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RESEARCH

Performance evaluation of proactive, reactive, and hybrid routing protocols for small, medium, and large mobile *ad hoc* networks

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The popularity of wireless *ad hoc* networks is increasing daily. Examples of such networks are MANETs, VANETs, and Sensor networks. These types of wireless networks are dynamic and have different working features in common, and it is not always obvious to know which network type should be used given the needs of users. Determining the best protocols for a particular sort of wireless network's problems is frequently another challenge. We evaluate the above-mentioned networks to fill this gap and ultimately demonstrate that MANET is the best option since it can be easily deployed anywhere, at any time, to meet the needs of the majority of users. For evaluation purposes, we used prominent network evaluation parameter metrics, i.e., End-to-end Delay, Network Throughput, and Packet delivery ratio. We compare three different MANET routing protocol types—PROACTIVE, REACTIVE, and HYBRID—one from each type; DSDV [Proactive], TORA [Hybrid], and AODV [Reactive]. The simulations and their results for both small and large systems were done on the OPNET simulator. According to MANET, DSDV outperforms other protocols in networks with high node densities in terms of the same metrics, while TORA performs better in networks with low node densities in terms of packet delivery ratio, end-to-end delay, and throughput.

Keywords: evaluation metrics, mobile *ad hoc* networks, network size, performance evaluation, routing protocols, simulation

1. Introduction

Wireless networks are any form of computer networks with topologies that are not dependent on any kind of pre-existing infrastructure. This type of wireless network is decentralized, as opposed to access points and routers, which are commonly utilized in centralized wireless networks. Wireless *ad hoc* networks can be categorized into three groups based on the application they are intended for: VANET, MANET, and SENSOR networks.

A wireless network made up of moving nodes that has the capacity to spontaneously self-organize into a fleeting, incredibly dynamic, and infrastructure-free network (1) is the first type of *ad hoc* network. Monitoring of environmental and physical conditions is possible through the deployment of autonomous and distributed sensors in a wireless sensor network (2). A VANET (3) is a network that connects mobile nodes, such as cars and other vehicles, that are placed within 100 to 300 meters of one another. As a result, a network with a wide coverage is created. This type of network is frequently used in communication technology where each node is linked to one or more sensors.

Although each of these networks uses a little different approach and performs at a slightly different level, they all aim to provide mobile users with services without the need for cable connections. Various studies (4) have revealed that mobile *ad hoc* networks provide various benefits over other wireless networks. A self-organizing network can be built anywhere, at any time, and it offers robustness, increased flexibility, and reduced communication costs.

Hybrid routing protocols are the best routing protocols as they combine the best features of proactive and reactive protocols and this study primarily focuses on mobile *ad hoc* networks especially on this type of routing protocols.

We thoroughly evaluate the effectiveness of various MANET routing protocols, including Proactive, Reactive, and Hybrid. The three popular routing protocols AODV [Reactive], DSDV [Proactive], and TORA [Hybrid] are the core subject of our final discussion.

The remainder of this paper is divided into the following sections: The relevant work is covered in Section II. Chapter III provides a summary of the routing protocols used in the performance evaluation. Section IV provides the materials and methodology as well as the simulation details. In Section V, the results and discussions are reviewed, and in Section VI, the conclusion is provided.

2. Related works

Rakesh Kumar Jha et al. (1), in their paper, reported coincidental routing of the DSR and TORA routing algorithms in a network that they analyzed for security issues. The two categories of node workstations were those with proxies-enabled and those without. In both cases—without and with security—they found that TORA is more appropriate for configurations with 50 fixed node workstations. Once the proxy is enabled, the network exhibits the same behavior, supporting their conclusion that TORA routing is appropriate in a proxy-enabled environment. Proxy usage, however, has a substantial impact on DSR routing.

Ad hoc networking is the key development in fourth-generation wireless technology, according to Pravin Ghosekar et al. (2), who discussed it. It is a strong candidate to displace mobile phones as the *de facto* standard for personal ubiquitous communication due to its inherent flexibility, ease of preservation, absence of infrastructure requirement, auto-configuration, self-administration capabilities, and significant cost advantages. *Ad hoc* networks hold enormous potential, and this is beginning to be understood by both the scientific community and business. They emphasized that any outstanding technical and financial difficulties must be properly resolved in order to take advantage of this opportunity. The potential of MANET technology can only be fully exploited in this way.

The research by Dhenakaran et al. focused mostly on routing algorithms (3), which they saw as the most challenging problem given the changing topology of unplanned networks. They claimed that there were a number of pre-planned, cost-effective routes that would yield more favorable outcomes. They compared and summarized various routing protocols that have been previously proposed.

The Vehicular *Ad hoc* Network (VANET) topology-based routing attacks were thoroughly examined by Khandelwal et al. (4). They claimed that to accomplish this, one must employ special VANET communication techniques. They looked at vehicle-to-vehicle communication as well and found that drivers can exchange important traffic data with one another or with infrastructure on the side of the road, like details on dangerous road conditions and accident locations.

They also discovered that a greater understanding of traffic conditions can aid in addressing the issue of accidents. Vehicle communications can also be useful for traffic control and observation. Several automobile *ad hoc* network attacks were their main emphasis. Their research could help create privacy-preserving technologies or provide an overview of those now in use.

3. Types of routing protocols in MANET

3.1 Categories of routing protocols

For MANET, a number of routing protocols have been developed and are in use. Protocols that are proactive, reactive, and hybrid can all be combined. In addition to taking into account the nodes to which packets are not to be broadcast, proactive routing protocols (3) maintain routes between each participating node and every other node in the networks.

They achieve this by keeping up-to-date routing tables which are stored at each node and contain details about the network structure. Both the link-state and distance-vector methods are applied. Routing protocols are reactive (4) in that they don't keep track of the network topology; instead, a path is found as it is required. The properties of reactive and proactive protocols are combined in hybrid protocols (5).

Utilizing network metrics such as routing structure, periodic updates, control overhead, routing acquisition, delay, bandwidth requirement, and power requirements, we assessed the performance of the three routing protocols in order to demonstrate the advantages of hybrid routing protocols over proactive and reactive protocols. The findings are shown in **Table 1**.

Table 1 shows that the hybrid protocol is the most effective. Because Hybrid protocol is the only protocol with all the best characteristics set at a medium level and never low. It is the protocol that also features a flat organizational structure, frequent updates, and minimal bandwidth and power requirements (6).

TABLE 1 | Comparative Evaluation of three Types of Routing Protocols in MANETs.

Protocols	Routing Structure	Periodic Updates	Control Overhead	Routing Acquisition Delay	Bandwidth requirement	Power Requirements
Proactive	Both Flat and hierarchical structures	Yes, some may use Conditional Updates	High	Low	High	High
Reactive	Mostly Flat, Except for CBRP	Some nodes may require Periodic beacons.	Low	High	Low	Low
Hybrid	Flat	Yes	Medium	Lower for Intra-zone; Higher for Inter-zone	Medium	Medium

3.2. Popular routing protocols for each category

3.2.1 AODV [Reactive routing protocol]

Source-driven routing protocols include *ad hoc* on-demand distance vector routing, or AODV (7). Whenever a source node transmits a message to a target node using this protocol, without routing, RREQ is sent first. The adjacent node checks to determine if the destination node's address matches the source node's address when the detonator receives an RREQ containing those addresses. If so, it sends an RREP to the source node; if not, it maintains flooding the network's RREQ while looking through the routing tables for routes that might assist a packet get to the destination node; if a route is located, it sends an RREP to the source node. By regularly broadcasting hello messages, the AODV protocol can assist routing nodes. The system deletes faulty records or data and delivers an ERROR message to the nodes when a link breaks.

3.2.2. DSDV [Proactive routing protocol]

DSDV is a table-driven routing technique based on the Bellman–Ford algorithm. In 1994, Bhagwat and Perkins created it. The routing loop problem was primarily resolved by the algorithm. A sequence number is assigned to each entry in the routing table; this number is ordinarily even when a connection is available and odd when it is not. The source node must include the number in the ensuing update because it is generated by the destination. For communication purposes, routing information is disseminated across nodes within the transmission range by providing more frequently smaller incremental updates rather than entire dumps (8).

3.2.3 TORA [Hybrid routing protocol]

Being hybrid protocol with no centralized control, TORA (Temporally-Ordered Routing Algorithm) is totally distributed since routers only need to keep track of information about neighboring routers, or one hop knowledge. For all *Ad Hoc* routing, this is necessary. Similar to a routing strategy using distance vectors, TORA upholds based on the specific destination. TORA logically contain three main functionalities i.e. route creation, route maintenance and route erasing. Route creation tends to establish direct sequenced link between nodes towards destination. Routes are maintained according to the network topology change such that re-establishment of routes occurs during some finite period of time. TORA implement a new algorithm with more efficiency towards topology change and with the possibility of network portioning detection, the erasing route functionality. As soon as the links partitioned links are detected from the destination, they are marked as undirected links and should be erased.

4. Research methodology

The tools and procedures we used to evaluate the various categories of routing protocols are discussed.

4.1. Simulation environment

AODV [Reactive], DSDV [Proactive], and ZRP [Hybrid] are the three hybrid protocols that are specifically illustrated using a simulation model based on OPNET Simulator. IEEE 802.11 for wireless LANs and the Two-Ray Ground radio propagation model are both used by the MAC layer. The bitrate is now 2 Mb/sec higher. The delivery of error-free wireless channels also makes use of omnidirectional antennas and models. The simulation time ranged from 10 to 100 to 120 s for each protocol implementation scenario.

4.2. Movement model

The three different forms of MANET routing protocols, AODV [Reactive], DSDV [Proactive], and TORA [Hybrid], are compared using a thorough simulation model built on the OPNET Simulator platform. At the MAC layer, two radio propagation models are both utilized: IEEE 802.11 for wireless LANs, and Two-Ray Ground. To simulate node movement, we employ the random waypoint model. Nodes move uniformly and equally at a speed of [20 m/s].

4.3. Network size and communication model

With a field size of 1,500 by 1,500 and between 10 and 50 nodes, we take different network sizes into consideration. We alter the number of nodes in order to contrast how well the protocol performs at low and high node densities. For the source and destination nodes, random picks are made. The links start in the simulations at random. For all types of routing, the same traffic and mobility patterns are used. Each of the six research situations has a maximum network interface queue size for routing and data packets of 50 packets, with a fixed data packet size of 1,000 bytes.

4.4. Routing metrics

For both low- and high-density networks, we compare the effectiveness of the aforementioned routing methods using the three metrics listed below.

(i) Packet delivery ratio: The packet delivery ratio (PDR), a network indicator, measures the percentage of total packets sent from source nodes to destination nodes that are delivered. The objective is for most data packets to be delivered to the destination. As PDR increases, so does the network's performance (9).

$$\text{Packet Delivery Fraction} = \Sigma \text{ Number of received}/ \Sigma \text{ Number of sent packets} \quad (1)$$

(ii) End-to-end delay: The amount of time it takes a packet to get from its source to its destination is known as end-to-end delay. Numerous factors, such as network congestion, queuing delays, propagation delays, and processing delays, have an impact on it. An essential measurement for assessing the performance of a network connection is end-to-end delay. Packets will reach their destination swiftly and with little delay if the end-to-end delay is low (10).

$$\text{End} - \text{to} - \text{end delay ratio} = \Sigma\,(\text{Packet} - \text{arrive time} - \text{Packet} - \text{send time}) / \Sigma \text{ Number of connections} \quad (2)$$

(iii) Throughput: Throughput in wireless sensor networks is defined as the number of packets that are successfully sent from the source to the destination each second. When a network is well-designed, the value should be high, and if it is subject to an assault of any kind, the throughput value will drop significantly.

$$\text{Throughput} = \text{Received data}/ \text{Data Transmission Period} \quad (3)$$

TABLE 2 | Parameter values for simulation.

Parameter	Values
Number of nodes	50
Interface type	Phy/WireLowPhy
Channel	WireLow Channel
Mac type	Mac/802_11
Queue type	Queue/DropTail/PriQueue
Queue length	150 Packets
Antenna type	Omni Antenna
Propagation type	TwoWayGround
Size of packet	1024
Protocol	AODV, DSDV, and TORA
Traffic	CBR
Simulation area	1500M*1500M
Node mobility speed	20 m/s

4.5 Parameter values for simulation

5. Result and discussion

5.1. Introduction

We compare three routing protocols' performance in networks with nodes between 10 and 50 nodes. We conducted the simulation for each experiment throughout a duration range of 0 to 120 s, pausing as necessary every 10 or 20 s. Up to 120 s can pass during the simulation. A tool for simulating the behavior and functionality of any sort of network is the OPNET Network Simulator. OPNET Network Simulator stands out from other simulators mostly because of its strength and adaptability. Pre-built models of protocols and gadgets are available from IT Guru. It enables the creation and simulation of various network topologies. You cannot add new protocols or change the behavior of existing ones since the collection of protocols and devices is fixed (11).

5.2 Comparative analysis

We use several routing measurements to compare the performance of the three different types of traditional routing protocols.

5.2.1. Comparative analysis using the PDR metric

Using the Packet Delivery Ratio parameter metric in OPNET Simulator, a performance analysis of the three different types of routing protocols, AODV, DSDV, and TORA, is carried out **Table 2**.

The results of the PDR performance evaluation are shown in **Table 3** and **Figure 1** with a range of node counts. Despite a modest PDR decreases as the number of nodes rises,

TABLE 3 | PDR of the three Categories of Protocols varying number of Nodes.

Number of Nodes	TORA	AODV	DSDV
10	0.95	0.93	0.9
15	0.948	0.929	0.897
20	0.945	0.925	0.895
25	0.943	0.923	0.892
30	0.94	0.909	0.888

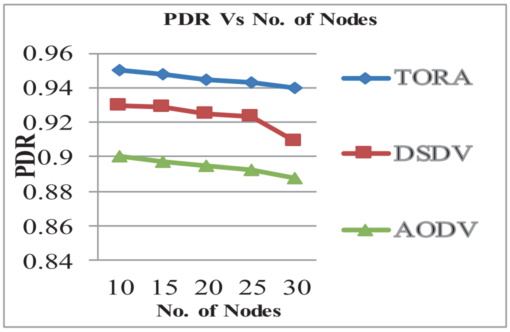

FIGURE 1 | PDR vs. No. of Nodes.

TABLE 4 | PDR of TORA and DSDV varying number of receivers.

Number of Receivers (Nodes)	Packet Delivery Ratio	
	TORA	DSDV
10	0.95	0.935
15	0.953	0.938
20	0.953	0.94
25	0.953	0.945
30	0.953	0.948

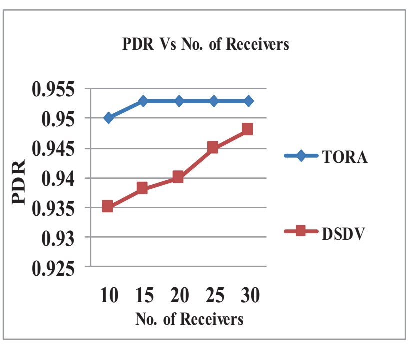

FIGURE 2 | PDR vs. No. of Receiver Nodes.

TORA maintains a high Packet Delivery Ratio throughout the simulation time, in contrast to the other two methods. The same problem applies to other techniques that can't manage excessively dense networks.

The PDR of the TORA is compared with the DSDV, as can be shown in **Table 4** and **Figure 2**. When evaluating performance, the number of receivers is taken into consideration. The number of receivers used during the simulation process ranges from 10 to 30 nodes. TORA achieves the best outcomes as a result of its two unique features—the option to select a steady path and the availability of excellent connection quality. The PDR of both methods steadily increases in direct proportion to the number of receivers, which is an unusual observation. The fact that TORA maintains a high PDR that DSDV never reaches serves as evidence of its superior performance.

TABLE 5 | Comparison of End-to-End Delay of existing approaches.

Number of Nodes	TORA	DSDV	AODV
10	0.5	1.2	1.5
15	3	2.5	4.3
20	7	8.8	8.8
25	9	12	12
30	12	15	16

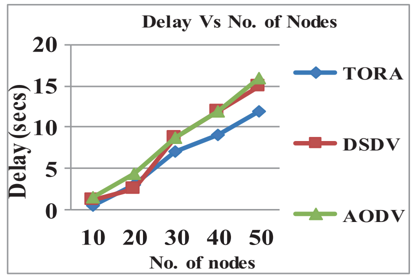

FIGURE 3 | End-to-End Delay vs. No. of Nodes.

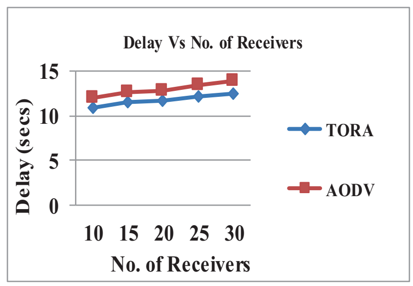

FIGURE 4 | End-to-End Delay vs. No. of Receiver Nodes.

5.2.2 Performance evaluation with delay

The TORA protocol is better than the ones currently in use because, as shown in **Table 5** and **Figure 3**, the TORA protocol's latency is maintained at a lower level for the duration of the simulation when the end-to-end delay parameter and the number of nodes are changed. The optimal behavior of the TORA protocol is achieved by selecting paths with lower distance and reachability values over those initially selected as optimal paths.

TABLE 6 | Delays for TORA and DSDV with the varying number of receivers.

Number of Receivers (Nodes)	End-to-End Delay [(secs)]	
	TORA	AODV
10	11	12
15	11.5	12.6
20	11.8	12.9
25	12.2	13.5
30	12.5	14

TABLE 7 | Throughputs of TORA and DSR varying number of receivers.

Number of Receivers (Nodes)	Throughput [kb/s]	
	TORA	AODV
10	0.97	0.93
15	0.968	0.927
20	0.965	0.925
25	0.963	0.923
30	0.96	0.921

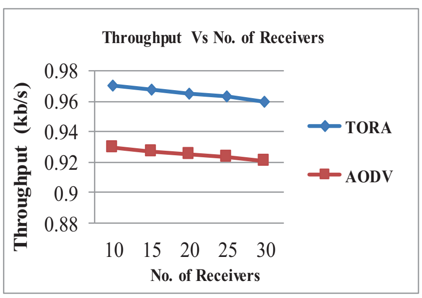

FIGURE 5 | Throughput vs. No. of Receiver Nodes.

Figure 4 and Table 6 compare TORA and AODV side by side. TORA outperforms the AODV protocol because it maintains a reduced end-to-end delay ratio for both the low and high number of receivers.

5.2.3 Evaluation using throughput

Table 7 and Figure 5 display the effects of the total number of packets the source received from different receivers. The experiment's results show that when receiver counts rise, both protocols' throughput numbers fluctuate, going from high to poor as a result of many receivers simultaneously accessing the same channel. Even though throughput values are dropping, TORA still outperforms AODV thanks to larger throughput values.

6. Conclusion

Three alternative wireless *ad hoc* networks' functionalities were evaluated in the initial stage of our investigation: VANET, MANET, and SENSOR. The best network is MANET since it may be created at any time. We investigated the three main types of MANET protocols: proactive, reactive, and hybrid, and discovered that the hybrid MANET protocol, which combines the greatest features of the other two, is the best since it can manage any network regardless of its size or requirements. We decided to conduct a third performance study of the three different MANET routing protocols using OPNET simulations for both low- and high-density MANETs due to the unique characteristics of the hybrid protocol. In this study, three performance metrics were used: throughput, end-to-end delay, and packet delivery ratio. In terms of quick and effective information dissemination, TORA, the hybrid protocol, performs better than the proactive and reactive protocols since it was able to achieve higher end-to-end packet delivery ratios, lower end-to-end delays, and higher throughput in every research study situation.

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