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# Design and Analysis of a Bandwidth Aware Adaptive Multipath N-Channel Routing Protocol for 5G Internet of Things (IoT)

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**Abstract**

Large numbers of mobile wireless nodes that can move randomly and join or leave the network at any moment make up mobile ad-hoc networks. A significant number of messages are delivered during information exchange in populated regions because of the Internet of Things' (IoT) exponential increase in connected devices. Congestion can increase transmission latency and packet loss by causing congestion. More network size, increased network traffic, and high mobility that necessitate dynamic topology make this problem worse. An adaptive Multipath Multichannel Energy Efficient (AMMEE) routing strategy is proposed in this study, in which route selection strategies depend on forecasted energy consumption per packet, available bandwidth, queue length, and channel utilization. While multichannel uses a channel-ideal assignment process to lessen network collisions, multipath offers various paths and balances network strain. The link bandwidth is split up into a few sub-channels in the multichannel mechanism. To reduce network collisions, several source nodes simultaneously access the channel bandwidth. The cooperative multipath multichannel technique offers several paths from a single source or from several sources to the destination without colliding or becoming congested. The AMMEE routing approach is the basis for path selection. A load- and bandwidth-aware routing mechanism in the proposed AMMEE chooses the path based on node energy and forecasts their lifetime, which improves network dependability. The outcome demonstrates a comparative analysis of various multichannel medium access control (MMAC) techniques, including Parallel Rendezvous Multi Channel Medium Access Protocol (PRMMAC), Quality of Service Ad hoc On Demand Multipath Distance Vector (QoS-AOMDV), Q-learning-based Multipath Routing (QMR), and Topological Change Adaptive Ad hoc On-demand Multipath Distance Vector (TA-AOMDV) and the proposed AMMEE method. The results show that the AMMEE approach outperforms alternative systems.

**Keywords:**
MANET;
Multichannel;
AMMEE;
Congestion;
Energy;
Delay;
Dropping.

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## 1- Introduction

Independent mobile nodes are randomly placed in mobile ad hoc networks and have the ability to exit or join the network while in motion. To exchange information, these nodes connect wirelessly with one another. Ad hoc enables the fast addition of new devices. Network devices are free to travel in any direction, creating a dynamic topology. A network's design presents many difficulties and problems, making it an extremely challenging endeavor. Every node has the ability to function as a router, sending packets from source to destination. Any personal computer, cell phone, or other devices can serve as one of these nodes. Small networks to very large dynamic networks are covered by Mobile Ad hoc Network (MANETs) and IoT applications. Examples include Vehicular Ad hoc Network (VANET) applications,

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low-level applications like classroom conference rooms, automated warfare fields, rescue operations, and emergency operations [1]. These networks use many hops for node-to-node communication. The sender employs an intermediary node for communication when sending data packets to the destination node. As a result, every node in a network has a crucial function. An effective routing method is necessary to satisfy the requirements of the design restrictions of IoT-enabled MANETs. Routing offers methods for choosing the best path within a network. When the data packet is processed from source to destination by choosing the best path between sender and receiver, the routing protocol facilitates communication between routers. A routing protocol's design is an extremely difficult endeavor.

There have been numerous routing protocols proposed so far. These protocols, which are applicable in IoT for mobile devices [2], can be broadly categorized as reactive, proactive, and hybrid protocols [3, 4], as follows: (i) In this type of protocol, such as the destination sequence distance vector (DSDV), mobile nodes update their routing tables by routinely exchanging routing information between them. Proactive routing protocols produce a lot of control messages and raise network overhead because of this information exchange. Thus, current routing protocols are not appropriate for MANETs and the Internet of Things; ii) Reactive routing techniques like Ad hoc on demand distance vector (AODV) and dynamic source routing (DSR) have been developed for MANETs to get around the shortcomings of proactive protocols. In this situation, each node performs proactively when it is outside the region and reactively when it enters the region close to its destination. Reactive routing also involves route discovery and route maintenance. The choice of a routing method that guarantees timely and successful data packet transmission with increased packet delivery rates determines the performance of the network [5, 6]. By boosting throughput and lowering overhead, a smart routing protocol prevents network congestion. Several protocols have been put out in the literature [7, 8] to address network congestion.

Combining computing, communication, and caching reduces the overall latency when relaying sensed data to the cloud as necessary. Caching occurs at several network layers. The detected data will be briefly stored locally at a cache and will either be totally consumed locally without transmission or processed locally before being transmitted as aggregated and compressed data to the cloud. By controlling the sensed data locally, as shown in figure 1, this method can significantly help to reduce congestion in MANETs and IoT situations by mitigating the influence of the sensing bottleneck owing to huge data transmission for a variety of sensing capabilities [9]. When there are too many data packets present in the subnet, congestion occurs in networks. When a network carries more load, that is, the number of packets delivered to it than it can handle, that is when congestion occurs. Packet loss and bandwidth degradation are caused by congestion. Congestion affects the overall coverage area but does not overburden mobile nodes in MANETs and IoT.

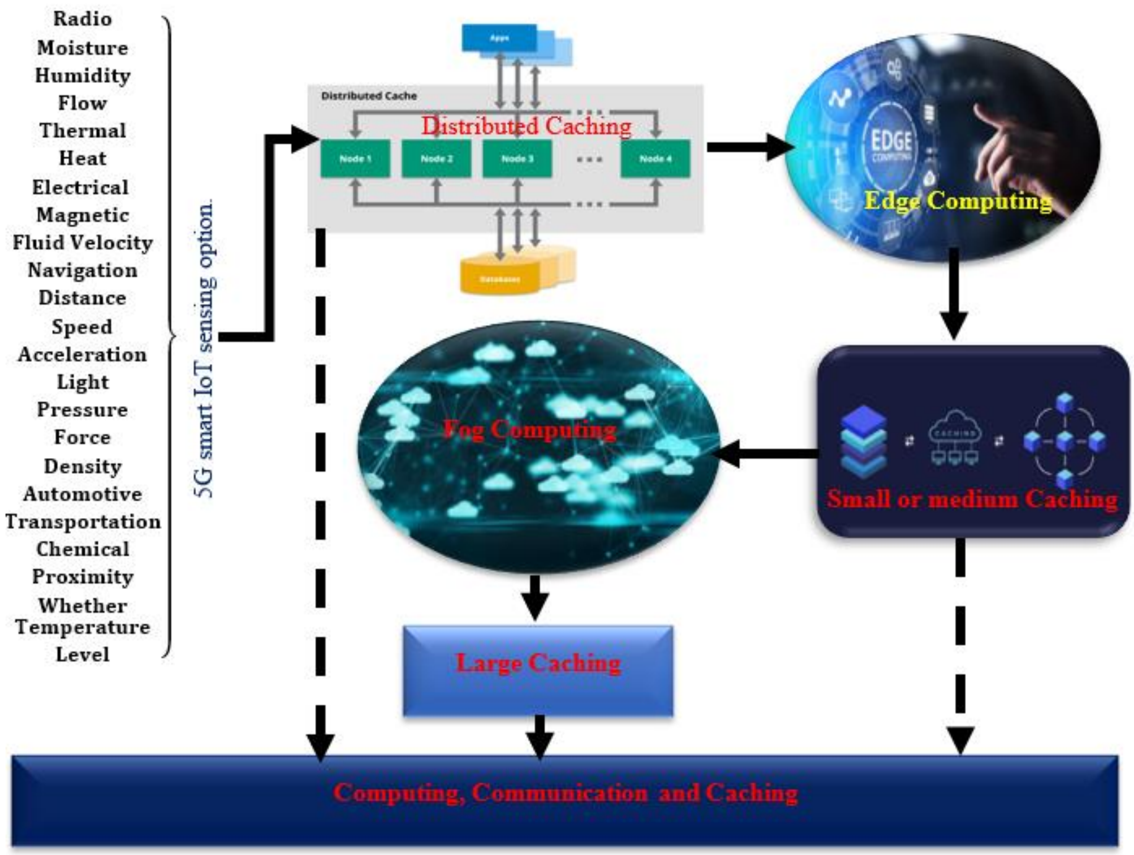


**Figure 1. IoT 5G smart sensing scenario to handle sensing bottlenecks with multiple caching, compute, and communication support**

The following problems can occur in the network if the chosen routing protocol is inadequate to handle congestion [10].

a. Increased delay determines the presence of congestion by calculating the anticipated delivery time. Network congestion may be a factor if there is a significant delay. In these circumstances, it is preferable to use an alternative route, but the choice of new route and the search procedure are both influenced by the chosen routing protocol.

b. To reduce network load, congestion control algorithms either lower the sending rate or delete packets at intermediary nodes, which results in an increase in packet loss. This process raises the ratio of dropped packets, which ultimately lowers network throughput [11]. Figure 2 shows a scenario of congestion with many senders and recipients.

c. High overhead in multipath routing calls for more processing. More retransmission attempts are needed for the selection of an alternate path in cases of congestion, which raises network overhead.

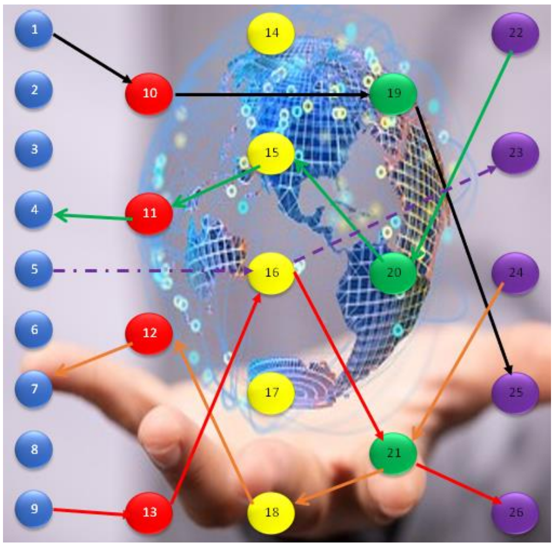

**Figure 2. Congestion scenario with multiple senders and receivers**

Emerging technologies like big data, IoT [12], and the fifth generation (5G) cellular network have revolutionized the world over the past ten years by enabling the realization of "anything, anyone, anytime, everywhere [13, 14]. The IoT is a global network based on accepted communication protocols that use several different technologies to collect and provide observation data from the real world [15] for IoT applications. Over the past ten years, there has been a noticeable transition from non-IoT to IoT devices. In fact, it is anticipated that by 2030, 75% of all electrical and electronic devices will be IoT. Larger size, higher velocity, more modes, higher data quality, and heterogeneity are characteristics of the huge data that they will produce [16]. In the meantime, the development of 5G networks is increasingly serving as a primary engine for the expansion of IoT. 5G is anticipated to offer increased coverage, better throughput, lower latency, and huge capacity connection density [13, 17], paving the path for the Internet to connect billions of sensors. For 5G networks to be effectively adapted to IoT, several potential approaches and technologies have also been put forth, including millimeter-wave (mmWave), massive multiple-input, multiple-output (MIMO), and machine-to-machine (M2M) communications. Hence, homogeneous and heterogeneous sensor networks can connect many sensing devices and greatly aid in the provision of sophisticated services for people [18].

People are being compelled to comprehend the conceptual framework, potential, and constraints of 5G-IoT and its derivative big data due to the increased interest in these topics. IoT data provides new issues for both 5G and IoT because of their distinctive qualities. These challenges include trust [19], security, and privacy, as well as a direct influence on computational complexity and cost in the areas of data storage and processing. In the meanwhile, many circumstances present difficulties with channel utilization and transmission efficiency. Hence, more sophisticated techniques like machine learning and deep learning are needed to process massive amounts of data and optimize the transmission channel [20]. We suggest the 5G Intelligent Internet of Things (5G I-IoT), an Internet-connected framework that uses next-generation communication techniques to transfer and process data, considering those problems and requirements.

Due to the flexibility of the network deployment, researchers from all over the world are investigating communication based on the IoT 5G network idea. It allows for fixed-free, high-speed peer-to-peer data transmission. Since there is no central authority in the communication-based IoT 5G network and the devices move randomly, the already complex network becomes much more complicated. This constant random movement is problematic because it prevents the use of previously determined routes. Routing algorithms commonly used in network infrastructure are not suitable in this case due to the large amount of route calculations and frequent changes in network topology. Therefore, the research community has created various routing protocols to address the problems posed by the mobility of devices within networks [21, 22]. Most of the early research on routing protocols considered only one way to route traffic, limiting the ability of a device to efficiently use all links to its destination. In recent years, academia has explored multipathing protocols to improve IoT 5G network performance. They were developed as an ideal solution for modern telecom-based IoT 5G networks and their derivative networks. Adding links can greatly improve network performance and efficiency, as devices can balance the traffic load across many paths to the same destination [23].

Limited battery life of electronics devices is also a challenge for IoT 5G networks-based telecommunication, requiring optimized energy efficiency to sustain network activity. Many other methods have been used to conserve energy, such as sharing knowledge about energy needs and limiting broadcasts to clusters to stay within routing protocol metrics [24]. Most of the power-saving recommendations are based on single-path routing protocols only. However, choosing the same path each time to forward traffic from a source node to a destination node impacts the efficiency of routing protocols and impacts the battery life of intermediate devices. As a result, when the same path to a destination is chosen for forwarding traffic, it becomes less efficient and reduces the battery life of the device. On the other hand, when established routes become stale due to the random movement of devices, repairing the routes generates a large amount of overhead traffic, leading to increased energy consumption and impacting the performance of routing protocols.

### *1-1- Contribution*

The goal of this study is to optimize the performance of the 5G IoT network in terms of energy consumption, congestion, energy usage per packet, energy metric cost function, bandwidth metric cost function, queue length metric cost function, estimation of channel capacity, and comparison with PRMMAC, MMAC, TA-AOMDV, and QoS-AOMDV protocols. To limit the energy consumption of certain devices and ensure that mobility does not affect packet routing, this study attempts to identify routing protocols to the destination while balancing the burden on all devices. Based on each node's accessible factors, such as battery energy level, mobility data, and device queue length size, an AMMEE algorithm for routing protocols is analyzed. To quantify the available bandwidth and aid in choosing the best protocols and paths to the destination device, a multiple-characteristic route selection measure is also provided. The choice of optimal protocols and paths to the destination device is quantified using a multiple-characteristic route selection measure that is also given. Because of this, the proposed AMMEE routing protocols try to choose the best path from source to destination devices, which reduces device energy consumption, balances device traffic load, and enhances network and route stability during data transmission in 5G IoT devices.

## 2- MANET Different Routing Protocols

MANET is made up of a minimum of two and more independent mobile nodes that connect with one another either directly or indirectly via radio waves. Due to several benefits and uses, the MANET industry is rapidly expanding. To determine the best route from source to destination, routing protocols are utilized. Broadcasting is an essential and frequent operation in an ad-hoc network [25]. This method involves sending a message from one node to the remainder of the network. Each network's routing protocol is crucial for creating the link between the sender and receiver. As the receivers are not readily available on the network, a routing protocol must be used to get to the destination. Because nodes are constantly changing and a dynamic link is created for routing, MANET routing protocols are different from conventional wireless routing techniques. With MANET, there are many different routing protocols, but only a few of them perform well, like AODV. Proactive, reactive, and hybrid routing protocols are categorized in MANET. All the protocols have unique routing strategies that employ various link-establishing methods.

Proactive protocols, also called table-based protocols, continuously analyze and maintain consistent and up-to-date routing information in the network when packets need to be forwarded and the routes are already known. After successful data delivery, table-based routing protocols maintain routing records, so all routing entries cannot be removed or deleted. The main advantage of this routing strategy is that all routing data from a given sender to a given recipient is stored in one record, so the routing procedure does not have to start from scratch [26]. Within a dynamic network, nodes move at varying speeds and are able to move in several directions. Proactive routing methods are not effective in this type of network. This form of routing technique creates overhead within the network [27]. DSDV [28] and Optimized Link State Routing (OLSR) [29] are the proactive routing protocols.

The Routing on Demand protocol does not track routing and provides options to purge or remove all routing entries after successful data delivery. With this routing strategy, a record does not contain all the routing information from a specific sender to a specific recipient, eliminating the need to start the routing operation from scratch. This method of handling node mobility is preferable when it is high. The route that must be kept up here is not documented. This method of routing has resulted in decreased overhead. AODV and DSR [29–31] are the reactive routing protocols.

The usage of several routing protocol types in various zones is flexible thanks to the hybrid routing protocol methodology. Because the internet is the best alternative for long-distance communication or routing, MANET performs better in tiny, fixed-size networks. However, in MANET, a hybrid routing strategy can be used to span a vast area. We can employ both a proactive and a reactive technique for data distribution using a hybrid approach. ZRP is one illustration of a hybrid routing strategy [32]. Inter-zone and external zone routing protocols are additional categories for the hybrid approach [33].

There are also more protocols that work together to enhance MANET performance. The locality and movement velocity of mobile nodes can be tracked using the LAR, LAR-1, and LAR-2 protocols [34, 35]. Every node keeps track of the locations of any other nodes nearby that are taking part in the routing process.

Many categories of mobile ad hoc routing exist. For the ad hoc network, reactive routing techniques like DSR and AODV are more practical [36, 37]. The AODV-based routing protocol is more practical, according to the comparative analysis of MANET routing protocols, because it has a lower energy need, experiences less delay, and provides the quickest path for communication in a dynamic environment. Using multipath routing, this protocol is further improved to balance network traffic and reduce congestion.

There is no limit to the number of senders and recipients, and multipath routing is the procedure of finding different paths between a single sender and a single recipient [38, 39]. To build multiple routes using one or more intermediary network nodes, many senders are simultaneously engaging in the routing process. Common nodes and linkages can be utilized along the way. To connect with the destination, the source sends a request, and the process of connection formation and unipath routing are identical. Links that are disjoint and non-disjoint have the fundamental drawback of improperly utilizing the multipath notion. It is challenging to use the common node or connection in another path if they are engaged in communication. When a network has fewer nodes, this kind of issue arises. The likelihood of choosing non-disjoint or link-disjoint routes is decreased if the nodes are numerous enough and not densely populated. In multipath routing, it is much better to individually choose each path to manage load and make efficient use of energy in the network. AOMDV manages the multipath communication in that scenario [38]. The introduction of multipath routing in MANET is hampered by several factors, including distance, scalability, security, mobility, energy concerns, and search direction. Ad-hoc on-demand multipath routing can improve network throughput, data reception speed, and billing load balancing [40].

### *2-1- Congestion Awareness-based Cross Layer MAC Protocol*

A new MAC protocol that improves end-to-end throughput fairness and has a per-flow idea of fairness for channel access has been put out by Asfour & Serhrouchni; moreover, a new load-balanced routing method that enhances fairness even when the underlying MAC is equitable concerning flows has been suggested [41]. To satisfy the QoS needs of real-time applications, Chen et al. have presented a QoS-aware routing protocol that combines an admission control mechanism and a feedback scheme. To operate on network traffic, the QoS-aware routing protocol makes use of an approximation of the bandwidth estimate [42]. An algorithm for congestion control has been proposed by Sharma et al. (SPCC). To choose the shortest path between a source and a destination, this method employs the PEER approach. During path establishment, the link cost is determined using two factors. The terms “transmission power” and “reception power” refer to these variables. Path costs are used to reduce traffic congestion. Cross-layer-based QoS routing (CBQR), presented by Sharma et al., enables congestion management and route stability. It has a cross-layer network design that is QoS-based, congestion-aware, and bandwidth-aware. When data is transported from the source to the destination, the source node selects the path that satisfies load and link capacity according to the protocol's operation at the physical, MAC, and network layers. Congestion is prevented by using link information [43].

### *2-2- Rate Control-oriented Protocol*

Based on the transmission rate, congestion is avoided with these methods. Network status is communicated to the sending node for this reason so that it can lower its sending rate to prevent congestion if an intermediate node is congested or if a bottleneck link develops somewhere in the middle. Several methods for rate control mechanisms have been proposed in the literature; some of them are given below. The approach proposed by Soundararajan & Bhuvaneswaran [44] is known as multipath load balanced and rate-based congestion control (MLBRCC). With this method, the application receives network information from the destination node and modifies its transmitting pace in response to network conditions. There are other different methods described in the literature through which the sender can modify its data rate in response to network conditions. These plans incorporate integrated linear message rate management, which prevents congestion by utilizing wireless's built-in precision control capabilities. The method known as Rate Effective Network Utility Maximization (RENUM) reduces the data rate of the link between the source and the destination. Instead of using the sender as the network utility, the framework uses the destination node [45].

A multipath protocol built on energy awareness and congestion control has been proposed by Le et al. This protocol chooses lighter routes instead of taking any crowded or high-energy routes. A multipath connection's ability to simultaneously transmit numerous flows is one of its features. The suggested technique calculates the energy required for data reception and transmission between two end hosts. End-to-end energy consumption is computed on the sender side, and data and ACK costs are calculated on the receiving side [46]. Multipath TCP's energy-aware congestion control (ecMTCP) moves traffic from heavily used pathways to less crowded ones. Moreover, it switches between paths with greater and lower energy costs. Using this method, load balancing and energy-saving pathways are obtained. For mobile ad hoc networks, Sheeja et al. have presented an efficient congestion avoidance technique [47]. The plan consists of the following three steps: (i) Network monitoring to determine the status of congestion. (ii) Congestion detection based on queue length, channel contention, and overall congestion status by counting the number of dropped packets; and (iii) Avoiding all congested paths and creating a route free of congestion from source to destination. By reducing latency, the plan raises packet delivery percentage and network throughput. The offered load at the queue of node k, represented by, is used to determine the likelihood of packets in the queue, according to the author.

$$P(Q) = \left(1 - L_{offk}\right)L_{offk}^{1} \tag{1}$$

When $t_1$ and $t_2$ are used as the starting and finishing times, respectively, the packet loss rate is given in Equation 2. The formula for calculating the packet drop ratio is found in Equation 3, where $P_{dn}$ stands for the number of dropped packets, $P_{mn}$ for the number of packets that were misrouted, and $P_{mn}$ for the overall number of sent packets [47].

$$P_{LR}(t_1, t_2) = \frac{\int_{t_1}^{t_2} 1\{G(t) - D_t\}^{dF(t)}}{\int_{t_1}^{t_2} dF(t)} \tag{2}$$

$$PDR = \left(\frac{P_{dn} \times P_{mn}}{P_{tn}}\right) \times 100 \tag{3}$$

By including mechanisms for congestion control and route repair in RREQ packets, Xia et al. have improved the currently implemented AODV. On each node, the queue size is preserved. By evaluating the degree of busyness on a node, an intermediary node can evaluate the congestion according to buffer size. If the node is not in use, RREP is transmitted through it right away. If not, it discards the RREP packet [48]. Early detection congestion and control routing techniques were created by Senthilkumaran & Sankaranarayanan (EDAODV) [49]. When congestion affects a node in both the forward and reverse directions or in a bidirectional manner, this algorithm seeks to provide an alternate path. This technique has three phases: (a) route discovery; (b) early congestion detection (bidirectional path discovery). Each node maintains two routing tables, one of which, the alternate routing table (ART), maintains alternate paths by correlating an entry to the principal routing table (PRT), which is kept throughout the primary path establishment phase for various destinations [49].

A process called dynamic congestion detection and control routing (DCDR) [50] lowers congestion by establishing congestion-free pathways during the initial stage of route establishment. This approach uses CFS, which is a one- or two-hop neighbor, to configure all congestion-free pathways. In Senthilkumaran & Sankaranarayanan [51], authors have reported a prediction-based control mechanism that makes decisions based on knowledge already known and a set of parameters. To increase the effectiveness of MANET, Simaiya et al. devised the RED algorithm, which was extended by IRED [52]. The RED system is based on an active queue management strategy in which the network notifies the destination node of the level of congestion. IRED, however, employs a priority queue that is based on active queue management. With this method, packet loss is caused by two things: the rate of receiving data and the size of the queue. There are fewer packet losses and less congestion. Current methods of route discovery rebroadcast route request packets until the desired route to the target node is established. Yet, when data is transferred from source to destination using this approach, broadcast storm problems arise. Congestion is created at intermediate nodes. Early congestion detection and self-treatment The AODV routing protocol (EDCSCAODV), which builds on the active queue management model and computes routes for each node, is an improvement on the original AODV. This system can identify congestion in its early stages and send a warning message to every neighboring node. Neighbors nod in agreement when they learn about a congestion-free path after getting network information. This method increases the packet delivery ratio while decreasing network latency [49]. To alleviate network congestion, Ferreira & Alam [53] suggest a hybrid technique comprising rate control and resource control. Every node forwards an RREQ packet to an adjacent node during the route-finding process. All neighbor nodes are alerted by sending control messages if a congested node is discovered on the path to the destination. To choose an alternative path, all asking nodes in this process are alerted by setting a flag value. The queue lengths of the nodes are examined for path selection and data rate adaptation in the Data Rate Adaptive (DRA) scheme to prevent congestion. The fundamental problem is that every node periodically exchanges its queue length with nearby nodes, adding communication overhead and perhaps exacerbating congestion circumstances.

## 3- Energy Consumption and Congestion Problems in MANET

Due to congestion brought on by constrained bandwidth capacity, data packet loss is encouraged in MANET. Unicast routing increases the chance of congestion since only one path is constructed linking the source and end points [54, 55]. Active ad-hoc routing protocols cannot supply loads equally within the network because there is no mechanism for sharing load information with neighbors. The fact that nodes cannot maintain load consideration through numerous network paths remains a major MANET problem. A data packet from sender S is routed to target D via middle nodes A and C. A destination cannot process data as fast as a source that continuously sends data packets. Packets start to be collected on links A and C but are not forwarded in time and are dropped. Congestion inevitably increases response time because packets routed from a congested link repeatedly flood the network with RREQ and RREP packets for connection establishment [7]. These networks' ability to join and organize themselves independently without a topology is what has led to their proliferation.

Routing is difficult due to the nature of MANET, namely its dynamic architecture and distributed connections. If the mobile node holds an enormous volume of information before sending it, the redundant information should also be delayed. A bottleneck arises when a finite amount of buffer space fills up and additional data, old and new, must be discarded. As a result, resources, including communication and node bandwidth, are mutually consumed, and packet loss reduces the accuracy of event detection. Therefore, a routing method that can reliably distribute data transfers among nodes and improve MANET performance is considered essential. Therefore, even if a particular hop in a link loses some data, other hops in the network are used, so packets can be diverted from different paths so that no loss occurs as data accumulates. I need a way to transfer. Get the rest of the data (via an alternate route). Energy efficiency can be an issue, especially when designing routing protocols. It is difficult for a routing protocol to meet all requirements. In other words, there is no single energy-efficient routing protocol that can meet all requirements in all possible cases [54]. Links are broken due to unnecessary data loss and delays. Even if two nodes are open for interaction, they are not immediately chosen for data routing. Selecting multiple paths is one approach, but energy-efficient multipath routing is required to save energy and reduce congestion.

## 4- Predictive Energy usage per Packet based AMMEE Methodology

A multipath routing strategy provides three different communication paths to a source node by utilizing node capacity to balance network load. For single-pass on-demand routing, the current multipath routing, AOMDV, is more efficient. The proposed protocols improve the performance of energy-efficient multi-channel AOMDV routing. It is based on multi-channel communication and load balancing based on node capacity. A node's capacity is determined when requesting a route. Queue length, remaining power, per-packet power usage, and bandwidth capacity are all provided by each node. All the collected data is used to calculate the destination node cost function, and based on the calculated cost function, the three best paths are selected. The cost function plays a significant role in our suggested strategy. Even if multiple paths are available during the path discovery process, only the first three paths with the lowest cost function values are selected for data transfer. Based on the calculated node capacity, the source will send data on all three selected paths during data communication. The AMMEE protocol under consideration efficiently transmits data while improving network performance. Another multichannel strategy assists in preventing collisions while competing with multiple senders in a single node collected from various sources. Because it creates channel usage and optimum channel tables, it can handle three channels at once and build three sender nodes simultaneously. This method minimizes network collisions by providing separate channels for requesting information from three senders simultaneously. With the least amount of power consumption-based routing, the existing energy-based dynamic source routing using the MMAC protocol, the energy-based destination sequence vector routing using the PRMMAC protocol, and the proposed approach using QoS-AOMDV routing with multichannel access protocols all improve throughput and packet delivery rates. Topology shift adaptive ad-hoc multipath routing protocol, on-demand multipath distance vector [55].

### *4-1- Energy Metric Cost Function in AMMEE Protocol*

Paths are selected using the energy matrix cost function of the proposed AMMEE protocol. Factors such as the residual energy of the node determine how the cost function is calculated. Though the path detection activity starts at the source node and sends routing packets to find the path, the discovery packets arrive at the node and provide the latest or remaining energy level data (in joules) and energy per packet. Get consumption. Estimate the expected lifetime of a node.

$$N_i^{npkt} = \frac{E_i^{resudual}}{E_i^{consume}} \tag{4}$$

$$\overline{N_{path}^{npkt}} = \frac{1}{N}\sum_{i=1}^{N} N_i^{npkt} \tag{5}$$

$$N_{min}^{npkt} = \min_{1\leq i\leq N} N_i^{npkt} \tag{6}$$

where, $N_i^{npkt}$ indicates anticipated number of packets forwarded from the available residual energy, $N$ indicates the number of hops saved in RREQ, $\overline{N_{path}^{npkt}}$ indicates average number of packets forwarded, $N_{min}^{npkt}$ indicates minimum number of packets forwarded.

Figure 3 shows how the energy metric cost function in the AMMEE protocol is evaluated for energy consumption in contrast to alternative solutions when there are different numbers of nodes. The percentage of exhausted energy resources distributed across the various nodes throughout the transmission, aggregation, and reception of network data is known as energy consumption. An average reduction in energy usage over the network field of between 9.5% and 17.9% is seen when using the AMMEE protocol. Table 1 shows the performance of the AMMEE protocol for a simulation area of 300×300 and a range of nodes from 10 to 500 when the deployment range is random in nature.

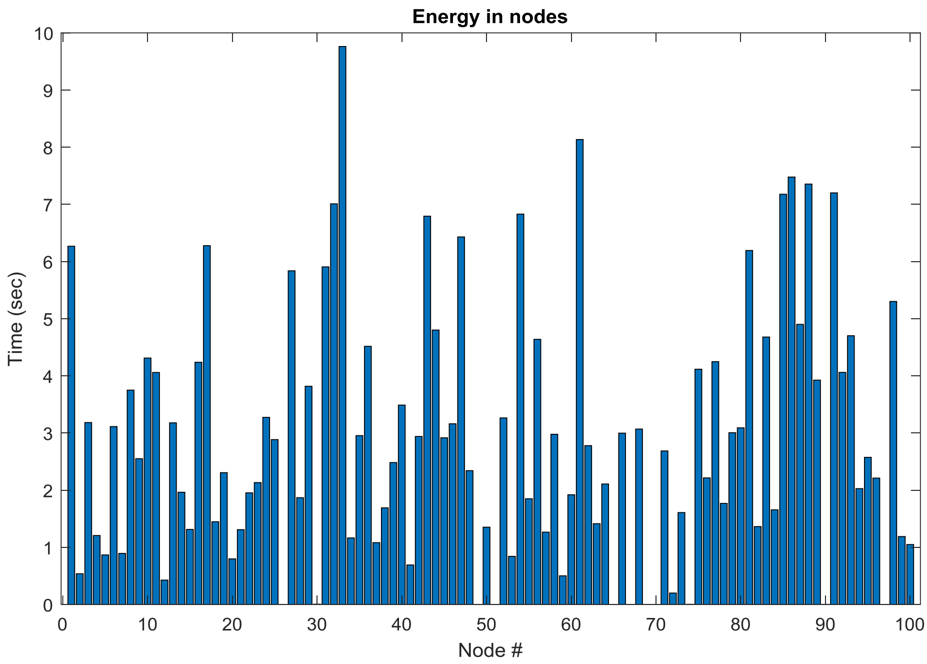


**Figure 3. Energy metric cost function in the AMMEE protocol**

**Table 1. The performance of AMMEE protocol for simulation area 300 × 300 $m^2$ and range of nodes 10 to 500**

| Number of packets | Delivery Fail Rate | Total Time | Total Energy | Packet Delivery Rate |
|---|---|---|---|---|
| 10 | 0 | 4.7038 | 35.6625 | 100 |
| 50 | 2 | 57.4757 | 233.8434 | 98 |
| 100 | 5 | 96.6956 | 388.8618 | 95 |
| 150 | 10.6667 | 148.7908 | 608.1622 | 89.3333 |
| 200 | 12 | 183.3253 | 896.9072 | 88 |
| 250 | 16 | 278.8975 | 1.4022e+03 | 81.2000 |
| 300 | 16.6667 | 309.2957 | 2.0719e+03 | 81.3333 |
| 350 | 17.5000 | 372.0920 | 3.4173e+03 | 75.2500 |
| 400 | 17.2500 | 341.9306 | 3.0461e+03 | 74 |
| 450 | 14.2222 | 342.3999 | 3.7416e+03 | 73.3333 |
| 500 | 11.6000 | 369.7062 | 4.3672e+03 | 69.4000 |

### *4-2- Bandwidth Metric Cost Function in AMMEE Protocol*

Another statistic used in calculating the cost factor is the bandwidth factor. The channel busy and idle states are defined by Equation 7. This is useful when estimating channel usage between nodes.

$$u_i(t) = \begin{cases} 0 & H_0(Idle) \\ 1 & H_1(Busy) \end{cases} \tag{7}$$

In Equations 8 and 9, which were developed to determine channel utilization and available bandwidth, respectively,

$$U_i(t, t + M\zeta) = \frac{1}{M}\sum_{m=1}^{M} u_i(t + m\zeta) \tag{8}$$

where $M$ is the number of samles and $\zeta$ is the sampling intervals:

$$B_i(t, t + M\zeta) = B_{channel}^{gross}[1 - U_i(t + m\zeta)] \tag{9}$$

where $B_{channel}^{gross}$ indicates the gross bandwith of channel.

### 4-3- Queue Length Metric Cost Function in AMMEE Protocol

Use Equation 10 for the idle queue length of the i[th] node to determine the queue length. The minimal length of a queue that is idle and the typical queue length of a path are obtained using Equations 11 and 12 accordingly.

$$QL_i^{idle} = QL_i^{initial} - QL_i^{occupied} \tag{10}$$

$$QL_{min}^{idle} = \min_{1 \le i \le N} QL_i^{idle} \tag{11}$$

$$\overline{QL_{path}^{idle}} = \frac{1}{N}\sum_{i=1}^{N} QL_i^{idle} \tag{12}$$

While various layers of network protocol architecture perform forward packet counting capacity as a function of remaining power, available bandwidth, and queue length, our proposed AMMEE protocol is an efficient Use a layered network architecture for flexible route selection procedures. Each node in the AMMEE protocol contains details about the number of expected packets to transfer, available bandwidth, and queue length. A routing request packet (RREQ) containing this data is sent to the destination node.

The cost function is determined by all three components, which are each depicted in Equations 13 to 15 separately, during which the end node accepts RREQ.

$$C_j^{npkt} = \frac{\overline{N_{path}^{npkt}}}{N_{path}^{npkt}} \tag{13}$$

$$C_j^{QL} = \frac{\overline{B_{path}}}{B_{min}} \tag{14}$$

$$C_j^{QL} = \frac{\overline{QL_{path}^{idle}}}{N_{min}^{idle}} \tag{15}$$

$C_j^{npkt}$, $C_j^{bandwidth}$, and $C_j^{QL}$ are extra encapsulation fields included in destination RREQ packets that are used in Equation 16 to calculate the cost function for each individual path.

$$C_j = \alpha . C_j^{npkt} + \beta . C_j^{bandwidth} + \gamma . C_j^{QL} \tag{16}$$

$\alpha+\beta+\gamma=1$ also allows for varying values of $\alpha$, $\beta$, and $\gamma$ depending on network performance. In the equation, the letters $\alpha$, $\beta$, and $\gamma$ stand for various network properties. Equation 17 contains the weight coefficient for three factors.

$$\alpha = 1 - \frac{\overline{E_{path}^{residual}}}{\overline{E_j^{initial}}}$$
$$\beta = \frac{1-\alpha}{2} . \frac{\overline{B_j}}{B_{channel}^{gross}} \tag{17}$$
$$\gamma = \frac{1-\alpha}{2} . \frac{\overline{QL_j^{idle}}}{QL_j^{initial}}$$

### 4-4- Channel Capacity Estimation

Direct correlation between channel capacity and bandwidth so that the section on channel capacity measurement might be formulated. Calculate the likelihood that interface $i(i \neq j)$ will be in use when a packet arrives on channel $j$ using Equation 18.

$$\rho_s(j) = \sum_{\forall i \neq j} interfaceUsages(i) \tag{18}$$

The expected transmission time (ETT) is measured in Equation 20, where Equation 20 estimates the switching cost of channel j, where ETX is the anticipated number of transmissions tries, B is the link's data rate, and S is the typical packet size.

$$SC(j) = p_s(j) \times SwitchingDelay \tag{19}$$

$$ETT = ETX \times \frac{S}{B} \tag{20}$$

The forwards information packet failure probability from source $X$ to destination $Y$ on channel $j$ determines $(pf)$ in the Equation 20 formalized to the likelihood of link failure, and the reverse packet loss probability is $(pr)$.

$$\rho = 1 - (1 - \rho f) \times (1 - \rho r) \tag{21}$$

$$ETX = \frac{1}{1-\rho} \tag{22}$$

$ETTi$ is the $ETT$ cost of the $ith$ hop of the path, and Equation 22 formulates this cost as the entire $ETT$ cost of any channel $j$ that is defined by $X_j$.

$$X_j = \sum_{\forall i, such that\ c_i = j} ETT_i \tag{23}$$

Equation 24, a weighted average of two components defined by MCR, uses ci as the i$^{th}$ hop's channel and $SC\ (ci)$ as the switching cost;

$$MCR = (1 - \beta) \times \sum_{i=1}^{n} \big(ETTi + SC(Ci)\big) + \beta \times \max_{1 \le j \le c} Xj \tag{24}$$

## 5- Design, Implementation, and comparison of the AMMEE Protocol

The AOMDV routing protocol enhances multipath multichannel routing. This section explains the network architecture, frame format specifications, layer configuration of the protocol, and operation of the AMMEE protocol. Figure 4 shows multi-channel, multi-path, and ad-hoc communication architectures. 1-9 represent 9 sources and 22-26 represent 5 receivers. Nodes 1, 2, and 3 use four channels to transmit data on the same frequency as $f_1$. Nodes 5, 6, 7, 8, 9, frequency $f_2$.

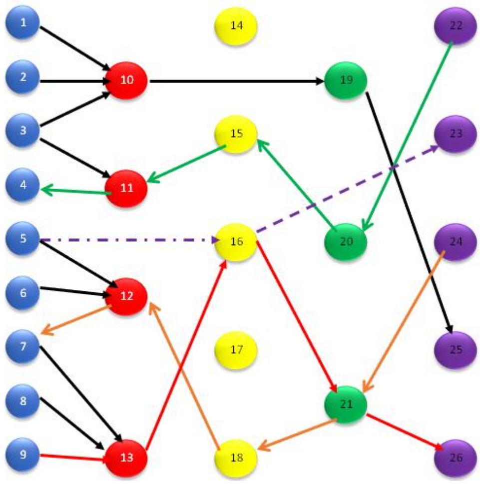


**Figure 4. Multichannel and multipath architecture of the Adaptive Multipath Multichannel Energy-Efficient protocol**

To accommodate the new AOMDV protocol frame format called AMMEE, which includes the eight additional fields described in Figure 5, each connected intermediate node calculates its per-packet download rate during the RREQ message. This helps predict how many packets will be transferred during the RREQ message. If the packet sizes are the same, the nodes are the same.

<table>
<tr><td>0 7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13 23</td><td>24 31</td></tr>
<tr><td>Type</td><td>J</td><td>R</td><td>G</td><td>D</td><td>U</td><td>RESERVED</td><td>HOP Count</td></tr>
<tr><td colspan="8">FREQ Broadcast ID</td></tr>
<tr><td colspan="8">Destination IP Address</td></tr>
<tr><td colspan="8">Destination Sequence Number</td></tr>
<tr><td colspan="8">Originator IP Address</td></tr>
<tr><td colspan="8">Originator Sequence Number</td></tr>
<tr><td colspan="4">Lifetime</td><td colspan="4">Time Stamp</td></tr>
<tr><td colspan="2">Expected Minimum Number of Packet Forward</td><td colspan="2">Packet Size</td><td colspan="3">Expected Average Number of Packet Forward</td><td>Packet Size</td></tr>
<tr><td colspan="4">Minimum Queue Length</td><td colspan="4">Average Queue Length</td></tr>
<tr><td colspan="4">Minimum Available Bandwidth</td><td colspan="4">Path Available Bandwidth</td></tr>
</table>

**Figure 5. RREQ Frame format of the AMMEE protocol, modified from the frame format of the Ad Hoc On-Demand Multipath Distance Vector (AOMDV) routing protocol**

We also calculate the typical number of packets forwarded by all connected nodes along the path based on the energy parameter. We obtain the node's available bandwidth and queue length in frame format as well before averaging the bandwidth and queue length, respectively.

AOMDV routing is the foundation of this power-efficient multipath multichannel routing protocol, which has new header fields added to compute path stability identification. Through the AMMEE protocol, a source starts an RREQ message that is broadcast to all neighbors. Every neighbor computes all the relevant values, packs them into RREQ packets, and transmits them to the layer below them in the neighbor stack.

When an RREQ packet travels via many routes to reach a receiving node, the receiver creates a unique routing table for each loop-free route and uses a cost function to determine the first three routes with the lowest value. increase. For data connection on the three best paths selected, the receiving node will produce an RREP message and send an ACK message to the transmitting node on the subsequent run. The source node generates the data and starts transmitting it over numerous pathways utilizing a multichannel-based technique as soon as it receives the acknowledgment from the receiving node.

Table 2 shows the numerical analysis for three different scenario simulations of network nodes (50, 100, and 150). Protocol performance is measured based on the parameters considered. The defined simulation parameters are adopted to develop networks for further analysis. The output effect of the network depends on the input parameters. The output effect of the network depends on the input parameters. For multi-channel access media access techniques with routing between transmitters and receivers, the proposed MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and AMMEE protocols were considered, and the entire simulation was run in the MATLAB R2023a version. It will be executed. Packet delivery speed is also called the percentage of data reaching its intended recipient. The PDR is higher, but this means the network is performing well in terms of data delivery. The impact on the network is highly dependent on the performance of PDR, which evaluates the algorithm's efficiency in terms of successful communication. An analysis of the results presents proposed methodologies for six different routing protocols on multi-channel interfaces: MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and AMMEE. AMMEE's PDR performance is superior compared to other protocols. The protocol was mentioned. AMMEE is especially suitable for small networks with low mobility, so it gives better results than other protocols. In Figure 6, the PDR performance of AMMEE gives better results compared to PRMMAC, QoS-AOMDV, and TA-AOMDV protocols. The PDR has been analyzed for the 50, 100, and 150 numbers of nodes in the network. AMMEE's PDR is an effective energy-based multipath multichannel routing scheme. Because AMMEE is widely used in small networks with low mobility conditions, the result outperforms all other protocols.

$$PDR = \frac{\sum_{k=0}^{n} r_i^{pkt}}{\sum_{l=0}^{m} s_i^{pkt}} \times 100 \tag{25}$$

**Table 2.** **Packet delivery ratio comparison of different protocol in percentage**

| Nodes in the Network | AMMEE | TA-AOMDV | QMR | QoS-AOMDV | PRMMAC | MMAC |
|---|---|---|---|---|---|---|
| 50 | 96.67 | 86.87 | 83.67 | 82.76 | 63.49 | 69.38 |
| 100 | 97.29 | 88.46 | 85.87 | 84.67 | 64.89 | 70.23 |
| 150 | 98.28 | 92.38 | 87.73 | 85.74 | 68.72 | 74.56 |

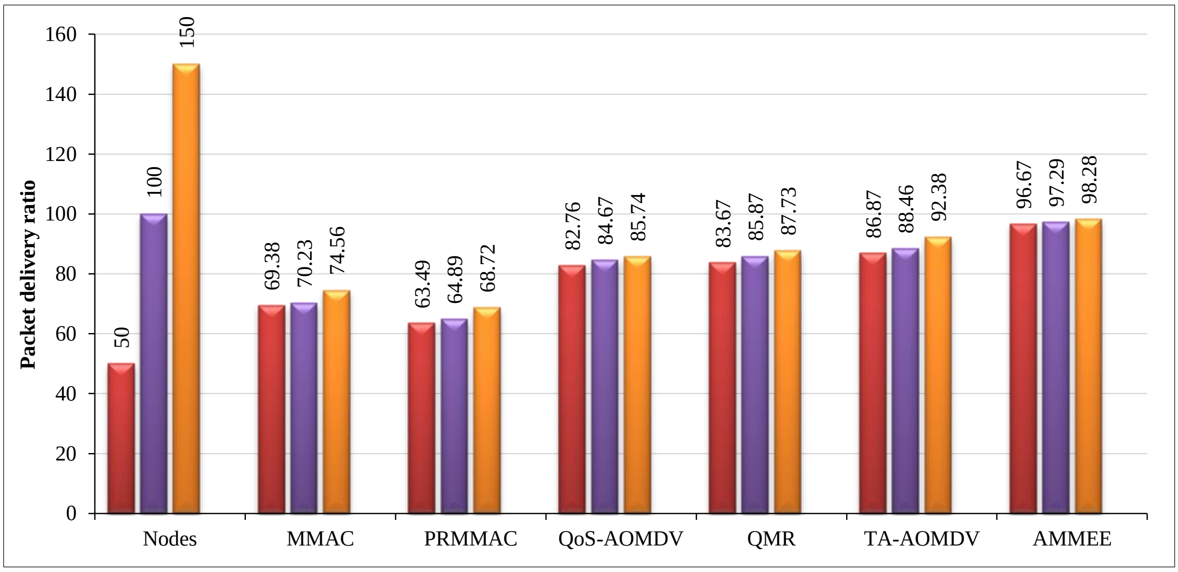


**Figure 6.** **Packet delivery ratio comparison of MMAC, PRMMAC, QoS-AOMDV, TA-AOMDV and AMMEE protocols**

The PDR presented in Equation 25 is the packet delivery ratio in percent, the number of packets received $r_i^{pkt}$ by the receiving node in the network, and the number of packets sent $s_i^{pkt}$by the source node in the network.

Table 3 demonstrates that the AMMEE protocol performs better than all other protocols, with packet drop rates of 3.33% for a scenario with 50 network nodes, 2.71 % for a situation with 100 network nodes, and 1.72% for a scenario with 150 network nodes.

**Table 3. Packet dropping ratio comparison of different protocol in percentage**

| Nodes in the network | AMMEE | TA-AOMDV | QMR | QoS-AOMDV | PRMMAC | MMAC |
|---|---|---|---|---|---|---|
| 50 | 3.33 | 13.13 | 16.33 | 17.24 | 36.51 | 30.62 |
| 100 | 2.71 | 11.54 | 14.13 | 15.33 | 35.11 | 29.77 |
| 150 | 1.72 | 7.62 | 12.27 | 14.26 | 31.28 | 25.44 |

One of the fundamental network metrics you should track when keeping tabs on your network performance is network packet loss. The quantity of data packets that were successfully transmitted from one location in a network but were dropped during data transmission and never made it to their intended location is referred to as packet loss. The user experience might be impacted by incomplete or delayed data transfers, which can influence network and application performance.

Route not found, MAC errors, channel busy, time-to-live timeouts, network congestion, and many other factors can cause data loss in communications. TA-AOMDV works well when nodes are deployed in denser networks, but it is not known whether it will always work well when mobile nodes are present in highly mobile networks. All protocols in use today, including TA-AOMDV, work admirably when it comes to successfully delivering data to legitimate recipients. Figure 7 shows the percentage of dropped data that was not properly received by the receiving node, based on the resulting graph. In the resulting analysis, six routing protocols are presented, including MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and AMMEE technology, which has been proposed as an effective energy-based multipath multichannel routing protocol. The graph shows the results of the proposed AMMEE routing protocol. This resulted in less data drop, with 3.33%, 2.71%, and 1.72% data drops for 50, 100, and 150 nodes, respectively. This shows that the proposed AMMEE routing protocol outperforms all other routing protocols with identical simulation parameters.

$$AVG(Drop) = \frac{\sum_{k=0}^{n} r_i^{pkt} - \sum_{t=0}^{p} d_i^{pkt}}{\sum_{l=0}^{m} s_l^{pkt}} \times 100 \quad (26)$$

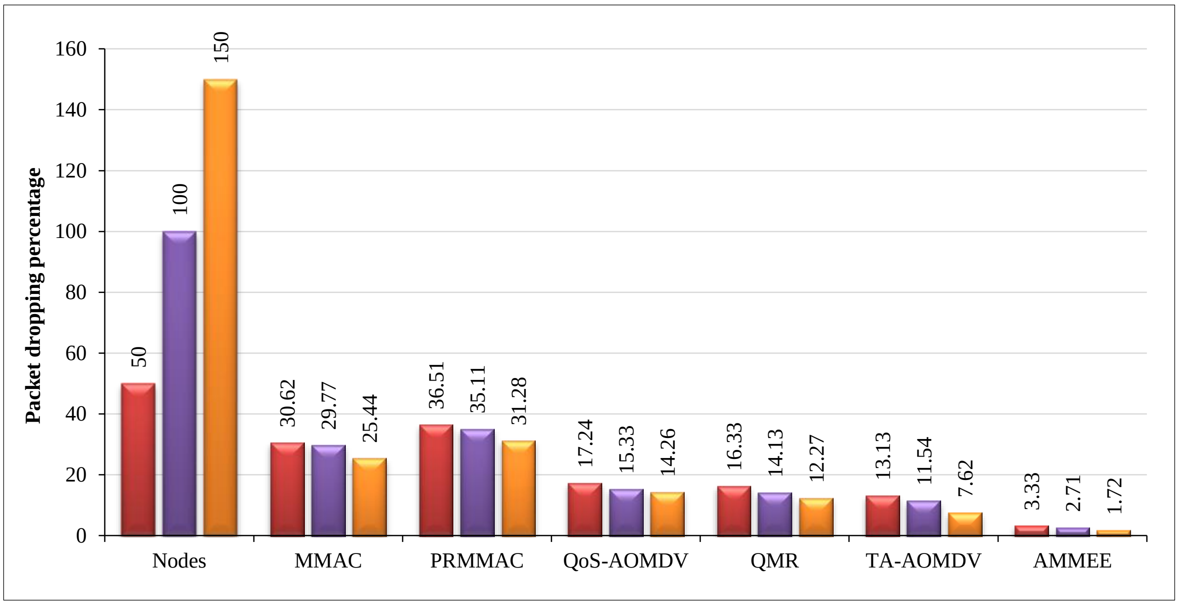


**Figure 7. Packet dropping ratio comparison of MMAC, PRMMAC, QoS-AOMDV, TA-AOMDV and AMMEE protocols**

Here, AVG (Drop) stands for average packet drop in percentage, $r_i^{pkt}$ denotes the number of packets received by the network's receiver node, $d_i^{pkt}$ denotes packet drops, and $s_l^{pkt}$ is the number of packets sent by the source node.

The aggregate throughput, also known as system throughput, is the total data rate sent to all network endpoints. Throughput can be calculated numerically by using the queueing theory, where the load in packets per time unit is marked as the arrival rate, and the drop in packets per time unit is represented as the departure rate. Throughput is virtually synonymous with digital bandwidth usage. Throughput is defined as the number of packets that arrive at the destination in a certain amount of time. Network traffic and idle bandwidth both affect the network's throughput. The throughput is higher when the network bandwidth is fully utilized for data transmission; however, real communication throughput is significantly reduced when network bandwidth is consumed by congestion or network jamming.

$$Throughput = \frac{\sum_{k=0}^{n} R_i^{Byte}}{t^{Sim}} \tag{27}$$

Here, $R_i^{Byte}$ is the total number of bytes that all real receivers have received, and $t^{Sim}$ is the simulation's duration in seconds. We present the numerical throughput study of six distinct mobile ad hoc network protocols in Table 4. We examined each protocol's throughput and calculated the overall average throughput, which is shown in the table with respect to 50, 100, and 150-node scenarios. The average throughput of the proposed AMMEE is 0.868333 Mbps, TA-AOMDV is 0.80333333 Mbps, QMR average throughput is 0.577 Mbps, QoS-AOMDV produces 0.534333333 Mbps, PRMMAC produces 0.422 Mbps, and MMAC is 0.670333 Mbps.

**Table 4. Throughput analysis of different protocols in megabits per second (Mbps)**

| Nodes | AMMEE | TA-AOMDV | QMR | QoS-AOMDV | PRMMAC | MMAC |
|---|---|---|---|---|---|---|
| 50 | 0.771 | 0.699 | 0.561 | 0.489 | 0.321 | 0.619 |
| 100 | 0.911 | 0.83 | 0.569 | 0.542 | 0.463 | 0.691 |
| 150 | 0.923 | 0.881 | 0.601 | 0.572 | 0.482 | 0.701 |

Figure 8 displays the throughput result analysis for six different routing protocols used in a multichannel environment, including MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and the proposed AMMEE routing protocol approach. The AMMEE bar graph shows the throughput of the Efficient Energy-based multipath multichannel routing system, which spans from 0.771 Mbps to 0.923 Mbps. The proposed Adaptive Efficient Energy-based Multipath Multichannel Routing Protocol outperforms all other routing protocols when compared to them using the same simulation conditions.

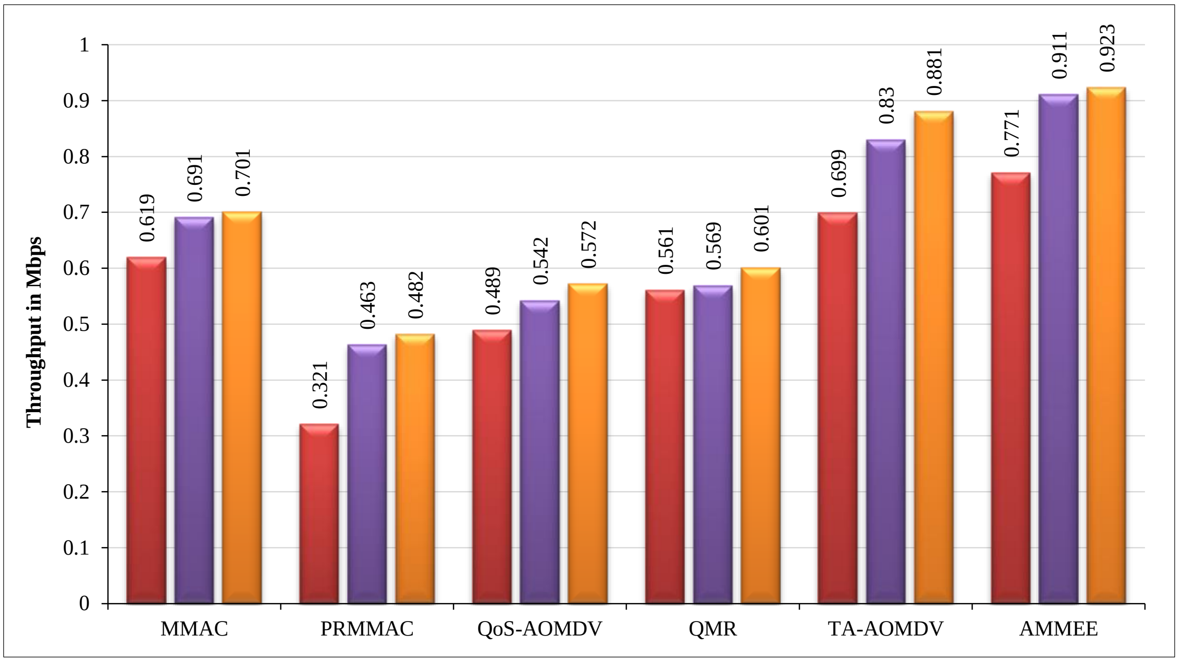


**Figure 8. Throughput comparison of MMAC, PRMMAC, QoS-AOMDV, TA-AOMDV and AMMEE protocols**

The network nodes' average energy usage is displayed through the energy consumption analysis. The network must be made more energy-efficient through the analysis of energy use. The analysis compares the number of mobile nodes in the X-axis to the typical amount of energy used in the Y-axis in joules.

Six distinct routing protocols, including MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and the suggested methodology for the AMMEE routing protocol, are shown in the result analysis for a multichannel environment. According to Figure 9, the flowchart of the AMMEE algorithm routing protocol uses 0.059, 0.271, and 0.391 J of energy for every 50 mobile nodes, 100 mobile nodes, and 150 mobile nodes, respectively. The proposed methodology results in less overall energy use in joules. As a result, it can be said that the suggested practice uses less energy when communicating.

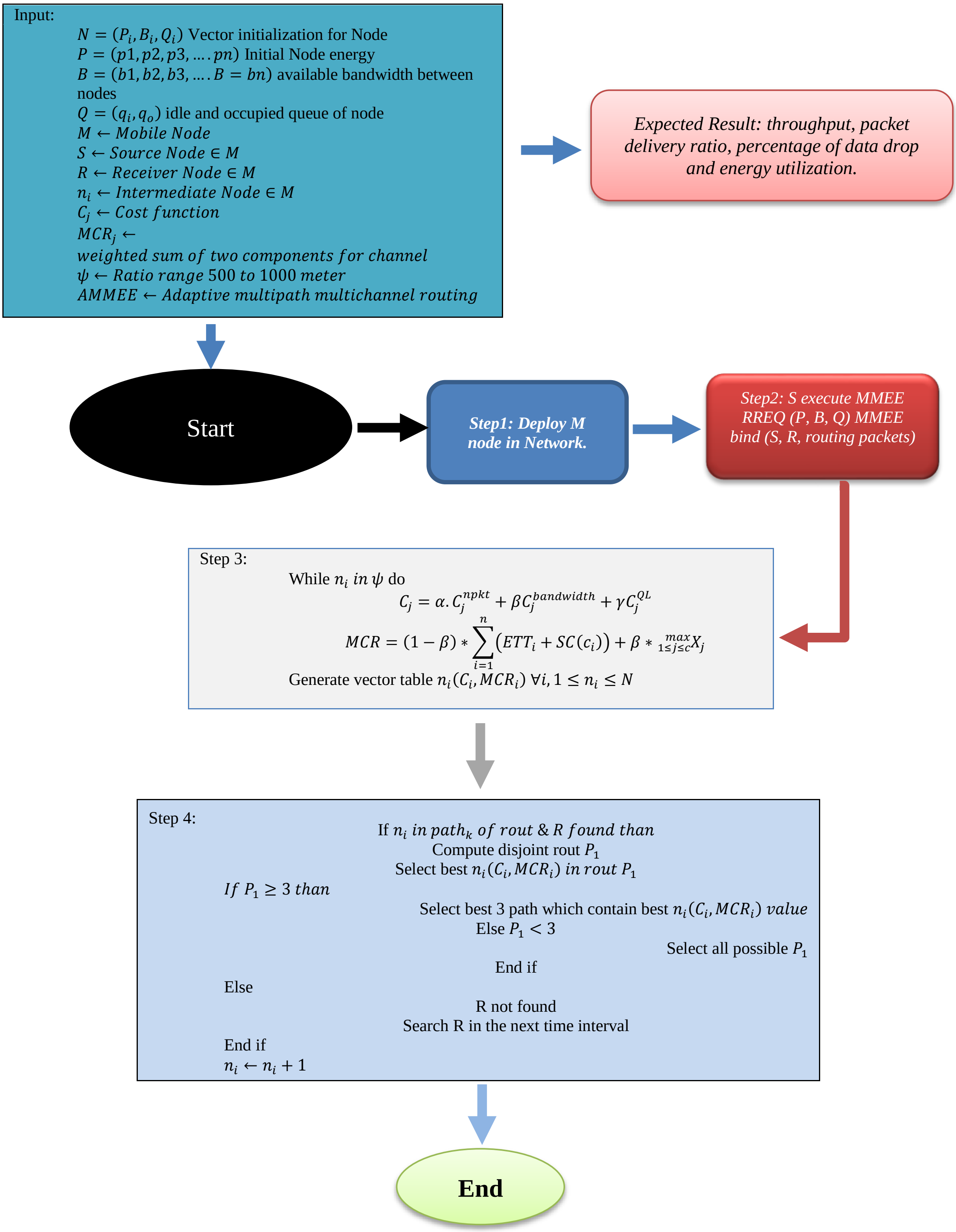


**Figure 9. Flowchart of Adaptive Multipath Multichannel Energy-Efficient (AMMEE) algorithm**

$$Energy\ (c) = \frac{\sum_{i=0}^{n} E_i - \sum_{i=0}^{n} R_i}{n} \tag{28}$$

Here, $Energy\ (c)$ stands for average energy consumption in joules, $\sum_{i=0}^{n} E_i$ for the total amount of mobile nodes' initial energy, $\sum_{i=0}^{n} R_i$ for the total amount of their remaining energy, and n for the total number of mobile nodes in the network. In Figure 10, the average energy utilisation of various protocols is compared in Joules. The AMMAC routing protocol, which uses 0.269J, 0.783J, and 0.714J for networks with 50, 100, and 150 nodes, respectively.

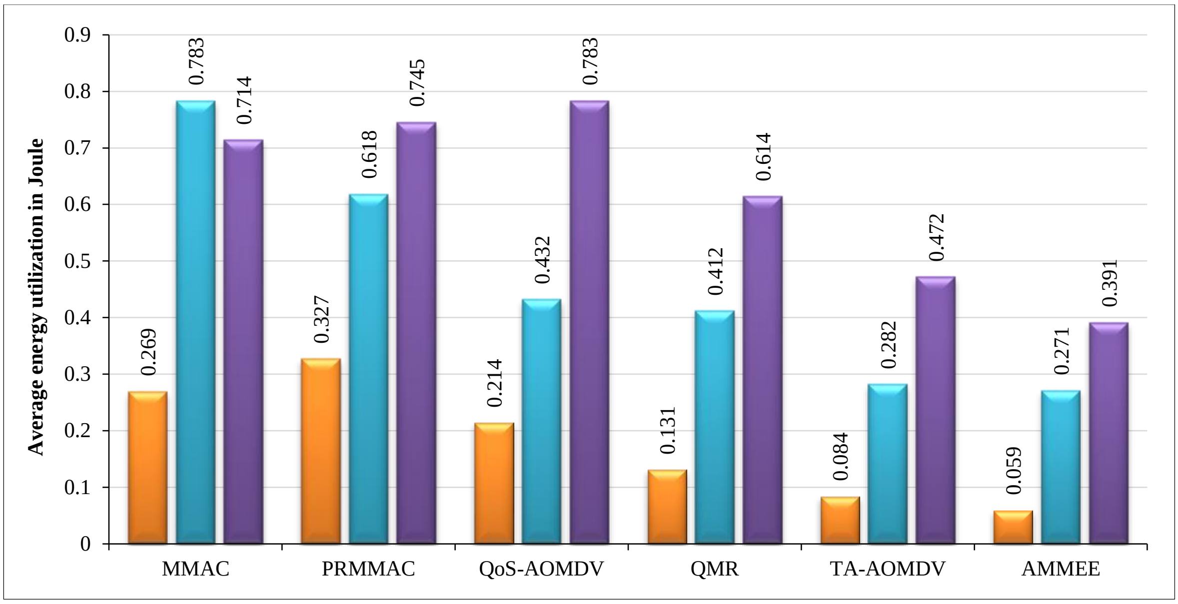


**Figure 10.** **The Average energy utilization analysis of MMAC, PRMMAC, QoS-AOMDV, TA-AOMDV and AMMEE protocols**

Table 5 compares the energy utilization across several network nodes of different protocols. The MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and proposed AMMEE are all displayed in the table, which demonstrates that the proposed method lengthens network lifetime. The average energy use was reduced by the suggested adaptive multichannel multipath routing.

Any communication must consider network delay, which is the time it takes for a packet to transit across the network from source to destination. The average end-to-end delay in milliseconds is displayed in Figure 11 as the total time required for all transmitted packets divided by the total time in a millisecond. The graph contrasts the average end-to-end delay of the AMMEE network with that of other protocols. Table 6 presents the average delay results in numerical format. In comparison to the current routing protocol, our network performs well because the suggested solution requires less average transmission time from the source to the recipient node. The average delays for 50, 100, and 150 mobile nodes are 0.214 ms, 0.318 ms, and 0.523 ms, respectively, according to the proposed AMMEE protocol.

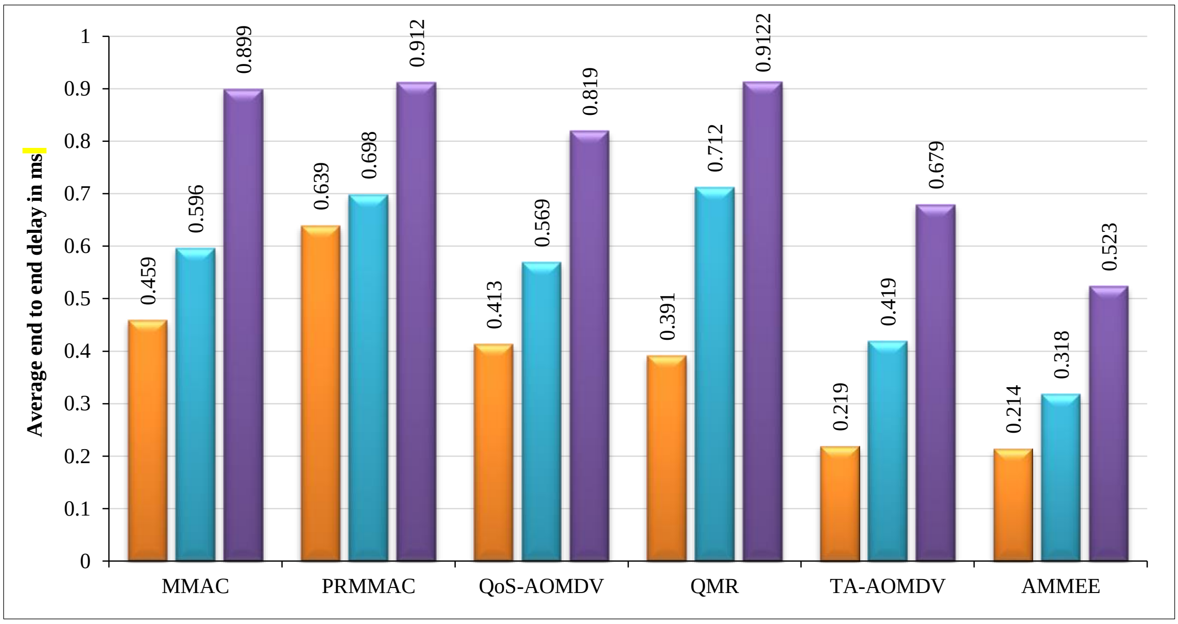


**Figure 11.** **Average end to end delay of analysis of MMAC, PRMMAC, QoS-AOMDV, TA-AOMDV and AMMEE protocols**

Comparative studies reveal that the average delay of six mobile ad hoc network protocols is 0.69 ms for MMAC, 0.651 ms for PRMMAC, 0.749 ms for QoS-AOMDV, 0.600 ms for QMR, 0.647 ms for TA-AOMDV, 0.439 ms for MMEE, and 0.351 ms for MMEE. The analysis indicates that, when compared to all other routing protocols already in use, the suggested AMMEE generates the lowest average delay, while PRMMAC, with an average delay of 0.749 ms, produces the highest.

**Table 5.** The Average energy utilization comparison of different protocols in Joules

| Nodes | AMMEE | TA-AOMDV | QMR | QoS-AOMDV | PRMMAC | MMAC |
|---|---|---|---|---|---|---|
| 50 | 0.059 | 0.084 | 0.131 | 0.214 | 0.327 | 0.269 |
| 100 | 0.271 | 0.282 | 0.412 | 0.432 | 0.618 | 0.783 |
| 150 | 0.391 | 0.472 | 0.614 | 0.783 | 0.745 | 0.714 |

**Table 6.** Average end to end delay of different protocols in milliseconds (ms)

| Nodes | AMMEE | TA-AOMDV | QMR | QoS-AOMDV | PRMMAC | MMAC |
|---|---|---|---|---|---|---|
| 50 | 0.214 | 0.219 | 0.391 | 0.413 | 0.639 | 0.459 |
| 100 | 0.318 | 0.419 | 0.712 | 0.569 | 0.698 | 0.596 |
| 150 | 0.523 | 0.679 | 0.9122 | 0.819 | 0.912 | 0.899 |

## 6- Conclusion

Wireless media is more popular than wired media in the modern telecommunications network era because it uses a multipoint approach and can cover large areas without the need for wired cables. One way to access wireless data transfer support is through mobile ad-hoc routing. Ad-hoc networks are useful for covering remote areas and emergencies (tsunamis, military operations, etc.), but have the drawback of being unreliable due to device mobility, low power, and limited device capacity. The AMMEE protocol for energy-efficient, secure multipath routing is proposed. The proposed protocol's main goals are to improve load balancing and network stability. In this research, we proposed an AMMEE routing protocol that surpasses existing protocols such as MMAC, PRMMAC, QoS-AOMDV, QMR, and TA-AOMDV to improve network stability and load balancing. TA-AOMDV solves the problem of load balancing and improves QoS in high-speed mobile ad-hoc networks, but MANET's nature of node movement also causes increased delay and routing overhead. As a result, we found that TA-AOMDV is not an ideal solution for reducing high-speed network overhead. To improve the QoS parameters of the network, the proposed AMMEE protocol applies a multi-path mechanism to balance network load and a multi-channel approach to allocate channels based on node demand. The simulations were performed in scenarios of 50, 100, and 150 network nodes over a range of velocities between 15 m/s and 25 m/s, which is the average velocity of mobile nodes, indicating that the AMMEE protocol can be used for medium-speed MANETs. The AMMEE's packet delivery rate outperforms MMAC by 31.81%, PRMMAC by 43.02%, QoS-AOMDV by 14.63%, QMR by 12.03%, and TA-AOMDV by 6.39%. Along with the fact that AMMEE has lower latency than other interesting protocols, this also highlights another aspect of ad-hoc mobile networks. AMMEE's research is more suitable for medium-speed ad-hoc mobile networks, and the design prototype is beneficial and implementable for demand-driven traffic MANETs.

Overall, AMMEE maximizes network uptime by evenly distributing the load on each node. It also reduces packet dropping ratio, average energy utilization, average end-to-end delay, and enhances packet delivery ratio and throughput compared to MMAC, PRMMAC, QoS-AOMDV, QMR, and TA-AOMDV protocols. This task can be further improved in a similarly adapted network with mobile sensor nodes of suitable speed.

## 7- Declarations

### 7-1- Author Contributions

Conceptualization, S.S.; methodology, S.S.; software, S.S.; validation, S.S., J.S., and B.L.; formal analysis, S.S. and J.S.; investigation, S.S.; resources, S.S.; data curation, S.S.; writing—original draft preparation, S.S.; writing—review and editing, S.S. and J.S.; visualization, B.L.; supervision, S.S. and J.S.; project administration, B.L. All authors have read and agreed to the published version of the manuscript.

### 7-2- Data Availability Statement

The data presented in this study are available in the article.

### 7-3- Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

### 7-4- Institutional Review Board Statement

Not applicable.

### 7-5- Informed Consent Statement

Not applicable.

### *7-6- Conflicts of Interest*

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

## 8- References

[1] Walikar, G. A., & Biradar, R. C. (2017). A survey on hybrid routing mechanisms in mobile ad hoc networks. Journal of Network and Computer Applications, 77, 48–63. doi:10.1016/j.jnca.2016.10.014.

[2] Ud Din, I., Guizani, M., Hassan, S., Kim, B. S., K. Khan, M., Atiquzzaman, M., & Ahmed, S. H. (2019). The Internet of Things: A Review of Enabled Technologies and Future Challenges. IEEE Access, 7, 7606–7640. doi:10.1109/ACCESS.2018.2886601.

[3] Yadav, A. K., & Tripathi, S. (2017). QMRPRNS: Design of QoS multicast routing protocol using reliable node selection scheme for MANETs. Peer-to-Peer Networking and Applications, 10(4), 897–909. doi:10.1007/s12083-016-0441-8.

[4] Das, S. K., & Tripathi, S. (2015). Energy Efficient Routing Protocol for MANET Based on Vague Set Measurement Technique. Procedia Computer Science, 58, 348–355. doi:10.1016/j.procs.2015.08.030.

[5] Kanellopoulos, D. (2019). Congestion control for MANETs: An overview. ICT Express, 5(2), 77–83. doi:10.1016/j.icte.2018.06.001.

[6] Saraswathi, R., Srinivasan, J., & Aruna, S. (2022). An Energy Efficient Routing Protocol and Cross Layer Based Congestion Detection Using Hybrid Genetic Fuzzy Neural Network (HGFNN) Model for MANET. Journal of Algebraic Statistics, 13(2), 1007–1019.

[7] Ghaffari, A. (2017). Real-time routing algorithm for mobile ad hoc networks using reinforcement learning and heuristic algorithms. Wireless Networks, 23(3), 703–714. doi:10.1007/s11276-015-1180-0.

[8] Sarfaraz Ahmed, A., Senthil Kumaran, T., Syed Abdul Syed, S., & Subburam, S. (2015). Cross-layer design approach for power control in mobile ad hoc networks. Egyptian Informatics Journal, 16(1). doi:10.1016/j.eij.2014.11.001.

[9] Bouras, M. A., Ullah, A., & Ning, H. (2019). Synergy between Communication, Computing, and Caching for Smart Sensing in Internet of Things. Procedia Computer Science, 147, 504–511. doi:10.1016/j.procs.2019.01.244.

[10] Umapathi, N., Ramaraj, N., Balasubramaniam, D., & Adlin mano, R. (2015). A Hybrid Ant Routing Algorithm for Reliable Throughput Using MANET. Advances in Intelligent Systems and Computing, 127–136. doi:10.1007/978-81-322-2268-2_14.

[11] Khan, M. S., Waris, S., Ali, I., Khan, M. I., & Anisi, M. H. (2018). Mitigation of Packet Loss Using Data Rate Adaptation Scheme in MANETs. Mobile Networks and Applications, 23(5), 1141–1150. doi:10.1007/s11036-016-0780-y.

[12] Whitmore, A., Agarwal, A., & Da Xu, L. (2015). The Internet of Things—A survey of topics and trends. Information Systems Frontiers, 17(2), 261–274. doi:10.1007/s10796-014-9489-2.

[13] Agiwal, M., Roy, A., & Saxena, N. (2016). Next generation 5G wireless networks: A comprehensive survey. IEEE Communications Surveys and Tutorials, 18(3), 1617–1655. doi:10.1109/COMST.2016.2532458.

[14] Singh, S. (2021). Environmental Energy Harvesting Techniques to Power Standalone IoT-Equipped Sensor and Its Application in 5G Communication. Emerging Science Journal, 4, 116–126. doi:10.28991/esj-2021-sp1-08.

[15] Singh, S. (2021). Minimal Redundancy Linear Array and Uniform Linear Arrays Beamforming Applications in 5G Smart Devices. Emerging Science Journal, 4, 70–84. doi:10.28991/esj-2021-sp1-05.

[16] Du, X., Xiao, Y., Ci, S., Guizani, M., & Chen, H.-H. (2007). A Routing-Driven Key Management Scheme for Heterogeneous Sensor Networks. 2007 IEEE International Conference on Communications, Glasgow, United States. doi:10.1109/icc.2007.564.

[17] Yıldız, A., Džakmić, Š., & Saleh, M. A. (2019). A short survey on next generation 5G wireless networks. Sustainable Engineering and Innovation, 1(1), 57-66. doi:10.37868/sei.v1i1.93.

[18] Hancke, G. P., & Hancke Jr, G. P. (2013). The role of advanced sensing in smart cities. Sensors, 13(1), 393-425. doi:10.3390/s130100393.

[19] Yan, Z., Zhang, P., & Vasilakos, A. V. (2014). A survey on trust management for Internet of Things. Journal of Network and Computer Applications, 42, 120–134. doi:10.1016/j.jnca.2014.01.014.

[20] Mohammadi, M., Al-Fuqaha, A., Sorour, S., & Guizani, M. (2018). Deep learning for IoT big data and streaming analytics: A survey. IEEE Communications Surveys and Tutorials, 20(4), 2923–2960. doi:10.1109/COMST.2018.2844341.

[21] Bani-Bakr, A., Dimyati, K., Hindia, M. H. D. N., Wong, W. R., Al-Omari, A., Sambo, Y. A., & Imran, M. A. (2020). Optimizing the number of fog nodes for finite fog radio access networks under multi-slope path loss model. Electronics (Switzerland), 9(12), 1–23. doi:10.3390/electronics9122175.

[22] Bani-Bakr, A., Hindia, M. N., Dimyati, K., Zawawi, Z. B., & Tengku Mohmed Noor Izam, T. F. (2022). Caching and Multicasting for Fog Radio Access Networks. IEEE Access, 10, 1823–1838. doi:10.1109/ACCESS.2021.3137148.

[23] Tilwari, V., Hindia, M. H. D. N., Dimyati, K., Jayakody, D. N. K., Solanki, S., Sinha, R. S., & Hanafi, E. (2021). MBMQA: A multicriteria-aware routing approach for the IoT 5G network based on D2D communication. Electronics (Switzerland), 10(23), 2937. doi:10.3390/electronics10232937.

[24] Biswas, K., Muthukkumarasamy, V., Chowdhury, M. J. M., Wu, X. W., & Singh, K. (2023). A multipath routing protocol for secure energy efficient communication in Wireless Sensor Networks. Computer Networks, 232. doi:10.1016/j.comnet.2023.109842.

[25] Shanmugam, K., Subburathinam, K., & Velayuthampalayam Palanisamy, A. (2016). A Dynamic Probabilistic Based Broadcasting Scheme for MANETs. Scientific World Journal, 1832026. doi:10.1155/2016/1832026.

[26] Singh, S., Assaf Mansour, H., Kumar, A., & Agrawal, N. (2017). Speaker Recognition System for Limited Speech Data Using High-Level Speaker Specific Features and Support Vector Machines. International Journal of Applied Engineering Research, 12(19), 8026-8033.

[27] Yadav, N. S., & Yadav, R. P. (2008). Performance comparison and analysis of table-driven and on-demand routing protocols for mobile ad-hoc networks. International Journal of Electronics and Communication Engineering, 2(12), 2809-2817.

[28] Perkins, C. E., & Bhagwat, P. (1994). Highly dynamic Destination-Sequenced Distance-Vector routing (DSDV) for mobile computers. Proceedings of the Conference on Communications Architectures, Protocols and Applications - SIGCOMM '94, 234–244. doi:10.1145/190314.190336.

[29] Clausen, T. H., Polytechnique, É., Jacquet, P., & Adjih, C. (2003). Real Time in AH hoc networks and VANet View project Design and Development of Applications in Vehicular Enviroment View project. Optimized Link State Routing Proto col (OLSR), Network Working Group, France.

[30] Perkins, P., Belding-Royer, E., & Das, S. (2003). Ad hoc On-Demand Distance Vector (AODV) Routing. Network Working Group. Request for Comments, 3561, 1-73.

[31] Eze, E. C., Zhang, S. J., Liu, E. J., & Eze, J. C. (2016). Advances in vehicular ad-hoc networks (VANETs): Challenges and road-map for future development. International Journal of Automation and Computing, 13, 1-18. doi:10.1007/s11633-015-0913-y.

[32] Haas, Z. J., Pearlman, M. R. & Samar, P. (2023). Internet-Draft. Available online: http://www.ietf.org/ietf/1id-abstracts.txt (accessed on February 2023).

[33] Johnson, D. B., & Maltz, D. A. (1996). Dynamic Source Routing in Ad Hoc Wireless Networks. Mobile Computing, 153–181. doi:10.1007/978-0-585-29603-6_5.

[34] Gupta, N., & Gupta, R. (2012). Route-discovery optimization in LAR: a review. In Proceedings of the International Conference on Soft Computing for Problem Solving (SocProS 2011) December 20-22, 2011: Volume 2, 877-884. doi:10.1007/978-81-322-0491-6_80.

[35] Zhu, Y., Zhang, J., & Partel, K. (2011). Location-aided routing with uncertainty in mobile ad hoc networks: A stochastic semidefinite programming approach. Mathematical and Computer Modelling, 53(11-12), 2192-2203. doi:10.1016/j.mcm.2010.08.025.

[36] Yadav, N. S., & Yadav, R. P. (2008). Performance Comparison and Analysis of Table- Driven and On-Demand Routing Protocols for Mobile Ad-hoc Networks. International Journal of Information Technology, 4(2), 101-109.

[37] Adam, S. M., & Hassan, R. (2013). Delay aware Reactive Routing Protocols for QoS in MANETs: a Review. Journal of Applied Research and Technology, 11(6), 844–850. doi:10.1016/s1665-6423(13)71590-6.

[38] Saba Farheen, N. S., & Jain, A. (2022). Improved routing in MANET with optimized multi path routing fine-tuned with hybrid modeling. Computer and Information Sciences, 34(6), 2443–2450. doi:10.1016/j.jksuci.2020.01.001.

[39] Marina, M. K., & Das, S. R. (2006). Ad hoc on-demand multipath distance vector routing. Wireless Communications and Mobile Computing, 6(7), 969–988. doi:10.1002/wcm.432.

[40] Mueller, S., Tsang, R.P., & Ghosal, D. (2004). Multipath Routing in Mobile Ad Hoc Networks: Issues and Challenges. Performance Tools and Applications to Networked Systems. MASCOTS 2003, Lecture Notes in Computer Science, 2965. Springer, Berlin, Germany. doi:10.1007/978-3-540-24663-3_10.

[41] Asfour, T., & Serhrouchni, A. (2001). The Coexistence of Multicast and Unicast over a GPS Capable Network. Networking — ICN 2001. ICN 2001. Lecture Notes in Computer Science, 2093. Springer, Berlin, Germany. doi:10.1007/3-540-47728-4_5.

[42] Chen, L., & Heinzelman, W. B. (2005). QoS-aware routing based on bandwidth estimation for mobile ad hoc networks. IEEE Journal on Selected Areas in Communications, 23(3), 561–572. doi:10.1109/JSAC.2004.842560.

[43] Sharma, S., Jindal, D., & Agarwal, R. (2017). An approach for congestion control in mobile ad hoc networks. International Journal of Emerging Trends in Engineering and Development, 3(7), 217-223.

[44] Soundararajan, S., & Bhuvaneswaran, R. S. (2012). Multipath rate based congestion control for mobile ad hoc networks. International Journal of Computer Applications, 55(1), 42-47.

[45] Pham, Q. V., & Hwang, W. J. (2016). Network utility maximization-based congestion control over wireless networks: A survey and potential directives. IEEE Communications Surveys & Tutorials, 19(2), 1173-1200. doi:10.1109/COMST.2016.2619485.

[46] Le, T. A., Hong, C. S., Razzaque, M. A., Lee, S., & Jung, H. (2012). EcMTCP: An energy-aware congestion control algorithm for multipath TCP. IEEE Communications Letters, 16(2), 275–277. doi:10.1109/LCOMM.2011.120211.111818.

[47] Sheeja, S., & V.Pujeri, R. (2013). Effective Congestion Avoidance Scheme for Mobile Ad Hoc Networks. International Journal of Computer Network and Information Security, 5(1), 33–40. doi:10.5815/ijcnis.2013.01.04.

[48] Xia, L., Liu, Z., Chang, Y., & Sun, P. (2009). An Improved AODV Routing Protocol Based on the Congestion Control and Routing Repair Mechanism. WRI International Conference on Communications and Mobile Computing, Kunming, China. doi:10.1109/cmc.2009.307.

[49] Senthil kumaran, T., & Sankaranarayanan, V. (2011). Early Congestion Detection and Self Cure Routing in Manet. Computer Networks and Information Technologies. CNC 2011, Communications in Computer and Information Science, 142, Springer, Berlin, Germany. doi:10.1007/978-3-642-19542-6_110.

[50] Soni, H., & Mishra, P. K. (2013). Congestion control using predictive approach in mobile ad hoc network. International Journal of Soft Computing and Engineering, 3(4), 76-78.

[51] Senthilkumaran, T., & Sankaranarayanan, V. (2013). Dynamic congestion detection and control routing in ad hoc networks. Journal of King Saud University - Computer and Information Sciences, 25(1), 25–34. doi:10.1016/j.jksuci.2012.05.004.

[52] Simaiya, S., Shrivastava, A., & Keer, N. P. (2014). IRED algorithm for improvement in performance of mobile ad hoc networks. Proceedings - 2014 4th International Conference on Communication Systems and Network Technologies, CSNT 2014, 283–287. doi:10.1109/CSNT.2014.62.

[53] Ferreira, J., & Alam, M. (2017). Future Intelligent Vehicular Technologies. Springer, Cham, Switzerland. doi:10.1007/978-3-319-51207-5.

[54] Lochert, C., Scheuermann, B., & Mauve, M. (2007). A survey on congestion control for mobile ad hoc networks. Wireless Communications and Mobile Computing, 7(5), 655–676. doi:10.1002/wcm.524.

[55] Beg, A., Mostafa, S. M., AbdulGhaffar, A. A., Sheltami, T. R., & Mahmoud, A. (2022). An Adaptive and Spectrally Efficient Multi-Channel Medium Access Control Protocol for Dynamic Ad Hoc Networks. Sensors, 22(22), 8666. doi:10.3390/s22228666.