electronics

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Extended Comparison and Performance Analysis for Mobile Ad-Hoc Networks Routing Protocols Based on Different Traffic Load Patterns and Performance Metrics

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Abstract: A mobile ad-hoc network (MANET) is a network of mobile nodes that dynamically form a transitory network lacking any existence of infrastructure and any form of centralized management. Nodes in ad hoc networks are powered by batteries with a limited lifespan and communicate in a restricted bandwidth. The unpredictable environment of a MANET may run into a major concern in the routing mechanism, therefore the need for a routing protocol with robust performance is still one of the key challenges in MANET deployment. In this work, a comparative comparison and extensive simulation analysis have been carried out for three major routing protocols: destination sequenced distance vector (DSDV), dynamic source routing (DSR) and ad hoc on-demand distance vector (AODV). Protocol evaluation has been extended by considering several simulation arrangements, different classes of traffic load patterns and diverse performance metrics. Based on packet rate change, node quantity and node speed, simulation scenarios were generated. Protocols were investigated against energy consumption, throughput, lost packets, routing load and packet delivery fraction for three types of traffic load patterns regular, irregular and joint traffic. DSR and AODV protocols proved to be more reliable when joint traffic was implemented when node speed and packets variations are considered. DSDV protocol verifies outstanding response over other protocols in terms of energy consumption when either regular or irregular traffic is applied. The simulation results for DSR protocol have verified the superiority over other protocols in 9 simulation scenarios when diverse metrics are considered. DSDV showed optimal performance in 7 cases, especially at low packet rates and in networks with minimum number of nodes. Similarly, AODV protocol showed outstanding performance in 6 scenarios, when higher packet rates and node mobility are considered.

Keywords: MANET; DSDV; DSR; AODV

Citation: Razouqi, Q.; Boushehri, A.; Gaballa, M.; Alsaleh, L.; Abbod, M. Extended Comparison and Performance Analysis for Mobile Ad-Hoc Networks Routing Protocols Based on Different Traffic Load Patterns and Performance Metrics. *Electronics* **2024**, *13*, 2877. https://doi.org/10.3390/electronics13142877

Academic Editor: Sacco Alessio

Received: 8 April 2024
Revised: 14 July 2024
Accepted: 16 July 2024
Published: 22 July 2024

1. Introduction

The technical evolution of MANETs has undergone significant technological breakthroughs. MANETs were first developed in the 1970s with DAPRA's packet radio networks and have evolved through phases of enhanced routing protocols, including DSAR and AODV in the 1990s and more sophisticated techniques addressing security, scalability and energy efficiency in the 2000s. The integration of technologies such as the IoT and 5G has expanded the application of MANETs, allowing for modern communication technology for smart cities and vehicular networks [1].

MANETs are characterized to be deployed on the fly; hence no exclusive infrastructure is needed, and no wires are involved. As in [1,2], an ad hoc network arrangement can change actively with time, so it could be an appropriate selection for realistic applications such as data sharing in a business meeting or between military soldiers on the move. In mobile ad hoc networks, mobile nodes cooperate to forward data packets from source to destination node; therefore one of the most significant issues in MANETs is the routing mechanism. Several factors need to be considered in MANETs to create an efficient route between a pair of mobile nodes:

(a) Dynamic topology: The nodes are mobile devices that are capable of moving freely in a random manner; hence the topology of the network keeps changing with time, and thus the routing protocols for such networks must be adaptive to that variation.
(b) Power awareness: since the nodes in MANETs typically run on batteries and deployed in varying environments, they face strained power requirements, which implies that the routing protocols must be able to preserve nodes energy for extended time intervals.
(c) Network size: business applications of MANETS such as data sharing in conference meetings or classrooms may go through performance degradation due to overcrowding or vast distribution of mobile nodes while changing network size; this also could apply more constraints on the selected routing protocol.
(d) Quality of service (QoS) limitations: ad-hoc networks can handle multimedia applications that need high bandwidth and deal with a diversity of traffic streams; such applications are critically affected by the behaviors of the routing protocols. Finding and maintaining routes that meet specific QoS criteria is more complex than standard routing, as QoS routing protocols need higher computational and communication overhead.
(e) Link breakage recovery: Mobility of nodes in MANETs and frequent movement out of communication range cause link breakage in MANETs. Link breakage recovery techniques are necessary to maintain network stability. Proactive and reactive routing protocols also play a role in minimizing the impact of link breakage.
(f) Scalability: The increase of the network in size is a major concern in MANETs. To manage a large number of mobile nodes, scalability must be achieved by the chosen routing protocol. Scalability can be achieved by clustering or divide the network to segments. Also, hierarchical architecture can divide networks through segmentation into smaller and easier-to-manage networks.
(g) Security: The characteristics of MANETs, especially open-medium wireless communication, dynamic topology and decentralized architecture, require advanced security measures. Robust security measures are challenging in MANETs. Techniques like data encryption, authentication and intrusion detection must be implemented to detect threats as spoofing, eavesdropping, and denial-of-service (DoS) and distributed denial-of-service (DDoS) attacks.
(h) Interoperability: Interoperability is vital for seamless integration of MANETs with other communication systems, by ensuring that different protocols and devices can coexist peacefully. Standards-based protocols and interfaces facilitate interoperability, enabling MANETs to use heterogeneous devices and networks.

2. Literature Survey

Traditional routing protocols in mobile ad hoc networks, such as bacteria for aging optimization algorithm (BFOA), ad hoc on-demand distance vector (AODV), ad hoc on-demand multipath distance vector (AOMDV), dynamic source routing (DSR) protocols, destination sequence distance vector (DSDV), zone routing protocol (ZRP), ad-hoc on-demand multipath distance vector (AODMV) and temporally ordered routing algorithm (TORA), have been widely simulated and analyzed by authors for disparate network parameters and simulation environments.

In [3], a secure optimization routing algorithm was designed to address energy consumption and latency in MANETs. The study utilized the bacteria for aging optimization algorithm (BFOA) to develop an efficient routing approach. Initially, cluster heads (CHs) were determined through the employment of a fuzzy clustering method. The CHs were responsible for routing data packets, while detecting intruded nodes through a predefined threshold. The BFOA optimization algorithm was highlighted as a solution for secure routing in MANETs, offering faster convergence rates and improvements in storage, throughput and route connectivity. This technique demonstrated significant performance benefits by achieving minimal energy consumption, low latency and high throughput.

In [4], the authors evaluated the performance of MANETs with variation in transmission power over 40, 80 and 120 nodes using the AOMDV routing protocol. AODMV performs better than AODV for several performance metrics such as throughput, average end-to-end delay and average energy consumption. The simulation was conducted using QualNet Simulator in a MANET scenario with nodes placed over 1500 $\times$ 1500 m terrain. A comparison between the performance of AODV and AOMDV protocols was compared in terms of throughput, power consumption and average end-to-end delay. AOMDV outperformed AODV in throughput, especially with high node density, because of the AOMDV multipath routing capability. Moreover, average end-to-end-delay was lower with AOMDV, highlighting more efficient data packet delivery. AODMV can have lower energy consumption per node, as it uses multiple paths, which provides balance between the load and energy usage across the network more effectively than AODV. The study concluded that AOMDV has higher efficiency than AODV in dynamic and high-density MANET scenarios.

In [5], on-demand routing protocols AODV and destination sequenced distance vector (DSDV) were proposed to investigate the behaviors of those protocols in ad hoc networks. An exhaustive comparison has been made in terms of loop route structure, freedom, number of tables required, the capability of multiple routes and maintenance of the routes. Furthermore, MANETs' routing attacks, such as blackhole attacks, wormhole attacks, Greyhole attacks and Byzantine attacks were insightfully illustrated in terms of the routing protocol of the attack, the used approach, simulation environment and comparison of results, as well as techniques to mitigate each attack separately, addressing the challenge of detecting and mitigating attack and its effect on end-to-end delay, through additional overhead caused by detecting threats. Detecting attacks is a complex process that consists mainly of creating new tables to store responses from multiple nodes and analyze these responses, based on target sequence number threshold to determine the validity of the source of the response. Other techniques such as hash trees, route redundancy and route aggregation were introduced.

In [6], the routing protocols DSDV and AODV were simulated with the Gauss–Markov mobility model. The experiment assessed the performance of AODV and DSDV routing protocols in the form of routing overhead, node density, number of packets and number of hops count. In the experiment, it was observed that number of nodes in AODV is similar to that in DSDV, while the routing overhead increases in AODV simulation, in case of increasing the number of nodes, while the DSDV is not affected. The node density increases in case of higher number of nodes in ADAV and remains affected in DSDV experiment. The minimum value of routing overhead and number of hops count shows better performance. However, the maximum value of node density and number of packets received indicates better performance. Simulation results proved that DSDV achieves the minimum routing overhead and the maximum number of packets received. However, AODV achieved the maximum node density and minimum number of hops.

In [7], the impacts of variations in QoS parameter were studied and analyzed, combined with the choice of routing protocol, for network performance. The network performance is measured by calculating the average throughput, packed delivery ratio (PDR), average jitter and energy consumption. The simulation was carried out in NS-3 and DSDV and AODV routing protocols have been assessed. The paper compared the two routing protocols and designed the simulation, based on different factors, such as network size, number of nodes, number of sources, move speed, pause time, initial energy, packet type and packet length. The paper had two simulation scenarios: impact of network size on performance of routing protocols and impact of mobility on performance of routing protocols. DSDV performed less efficiently than AODV in the performance, measured by throughout and energy consumption and the second scenario concluded that AODV routing protocol achieves better throughput and DSDV routing protocol consumes less energy.

In [8], the authors introduce a study to evaluate several MANET routing protocols, while concentrating on metrics such as throughput, average end-to-end delay, packet delivery ratio (PDR) and nodes' residual energy. The procedures that were evaluated were ZRP (hybrid), DSDV (proactive) and AODV and DSR (reactive). The results showed that AODV had excellent throughput efficiency, which qualified it for use in large networks with significant data transmission requirements. On the other hand, ZRP showed instability with high packet drop rates and varying PDR values, even while it consumed a lot of energy and might extend network lifespan. Because DSDV is proactive, it has the lowest end-to-end delay, which is advantageous for applications that are sensitive to delays, such as streaming. The investigation demonstrates that reactive protocols perform better than their proactive and hybrid counterparts, with AODV and DSR outperforming ZRP and DSDV. This literature highlights the critical trade-offs in protocol selection, emphasizing the importance of matching protocol characteristics to specific network requirements.

In [9], the authors present an investigation for the routing protocols and their accompanying issues, with a particular emphasis on disaster management applications. It emphasizes the importance of efficient and robust communication in MANETs, underlining their important role in emergency and rescue operations. Various routing protocols, including AODV, DSR, OLSR and TORA were examined and had efficiency evaluated in terms of protocol complexity, overhead and end-to-end delay. This research makes a substantial contribution by identifying fundamental challenges relating to data security and integrity, which are still major concerns in MANET deployments. The study provides a valuable overview of cutting-edge routing systems, including insights into existing research issues, and suggests areas for further investigation. This includes investigating the integration of MANETs with emerging technologies like fog and cloud computing and the use of multi-objective and heuristic algorithms to improve network performance in smart city contexts. This literature not only advances our understanding of MANET routing protocols, but it also lays the groundwork for future research aimed at tackling the dynamic and complicated character of these networks.

The aim of this work can be summarized as follows

I. Extended simulation environments are generated to simulate the classical routing protocols DSR, AODV and DSDV in mobile ad hoc network by
    1. Creating various simulation environments based on different network parameters
    2. Implementing different traffic loads
    3. Considering various performance metrics

II. Analyzing the routing protocol behaviors to justify the simulation results

III. Specify and highlight the main universal differences between routing protocols and emphasize the significance of selecting the protocol, based on the application

We have implemented three types of traffic loads into the simulation environments: regular rate traffic, irregular rate traffic and joint rate traffic, which is a mixture of fixed and varying traffic loads. The examined performance metrics are energy consumption, average throughput, packet delivery ratio, total dropped packets and normalized routing load.

The following sections are organized as follows: overview of routing protocols is introduced, then simulation tool and mobility model considered in this work are discussed. The implemented traffic loads are presented in the traffic load section, then the inspected performance metrics and routing protocols simulation results are investigated and analyzed. A summary for the most consistent protocol based on network parameters is tabulated and finally concludes the simulation results.

3. Overview of Routing Protocols

Over the years, several routing protocols have been proposed for ad hoc networks. The existing routing protocols can be mainly classified into three categories as shown in Figure 1: proactive routing protocols, on-demand routing protocols and hybrid routing protocols [10]. In this work, we will go through more evaluation of the classical routing protocols and the proactive and the reactive types while more performance metrics and network parameters are involved.

A. Proactive Routing Protocols

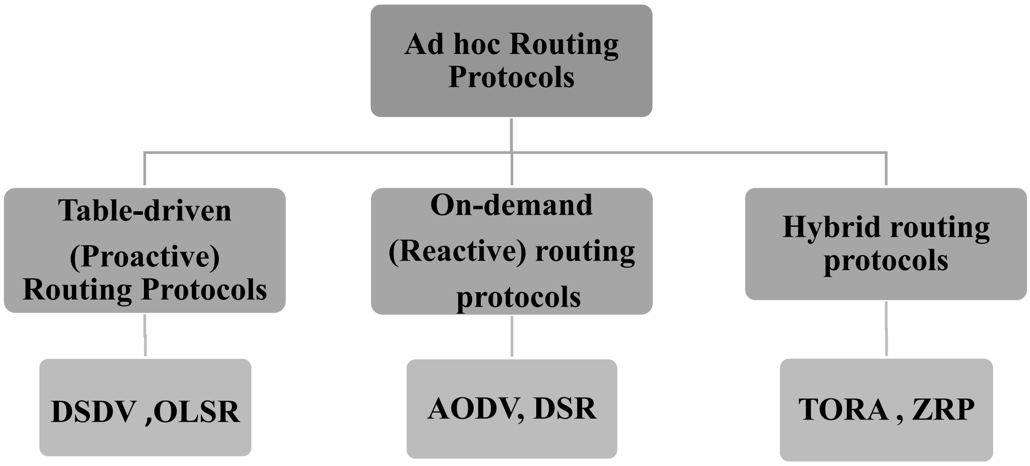

Figure 1. Classification of MANET routing protocols.

Proactive protocols as in [11] maintain the routing information even before it is needed, where route information is generally kept in the routing tables and is occasionally updated once the network topology is modified. In this category, any node that intends to communicate with another node needs to obtain the next hop neighbor on the route to the destination from its routing table. Examples of table-driven routing protocols are destination sequenced distance vector routing protocol (DSDV), wireless routing protocol (WRP) and cluster switch gateway routing protocol. In this work, we will focus on the DSDV protocol, which is mainly dependent on the routing information protocol used in parts of the internet and distance vector routing algorithm. In this protocol, each mobile host maintains a table that includes the next hop neighbor and the distance to the destination nodes in terms of number of hops [12]. It uses sequence numbers for the destination nodes to determine the freshness of a particular route, in order to provide loop-free routes to the destination by avoiding any short- or long-lived routing loops caused by stale routing information. If two routes have equal sequence numbers, the one with smaller distance metric number of hops to destination is advertised. The sequence number is incremented upon every modification sent by the host nodes. All the host nodes from time to time broadcast their tables to their neighboring nodes to preserve an updated view of the network. The tables can be modified in two ways, either incrementally or through a full dump. An incremental update is carried out when the node does not observe any major changes in the network topology, which only contains entries of the metrics in the routing tables that have changed since the last update. A full dump is achieved when network topology changes significantly, such that it could span many packets. DSDV promises loop-free routes to each destination and finds the optimal path by using average settling delay, which is a delay needed before advertising a route to avoid frequent routing table updates and any fluctuations caused by two similar routing advertisements.

One of the key benefits of the DSDV routing protocol is that the routing information to any node is accessible all times since routes to all the nodes are stored in the routing table. As in [13], regular updates of nodes routing tables may lead to a usage of battery power and network bandwidth even when the network is idle, thus restricting the number of nodes that can join the network. Additionally, these routing tables may include routes to destinations which are not required, which results in more memory consumption at each node as the size of the network increases. For these reasons, DSDV is effective for creating MANETs with small network capacity. Even if the number of nodes is higher, DSDV can perform well if the network topology does not vary rapidly. On the other hand, DSDV mainly fails to converge when both fast deviation from network configuration and high node mobility are considered.

B. Reactive Routing Protocols

Reactive procedure are also called on-demand protocol as in [14]. This type intends to restrict the bandwidth used by control packets in MANETs by eliminating the periodic table update messages necessary in the table-driven approach. If a node needs to send a packet to another node, then this category seeks out the route in an on-demand manner and establishes the connection to transmit and receive the packets. Generally, the on-demand protocols have two stages, route discovery and route maintenance. In the route discovery procedure, a node wishing to communicate with another node initiates a discovery mechanism; if the route is not included in the node cache, then the destination node replies with a valid route. The route discovery stage usually occurs by swarming the route request packets all over the network. The route maintenance phase involves inspection for broken links in the network and updating the routing tables. In this work, we will accentuate two conventional reactive routing protocols DSR and AODV.

I. DSR Route Discovery and Route Maintenance

The dynamic source routing protocol (DSR) is mainly based on the concept of source routing algorithm to discover routes, where a sender node specifies in the packet header the whole list of nodes that the packet must bypass to reach the destination node [15]. This basically means that every node just needs to forward the packet to its next hop specified in the header, and there is no need to verify its routing table, as in table-driven algorithm. Route discovery layout is shown simply in Figure 2, where the source node broadcasts route request packet (RREQ) to all its neighbors. Each neighboring node, in turn, rebroadcasts the route request to its neighbors if it has not already done so or if it is not the destination node, considering that the time to live (TTL) packet has not been exceeded. Each RREQ carries a sequence number generated by the source node and the path it has passed through; where the midway nodes upon receiving a RREQ packet, it needs to check the sequence number on that control packet before forwarding it, so it is forwarded only if it is not a duplicate RREQ. Upon reaching the destination node, it sends a reply packet (RREP) on that path back to the sender; this reply packet contains the route to that destination. The destination node chooses the best route received first and caches the other routes for future use. A route cache is preserved at every node, so that if an intermediate node that receives a RREQ has a route to the destination node in its own route cache, then it replies to the source node directly without broadcasting the RREQ anymore.

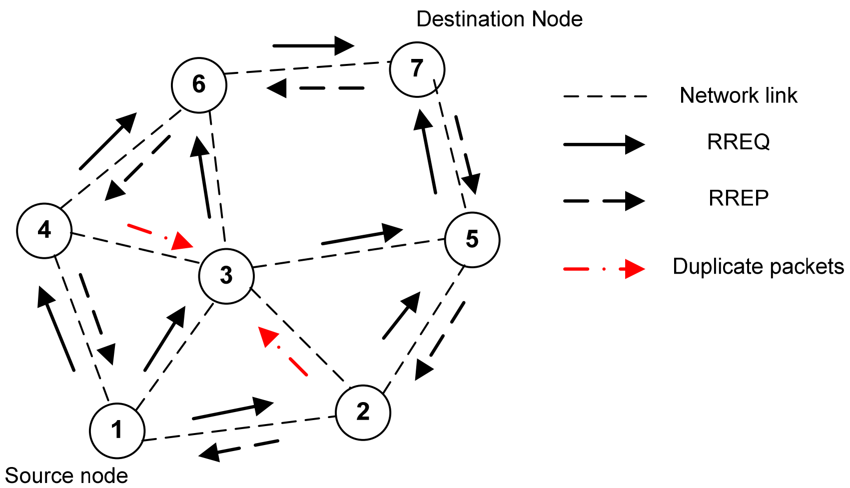

Figure 2. DSR route discovery.

The route maintenance procedure, as shown in [16], is accomplished whenever there is no link between any two nodes. When an intermediate node in the path moves away, causing a wireless link to break, a route error packet (RERR) is sent by the node that was connected to it to other nodes in the network so they will remove the routes that use that hop, so all routes including that broken link are removed from the node cache. As well, the source node reinitiates the route discovery procedure to find an alternative route to the destination. The route maintenance layout for DSR protocol is illustrated in Figure 3.

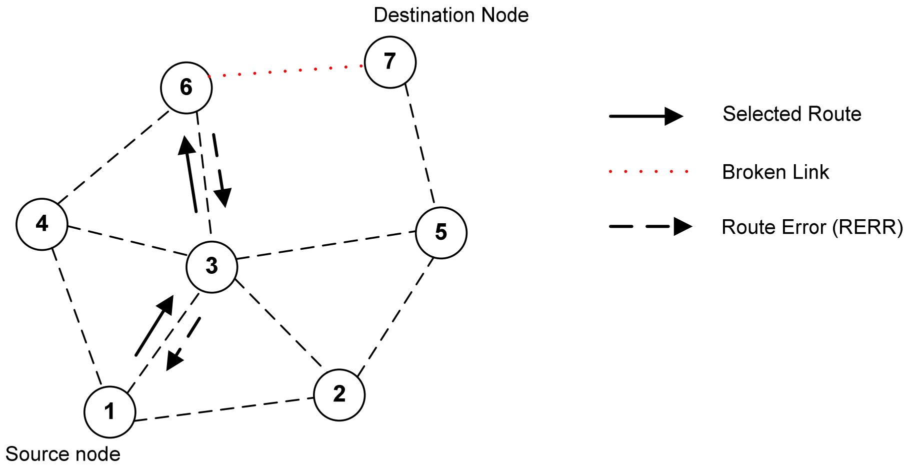

Figure 3. DSR route maintenance.

The main benefit that characterizes DSR is the sufficient recovery when route modification is detected in the network and there is no need for any periodic routing advertisement messages. On the other hand, the use of route caches is a good mechanism to reduce propagation delay, but as size of the network increases, the routing overhead also increases since each packet has to carry the entire route to the destination. The main limitation of DSR is that whenever a link break is declared, the RERR packet propagates to the original source, which in turn starts a new route discovery process where the out of order link is not repaired locally. DSR was designed mainly to work well in networks with up to two hundred nodes and a high rate of node mobility.

II. AODV Route Discovery and Route Maintenance

The ad-hoc on-demand distance vector (AODV) routing protocol employs a reactive approach to discover routes and a proactive mechanism for identifying the most up-to-date paths as in [17]. Moreover, it is designed to reduce overhead data traffic to improve network scalability and performance. It is proposed for mobile ad-hoc networks with capacities up to thousands of mobile nodes and can handle a relatively high mobility rate, as well as a diversity of data traffic levels. The schematic plan for the AODV route discovery process is shown in Figure 4, where the source node broadcasts RREQ packets similar to DSR. RREQ packets contains the source identifier (SId), destination identifier (DId), source sequence number (SSeq), destination sequence number (DSeq), broadcast identifier (BId) and TTL fields. The node also maintains a timer associated with every entry in order to delete an RREQ packet if the reply is not received before it expires. When an intermediate node receives an RREQ packet, it either forwards it or prepares a route reply RREP packet if it has a valid route to the destination in its cache.

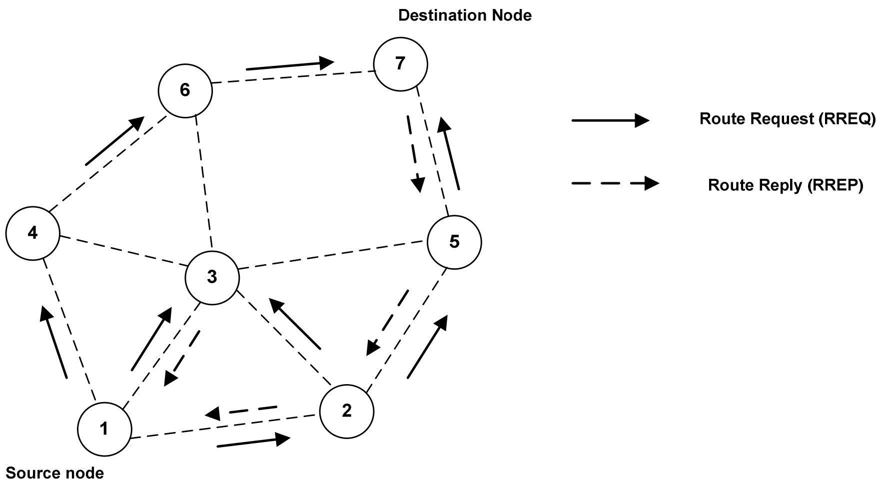

Figure 4. AODV route discovery.

The availability of a route at the intermediate node is determined by comparing the sequence number at the intermediate node with the destination sequence number in the "RREQ". Any duplicates in the "RREQ" are eliminated by intermediate node if the "Sid" and "Bid" of the "RREQ" packets are the same. Whenever an "RREP" packet is received by a node, it stores the information of the previous node in order to forward the packet to it as the next hop towards the destination; this represents a "forward pointer" to the destination node. According to these procedures, it is clearly perceived that each node maintains only the next hop information, unlike source routing, in which all the intermediate nodes on the route towards the destination are stored. The route maintenance phase diagram is simply shown in Figure 5, where all nodes that are active in the network periodically transmit hello messages that are special "RREP" messages. Thus, when one node does not receive a hello message from the neighbor node due to a lost connection between them, they adjust their routing table by deleting that path. Nodes also send "RRER" packets to the other neighbor nodes that are using that path, so that each node keeps a list of all the active surrounding nodes in each communication. However, AODV is restricted in which intermediate nodes can lead to inconsistent routes if the source sequence number is old and the intermediate nodes do not have the latest destination sequence number, thereby causing stale entries as shown in [18]. In addition, the periodic hello messages may lead to unnecessary bandwidth utilization.

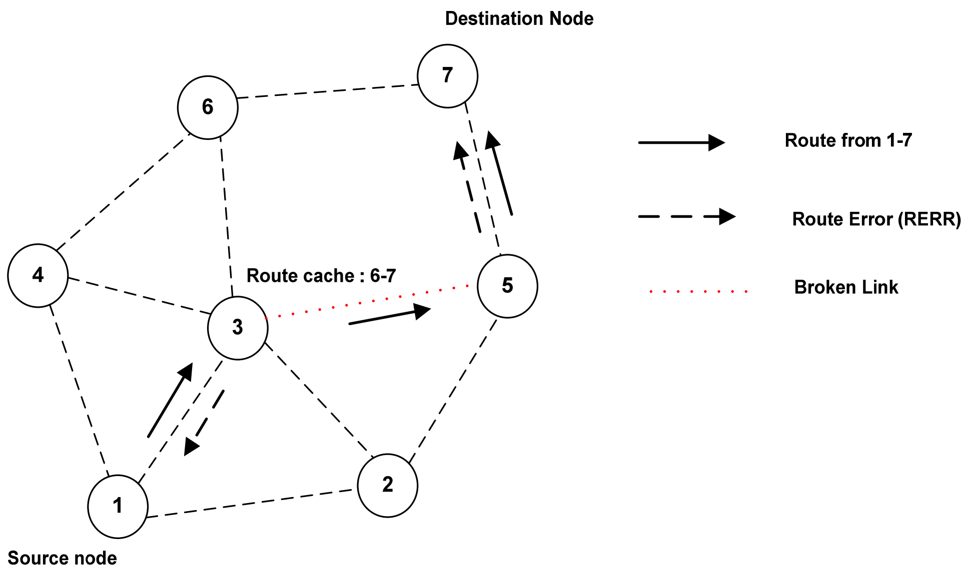

Figure 5. AODV route maintenance.

Usually, reactive routing protocols outperform proactive protocols in highly congested networks because periodic routing tables updates are not required; thus the number of routing packets in the network is minimized. On the other hand, multiple route caches feature in DSR protocol, which may result in higher routing load; this may impact the protocol behavior when end-to-end delay and packet delivery fraction metrics are examined in highly loaded networks. As in [19], we can end this overview section by introducing Table 1, which briefly illustrates the major features for DSR and AODV reactive routing protocols, which can enhance the analysis of the protocols' behaviors in the network simulation.

Table 1. DSR and AODV features.

Feature	DSR	AODV
Destination sequence number	Not utilized	Utilized
Periodic hello messages	Not essential	Essential for link breakage discovery
Routing mechanism	Source routing Multiple route caches per destination	Table driven one entry per destination.
Route storage method	Route caches	Routing tables
Timers	Not applied	Applied
Numerous route caches	Yes	No (path request initiated)
Optimal route to destination	Not always	All the time

4. Simulation Tool and Mobility Model

In this work, we decided to use a network simulator (NS3), because it is well established and widely considered by authors for ad hoc networks. Generally, network simulator has a desirable framework which is sufficient to construct the required simulation arrangements and realize objects such as network nodes, protocols and links. Network simulator framework contains utilities such as TCL debugger to debug TCL script and emulator to visualize a live network scenario [20,21].

In ad hoc networks, there is a high chance of node mobility due to the ad hoc nature and the type of applications; thus, node mobility has a major impact on the routing protocol behaviors. In this work, the random waypoint model implemented in NS3 has been adopted in the simulation environment to simulate nodes movements. The random waypoint model is widely used and analyzed in simulations of ad hoc routing protocols because of its simplicity and availability [22]. In the random waypoint model, a node is free to select its destination, speed and direction independent of neighboring nodes. The mobility model can be briefly described in such a way that the mobile node can begin the simulation after waiting for a specified time, and then it selects a random destination in the area and a random speed distributed uniformly between minimum and maximum speed. Then, after reaching its destination point, the mobile node waits again a fixed number of seconds before choosing a new waypoint and speed [23].

5. Traffic Load Patterns

Traffic loads play a significant role in understanding the performance of routing protocols for the practical deployment and implementation of MANETs. Different traffic load patterns such as regular, irregular and joint traffic reflect real-world traffic scenarios, in which data transmission can be continuous or infrequent, or a mix of both. Therefore, the scope of this paper is to evaluate routing protocols under these conditions, in order to identify the strengths and weaknesses of each protocol to ensure their appropriateness for different operational conditions in real life.

Throughout the literature, we have noticed that many authors focus on routing protocol behaviors against performance metrics, while variation in the applied traffic loads was limited. In this work, three types of traffic loads are implemented in the simulation environments besides the various performance metrics considered, to improve the protocol analysis and comparison.

Regular or constant bit rate traffic, irregular or varying bit rate traffic and the joint bit rate traffic are the traffic streams generated in the simulation scenarios. The regular rate class that is usually used for voice and data services representation, generates traffic at a constant rate and the packet size remains fixed during the packet transmission, as shown in [24]. The source for this regular packet stream is not busy and the source is continuously transmitting throughout the connection, which means that no still periods are involved, so the entire regular traffic streams can be generated in network simulator [25].

As in [26], the second type of traffic considered is the irregular or varying rate traffic, which creates traffic alternating between two states, active and idle. Typical applications of this type are video conferencing or computer network applications. In this type, traffic is generated during the active state at a fixed rate, while no stream is shown during the idle period. The duration of both periods is exponentially distributed and independent. By determining the average of both active and idle periods, diverse computations can be achieved, which are important in traffic modeling. We can use the burstiness nature of irregular traffic to indicate how occasionally a source initiates traffic. To create an irregular type using a network simulator, the traffic scenario is generated manually using exponential traffic and during active periods, and packets are generated at a fixed burst rate. Regarding the source destination pair, the packet size changes randomly according to exponential distribution.

The third type of traffic that created in the simulation sicarios, is the joint traffic pattern examined in [27,28]. This class is a mixture of regular and irregular data types. In joint traffic, we decided that irregular traffic represents most of a source stream while regular traffic represents less than quarter of the total generated traffic load.

In our study, three distinct traffic load patterns were employed: regular, irregular and joint traffic. Regular traffic indicates scenarios where a steady data flow is required, for example in continuous monitoring applications. Irregular traffic represents sudden torrents of data transmission, typically in emergency communications, as in catastrophes. A joint traffic pattern provides a complete assessment of the protocols in mixed traffic environments. Accordingly, these patterns cover a wide spectrum of real-world conditions, comprising robust results and practical conclusions.

6. Performance Metrics

In this section, performance metrics measured in protocols evaluations will be discussed. In NS3 simulator, several AWK programs are used to analyze and calculate these metrics from the trace files generated from simulation file as shown in [29].

- **Average Energy consumption (AEC):** the relation of sum of entire energy consumed by each node divided by the whole number of nodes

$$\text{AEC} = \frac{\sum_{n}^{i}(\text{Intial energy } y_i - \text{Final energy } y_i)}{\text{Total number of nodes}} \quad (1)$$

In general, the inspected routing protocol is indicated to be more efficient when a lesser amount energy is consumed during the simulation.

- **Average throughput**: the average number of packets arriving at the destination node per second.

$$\text{Throughput} = \frac{(\text{Number of received packets } \times \text{ Packet size } \times 8)}{\text{Total simulation time}} \quad (2)$$

This metric is utilized as a indicator of the reliability of the routing protocol when measured in different simulation environments.

- **Normalized routing load (NRL)**: the ratio between the number of routing packets transmitted and the number of data packets effectively received at the destination node.

$$\text{NRL} = \frac{\text{Number of tranmitted routing packets}}{\text{Number of received data packets}} \quad (3)$$

Typically, routing protocol aims to achieve a better performance while maintaining a minimum number of routing packets, thus higher NRL metric indicates more routing packets in the network and consequently lowering the efficiency of the routing protocol.

- **Total dropped packets**: the total number of dropped data packets that have not successfully been sent to the destination node. Received data packets are dropped in two cases, either the buffer is full, therefore no additional packets can be managed or the duration that the packet has been buffered exceeds the time limit.
- **Packet Delivery Fraction (PDF):** the ratio of whole number of packets successfully received by the destination nodes to the total number of packets sent by the source nodes all over the simulation.

$$\text{PDF} = \frac{\text{Number of received packets}}{\text{Number of transmitted packets}} \quad (4)$$

This metric reflects the reliability of a routing protocol in carrying packets from source to destination successfully.

7. Simulation Setup

Diverse simulation scenarios were proposed and implemented using network simulator, since it is open-source software in which different parameters in the simulation environment can easily be modified [30]. This paper explores the performance of DSDV, DSR and AODV routing protocols under different traffic conditions: regular, irregular and joint traffic patterns. The exhaustive approach is coupled with evaluation of key performance metrics, which offer insights into the practical deployment of these routing protocols in MANETs. This varied analysis characterizes the work of this paper and distinguishes it from previous studies, giving the full picture of the behavior of each protocol under diverse real-world scenarios. In Table 2, different simulation scenarios are shown based on number of nodes in the network, transmitted packet rate and node speed when regular traffic and irregular traffic loads are applied separately. In Table 3, joint traffic is considered for two simulation scenarios, while packet rate change and node speed are the key parameters examined.

Table 2. Simulation parameters for regular and irregular traffic.

Parameters	Scenario I	Scenario II	Scenario III
Area	500 m × 500m	500 m × 500 m	500 m × 500 m
Simulation interval (s)	150	150	150
Nodes quantity	20	10, 16, 20, 30, 50, 60	20
Extreme connections	10	Half the number of the nodes	10
Seed	1	1	1
Initial energy node (J) (transmit/receive)	25 (1.8/1.0)	25 (1.8/1.0)	25 (1.8/1.0)
Idle power	0.095	0.095	0.095
Energy reference	0.15	0.15	0.15

Table 2. *Cont.*

Parameters	Scenario I	Scenario II	Scenario III
Traffic class	regular	regular or irregular	regular or irregular
Packet rate (p/s)	12, 14, 16, 20, 28, 32	20	20
Packet size (byte)	512	512	512
Node velocity (m/s)	20	20	0, 4, 8, 16, 20, 24, 28
Pause time (s)	5	5	5
Energy reference	0.15	0.15	0.15

Table 3. Simulation parameters for joint traffic.

Parameters	Scenario IV	Scenario V
Area	500 m × 500 m	500 m × 500 m
Simulation interval (s)	150	150
Nodes quantity	20	20
Extreme connections	10	10
Seed	1	1
Initial energy node (J) (transmit/receive)	25 (1.8/1.0)	80 (1.8/1.0)
Idle power	0.095	0.095
Traffic class	Joint rate	Joint rate
Packet rate (p/s)	12, 14, 16, 20, 28, 32	20
Packet Size (byte)	512	512
Node velocity (m/s)	20	0, 4, 8, 16, 20, 24, 28
Pause time (s)	5	5
Energy reference	0.15	0.15

8. Simulation Results and Analysis

Applying just one type of traffic load in the simulation environment may not be adequate to creating a practical plan of routing protocol behaviors in ad hoc network. Applications served by ad hoc networks can produce several types of traffic that alternate between data, speech and video. In this section, we created diverse simulation scenarios where various traffic load patterns are implemented and different network parameters are considered. Routing protocols will be evaluated and analyzed with respect to energy consumption, average throughput, normalized routing load, packet delivery fraction and total dropped packets.

1. **Simulation Scenario I**
   Simulation Setup:
   - **Simulation Tool:** NS3 network simulator
   - **Area:** 1000 m × 1000 m
   - **Node Speeds:** 1 m/s: 10 m/s
   - **Packet Sending rates:** low speeds at 12 and 14 p/s and high speeds at 28 and 32 p/s
   - **Metrics:** average energy consumption, throughput, NRL, PDF and TDP

Use Case: In disaster recovery scenarios, MANETs are vital for establishing communication among rescue teams and command centers. This scenario focuses on the evaluation of the performance of AODV, DSDV and DSR under varying packet sending rates and different node speeds, to inspect how these protocols are effective in coordination and in making decisions on time.

Scenario Goals:

1. Determine how each protocol manages energy consumption at different packet sending rates
2. Assess the data delivery capability of each protocol under different traffic loads
3. Analyze routing overhead induced by each protocol
4. Evaluate the effectiveness and the reliability of data delivery

Results and Findings:

1. **Energy Consumption:** Figure 6 demonstrates protocol behaviors in terms of average energy consumption for different packet rates. The main findings are:
    (a) DSDV exhibited the best performance because of its efficient routing tables at low packet rates
    (b) AODV showed improved energy efficiency at high packet rates
    (c) DSR began to perform better than DSDV at packet rates higher than 20 p/s

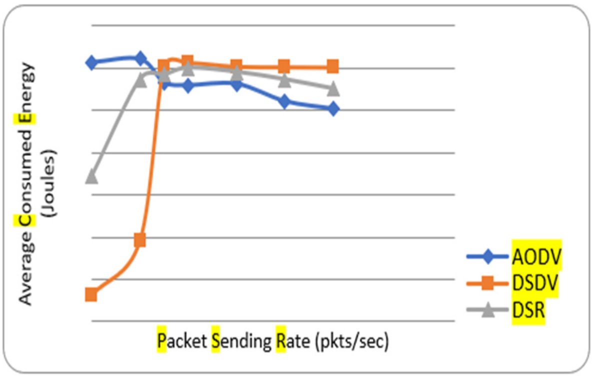

Figure 6. Average consumed energy vs. packet sending rate (regular traffic).

2. **Throughput Evaluation:** Figure 7 illustrates the effect of packet rate change on routing protocol behaviors when throughput metric is measured. The simulation outcomes can be summarized as follows:
    (a) DSR provided the most optimal throughput, attributed to its lower routing overhead at higher packet rates.
    (b) DSDV had the lowest throughput, with noticeable improvement as packet rates increased.

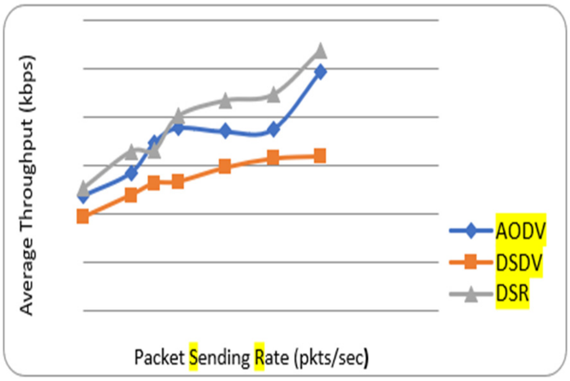

Figure 7. Average throughput vs. packet sending rate (regular traffic).

3. **NRL Analysis:** NRL metric is examined in Figure 8 and the simulation outcomes clarify the following:

(a) DSR showed the worst NRL at low packet rates due to frequent RREQ packets being needed to update stale links.
(b) DSDV and AODV had comparable NRL values at higher packet rates due to the use of periodic updates and routing tables.

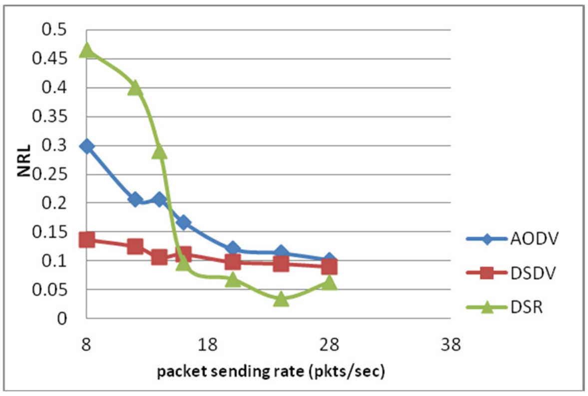

Figure 8. NRL load vs. packet sending rate (regular traffic).

4. **PDF and TDP Measurements:** In Figures 9 and 10, PDF and TDP metrics are examined, and the main simulation findings are as follows:
   - DSDV performed the worst protocol in terms of PDF and TDP. As packet rates and node speeds increased, DSDV struggled with stale routes and broken links.
   - DSR protocol showed superior performance with stable PDF and low TDP, benefiting from fast route discovery and multiple cached routes.

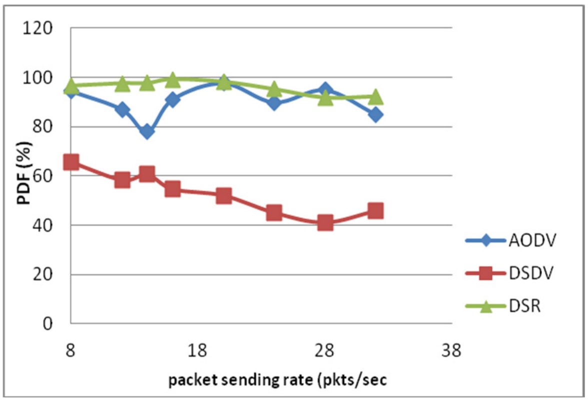

Figure 9. PDF vs. packet rate (regular traffic).

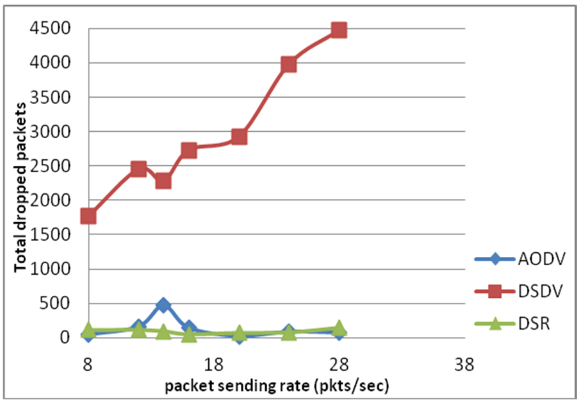

Figure 10. TDP vs. packet rate (regular traffic).

Scenario I discussion and analysis:

Energy Consumption: DSDV is suitable for low-traffic scenarios, due to its low energy consumption. AODV and DSR are more energy-efficient in cases of high traffic.

Throughput: DSR is optimal in cases requiring high throughput, such as real-time video streaming or large data transfer during disaster recovery.

NRL: DSR has the higher routing overhead at low packet rates; however, it has a stable performance at higher packet rates, making it adequate for dynamic environments.

Efficiency and Reliability: DSR's fast route recovery and multiple cached routes make it highly efficient and reliable in dynamic environments.

2. Simulation Scenario II

Simulation Setup:

- **Simulation Tool:** NS3 network simulator
- **Area:** 1000 m × 1000 m
- **Nodes:** 10, 16, 20, 30, 50 and 60 nodes
- **Source–Destination Pairs:** Half the number of active nodes
- **Traffic Patterns:** Regular and irregular traffic patterns
- **Metrics:** average energy consumption, throughput, NRL, PDF and TDP

Use Case: MANETs are deployed in search and rescue operations to establish communication networks among responders. This simulation scenario mainly inspects how the DSDV, DSR and AODV routing protocols can perform under varying numbers of nodes while different traffic loads are considered. Also, the simulation outcomes can contribute to investigating how the network can adapt to varying traffic patterns and at same time provide reliable data transfer especially in dynamic environments.

Scenario Goals:

1. Study the relationship between energy consumption and number of nodes
2. Evaluate the capability of each protocol to deliver data reliably under different node quantities
3. Understand the routing overhead induced by each protocol
4. Evaluate reliability and efficiency of data delivery

Results and Findings:

1. **Energy Consumption:**
   - **Regular Traffic:** Figure 11 shows that DSDV had the best performance with lower quantities of nodes and DSR showed superior performance at higher quantities of nodes due to route caching.

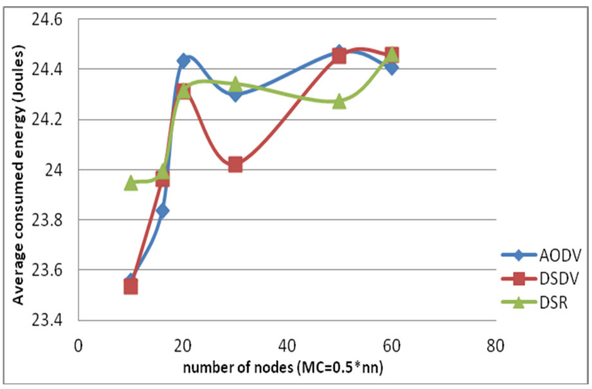

Figure 11. Energy consumption vs. number of nodes (regular traffic).

   - **Irregular Traffic:** Figure 12 showed decreased energy consumption compared to regular traffic with all protocols. DSDV performance decay at higher quantities of nodes, while DSR and AODV showed stable energy consumption

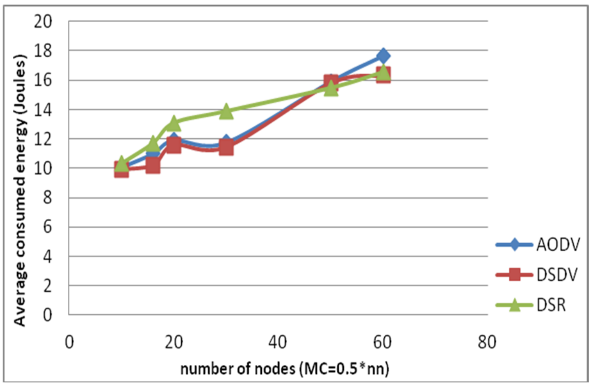

Figure 12. Energy consumption vs. number of nodes (irregular traffic).

2. **Throughput Evaluation:**
   - **Regular Traffic:** Figure 13 shows that DSR had the highest throughput, benefiting from lower routing overhead, while DSDV had the lowest throughput.

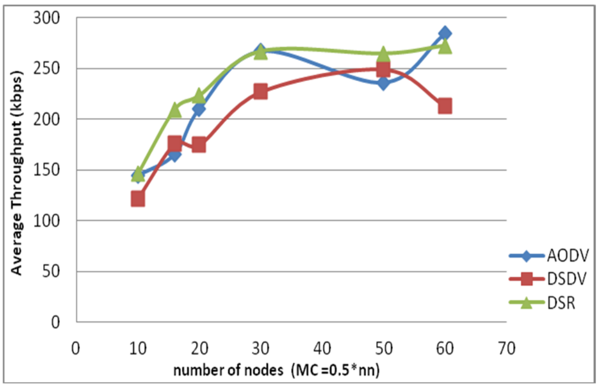

Figure 13. Throughput vs. number of nodes (regular traffic).

   - **Irregular Traffic:** in Figure 14, it is clear that DSR was superior in terms of throughput profiting from lower routing overhead, with higher throughput compared to regular traffic.

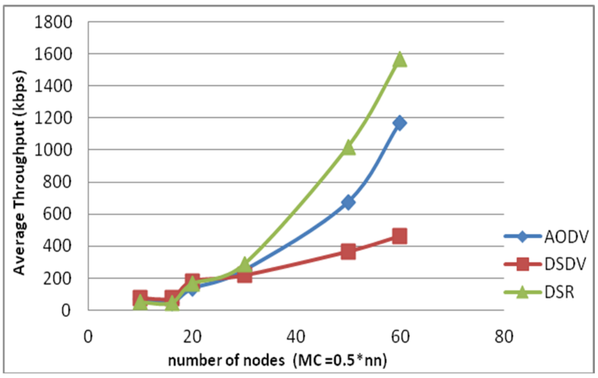

Figure 14. Throughput vs. number of nodes (irregular traffic).

3. **NRL Analysis:**
   - **Regular Traffic:** AODV had the highest NRL in Figure 15 at higher node quantities, while DSDV and DSR performed comparably.

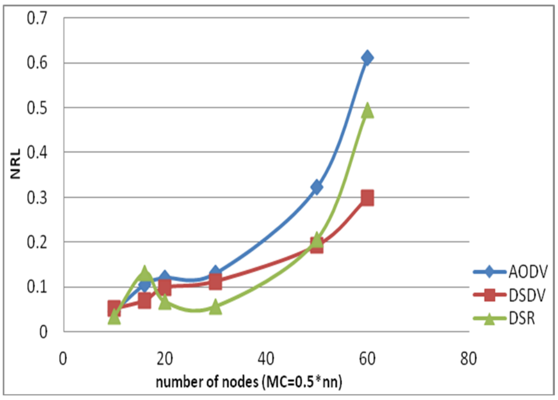

Figure 15. NRL vs. number of nodes (regular traffic).

- **Irregular Traffic:** DSDV had a higher NRL, as shown in Figure 16, with fewer nodes, as it uses constant routing table updates even during the "OFF" period. DSR demonstrated efficient NRL values with higher quantities of nodes, due reliable route caching.

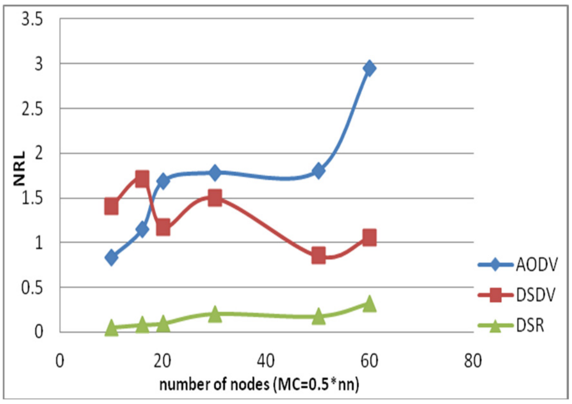

Figure 16. NRL vs. number of nodes (irregular traffic).

4. **PDF and TDP Measurements:**
   - **Regular Traffic:** Figures 17 and 18 indicate that DSDV provide inferior performance, while DSR and AODV is showing superior performance in terms of PDF and TDP.

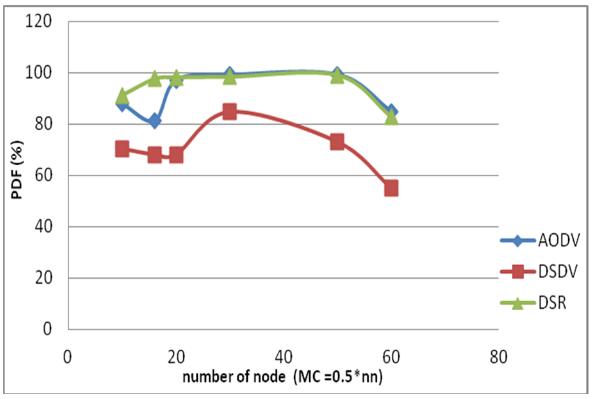

Figure 17. PDF vs. number of nodes (regular traffic).

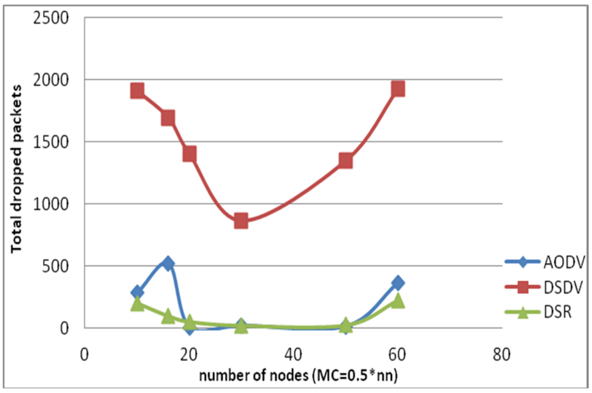

Figure 18. TDP vs. number of nodes (regular traffic).

- **Irregular Traffic:** DSR and AODV maintained superior performance, as seen in Figures 19 and 20, while DSDV showed improved performance with low node quantities.

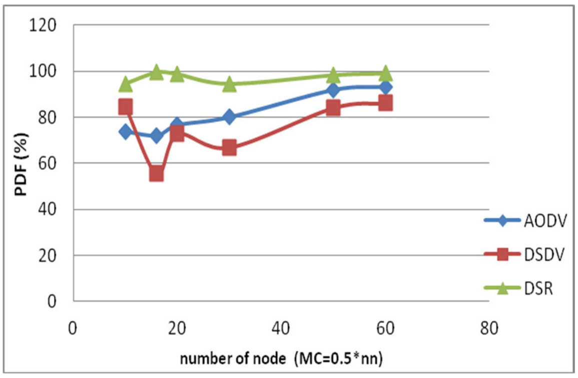

Figure 19. PDF vs. number of nodes (irregular traffic).

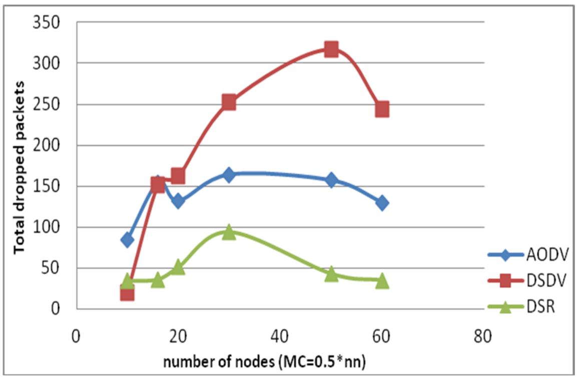

Figure 20. TDP vs. number of nodes (irregular traffic).

Scenario II discussion and analysis:

Energy Consumption: DSDV is optimal for networks with low node quantities and low traffic. DSR and AODV are more reliable in higher-load networks.

Throughput: DSR is the optimal choice for high-throughput applications, specifically in dynamic environments with varying quantities of nodes.

NRL: DSR has lower routing overhead with higher node quantities, which makes it suitable for large and dynamic networks.

Efficiency and Reliability: Both DSR and AODV offer reliable performance with high PDF and low TDP, which is vital for the sustainability of communication in urban search and rescue missions.

3. **Simulation Scenario III**
   Simulation Setup:
   - **Simulation Tool:** NS3 network simulator
   - **Area:** 1000 m × 1000 m
   - **Nodes:** 50
   - **Node Speeds:** Slow speed (1–10 m/s), moderate speed (16–20 m/s) and high speed (24–28 m/s)
   - **Traffic Patterns:** Regular and irregular traffic patterns
   - **Metrics:** average energy consumption, throughput, NRL, PDF and TDP

Use Case: In vehicular ad hoc networks (VANETs), vehicles move at different speeds, incurring the need for reliable and efficient communication to provide safety and traffic management. In this simulation scenario, we mainly need to figure out the impact of different node speeds and different traffic loads on the behavior of DSDV, DSR and AODV protocols when a fixed number of nodes in the network is considered.

Scenario Goals:

1. Determine the energy consumption of each protocol at different node speeds
2. Measure data delivery capability under different node speeds
3. Analyze routing overhead induced by each protocol
4. Evaluate reliability and efficiency of data delivery under different node speeds

Results and Findings:

1. **Energy Consumption:**
   - **Regular Traffic:** Figure 21 highlights that DSDV provided the best performance and consistent energy consumption across different speeds due to periodic routing table updates. DSR consumed more energy at higher speeds as route caches became ineffective, incurring the need for frequent route discovery.

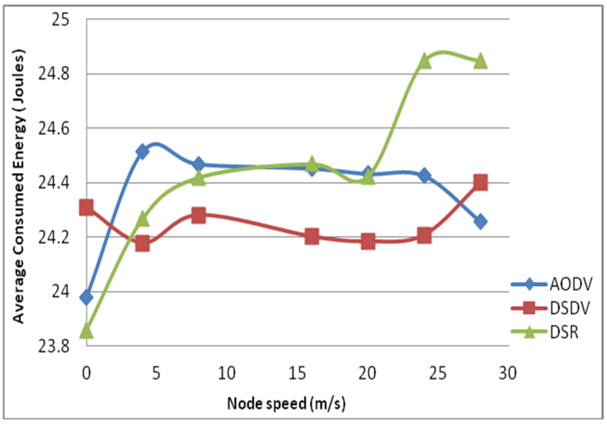

Figure 21. Energy consumption vs. node speed (regular traffic).

   - **Irregular Traffic:** Overall, all protocols in Figure 22, consumed comparably less energy than in regular traffic in Figure 21. In addition, DSR had the lowest performance due to frequent route discovery activations, which were caused by the "ON/OFF" nature of irregular traffic.

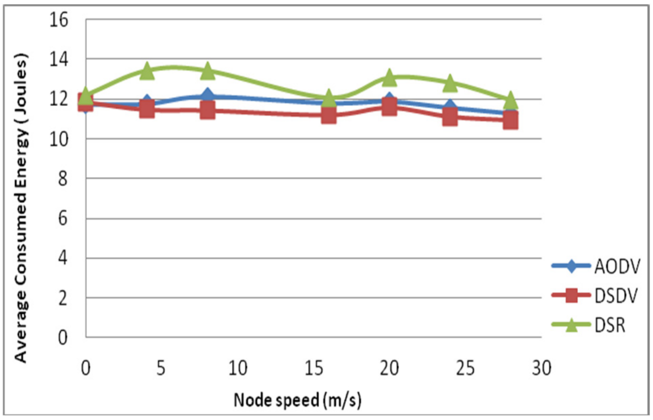

Figure 22. Energy consumption vs. node speed (irregular traffic).

2. **Throughput Evaluation:**
   - **Regular Traffic:** The simulation outcomes in Figure 23 indicate that DSR had the highest throughput at different node speeds due to lower routing overhead. On the other side, AODV showed lower performance at higher speeds due to frequent route discoveries occupying network bandwidth.

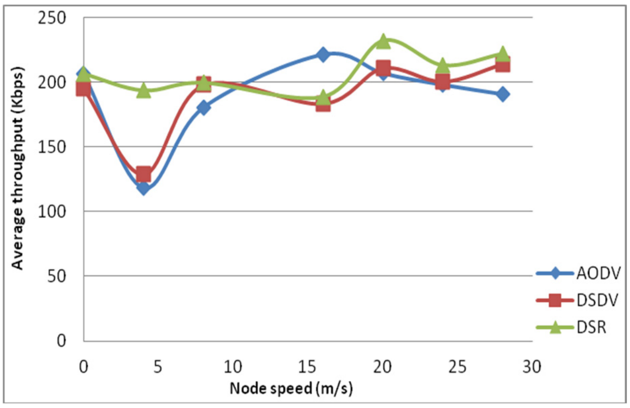

Figure 23. Throughput vs. node speed (regular traffic).

   - **Irregular Traffic:** Figure 24 indicates that DSR and AODV have comparable performance at lower node speeds. On the other hand, it is clear that both DSR and DSDV protocols can demonstrate improved throughput at speeds exceeding 18 m/s.

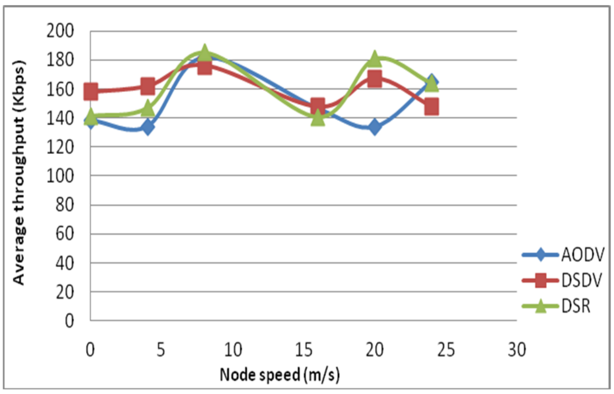

Figure 24. Throughput vs. node speed (irregular traffic).

3. **NRL Analysis:**
   - **Regular Traffic:** Generally, it can be noticed from Figure 25 that both AODV and DSR provide higher NRL values at different node speeds, which is mainly related to frequent route discovery requests. DSDV maintained consistent NRL across different node speeds, as it uses routing tables.

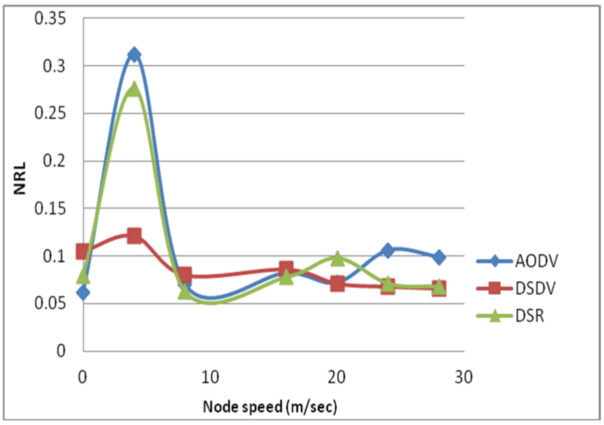

Figure 25. NRL vs. node speed (regular traffic).

   - **Irregular Traffic:** Figure 26 indicates that DSDV provided bad performance at different node speeds due to increased traffic load, while DSR showed a superior behavior, benefiting from the "ON/OFF" traffic pattern.

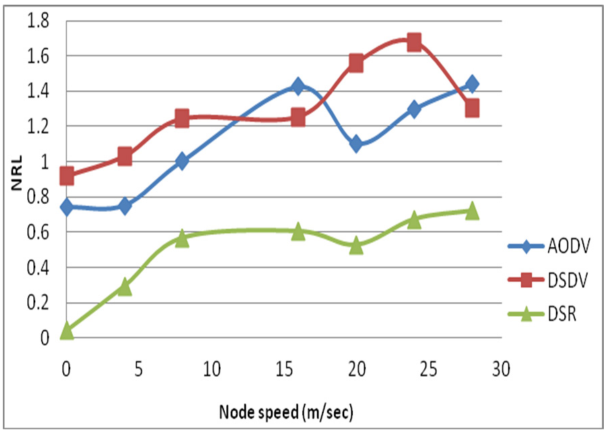

Figure 26. NRL vs. node speed (irregular traffic).

4. **PDF and TDP Measurements:**
   - **Regular Traffic:** In Figures 27 and 28, both DSR and AODV protocols demonstrate a comparable and reliable performance under different node speeds. On the other hand, DSDV showed the worst behavior, because of the problem of handling broken links.

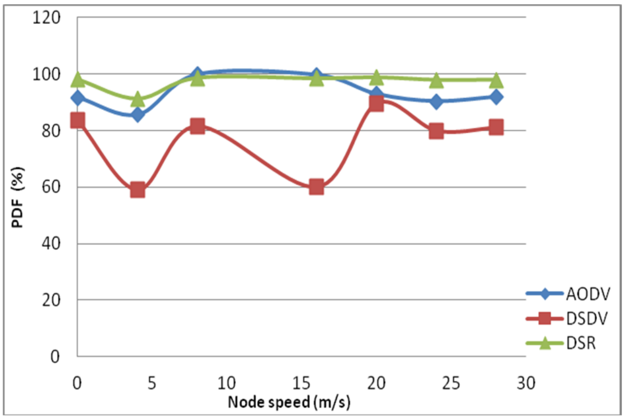

Figure 27. PDF vs. node speed (regular traffic).

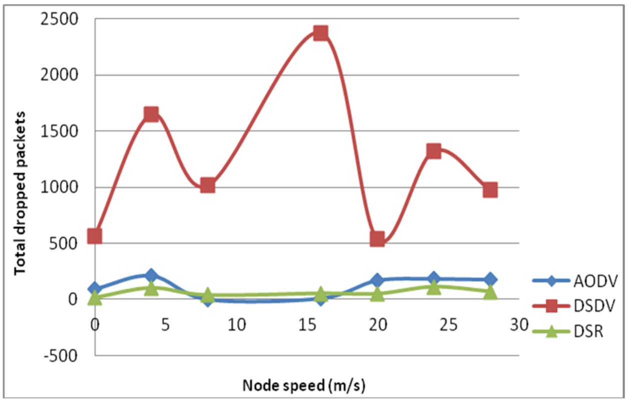

Figure 28. TDP vs. node speed (regular traffic).

- **Irregular Traffic:** In Figures 29 and 30, DSR provided a superior performance in terms of PDF and TDP metrics under high node speeds, and this adequate behavior is mainly related to its efficient route caching and reduced control packets. AODV showed a consistent performance, while DSDV struggled under higher node speeds, because of its broken links.

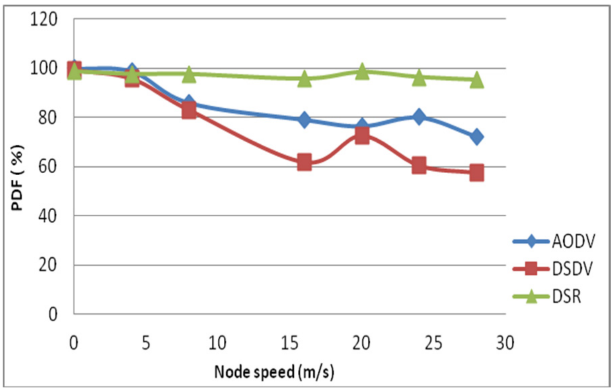

Figure 29. PDF vs. node speed (irregular traffic).

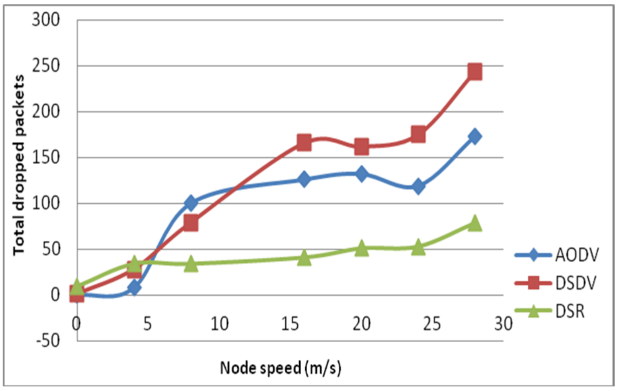

Figure 30. TDP vs. node speed (irregular traffic).

Scenario III discussion and analysis:

Energy Consumption: DSDV is efficient and reliable in low mobility environments due to its consistent energy consumption. DSR and AODV are more efficient at higher node speeds and in irregular traffic.

Throughput: DSR maintains high throughput in dynamic environments with varying node speeds.

NRL: DSR has the lowest routing overhead at higher speeds, which makes it a good selection for high-mobility networks. DSDV has a consistent NRL, which is beneficial in lower node speeds and stable environments.

Efficiency and Reliability: DSR and AODV protocols prove reliable performance with high PDF and low TDP and verify that these protocols can be a good candidate for applications demanding robust communication at different node speeds.

4. **Simulation Scenario IV**

   Simulation Setup:

   - **Simulation Tool:** NS3 network simulator
   - **Area:** 1000 m × 1000 m
   - **Nodes:** 50 nodes
   - **Traffic Pattern:** Joint traffic with 80% irregular and 20% regular traffic
   - **Packet Rates:** different packet rates
   - **Metrics:** average energy consumption, throughput, NRL, PDF and TDP

Use Case: The experiment simulates a practical MANET environment that incorporates different data streams, such as voice, video and data, by generating a mixture of irregular and irregular traffic loads. In this scenario, the joint traffic is implemented and mainly consists of 80% irregular traffic and 20% regular traffic. The main goal in this simulation scenario is to assess the performance of the routing protocols DSDV, DSR and AODV when different traffic loads are applied.

Scenario Goals:

1. Determine the energy consumption under joint traffic conditions
2. Assessing throughput under joint traffic conditions
3. Analyze routing overhead induced by each protocol
4. Evaluate the reliability and efficiency of the data delivery

Results and Findings:

1. **Energy Consumption:**
   - As seen in Figure 31, DSDV outperformed other protocols due to routing tables at low packet rates, while at high packets rate, AODV demonstrated the lowest energy profile as a result of its on-demand routing mechanism, which eliminates unnecessary routing activity.

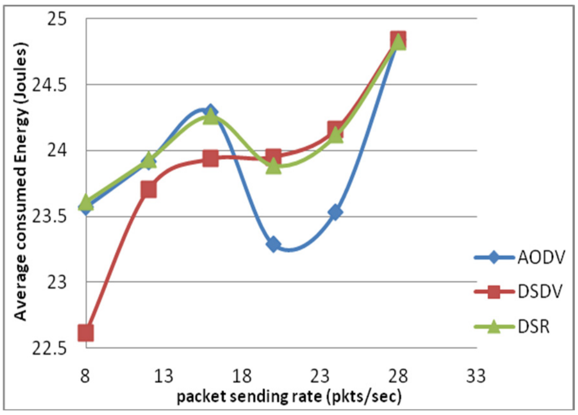

Figure 31. Energy consumption vs. packet rate (joint traffic).

2. **Throughput Evaluation:**
   - In Figure 32, where joint traffic load is implemented, DSR protocol shows the highest throughput, while AODV and DSDV protocols provide comparable performance.

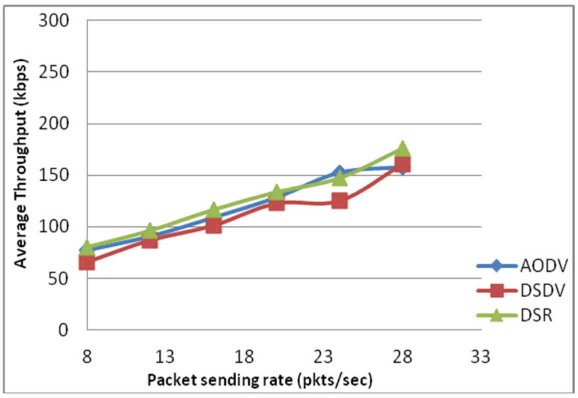

Figure 32. Throughput vs. packet rate (joint traffic).

3. **NRL Analysis:**
   - In Figure 33, DSR is mainly showing a reasonable lower NRL under joint traffic conditions, while DSDV proves the minimum NRL at packet rates higher than 24 p/s, indicating stable table routing updates.

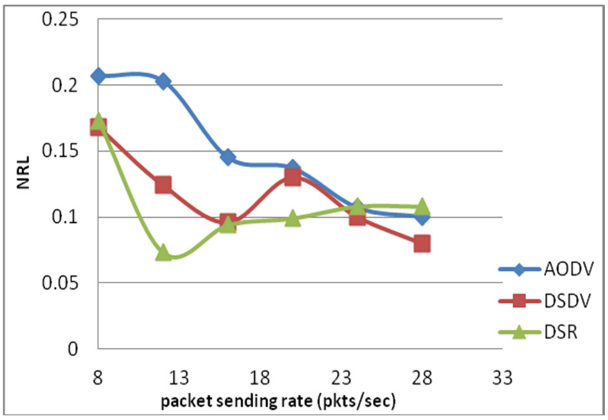

Figure 33. NRL vs. packet rate (joint traffic).

- AODV exhibited a higher NRL at low packet rates due to frequent RREQ packets, and then it started showing improvement at higher packet rates and fewer RREQ packets.

4. **PDF and TDP Measurements:**
   - In Figures 34 and 35, both DSR and AODV protocols maintained efficient and consistent performance in terms of PDF and TDP under joint traffic conditions. DSDV showed improvement in reducing dropped packets when joint traffic type is considered, due to the "ON/OFF" feature of irregular traffic, which allows for some time for buffer management and also allows for some time for routing table updates.

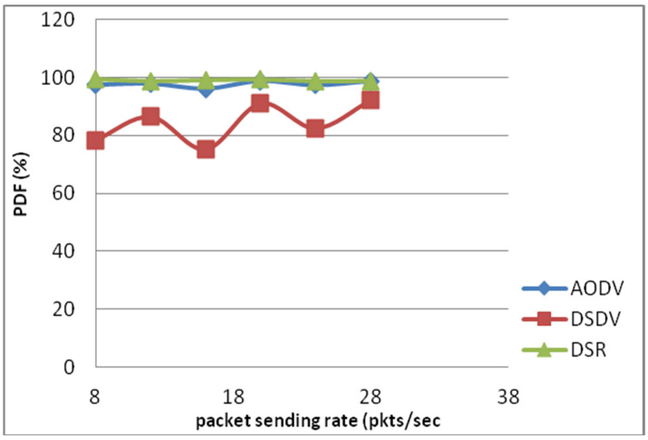

Figure 34. PDF vs. packet rate (joint traffic).

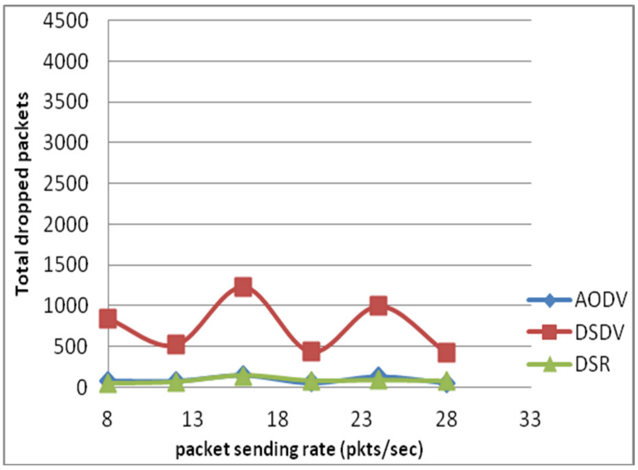

Figure 35. TDP vs. packet rate (joint traffic).

Scenario IV discussion and analysis:

Energy Consumption: DSDV is energy-efficient at low packet rates, while AODV becomes more energy efficient at higher packet rates because of its on-demand routing nature.

Throughput: DSR consistently provided the highest throughput, indicating that it can be an ideal selection for environments where data delivery capability is a priority.

NRL: DSR shows lower NRL compared to other protocols, making it more suitable for environments where traffic loads vary. On the other hand, DSDV and AODV protocols can be considered mainly at high packet rates.

Efficiency and Reliability: DSR and AODV maintained high efficiency and reliability under joint traffic conditions and DSDV showed improvement in reducing dropped packets due to irregular traffic "ON/OFF" intervals.

5. **Simulation Scenario V**

Simulation Setup:

- **Simulation Tool:** NS3 network simulator
- **Area:** 1000 m × 1000 m
- **Nodes:** 50 nodes
- **Traffic Pattern:** Joint traffic with 80% irregular and 20% regular traffic
- **Node speed:** different node speeds are applied
- **Metrics:** average energy consumption, throughput, NRL, PDF and TDP

Use Case: In this scenario, the joint traffic pattern is implemented and mainly consists of 80% irregular traffic and 20% regular traffic. The main goal in this simulation scenario is to evaluate the performance of the routing protocols DSDV, DSR and AODV when different node speeds are considered as key parameters in the environment.

Scenario Goals:

1. Determine energy consumption under different node speeds and joint traffic load
2. Analyze data delivery capability of each protocol
3. Analyze the routing overhead induced by each protocol
4. Evaluate the reliability and efficiency of data delivery when both the joint traffic pattern and different node speeds are implemented in the simulation environment

Results and Findings:

1. **Energy Consumption:**
   - In Figure 36, it can be noticed that at lower node speeds, DSDV outperformed other protocols because of its efficient routing table updates, while DSR protocol demonstrated the lowest energy consumption at higher node speeds.

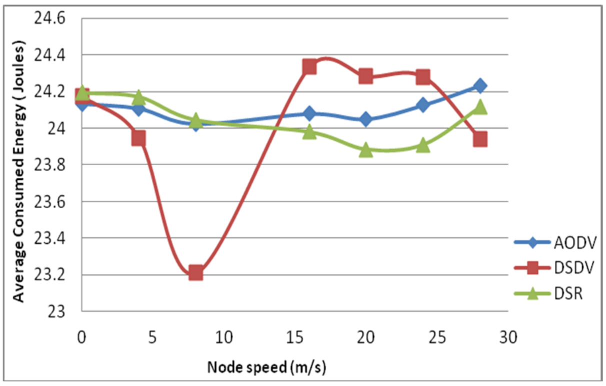

Figure 36. Energy consumption vs. node speed (joint traffic).

2. **Throughput Evaluation:**
   - In Figure 37, DSR demonstrated the highest throughput under joint traffic conditions, while AODV and DSDV showed comparable performance at different node speeds.
3. **NRL Analysis:**
   - In Figure 38, DSR provides the best performance regarding the NRL metric, especially at node speeds above 15 m/s. Similarly, DSDV shows improvement in reducing the NRL metric at node speeds around 10 m/s, which indicates stable routing table updates. On the other side, AODV shows high NRL values for higher node speeds due to frequent RREQ packet.

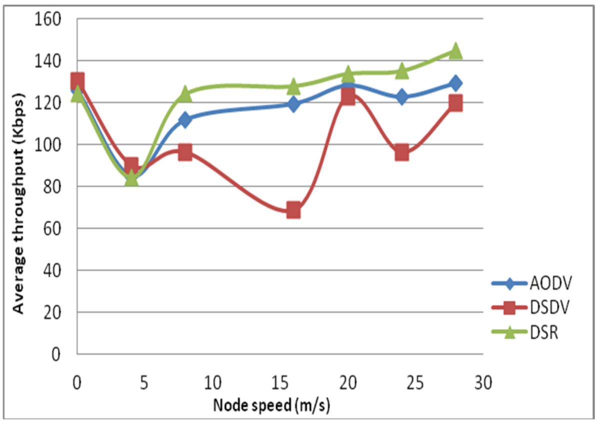

Figure 37. Throughput vs. node speed (joint traffic).

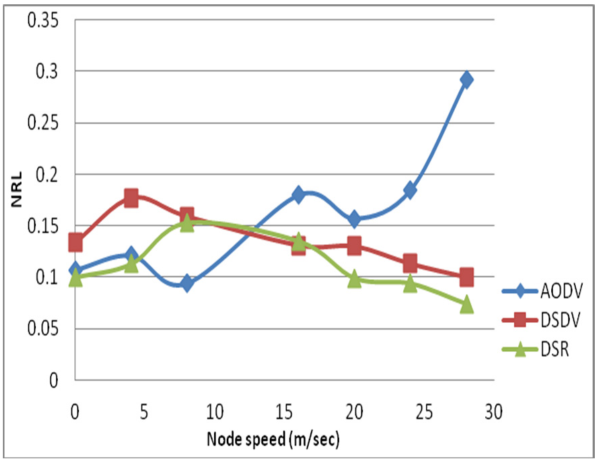

Figure 38. NRL vs. node speed (joint traffic).

4. **PDF and TDP Measurements:**
    - The simulation outcomes in Figures 39 and 40 indicate that both DSR and AODV provide reliable performance in terms of both PDF and TDP metrics at different node speeds. On the other side, the simulation results also imply that DSDV is not a good candidate protocol when joint traffic patterns and different node speeds are implemented simultaneously in the MANET environment.

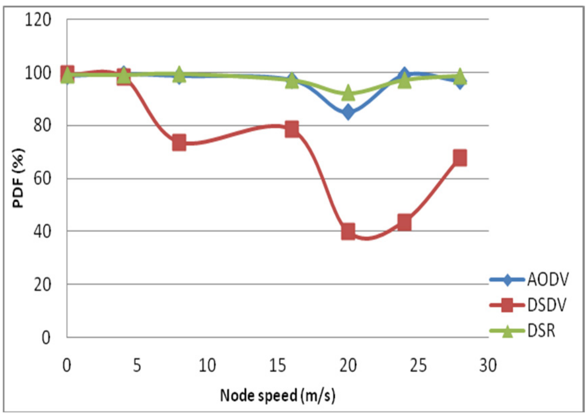

Figure 39. PDF vs. node speed (joint traffic).

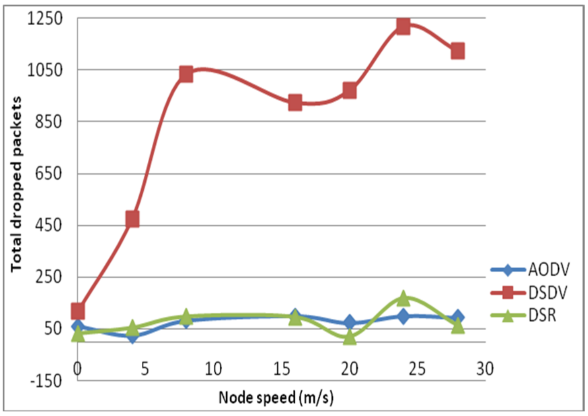

Figure 40. TDP vs. node speed (joint traffic).

Scenario V discussion and analysis:

Energy Consumption: overall, DSDV protocol is energy efficient at low node speeds, while DSR protocol demonstrated lowest energy consumption at higher node speeds.

Throughput: DSR protocol verifies its efficiency in delivering data packets compared to other protocols when joint traffic pattern is considered.

NRL: DSR protocol proves its superiority in providing lower NRL values, while AODV outcomes shows high NRL values especially at higher node speeds due to frequent RREQ packet.

Efficiency and Reliability: DSR and AODV verify high reliability in terms of PDF and TDP when joint traffic conditions are applied. In contrast, DSDV outcomes clarify that DSDV is not a good candidate protocol for joint traffic pattern when different node speeds are implemented in the MANET environment.

Routing Protocols: major differences and characteristics:

1- The nature of DSDV guarantees consistent routing table updates, leading to low energy consumption at lower traffic loads. The performance of DSDV is inversely proportional to the node mobility, based on the fact that it would need frequent routes updates.

3- DSR offers high throughput and low NRL in stable networks. However, due to its routing caching and source routing mechanism, it increases its energy consumption under high node mobility conditions.

3- AODV is characterized by an on-demand routing mechanism, which effectively balances routing overhead and energy consumption, but it shows bad performance when high node mobility environment is considered.

Theoretical Verification and Impacts on MANET

Validation for the theoretical insights for the examined routing protocols have been verified based on the simulation results. Additionally, the analysis for the simulation outcomes has also contributed towards understanding the behavior of the examined routing protocol when diverse simulation parameters are applied in MANET. Generally, the validation for the theoretical characteristics for the examined routing protocols based on the simulation outcomes can be summarized as follows:

1. DSDV protocol is energy-efficient at low traffic loads and less effective at higher loads because of its frequent routing updates.
2. DSR utilization of route caches leads to superior throughput and higher energy consumption at higher node mobility.
3. AODV offers some sort of balance between energy consumption and routing overhead but suffers at high node mobility due to frequent route discoveries.

Based on the simulation results previously discussed, we can choose the routing protocol that can provide the best performance taking into consideration the type of the implemented traffic load and the evaluated performance metric. Table 4 demonstrates the most candidate routing protocols when packet rate variation parameter is considered. Table 5 summarizes the most appropriate protocols that can be chosen when the node speed parameter is changing in the environment. Table 6 also illustrates the most recommended routing protocols when node quantity in the network are the key parameter. Consumed energy, throughput and NRL metrics are chosen here for this brief comparison.

Table 4. Best selected protocols (packet rate).

Network / Parameter	Metric	Regular Traffic	Joint Traffic
Packets rate	Throughput	DSR/AODV	DSR/AODV
	Consumed energy	DSR	AODV
	NRL	DSR	DSDV

Table 5. Best selected protocols (node speed).

Network / Parameter	Metric	Regular Traffic	Irregular Traffic	Joint Traffic
Node speed	Throughput	DSR	DSDV	DSR
	Consumed energy	DSDV	DSDV/AODV	DSR/DSDV
	NRL	DSDV	DSR	DSR

Table 6. Best selected protocols (node quantity).

Network / Parameter	Metric	Regular Traffic	Irregular Traffic
Nodes quantity	Throughput	DSR/AODV	DSDV
	Consumed energy	DSDV	DSDV
	NRL	DSDV	DSR

In Tables 4 and 5 when joint traffic load is considered, DSR protocol mainly proved the superior behaviors for most of the performance metrics considered. In Tables 5 and 6 when consumed energy metric is evaluated, DSDV protocol mainly show an outstanding performance when either regular or irregular traffic load is applied. Briefly, we can claim that the choice of the optimum routing protocol depends on many factors that may include network parameters, performance metric examined and implemented traffic load.

Numerically, DSR protocol consistently demonstrated superior performance in 9 scenarios in terms of throughput, PDF, TDP and NRL, when high packet rates, high node quantities and high node mobility environments are considered. DSDV has shown better energy consumption and routing stability in 7 cases, under irregular traffic, low node quantities and low packet rates. AODV showcased moderate performance in 6 scenarios under higher packet rates and node mobility environments.

The research in this area can also be enhanced by suggesting some factors to be considered for future work. Authors can Implement further factors that can influence MANET performance such as latency, security, Jitter and end-to-end Delay [31]. Another research direction may suggest the use routing protocols in conjunction with Deep Reinforcement Learning (DRL) algorithm [32], or with RL based Q algorithm [33] or with Deep Neural networks (DNN) based Long Short-Term Memory (LSTM) network [34], in order to more investigate the performance of the wireless communication networks when diverse performance metric and parameters are considered.

9. Conclusions

In this paper, we mainly work on providing an extended performance analysis for the three conventional ad hoc network routing protocols AODV, DSR and DSDV. To achieve this aim, various performance metrics have been examined, different types of traffic loads have been implemented in the simulation scenarios and diverse network parameters such as node speed, network node quantity and packet rate are considered. Various simulation environments have been created to enhance the simulation analysis and improve justifications for protocol behaviors.

Regular traffic, irregular traffic and joint traffic loads have been implemented in the simulation environments when evaluating the routing protocols. The inspected performance metrics are average energy consumption, average throughput, normalized routing load, packet delivery fraction and total dropped packets. Different simulation tools can be used in simulating ad hoc network, in this work we choose network simulator because the tool is well established and widely considered in authors' research for simulating wireless network. The resultant trace files have been parsed using diverse AWK programs to achieve the examined performance metrics. Simulation results demonstrate that none of the routing protocols could deliver the optimal performance for all examined metrics. DSR protocol proves to be more consistent for average throughput and packet delivery fraction in 9 instances when regular traffic and joint traffic loads are considered. On the other hand, results also reveal that DSR is not a suitable candidate with respect to energy consumption mainly when node speed and node quantity parameters are considered. DSDV protocol shows enhanced response over other protocols in 7 cases, in terms of energy consumption when either regular traffic or irregular traffic load is applied, and network size is the key parameter. For joint traffic scenario, DSDV shows better performance only for lower node speed. Regarding AODV protocol, the performance seemed to vary according to the traffic load implemented, but overall, it shows superiority over other protocols in 6 scenarios for joint traffic stream, when either throughput metric or energy consumption metric is measured versus packet rate. Overall, simulation results based on joint traffic load show comparable results to that obtained when regular traffic scenario is inspected.

Author Contributions: Conceptualization, Q.R.; Software, A.B.; Formal analysis, writing review, M.G.; Software, Data curation, L.A.; Writing review & editing, M.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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