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ADAPTIVE MULTI-CONSTRAINED QOS ROUTING IN MANET

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Abstract

The increasing demand for multimedia applications over MANET expects good QoS over packet delivery that can be provided only if QoS constraints are considered while routing the packets. The QoS metric to be considered in routing will be different for different applications. The challenge here is to identify and prioritize the QoS metrics to be considered for routing under various scenarios. MANET characteristics are previewed under the TCP/IP protocol stack parameter and impact on QoS metrics is analysed with Rough Set Theory. Adaptive Multiconstrained Quality of Service routing is proposed in consideration of dynamically adaptive multi-constrained QoS metrics. The AMQoS takes input from different layers of TCP/IP to understand the scenario on which packets are delivered. RST based decision rules are applied at the destination to filter out Route REQuest message. The results of AMQoS are compared against Priority Aware-DSR and Dynamic Source Routing.

Keywords: MANET, Multi-constrained, Quality of service, Rough set theory.

1. Introduction

The Mobile Ad-hoc NETwork (MANET) is a hybrid type of wireless network, which is a group of interconnected mobile devices is equipped with required radio hardware that can run on the network protocol stack. Mobile ad-hoc devices establish communication with other nodes in the network without any support from a base station, cellular tower, or satellite. Such a wireless network enables provision to create and join the network anytime, anywhere i.e., "on the fly [1]. The number of devices connected "on the fly" in scenarios like self-driving vehicles, tele-medicines, drones, military applications, automated robots, smart homes has been increased exponentially. This enables Internet of Things (IoT) applications to make use of heterogeneous devices such as various wireless sensors, smartphones, RFID, and smart visual tags to interoperate with each other seamlessly.

The huge amount of IoT devices connected to the network for various applications increases diversified traffic both quantitatively and qualitatively. Due to the mobility of participating IoT devices Wireless channel quality among participating nodes varies with time because of path loss, Doppler Effect, and fading [2]. In line with increased traffic and inherent MANET characteristics network survivability in case of failure of a node, removal of the link, and disruption of the facility is considered a major issue. A wide variety of applications running on MANET under these constraints, looking not only for safe delivery of information also better Quality of Service (QoS).

To achieve QoS, independently of routing protocol care should be taken at the Physical Layer and Medium Access Control (MAC) Layer. Communication over wireless channels is subject to variation in physical layer characteristics like Radio Signal Strength Indicator (RSSI), Signal Noise Ratio (SNR), maximum available bandwidth, actual queue size, and Link Quality Indicator (LQI) [3]. In a distributed network like MANET, MAC techniques must be adapted to avoid packet collision and controlled channel access. So both physical and MAC layers will make an impact on the packet delivery irrespective of the routing protocol [4].

The nodes participating in MANET routing have multiple roles to perform like traffic conditioning and buffer management. Packets transmitted over the traffic marked as high or low priority before being sent to the channel. Ultimately by utilizing a buffer management scheme in every node buffer, able to prioritize the service of packets. The applications on which packets are generated and its QoS requirement will make an impact on prioritizing the service of packets [5, 6]. The QoS requirements vary from application to application. For multimedia applications, the bandwidth and delay are the key parameters, whereas military applications have the additional requirements of security and reliability. For applications such as emergency search-and-rescue operations, availability is the key QoS parameter. Finally, the applications such as group communication in a conference call among the nodes in a lightweight network require that the transmission among them needs minimum energy consumption, hence battery life, and energy conservation can be the prime QoS parameters here. As more and more applications are added on top of an ad hoc network, the network should satisfy variable QoS requirements [7-9].

The traditional QoS enabled routing focuses on static QoS metrics irrespective of applications running on MANET. This may lead to a negative impact on other QoS parameters because of inherent MANET characteristics and QoS requirements of applications running on MANET. As and when the size of MANET grows and node mobility, it is so difficult to come up with a route that is aligned with multiple QoS constraints. So, it is proven that establishing a route with multiple QoS aspects is an NP-complete problem [10, 11]. Developing a configurable decision model that can dynamically consider multiple QoS parameters essential for MANET routing. Since inherent MANET characteristics contribute to the QoS of packet delivery, it is very much necessary to consider input from different layers of TCP/IP protocol stack [12]. This makes QoS enabled routing multi-layer model.

RST based analysis has been conducted on the multilayer stack parameter to analyse the influence of the stack parameter on QoS [13, 14]. Initially, a detailed study on RST has been conducted to evaluate the impact of stack parameters on different QoS metrics like energy, delay, goodput, and Packet Error Rate (PER). Trade-offs between stack parameters and a set of stack parameters are identified, which will make an impact on overall QoS in packet delivery. It can be concluded that, to derive optimized multi-constrained QoS enabled packet delivery transmission power level (T_X), packet payload size (l_D), and signal to noise ratio (SNR) should be maintained at a high level.

Considering the shortfall of existing single-constrained and multi-constrained QoS routing algorithms, Adaptive Multi-constrained QoS (AMQoS) routing is proposed. AMQoS is proposed to enhance the performance of packet delivery by balancing the utilization of QoS resources. This proposed routing algorithm will enhance the existing reactive DSR algorithm, which includes the QoS parameter and network stack parameters in the route discovery process. Accumulation of QoS and network stack parameter from different layers of TCP/IP protocol stack makes this cross-layer model. A proposed routing algorithm is integrating Rough Set based analysis of the multi-layer stack parameter on QoS of MANET to identify stack parameters to be considered while routing the packets. The performance of the proposed AMQoS routing algorithm is compared against PA-DSR for energy, goodput, PER, and delay.

The rest of the research article is organized as follows. Section 2 describes the relative work done on the same topic. Section 3 presents the TCP/IP protocol stack cross-layer model. In Section 4 Adaptive Multi-Constrained QoS Routing mechanism is proposed. A simulation environment for the experimental setup is put forward in Section 5. AMQoS results compared against DSR and PA-DSR in Section 6. The research article is concluded in Section 7.

2. Literature Review

The majority of QoS-enabled routing protocols targeted the number of hops and throughput for QoS enabled routing since the shortest path and throughput are the requirement of most of the applications [15]. These single constrained QoS enabled routing successful in delivering a specified single QoS metric. For example, in single constrained CEDAR routing only bandwidth is considered while routing [16]. Increasing usage of multimedia applications over MANET always demands less delay, low jitter, good packet delivery fraction. So the trend is moving from single constrained QoS routing to multi constrained QoS routing. The QMRPD (QoS Multicast Routing Protocol for Dynamic group topology) [17], GAMAN (Genetic Algorithm-based routing for MANETs) [18], HMCOP (Heuristic multi Constrained Optimal Path) are typical multi constrained routing protocols. Satisfying diversified QoS metrics under dynamic scenarios will be an NP-complete problem.

Single constrained QoS routing protocols proposed for MANET have inherent shortcomings in meeting stringent requirements on delay, energy, PDF, jitter, and other QoS parameter. To comply with multiple QoS parameters Multi-Constrained QoS aware multicast routing scheme based on AODV is proposed [19, 20]. Here the mobile nodes are used to find multicast routes, make the backbone for dependable multicast routing, and adapt to the dynamic topology. The multi-path approach is incorporated to reduce the time consumption of redirecting when the link fails due to node mobility [21]. Also, the source node can utilize the best path for data transmission to meet multiple QoS requirements.

MANET is facing serious challenges of interdependency when connecting to the internet for the rest of the world connection. The overwhelmed success of the internet, especially with layered architecture made MANET use a layered approach. It is very much necessary to adapt to a cross-layer paradigm in MANET, this will bring compatibility for applications running on MANET and its characteristics [22]. The traditional TCP/IP performs data encapsulation in the form of a standardized network connection. Along with TCP/IP OSI model is also used for data encapsulation. Strictly layered approaches made both of these models get affected by service quality and time of response. To overcome this, many cross-layer frameworks were proposed to enhance the quality of service concerned with performance and security. Pawlak [23, 24] studied the impact of cross-layer design and also implementation on an inter-layer interface to enhance the network performance.

Optimized Link State Routing (OLSR) is one of the most prominently used routing protocols over MANET, even though QoS is not considered, and power consumed protocol. The heuristic method has been proposed to select the best path based on Bit Error Rate (BER) and Weighted Connectivity Index (CI) [25]. To implement this cross-layer mechanism has to be incorporated since BER is from the physical layer and CI is from the network layer. The proposed scheme has been implemented on CBR and VBR traffic, results are analysed with throughput, Packet Delivery Fraction (PDF). The proposed method performs better compared to OLSR especially at the high traffic load.

Adaptive Multi QoS Cross-layer Cooperative Routing (AMCCR) enhances QoS performance by establishing cooperation between network, MAC, and physical layer [26]. Here at the initial stage channel state variation for effective communication has been done. the transmission mode is dynamically selected to instantiate the cooperative MAC scheme. Finally at the network layer decision has been taken to choose the optimized route by making use of the best-identified relay candidate in consideration of multiple QoS metrics. Results of AMCCR represent the significant advancement over the delay, throughput, and overall lifetime of the network [27].

3. TCP/IP Protocol Stack Multi-layer model

A drastic increase of users for ad-hoc networks puts a heavy load on the network resources, this makes it difficult to provide good QoS. To enable QoS, the study of the TCP/IP protocol stack model is very much necessary to understand the network behavior under different scenarios [28]. The physical layer in the TCP/IP protocol stack layer is responsible for bit error rate, sending rate, and throughput to achieve good QoS. The data link layer is responsible for setting priorities and scheduling the data flow to ensure QoS. The application layer deals with packet encoding and packet delivery fraction to provide good QoS. The QoS guarantee mechanism should be able to configure the protocol stack parameter available in different layers to efficient utilization of resources.

3.1. Factors affecting the MANET network set up

The stack parameter configuration is the plug-and-play of 7 different combinations for different stack parameter values. Overall 4500 packets are communicated between the sender and receiver under different combinations of stack parameter values. All experiments are conducted based on the distance; for different combinations of the remaining 6 parameters. Here both sender and receiver maintain packet information that contains RSSI, LQI, actual queue size, transmission number, and time of receiving. An analysis has been conducted on the measured data for different stack configurations and discussed outcomes from packet error rate, energy efficiency, goodput, and delay.

The physical layer of the TCP/IP protocol stack consists of distance (d) between nodes and the transmission power level (Ptx). At the MAC layer, the maximum number of transmissions (NmaxTries), the retry delay time for new retransmission (Dretry), and the maximum queue size (Qmax) of the queue on top of the MAC layer used to buffer packets when they are waiting for retransmission. Finally, at the Application layer packet inter-arrival time (Tpit) and the packet payload size (l_D) are incorporated. Table 1 gives a summary of these parameters and their value ranges as well as the rationales behind the considered values.

Table 1. TCP/IP protocol stack layers.

Layers	Parameters	Description	Impact on QoS
App	T_{pit}: Packet	T_{pit} is inversely proportional to packet arrival	PER, Goodput
	l_D: Packet payload size(bytes)	Directly proportional impact of l_D on Goodput	PER, Energy, Delay, Goodput,
MAC	Qmax: Maximum queue size(packets)	The values represent no queue, medium, and large queue	Delay
	Nmaxtries: maximum number of transmission	Maximum number of packet retransmission in packet lost	Goodput, Delay, PER
Phy	Ptx: transmission power level	Transmission power level to transfer the packet	Energy
	d: distance between nodes	Different distance between nodes in a network scenario	Delay, energy, Goodput

The link Quality of the MANET network setup is a key feature for good QoS. The link quality is usually determined by Signal to Noise Ration, links which have poor SNR lead to lower throughput and higher frame error rate. The higher transmission power level will deliver higher goodput with low PER. Maintaining a higher packet payload size avoids packet loss with an increase of delay in delivering the packets under heavy traffic scenarios.

$$QoS(SNR, lD, Tx) \tag{1}$$

3.2. Rough Set based multiple QoS parameter trade-off

The Rough Set Theory is a mathematical decision support system to deal with an imprecise information system. Taking a dynamic decision on route selection considering multiple parameters is also demands a strong decision support system. So RST is the best choice to derive multi-constrained QoS decision rules to select the route. The Rough Set Exploration System is a tool to implement RST concepts, used to analyse varying QoS values on different routes. The RSES incorporates different techniques like discretization, reduction, decision rules, and prediction of the RST. The derived decision rules are applied with Bayesian theorems probabilistic structure to identify the strength, certainty, and coverage of decision rules. Top 3 decision rules to accept the path on which packet should be forwarded based on high priority, certainty and coverage are given below:

$$Hops < Descetized\_threshold \,\&\&Energy > Descetized\_threshold \tag{2}$$

$$Delay < Descetized\_threshold\&\&Energy > Descetized\_threshold \tag{3}$$

$$Goodput > Descetized\_threshold\&\&Energy > Descetized\_threshold \tag{4}$$

4. Adaptive Multi-constrained QoS routing (AMQoS)

The AMQoS is a multi-path source routing algorithm, which considers multiple QoS parameters. The proposed routing process discovers the path on demand, by considering the multi-layer framework for different network stack parameters. The route selection process is adaptive, considers the characteristics of MANET based on the network stack parameter. Route selection strategy is changing with varying MANET stack parameters. Transmission of control packets will be limited by selecting routes in the destination, it will initiate the RREP packet only for selected routes. The node state transition in route construction is shown in Fig. 1.

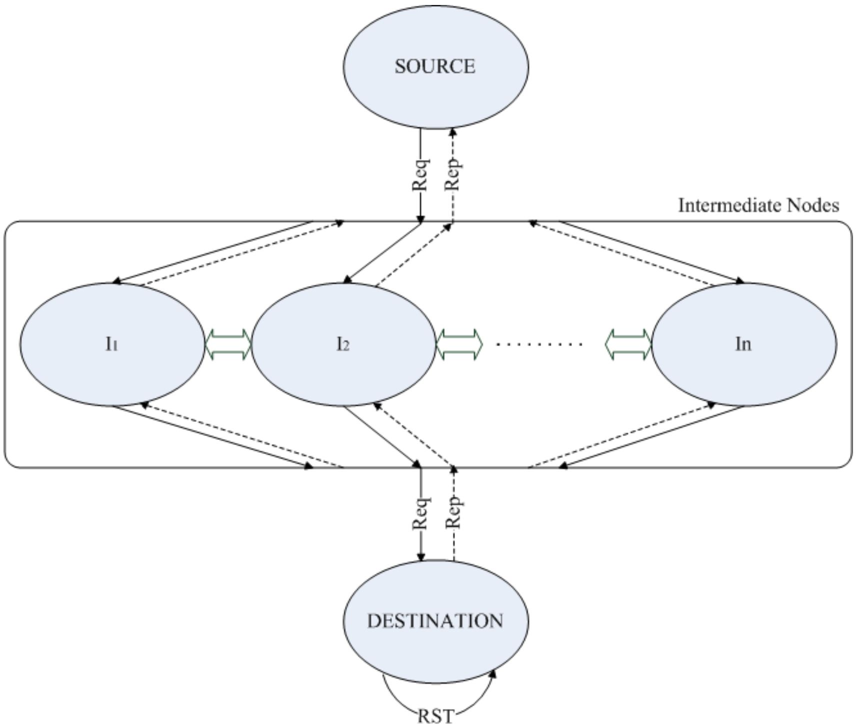

Fig. 1. Node state transition diagram.

4.1. RREQ packet construction

The initial stage of route discovery involves dynamically construct the routing path if a path is not available in the source cache. The source node constructs the RREQ packet and broadcast to its neighboring nodes in search of a route to reach a destination.

To identify RREQ packets from duplication source ID, destination ID, and request ID are normally included in the packet. The general DSR routing algorithm maintains intermediate nodes information in the packet header for traversal. So intermediate ID is maintained to store all intermediate node's information where RREQ packet traverses. The decision on route selection should be dynamic based on the network status. The networks stack parameter is making a high impact on network resources, enabling good QoS. The SNR, T_X, l_D is included in the RREQ message as a supporting parameter to justify the dynamically changing decision rules. The QoS parameters, on which decision will be taken are included. The energy, delay, and bandwidth are included in the RREQ message, based on which decision will be taken for the filtering of paths. The RREQ packet format is represented in Fig. 2.

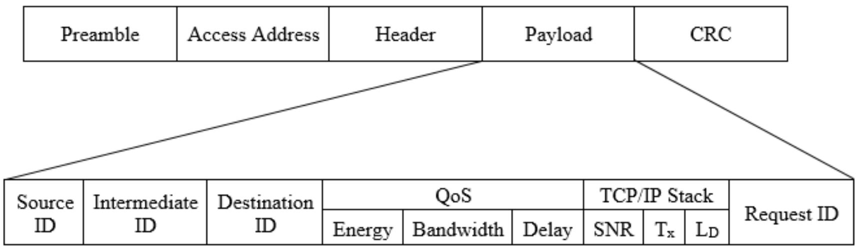

Fig. 2. RREQ packet format.

4.2. RREQ packet propagation

The neighboring node receives the RREQ message first searches in their route cache to find out available routes to reach the destination. If a route is available, append the route to the route header and forward in that route to reach the destination. In case of the non-availability of routes, the node ID of the current node will be added to the intermediate ID. Along with this network stack parameters and QoS parameters are compared against the current node information. Comparison of different parameters are given below:

- The hop count and delay are additive QoS metrics, calculating QoS metrics of such path is the summation of QoS information of all links participating in routing.

$$QoS\,(s, d) = QoS\,(s, u1) + \dots\dots\dots + QoS\,(ui, d) \tag{5}$$

- The Packet Error Rate is a multiplicative QoS metric, calculating QoS metrics of such path is a multiplication of QoS information of all links participating in routing.

$$QoS\,(s,d) = QoS\,(s,u1)\ x\ \dots\dots\dots x\ QoS\,(ui,d) \tag{6}$$

- The Energy and SNR are concave QoS metrics, calculating QoS metrics of such path is a comparison of QoS information of all links participating in routing.

$$QoS\ (s, d)\ =\ min\ \{QoS\ (s, u1)\ , \ldots, QoS\ (ui, d) \tag{7}$$

Modified QoS parameters and network stack parameters are updated in the RREQ message and forward to neighboring nodes. The same procedure continues until packets reach their destination. The complete overview of RREQ propagation is shown in Fig. 3.

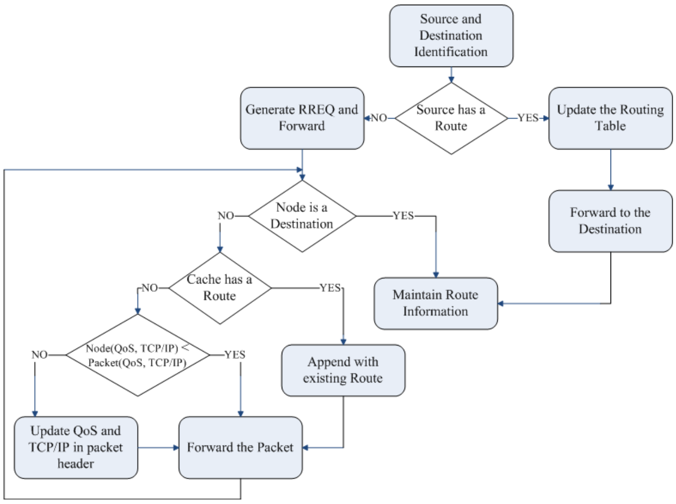

Fig. 3. AMQoS route discovery process.

4.3. Filtration of RREQ packets

Received RREQ messages at the destination node will be stored in their cache, along with their route request ID. Now destination node is aware of all the available routes along with their status on QoS resources and network stack parameters. Generating RREP messages for all available RREQ messages will have two issues over the network. The first one is the possibility of sending messages over the path, which has not maintained the required QoS resources. This will lead to packet loss and requests for retransmission. One more issue is, flooding the RREP message leads to QoS resource consumption.

Filtering the RREQ message will be done in consideration of information received, which are the QoS parameter and network stack parameter of all available routes. The rough set based on multiple QoS parameter trade-offs has been done to derive the decision rule on which RREQ packets are filtered out. These decision rules will be applied to incoming RREQ messages, and whichever satisfies will be taken out for generating RREP messages. The static decision rules on the dynamic MANET will not balance the QoS resources over the network. So network stack parameters are considered to add dynamism to the decision rule.

4.4. RREP packet construction

The RREP packet as represented in Fig. 4 should be constructed for filtered RREQ packets. The RREP packet informs about multiple QoS-enabled route information to the initiator of the route discovery process. If a current node or destination node has an entry in route cache, then the RREP packet is constructed by using the route in the same way. Otherwise, the current node will reverse the path from the route record of the filtered RREQ message. The RREP packet maintains source ID, destination ID, intermediate ID, and request ID.

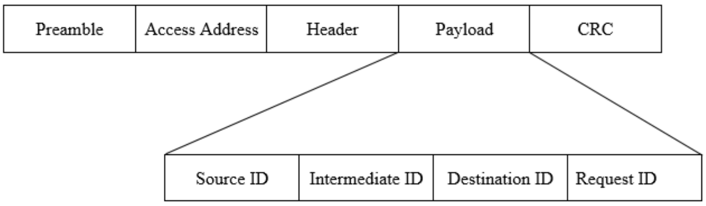

Fig. 4. RREP packet format

4.5. RREP packet propagation

To forward RREP to the source node, the destination node or intermediate node should have a route to reach. Destination node got the path to reach source node from RREQ message, RREP message followed the same. There might be a possibility that the interface between two nodes might not work in the same proportion both the direction. Wireless communication is unidirectional and non-symmetric because of a differing source of interference and variation in radio propagation patterns. This leads to the current intermediate node initiates a new RREQ and reverts with RREP for a newly identified path. The complete overview of RREP packet propagation is shown in Fig. 5.

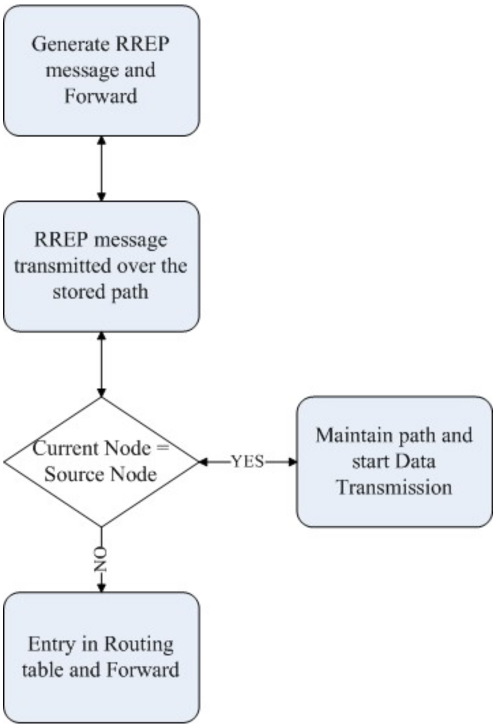

Fig. 5. Overview of RREP packet propagation.

4.6. Route maintenance

AMQoS is a multi-path source routing algorithm on the DSR platform like DSR AMQoS also maintains multiple paths in the source. The availability of alternative paths in dynamic network scenarios like MANET makes maintenance jobs simpler. The route maintenance phase makes use of the neighboring node's acknowledgment to get early information about route failure. The node's interfaces with neighboring nodes break due to dynamism of nodes will not receive the packet, similarly acknowledgment also not delivered. After a few iterations, not receiving acknowledgment initiates an error (RERR) message and propagates to all nodes whose route cache has maintained that link. Once the RERR message is received all nodes will delete the entry of the non-responding node from their route cache. When the source node received information about the broken link, initiates packet delivery from another available route. The complete overview of route maintenance is shown in Fig. 6.

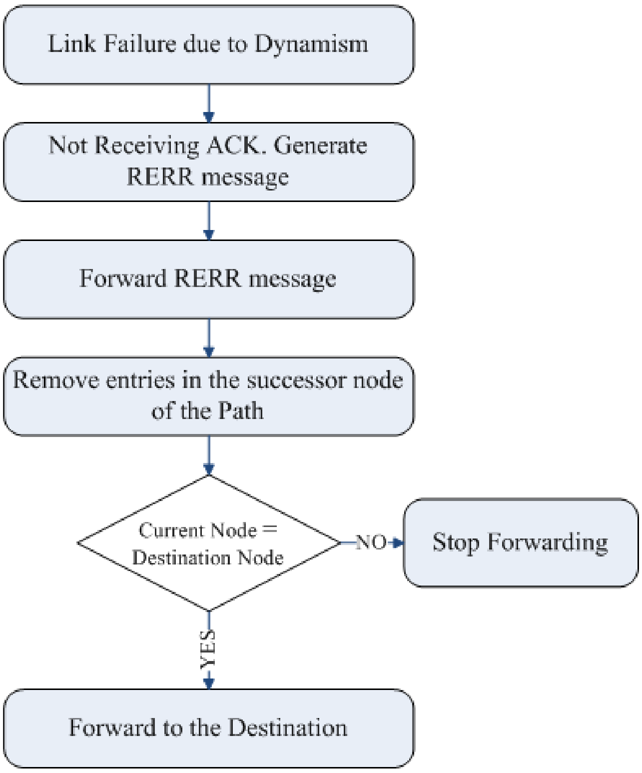

Fig. 6. Overview of route maintenance.

5. Simulation Environment

The AMQoS has been simulated in NS - 2.36. the experiment is conducted for varying numbers of nodes from 25 to 70 nodes, these nodes are randomly positioned in the 1000m x 1000m area. Every node is installed with a single network interface card and has a transmission range of 80 meters. The transmission power and receiving power are set in such a way that two neighboring nodes can communicate within their transmission range. The distributed coordination function of IEEE 802.11 for wireless LAN is used as the MAC layer protocol. The channel bandwidth limit for the radio propagation model is 2 Mbps and traffic generated will be of type CBR. Node mobility is fixed to random waypoint mobility with varying speeds 5 to 25m/s. The initial energy of all nodes is set to 100 joules, along with this energy consumption for transmission and receiving will set 0.7 and 0.3 joules respectively.

6. Result Analysis

The performance of AMQoS is compared with DSR and PA-DSR routing protocol for different network scenarios. The network with a varied number of mobile nodes ranges from 25 to 70 generated randomly in 1000m X 1000m area. The key analysis metrics used here are Goodput, Delay, Energy, and Packet Delivery Fraction. Figures 7-10 compare the performance of AMQoS against DSR and PA-DSR under the different number of mobile nodes. Analysis of performance variation between AMQoS, PA-DSR, and DSR routing protocol under varying mobile node speed for 30 nodes is shown in Figs. 11-14.

For 25 nodes, the proportion of energy variation against DSR is 0 and for 70 nodes, it is 23.01. Similarly, against PA-DSR, the proportion of energy variation is 0 and for 70 nodes, it is 9.62. For 5 ms node mobility, the percentage of energy variation against DSR is 1.66, while for 25 ms node mobility, it is 4.53. Similarly, for 5 ms node mobility, the percentage of energy variation against PA-DSR is 0.43, and for 25 ms node mobility, it is 2.71.

For 25 nodes, the percentage of delay variation against DSR is 1.21, and for 70 nodes, it is 22.40. Similarly, against PA-DSR, the proportion of delay variation is 0, and for 70 nodes, it is 10.40. For 5 ms node mobility, the percentage of delay variation against DSR is 2.46, while for 25 ms node mobility, it is 6.52. Similarly, for 5 ms node mobility, the percentage of delay variation against PA-DSR is 0 and for 25 ms node mobility, it is 3.26.

For 25 nodes, the proportion of goodput variation against DSR is 0.76, while for 70 nodes, it is 11.66. Similarly, against PA-DSR, the proportion of goodput variation is 0.59, and for 70 nodes, it is 6.47. For 5 ms node mobility, the proportion of goodput variation against DSR is 1.66, while for 25 ms node mobility, it is 7.31. Similarly, for 5 ms node mobility, the percentage of goodput variation against PA-DSR is 1.21, while for 25 ms node mobility, it is 4.91.

For 25 nodes, the proportion of PDF variation against DSR is 0 and for 70 nodes, it is 16.36. Similarly, against PA-DSR, the proportion of PDF variation is 0, and for 70 nodes, it is 12.28. For 5 ms node mobility, the percentage of PDF variation against DSR is 0, for 25 ms node mobility, it is 23.33. Similarly, for 5 ms node mobility, the percentage of PDF variation against PA-DSR is 0 and for 25 ms node mobility, it is 19.39.

The DSR works well with a lesser number of nodes, as the number of nodes increases the performance of DSR gets worse. Increasing traffic load in intermediate nodes due to more number of nodes will result in higher resource consumption, which will degrade the network performance. PA-DSR performs better compared to DSR in a big network and at a higher speed. On the other end, AMQoS always maintain an alternate path, which will reduce packet collision. This will result in a higher PDF in AMQoS. The AMQoS propagates a lesser number of control packets by filtering RREQ packets, it will yield better Goodput. Multipath routing spread the load across the network, so energy consumption will be uniformly distributed across all nodes.

Initially, for lesser speed, AMQoS perform similar to PA-DSR and DSR, as speed increases the performance gap gradually increases. The route computation overhead stabilizes when mobility speed is around 10 m/s. As mobility speed exceeds 10 m/s performance gap with computation overhead becomes wider. DSR suffers from high mobility, PA-DSR suffers less due to its QoS enabling mechanism. AMQoS perform better because of adaptability with network stack parameter, less computation overhead, and availability of multiple paths in case of route failure.

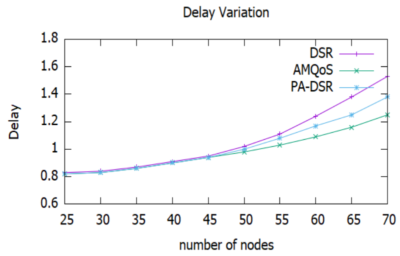

Fig. 7. Delay variation against varying nodes.

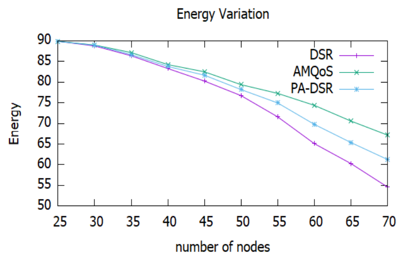

Fig. 8. Energy variation against varying nodes.

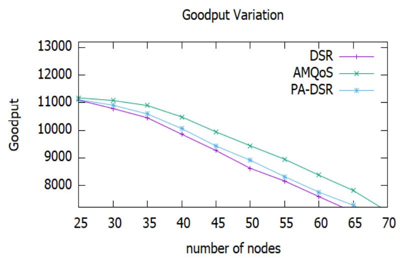

Fig. 9. Goodput variation against varying nodes.

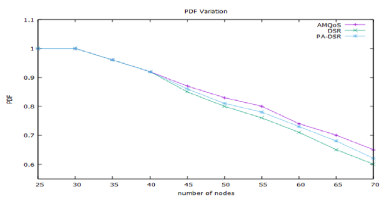

Fig. 10. PDF variation against varying nodes.

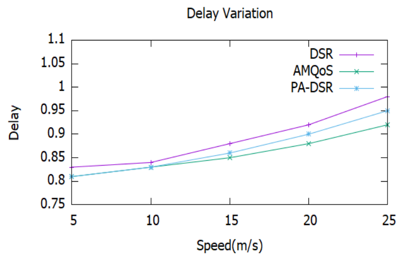

Fig. 11. Delay variation against varying speed.

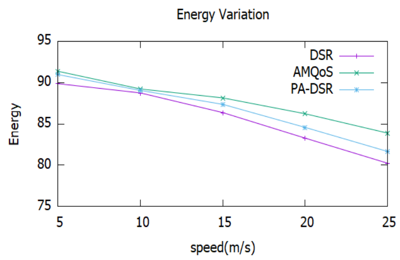

Fig. 12. Energy variation against varying speed.

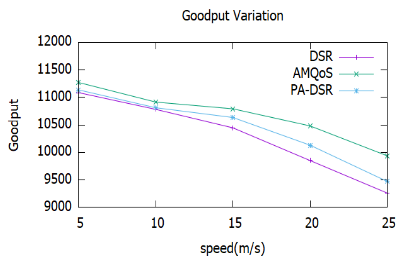

Fig. 13. Goodput variation against varying speed.

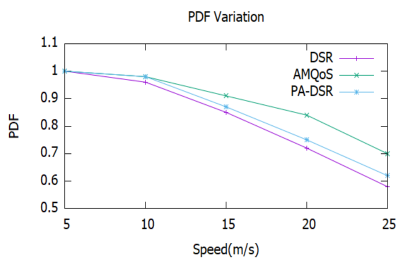

Fig. 14. PDF variation against varying speed.

7. Conclusions

The route selection strategies in the proposed AMQoS routing are adapted considering the characteristics of MANET and the type of applications being deployed on the network. The applications running on MANET demand a particular set of QoS requirements. TCP/IP protocol stack parameter has been considered to understand the MANET characteristics and trade-off of stack parameters with the QoS metric is analysed with RST. A resultant empirical model consisting of SNR, l_D, PTX is incorporated in AMQoS decision making. The dynamic threshold identification for the QoS metric is done by incorporating the discretization process of RST. AMQoS routing is to enhance the DSR by filtering received RREQ messages at the destination, which will control routing overhead. RST derived decision rules are applied on RREQ messages, only for selected RREQ messages RREP is generated and forwarded to the source. All routes extracted from RREP messages are maintained at the source node, which will have multiple routes for the destination. This will make route maintenance simpler; an alternate route is readily available in case of route failure.

The performance of AMQoS compared against DSR and PA-DSR for different QoS metrics in consideration of a varying number of mobile nodes and mobility speed. The QoS metrics used for analysis are Goodput, Delay, Energy, and Packet Delivery Fraction. The DSR works well with a lesser number of nodes, as the number of nodes increases the performance of DSR getting worse. PA-DSR comparatively suffers less in a larger network and high mobility due to its QoS enabling mechanism. On the other hand, the proposed AMQoS performs better than DSR and PA-DSR because of measures taken to uniformly spread the load across the network and to control the routing overhead.

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