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RESEARCH ARTICLE

Cross-Layer Information Driven Multi-Constraints Routing Protocol for QoS-Centric VoIP Services in MANETs-enabled IOTs: QLMCR-MVoIP

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Abstract – The last few years have witnessed significant up-surge in wireless communication systems including wireless sensor networks (WSNs) and Mobile Ad-hoc Networks (MANETs). Amongst the major innovations, the hybrid networks, especially designed with MANET as base network have gained widespread attention. For instance, MANET-based Internet of Things (MIoT), Vehicular Ad-Hoc Networks (VANET), Vehicular Ad-Hoc Sensor Network (VASNET) etc. These key innovations have led decisive up-surge in low-cost and personalized communication serving an array of applications including Voice-Based Internet Protocol which has emerged as a low-cost alternate to the Public Switched Telephone Networks (PSTNs). Despite significance of MANETs in Voice over Internet Protocol (VoIP) applications, guaranteeing quality-of-service (QoS) remains a challenge that keeps on mounting over scalable hybrid networks. Though, Session Initiated Protocols (SIP) have performed satisfactory towards VoIP; however, being centralized in nature its native realization over IEEE 802.11 protocol stack is infeasible. To alleviate it, it requires a robust routing protocol that might guarantee both reliability, low latency, high data rate as well as optimal resource allocation to the VoIP traffics to meet real-time demands. To achieve it, this paper proposed "Cross-Layer Information Driven Multi-Constraints Routing Protocol for QoS-Centric VoIP Services in MANETs-enabled hybrid networks (QLMCR-MVoIP). QLMCR-MVoIP protocol applies cross-layer information including VoIP traffic information from the application layer, packet velocity and congestion probability from the Medium Access Control (MAC) layer, adaptive link quality from the link layer and on-hop distant topology information from the network layer to perform best forwarding node (BFN) selection and subsequent forwarding path selection in hybrid networks like MANET-IoT and VASNET. It applies VoIP adaptive service differentiation and adaptive resource allocation (VA-SDARA) mechanism to ensure optimal resource allocation to VoIP traffic (data) for Quality-of-Service assurance (QoS). It ensured optimal resource allocation to the VoIP Real-Time Traffics (RTT) traffic while maintaining maximum possible resource for the non-real-time traffic during 100% resource consumption scenario. The depth simulation revealed that the proposed QLMCR-MVoIP protocol achieves average PDR of 96.66% and 95.45% for VoIP RTT traffic in MANET-IoT and VASNET networks. Similarly, it performs PDR of 95.81% and 94.64% for Non-Real-Time (NRT) traffic in MANET-IoT and VASNET network, respectively under the different operating conditions, signifying its suitability towards scalable communication services. The proposed QLMCR-MVoIP protocol efficacy over run-time network traffic with the increasing payloads across the deployed nodes remained unexplored. In future, the efforts can be made to simulate and examine its (i.e., QLMCR-MVoIP protocol) performance over the heterogeneous dynamic loads per node. Additionally, it can be simulated over routing protocol for low-power lossy (RPL) networks. These key inferences can be considered as the future scope.

Index Terms – MANET-IoT, VoIP Applications, Cross-Layer Routing Protocol, QoS/QoE, VoIP Adaptive Resource Allocation, Session Initiated Protocol.

1. INTRODUCTION

The last few years have witnessed exponential rise in wireless communication technologies serving an array of industries for real-time communications, business communications and analytics services. Amongst the major innovations, wireless sensor networks (WSNs), Mobile Ad-Hoc networks (MANETs) [1], Low-Power Lossy Networks (LLNs) [2][3], etc. have gained widespread attention globally; however, the decentralized and infrastructure-less network characteristics make MANETs one of the most used network technologies to meet major ad-hoc communication demands [4][5]. MANET is a decentralized and self-reconfiguring network solution comprising multiple nodes operating in cooperative or autonomous communications [1][4-6]. Being decentralized and mobile in nature, the nodes can move independently. Moreover, there can be some nodes like personal digital accessories (PDAs), laptop, mobile, sensors etc., which may move-in and move-out in a network and/or allied access-points or bridges [1-3]. Random mobility can give rise to the exceedingly high topological dynamism and hence link-vulnerability delay. Moreover, in MANET each node can act as either a host not or router involved in data forwarding or transmission [6][7]. During communication, a node can act as a random user or a router to forward data. In such application environment, any possible link-outage and adversaries like packet loss, congestion etc. can impact overall network performance (i.e., QoS) [8]. Moreover, to improve network's scalability varied hybrid wireless technologies including MANET as a base network, have been suggested. For instance, Mobile-IoTs [9-11], VANET [12][13], VASNET [14], etc. Despite being developed on IEEE 802.11 protocol, VANET involve MANET, especially designed to operate for inter-vehicular and intra-vehicular communications [12][13]. Similarly, VASNET involves VANET to perform communication between vehicle and the fixed wireless nodes such as road side units (RSU) or certain fixed control stations. In general, the hybrid networks are designed with two or multiple networks so as to ensure QoS under specific communication ecosystem [14]. Similarly, there can be different network conditions such as Mobile-WSNs, IoT-based smart-home, smart-city ecosystems ad-hoc networks deployed for disaster management involving Wireless Low Area Networks and MANETs , Wireless Body Area Network (WBAN) and MANETs, IoT-MANET, Wi-fi MANETs [15], etc., where two or multiple networks can be deployed together to serve cooperative communication demands. There are many other applications such as military communication, emergency, disaster management and recovery operations [16], vehicular surveillance and traffic management systems [17] where MANETs have been applied in conjunction with the other networks to serve QoS demands. However, guaranteeing QoS provision under network challenges like iterative link outage, packet losses, packet retransmission, delay etc. remains challenge for the industry.

The hybrid networks might involve varied communications including real-time traffics (RTT) such as calling or messaging and non-real-time traffics (NRT). In aforesaid hybrid networks, there are the different communication environments where Voice of Internet Protocol (VoIP), text-messaging etc. serves foundation for the RTT communication [18][19]. The ability to serve decentralized communication in infrastructure-less operating environment makes MANET-based hybrid network capable to serve VoIP-enabled services. Noticeably, VoIP is a technology that enables an alternate to the voice communication over Public Switched Telephone Network (PSTN). VoIP enables voice transmission by encapsulating and routing voice packets over Internet Protocol. In real-time, VoIP can serve video or voice calls over the internet that can be cost-effective communication solution to the masses [20]. Additionally, its ability to serve free long-distanced calls, caller-ID determination, caller blocking, video-conferencing which are mainly the RTT tasks make it potential. Modern communication systems frequently involve VoIP communication, text-messaging, content sharing amongst the nodes, message dissemination amongst the connected nodes at the different industrial ecosystems, conferences, seminars, commercial malls, battle fields etc. [21]. Interestingly, the priority of the services and allied content(s) can vary. Though, in aforesaid networks VoIP being RTT traffic requires optimal QoS assurance; yet ensuring fair QoS-provision for the NRT traffic is vital.

The use of VoIP applications demands establishment of a session between the users that involve the SIP [22]. In fact, in MANET-based VoIP, the SIP acts as a signaling protocol that controls multimedia communication sessions including session initiation, session-change, and session-termination. Despite the fact that the network adaptive SIP decisions enable QoS communication in VoIP applications; yet, it primarily relies on the efficacy of the routing protocol involved. In other words, to serve QoS to the VoIP applications a SIP protocol requires network-adaptive routing ability which could not only guarantee reliability of the transmission (or forwarding) but optimal resource allocation to the RTT traffic [22][23]. In fact, the SIP protocol being completely developed onto the centralized framework can't be deployed directly to the MANET or derived hybrid networks. And therefore, it requires a robust routing protocol as supplement to enable QoS-centric VoIP communication [24].

The frequent topological changes and link-outage, congestion, delay etc. can impact QoS/QoE delivery in MANET-driven hybrid network, especially for VoIP applications. Though, SIP protocols have been applied in MANET to improve QoS; yet, SIP being completely developed as centralized protocol can't be applied directly with the MANET, which is based on IEEE 802.11 protocol stack. For effective SIP realization with MANET, it requires an efficient routing protocol which could guarantee QoS/QoE under varied network conditions. To be noted, in reference to the QoS/QoE demands in VoIP applications, MANET protocol requires guaranteeing negligible end-to-end delay, minimum jitter, high throughput, negligible packet loss, etc. In addition, it also requires advance data-sensitive traffic queuing to accommodate RTT traffic for QoS/QoE assurance even under severe congestion and 100% resource exhaustion.

In this research, a novel and robust Cross-Layer Information Driven Multi-Constraints Link State Routing Protocol is proposed for QoS-based VoIP Services in hybrid networks like MANETs- IoTs, VASNETs, VIoTs, etc. Unlike traditional routing protocols, the proposed routing protocol extract cross-layer information from the different layers of the IEEE 802.11 protocol stack. More specifically, it exploits traffic type or data type information from the application layer, while MAC layer provides node (dynamic) details like congestion probability, packet velocity information. The data link layer on the other hand provides dynamic link quality information and throughput details, while network layer provides one hop-distant network topology information. Obtaining the different node parameters including the throughput, dynamic link quality, congestion information, node topology information (i.e., distance) and packet velocity, a BFN selection was done. Noticeably, since the proposed BFN selection mechanism is applied for each node, it reduces signaling overheads and allied delay significantly. Moreover, the use of multiple node parameters altogether towards BFN selection guarantees stable routing decision and allied best forwarding path selection. It helps achieving reliable communication across the MANET network. In addition to the aforesaid multi-constraints BFN selection strategy, the proposed work applies a novel VoIP traffic adaptive service differentiation and resource allocation strategy (VA-SDARA) that amours each node with dual-buffers, each dedicated for the RTT VoIP traffic and NRT traffic, respectively. In the proposed VA-SDARA model, in case of a node undergoes 100% resource consumption, to accommodate additional VoIP traffic data, the proposed model drops some of the recently attached packets in NRT buffer, where the data is queues in FIFO manner. Thus, it guarantees optimal resource allocation to the VoIP RTT traffic while ensuring maximum possible support to the NRT traffic and thus achieves QoS/QoE performance for the VoIP applications. The proposed MANET-IoT network is simulated by using MATLAB 2022b software tool, where the simulation results are quantified in terms of the PDR and PLR performances over VoIP RTT and NRT traffic data.

The simulation results and allied inferences confirmed that the proposed QLMCR-MVoIP protocol achieves average PDR of 96.66% and 95.45% for VoIP RTT traffic in MANET-IoT and VASNET networks. Similarly, it performs PDR of 95.81% and 94.64% for NRT traffic in MANET-IoT and VASNET network, respectively under the different operating conditions. Similarly, it achieved average PLR of 3.40%, 4.53% for MANET-IoT and VASNET networks, correspondingly for VoIP RTT transmission. Though, for NRT traffic it exhibited the average PLR of 3.94% and 5.36% in MANET-IoT and VASNET networks, correspondingly. The overall performance confirms robustness of the proposed routing protocol towards VoIP applications and allied QoS assurance in MANET-based hybrid networks like MANET-IoT and VASNET.

The remaining sections are divided as follows. Section 2 presents the related work, while overall system design and implementation is presented in Section 3. The simulation results and allied conclusion (or inferences) are given in Section 4 and Section 5, respectively. The references used are given at the end of the paper.

2. RELATED WORK

This section discusses the literatures contributing the different MANET routing protocols and its driven VoIP applications.

The rising significance of MANETs has motivated academia-industries to achieve superior performance in terms of higher throughput or packet delivery rate (PDR), low packet loss, low delay etc. to meet QoS demands. However, being exceedingly dynamic topology, scare bandwidth and resulting congestion, energy constraints etc. confine major state-of-arts to guarantee QoS services [25].

2.1. Routing in MANET

Adopting MANETs for dynamic topology and decentralized communication environment requires addressing topology-adaptive routing decisions [26]. However, the key challenge involved is its frequent link outage due to node mobility [27]. Those routing protocols designed towards wired networks can’t be suitable for MANETs due to their inability to produce low overhead while retaining fast transmission which are must for MANETs [28]. Both unicast as well as multicast protocols in MANET [29] inculcate certain flooding mechanism to guarantee successful packet transmission between the source and the destination node [30]. Functionally, it applied MAC layer to transfer packet from a source node to the neighboring nodes. However, in case of multi-hop transmission it might require identifying the best forwarding node (BFN) and re-broadcast till the packet reaches the destination. Though, flooding method can reduce redundant transmission in MANETs, yet it doesn’t guarantee QoS over a large scalable network [31]. Unlike unicast which applies single route to transfer data, the multicast methods apply multiple paths between unit sources to the multiple destinations. Some of the existing unicast routing protocols are Destination-Sequence Distance-Vector (DSDV), Wireless Routing Protocol (WRP), Optimized Link State Routing (OLSR), and Topology Broadcast based on Routing-Path Forwarding (TBRPF).Unfortunately, most of these protocols have applied single node parameter to perform routing decision. However, merely applying standalone parameter for routing over MANET can’t guarantee QoS performance. To address it temporally ordered Routing Algorithm (TORA), a reactive protocol is proposed. The key concept behind this protocol is its ability to perform self-routing and self-configuring ability where each node can make its routing decision autonomously [32]. Being reactive protocol in nature, TORA pertains to the link-reversal algorithm which makes it suitable for large and dense network. The majority of such routing protocols have either applied link-quality or resource information to perform self-configuring routing decisions [33].

2.2. VoIP and its Characteristics in MANET

In the past, a few efforts like [34][35] applied MANETs for VoIP applications; however, being dynamic in nature addressing frequent link-outage remained challenge to ensure QoS. [34]. The successful realization of VoIP requires robust MANET protocol [35], especially the one with the ability to adapt dynamic topology, link-outage and recovery demands, adaptive resource allocation etc. [35]. In the past a few efforts have been made by inculcating Constant Bit Rate (CBR), Transmission Control Protocol (TCP), ad-hoc routing, and multicast protocols with MANETs. The performance characterization reveal that the efficacy of such protocols can be satisfactory only with the optimal BFN selection and suitable coder [36]. Though, researches indicate the need of network-adaptive routing to meet QoS demands [36]. Despite such need there is no specific routing protocol which can accommodate heavy VoIP application under probable link-outage and congestion caused packet loss ratio in VoIP [37]. The QoS assurance for the telephonic conversation over a MANET remains vulnerable due to the continuous change in network parameters, such as delay, PDR due to node mobility behavior [38]. The real-time traffic over MANET is a considerable factor, especially for VoIP services [39]. QoS assurance in VoIP services over MANETs requires routing to be done by considering node mobility pattern, speed, and other network topological information. Yet, AODV and OLSR protocols need to improve adaptive routing decision and BFN selection to operate with the multi-hop IEEE 802.11b standard [40]. Additionally, considering node’s dynamic behavior and allied signal fluctuation can also help achieving QoS-oriented routing for VoIP services [41]. However, these approaches failed in addressing high variability of the network topology and bandwidth that impacts QoS decisively. To alleviate such problems, a source-node requires performing BFN selection adaptively to select the best transmission path delivering delay-resilient and link-adaptive transmission [41]. OLSR has exploited network statistics to improve routing decision; yet, most of the state-of-arts used standalone node parameter to perform best transmission path selection. Unlike AODV reactive protocol, OLSR can perform superior over complex mediums and network heterogeneity [42]. It can also be exhaustive towards VoIP applications, especially over dense and dynamic networks [42].and therefore, there is an inevitable need to design an adaptive control mechanism with adaptive routing and resource allocation control which can guarantee QoS to the VoIP packages while ensuring optimal resource to the non-real-time traffic or contents [43]. It can help improving both voice quality as well as scalability of the network. In addition, topology control by identifying the optimal forwarding node selection and routing path can help improving QoS for VoIP services [44-46]. Improving network capacity by performing data adaptive resource too can be effective towards QoS provision in MANETs.

In this reference, the authors [47] applied varied codecs to assess MANET performance for VoIP services. In [48] the authors assessed Dynamic Source Routing (DSR), Ad hoc On-demand Distance Vector (AODV), Temporally-Ordered Routing Algorithm (TORA) where they found that TORA can be suitable towards QoS in VoIP; however, requires better routing decision to control network traffic. AODV and DSR protocols were applied for QoS in VoIP in [49], where AODV exhibited superior. Unlike aforesaid protocols, the authors [50] applied cross-layer routing protocol for QoE improvement in MANETs. Interestingly, cross-layer routing protocol [50] exhibited superior over the other state-of-arts like AODV, OLSR and BATMAN for video transmission with IEEE 802.11g protocol stack. In [51] MAC layer information was applied to make WLAN routing for VoIP improvement. Recently, the authors [52] proposed perceptive queuing technique (CBCRTQ) for QoS assurance for VoIP services over MANET (by applying AODV bas protocol). In [53] VoIP performance was assessed over MANET by applying OLSR and TORA protocol, where OLSR protocol performed better towards VoIP services. AODV and Ant Hoc network protocols were assessed in [54] for VoIP over MANET in urban setup. The authors [55] found that AODV, OLSR and TORA protocols can perform better towards QoS of VoIP services by using MANETs; however, needs topology information, bandwidth information and adaptive scheduling, and link quality to achieve expected performance.

In the past, numerous routing protocols are proposed towards MANET; however, most of the state-of-arts including reactive protocols, proactive routing approaches, geographical routing protocols and hybrid protocols could employ merely standalone node or network parameter to perform routing decision. Additionally, the efficacy of the SIP driven VoIP applications primarily depends on the optimality of the routing protocol and allied best forwarding node (BFN) selection strategy.

3. PROPOSED SYSTEM

This section discussed the overall proposed model and its implementation.

3.1. MANET-IoT Hybrid Network Deployment

In this work, MANET-IoT hybrid network is considered for VoIP applications, where the connected nodes are both mobile as well as static in nature. The targeted network can be illustrated as that of VASNET that structurally encompasses

VANET (a Mobile ad-hoc network) and WSNs. In this network, the mobile nodes can be moving independently (say, vehicles), while the fixed WSN or LLN nodes can be the road side units (RSU), also called road infrastructure unit or control station. In function, the moving nodes require performing vehicle-to-vehicle (V2V) communication (i.e., within the deployed MANET nodes) as well as vehicle-to-infrastructure (V2I) communication to perform VoIP services. Similarly, the target hybrid network can be defined as a Smart-Home network where the moving nodes such as PDAs, mobile phones, remote controllers etc. can be the mobile nodes, while the sensors like smoke sensor, fan-sensor, light-sensor, and varied other actuators can be the static sensor nodes. In such hybrid network, the mobile node can be the freely moving nodes that can frequently come in and go out of the node's radio range, thus making overall link-quality dynamic or vulnerable. In this case, the problem is to ensure VoIP communication optimal and QoS-enriched amongst the node to meet (QoS) communication demands. In this reference, our proposed QLMCR-MVoIP protocol intends to design a robust cross-layer routing protocol which could guarantee reliable and QoS-centric communication so as to support SIP protocol to make VoIP communication optimal. In sync with the MANET-based hybrid network towards VoIP application demands, we designed and deployed two different network models; MANET-IoT and VASNET. Here, the deployed MANET nodes were assigned two buffers distinctly, where one buffer was allocated for the VoIP RTT traffic, while another buffer was assigned towards NRT traffic. Each deployed node has unique NodeID, radio range. Though, their packet structure was maintained same. The allied packet structure encompassed three sections, first NodeID header, data block and tail flag bit. Once deploying the nodes, the communication was performed where each node (willing to initiate transmission) initiates beacon message as multicast message and receiving the response from the nodes as unicast message it estimates different node parameters from their respective IEEE 802.11 protocol stack. Additionally, it also helps in estimating the PDR or throughput that put foundation for the dynamic link quality estimation, which is discussed in the subsequent section. The unicast message also provides topological information to identify the one-hop distance nodes so as to initiate further BFN selection task. The detailed discussion of the proposed routing model is given in the following sections.

As stated above, the proposed hybrid network deploys a large number of MANET nodes randomly across the network region (here, we considered the dimension of the network as 500×500 meters network). Each of the deployed MANET node has its unique characteristics like energy model, radio range, NodeID etc. Since, in the proposed model each MANET node is assigned the right to form its best forwarding path and therefore receiving unicast response it estimates inter-node distance. For example, for a MANET node i and j, the node(s) estimated inter-node distance d_{ij} by using equation (1). Noticeably, to ensure link-adaptive and reliable communication only that (one-hop distant) node falling within the radio range is considered for further BFN selection decision. In other words, it follows the condition R_{DSRC} (i.e., $d_{ij} < R_{DSRC}$), and those nodes falling under on-hop distant distance, are annotated as the neighbor node.

$$d_{ij} = \sqrt{(x_i - x_j) + (y_i - y_j)} \tag{1}$$

We measured the node's connectivity in terms of the nodes which are connected directly. Thus, the neighbor node a moving node i at certain instant t is defined as per the equation (2).

$$\sum_{j=1}^{n} \mathrm{dis}(i, j, t) < \text{Transmission Range} * (\text{Node } i) \tag{2}$$

In equation (2), $\mathrm{dis}(i, j, t)$ distance is calculated only when the link is established and the nodes i and j are the one-hop distant neighbor node at time t. The MANET node can move independently or randomly across the network space with respective speed and direction; though, their speed and direction can be highly responsible for their connected link probability, link duration and respective PDR performance (say, reliability). Thus, with such random network condition, we considered free flow traffic state (FFTS) model that considers a normal node distribution across the network region. With such network model, the probability density function (PDF) is measured as per equation (3).

$$\mathrm{PDF} = \frac{1}{\sqrt{2 * \pi * \sigma^2}} e^{\frac{-(V-\mu)^2}{2\sigma^2}} \tag{3}$$

In equation (3), the parameter σ^2 presents the standard deviation of the node's speed, while the node's speed is defined as μ. Thus, the MANET node with the nearest distance and speed would be the one-hop neighbor node and their respective node characteristics would be considered for further BFN selection and routing decision. The QLMCR-MVoIP protocol calculates the mean speed of the one-hop distant node by means of the equation (4).

$$\mu_{\mathrm{Neighbour}} = \sum_{i=0}^{n} \frac{\mathrm{Distance}}{\mathrm{time}} \tag{4}$$

Thus, the topological node position of a moving MANET node is measured as L_T equation (5), where the local parameters x_t and y_t represent the position coordinate of the mobile node at time t.

$$L_T = (x_t, y_t) \tag{5}$$

The mean speed of the moving node is measured as per equation (6).

$$\mu_{Speed} = \frac{1}{T}\sum_{t=1}^{T}\sqrt{(x_t - x_{t-1})^2 + (y_t - y_{t-1})^2} \quad (6)$$

In equation (6), the parameters T and t be the periodic time and the instant time, respectively. In this manner the normalized speed of each moving node is measured as per the equation (7).

$$\mu_n = \frac{v_i - \mu_{Speed}}{\sigma} \quad (7)$$

In equation (7), v_i be the speed of a Mobile node. Thus, estimating the average vehicle speed and one-hop distant node's speed the connected one-hop distant nodes are obtained as per equation (8)

$$CN(i) = \beta_1\mu_n + \beta_2 oneHNeigh(i) \quad (8)$$

In equation (8) $oneHNeigh(i)$ signifies the total number of the adjacent nodes radio range more than the inter-node distance. Towards multi-metric BFN selection, we used weight factors β_1 and β_2, where $\beta_1 + \beta_2 = 1$. Noticeably, the above conditions enabled confining the one-hop distance network condition, where the transmitting node can assess connected node's cross-layer information to make proactive routing decision. Moreover, these information helps QLMCR-MVoIP protocol re-configuring the best forwarding path to perform VoIP communication. Now, once configuring the one-hop distance network topology, respective cross-layer information (from the IEEE 802.11 protocol stack) is obtained. Subsequently, the proposed QLMCR-MVoIP protocol exploits multiple node parameters to perform BFN selection and allied best forwarding path selection. The detailed discussion of the proposed BFN model is given in the subsequent sections.

3.2. Cross-Layer Information Driven Multi-Constraints BFN Selection

As discussed in the previous sections, the proposed QLMCR-MVoIP protocol applies multiple nodes parameter to perform BFN selection. The key purpose of the targeted multiple constraints driven BFN selection method is to apply dynamic cross-layer information from the MANET node in such manner that only that specific node fulfilling QoS-centric aspects get selected as the BFN. In other words, unlike traditional MANET routing protocols where merely single node parameters like congestion, residual energy or distance are used to perform BFN selection, our proposed QLMCR-MVoIP protocol applies multiple parameters including congestion, one-hop distant node position, PDR, dynamic link quality information, packet velocity and VoIP traffic type to perform BFN selection. A snippet of the parameters selected and allied motive is given in Table 1.

Table 1 Multi-Constraints Parameter Selection Towards QoS Assurance

SN	Parameters	IEEE 802.11 Layer	Motive	Goal
1.	VoIP Traffic types	Application Layer	Service Differentiation and Adaptive Resource Allocation; QoS-oriented Queuing	Best Forwarding Node Selection and Adaptive Route Estimation for QoS Assurance
2.	Cumulative Congestion	MAC Layer	Congestion Estimation for each candidate forwarding node	
3.	Packet Velocity	MAC Layer	Packet Injection rate estimation for each candidate forwarding node	
4.	Link Quality	Data Link Layer	Dynamic Link Quality Estimation for each candidate forwarding node	
5.	Distance Information	Network Layer	One-hop distance estimation to enable reliable transmission towards the destination node	

As depicted in the Table 1, the QLMCR-MVoIP protocol applies dynamic information from the different layers of the MANET's IEEE 802.11 protocol stack. More specifically, it applies information from the Application layer, MAC layer, Data Link layer and Network layer. Here, the application layer provides VoIP traffic details such as the data type and its priority (say, real-time traffic (RTT) such as Voice data, alarm messages etc., and non-real-time traffics including data logs or multimedia contents). This information enables QLMCR-MVoIP protocol to schedule the resource in such manner that it guarantees optimal resource towards VoIP RTT traffic while maintaining maximum possible resources to the NRT traffic or data. This service differentiation ability can not only help in improving resource allocation but can also enable QLMCR-MVoIP protocol to perform dynamic queuing. In MANET-based networks the key problem is abrupt change in node topology and resulting congestion probability. The unpredictable node movement can give rise to the frequent congestion probability that consequently can cause data drop and hence retransmission. This as a result can impose delay and hence can impact QoS/QoE performance. Considering this fact, we have considered congestion probability on each neighbor node to perform BFN selection. To ensure that the BFN node ensures data transmission successful within the deadline time, we estimated packet velocity information of the deployed neighbor node. Thus, the packet velocity was also considered as BFN selection criteria. Considering node mobility and its impact on link vulnerability, we have applied dynamic link quality measure as one of the conditions for BFN selection. Additionally, we also applied inter source-destination node distance from the BFN node as the BFN selection criteria. Thus, exploiting aforesaid VoIP traffic type, cumulative congestion degree, packet velocity, dynamic link quality and inter-node distance information as decision variable a multi-constraints BFN selection for further routing decision. In addition to the proposed BFN selection measure, the QLMCR-MVoIP protocol applies AV-SDARA mechanism where each node was assigned dual-buffer strategy with VoIP sensitive resource allocation. This as a result makes overall routing robust to ensure QoS delivery for VoIP applications. The QLMCR-MVoIP protocol and allied BFN selection model encompasses the following components:

1. Topology Adaptive Proactive Network Table Management,
2. Congestion Estimation,
3. Packet Velocity Estimation,
4. Dynamic Link Quality Estimation, and
5. VoIP-Adaptive Service Differentiation and (Adaptive) Resource Allocation.

The detailed discussion of the overall proposed multi-constraints BFN selection is given in the subsequent sections.

3.2.1. Topology Adaptive Proactive Network Table Management

In VoIP applications, including rural as well as urban network environment there can be non-linear traffic caused due to the MANET nodes and static nodes caused data dissemination requests. On the other hand, the deployed nodes can have exceedingly high dynamism and hence a node might come in and go out of the radio range of the transmitting node or sender. This as a result can cause frequent link-outage and hence data drop. To alleviate it, the proposed MANET-based hybrid network protocol intends to apply proactive network management where the topological details are updated on a regular interval so as to alleviate any stale-data based routing and hence data loss. Considering it as motivation, we performed proactive network management where we prepare a node table which is updated after each 20 seconds. In other words, each deployed node transmits a multicast beacon message and receives unicast response from one hop distant nodes, based on which it estimated aforesaid node information (Table 1) to update the node table proactively. Realizing the fact that the non-one-hop distant nodes too can send the unicast response being in mobility, the proposed model constrains unicast response from only the on-hop distant node.

Consider N_j states the one-hop distant MANET node while BFN_i be the BFN candidate. In this manner, the proactive node table is updated as per equation (9).

$$N_T = \left\{ BFN_{i\in N_j} \mid D_{Euclidiand} - D_{Euclidianf} \geq 0 \right\} \tag{9}$$

In equation (9), $D_{Euclidiand}$ states the Euclidean distance between the source node to the nearest destination node, while $D_{Euclidianf}$ be the distance between the source node and the nearest BFN node, correspondingly. This topological information is applied to perform BFN selection and allied routing decision.

3.2.2. Congestion Estimation

The swift topological changes and node density can cause congestion frequently. To ensure reliable and QoS-oriented communication the proposed routing protocol performs cumulative congestion estimation for each MANET node in the network. A node with the minimum buffer congestion probability is considered for BEN in the proposed MANET-IoT hybrid network. To measure congestion probability, the proposed QLMCR-MVoIP routing protocol applies the buffer details of each node to assess its congestion probability. To be noted, being a dual-buffer based VA-SDARA model, we have assigned two buffers each dedicated for the VoIP-RTT data and NRT data. Thus, applying buffer conditions, we estimated congestion probability P_{CON} equation (10) for each node. Let, B_{VoIP_NRT} be the buffer available at a node, while B_{NRT_Max} be the maximum buffer capacity of the NRTT buffer of each node. Considering, B_{VoIP_RTT} and $B_{VoIP\_RTT\_Max}$ be the available buffer and the maximum buffer available for the real-time traffic buffer, respectively. We applied equation (10) estimates congestion probability estimation for each node.

$$P_{CON_r} = \frac{B_{NRT} + B_{VoIP\_RTT}}{B_{NRT\_Max} + B_{VoIP\_RTT\_Max}} + \sum_{i=1}^{\mathbb{N}} P_{CON_{ri}} \quad (10)$$

In equation (10), the parameter P_{CON_r} signifies the cumulative congestion degree at a specific MANET node r. $P_{CON_{ri}}$ states the overall congestion imposed due to the connected one-hop distant nodes. In this manner, the cumulative congestion is measured as the addition of current buffer consumed and the congestion or buffer demand by the neighboring connected node(s). A node with the minimum cumulative congestion degree P_{CON} is selected for BFN. In this work, we considered P_{CON} equation (10) as one of the decision variables towards targeted BFN selection criteria.

3.2.3. Packet Velocity Estimation

VoIP services or allied application demand MANETs to ensure timely and jitter-free data transmission to meet QoS/QoE demands. The different applications including MANET-IoTs, VASNET, VANET etc. To guarantee QoS/QoE for VoIP applications QLMCR-MVoIP requires transmitting data within the deadline time and therefore we measured packet velocity or injection rate of each node to assess its suitability to become BFN node.

Thus, the proposed QLMCR-MVoIP protocol considers only that specific node having the highest packet velocity to become the BFN node. In order to measure packet velocity performance of each node, QLMCR-MVoIP exploited distance information, round trip time and the light's velocity in air. The proposed model measured the Euclidian distance between the MANET nodes (as well as MANET node and WSN static node), average round trip time (RTT_{Ti}). In this work, the round-trip time information was measured as the time-difference between the transmitted and the received signal equation (11).

$$RTT_{Ti} = \frac{\sum_{i=0}^{N} R_{At}^{i} - V_{Pt}^{i}}{N} \quad (11)$$

In equation (11), the parameter R_{At}^{i} signifies the time when a MANET node gets the response message transmitted by the neighboring (one-hop distant node). The other parameter V_{pt}^{i} states the time-instant at which a MANET node transmitted packet i. The parameter N states the total received packets. In this work, QLMCR-MVoIP protocol estimates the Euclidian distance between source and the nearest destination node. Thus, with these details a node applies distance vectors and average round-trip-time information to derive packet velocity $V_{\mathcal{t}}$ by using equation (12).

$$V_{\mathcal{t}} = \left(\frac{D_{ESD}^{i} - D_{ENS}^{i}}{RTT_{Ti}}\right) \quad (12)$$

In equation (12), D_{ESD}^{i} presents the Euclidean distance between a source node i and the sink node. The other distance parameter D_{ENS}^{i} states the distance between the source and the nearest sink node in the deployed MANET-IoT network. Our proposed QLMCR-MVoIP protocol employed the maximum radio signal's speed in open air (S_{Max}) to derive packet velocity (V_{PKT_i}) of the $i - th$ node. In equation (13), S_{Max} is fixed as 3×10^{-8} m/s.

$$V_{PKT\_i} = \left(\frac{V_{\mathcal{t}}}{S_{Max}}\right) \quad (13)$$

Thus, the QLMCR-MVoIP protocol applied aforesaid packet velocity information as a criterion to perform BFN selection.

3.2.4. Adaptive Link Quality Estimation

To ensure reliable and QoS communication, the QLMCR-MVoIP protocol requires estimating dynamic link quality of each (on-hop distant) node. Recalling the fact that in the deployed MANET-IoT network the MANET nodes can be mobile in nature and hence can come in and go out of the radio range of a node and hence can undergo frequent link-outages.

Considering a node with such link-vulnerability as BFN can cause partial or complete packet loss and hence delay and hence can impact overall QoS/QoE aspects. To alleviate this problem, our proposed QLMCR-MVoIP protocol intends to consider only that node having reliability dynamic link quality feature as BFN node. To achieve it, QLMCR-MVoIP protocol applies packet delivery rate (PDR) at the MAC layer to derive adaptive link quality equation (15).

$$PDR_{ij} = \frac{N_{rx\_ji}}{N_{tx\_ij}} \quad (14)$$

$$\eta_{ij} = \alpha * \eta_{ij} + (1 - \alpha) * \left(PDR_{ij}\right) \quad (15)$$

In above equations (14) and (15), PDR_{ij} states the PDR performance between the node i and j. Here, N_{rx_ji} and N_{tx_ij} be the received packets and the transmitted packets, correspondingly. Here, i and j are the source and the destination node, correspondingly. Here, η_{ij} states the adaptive link quality between the nodes, i and j. The parameter α be the network coefficient, existing in the range of 0 to 1.

In this work, we fixed $\alpha = 0.6$. In this work, the adaptive link quality information is considered as a decision variable to perform BFN selection and routing decision.

3.3. VoIP-Adaptive Service Differentiation and (Adaptive) Resource Allocation

In VoIP applications, there can be the traffic packets which are supposed to be delivered within the deadline time. Such traffic can be annotated as the RTT traffic. For example, voice data, control signals, messages etc. can be labelled as RTT traffic. On the other hand, there can also be the data packets which don't have any definite deadline time or predefined mission critical communication conditions.

In this case, to ensure QoS/QoE delivery QLMCR-MVoIP protocol requires delivering VoIP RTT data successfully within the deadline time, while the NRT traffic data can be delivered as soon as the node finds sufficient resource (without any deadline time condition). To cope up with aforesaid QoS/QoE demand, our proposed routing protocol applies dual-buffer provision to perform adaptive resource allocation and queuing. We perform service differentiation at the application layer and classifies each VoIP traffic as VoIP RTT traffic and NRT traffic. To enable QoS-adaptive resource allocation, our proposed QLMCR-MVoIP protocol applies VoIP adaptive service differentiation and adaptive resource allocation (VA-SDARA). Here, each node is applied two buffers, each dedicated for the VoIP RTT traffic and NRT data. Each of these buffers follow first in first out (FIFO) queuing.

During run-time communication in case a MANET node gets 100% consumed, the proposed QLMCR-MVoIP protocol drops some of the recently attached packets from the NRT buffer which are queued in FIFO manner. Unlike traditional resource allocation approaches where a node requires dropping complete data from the NRT buffer, our proposed VA-SDARA protocol drops merely a few recently attached packets from the NRT buffer so as to accommodate the VoIP RTT traffic (or data). Noticeably, we prioritized VoIP RTT traffic over other NRT data. To assess priority of the VoIP RTT traffic we used equation (16). Here, the packets with the minimum $\mathrm{T_{Factor}}$ is assigned high priority for RTT buffer allocation.

$$\mathrm{T_{Factor}} = \frac{\mathrm{R_{time\_i}}}{\mathrm{d_i^j}} \tag{16}$$

In equation (16), $\mathrm{R_{time\_i}}$ states the residual deadline time, while $\mathrm{d_i^j}$ be the Euclidian distance between the source i and the destination j node. In this work, $\mathrm{R_{time\_i}}$ states the residual time which is measured by applying the time of arrival (TOA) information of each packet.

The proposed model updates $\mathrm{R_{time\_i}}$ value for each packet. The RTT packet possessing minimum $\mathrm{T_{Factor}}$ is assigned higher priority. Thus, based on the aforesaid priority VA-SDARA model performed resource allocation and queuing in the buffer.

3.4. Multi-Constraints BFN Selection and Dynamic Routing for QoS assurance

In this work, to guarantee QoS assurance in MANET-IoT network, we applied different cross-layer information including one-hop distant node position, packet velocity information, adaptive link quality and cumulative congestion degree at each node to perform BFN selection. To achieve it, we measured node score for each one-hop distant neighbor node (say, $\mathrm{BFN_{Score\_i}}$).

$$\mathrm{BFN_{Score\_i}} = \beta_1 * \mathrm{Hop_{ij}} + \beta_2 * \mathrm{P_{CON_r}} + \beta_3 * \eta_{ij} + \beta_4 * \mathrm{V_{PKT\_i}} \tag{17}$$

In equation (17), φ states the weight parameter, which can be decided on the basis of the network's demands. For instance, there can be the VoIP applications such as MANET-IoT (ex. Smart Home) where the phone can be the mobile node, while the static sensors can be the LLN/WSN node. In this case, being in a definite indoor condition the link outage probability can be relatively low. On the contrary, in another application like VANET or VASNET where there can be the large independently moving mobile nodes undergoing congestion, link-outage etc.

These varied network conditions might require the different priority (and hence network coefficient or weights) to ensure reliable and QoS-sensitive communication. Since, in this work we considered MANET-IoT and VASNET as the two network conditions, where the earlier has the lower mobility in comparison to the later (i.e., VASNET). In this reference, we assigned $\beta_1 = \beta_4 = 0.2$, while $\beta_2$and β_3 was assigned as 0.3. Similarly, for VANET, we assigned $\beta_2 = \beta_3 = \beta_4 = 0.3$ and $\beta_1 = 0$. Noticeably, the sum of all network coefficients is always unit value or 1 equation (18).

$$\sum_{i=1}^{N=4} \varphi_i = 1 \tag{18}$$

Table 2 Network Coefficient Assignment

Network Coefficient	MANET-IoT	VASNET
β_1	0.2	0.1
β_2	0.3	0.3
β_3	0.3	0.3
β_4	0.2	0.3

Thus, estimating the node's BFN_{Score_i} score for the $i-th$ node, the transmitter decides whether to consider or deploy as the BFN node. Once estimating the node score for each one-hop distant node, QLMCR-MVoIP protocol performs sorting of the node score BFN_{Score_i} and the node with the highest score is considered as the BFN node based on which the best forwarding path is selected as in the algorithm 1.

```
Input: No. of Nodes, Source Node, Destination Node
Output: Best Forwarding Node
Step-1: Deploy the network with N-nodes with respective heterogeneous characteristics (radio range, energy)
Step-2: Initiate Node Discovery by transmitting Multicast Beacon Message (HELLO) to the one-hop distant nodes
Step-3: Collect Unicast Acknowledgement (ACK) Message
Step-4: Collect cross-layer information of the one-hop distant nodes including the following:
    $CN(i) = \beta_1 \mu_n + \beta_2 oneHNeigh(i) - (8)$
    $P_{CON_r} = \frac{B_{NRT} + B_{VoIP\_RTT}}{B_{NRT\_Max} + B_{VoIP\_RTT\_Max}} + \sum_{i=1}^{\mathbb{N}} P_{CON_{ri}} - (10)$
    $V_{PKT\_i} = \left(\frac{\mathrm{V}_t}{\mathrm{S}_{\mathrm{Max}}}\right) - (13)$
    $\eta_{ij} = \alpha * \eta_{ij} + (1 - \alpha) * \left(PDR_{ij}\right) - (15)$
Step-5: Estimate Node Score by applying equation (8), (10), (13) and (15), as per (17)
    $BFN_{Score\_i} = \beta_1 * Hop_{ij} + \beta_2 * P_{CON_r} + \beta_3 * \eta_{ij} + \beta_4 * V_{PKT_i} - (17)$
Step-6 Select the Best Forwarding Node with the highest value of (17).
Step-7: Initiate transmission with the selected BFN node.
```

Algorithm 1 Best Forwarding Node selection

In this manner, applying the proposed BFN node selection and allied best forwarding path selection measure, QLMCR-MVoIP protocol performs communication towards VoIP applications. The simulation results and allied inferences are discussed in the subsequent sections.

4. RESULTS AND DISCUSSION

In this paper, we focused on designing a robust Cross-Layer Information Driven Multi-Constraints Link State Routing Protocol named QLMCR-MVoIP was developed for QoS-Centric VoIP Services in MANETs-enabled hybrid networks. QLMCR-MVoIP protocol being a decentralized routing protocol or proactive routing model was designed that in conjunction with the SIP protocol can enable QoS/QoE communication for MANET-based hybrid network.

The proposed MANET-based hybrid network and allied routing protocol was designed as a cross-layer information driven routing model, where the key emphasis is to exploit (cross-layer information) node information encompassing VoIP traffic types, packet velocity, dynamic link quality, network topology information altogether to perform BFN selection and subsequent best forwarding path selection to meet QoS demands. These network parameters were applied to derive a cumulative node score value which was sorted in the descending order. Once estimating aforesaid cumulative node score value for each deployed node, the node with the highest score was defined and labelled as BFN node.

Thus, identifying BFN node, QLMCR-MVoIP protocol performed best forwarding path estimation for each source-destination node so as to achieve successful data dissemination or delivery. Additionally, QLMCR-MVoIP applied VA-SDARA to perform VoIP traffic adaptive resource allocation so as to provide optimal resources for the RTT traffic, while guaranteeing maximum possible resource for the NRT data.

The priority and allied QoS-sensitive queuing model enabled VA-SDARA model achieving superior resource efficacy and delay-resilient transmission to meet VoIP application demands. To assess efficacy of the proposed routing protocol we deployed two different simulation networks, especially designed with MANET as the base network technologies.

In other words, we designed MANET-IoT network and VASNET, distinctly for respective simulations and performance characterization. Noticeably, the common feature between the MANET-IoT and VASNET is that both embody MANET mobile nodes as well as static WSN node.

In MANET-IoT environment such as Smart Factory or Smart City, there can be the different mobile nodes functional based on IEEE 802.11 protocol stack. Additionally, such network can also have the relay node or the base station operational with IEEE 802.15.4 protocol stack (Ex. LLNs in IoT). Similar to the MANET-IoT, VASNET network too can have mobile nodes or vehicles that in conjunction with the road side units (RSU) which is a WSN sensor node performs communication.

We examined performance of the proposed QLMCR-MVoIP protocol in terms of the packet delivery ratio (PDR) and packet loss ratio (PLR) for both VoIP RTT traffic as well as NRT traffic data.

We performed simulation over the different packet sizes (say, payload) as well as node density (i.e., the number of nodes deployed over the network region. The mathematical models applied to measure PDR and PLR performance (in percentile (%)) are given in equations (19) and (20), respectively.

$$PDR(\%) = \frac{\sum_{i=1}^{n} R_i}{\sum_{i=1}^{n} T_i} \times 100\% \tag{19}$$

$$PLR\ (\%) = (1 - PDR)\% \tag{20}$$

The simulation environment and allied (setup) parameters considered in this work are given in Table 3.

Table 3 Simulation Parameters

Parameter	Specification
Number of Nodes	Mobile Nodes-50, 100, 150, 200, 250 and 300 Static Nodes- 10 Static Node acts as the Gateway node (MANET-IoT), Relay Node or RSU (VASNET)
Network Region	1000 × 1000 m
Payload (Packets @512 byte each)	100, 200, 500, 1000, 1500 and 2000.
Physical (MANET)	IEEE 802.11 PHY
MAC (MANET)	IEEE 802.11 MAC
Physical (WSN)	IEEE 802.15.4 PHY
MAC (WSN)	IEEE 802.15.4 MAC
Protocol	QLMCR-MVoIP (an improved OSLR protocol)
Link-layer	CSMA-CD
Radio Range	200 meter
Packet deadline time	5 Seconds.
Traffic	CBR
Mobility	Athlete Running Competition
Simulation Period	500 Seconds.
Traffic Payload	VoIP real-time traffic (RTT-Voice) and Non-real-time traffic (NRT-text)
Transmitter Power	100 mW
Message Type	Unicast, Multicast
Simulation Tool	MATLAB 2022b

The proposed QLMCR-MVoIP protocol was developed by using MATLAB 2022b simulation software, where the simulation was performed over a central processing unit (CPU) armored with Microsoft Office operating system, Intel-i5 processor, 16 GB RAM functional at 3.2 GHz frequency. The simulation results obtained are discussed in the following sub-sections.

To assess robustness of the proposed QLMCR-MVoIP protocol we simulated it with both MANET-IoT set as well as VASNET. Noticeably, since both these networks embody mobile MANET nodes and static anchor node or relay node, we only changed the network sensitive weights in Table 2. In this case, the respective weight parameter assigned towards link-quality is higher in VASNET (0.3), in comparison to the topology related weight (0.2). Thus, changing the weight coefficients (Table 2) we simulated both MANET-IoT as well as VASNET network over the different payloads and node densities. In sync with the VoIP QoS constructs which can have both RTT as well as NRT traffic we have examined performance for both these data traffic, separately.

The simulation results obtained for the different network models (i.e., MANET-based hybrid networks) were tabulated (Table 4- Table 7) and presented visually to improve presentation. The simulation results over the different payloads and node density are given in the Table 4 and Table 5, respectively. The results (Table 4 and Table 5) depict that the proposed QLMCR-MVoIP protocol exhibits the average PDR (%) of 96.66% over MANET-IoT ecosystem, while the same simulation condition yielded the average PDR of 95.32% for the VoIP RTT traffic. Noticeably, the highest PDR observed over MANET-IoT and VASNET network models were 97.4% and 96.7%, respectively (Table 4). Interestingly, observing the results (Table 4 and Figure.1 and Figure. 2), it can be found that though there exists certain decrease in PDR with the increase in payload; however, the decrease in PDR is very small, signifying robustness of the proposed routing protocol towards QoS assurance in VoIP applications. The PDR performance over NRT traffic to exhibited that the proposed QLMCR-MVoIP protocol achieves average PDR of 96.24% for MANET-IoT and 95.57% for the VASNET network. This result confirms robustness of the proposed routing protocol to retain high PDR performance for both VoIP RTT traffic as well as NRT packets over the different networks (Figure. 2). This efficacy confirms suitability of the QLMCR-MVoIP protocol towards real-time VoIP applications.

Table 4 PDR (%) Performance of Proposed QLMCR-MVOIP Over the Different Payload Conditions

Payload	PDR (%)			
	VoIP RTT		VoIP NRT	
	MANET-IoT	VASNET	MANET-IoT	VASNET
100	97.41	96.72	96.97	96.61
200	96.9	96.59	96.59	96.29
500	96.77	95.93	96.28	95.87
1000	96.51	94.29	96.12	95.16
1500	96.4	94.22	95.81	94.82
2000	95.99	94.18	95.69	94.69

Table 5 PLR (%) Performance of Proposed QLMCR-MVOIP Over the Different Payload Conditions

Payload	PLR (%)			
	VoIP RTT		VoIP NRT	
	MANET-IoT	VASNET	MANET-IoT	VASNET
100	2.39	3.38	3.03	3.39
200	3.1	3.31	3.41	3.71
500	3.33	4.07	3.72	4.13
1000	3.49	5.71	3.88	4.64
1500	3.6	5.78	4.19	4.18
2000	4.01	5.82	4.31	5.31

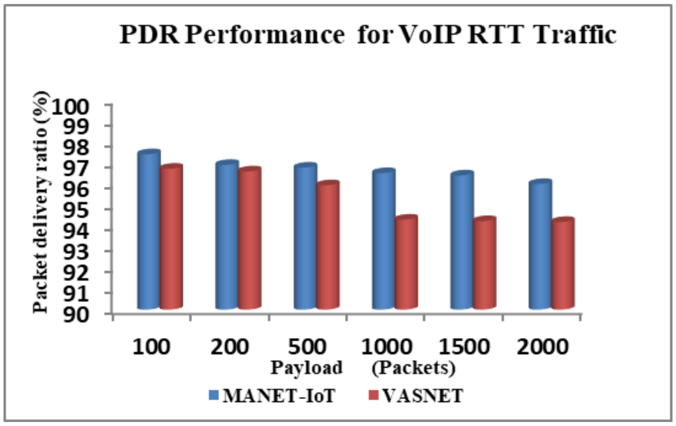

Figure 1 PDR Performance of Proposed QLMCR-MVOIP for the RTT Traffic Over the Different Payloads

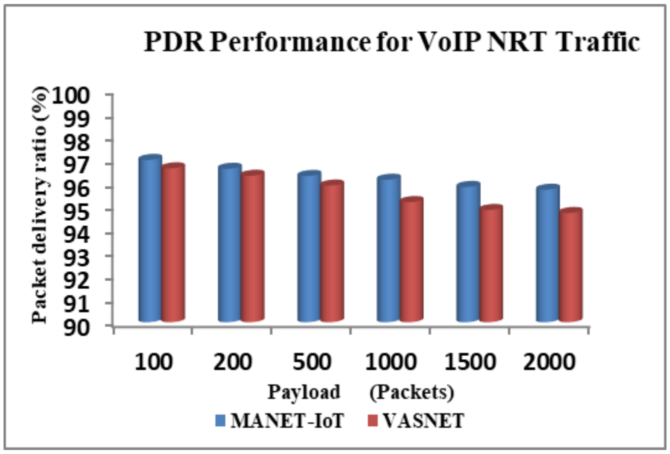

Figure 2 PDR Performance of Proposed QLMCR-MVOIP for the NRT Traffic Over the Different Payloads

The PLR performance characterization over the VoIP RTT traffic to exhibited that the proposed QLMCR-MVoIP protocol shows average PLR of 3.32% and 4.67% in MANET-IoT and VASNET networks, especially over the different payload conditions, correspondingly (Figure. 3). Noticeably, the PLR performance was obtained for the VoIP RTT traffic. On the contrary, for the NRT packets or traffic the proposed QLMCR-MVoIP protocol exhibited the average PLR of 3.75% and 4.22% (Table 5) for the MANET-IoT and VASNET networks (over the different payloads). The depth performance characterization revealed that the PLR increase is very minute over increasing payload condition and hence can be suitable over real-time VoIP services including voice communication and messaging services.

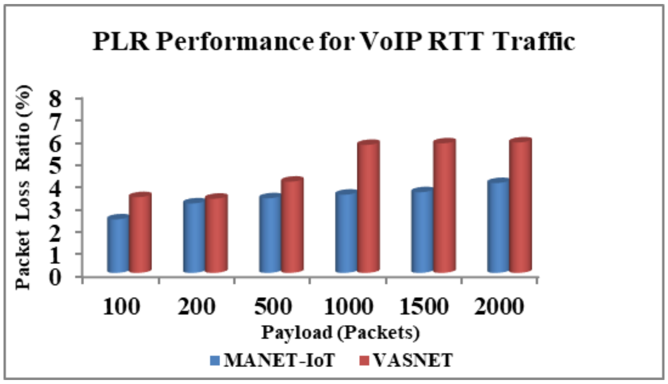

Figure 3 PLR Performance of Proposed QLMCR-MVOIP for the RTT Traffic Over the Different Payloads

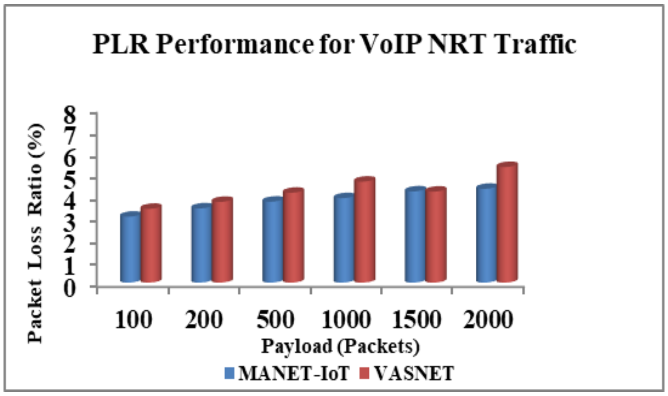

Figure 4 PLR Performance of Proposed QLMCR-MVOIP for the NRT Traffic Over the Different Payloads

Realizing real-world network conditions, where the number of nodes (especially the mobile nodes) can vary over the run-time or the simulation period, we assessed efficacy of the proposed QLMCR-MVoIP protocol over the different node densities. We examined the performance over the different node densities in each of the deployed MANET based hybrid networks (i.e., MANET-IoT and VASNET). More specifically, we simulated our proposed QLMCR-MVoIP protocol over the node counts of 50, 100, 150, 200, 250 and 300. The simulation results obtained for the VoIP RTT traffic as well as NRT packets are given in the Tables 6 and 7, respectively. The graphical depiction of the PDR performance for the VoIP RTT and NRT traffics are given in Figure. 5 and 6, respectively. While the PLR performance over the different network densities (by the deployed MANET-IoT and VASNET) are presented in Figure. 7 and Figure. 8.

Table 6 PDR (%) Performance of Proposed QLMCR-MVOIP Over the Different Node Densities

Nodes	PDR (%)			
	VoIP RTT		VoIP NRT	
	MANET-IoT	VASNET	MANET-IoT	VASNET
50	97.2	96.98	96.21	96.42
100	96.9	96.59	96.09	96.09
150	96.89	96.21	95.99	95.67
200	96.66	94.29	95.82	95.36
250	96.54	94.22	95.6	94.02
300	95.86	95.23	95.39	93.71

Table 7 PLR (%) Performance of Proposed QLMCR-MVOIP Over the Different Node Densities

Nodes	PLR (%)			
	VoIP RTT		VoIP NRT	
	MANET-IoT	VASNET	MANET-IoT	VASNET
50	2.8	3.02	3.79	3.58
100	3.1	3.31	3.91	3.91
150	3.11	3.79	4.01	4.33
200	3.34	5.71	4.12	4.64
250	3.46	5.78	4.4	5.98
300	5.15	4.77	4.61	6.29

Observing the results (Table 6) for the PDR performance, we can find that the proposed QLMCR-MVoIP protocol exhibits average PDR of 96.67% for the VoIP RTT traffic (Figure. 5), while the same exhibits 95.58% of PDR towards NRT traffic. For the VoIP RTT traffic the QLMCR-MVoIP protocol exhibits PDR (%) of 97.2%, 96.9%, 96.89%, 96.66%, 96.54% and 95.86% for the node densities of 50, 100, 150, 200, 250 and 300 nodes, respectively for MANET-IoT network. Here, it can be observed that even with increasing network densities 600%, the reduction in PDR is merely 1.34%. It shows robustness of the proposed protocol towards the network of any size and hence justifies its efficacy or scalability towards the dense network as well.

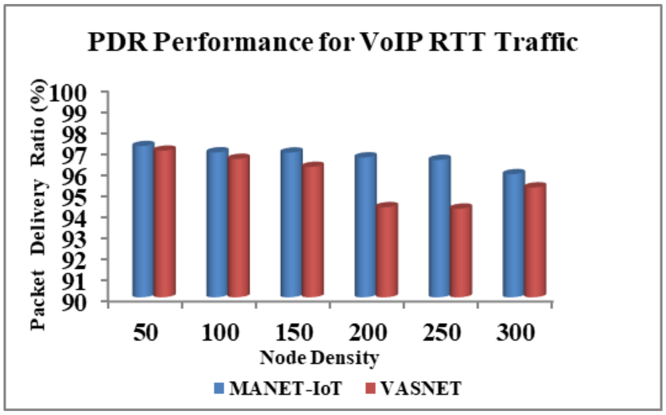

Figure 5 PDR for the Proposed QLMCR-MVOIP RTT Traffic Over the Different Node Densities

For VASNET it shows the PDR of 96.98%, 96.59%, 96.21%, 94.29%, 94.22% and 95.235 for the node densities of 50, 100, 150, 200, 250 and 300 nodes, respectively. It confirms the robustness of the proposed model towards real-time vehicular communication which can undergo abrupt node density change and hence resulting node parameters or network conditions like congestion, delay etc.

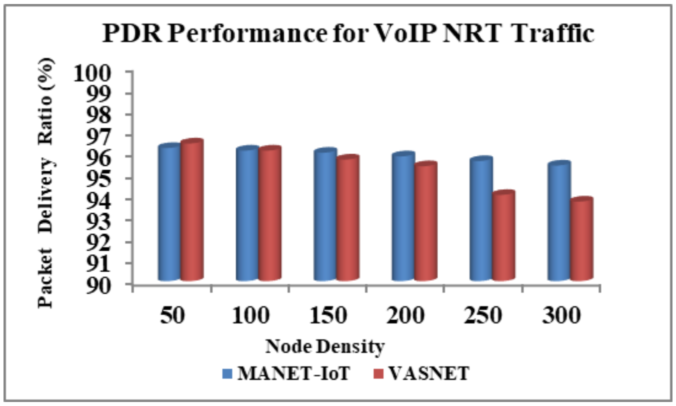

Figure 6 PDR for the Proposed QLMCR-MVOIP NRT Traffic Over the Different Node Densities

The PLR performance as well (Table 7 and Figure. 7 and Figure. 8) confirms that the proposed QLMCR-MVoIP protocol exhibits PLR of 3.49% and 4.39% for VoIP RTT over the deployed MANET-IoT and VASNET, respectively. Similarly, it shows the average PLR (%) of 4.14% and 4.78% in MANET-IoT and VASNET, respectively for the NRT traffic.

Our proposed QLMCR-MVoIP protocol exhibited superior performance (PDR=96.66%) over the existing method [56] that could achieve the highest PDR of 90%. Here, the role of multi-constraint BFN selection and routing can't be ruled-out.

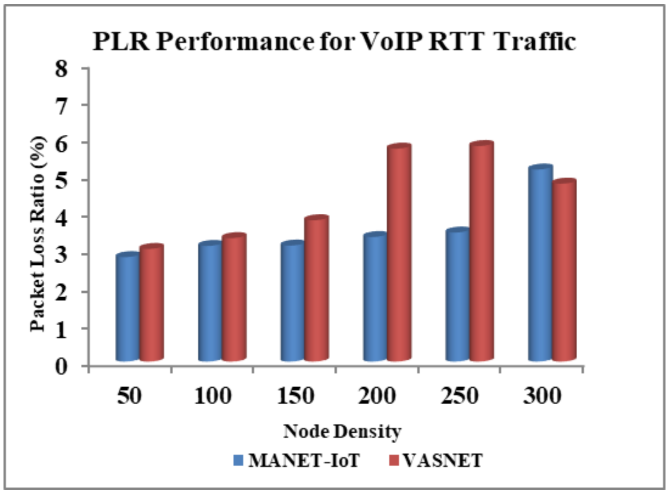

Figure 7 PLR for the Proposed QLMCR-MVOIP RTT Traffic Over the Different Node Densities

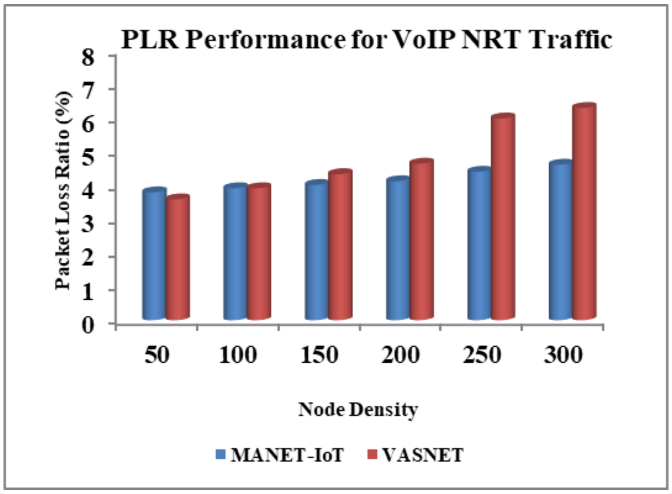

Figure 8 PLR for the Proposed QLMCR-MVOIP NRT Traffic Over the Different Node Densities

Table 8 Average PDR Performance of Proposed QLMCR-MVOIP Over the Different Network Conditions

Network Conditions	PDR (%)			
	VoIP RTT		NRT	
	MANET-IoT	VASNET	MANET-IoT	VASNET
Payload	96.66	95.32	96.24	95.57
Density	96.67	95.58	95.39	93.71

Table 9 Average PLR Performance of Proposed QLMCR-MVOIP Over the Different Network Conditions

Network Conditions	PLR (%)			
	VoIP RTT		NRT	
	MANET-IoT	VASNET	MANET-IoT	VASNET
Payload	3.32	4.67	3.75	4.43
Density	3.49	4.39	4.14	6.29

Though, in our previous work [57] where we designed an improved OLSR protocol that resulted PDR of almost 98%, it lacked numerous abilities such as multi-constraints BFN selection and particularly the dynamic resource allocation and queuing for VoIP RTT and NRT traffics, distinctly. Despite the average PDR of 96.66%, the proposed QLMCR-MVoIP protocol seems superior over the existing cross-layer routing model [57]. The overall results (Table 8 and Table 9) signify that the proposed model can be efficient to serve QoS and reliable data transmission over both dense networks as well as with dynamic payload conditions. It makes QLMCR-MVoIP suitable to achieve QoS expectation in the targeted VoIP application or allied services over MANET-based hybrid networks like MANET-IoT or VASNET. Observing the results for VoIP RTT and NRT traffic (Table 8) it can be found that the proposed routing protocol retains almost similar performance in both data types. This could be possible only due to the dual-buffer mechanism with VA-SDARA resource allocation strategy. Though, the role of multi-constraints BFN selection measure enabled reliable data transmission for both VoIP RTT as well as NRT traffic, which achieved optimal efficacy in all network conditions.

5. CONCLUSION

Realizing the previous inferences that despite significance SIP being centralized protocol can't be applied with MANETs directly, and hence requires certain more efficient routing protocol to enable scalable VoIP applications. On the contrary, dynamic topology, link-outage probability, congestion, delay etc. can impact overall QoS performance in MANET-based VoIP applications. To alleviate such issues and enable QoS/QoE assurance, MANET-IoT network requires robust routing with optimally crafted VoIP sensitive resource allocation strategy. Considering it as motivation, in this work a robust and novel "Cross-Layer Information Driven Multi-Constraints Protocol is proposed for QoS-Centric VoIP Services in MANETs-enabled hybrid networks (QLMCR-MVoIP). It hypothesized that unlike standalone parameter-based routing protocol, the use of multiple node parameters altogether can enable optimal best forwarding node (BFN) and hence best forwarding path for QoS communication. To enable QoS, QLMCR-MVoIP applies cross-layer information including VoIP traffic information from the application layer, packet velocity and congestion probability from the Medium Access Control (MAC) layer, adaptive link quality from the link layer and on-hop distant topology information from the network layer to perform BFN selection for QoS-adaptive transmission. QLMCR-MVoIP applies a dual-buffer and VoIP adaptive service differentiation and adaptive resource allocation (VA-SDARA) process that guarantees optimal resource allocation to the nodes for QoS/QoE provision. It guaranteed optimal resource allocation to the VoIP RTT traffic while maintaining maximum possible resource for the NRT traffic during 100% resource consumption conditions. The simulation results and allied inferences confirmed that the proposed QLMCR-MVoIP protocol achieves average PDR of 96.66% and 95.45% for VoIP RTT traffic in MANET-IoT and VASNET networks. Similarly, it performs PDR of 95.81% and 94.64% for NRT traffic in MANET-IoT and VASNET network, respectively under the different operating conditions. Similarly, it achieved average PLR of 3.40%, 4.53% for MANET-IoT and VASNET networks, correspondingly for VoIP RTT transmission. Though, for NRT traffic it exhibited the average PLR of 3.94% and 5.36% in MANET-IoT and VASNET networks, correspondingly. The results confirm robustness of the proposed routing protocol towards VoIP applications and allied QoS assurance in MANET-based hybrid networks like MANET-IoT and VASNET.

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