoc mobile networks based on the Bellman-Ford algorithm. It was developed by C. Perkins and P. Bhagwat in 1994. The main contribution of the algorithm was to solve the routing loop problem. Each node maintains a list of all destinations and number of hops to each destination. Each entry in the routing table contains a sequence number, the sequence numbers are generally even if a link is present; else, an odd number is used. The number is generated by the destination, and the emitter needs to send out the next update with this number. Routing information is distributed between nodes by sending full dumps infrequently and smaller incremental updates more frequently. The broadcast of route updates is delayed by settling time. The only improvement made here is avoidance of routing loops in a mobile network of routers. With this improvement, routing information can always be readily available, regardless of whether the source node requires the information or not. In DSDV, a sequence number is linked to a destination node, and usually is originated by that node (the owner). The only case that a non-owner node updates a sequence number of a route is when it detects a link break on that route. An owner node always uses even-numbers as sequence numbers, and a non-owner node always uses odd-numbers. With the addition of sequence numbers, routes for the same destination are selected as under:

1) A route with a newer sequence number is preferred.
2) In case two routes have a same sequence number, the one with a better cost metric is preferred.

The list which is maintained is called routing table. The routing table contains all available destinations' IP address, next hop IP address, number of hops to reach the destination, sequence number assigned by the destination node and install time. The sequence number is used to distinguish stale routes from new ones and thus avoid the formation of loops. The stations periodically transmit their routing tables to their immediate neighbors. A station also transmits its routing table if a significant change has occurred in its table from the last update sent. So, the update is both time-driven and event-driven. As stated above one of "full dump" or an incremental update is used to send routing table updates for reducing network traffic. A full dump sends the full routing table to the neighbors and could span many packets whereas in an incremental update only those entries from the routing table are sent that has a metric change since the last update and it must fit in a packet. If there is space in the incremental update packet then those entries may be included whose sequence number has changed. When the network is relatively stable, incremental updates are sent to avoid extra traffic and full dump are relatively infrequent. In a fast-changing network, incremental packets can grow big so full dumps will be more frequent. Each route update packet, in addition to the routing table information, also contains a unique sequence number assigned by the transmitter. The route labeled with the highest (i.e. most recent) sequence number is used. If two routes have the same sequence number then the route with the best metric (i.e. shortest route) is used. Based on the past history, the stations estimate the settling time of routes. The stations delay the transmission of a routing update by settling time so as to eliminate those updates that would occur if a better route were found very soon. Each row of the update send is of the following form:

<Dest. IP Address, Dest. Sequence Number, Hop Count>

After receiving an update neighboring nodes utilizes it to compute the routing table entries. To damp the routing fluctuations due to unsynchronized nature of periodic updates, routing updates for a given destination can propagate along different paths at different rates. To prevent a node from announcing a routing path change for a given destination while another better update for that destination is still in route, DSDV requires node to wait a settling time before announcing a new route with higher metric for a destination.

C. DSR [5, 7]

It is an Adhoc routing protocol which is based on the theory of source-based routing rather than table-based. This protocol is source-initiated rather than hop-by-hop. It is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. DSR allows the network to be completely self-organizing and self-configuring, without the need for any existing network infrastructure or administration. Dynamic Source Routing, DSR, is a reactive routing protocol that uses source routing to send packets. It uses source routing which means that the source must know the complete hop sequence to the destination. Each node maintains a route cache, where all routes it knows are stored. The route discovery process is initiated only if the desired route cannot be found in the route cache. To limit the number of route requests propagated, a node processes the route request message only if it has not already received the message and its address is not present in the route record of the message. As mentioned before, DSR uses source routing, i.e. the source determines the complete sequence of hops that each packet should traverse. This requires that the sequence of hops is included in each packet's header. A negative consequence of this is the routing overhead every packet has to carry. However, one big advantage is that intermediate nodes can learn routes from the source routes in the packets they receive. Since finding a route is generally a costly operation in terms of time, bandwidth and energy, this is a strong argument for using source routing. Another advantage of source routing is that it avoids the need for up-to-date routing information in the intermediate nodes through which the packets are forwarded since all necessary routing information is included in the packets. Finally, it avoids routing loops easily because the complete route is determined by a single node instead of making the decision hop-by-hop. The protocol is composed of the two main mechanisms of "Route Discovery" and "Route Maintenance", which work together to allow nodes to discover and maintain routes to arbitrary destinations in the ad hoc network. All aspects of the protocol operate entirely on demand, allowing the routing packet overhead of DSR to scale automatically to only what is needed to react to changes in the routes currently in use. The protocol allows multiple routes to any destination and allows each sender to select and control the routes used in routing its packets, for example, for use in load balancing or for increased robustness.

4) Route Discovery

Route Discovery is used whenever a source node desires a route to a destination node. First, the source node looks up its route cache to determine if it already contains a route to the destination. If the source finds a valid route to the destination, it uses this route to send its data packets. If the node does not have a valid route to the destination, it initiates the route discovery process by broadcasting a route request message. The route request message contains the address of the source and the destination, and a unique identification number. An intermediate node that receives a route request message searches its route cache for a route to the destination. If no route is found, it appends its address to the route record of the message and forwards the message to its neighbors. The message propagates through the network until it reaches either the destination or an intermediate node with a route to the destination. Then a route reply message, containing the proper hop sequence for reaching the destination, is generated and unicast back to the source node.

5) Route maintenance

Route Maintenance is used to handle route breaks. When a node encounters a fatal transmission problem at its data link layer, it removes the route from its route cache and generates a route error message. The route error message is sent to each node that has sent a packet routed over the broken link. When a node receives a route error message, it removes the hop in error from its route cache. Acknowledgment messages are used to verify the correct operation of the route links. In wireless networks acknowledgments are often provided as e.g. an existing standard part of the MAC protocol in use, such as the link-layer acknowledgment frame defined by IEEE 802.11. If a built-in acknowledgment mechanism is not available, the node transmitting the message can explicitly request a DSR-specific software acknowledgment to be returned by the next node along the route.

D. ADOV [1, 3]

It is a variation of Destination-Sequenced Distance-Vector (DSDV) routing protocol which is collectively based on DSDV and DSR. It aims to minimize the requirement of system-wide broadcasts to its extreme. It does not maintain routes from every node to every other node in the network rather they are discovered as and when needed & are maintained only as long as they are required. The establishment of unicast routes by AODV is explained as under:

1) Route Discovery

When a node wants to send a data packet to a destination node, the entries in route table are checked to ensure whether there is a current route to that destination node or not. If it is there, the data packet is forwarded to the appropriate next hop toward the destination. If it is not there, the route discovery process is initiated. AODV initiates a route discovery process using Route Request (RREQ) and Route Reply (RREP). The source node will create a RREQ packet containing its IP address, its current sequence number, the destination's IP address, the destination's last sequence number and broadcast ID. The broadcast ID is incremented each time the source node initiates RREQ. Basically, the sequence numbers are used to determine the timeliness of each data packet and the broadcast ID & the IP address together form a unique identifier for RREQ so as to uniquely identify each request. The requests are sent using RREQ message and the information in connection with creation of a route is sent back in RREP message. The source node broadcasts the RREQ packet to its neighbours and then sets a timer to wait for a reply. To process the RREQ, the node sets up a reverse route entry for the source node in its route table. This helps to know how to forward a RREP to the source. Basically a lifetime is associated with the reverse route entry and if this entry is not used within this lifetime, the route information is deleted. If the RREQ is lost during transmission, the source node is allowed to broadcast again using route discovery mechanism.

2) Expanding Ring Search Technique

The source node broadcasts the RREQ packet to its neighbours which in turn forwards the same to their neighbours and so forth. Especially, in case of large network, there is a need to control network-wide broadcasts of RREQ and to control the same; the source node uses an expanding ring search technique. In this technique, the source node sets the Time to Live (TTL) value of the RREQ to an initial start value. If there is no reply within the discovery period, the next RREQ is broadcasted with a TTL value increased by an increment value. The process of incrementing TTL value continues until a threshold value is reached, after which the RREQ is broadcasted across the entire network.

3) Setting up of Forward Path

When the destination node or an intermediate node with a route to the destination receives the RREQ, it creates the RREP and unicast the same towards the source node using the node from which it received the RREQ as the next hop. When RREP is routed back along the reverse path and received by an intermediate node, it sets up a forward path entry to the destination in its routing table. When the RREP reaches the source node, it means a route from source to the destination has been established and the source node can begin the data transmission.

4) Route Maintenance

A route discovered between a source node and destination node is maintained as long as needed by the source node. Since there is movement of nodes in mobile adhoc network and if the source node moves during an active session, it can reinitiate route discovery mechanism to establish a new route to destination. Conversely, if the destination node or some intermediate node moves, the node upstream of the break initiates Route Error (RERR) message to the affected active upstream neighbors/nodes. Consequently, these nodes propagate the RERR to their predecessor nodes. This process continues until the source node is reached. When RERR is received by the source node, it can either stop sending the data or reinitiate the route discovery mechanism by sending a new RREQ message if the route is still required.

E. TORA [9, 10]

It is a distributed highly adaptive routing protocol designed to operate in a dynamic multihop network that is based on the link reversal algorithm. The main concept of this protocol is that the network for any source node can be "visualized" as a Directed Acyclic Graph (DAG) rooted at the destination node. When a link between the source and the destination fails, the nodes reverse the direction of the links and update the previous nodes in the path. Additionally, each node maintains multiple paths to a given destination and is capable of detecting any partitions in the network. To accomplish such behavior, a value, "height," is associated with each node at all times. These values can be ordered in comparison to the "height" of each neighboring node. Data flow occurs from a node with a higher value to a node with a lower value. When a node cannot detect the height value of one of its neighbors, it does not forward data packets to that node. TORA disseminates control messages in a small local area, not in the entire network, thus preserving bandwidth and minimizing processing time in the nodes. When a link failure occurs, there is no need for a large-scaled dissemination of control packets, as they can be limited to the small region where the link failure occurs. TORA requires bidirectional links between the nodes in the network and synchronization from an internal or external mechanism, e.g., Global Positioning System (GPS). The protocol is loop-free, as the route formation is based on the DAG that is a loop-free data structure, and supports only unicasting routing. TORA has four basic functions: route discovery, route maintenance, route erasing, and route optimization. Finally, TORA is not a self-operating protocol, but requires the existence of the Internet MANET Encapsulation Protocol (IMEP) as the underlying network layer protocol. TORA uses an arbitrary height parameter to determine the direction of link between any two nodes for a given destination. Consequently, multiple routes often exist for a given destination but none of them are necessarily the shortest route. To initiate a route, the node broadcasts a QUERY packet to its neighbors. This QUERY is rebroadcasted through the network until it reaches the destination or an intermediate node that has a route to the destination. The recipient of the QUERY packet then broadcasts the UPDATE packet which lists its height with respect to the destination. When this packet propagates in the network, each node that receives the UPDATE packet sets its height to a value greater than the height of the neighbour from which the UPDATE was received. This has the effect of creating a series of directed links from the original sender of the QUERY packet to the node that initially generated the UPDATE packet. When it was discovered by a node that the route to a destination is no longer valid, it will adjust its height so that it will be a local maximum with respect to its neighbours and then transmits an UPDATE packet. If the node has no neighbors of finite height with respect to the destination, then the node will attempt to discover a new route as described above. When a node detects a network partition, it will generate a CLEAR packet that results in reset of routing over the adhoc network.

IV. Performance Metrics

The Internet Engineering Task Force MANET working group suggests two different types of metrics for evaluating the performance of routing protocols of MANETs. In accordance with RFC 2501, routing protocols should be evaluated in terms of both quantitative metrics and qualitative metrics. These metrics should be independent of any given routing protocol.

A. Quantitative Metrics [6]

The following is a list of quantitative metrics that can be used to assess the performance of any routing protocol.

a) *Packet Delivery Ratio:* The packet delivery fraction is defined as the ratio of number of data packets received at the destinations over the number of data packets sent by the sources. In other words, fraction of successfully received packets, which survive while finding their destination, is called as packet delivery ratio.

b) *Average End-to-End Delay:* This is the average time involved in delivery of data packets from the source node to the destination node. In other words, it is the average amount of time taken by a packet to go from source to destination. The end-to-end delay includes all possible delays in the network caused by route discovery latency, retransmission by the intermediate nodes, processing delay, queuing delay and propagation delay. To compute the average end-to-end delay, add every delay for each successful data packet delivery and divide that sum by the number of successfully received data packets.

c) *Packet Loss:* Packet loss occurs when one or more packets being transmitted across the network fail to arrive at the destination. It may be due to path breaks caused by the mobility of nodes and node failure due to a drained battery. It is defined as the number of packets dropped by the routers during transmission.

d) *Normalized Routing Load:* 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 the destination nodes. In other words, it is the ratio between the total numbers of routing packets sent over the network to the total number of data packets received.

B. Qualitative Metrics [6]

The following is a list of desirable qualitative properties of MANET routing protocols:

a) *Loop Freedom:* This refers mainly, but not only, to all protocols that calculate routing information based on the Bellman-Ford algorithm. In a wireless environment with limited bandwidth, interference from neighboring nodes' transmissions and a high probability of packet collisions, it is essential to prevent a packet from "looping" in the network and thus consuming both processing time and bandwidth.

b) *On-Demand Routing Behavior:* Due to bandwidth limitations in the wireless network, on-demand, or reactive-based, routing minimizes the dissemination of control packets in the network, increases the available bandwidth for user data, and conserves the energy resources of the mobile nodes. Reactive routing protocols introduce a medium to high latency.

c) *Proactive Behavior:* Proactive behavior is preferable when low latency is the main concern and where bandwidth and energy resources permit such behavior. Mobile nodes in vehicular platforms do not face energy limitations.

d) *Security:* The wireless environments, along with the nature of the routing protocols in MANETs, which require each node to participate actively in the routing process, introduce many security vulnerabilities. Therefore, routing protocols should efficiently support security mechanisms to address these vulnerabilities.

e) *Unidirectional Link Support:* Nodes in the wireless environment may be able to communicate only through unidirectional links. It is preferable that routing protocols be able to support both unidirectional and bidirectional links.

f) *Sleep mode:* In general, nodes in a MANET use batteries for their energy source. The protocol should be able to operate, even though some nodes are in "sleep mode" for short periods, without any adverse consequences in the protocol's performance.

V. Results

An effort has been made to perform simulation over NS 2 and developing a self created network scenario using TCL. The results are summarized [1, 6, 7, 8] as under:

A. Comparison of routing protocols on the basis of quantitative metrics

The results of the simulation over NS-2 indicate that performance of the DSR protocol is superior to that of DSDV. The PDR for DSDV and DSR is always greater than 92 percent. The basic difference between these two protocols is very less but generally the PDR given by DSR protocol is more than that given by DSDV for most of the cases. The average end-to-end delay is less for DSDV protocol in comparison to that given by the DSR protocol. AODV performance depended on the mobility of nodes. Under low mobility, AODV has a lower packet delivery ratio, higher normalized routing and a higher end-to-end delay than DSR. In networks with a small number of nodes and low mobility, AODV does not suggest a good solution as a routing protocol. However, AODV has better performance in networks with higher mobility and a greater number of nodes. Basically, AODV is the proper efficient routing protocol for any kind of network application with high mobility that consists of up to 80 or more nodes. However, DSR performance decreases in networks with higher mobility, disclosing that source routing cannot efficiently adapt the network topology changes that are caused by the frequent movement of the mobile nodes. The same set of observations was obtained when comparing DSR performance in networks with an increasing number of nodes. Under this scenario, DSR presents lower performance than AODV in terms of the packet delivery ratio and end-to-end delay. To summarize, it is concluded that DSR is a good candidate as the routing protocol in networks with small number of nodes and low mobility. The AODV performed particularly well, delivering PDR as 87% to 100% regardless of mobility rate. But AODV fails when the node density increases. OLSR shows consistent performance. The average end to end delay of packet delivery was higher in OLSR as compared to AODV. AODV demonstrates significantly lower routing load than OLSR. The AODV protocol performs better in the networks with static traffic than OLSR. The OLSR protocol is more efficient in networks with high density and highly sporadic traffic.

B. Comparison of table driven routing protocols on the basis of qualitative metrics

The proactive protocols OLSR and DSDV are loop-free. OSLR, as a modification of the link state algorithm, does not introduce any loops into the routing process, except for oscillations when the link costs depend on the amount of traffic carried by the link. In the MANET scheme, however, link cost depends on the number of hops from a source to a destination, thus avoiding oscillations. DSDV solves the pathologies that the Distance Vector algorithm introduces, by the use of destination sequence numbers. The proactive behavior of these protocols is guaranteed by the periodic exchange of control messages. At any given time, every node has at least one route to any possible destination in the network. We say "possible destination" because the physical existence of a node in the network does not necessarily mean that the node is active or that a route to the node exists, because the node may be out of the transmitting range of all other nodes in the network. None of the above protocols addresses the security vulnerabilities that are obvious in wireless networks. The proper function of these protocols is based on an assumption that all the nodes exist and operate in a secure environment where link-and physical-Layer security mechanisms are in place. However, DSDV is more secure than OLSR, as OLSR functionality is based on the proper behavior of the MPRs. DSDV do not support unidirectional links. However, in wireless communication, unidirectional links will exist and should be supported to take advantage of any possible paths from a source node to a destination node. In MANETs, especially, there is no such "luxury" as ignoring any possible paths, as routing protocols should take advantage of any link to calculate routes in the network. OLSR designers take into account these limitations of the wireless network and support both bidirectional and unidirectional links. As for the "sleep mode" operation, only OLSR considers some extensions in its current existing design to support such an operation. In a wireless ad-hoc network, in which nodes depend mainly on batteries for their energy source, the sleep mode is a serious attribute that should be supported by any routing protocol. Multicasting is not considered by any of the above protocols. In real situations in tactical communications, data will be destined to a group of nodes, rather than to an individual node. Unicasting will decrease the bandwidth available for user data when the same message has to be delivered to multiple nodes. There is a flat routing philosophy of DSDV and OLSR. Table 1 summarizes the performance of the above protocols:

C. Comparison of on-demand routing protocols on the basis of qualitative metrics

The reactive protocols DSR, AODV and TORA are loop-free. None addresses security vulnerabilities that exist in a wireless ad-hoc network. However, there are certain proposals for providing secure routing at Layer 3 for all the above protocols. Although security is a major concern in military communications, we find that the proposed security mechanisms will increase processing time, power consumption, and latency. Note that reactive routing protocols already suffer from high latency in the network. Only DSR in its current state, without any modification, can support both bidirectional and unidirectional links. However, DSR will introduce high routing overhead as routing information is stored at the data packets' header. Thus, DSR will not scale well in large networks if communicating nodes are located at opposite edges of the network. None of the three protocols supports the "sleep mode," another important factor for power preservation, especially in battery-powered mobile nodes. TORA seems to be a more power-effective protocol, as it localizes most of its function in a small area, not in the entire network. However, the exchange of HELO messages by the underlying IMEP protocol will introduce power consumption. AODV will consume more power than DSR due to the exchange of periodic HELO messages. Only AODV supports multicasting, another important attribute of a routing protocol. None of these protocols depends on any kind of node with special or crucial tasks. All nodes in the network have the same tasks and play the same role in the routing process. This is important, because the lack of "critical" nodes guarantees the inexistence of any single point of failure in the network. TORA does not necessarily find the shortest path between a source/destination pair, as data flows form nodes with higher height to nodes with lower height. Table 3 summarizes the performance of the above protocols based on qualitative metrics. Finally, we suggest that AODV and DSR would be good candidates for the routing protocol in tactical mobile ad-hoc wireless networks. Therefore, we choose both AODV and DSR for further evaluation in our simulation.

VI. Conclusion and Future Scope

In this research paper, an effort has been made to concentrate on the behavioral study and performance analysis of various prominent routing protocols viz. DSDV, DSR, AODV and TORA on the basis of quantitative and qualitative metrics. Based on the performance analysis, recommendations have been made about the significance of either protocol under different circumstances and the analysis concludes that both protocols are good in performance in their own categories. Moreover, due to the dynamically changing topology and infrastructure less property, secure and power aware routing is hard to achieve in mobile adhoc networks. An attempt will be made to cope up these issues in our future research work by proposing a solution for secure and power aware routing.

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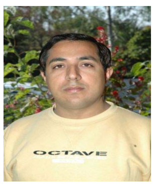

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