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RESEARCH ARTICLE

Design and Analysis of an Energy-Efficient Load Balancing and Bandwidth Aware Adaptive Multipath N-Channel Routing Approach in MANET

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ABSTRACT Mobile Ad Hoc Network (MANET) is a collection of spontaneous nodes that form a dynamic network without any centralized administration. Routing decisions for mobile communication is a challenging task because the continuous movement of nodes increases the routing overhead and energy consumption. Numerous studies have been conducted in the field of MANET to reduce the routing decision overhead and energy consumption. Their concepts are good for improving efficiency in terms of load balancing, congestion control, and energy consumption. This article provides new concepts that are able to give better outcomes. This paper, proposes an adaptive Multipath Multichannel (N-channel) Energy Efficient (MMEE) routing approach in which route selection strategies are dependent on predictive energy consumption per packet (calculated accustomed data delivery), available bandwidth, queue length, and channel utilization. Multipath provides multiple routes and balances network load, whereas multichannel reduces network collisions via a channel ideal assignment mechanism. In the multichannel mechanism, link bandwidth is divided into multiple sub-channels. Multiple source nodes access the channel bandwidth in a simultaneous manner that minimizes the network collision. The collaborative multipath multichannel mechanism provides more than one path between a single source or multiple sources to the destination without collision and congestion. The path selection is based on the MMEE routing approach. In the proposed MMEE, a load and bandwidth aware routing method selects the path, based on node energy and predicts their lifetime, which increases the network reliability. The result shows the comparative analysis between various multichannel medium access techniques such as MMAC, 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), Topological Change Adaptive Ad hoc On-demand Multipath Distance Vector (TA-AOMDV), and the proposed MMEE method. The outcome concludes that the MMEE method performs better than other schemes. The proposed MMEE protocol provides better performance in terms of percentage of data received, throughput, and minimum energy utilization.

INDEX TERMS AOMDV, congestion, energy, MANET, MMEE, multichannel.

I. INTRODUCTION

MANET is a collection of mobile nodes that communicate with other nodes in an open environment without the presence of any centralised authority. These networks are extremely versatile and can be used for a wide range of applications because they don't have any pre-existing infrastructure. The limited range of wireless interfaces necessitates the use of intermediary nodes in most cases. This means that each node in multi-hop ad-hoc networks has to act as a router, sender

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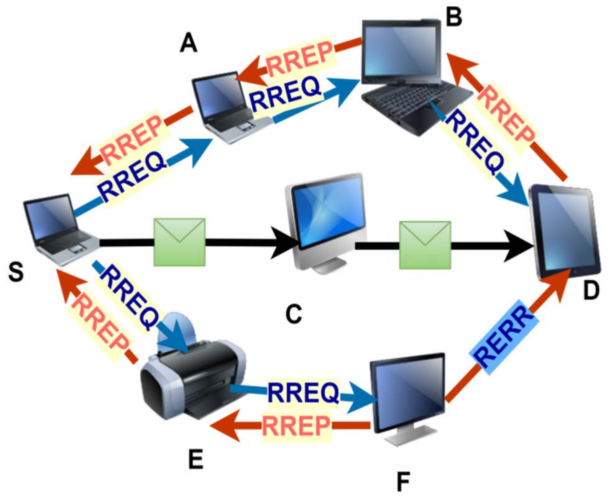

FIGURE 1. Example of MANET.

and receiver [1], [2]. Congestion is one of the challenges in the network, and it is not possible to remove congestion from the network. Heavy congestion means more loss of data [3], [4]. The senders are continuously sending the data packets, and the intermediate nodes' responsibility is to forward the data to the next node or destination. The nodes consumes energy for each and every operation, if a data packet is dropped, the data is again retransmitted to the destination [5]. Retransmission means wastage of resources, and energy is a valuable resource for communication [6]. The retransmission consumes bandwidth and affects the performance of new senders. Congestion can be reduced by using a multipath and buffer management scheme. Internal changes in the standardised packet format are required to control loss of resources. In mobile multi-hop ad-hoc networks, finding a route between communication endpoints is a major challenge. A number of approaches to this problem have been proposed in recent years, but no routing algorithm has yet been found that works in all circumstances. The example of MANET is mentioned in Figure 1.

In Figure 1, the sender wants to establish a connection and chooses the shortest path to its destination for data transfer. The route S-C-D is the shortest route for transferring data to destination D by source S. The Route Request (RREQ) packets are flooded by the sender to reach their destination, and each node replies to the sender's packet by sending its own Route Request (RREQ) packet. If there is no link available due to the out of range of nodes or D, then a Route Error (RERR) message will be generated.

The dynamic network is useful for real-time applications where a remote location needs a communication backbone through light-weight devices. In contrast, mobile devices are very useful for providing communication using a multipoint mechanism. The mobile nodes are free to move in a limited area without the presence of any centralized administration [1]. In a multipoint setting, the mobile device can choose the best route, forward data, and set up a network. In multipath routing, the strategy source node sends the data through more than one available path, simultaneously utilizes all paths to minimize the network delay or improve the load balance factor. AOMDV is one of the multipath methods to provide multipath communication in a mobile ad hoc network [7], [8]. The hybridization of uni-path and multipath routing and location-based routing also gives better performance [9], [10].

Multichannel is another approach to separating the bandwidth for different transmissions at the same time by carrying multiple data streams without collision. This paper hybridizes both techniques with an energy-aware approach to analyzing the network efficiency concerning node capacity, network load balancing, channel utilization and congestion control.

This research focuses on network and data link layer adoption. In the network layer applies the multipath multipoint route selection strategy, and for multichannel, energy-aware technique is incorporated under the data link layer. Disaster management, rescue operations, and military fields are the applications of MANET [1], [11], [12]. Also, using MANET in multimedia applications is an interesting way to use it [13]. Limited bandwidth, limited range of nodes, random motion of mobile nodes, energy efficient routing and symmetric nodes are the challenges in MANET [14], [15].

In the current scenario, mobile ad hoc network are gaining popularity due to the advancement of their demands in various applications such as the internet of things (IoT) [16]. The sensor nodes are also able to collect and forward information. The MANET nodes are also sensors, and after sensing, they start the communication process, which is also able to support high-speed networks [17].

In this research work, the rest of the sections describe the flow of work, such as Section II is about the routing protocols in MANET, and Section III defines the working of multipath routing. Section IV describes the problem due to congestion and energy. Section V is related to work in the field of a multipath multichannel strategy, with its pros, cons, and further possibilities. Section VI describes proposed work, while Section VII describes protocol design. Section VIII describes the proposed algorithm, and Section IX describes the result. In the last section, X conclude the research work with future enhancement.

II. ROUTING PROTOCOLS IN MANET

A wireless mobile ad hoc network (MANET) consists of two or a lot of autonomous mobile nodes, each of which communicates directly or indirectly with the neighbor nodes within its radio range. The sector of MANET is speedily growing as a result of varied advantages and applications. Routing protocols are used to find the route between source to destination. In an ad-hoc network, broadcasting is a necessary and common operation [18], [19], [20]. Distributing a message from one node to the rest of the network is what this process is all about. The routing protocol in any network plays an important role in establishing the connection between the sender and receiver [21], [22]. The receivers are not directly available on the network, so there is a need here to reach the destination by routing protocol. The MANET routing protocols are not the same as traditional wireless routing protocols because the nodes are continuously changed and a dynamic link is established for routing. There are a number of routing protocols in MANET, but the performance of only a few is better, like AODV. In MANET, the classification of routing protocols is proactive, reactive, and hybrid [21], [22], [23]. The routing mechanisms of all the protocols are different, and they use different techniques for link establishment.

A. PROACTIVE OR TABLE-DRIVEN ROUTING

When a packet needs to be forwarded and the path is already known, proactive protocols, also known as table-driven, continuously analyses and maintain consistent and up-to-date routing information inside the network. The table-driven routing protocols maintain a record of routing, and after the successful delivery of data, there is no provision to erase or remove all the routing entries. The major advantage of this routing approach is that there is no need to initiate the route procedure from the beginning because all the route information from a particular sender to a particular receiver is available in record. In the dynamic network, nodes' speeds vary, so they are free to move in any direction. The proactive routing protocols are not efficient for that kind of network. This type of routing protocol unnecessary produces overhead in a network [24]. The proactive routing protocols are DSDV [25] and OLSR [26].

B. REACTIVE OR ON-DEMAND ROUTING

The on-demand routing protocols do not maintain a record of routing, and after the successful delivery of data, they have provision to erase or remove all the routing entries. In this routing approach, there is no need to initiate the route procedure from the beginning because all the route information from a particular sender to a particular receiver is not available in record. If the node mobility is high, then this type of approach is better for handling it. There is no record of the route required to be maintained here. This routing approach has produced less overhead. The reactive routing protocols are AODV [27] and DSR [28].

C. HYBRID ROUTING PROTOCOLS

The hybrid routing protocol approach provides flexibility to use different types of routing protocols in different zones. MANET provides better results in small fixed-size networks because, in the case of long-range communication or routing, the internet is the best option. But it is possible to cover a large area through a hybrid routing approach in MANET. With the help of a hybrid approach, we can use a proactive and reactive approach for data delivery. ZRP is an example of a hybrid routing approach [29]. The hybrid approach is further classified into inter zone routing, external zone routing protocols [30].

There are different other protocols that are also cooperative in improving the performance of MANET. The LAR, LAR-1 and LAR-2 protocols are able to maintain a record of the location and mobility speed of mobile nodes [31], [32]. Each and every node is maintaining a record of the location of all nearby node/s which are participating in the routing procedure.

Mobile ad hoc routing is classified into different categories. Reactive routing protocols such as DSR, AODV is more feasible for the ad hoc network [22], [24]. From the comparative analysis of MANET routing protocols, it is concluded that the AODV-based routing protocol is more feasible due to its low energy requirement, low delay, and gives the shortest path for communication in a dynamic environment. That protocol is further enhanced through multipath routing methodology to balance the network load and minimize network congestion.

III. AOMDV (MULTIPATH ROUTING)

Multipath routing is a process to discover the multiple routes between a single sender and a single receiver [33], [34], [35], but there is no restriction on multiple senders and multiple receivers. Multiple senders are simultaneously participating in the routing and establishing multiple routes using the same or multiple intermediate nodes in the network. It is possible to use common links and common nodes in the route. The source sends a request to establish a connection with the destination. The procedure of connection establishment is the same as the process of unipath routing. The multipath routing scenario with different possibilities of route selection is mentioned in Figure 2. Here, the sender S1 selects multiple routes for sending the data to destination D1 but selects only one route at a time for transferring data between the sender and receiver. The senders S2 and S3 also use the same procedure for route selection in MANET. The rest of the routes are available as backup routes if the primary route fails, then alternate routes are instantly available for forwarding the data to the receiver without any loss in network. The number of backup routes for S2 and D2 is greater as compared to S1 and S3. In Figure 2, we clearly mentioned the routes of different senders because different senders are sharing the same node or link for sending.

The same node and link are part of the main shortest route or part of an alternative route for the same sender and receiver or different sender and receiver in the network. In Figure 2, there are a number of routes by which a source reaches a destination. Here the sources are S1, S2 and S3, and the destinations are D1, D2 and D3. Figure 2 shows node disjoint, link disjoint and no-disjoint routes. Figure 2 clearly shows the route information between sources and destinations. The routes in which no node is common and no link is common are the node disjoint routes [34], [35]. Only S1-I1-I3-D1 is the node disjoint route. In the rest of the routes, if a node is common only, it means the route is a linked disjoint route. The routes, S2, I11-I13-I12-I14-I10-D2 and S3-I16-I12-I17-D3 are link disjoint routes. The routes in which node and link are common are the non-disjoint routes. In the routes S1-I2-I4-I7-I8-I6-D1 and S1-I2-I5-I8-D1, node I2 is common and link S1-I2 is common. As in S1-I2-I4-I7-I8-I6-D1 and

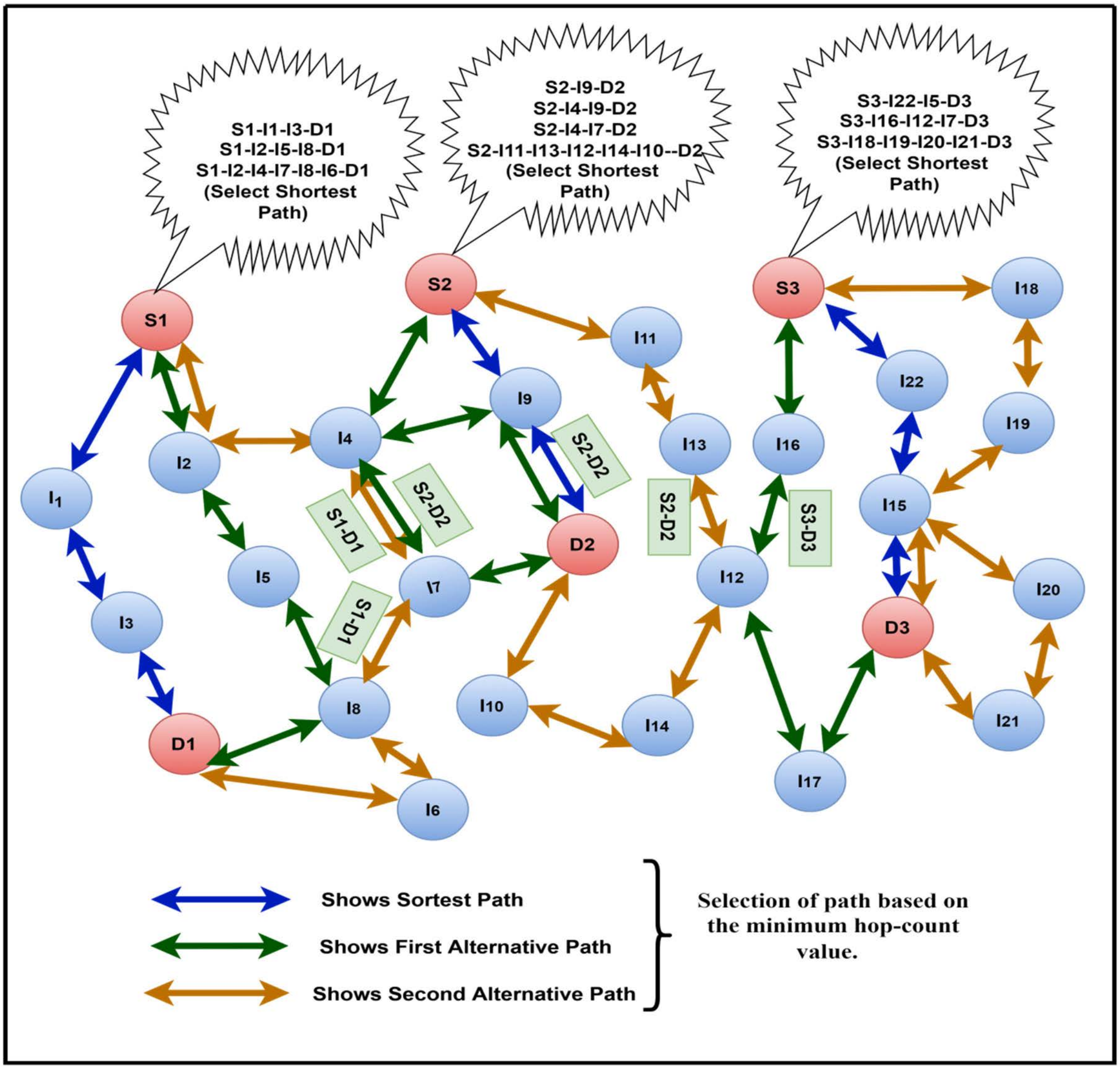

FIGURE 2. Multipath routing example with more than one source and one destination.

S2-I4-I7-D2, node I7 is shared, as are links I4 and I7. There are some links presented in Figure 2.

The main disadvantage of link disjoint and non-disjoint is that they do not utilize the multipath concept properly. If the common node or common link is busy in communication, then it is difficult to utilize that node or link in another path. This type of problem occurs when fewer nodes exist in a network. If the number of nodes is large enough and not densely populated, the chances of link disjoint routes or non-disjoint routes selection will be reduced. It's much better in multipath routing to separately select all the paths to handle load properly and utilize energy properly in the network. In MANET multipath routing faces multiple challenges to adopting the route, such as security, energy issues, scalability, mobility, distance and direction of search, but AOMDV handles the multipath communication in that situation [34]. Ad hoc on-demand multipath routing is a great way to improve network performance in terms of network throughput, percentage of data received, and fare load balancing [36].

A. ADVANTAGES OF MULTIPATH AOMDV ROUTING PROTOCOLS

The multipath routing protocols are able to handle load efficiently in dynamic network [33], [34], [35]. Some advantages of multipath routing are:

- AOMDV Multipath routing minimizes the overall route overhead and balances the network overhead.
- AOMDV is able to handle the excessive load and balance the load by using the alternative paths. Packet dropping decreases as node energy utilization increases.
- It helps to provide multiple shortest paths between the sender and the receiver node.
- Through the AOMDV, network resources are fairly utilized and this decreases network congestion.

- If established routes fail for any reason in the network, backbone routes are available.
- It reduces the possibility of congestion in the network and handles the loss of data packets in network.

B. MULTIPATH ROUTING ISSUES

Multipath routing has some issues but needs to improve, like route request storming and inefficient route discovery. Some of the issues discussed are. [33], [34], [35], [36]:

- **Huge Request and Reply Packets.**

During the route discovery process, multiple source nodes generate a huge quantity of route request packets and receive replies from request acceptor nodes. Senders spread or broadcast the routing packet to find out the number of efficient routes. It increases the processing time in intermediate nodes due to the number of duplicate packets arriving at these nodes. That means that duplicate route packets add overhead to the network and slow down the setup phase, which leads to heavy flooding of route request and replay packets.

- **Inefficient Route Discovery.**

It's also associated with route request flooding because, in the multipath route execution process, the intermediate node avoids the route reply forwarding due to finding or analyzing a node disjoint or link disjoint path. Hence, the sender nodes still wait to get the response of the requested route from the destination node.

- **Alternative Route Stability**

The senders select multiple paths for sending data, but the stability of alternative paths is the major issue here for routing. The alternative path is to assume full load and break due to reaching out of range, then switch to the next path for remaining communication. The number of multiple paths established depends on the number of nodes in the network. If the network is dense, then it's possible to establish a greater number of backup routes for sending data to the destination.

Normal unipath routing such as AODV and DSR takes a lot of time to discover the route from source to destination due to single path and node dynamic movement [27], [28]. So, the multipath routing protocol AOMDV decreases the time consumption for the route discovery process. It gives multiple paths for communication and at least one of the paths is alive for communication.

IV. CONGESTION AND ENERGY CONSUMPTION PROBLEM IN MANET

Congestion occurs due to limited bandwidth capacity, which invites data packet loss in MANET. Because only a single route is established between source and destination in unicast routing, the likelihood of congestion is higher [37], [38].The active ad hoc routing protocol lacks a mechanism for communicating load information to neighbors and thus cannot distribute load evenly across the network. It remains a major issue in MANET that nodes cannot maintain load balancing across different routes on the network. In Figure 3, The sender S sends data packets to destination D through intermediate

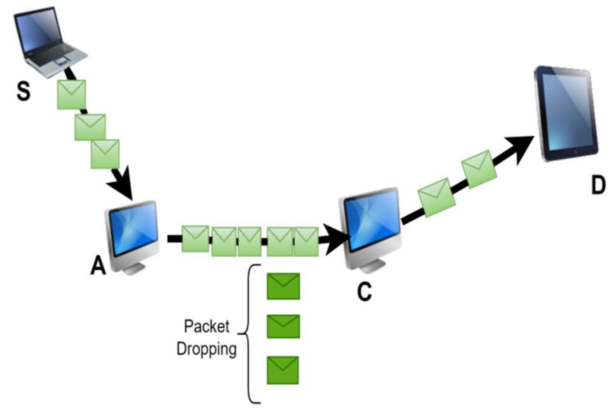

FIGURE 3. Packet dropping due to congestion.

nodes A and C. The source continuously sends data packets, but the destination is not able to handle the data at the same rate. The packets start to assemble on between link A and C but due to not forwarding in time, the packets are dropped. Congestion definitely increases delay because packets are forwarded from a congested link and again flood RREQ and RREP packets into the network for connection establishment, which increases routing load [38]. This growth is due to the fact that these networks don't have a topology and can make their own connections and organize themselves.

The properties of MANET, such as dynamic topology and decentralized connectivity, make routing a difficult task. While the mobile nodes entertain a large amount of data before forwarding it, the ''unnecessary'' data must be buffered. Congestion occurs when the limited buffer space becomes full, and the extra data (new or old) must be dropped. This escorts the mutual dissipation of communication and assets such as node bandwidth while also impeding event detection reliability due to packet losses. As a result, routing protocols that can consistently dispense data transfer among nodes and thus improve MANET performance are deemed necessary. So, we need an approach that can send packets from multiple paths, so that if part of the data is dropped at any hop in the link, it never causes loss at the end when it is accumulated, because data is reached in the network from other hops (via alternative routes).

Energy efficiency may be a challenge faced particularly in planning a routing protocol. A single routing protocol is difficult to satisfy all needs. i.e., one routing protocol can't be a solution for all energy-efficient protocol that designed to provide the most potential necessities, according to bound needed situations [39].In Figure 4, it is clearly mentioned that the energy level of node A and node C is depleting rapidly.

The link is broken due to un-necessary loss of data and retransmission of data. Meanwhile, the nodes E and F are available for communication, but they are not directly selected for routing the data. Multiple route selection is one option, but to secure energy and reduce congestion, energy efficient multipath routing is required.

Energy is the main source of communication and every node may be contained within self-battery backup power by

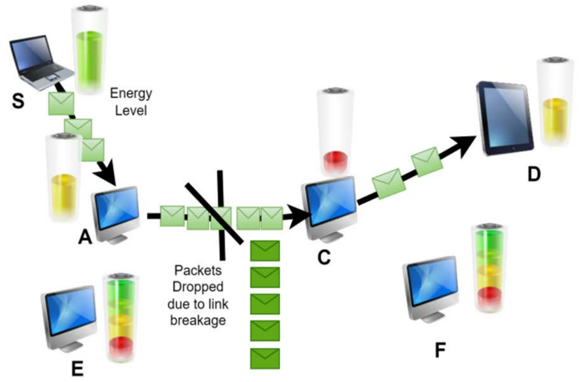

FIGURE 4. Packet dropping due to energy lost.

wireless adapter or natural sources like sunlight or wind, but in every place it's not possible [39]. Various studies propose various techniques for dealing with energy issues in various ways, but they do not work in all constraints. is possible to establish a strong route using multipath and by that, also enhance the lifetime of nodes. These nodes are generally powered by batteries with limited energy provision. The limited battery bower of nodes in the network is the crucial issue, and their utilization is additionally necessary to improve the routing capability [40]. Some problems with early energy depletion due to congestion and improper channel utilization may occur:

- When a node's energy is depleted, it ceases to function. This failure could doubtless lead to the partitioning of the entire network.
- The network petitioning means the divide the established route and unnecessary detonation of limited node energy.
- The more links break, the more likely it is that there will be a flood of RREQ and RREP packets, which leads to more overhead.
- Energy potency is still a key performance metric because using energy efficiently will make the network last longer, which is very important for improving the network's ability.

The novel approach of energy estimation to find out broken links and re-establish paths based on the energy of the nodes that manage the network topology and routing strategy in MANET It's indicated that these effects were harmful within the mentioned number of network parts.

V. RELATED WORK

The research contribution is also helpful for thinking about the innovations in the field of MANET. In the modern world, mobile devices are able to do multiple tasks and definitely for those that require battery power or backup, but efficient utilization is the best option to enhance the battery life time. This section discusses contribution of the mobile ad hoc network communication by researcher in the area of routing strategy and network issues. Previous works may be having limitations and strengths are mentioned in table 1.

In the given table 1, I discussed the previous work that was published in 2017–2022. All previous researches are unique and show better performance as compared to other older works. Some of the approaches show low PDR (73% maximum) value and high delay as compared to other previous schemes [46], and PDR is 40% only mentioned in [41]. The low performance shows the degradation, but it is true that the performance is better than mentioned previous schemes in particular research paper [41], [46]. Innovative ideas are helpful to make the research more effective, and sometimes it is complex, and sometimes it is quite simple. The proposed MMEE approach is able to handle the energy consumption, utilize bandwidth, maximize throughput, PDR, and minimize data loss and average end-to-end delay. The low data drop and delay show that there is less overhead and proper reception of data at the destination. The performance of MMEE is compared to the protocols TA-AOMDV, QMR, and QoS-AOMDV [46]. In MMAC and PRMAC performance, the rest of the research does not consider all the performance parameters and also does not consider all the factors that affect the performance of dynamic networks.

VI. PROPOSED WORK

The multipath routing approach provides three alternative routes to the source nodes for communication that balance the network load with the help of node capacity. Existing multipath routing AOMDV is more efficient as a single-path on-demand routing. The proposed mechanism enhances the AOMDV routing behavior (which is named as multipath multichannel energy efficient (MMEE)). It is based on node capacity-based load sharing and multichannel communication. Node capacity is identified during the route requesting time. Every node provides information about queue length, residual energy, per packet energy utilization, and bandwidth capacity. All of the information gathered is used to compute the cost function at the destination node and select the three best paths based on the computed cost function. In our proposed approach, the cost function is important. While multiple paths exist in the route discovery process, it selects only the best three routes for data transmission whose cost function value is lower. During the data communication, the source sends the data by all three selected paths based on the node's computed capacity. The proposed MMEE protocol sends the data in an efficient way and improves network performance. Another multichannel mechanism assists in removing collisions when competing with more than one sender in a single (acquired from other sources) node. It handles three channels at a time and generates three sender nodes at the same time because it generates the table of channel utilization and ideal channel. This technique provides a separate channel to demand from three senders at the same time while minimizing network collisions. The proposed approach gives better throughput and packet delivery ratio with minimum energy consumption-based routing as compared to existing energy-based dynamic source (EDSR) routing with multichannel medium access (MMAC) protocol,

TABLE 1. Comparison of various previous techniques (consider articles from 2017 to 2022).

Reference	Technique Proposed	Aim of Research	Demerits	Energy Consumption/ Utilization	Bandwidth Utilization	Throughput/ Delay	Possible Enhancement
Surjeet Dalal et al. [41]	Proposed a congestion control queue estimation and scheme in MANET cloud for better bandwidth utilization.	The aim of research is to improve the node energy utilization and proper bandwidth available to nodes for communication.	The over queue length is the prediction of congestion status. The higher data rate shows the degradation in PDR and improvement in end-to-end delay.	Not Evaluated.	Poor bandwidth utilization in higher data rate	Both are evaluated.	Set the equation for energy calculation and queue estimation and synchronize by consumption and capacity.
Mohammad Sirajuddin et al. [42]	Proposed a trust based multipath protocol for improving QoS (TBSMR).This technique used multipath approach and detect attacker presence.	The main aim of the TBSMR is to control the congestion and used data forwarding approach for malicious node detection.	The only multipath approach is not sufficient to control the congestion. The attacker node infection is not evaluated. The energy loss due to attacker is not cleared in the research.	Not Evaluated.	Poor bandwidth utilization	Both are evaluated.	Trust value based on attacker infection. For energy utilization use the node have low mobility and sufficient energy for the routing. For congestion control use the rate control mechanism after detect congestion.
Ms. Vrushabha J Muramkar et al. [43]	Proposed the concept of sending the high priority data first then change the low energy node with node having sufficient energy for link stability.	Reduce the unnecessary consumption of mobile nodes but scheme is not completely feasible.	The performance is only compared with simple AODV protocol.	Improving Energy Utilization.	Better because of set priority of communication.	Not Evaluated/ minimizes the delay in routing.	The improvement in results further possible by control the mobility of nodes.
Bhanumathi Velusamy et al.[44]	Proposed the MFNMR for finding the node dis-joint path and select the path that consumes less energy in	The aim is to improve the energy utilization and reduces overhead and delay.	The nodes mobility speed is not considered more than 10m/s and backup path analysis only measures up to 120 seconds.	Measured but in low mobility and load. Actual load not mentioned.	Better in low mobility speed and backup route role for better bandwidth available	Maximize through put and delay but constraints are limited.	Measures the quantity of data packets send, receive and loss. Also measures the control overhead

TABLE 1. ***(Continued.)*** **Comparison of various previous techniques (consider articles from 2017 to 2022).**

	routing.				only for up to certain time limit.		packets w.r.t the packets received in network.
Shahenda Sarhan et al. [45]	Proposed the Elephant Herding Optimization Technique AOMDV scheme that selects the path that consumes less energy and forward large number of packets in network.	The aim is to improve the network lifetime and reduces the unnecessary energy consumption.	The node speed is only 5m/s and if the route selection based on energy consumption, then what is the importance of AOMDV.	Measured in constant speed. Evaluated in different mobility speed not in random mobility speed.	Better in low mobility speed and backup route role for better bandwidth.	Better in fixed mobility speed and backup route selection procedur e not clearly mention ed.	The radio range can be considered up to 550 meters and evaluate the performance in random mobility
Zheng Chen et al. [46]	Proposed the TA-AOMDV routing approach to improve the QoS routing in high-speed MANET	Improve the utilization of bandwidth, queue length and energy.	The speed of nodes in MANET is not same. The criteria of evaluation are not satisfactory.	Evaluate average energy consumption but there is negligible difference in QAM and TA-AOMDV.	Fair Bandwidth utilization but the bandwidth availability in high-speed network is not mentioned.	Maximi ze through put/ Minimiz es Delay.	The CBR data rate is 50Kbps maximum consider for simulation but in high-speed communicati on up to 1GBps provides better performance.
Yamini Swathi L et al. [47]	Proposed the MMPRP approach that based on TTL enhancement and clustering of nodes for better efficiency.	Improves the energy utilization by using clustering approach for routing. No information of clustering protocol information not mentioned in paper.	Simulation time is less (only 10 seconds), Energy consumption parameters are not mentioned.	Not Evaluated.	Fair bandwidth utilization shows in 10 sec time only.	Maximi ze through put/ Minimiz es Delay.	It's possible to evaluate the energy consumption in retransmissio n. Focus on suddenly loss of session problem.
Tongguan g Zhang et al. [48]	Proposed the MPTCP approach for improving QoS and QoE using markov chain model.	The main aim of the research is to predict the mobility of nodes and establish strong multipath	There is no need in network to work out on all different interfaces because it's also enhanced the chances overhead and delay	Not Evaluated	Utilized by Measured all interfacing in 180mbps and 360 mbps speed in all scenarios in	Not measure d, only focus on probabil istic.	In the dynamic network location prediction of all the interface not important but strong

TABLE 1. ***(Continued.)*** **Comparison of various previous techniques (consider articles from 2017 to 2022).**

		connections.			network.		connection establishment parameter is important. So, focus on it.
Antra Bhardwaj et al. [49]	Proposed an AOMDV-GA algorithm for check the fitness function (FFn) of the multipath routes for establish strong connection.	The main aim of research is to ignore the faulty nodes in route selection and not select faulty route/s for routing the data packets.	In dynamic network multiple paths are more reliable than single path. The fitness function not need here to ignore some not fit nodes. FFn role with GA are not clear with residual energy (e), shortest path (sp), low traffic (lt) on route and random packet dropping(rpd)	Not Evaluated	Improved the bandwidth utilization.	Measured in different node density scenarios and uniform simulation time.	The data or route establishment packet format necessarily need to mentioned in the paper. The explanation of FFn required for Ee, sp, lt and rpd.
Anand Nayyar and Rajeshwar Singh [50]	Proposed a IEEMARP (Improvised energy-efficient multipath ant colony optimization (ACO) based routing protocol), a novel ACO-based multipath routing protocol based on energy conservation for WSN.	The main aim is to figure out the best way to route data from source to destination by taking into account connections that go in more than one direction and keeping up with the routing protocol.	Simulation time is mentioned at 150s, 300s, 500s to measure performance, but results are mentioned at 150s only. Delay is measured up to 140s for all protocols. So, there is uncertainty in performance evaluation. The paper does not include data on energy consumption in the 200s or performance in the 300s and 500s. No use of fuzzy logic in proposal.	Evaluated but not match with given simulation time (exactly).	Utilized by using multipath.	Evaluated but end time is different in both.	It's possible to design mathematical equation i.e., feasible with all-time units. Possible to measures channel utilization.
Amir Abdelkader Aouiz et al. [51]	Proposed a CBMLB protocol. This is an expansion of the existing AOMDV multipath protocol. The CBMLB	CBMLB aim is to distribute the load among available alternative routes in order to reduce the load on centrally	TTL value selection depends on the hop count value. There is no use of multipath with the TTL extension. In the case of a dense network, channel busy and access mechanisms	Not Evaluated.	Not utilized properly.	Evaluated.	They can use the concept of dynamic TTL value for reduce the link breakage. Use light loaded path for routing in

TABLE 1. *(Continued.)* **Comparison of various previous techniques (consider articles from 2017 to 2022).**

	protocol offers the least congested and disjointed communication route.	congested nodes and improve the channel busyness ratio of the lightly loaded path.	will be more complex.				place of shortest path.
Rohit Kumar et al.[52]	Proposed a scheme in which each device contains *n* transceivers and the number of available channels is equal to the transceivers can switch between channels as needed and tune to any channel.	The main aim of research is proper channel utilization. The physical medium has multiple channels. The MAC (Medium Access Control) layer should use in the best way possible.	Mentioned the power consumption parameters but power parameter analysis missing in results. In multichannel allocation effect on power consumption not evaluated. S/N ratio analysis also missing to evaluate antenna analysis. MIMO concept is not clear.	Not Evaluated.	Utilized by using multiple channel approach.	Evaluated.	It's possible to use afocus on bandwidth utilization properly and analyze the effect on energy consumption.
Nawaf S. Mirza [53]	Proposed the RIVC-MB in which RIVS technique that detect early switch over to an alternative path and MB try to reduce the waiting time of remaining senders.	Control the suddenly link breakage problem and provide immediate access of medium (channel) to new senders in network.	Practically, early detection of loss of the session not possible and in multipath protocol there is no need to switch the path by any approach it is the oblivious procedure.	Not Evaluated.	Better bandwidth utilization because of multichannel.	Not Evaluated /Minimizes Delay.	Calculate the congestion status before and after the RIVC-MB approach.
Rakesh Kumar Sahu [54]	Proposed the AOMDV-ER that uses the concept of recoiled nodes and RSS. The nodes that are less in range having probability more to participate in	The aim is to improve the energy utilization and reduces overhead.	Why the random motion of nodes is not taken and the energy exhausted in communication. In performance fig 11(b) is showing more residual energy in rest of the performance.	Evaluated but it is user defined.	Better with the considered parameters but these parameters are not full feasible for measurement criteria.	Maximize throughput/ Not evaluated.	Try to create the actual environment of MANET. Set the threshold on mobility speed after residual energy estimation.

TABLE 1. *(Continued.)* **Comparison of various previous techniques (consider articles from 2017 to 2022).**

	routing.						
Zeyad M. Alfawaer [55]	Proposed the SONET technique proposed for select best neighbor having less hop count	Compare the performance of AODV and DSR. The better performance means better QoS.	No new approach used for enhance the network life time.	Not Evaluated.	Better in AODV because of no cache storage as DSR.	Better in AODV as compare to DSR.	Possible to use approach for improve the life of mobile nodes or reduce energy consumption.
Priyanka Bhardwaj [56]	Proposed the Bandwidth estimation-based route selection technique used for multipath routing.	Improves Bandwidth utilization and balance the load in network properly.	Not Evaluate the load on each node. It is helpful for load distribution.	Not Evaluated.	The performanc e of BCBR is better than the AODV, CAAODV(H) and CAAODV(L).	Not Evaluate d because bandwid th estimati on at the time of routing effects on perform ance.	No need in simulation to fix the mobility speed because in real scenario nodes mobility is random.
Shereen Omar [57]	Proposed the technique MACNRP for reduce the load in network and establish multiple paths for improving data delivery.	Control the PUs involvement for better utilization of multiple channels and balance load.	Less involvement of PUs affects the security factor in network. Normal nodes are not trustful. Also not focus on overhead.	Not Evaluated.	Better bandwidth utilization because of multichann el.	Maximi ze through put/ Minimiz es Delay.	Calculate the energy consumption of nodes for lifetime estimation.
Mahadev A. [58]	Proposed the QMR cross layer approach to improve the QoS of multipath routing protocol in MANET. The path selection based on RSS	The main aim is to reduce the energy consumption of nodes and improve multipath QoS.	The performance only evaluated in single node density scenario. The QOS-AOMDV is very old approach (proposed in 2011).	Evaluated but only in single node density scenario with constant speed.	More bandwidth requirement for data but utilization is better.	Better in constant mobility scenario. Compar ed with QOS-AOMD V.	Proper explanation of cross layer approach is required and need to change the actual packet format.

TABLE 1. *(Continued.)* **Comparison of various previous techniques (consider articles from 2017 to 2022).**

	and nodes residual energy.						
Y. Harold Robinson [59]	Proposed the Link Disjoint Multipath (LDM) approach for balance the load and choose light weighted path for routing.	The main of LDM approach is to reduce congestion and balance the load in MANET.	Only focus on the un-used time slots for communication but it is time consuming and chances of collision increases.	Measured and performance is better.	Utilized by applied proposed approach but collision chances are high.	Through put not measure d but delay is less as compare d to previous scheme.	For better bandwidth utilization. In case of time slot allotment not wait for slot but directly allocate slot to sender.

energy-based destination sequence vector (EDSDV) routing with Parallel Rendezvous Multi Channel Medium Access Protocol (PRMMAC), and Quality of Service in ad hoc on-demand multipath distance vector (QoS-AOMDV) routing with multichannel access protocol. Topological change Adaptive Ad hoc On-demand Multipath Distance Vector (TA-AOMDV), Multipath Routing Protocol (QMR).

The proposed methodology combines an energy approach with bandwidth, queue utilization, and multipath selection based on channel capacity. In the subsection describing how the calculation or equation is formulated and the computer network path.

A. ENERGY METRIC

The proposed MMEE protocol selects the route on the basis of cost function. The calculation of the cost function depends on one parameter, such as the residual energy of nodes. While the route discovery process initiates the source node and broadcasts a route packet to search for a route, that search packet arrives in the node and retrieves the information of recent or residual energy level in joule, as well as per packet energy consumption, which is important for predicting the node's expected life time. The list of symbols and their descriptions are mentioned in table 2.

$$N_i^{npkt} = \frac{E_i^{residual}}{E_i^{consume}} \tag{1}$$

$$\overline{N_{path}^{npkt}} = \frac{1}{N}\sum\nolimits_{i=1}^{N} N_i^{npkt} \tag{2}$$

$$N_{min}^{npkt} = \min_{1\le i\le N} N_i^{npkt} \tag{3}$$

N_i^{npkt} → Expected number of packets forward from residual energy

N→ Number of hops saved in RREQ

$\overline{N_{path}^{npkt}}$ → Average number of packets forward

N_{min}^{npkt} → Minimum number of packets forward.

B. BANDWIDTH METRIC

The bandwidth factor is another parameter to calculate the cost factor. In equation (4), we define the busy and idle states of a channel, which is useful to calculate channel utilization between nodes.

$$u_i(t) = \begin{cases} 0 & H_0(idle) \\ 1 & H_1(busy) \end{cases} \tag{4}$$

In equation (5), formulated to calculate the channel utilization and equation (6), formulated to estimate available bandwidth,

$$U_i(t, t+M\zeta) = \frac{1}{M}\sum\nolimits_{m=1}^{M} u_i(t+m\zeta) \tag{5}$$

$$B_i(t, t+M\zeta) = B_{channel}^{gross}[1 - U_i(t+m\zeta)] \tag{6}$$

where M: Number of samples

ζ : Sampling Interval

$B_{channel}^{gross}$: Channel Gross Bandwidth

In the below equations, (7) and (8) are used to calculate the average and minimum bandwidth of i[th] link, respectively.

$$\overline{B_{path}} = \frac{1}{N}\sum\nolimits_{i=1}^{N} B_i \tag{7}$$

$$B_{min} = \min_{1\le i\le N} B_i \tag{8}$$

C. QUEUE LENGTH METRIC

In order to calculate the queue length, use the equation (9) for the idle queue length of i[th] node. The equations (10) and (11) are used to retrieve the minimum length of queue as idle and the average queue length of a path, respectively.

$$QL_i^{idle} = QL_i^{initial} - QL_i^{occupied} \tag{9}$$

$$QL_{min}^{idle} = \min_{1\le i\le N} QL_i^{idle} \tag{10}$$

$$\overline{QL_{path}^{idle}} = \frac{1}{N}\sum\nolimits_{i=1}^{N} QL_i^{idle} \tag{11}$$

However, the capacity of number of packets forward based on remaining energy, available bandwidth and queue length function in network protocol architecture is performed by

TABLE 2. Symbols and their description.

S. No.	Abbreviation	Definition
1	N_i^{npkt}	Expected number of packets forward from residual energy
2	N	Number of hops saved in RREQ
3	$\overline{N_{path}^{npkt}}$	Average number of packets forward
4	N_{min}^{npkt}	Minimum number of packets forward
5	M	Number of samples
6	ζ	Sampling Interval
7	$B_{channel}^{gross}$	Channel Gross Bandwidth
8	$u_i(t)$	Channel Utilization between nodes
9	$\overline{B_{path}}$	Average bandwidth of i node
10	B_{min}	Minimum bandwidth of i node
11	QL_i^{idle}	Idle queue length of node i
12	QL_{min}^{idle}	Minimum length of queue as idle length of path
13	$\overline{QL_{path}^{idle}}$	Average queue length of path
14	C_j^{npkt}	Cost function for average number of packets forward
15	$C_j^{bandwidth}$	Cost function for average bandwidth
16	C_j^{QL}	Cost function for queue length of node i
17	α, β and γ	Weight coefficient for three parameters
18	MCR	Weighted sum of two components for channel estimation
19	$MMEE$	Multipath multichannel routing
20	ETX	Expected number of transmission attempts
21	pf	Probability of link fail
22	ETT	Expected transmission time
23	SC(c_i)	Switching cost for the i^{th}
24	c_i	Channel used on i^{th} hop
25	N	Vector initialize for node
26	P	Initial node energy
27	B	Available bandwidth between nodes
28	Q	Idle & occupied queue of node
29	M	Mobile nodes
30	S	Source node ∈M
31	R	Receiver node ∈M
32	n_i	Intermediate nodes ∈M
33	Ψ	Radio range 550 meters

different layers, so in our proposed MMEE protocol, the efficient route selection procedure by cross-layer network architecture. MMEE protocol during the route request process, every node includes information about the expected number of packets forward, available bandwidth, and queue length. This information is encapsulated in the route request packet (RREQ) and sent to the destination node.

While the destination node receives RREQ, the cost function is calculated by all three factors, which are shown in equations (12), (13) and (14) respectively.

$$C_j^{npkt} = \frac{\overline{N_{path}^{npkt}}}{N_{min}^{npkt}} \tag{12}$$

$$C_j^{bandwidth} = \frac{\overline{B_{path}}}{B_{min}} \tag{13}$$

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

In the destination RREQ packet receives that contain extra encapsulate field are C_j^{npkt}, $C_j^{bandwidth}$ and C_j^{QL} which uses to calculation the cost function of the respective path by equation (15)

$$C_j = \alpha \cdot C_j^{npkt} + \beta \cdot C_j^{bandwidth} + \gamma \cdot C_j^{QL} \tag{15}$$

In the equation α, β and γ reflects different network features, it also $\alpha + \beta + \gamma = 1$ different value of α, β and γ can be depends on network performance. The weight coefficient for three parameters is given in equation (16).

$$\begin{cases} \alpha = 1 - \frac{\overline{E_{path}^{residual}}}{E_j^{inital}} \\ \beta = \frac{1-\alpha}{2} \cdot \frac{\overline{B_j}}{B_{channel}^{gross}} \\ \gamma = \frac{1-\alpha}{2} \cdot \frac{QL_j^{idle}}{QL_j^{initial}} \end{cases} \tag{16}$$

D. CHANNEL CAPACITY MEASURING

Channel capacity directly proportional to bandwidth, So that the section formularized about channel capacity measure. In the equation (17) calculate estimation of probability of channel j where interface usage i (i ≠ j) when packet arrive on channel j.

$$\rho_s(j) = \sum\nolimits_{\forall i \neq j} InterfaceUsage(i) \tag{17}$$

In the equation (18) measure the switching cost of channel j, where equation (19) measures the expected transmission time (ETT) where ETX is expected number of transmission attempts, B the data rate of the link and S is the average packet size.

$$SC(j) = p_s(j) * SwitchingDelay \tag{18}$$

$$ETT = ETX * \frac{S}{B} \tag{19}$$

In the equation (20) formulized to probability of link fail where (pf) is some channel j depends of forward packet loss probability from X to Y on channel j and reverser packet loss probability is (pr).

$$\rho = 1 - (1 - \rho f) * (1 - \rho_r) \tag{20}$$

$$ETX = \frac{1}{1 - \rho} \tag{21}$$

In the equation (22) formulate for total ETT cost of any channel j which define by X_j, where ETT_i is a ETT cost of i^{th} hop of path.

$$X_j = \sum\nolimits_{\forall i, such that c_i = j} ETT_i \tag{22}$$

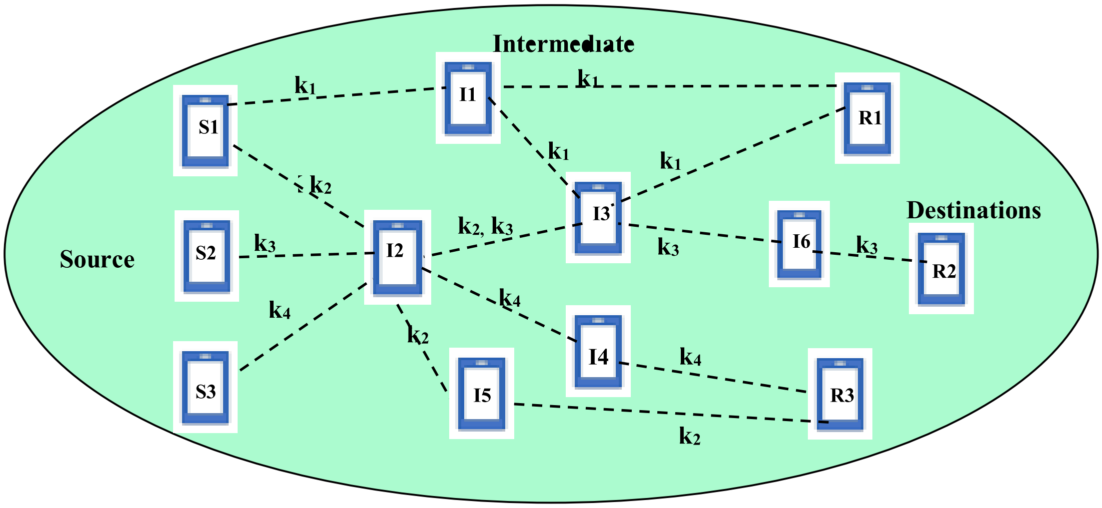

FIGURE 5. Network architecture of MMEE protocol in multichannel and multipath structure.

Equation (23) is a metric of weight sum of two component define by MCR where SC (c_i) is switching cost for the i^{th} ho and c_i is the channel used on i^{th} hop.

$$MCR = (1-\beta) * \sum_{i=1}^{n} (ETT_i + SC(c_i)) + \beta * \max_{1\le j\le c} X_j \tag{23}$$

VII. MMEE PROTOCOL DESIGNING AND WORKING ARCHITECTURE

Multipath multichannel routing is enhanced by the AOMDV routing protocol. In this section, we talk about how the network architecture is set up, what the frame format requirements are, how the protocol is set up by layering, and how the MMEE protocol works.

A. NETWORK ARCHITECTURE OF MMEE PROTOCOL

Figure 5 depicts the Multichannel Multipath Ad hoc Communication Architecture, with S1, S2, and S3 representing the three sources and R1, R2, and R3 representing the three receivers. Node S_1 uses the channels K_1, K_2 to transmit the data at the same frequency as f1. Node S_2 uses K_3, with a frequency of f2. Node S_3 uses K_4, with a frequency of f_3. In the figure, I_2 and I_3 links carry the f1 and f2 frequencies with separate channels K_2 and K_3.

B. MMEE NEW FRAME FORMAT

In order to address the new frame format of the AOMDV protocol named MMEE, which contains an extra eight fields mentioned in Figure 6, During the RREQ message, every connected intermediate node calculates the per packet discharging rate, which is useful to predict how many packets will be forwarded by node while the packet size is the same. Based on the energy parameter, it also calculates the average number of packets forwarded by all connected nodes in the path.

In the frame format, it also takes the node's available bandwidth and available queue length and finally calculates the average of the bandwidth and queue length, respectively.

C. MMEE PROTOCOL LAYER ARCHITECTURE

Figure 7 shows the layer architecture of MMEE protocol. The source node sends an RREQ message containing the expected packet send, which is calculated based on the per packet energy discharge rate, available bandwidth, and minimum queue length. The RREQ message comes into the intermediate node, which takes the arrival frame and processes it. During the processing, the node finds value required for expected packets, available bandwidth, and available queue. These entire requirements are filled by the respective layers, such as the physical layer responsible for calculating per packet discharge rate, the MAC layer providing available bandwidth, and LLC layer providing information about available queue length. The MMEE protocol works in a cross-layer-based approach after getting P, B, and Q values encapsulated and forward to the next neighbour till the receiver node. At the end of receiver node, all RREQ packets come and are stored in the respective table. Multipath routing creates multiple path tables and stores all relevant information. The receiver node takes the entry from the path table and computes cost of each path. After computation, select the three best paths whose cost value is lower, and the receiver will generate a RREP message and send an ACK message using the best three paths.

D. MMEE PROTOCOL WORKING ARCHITECTURE

Figure 8 shows MMEE protocol working module. Multipath multichannel energy efficient routing protocol designed from AOMDV routing where new header fields are attached for calculation of path stability identification. The source initiates an RREQ message using the MMEE protocol and broadcasts it to all neighbour nodes. Every neighbour node computes all the required values and encapsulates them in RREQ packets for broadcast to the next level of neighbors.

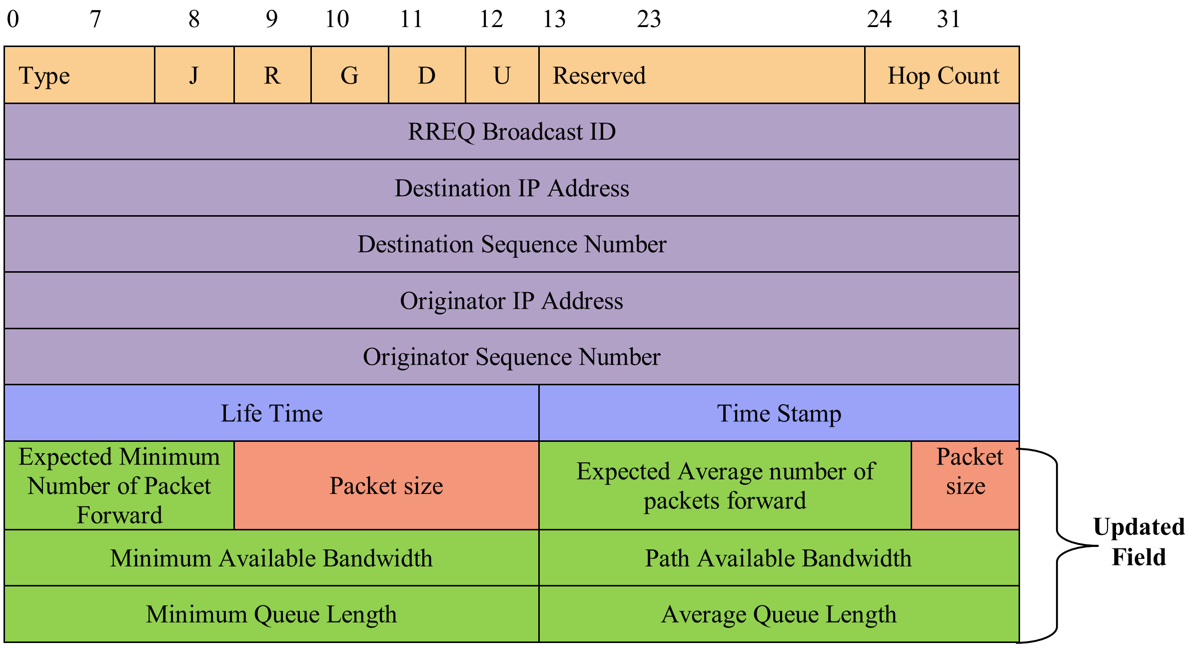

FIGURE 6. RREQ Frame format of MMEE protocol modified of AOMDV frame format.

While the RREQ packet comes in to the receiver node by multiple paths, the receiver generates the individual routing table for every loop free path and applies the cost function to identify the best three paths whose value is less. In the next execution, the receiver node generates the RREP message and sends the ACK message to the sender node for data communication via the selected three best paths. While the source node receives an ACK from the receiver nodes that generates data and starts data sending over multiple paths using a multichannel based mechanism.

VIII. PROPOSED ALGORITHM

This section describes the proposed algorithm and its input parameters, procedure, and output. We define the step-by-step execution of an energy-efficient multipath multichannel mechanism in a mobile ad-hoc network using the algorithm and meet the network output expectation.

IX. SIMULATION ARCHITECTURE

This section describes the proposed algorithm and its input parameters, procedure, and output. Through the algorithm, they define the step-by-step execution of energy-efficient multipath.

A. SIMULATION ENVIRONMENT

This paper varied the number of nodes and simulated the network scenario using network simulator-2 and analyzed the network behavior through node variation [60], [61]. The Network Simulator-2 is designed by the joint venture of Berkeley and California University. Here we simulate the mobile ad hoc radio environment. We have used a mobility extension to ns that is developed by the CMU Monarch project at Carnegie Mellon University. Figure 9 shows the essential design of network simulator-2 (NS2).

B. SIMULATION PARAMETER

The simulation parameters that are considered for simulations are mentioned in Table 3. The performance of protocols is measured based on considered parameters. The defined simulation parameters are adopted to develop the network for further analysis. The output impact of the network depends on the input parameter. For routing with multichannel access medium access technique between sender and receiver, the protocols MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and proposed MMEE are considered, and the entire simulation is performed in NS-2 simulator version 2.31 [60], [61]. Network Simulator-2 is installed on Windows 7 with Cygwin software that provides a Linux environment in Windows.

C. PACKET DELIVERY RATIO ANALYSIS

Packet delivery ratio is also known as the percentage of data that makes it to its intended recipient. While the PDR is higher, it means the network performs well concerning data delivery. The network impact is highly dependent on PDR performance, which judges the algorithm efficiency in terms of successful communication. In the result, the graph X-axis represents the mobile node for the test case, and the Y-axis represents the percentage of data received by the genuine receiver nodes. The analysis of the results reveals six distinct routing protocols in the multichannel interface, namely MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and the proposed methodology for efficient energy-based multipath multichannel routing protocol (MMEE). In Figure 10, the PDR performance of MMEE provides pleasant results

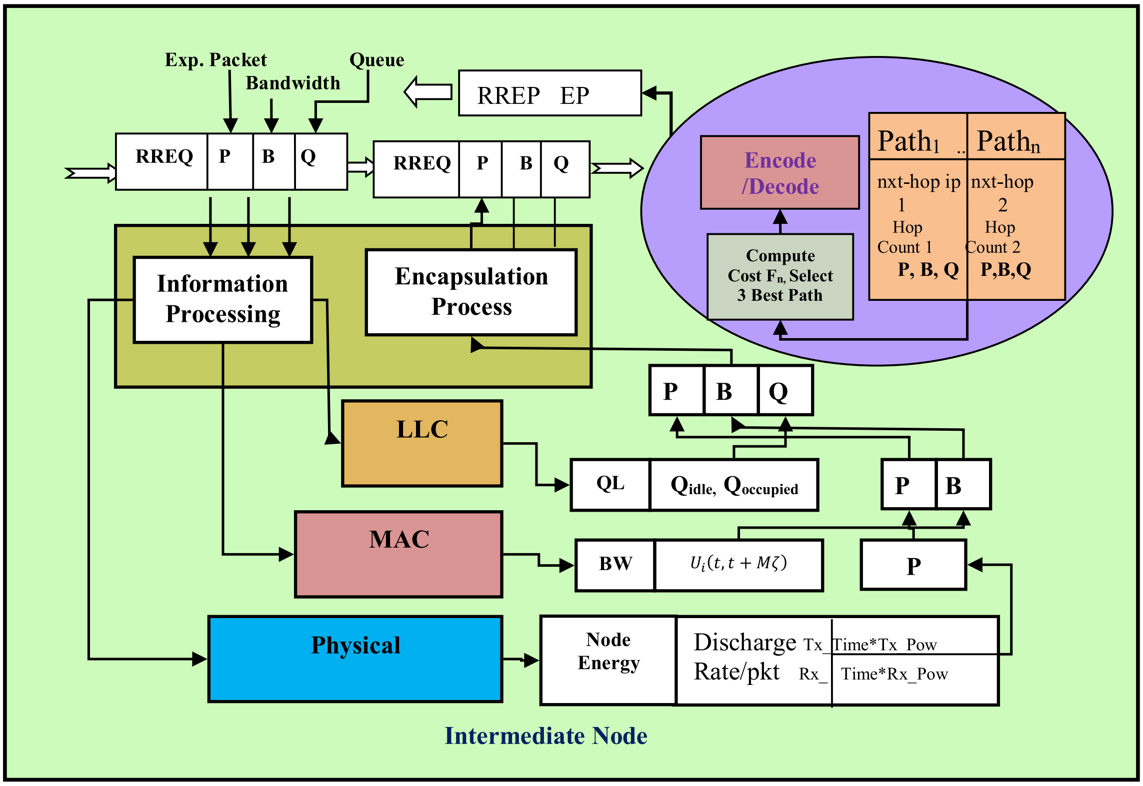

FIGURE 7. MMEE Protocol Layer architecture represent functionally of each layer.

as compared to the rest of the mentioned protocols. In the figure 10, red bar indicates the PDR performance of the energy-based dynamic source (EDSR) routing with multi-channel medium access (MMAC) protocol. Similarly, the green bar shows the packet delivery ratio performance for the energy-based destination sequence vector (EDSDV) routing with Parallel Rendezvous Multi-Channel Medium Access Protocol (PRMMAC).

The blue bar shows the packet delivery ratio for the Quality of Service in ad hoc on demand multipath distance vector (QoS-AOMDV) routing with multichannel access protocol, which is an average performance delivery as compared to the rest of protocol. The pink bar in figure 6 shows the packet delivery ratio for the QoS aware weight based on demand Multipath Routing protocol (QMR), which performs higher PDR as compared to MMAC, PRMMAC, and QoS-AMODV. In the graph, the cyan graph shows the PDR performance of Topological Change Adaptive Ad hoc On-demand Multipath Distance Vector (TA-AOMDV) in a multichannel environment, which is better than all other existing protocols but lower than the proposed (MMEE) protocol. The chocolate bar shows the PDR result of proposed methodology, which is an efficient energy, based multipath multichannel routing protocol (MMEE). The result performs better than all other protocols because MMEE is well adopted for small networks with low mobility environments.

$$\mathrm{PDR} = \frac{\sum_{k=0}^{n} r_i^{pkt}}{\sum_{l=0}^{m} s_l^{pkt}} * 100 \tag{24}$$

Here PDR is packet delivery ratio in percentage, r_i^{pkt} number of packets receives by receiver node in network and s_l^{pkt} number of packets sends by source node in network.

Table 4 provides an analytical value for the percentage of data received. Table 4 shows the numerical analysis with respect to different numbers of node scenarios (10, 20, and 30) that are used for simulation. If we have increased the nodes, the PDR performance is increased in every routing protocol except for MMAC protocol, which is 71.33% in 10 node case, 69.19% in 30 node case, and 74.12% in the 50-node scenario. Table 2 shows that the proposed protocol performs better PDR as compared to all other protocols, which are 90.43% in case of 10 node, 94.8% during 30 node, and 95.15% in case of 50 node scenario.

D. PERCENTAGE OF PACKET DROP

Data drops in communication for many reasons, such as route not found, MAC error, channel busy, time to live expires, network congestion, and many more. TA-AOMDV works well while nodes are deployed in a network that is denser, but it's not sure to every time mobile nodes are available in a network with high-mobility. TA-AOMDV or other existing protocol performs well with respect to successful data delivery to a genuine receiver. In this figure 11, we describe the percentage of data dropped which is not properly received by the receiver node, by the result graph. The X-axis represents the number of mobile nodes taken during testing, and the Y-axis represents the percentage of data drops during communication. The result analysis shows six different

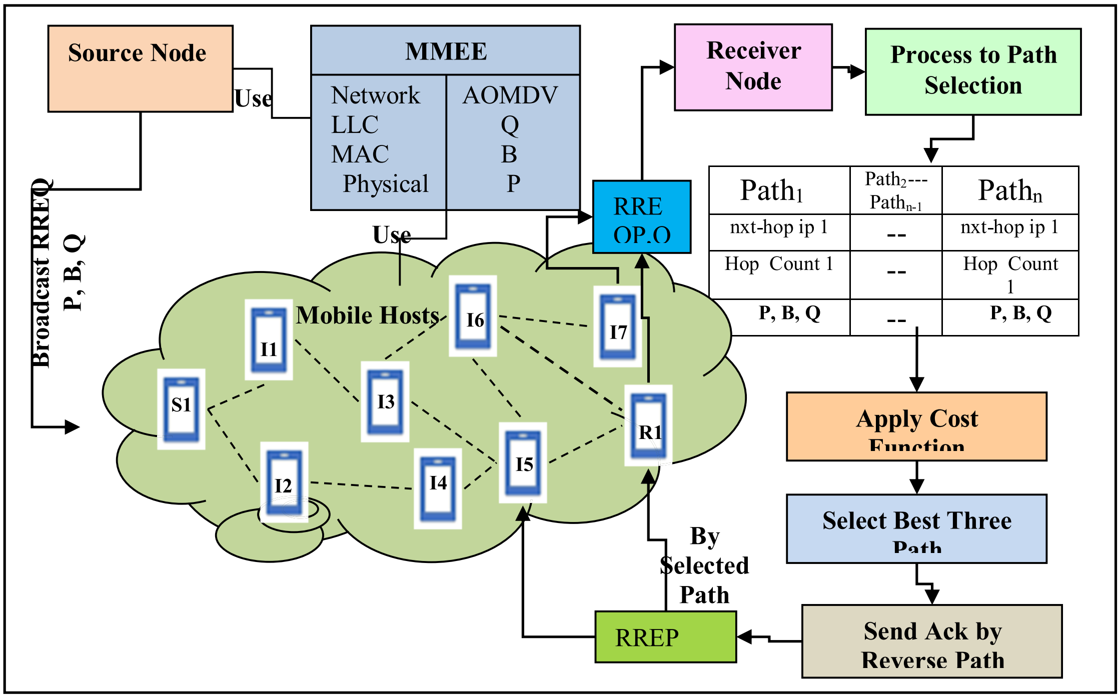

FIGURE 8. MMEE protocol working architecture.

routing protocols, i.e. MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and the proposed (MMEE) methodology for efficient energy-based multipath multichannel routing protocol. The red bar in the graph shows the percentage of data dropped analysis for the MMAC routing protocol, which produces data drops of 25% to 30%. The green bar in the graph shows the percentage of data dropped analysis for the PRMMAC routing protocol, which generates higher data drops as compared to all other protocols. That range is 30% to 35%. The blue bar in the graph shows the percentage of data drop analysis for the QoS-AOMDV routing protocol, which generates data drop (15% to 18%). The pink bar in the graph shows the percentage of data drop for the (QMR) protocol and found that the range is 12% to 15%. The cyan bar graph in Figure 11 depicts the data drop result of the TA-AOMDV protocol, which is between 6% and 12%. In the graph, chocolate shows the data drop result of proposed methodology Efficient Energy-based multipath multichannel (MMEE) routing protocol, which ranges from 5% to 10%, which produces a lower data drop. Compared to all the other routing protocols under the same simulation parameters, it shows that the proposed Efficient Energy-based multipath multichannel routing protocol has fewer packets drop in the network, i.e. it performs better than all the other routing protocols.

$$AVG(Drop) = \frac{\sum_{k=0}^{n} r_i^{pkt} - \sum_{t=0}^{p} d_i^{pkt}}{\sum_{l=0}^{m} s_l^{pkt}} * 100 \tag{25}$$

Here $AVG\,(Drop)$ is average packet drop in percentage, r_i^{pkt} number of packets receives by receiver node in network, d_t^{pkt} number of packets drop and s_l^{pkt} number of packets sends by source node in network.

Table 5 shows the numerical analysis of the percentage of data drops. Table analysis revealed 10, 30, and 50 mobile node scenarios. In the graph we see that the MMAC protocol's average data drop is nearly 28.45%, the PRMMAC protocol 32.53%, QoS-AMODV protocol average drop of 16.19%, QMR protocol 13.71%, TA-AOMDV protocol drop data of 9.44%, and in the proposed MMEE case, the average data drop of nearly 6.54%. It's clear that the MMEE protocol reduces the average amount of data that gets lost on a network.

E. THROUGHPUT ANALYSIS

The number of packets that are received at the destination per unit of time is known as throughput. The throughput of the network depends on network idle bandwidth and network traffic. When the network bandwidth is completely utilized by data transmission, the throughput is higher, but if any congestion or network jamming consumes the network bandwidth, the performance of real communication throughput is very lower. The analysis shows the number of the mobile nodes in the X-Axis compared with the throughput in Mbps shown by the Y-Axis.

$$Throughput = \frac{\sum_{k=0}^{n} R_i^{Byte}}{t^{Sim}} \tag{26}$$

Here R_i^{Byte} is total number of bytes receives by all genuine receiver, t^{Sim} simulation time in seconds.

The result analysis is shown in figure 12 for six different routing protocols in a multichannel environment, i.e.,

Algorithm 1 MMEE RREQ (P, B, Q)

Input:

$N = (P_i, B_i, Q_i)$ Vector initialize for node

$P = (p_1, p_2, p_3 \ldots p_n)$ initial node energy

$B = (b_1, b_2, b_3 \ldots\ldots b_n)$ available bandwidth between nodes

$Q = ((q_i, q_o)$ idle & occupied queue of node

$M \leftarrow$ mobile nodes

$S \leftarrow$ source node $\in$M

$R \leftarrow$ receiver node $\in$M

$n_i \leftarrow$ intermediate nodes $\in$M

$C_j \leftarrow$ cost function

$MCR_j \leftarrow$ weighted sum of two components for channel estimation

$\Psi \leftarrow$ radio range 550 meter

MMEE$\leftarrow$ multipath multichannel routing

Result: throughput, packet delivery ratio, percentage of data drop and energy utilization

Begin:

Step1: Deploy M node in Network

Step2: *S* execute *MMEE RREQ (P, B, Q)*

MMEE bind(*S*, *R*, routing packets)

Step3:

While n_i in ψ **do**

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

$$MCR = (1 - \beta) * \sum_{i=1}^{n} (ETT_i + SC(c_i)) + \beta * \max_{1 \le j \le c} X_j$$

Generate vector table $n_i(C_i, MCR_i) \forall n_i,\ 1 \le n_i \le N$

Step4: If n_i in $path_k$ of route & R found **than**

Compute disjoint route P_l

Select best $n_i(C_i, MCR_i)$ in route P_l

If $P_l \ge 3$ **than**

Select best 3 path which contain best $n_i(C_i, MCR_i)$ value

Else $P_l < 3$

Select all possible P_l

End if

Else

R not found

Search R in next time interval

End if

$n_i \leftarrow n_i + 1$

End do

MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV and the proposed methodology for Efficient Energy-based Multipath Multichannel (MMEE) routing protocol. The red bar in the graph shows the throughput analysis for the MMAC routing protocol, which ranges from 0.62Mbps to 0.70Mbps.

The green bar in the graph shows the throughput for the PRMMAC routing protocol in the range of 0.32Mbps to 0.47Mbps. The blue bar in the graph shows the throughput for the QoS-AOMDV routing protocol, which ranges from 0.49Mbps to 0.56Mbps. The pink bar in the graph shows the throughput for the QMR protocol that produces higher than the MMAC, PRMMAC, and QoS-AOMDV routes. The range of throughput produced by QMR is 0.55Mbps to 0.59Mbps. In the resultant figure, TA-AOMDV routing throughput is represented by the cyan bar graph, which ranges from 0.7Mbps to 0.88Mbps. Proposed methodology The Efficient Energy-based multipath multichannel routing protocol throughput is represented by chocolate bar graph, which ranges from 0.76Mbps to 0.9Mbps. Compared to all the other routing protocols under the same simulation parameters, the proposed Efficient Energy-based Multipath Multichannel Routing Protocol performs better than all the other routing protocols. In this comparative result graph, we get the throughput analysis and conclude that the proposed MMEE approach provides higher throughput as compared to existing MMAC, PRMMAC, QoS-AOMDV, QMR, and TA-AOMDV protocols.

In Table 6, we provide the numerical analysis of six different protocols for mobile ad hoc networks. In the table with respect to 10, 30, and 50 node scenarios, we analyse the throughput of each protocol and compute the average throughput of all the protocols. The MMAC provides an average throughput of 0.66Mbps, PRMMAC provides 0.41Mbps, QoS-AOMDV produces 0.52Mbps, QMR average throughput is 0.57Mbps, TA-AOMDV provides 0.8Mbps, and the proposed MMEE provides an average throughput of 0.85Mbps.

F. ENERGY UTILIZATION ANALYSIS

The energy consumption analysis shows the average energy consumed by the nodes in the network. The energy consumption analysis is necessary to make the network more energy efficient. The analysis shows the number of mobile nodes in the X-Axis compared with the average energy consumed in joules in the Y-Axis.

The result analysis shows six different routing protocols in a multichannel environment, i.e., MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and the proposed methodology for Efficient Energy-based Multipath Multichannel (MMEE) routing protocol. In Figure 13, the red bar in the graph shows the energy consumption for the MMAC routing protocol, which consumes 0.27J, 0.68J, and 0.70J with respect to 10, 30, and 50 mobile nodes. The green bar in the graph shows the energy consumption for the PRMMAC routing protocol and the energy consumption is 0.32J, 0.60J, and 0.78J.

The blue bar in the graph shows the energy consumption analysis for the QoS-AOMDV routing protocol, for which energy consumption is 0.19J, 0.44J, and 0.73J with respect to 10, 30, and 50 mobile nodes. The pink bar in the graph shows the energy consumption analysis for the QMR protocol and gets energy consumption of 0.11J, 0.41J, and 0.62J. In the result, the cyan bar graph represents the energy consumption in the TA-AOMDV protocol and the energy consumption of 0.08J, 0.29J, and 0.46J for 10, 30, and 50 mobile node scenarios, respectively. The chocolate bar graph shows the result of proposed methodology for Efficient Energy-based

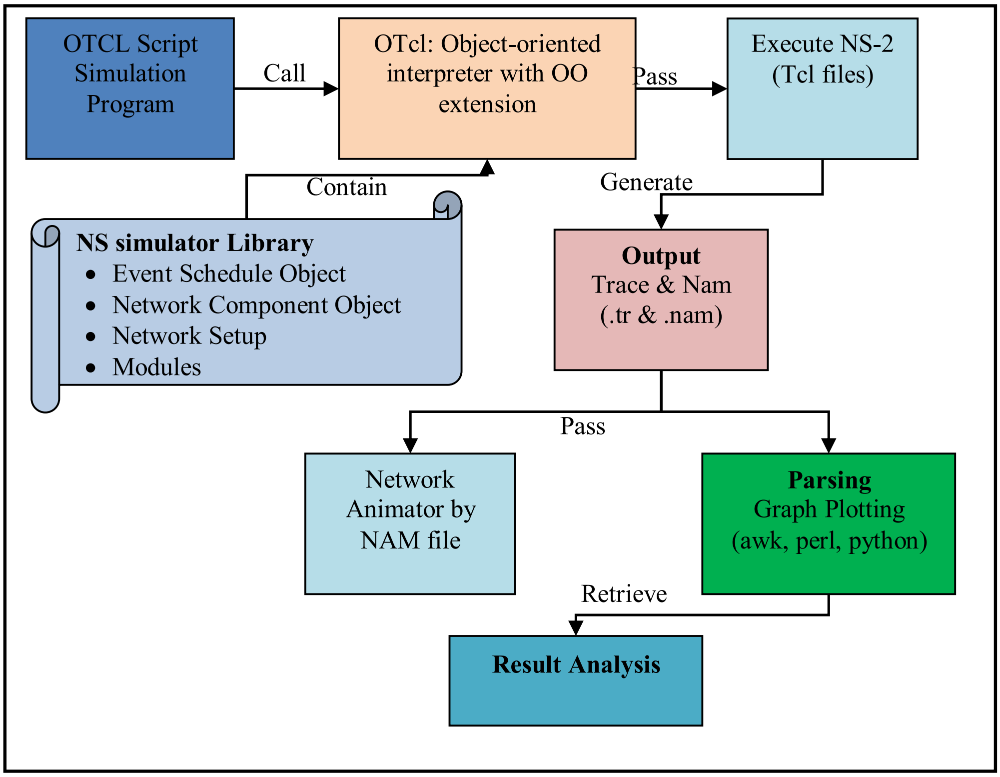

FIGURE 9. Basic interface architecture of NS-2.

TABLE 3. Simulation parameter.

Parameters	Input
Deploy Mobile Nodes	10, 30, 50
Layout for Analysis	800*800m^2
Network Layer	TA-AOMDV, QMR, QoS-AOMDV, PRMMAC, MMAC, Proposed MMEE
Channel	Multichannel
Analysis Time (Seconds)	100
Transport Layer	TCP, UDP
Data Traffic Type	CBR, FTP
Amount of Packet in (Bytes)	512, 1024
Network Connection	Random
Node Mobility (m/s)	Random

multipath multichannel (MMEE) routing protocol. In that case, energy consumption is less as compared to all existing protocols with respect to 10, 30, and 50 mobile node scenarios, which are 0.06J, 0.26J, and 0.4J. Compared to all the other routing protocols under the same simulation parameters, the proposed Efficient Energy-based Multipath Multichannel Routing Protocol performs better than all the other routing protocols. The average energy consumed in joules is lower for the proposed methodology. From the result, it is concluded that the proposed methodology consumes less energy while communication takes place.

$$Energy(c) = \frac{\sum_{i=0}^{n} E_i - \sum_{i=0}^{n} R_i}{n} \tag{27}$$

Here $Energy(c)$ is average energy consumption in joule, $\sum_{i=0}^{n} E_i$ is sum of initial energy of all mobile nodes, $\sum_{i=0}^{n} R_i$ is sum of remaining energy of all mobile nodes and n is number of mobile nodes in network.

In Table 7, we compare the energy consumption in different network scenarios. The table shows the MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and proposed multi-path multichannel technique (MMEE) and concludes that the proposed method increases the network lifetime. The analysis produces average energy consumption for 10, 30, and 50 nodes with respect to protocol MMAC of 0.55J, PRMMAC is 0.56, QoS-AOMDV is 0.45J, QMR produces 0.38J, TA-AOMDV produces 0.27, and the proposed MMEE consumes 0.24J energy. The proposed multichannel multi-path routing minimized the average energy utilization.

G. AVERAGE DELAY ANALYSIS

Network delay is an important parameter for any communication because it refers to the total time taken for a packet to be transmitted across the network from source to destination. Figure 14 shows the average end-to-end delay in milliseconds, which means the sum of the time taken

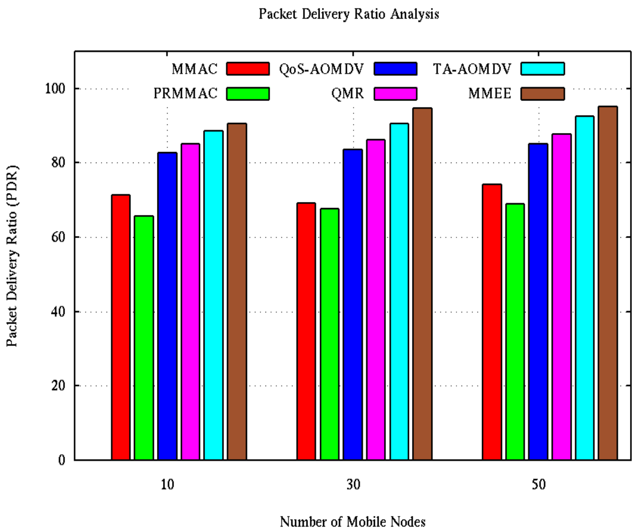

FIGURE 10. **Packet delivery ratio analysis.**

TABLE 4. **Packet delivery ratio comparison.**

Packet Delivery Ratio[%]						
No of Nodes	MMAC	PRMMAC	QoS-AOMDV	QMR	TA-AOMDV	MMEE
10	71.33	65.78	82.76	84.9	88.63	90.43
30	69.19	67.65	83.62	86.1	90.47	94.8
50	74.12	68.98	85.05	87.7	92.56	95.15

for all transmitted packets divided by the total time taken in a millisecond. In the graph, the network average end-to-end delay of MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and MMEE is compared. The X-Axis shows number of mobile nodes and Y-Axis shows average end-to-end delay.

Red bar graph shows the result of the MMAC protocol average delay in 10, 30, and 50 mobile node scenarios, which is 0.54ms, 0.62ms, and 0.91ms respectively. The PRMMAC protocol result is shown by the green bar graph, which is 0.62ms, 0.71ms, and 0.89ms respectively. In the figure, blue bar graph represents the average end-to-end delay of QoS-AOMDV routing protocol, which produces 0.36ms, 0.57ms, and 0.83ms. Similarly, the pink bar graph shows the result of QMR protocol, which is 0.41ms, 0.7ms, and 0.92ms with respect to 10, 30, and 50 mobile nodes. The cyan bar graph represents the result of TA-AOMDV delay in terms of milliseconds, which is 0.3ms, 0.46ms, and 0.69ms. Similarly, the proposed multichannel multipath energy efficient (MMEE) protocol gives the average delay as 0.21ms, 0.35ms, and 0.54ms with respect to 10, 30, and 50 mobile nodes.

In the simulation, we deploy three different scenarios such as ten, thirty, and fifty mobile nodes and analyze the behavior of average delay for MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and proposed multipath multichannel

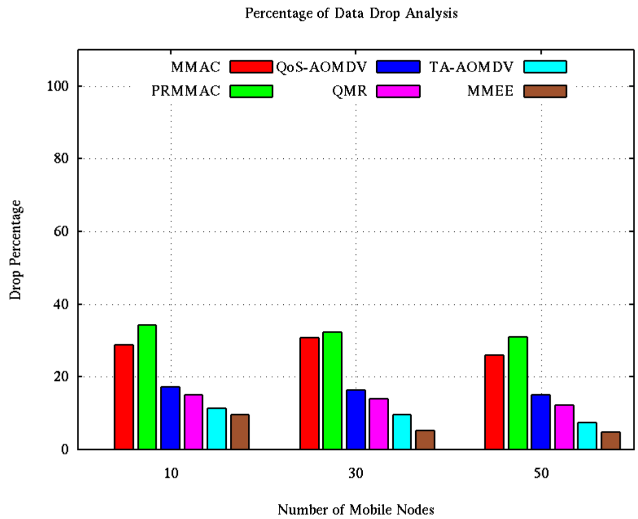

FIGURE 11. **Percentage of data drop analysis.**

TABLE 5. **Comparison of percentage data drop.**

Data Drop Analysis [%]						
No of Nodes	MMAC	PRMMAC	QoS-AOMDV	QMR	TA-AOMDV	MMEE
10	28.67	34.22	17.24	15.0	11.37	9.57
30	30.81	32.35	16.38	13.8	9.53	5.2
50	25.88	31.02	14.95	12.2	7.44	4.85

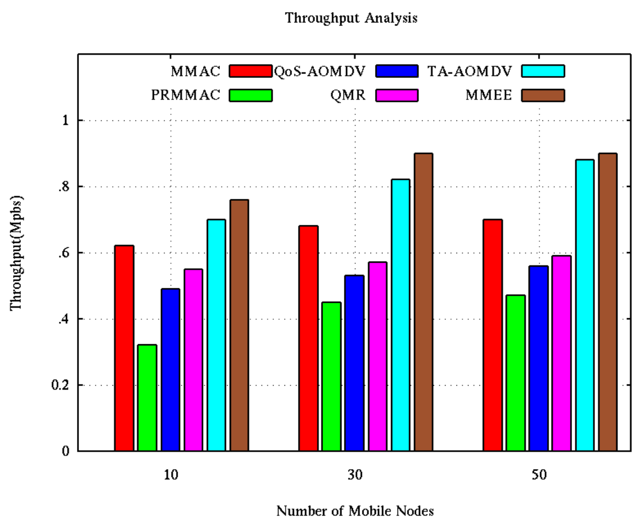

FIGURE 12. **Throughput analysis.**

energy-based (MMEE) approach. The resulting graph shows that the proposed technique's average delay is lower than all existing routing protocols and all three environments.

Table 8 shows average delay result in numeric format and found that the proposed approach takes lower average transmission time from source to receiver node, which means our network performance, is good as compared to the existing

TABLE 6. Throughput comparison.

Throughput Analysis [Mbps]						
No of Nodes	MMAC	PRMMAC	QoS-AOMDV	QMR	TA-AOMDV	MMEE
10	0.62	0.32	0.49	0.55	0.7	0.76
30	0.68	0.45	0.53	0.57	0.82	0.9
50	0.70	0.47	0.56	0.59	0.88	0.9

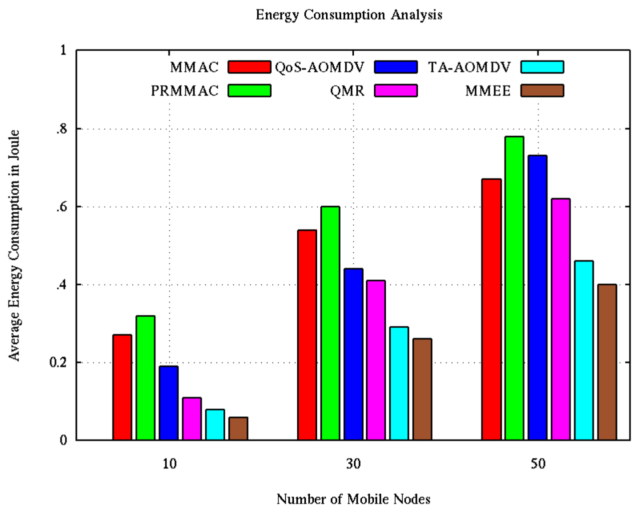

FIGURE 13. Average energy utilization analysis.

TABLE 7. Energy consumption comparison.

Energy Consumption Analysis [Joule]						
No of Nodes	MMAC	PRMMAC	QoS-AOMDV	QMR	TA-AOMDV	MMEE
10	0.27	0.32	0.19	0.11	0.08	0.06
30	0.68	0.60	0.44	0.41	0.29	0.26
50	0.70	0.78	0.73	0.62	0.46	0.4

routing protocol. In table 8 comparative analyses, the average delay of six mobile ad hoc network protocols, i.e. MMAC, which generates 0.69ms, PRMMAC 0.74ms, QoS-AOMDV 0.58ms, QMR generates 0.67ms, TA-AOMDV generates 0.48ms, and MMEE produces an average delay of 0.36ms. The result concludes that the proposed MMEE generates the lowest average delay as compared to all other existing routing protocols and PRMMAC generates the highest average delay, which is 0.74ms.

H. IMPACT OF MULTIPATH MULTICHANNEL FOR ENERGY-BASED ROUTING

Mobile ad-hoc networks provide a new height to the communication network because the movable nodes form a network in a costless manner. In previous work, a number of routing approaches were designed to modify the routing behavior

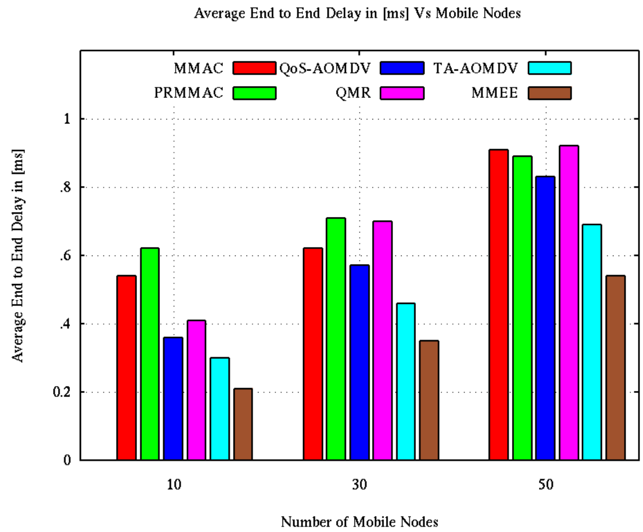

FIGURE 14. Average end to end delay.

TABLE 8. Analysis of average end to end delay [ms].

Average End to End Delay [ms]						
No of Nodes	MMAC	PRMMAC	QoS-AOMDV	QMR	TA-AOMDV	MMEE
10	0.54	0.62	0.36	0.41	0.3	0.21
30	0.62	0.71	0.57	0.7	0.46	0.35
50	0.91	0.89	0.83	0.92	0.69	0.54

effectively, i.e., dynamic source routing (DSR) useful for security purposes, which is adopted with the MMAC protocol in the analysis, ad-hoc on-demand distance vector routing (AODV) useful for shortest path communication and delay minimization, which is used with QMR; and similarly, the AOMDV routing protocol helps to balance the load of the network. Adopt the protocol with TA-AOMDV in the analysis. The proposed, energy-efficient multipath multichannel mechanism efficiently handles multiple source nodes with a minimum energy requirement, which provides collision-free communication. The above section compares the results of MMAC, PRMMAC, QoS-AOMDV, QMR, TA-AOMDV, and proposed MMEE routing and concludes that the proposed approach gives better results concerning throughput, packet delivery ratio, percentage of data dropped, and energy utilization.

X. CONCLUSION

In the recent era of communication networks, wireless media is more widely used than wired media due to its ability to cover a large area of range with the multipoint method without the need for wired cable. Mobile ad hoc routing is one of the techniques to access the wireless medium for transferring data, and it is useful for covering remote areas, emergency areas (i.e., tsunamis, military service, etc.), but the ad hoc network disadvantage is that it is less reliable due to the mobility of devices, low energy, and limited device capacity. In this paper, we develop a multichannel multipath energy efficient (MMEE) route to improve the network reliability as well as load balancing as compared to existing routes, i.e., MMAC, PRMMAC, QoS-AOMDV, QMR, and TA-AOMDV. TA-AOMDV solves the problem of load balancing and improves the QoS of high-speed mobile ad hoc networks, but due to MANET's nature with respect to node movement, it increases the delay and routing overhead, so we found that TA-AOMDV is not a proper solution for high-speed networks to minimize overhead. The proposed MMEE protocol uses multichannel techniques which assign the channel based on node demand and also applies a multipath mechanism which balances the network load to improve the QoS parameter of the network. The simulation was done in 10, 30, and 50 node scenarios with a speed range between 5 m/sec and 10 m/sec, which is the average speed of mobile nodes, so we conclude that the MMEE protocol is feasible for average speed MANET. As a result, we get the performance of the packet delivery ratio of MMEE at 21.91% higher than the MMAC, 25.99% higher than PRMMAC, 9.65% higher than QoS-AOMDV, 7.17% higher than QMR, and 2.9% higher than TA-AOMDV. Similarly, the delay of MMEE is lower than other exciting protocols and also increases another parameter of mobile ad hoc networks. The MMEE work is more adoptable for average speed mobile ad hoc networks and the design prototype is implementable and useful for demand-driven MANET. The work will continue by making fuzzy rules that will reduce traffic and make better use of energy.

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