Cross Layer Architecture Based QoS Centric Routing Protocol for Mission-Critical Communication in MANET

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Abstract - The exponential rise in mobile wireless communication demands and associated Quality of Service (QoS) provision has alarmed academia-industries to achieve highly efficient and reliable communication system. Mobile Adhoc Networks (MANETs) being one of the dominating wireless communication system possesses significant potential to meet major communication demands; however exceedingly high topological changes and network condition imposes numerous complexities including link-vulnerability, congestion etc. With motivation to exploit network condition aware routing model, this paper proposes a robust and efficient cross layer architecture based QoS centric routing protocol for mission critical communication over MANETs (CLA-QRPM). Unlike classical routing approaches CLA-QRPM protocol exploits three key layers of the IEEE 802.11 protocol stack, Application layer, Network layer and MAC layer. The CLA-QRPM routing protocol functions Proactive Network and node Table Management, Service Differentiation and Fair Resource Scheduling and congestion detection and avoidance at the Network layer, Dynamic Link Quality Estimation and Packet Injection Rate estimation at MAC layer. In addition, based on application specific environment service differentiation can be performed at Application layer as well. Considering dynamic network condition and topological variations our proposed CLA-QPRM routing protocol applies Dynamic Link Quality, Packet Injection Rate or velocity and Current Congestion probability at a node to characterize its suitability to become best forwarding node. Identifying the best forwarding node, CLA-QRPM model constitutes best forwarding path to ensure reliable, QoS centric and delay resilient transmission for mission critical communication over MANETs. Simulation reveals that the proposed routing model exhibits higher throughput, minimum loss and deadline miss ratio that augments QoS provision in MANETs.

Index terms - *Cross-layer routing protocol; MANET, Quality of Service; Mission Critical Communication*

1 INTRODUCTION

DEVELOPMENT of the communication systems, primarily the wireless networks have grown exponentially to meet increasing data transmission and communication demands. Since last few years high pace rise in wireless communication systems has been witnessed globally that requires fulfilling optimal performance and Quality of Service (QoS) provision to the end users. It has motivated academia-industries to explore and achieve more efficient and robust routing solution to support reliable data communication. Amongst major wireless communication technologies, Mobile Ad-hoc Networks (MANETs) have gained immense attention whose decentralized, and infrastructure-less natures open up a broad horizon for employability.

MANETs, serve major communication systems by deploying mobile nodes randomly across the network region that as a result increases topological variation, network condition changes etc.MANETs is one of the dominant wireless communication systems which are serving communication demands by incorporating sensor or node mobility in ad-hoc manner. Randomly deployed mobile nodes constitute MANETs, which are dynamic in nature while avoiding any complicated infrastructure. This as a result reduces set-up time as well as overall latency, hence serves QoS centric demands. However, its inherent characteristics such as node mobility and resulting topological variations impose network uncertainty and link outage probability. Some or even all nodes of MANETs can work as a router to enable communication between two hosts in typical communication environments by incorporating multi-hop transmission and/or routing. In last few years the high pace rise in Internet of Things (IoTs) ecosystems and allied applications has exploited MANETs to serve numerous

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applications foe which enabling reliable and deadline sensitive transmission is must [1][2][31][32]. Functionally, MANETs constitutes of various devices like mobile phones, laptops, pocket-computers with wireless connectivity. Being decentralized and infrastructure less network, topological changes are inevitable that as a result makes QoS centric and reliable transmission difficult. Typically, the dynamic network topology imposes network to undergo parameter changes like, link quality variation over run or simulation period, increased link outage probability, node resource (i.e., bandwidth and energy) availability and packet rate, which is also called injection ratio. Such network dynamism in MANETs frequently affects reliability of the data transmission and QoS assurance. Even without accommodating fixed infrastructure such as additional access points or base stations in all the comprising nodes of MANETs along with maintaining cooperative network connectivity, mobility affects node characteristics and overall transmission efficiency. Each node in MANETs contains a well-defined routing protocol to perform data communication or forwarding to the next hop nodes to let data reach its destination. Under mobility if two nodes are in radio range, they can directly communicate with each other, else opts multi-hop transmission by forwarding its data to the next hop node so as to ensure timely and reliable data transmission. Noticeably, in major application environments MANETs are used to provide emergency or mission critical communication that requires timely (say deadline sensitive or delay resilient) data delivery and reliable transmission. To meet these demands, MANETs require enabling an optimal and robust routing model for which Best Forwarding Node (BFN) selection can be of utmost significance.

A typical communication system can have both real-time data (RTD) as well as Non-Real-Time (NRT) data. Undeniably, exploring in depth it can be found that MANETs require facilitating optimal and QoS centric communication for event-driven data which is typically the RTD. Identifying RTD amongst other data stream, including Non-Real time data (NRT) can be vital to assist QoS provision. However, fulfilling QoS provision by providing mission critical RTD with best possible NRT transmission can be of utmost significance. To achieve it the knowledge of data type and respective priority can be significant which could be availed through service differentiation model at the application layer of the protocol stack. In fact, to assure reliable and suitable data delivery, it is must to make best possible control decisions by identifying the data types and adding proper resources or transmission precedence. The use of enhanced Service Differentiation (SD) can enable data type (i.e., RTD, NRT) classification that can help assigning optimal resources for QoS assurance over MANET. SD can help identifying type of data under process that eventually could help MAC layer and Network layer to perform optimal resource scheduling [2-5]. Similarly, identifying packet velocity at a node can assist PHY layer to control power management and link-adaptive transmission [4]. Similarly, congestion probability and link quality estimation at a node can help MAC to select a node with suitable network characteristics to support reliable data transmission. Achieving the key network parameters such as link quality, congestion, resource availability, packet velocity etc and synchronizing it across the different layers of the IEEE 802.11 protocol stack can ensure optimal BFN selection to support reliable data transmission and hence QoS provision over MANET. On contrary, these parameters are obtained at different layers of the IEEE 802.11 protocol stack and hence sharing this information across the layers can be vital to perform BFN decision. To achieve it, employing Cross-layer architecture can be of utmost significance [2][3][20][21][28] [30-34]. Considering QoS oriented communication over MANETs, primarily event-driven data transmission, it is inevitable to ensure high Packet Delivery Ratio (PDR), higher throughput, minimum packet drop, low latency and end-to-end delay, and maximum possible resource (i.e., bandwidth) utilization [5]. In practice, enabling optimal route decision or forwarding path selection can be of great significance. Primarily, under mobile topological condition where there is significantly high topological variation estimating BFN is highly tedious. In addition, applying key node information to characterize suitability of a node to become BFN can also play vital role in QoS centric communication. Performing BFN selection under mobility maintaining efficient node table, network and node parameter state information is must. Identifying optimal network parameters such as inter-node link quality, buffer availability at a node, congestion probability, residual energy, etc for a node can characterize a node to become BFN under dynamic topology [5] [30-34]. It motivates authors to develop a highly robust and efficient cross-layer architecture-based routing protocol for mission critical communication over MANET. Being highly dynamic network proactive network management scheme could assist dynamic node parameter update, which could be exploited at the different layers of the protocol stack to perform optimal BFN selection. Hypothetically, we assume that the selection of BFN based on multiple parameters such as its buffer capacity, packet velocity, link quality, distance etc can ensure optimal forwarding link formation that eventually will ensure reliable data transmission with minimum data drop probability (due to minimum or negligible link outage probability), minimum deadline miss ratio, minimum latency etc. Interestingly, the proposed routing protocol intends to develop a highly robust resource scheduling scheme that could ensure optimal resource provision to the event driven RTD data, while ensuring maximum possible resources to the NRT data. It would be vital to balance QoS provision for both RTD as well as NRT data types. With the above stated motivation, in this paper highly robust cross layer architecture based QoS centric routing protocol has been developed for MANET. Unlike classical cross layer models, our proposed routing protocol applies an enhanced SD model, proactive network management, congestion detection and routing decision model at the link layer, dynamic link quality and packet injection rate (i.e., packet velocity) estimation at the MAC layer, and Power Switching at the PHY layer of the IEEE 802.11 protocol stack. MATLAB simulation of the proposed cross-layer routing protocol has exhibited higher throughput and minimum packet loss while ensuring minimum deadline miss ratio. It signifies the robustness of our proposed QoS centric MANET routing protocol for mission critical communication.

The other sections of the presented manuscript are divided as follows. Section II discusses the related work, while the proposed routing model and its implementation are presented in Section III. Section IV discusses the results obtained, which is followed by the conclusion and future scopes in Section V. References used in this study are presented at the end of the manuscript.

2 RELATED WORK

Ad-hoc network being a decentralized and infrastructure less network provides wireless communication by means of the radio propagation in air. Typically, it functions as a router and provides data transmission between adjacent nodes by applying multi-hop routing. MANET is a type of communication in radio networks, in which network coverage area is larger than radio range of single nodes, and hence to reach a defined destination a node can use other nodes as relays. Traversal over multiple hops often impacts the overall latency, energy consumption and QoS condition. On the other hand, mobility in MANET causes significantly high link vulnerability that puts question over the reliability of the service delivery. Under such conditions QoS provision often remains a challenging task for academia-industries. On contrary, in last few years the robustness of MANETs has enabled it as a potential wireless communication solution for which numerous efforts have been made. Amongst potential approaches efforts like routing optimization at various layers of the protocol stack [6-8] have exhibited satisfactory outcome. In recent literatures, authors [6-8] emphasized on achieving timely and reliable data communication to achieve QoS provision. Authors [9] suggested to implemented retransmission and replication approaches to achieve QoS delivery; however, retransmission is time consuming and replication leads to inefficient resource consumption or bandwidth utilization. This as a result violates the principle of QoS assurance. To alleviate such issues, authors [10][11] suggested multipath transmission that as a result could reduce probability of congestion and data drop in case of insufficient or improper link condition. However, such approaches could impose computational cost as well as energy consumption. Considering energy efficient routing, link quality based multipath transmission a protocol was developed in [10]. To achieve it authors applied connectivity graph assisted routing decision model which exploited minimum hop counts and maximum link quality as network parameters to form connectivity graph. Authors in [11] developed a routing protocol named Sequential Assignment Routing (SAR) to constitute multiple paths between source and destination. To achieve it, they formed multiple trees where the root of the individual tree was a one-hop neighbor. In this way, the root with the highest residual energy was selected as the BFN. In addition, to ensure reliable communication authors considered energy of each path and data priority to perform QoS centric routing. In other literature [12] end-to-end delay of each possible path and each participating node's residual energy were selected to optimize throughput for best effort data traffic. However, to ensure higher priority to RTD data, they assumed to have a classifier that classifies traffic into RTD and NRT types. To meet up QoS goals in MANET, authors considered bandwidth reservation policy and node-entropy parameter as the route decision variable. To augment network lifetime and optimize buffer authors [13] considered constrained buffer-based MANET. During dynamic transmission, they suggested to incorporate the concept of Markov chain that enables feasible and input rate-dependent throughput and packet loss ratio achievement. Authors applied M/G/1/K queuing concept, end-to-end delay to assess the impact of deadline time (packet's end-to-end delay) and buffer size on network throughput, delay and packet loss. To ensure one-to-many node communication over MANETs, authors [14] developed a multicast routing protocol that applied multiple multicast trees in which the individual multicast tree can meet a predefined bandwidth demands to ensure reliable transmission. Here the use of network coding enabled resource conservation and reliable transmission over MANETs. To address mobility in MANETs, author [15] applied kNN query processing concept that enables efficient query classification. Similar research has done in [16] where Filling Area (FA) concept was applied to process kNN queries that assured low overhead and minimal search space. Different node parameters such as delay, and bandwidth occupancy were assessed dynamically over MANET routing. In [27] authors concentrated on energy conservation in MANET by applying energy consumption as objective function of Ad Hoc on Demand Multipath Distance Vector (AOMDV) routing protocol. They applied a fitness function value to achieve the best path from source node to destination node for minimum energy consumption over multipath routing. Knowing dynamic topology of MANETs, authors [17] found energy replacement infeasible and hence proposed clustering based model. Authors suggested the use of Genetic Algorithm (GA) for CH selection, where a node with maximum reliability or network rank was considered as objective function to select CH. In [18] AODV/DSR protocol was developed in which AODV established a route to the destination only on demand. In [23] a weight-based clustering approach was suggested that exploited the cumulative weight metric obtained for different parameters such as inter-node distance, radio range of the node and residual energy to perform CH selection and routing.

MANETs being a dynamic topology based outing model require awareness of all network parameters that as a result could help in making optimal routing decision. To achieve it developing cross layer model can be of utmost significance [19]. Considering efficacy of cross-layer model authors [20] developed a QoS centric routing approach which was augmented with real time scheduling at the network layer with augmented Rate Monotonic Algorithm (RMA) and Earliest Deadline First (EDF) scheme. In [21] to develop a cross layer model network parameters such as node density and MAC queue were used to make sure channel state awareness that helped in QoS centric routing decision. A cross layer routing protocol was developed in [22] where authors developed underlay model at the network layer of IEEE 802.11 standard. To minimize the issue of flooding overhead they developed a cross-layered location restricted energy efficient routing approach that supported optimal end-to-end guarantee at the transport layer. A cross layer model was developed in [22] where at the network layer underlay model was developed based on the protocol stack IEEE standard 802.11. To minimize the issue of flooding overhead authors proposed a cross-layered location restricted energy efficient routing approach. This approach ensured optimal end-to-end guarantee at the transport layer. Later on, author [23] proposed a design of cross-layer framework between application and MAC and between MAC and transport layer. A joint optimization model was developed in [24] which were applied in between MAC layer and the application layer of IEEE 802.11 protocol stack that enabled mapping of video frames on the basis of its priority and network traffic load. To augment QoS provision and reliable communication, authors [24] developed a multipath DSR-based routing protocol. Authors applied a load balancing model that reduced end-to-end delay and data drop probability. In [25] cross-layer architecture-based MANET routing protocol named ViStA-XL was developed to assist efficient video-streaming services. In their proposed model a real-time XL Optimizer (XLO) was incorporated to gather node information and network status information from the different layers of the protocol stack. To reduce error between received and transmitted video, XLO exhibited dynamic decision for the different layers of the protocol stack. A cross layer model DEL-CMAC was developed for distributed energy-adaptive location-based CMAC protocol named DEL-CMAC for MANET, authors [27] exploited cross-layer design concept. Authors [26] developed QoS centric routing model. A Hierarchical Cross Layer Optimization Protocol (HCLP) was developed in [28] that focused primarily on achieving high resource utilization, minimum delay and minimum jitter in MANET. In [19], a cross-layer routing model was developed, where once assigning application authors estimated cost of each path in between source and the sink.

Assessing the above discussed models, it can be found that though cross-layer architecture can enable QoS and reliable communication over MANET, very fewer efforts have been made. In spite of using single layer model with one or two network parameters, the inclusion of multiple layers and real time network parameters estimation, say network condition aware routing can be vital to deal with mobility over MANET and ensure reliable communication.

3 Problem Formulation

As discussed in the previous sections, MANETs require optimal routing mechanism to assure reliable data transmission across the network while fulfilling timely data delivery, minimum retransmission probability and energy consumption. In addition, network condition aware routing decision and data sensitive resource allocation can be vital to achieve QoS delivery in MANET. This research work emphasizes on exploiting all possible network awareness features to exhibit synchronized routing decision. To ensure QoS provision and reliable data communication over MANETs enabling optimal forwarding path selection is of vital. Predominantly under dynamic topology conditions, there can be exceedingly high topological variation that as a result could force network to undergo high transition and node as well as network's parameter changes. Under such conditions performing optimal BFN selection is highly intricate task. While performing BFN selection under such conditions, maintaining efficient (network) information is must that as a result could help in enabling optimal proactive routing decision. BFN plays an important role in QoS centric and reliable transmission over MANET. To achieve it here we assume that each deployed node has node information about one-hop distant node. Here, to deal with dynamic topology proactive node management and routing protocol has been proposed. Being dynamic network, proactive node management strategy could be applied that could assist network and/or node parameter estimation dynamically to help appropriate BFN selection process. In our proposed routing protocol, each node possesses routing protocol that assists it to have node information from the different layers of the protocol stack. Considering QoS objectives, our proposed model exploits dynamic link quality, congestion probability at node, buffer availability, packet velocity, packet injection rate or velocity etc. These parameters can be applied to examine suitability of a node to become BFN for reliable data transmission. On the other hand, the selection of the BFN primarily depends on multiple parameters like buffer capacity, packet injection rate, link quality, etc; our proposed cross layer model intends to exploit these parameters from the different layers of the IEEE 802.11 protocol stack. Our proposed routing protocol exploits those parameters from the different layers and makes optimal BFN selection that enables reliable data transmission with minimum data drop probability, maximum possible throughput, minimum deadline miss ratio, optimal and fair resource utilization, and minimum latency. In addition, considering mission critical communication purposes where enabling timely data delivery is of utmost significance in this research paper a novel service differentiation and fair resource scheduling model is developed. The proposed SD model can perform data classification as RTD and NRT which has been further augmented with a novel QoS centric fair resource allocation strategy.

To enable QoS centric communication, sharing and applying dynamic network parameters from different layers of the protocol stack can help in making efficient routing decision. For illustration, our proposed routing model applied SD scheme which could at first identify the type of data characterizing its significance for QoS provision. Such classification might help MAC layer and Network layer to perform resource allocation and management. Similarly, identifying a node with minimum buffer time and maximum packet velocity can assist physical layer to execute optimal dynamic power management (DPM) and multi-rate switching control (MRSC). To assure reliable data transmission applying a node and path with sufficient buffer and congestion free path is must. Thus, estimating congestion probability and link quality of a node can help MAC layer of IEEE 802.11 protocol stack to avoid the node with low buffer availability and congestion probability. It could avoid link outage and data drop probability. With this motivation, in this paper these parameters have been retrieved from the different layers of the protocol stack and are shared across the layers to make optimal routing decision. With this motivation, in this paper a highly robust and efficient Cross layer Architecture based QoS centric Routing Protocol for MANET (CLA-QRPM) has been developed. A snippet of the proposed cross-layer architecture is given in Fig. 1. Our proposed routing protocol exploits Network layer, and MAC layer of the IEEE 802.11 protocol stack. At the network layer our proposed CLA-QRPM protocol exhibits Service Differentiation and Fair Resource Scheduling (SDFRS), Dynamic Congestion Detection (DCD) and Proactive Network/Node table management. Similarly, at the MAC layer of IEEE 802.11 standard, packet injection rate of velocity (per node) has been estimated along with the dynamic link quality estimation. Since, enabling efficient DPM and MRSC mechanism could help making optimal resource utilization and timely data delivery, certain physical switching or dynamic power management (DPM) model can be developed. Thus, achieving different network parameters and synchronizing it across the layers can help CLA-QRPM to make optimal routing decision to achieve higher throughput, minimum packet loss probability, minimum link outage probability, latency and or deadline miss ratio etc. The detailed discussion of the proposed routing model, i.e., CLA-QRPM is given in ascending section.

4 CLA-QRPM

This section primarily discusses the key functions and respective implementation of the proposed routing protocol (i.e., CLA-QRPM). As stated in Fig. 1, CLA-QRPM primarily exploits the application, network, and MAC layer of the IEEE 802.11 protocol stack. As an optimal routing decision model our proposed CLA-QRPM protocol intends to employ key real time network parameters like load type, congestion probability or congestion at a node, buffer availability at a node, packet's deadline time, packet injection rate at a node or packet velocity, dynamic link quality. To achieve these parameters and enable optimal BFN selection in MANETs, CLA-QRPM model applies different functions at the different layers. The key functions of the proposed CLA-QRPM routing protocol is given as follows:

4.1 Proactive Network Table Management
4.2 Service Differentiation and Fair Resource Allocation
4.3 Congestion Detection and Avoidance Model
4.4 Dynamic Link Quality Measurement
4.5 Packet Velocity Measurement
4.6 Cumulative Rank Matrix Estimation and Best Forwarding Path Selection

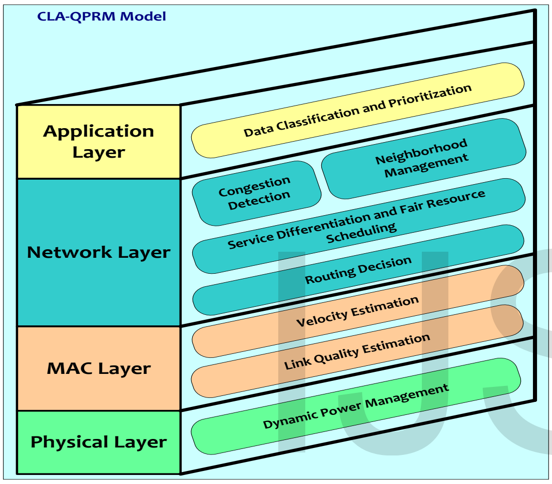

Fig. 1. Proposed Cross layer Architecture for QoS centric Routing Protocol for MANETs (CLA-QRPM)

A brief of the proposed CLA-QRPM routing protocol is given as follows:

4.1 Pro-active Network Table Management

As already discussed, due to mobility in MANETS there is exceedingly high topological changes and transient network parameter variations. Under such conditions performing routing decision based on stale information or outdated network parameters might lead link outage and hence data loss. Typically, nodes in classical MANETs are having defined parameters such as energy capacity, maximum buffer capacity, radio range etc, and hence under dynamic topology the key parameters such as link connectivity and buffer availability may change over run-period. Such parametric changes might even be affected due to varying payload conditions, varying signal to noise ratio or link connectivity changes, etc. There can be the situation when a node might hold the forwarding data for a long time that as a result could stop data to reach within defined deadline time. Meanwhile, over varying topological conditions, a node might undergo buffer deficiency and hence may require additional buffer to ensure reliable data transfer. Similarly, over simulation period in MANET inter-node distance might vary and hence link connectivity would also change. In such conditions static or pre-defined parameters-based routing decision could lead link outage. Due to large variations in network parameters, updating these parameters pro-actively is unavoidable. In other words, to cope up with the dynamic topology MANETs require robust proactive network management and node tables update strategy. With this motivation in this paper CLA-QPRM protocol applies proactive network and node table management that enables dynamic network or/and node parameter update to assist reliable BFN selection and routing decision process. In addition, it avoids continuous node discovery phase that reduces signaling overheads and energy consumption. In our proposed routing approach, node parameter is updated dynamically that enables swift routing decision. Here, each node maintains a single-hop neighboring node details by transmitting a beacon message. Here, the transmission message comprises significant node information, along with its characteristics such as the NodeID, highest buffer capacity, current (available) buffer status, node position, packet holding period, current packet velocity, dynamic or current link quality, etc. In our proposed Proactive node table management strategy the key network parameters stored are, NodeID, node position, current link quality, inter-node distance, packet velocity etc; however since parameters like packet injection rate or velocity can be estimated mathematically (discussed later) hence we have considered only three parameters NodeID, node position, current link quality to be communicated through beacon message or ACK. It reduced computational cost as well as memory consumption. Here, each control packet is of 42 bytes, which is split into three fields; NodeID (16 bits), Current node status (192 bits to store link quality, current buffer availability) and node position field (128 bits). In our proposed routing protocol once transmitting beacon message each node collects on-hop neighboring (node) information which is updated continuously. One of the key issues in MANET is packet collision during transmission and therefore to avoid it node multicasts beacon message that operates in coordination with an offset timer. In our proposed CLA-QRPM routing protocol offset timer is decided on the basis of a normal homogeneous distribution approach. Once receiving any request for packet transmission, node resets its offset timer. Here, a node present at one-hop updates the nearest destination in the table. Let $\mathrm{N_j}$ be the one-hop distant neighbor and $\mathrm{BFN_i}$ be the potential or most suitable forwarding node. Mathematically the node table is updated using Eq. (1), where $\mathrm{Eucl_F}$ and $\mathrm{Eucl_d}$ signify the Euclidean distance in between the best forwarding node and the source node to the nearest destination.

$$\mathbb{N}_{Table} = \{BFN_i \in \mathbb{N}_j | Eucl_d - Eucl_F \geq 0\} \qquad (1)$$

4.2 Service Differentiation and Fair Resource Scheduling (SDFRS)

To ensure QoS centric communication, data awareness and associated resource scheduling play decisive role. There are numerous application environment where providing sufficient resources (i.e., buffer) for successful or QoS centric transmission is must. In MANETs there can be different data types to be communicated including RTD as well as NRT data. Primarily, providing sufficient buffer or bandwidth for RTD data is must; however, maintaining an optimal resource provision to NRT data types can be of utmost significance. With this motivation in our proposed CLA-QRPM routing protocol both RTD as well as NRT data have been considered. Here we assume to have a data classifier such as EARS [35] that could classify data into two broad types, RTD and NRT. Once identifying or classifying the data, CLA-QRPM intends to perform efficient resource allocation to each data types while maintaining optimal resource provision to RTD data with maximum possible resources for NRT data types. To achieve it in our proposed CLA-QRPM protocol, each node is assigned two distinct types of buffer, each for RTD as well as NRT data types. Here, each buffer possesses equal buffer capacity. In CLA-QRPM model in case a node undergoes complete buffer consumption for RTD data and requires additional buffer for successful transmission, then it can borrow the supplementary buffer from the NRT buffer where the data are stored in normal First-In-First-Out (FIFO) manner. MANET being a dynamic topology network might undergo congestion and a situation where both RTD as well as NRT buffers are filled in that case CLA-QRPM routing protocol applies a novel fair resource scheduling approach (i.e., SDFRS), in which to meet the demand of buffer for RTD data, NRT drops a recently added data in FIFO queue. Though, the data elements are stored in FIFI manner dropping a few elements which are connected recently can't affect overall performance significantly. On contrary, in major classical approaches to provide additional buffer for RTD, buffer for NRT is cleared or emptied complexly that violates QoS principle for cumulative network performance. On contrary, our proposed routing protocol enables optimal resource provision to the RTD while ensuring maximum possible resource to the NRT that balances tradeoff of resource utilization to assure QoS provision. This mechanism avoids high waiting time or holding period at a node that eventually augments overall performance of the network.

4.3 Congestion Detection and Avoidance Model

Undeniably, during transmission over MANETs, there would always be the probability of data flow that as a result may impose congestion on a node. The probability of congestion gets increased many folds during mobile topology that as a result increases probability of packet drop and retransmission causing QoS violation and energy exhaustion. To deal with this problem authors have recommended timer-based transmission. In this mechanism, each node can transmit beacon message to the multiple nodes in the network whose frequency could be controlled through a predefined timer called offset timer. Once receiving any transmission request, CLA-QRPM at first resets allied timer that avoids ACK from the node. It makes our proposed system computational efficient and reduces signaling overheads. In addition, CLA-QRPM avoids storage of any path significant path or node's information. Due to dynamic topology condition a node may receive more payload request to carry relative to its maximum carrying capacity, and undeniably over simulation period buffer availability may vary thus increasing probability of congestion. It often results into data drop and retransmission causing huge energy exhaustion. To alleviate this problem, CLA-QRPM model implements a robust Congestion Detection and Avoidance Model (CDAM) that continuously assesses dynamic buffer capacity and the remaining buffer availability of node to detect congestion. Our proposed CDAM model exploits the maximum buffer capacity of a node and the current buffer availability to assess congestion probability at a node in MANET. Once transmitting beacon message, a node can retrieve the resource availability (i.e., buffer availability) of a one-hop distant node. Though to ensure QoS provision and reliable transmission a node with sufficient buffer availability can be efficient. With this motive, once identifying a node with the lower buffer availability as compared to the expected or required memory for data transmission, CDAM avoids that node to assist CLA_QRPM based BFN selection. Only a node with sufficient buffer availability and congestion free status is selected for BFN formation. It reduces any likelihood of data drop, retransmission, end-to-end delay and energy consumption that augments QoS assurance in MANETs. In addition, our proposed CLA-QRPM model functions in conjunction with above stated SDFRS model that applies two distinct buffers for RTD and NRT data each node that helps in better resource management and congestion avoidance. As already discussed in SDFRS model the RTD type data is stored in a prioritized manner while NRT data is stored in FIFO manner. Since, in real time application each packet possesses defined deadline time and hence requires data to reach within the deadline time to make optimal decision. CLA-QRPM model facilitates higher priority to the RTD data while enabling maximum possible resource to the NRT data. In our model to ensure delay resilient communication RTD transmission is scheduled as per respective deadline time. To achieve this objective, CLA-QRPM considers distance between the source sensor node and the sink. Noticeably, to facilitate the highest possible priority for event driven RTD delivery over MANET it is inevitable to have minimum value of $\mathcal{T}_{Ratio}$, given in Eq. (2).

$$\mathcal{T}_{Ratio} = \frac{\mathcal{T}_{d\_i}}{d_i^j} \qquad (2)$$

where $\mathcal{T}_{d\_i}$ signifies the residual deadline time, while other parameter d_i^j states the Euclidian distance between the forwarding node i and the nearest sink j. Here, the deadline time is estimated by using the arrival time of the individual packet. $\mathcal{T}_{d\_i}$ is updated for each packet before transmitting and the queue time is subtracted from $\mathcal{T}_{d\_i}$. Here, we use current buffer availability information to estimate the congestion probability at MANET's node. In addition, CLA-QRPM model introduces a parameter called Node Congestion Index (NCI) which comprises node information along with its association with neighboring node subset $\mathbb{S}_n$. We estimate NCI using Eq. (3) where $\mathrm{CNI}_{\mathrm{NRTMem}}$ and $\mathrm{CNI}_{\mathrm{RTDMem}}$ signify the memory available in NRT related normal FIFO queue and the RTD related buffer in prioritized queue, correspondingly. $\mathrm{CNI}_{\mathrm{RTDMax}}$ and

$\mathrm{CNI}_{\mathrm{NRTMemMax}}$ and signify the highest memory or buffer capacity of the RTD and the NRT data. Thus, the overall CNI for connecting nodes in $\mathbb{S}_{\mathrm{n}}$ can be obtained as

$$CNI_r = \frac{CNI_{NRTMem} + CNI_{RTDMem}}{CNI_{NRTMemMax} + CNI_{RTDMax}} + \sum_{i=1}^{\mathrm{N}} CNI_{ri} \quad (3)$$

Estimating the memory or the buffer availability of each node and allied congestion probability, the routing model decides applicability of that node to become forwarding node. A node with congestion free and sufficient buffer availability is considered for forwarding node and or path selection. This can assure reliable data transmission over MANETs with least possibility of data drop and overflow. In addition, it avoids the problem of packet collision.

4.4 Link Quality Measurement

To ensure QoS provision for MANETs, it is needed to assess the link quality of the participating nodes dynamically that could characterize the suitability of a node for becoming best forwarding node. Mobility in MANET could impose topological changes and hence inter-node distance variation. Undeniably due to fixed radio range the dynamism might cause link quality variation based on inter-node distance. In such conditions, assessing link quality dynamically to decide its suitability for reliable forwarding path selection can be vital. In this paper, CLA-QRPM model applies a proficient dynamic link quality estimation model at the MAC layer of the IEEE 802.11 protocol stack. The detail of the dynamic link quality estimation model can be found in [34]. In our proposed model CLA-QPRM model applies current packer received ratio to estimate link quality. Mathematically the applied dynamic link quality assessment model is presented using (4).

$$\eta = \alpha * \eta + (1-\alpha) * \left(\frac{\mathrm{N}_{rx}}{\mathrm{N}_{tx}}\right) \quad (4)$$

In Eq. (4), η presents the dynamic link quality. The packet received ratio provides the efficiency of the communication link. The other parameters N_{rx} and N_{tx} provides the total number of received packets and the transmitted packets, respectively. Here, α remains in the range of 0 to 1. Our proposed CLA-QRPM routing protocol identifies a node with maximum link quality to form BFN and forwarding path. It strengthens proposed routing protocol to ensure reliable data transmission through the formed path in MANET.

4.5 Packet Injection Rate Estimation

MANET which has gained significant attention across academia-industries to perform networking support in numerous mission critical applications where timely data delivery is must. In such applications selecting a node and hence path with each-node minimum holding period can be vital to reduce latency or end-to-end delay that eventually supports QoS provision. In our proposed CLA-QRPM routing protocol we estimate packet injection rate or holding period of a node that signifies the time to which a node holds data before forwarding. A node with the minimum holding period or the maximum packet velocity or injection rate is considered for selecting BFN. Here, we have applied packet delay parameter to estimate packet velocity at each node in the MANET. In CLA-QRPM model packet delay is applied to estimate inter-node distance between neighboring node and the nearest destination. CLA-QRPM routing protocol applies Euclidian distance and relative distance, round trip time ($\mathrm{ARTT}_{\mathrm{Ti}}$) etc to estimate packet velocity. In our model, the Euclidian distance is obtained in between source and the nearest destination, while the relative distance is obtained in between the neighboring node and the nearest destination. In addition, the average round trip time and the speed of radio signal in air. Mathematically, a speed factor $\mathbb{V}_t$ is obtained using Eq. (5).

$$\mathbb{V}_t = \left(\frac{\mathbb{D}_{ESD}^{i} - \mathbb{D}_{ENS}^{i}}{ARTT_{Ti}}\right) \quad (5)$$

Now, applying Eq. (5), we have estimated the packet velocity ($\mathbb{V}_{\mathrm{packet}}$), using Eq. (6). Here, $\mathbb{V}_{\mathrm{packet}}$ signifies the highest rate of data transmission at a given transmission power $(\mathbb{P}\mathrm{tx})$.

$$\mathbb{V}_{\text{packet}} = \left(\frac{\mathbb{V}_t}{\mathbb{R}_{MaxSpeed}}\right) \tag{6}$$

In Eq. (6) $\mathbb{D}_{\text{ESD}}^{\text{i}}$ signifies the Euclidean distance in between the source i and the destination node. Noticeably, $\mathbb{D}_{\text{ENS}}^{\text{i}}$ presents the distance between the source and the (nearest) sink. Here, $\mathrm{R}_{\text{MaxSpeed}}$ signifies the maximum possible speed of the radio signal in air. In our proposed CLA-QRPM routing protocol the speed of radio signal is assumed to be equal to the speed of light (3×10^{-8}m/s). In our proposed model round trip time is estimated as the difference in time of the packet transmission and the reception of the ACK signal. Mathematically, it is estimated as:

$$ARTT_{Ti} = \frac{\sum_{i=0}^{N} R_{At}^{i} - v_{Pt}^{i}}{\mathcal{N}} \tag{7}$$

In Eq. (7), the variables R_{At}^{i} and S_{pt}^{i} signifies the time of ACK receiving and the packet transmission, respectively. The other variable $\mathcal{N}$ states the total packets transmitted. Thus, estimating the packet velocity for each node we have used it as a node specific parameter to decide its suitability to be a best forwarding node or path.

4.6 Cumulative Rank Matrix Estimation (CRME) and Best Forwarding Path Formation

Once estimating the above stated dynamic network parameters of the participating nodes, it was used to perform BFN selection. To achieve it we estimated a (node) rank parameter called Cumulative Rank Matrix (CRM) (8). As already stated, CLA-QRPM routing protocol applies multiple three key network parameters; Congestion Probability, Dynamic Link Quality and Packet Injection Rate or velocity to perform best forwarding path selection, followed by best forwarding path formation and data transmission. The proposed CRM value is obtained using Eq. (8).

$$CRM_i = \omega_1 * \eta_i + \omega_2 CNI_i + \omega_3 * \mathbb{V}_{\text{packet}_i} \tag{8}$$

In Eq. (8), ω states the weight parameter which can be decided based on network preferences or on application specific environment. In above expression, CRM signifies the cumulative rank of a node (i). Noticeably, ω is assigned in such manner that $\sum_{\text{i}=1}^{3} \omega_{\text{i}} = 1$. The variable η states the dynamic link quality. Once estimating CRM of each participating node, the estimated rank $\text{CRM}_{\text{i}\in\text{TotalNodes}}$ are updated in the decreasing order and a node with the maximum CRN is considered as BFN for further data transmission over MANETs.

5 RESULTS AND DISCUSSIONS

Considering the significance of QoS centric routing protocol for MANETs in this research paper a robust routing protocol named "Cross-Layer Architecture Based QoS Centric Routing Protocol for MANETs (CLA-QRPM)" was developed. Considering the network dynamism unlike classical clustering-based approaches, our proposed CLA-QRPM model was augmented in such manner that it exploited major (significant) layers of the IEEE 802.11 protocol stack. Primarily, it exploited Application layer, Network layer and MAC layer that enabled proactive network management and dynamic network parameter estimation, such as dynamic link quality, congestion probability, QoS centric resource scheduling, packet injection rate etc. Here, the prime motive was to retrieve different key network parameters from the different layers and synchronize network decision process to achieve the best forwarding path selection and/or forwarding path formation. To achieve it different network parameters were applied to assess suitability of a node to become BFN under dynamic topology and node characteristics conditions. To achieve QoS centric and efficient routing for event driven communication (say, mission critical applications) in MANETs, CLA-QRPM model incorporated key components like, Proactive Network Table Management, Service Differentiation and Fair Resource Allocation, Congestion Detection and Avoidance Model, Dynamic Link Quality Measurement, Packet Velocity Measurement, and Cumulative Rank Matrix Estimation and Best Forwarding Path Selection. Architecturally, CLA-QRPM routing protocol exhibits key functions of proactive network/node management, SDFRS and based data prioritization and resource scheduling, and dynamic buffer assessment-based congestion detection at the network layer of the IEEE 802.11 protocol stack. CLA-QRPM model performed dynamic link quality estimation and packet injection rate estimation at the MAC layer. In addition to this our proposed CLA-QRPM protocol provides the possibility of physical layer functions such as DPM and multi-rate transmission. However, developing DPM and multi rate transmission have not been addressed in this paper. Thus, obtaining CRME matrix for each node the BFN selection has been done, which has been followed by the formation of the best forwarding path. To assess efficiency CLA-QRPM model applies both RTD as well as NRT data to perform communication over MANET. The overall proposed routing protocol has been developed using MATLAB 2012b software platform. A snippet of the experimental setup and other network variables is given in Table I.

Table I Experimental Setup

Parameter	Specification
Operating System	Windows 2010, 8GB RAM, Intel i5 processor.
Simulation Tool	MATLAB 2012b
Protocol	CLA-QRPM
Data Link	CSMA
Physical	IEEE 802.11PHY
MAC	IEEE 802.11MAC
Mobile Nodes	60
Radio Range	100 meter
Packet Deadline time	10 sec.
Mobility	Circular
Weight parameters	$\omega_{1(LQE)} = 0.4$ $\omega_{2(Cong)} = 0.3$ $\omega_{3(P\_Vel)} = 0.3$
Simulation Period	480 Sec.
Payload	250, 500, 750, 1000, 1250, 1500, 1750, 2000, 2250, 2500, 2750, 3000.

Considering QoS centric and mission critical communication where reliable and timely data delivery is must, we have given more weight to the link quality ($\omega_{1(LQE)} = 0.4)$ (due to dynamic topological changes and vulnerability of link outage) and equal weight for congestion and packet velocity parameters ($\omega_{2(Cong)} = 0.3$, $\omega_{3(P\_Vel)} = 0.3$. Here, the predominant goal is made on achieving maximum or optimal throughput (i.e., packet delivery), minimum packet loss and minimum (say, negligible) deadline miss. The inclusion of SDFRS model assures optimal tradeoff between RTD and NRT resource allocation to meet QoS delivery over MANETs. In our model circular mobility pattern is considered, where each node intends to deliver data through best forwarding node towards the destination within the defined deadline time. Though a number of approaches such as Ad-hoc on demands distance vector routing protocol (AODV) have been proposed for MANET routing; however very less effort is made on exploiting cross layer model for QoS provision. However, performing in depth assessment we have identified a model named Cross Layer based AODV (CLAODV) routing protocol [30] for performance assessment. Authors [30][33] could not address the key network adversaries such as link outage, contention, retransmission, packet holding time (at node) and packet velocity to perform routing decision. Similarly, authors [2-4] have developed cross-layered architecture where they have considered congestion status in MANET to decide BFN. However, these routing models emphasizes on congestion avoidance in MANET. To assess performance, we have examined CLA-QRPM and the existing CLAODV protocol, which is similar to the proposals in [2-4] in terms of data delivery and packet loss for both NRT as well as RTD. In addition, the relative performance assessment of the deadline miss is also considered.

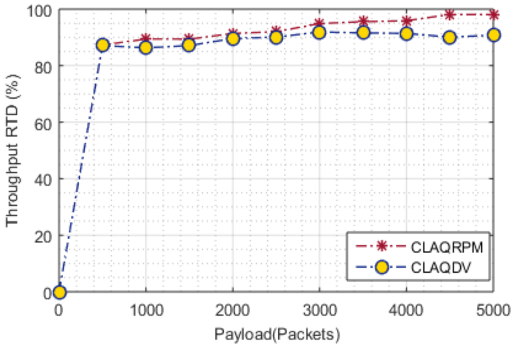

Fig. 2. RTD packet delivery

The throughput performance of the proposed CLA-QRPM routing protocol and existing CLAODV routing approach is given in Fig. 2. As depicted through the results (Fig. 2), CLA-QRPM routing protocol exhibits maximum throughput of 98.1% for RTD data. Similarly, the throughput for NRT data is obtained as 93.7% (Fig. 4). Here, observing the results, it can be found that the proposed CLA-QRPM routing model exhibits optimal throughput while ensuring the maximum possible NRT data transmission success. The throughput of 98.1% exhibits appreciable performance under dynamic network conditions. On the other hand enabling such high throughput ensures minimum data transmission and hence avoids unwanted energy exhaustion.

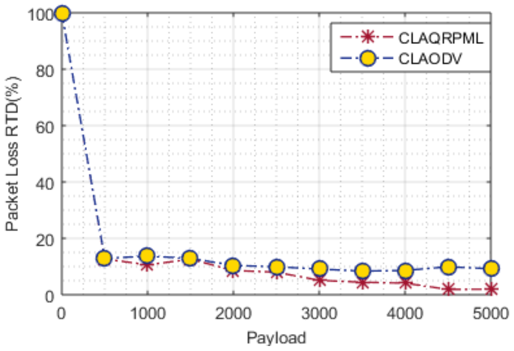

Fig. 3. RTD packet loss

Fig. 3 presents the RTD packet loss by our proposed CLA-QRPM routing protocol and the existing cross layer based AODV routing protocol (CLAODV). Considering the results obtained, it is evident that our proposed routing model exhibits minimum 1.9% packet loss while the existing CLAODV protocol exhibits 6.7% of the packet loss. It signifies the robustness of our proposed routing model over merely single parameter (i.e., congestion aware) based routing decision [30][2-4]. Unlike CLAODV model, we have applied multiple (dynamic) network parameters that augment the BFN decision process to exhibit more efficient and QoS centric transmission over MANET. Noticeably, since our proposed routing model exhibits higher successful data delivery the probability of packet retransmission is minimum that makes it (CLA-QRPM) energy efficient and robust. Undeniably, the inclusion of SDFRS model for optimal resource allocation makes our proposed CLA-QRPM protocol exhibit higher packet deliver for RTD data. Fig. 4 exhibits throughput for NRT data. Appreciably, our proposed CLA-QRPM routing protocol has exhibited higher throughput for NRT data than the exiting CLAODV routing model. The packet loss observed for NRT data type is shown in Fig. 5. Here, it can be easily found that our proposed CLA-QRPM routing model exhibits low packet loss than the classical routing approaches. In the referred protocol [30][2-4] authors have focused only one identifying a node with congestion free transmission to make BFN selection and have not addressed the issue of resource scheduling, and hence causing packet loss. Here, the efficacy of our proposed CLA-QRPM model due to robust multiple network parameters based BFN selection can be easily observed.

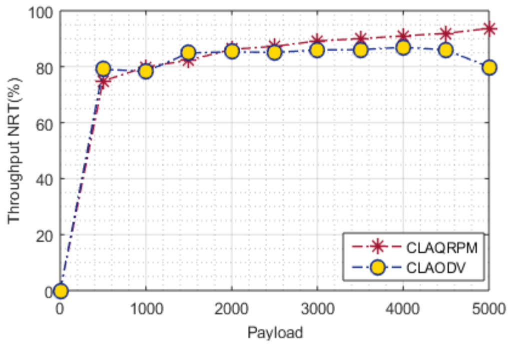

Fig. 4. NRT data throughput

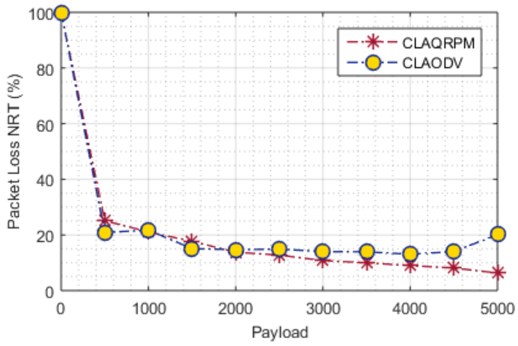

Fig. 5. NRT packet loss

Noticeably, our proposed CLA-QRPM routing protocol applies SDFRS that ensures optimal resource provision to the RTD data, while ensuring that during congestion and resource scheduling not much or significant packets are dropped from the NRT buffer. It strengthens our proposed model to exhibit higher throughput for both RTD as well as NRT. It enables CLA-QRPM to ensure QoS provision for both RTD as well as NRT even under exceedingly high topological changes. For mission critical communication or event driven communication over MANETs, enabling minimum or negligible deadline miss ratio is must. Here, it must be noted that the deadline miss ratio signifies the probability of a packet to reach destination after defined receiving time or deadline time. Fig. 6 exhibits the deadline miss ratio by our proposed CLA-QRPM routing protocol and existing CLAODV protocol. Here, it can be seen that CLA-QRPM model exhibits low deadline miss as compared to the CLAODV. Recalling the robustness of our proposed CLA-QRPM model where we have applied dedline time of a packet to decide prioritization and resource allocation to perform transmission decision, the results affirms affirmative performance by our proposed model. Here, the efficacy of our proposed multiple parameters based BFN selection model can be easily observed.

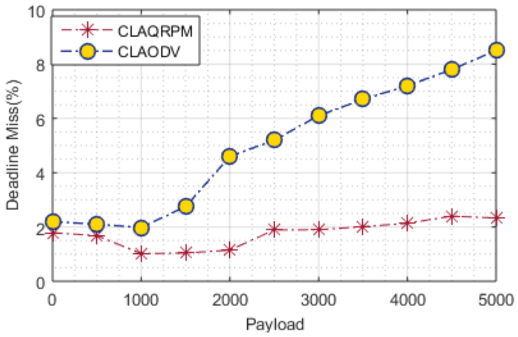

Fig. 6. Deadline-miss ratio

Thus, observing overall results and the contribution made, it can be stated that our proposed CLA-QRPM routing protocol can be highly efficient and robust to serve timely and reliable data delivery for event driven communication over MANETs. In addition, the performance reveals that it can be efficient towards energy as well as computational efficient routing purpose for major MANET applications.

6 CONCLUSION

The decentralized and infrastructure less feature of Mobile Ad-hoc network (MANET) has made it a potential networking solution to be used in major applications ranging natural disaster management, vehicular communication, industrial communication etc. Though, being a dominating mobile communication system, exceedingly high network topology and mobility pattern in MANETs make it trivial to achieve Quality of Service (QoS) delivery, particularly for event-driven (mission-critical) communication. With this motivation, in this research paper a robust QoS Oriented Cross-Synch Routing Protocol for Event Driven, Mission-Critical Communication has been developed for MANET. The proposed routing model exploits cross-layer routing architecture by applying network layer, MAC layer and physical layer information of IEEE 802.11 standard to perform optimal best forwarding node selection and reliable path formation. Our proposed protocol performed proactive node management, service differentiation-based data prioritization and fair resource scheduling, and dynamic buffer assessment based congestion detection at the network layer, dynamic link quality estimation and packet velocity estimation at the MAC layer of the protocol stack. Our proposed MANET routing protocol applies dynamic link quality, congestion probability and packet velocity of a node for best forwarding node selection to form forwarding path. The concept of cross-layer design enabled routing model to share dynamic network conditions or states across the IEEE 802.11 protocol that eventually assure QoS centric BFN selection and reliable data transmission. The simulation results have revealed that the proposed routing protocol exhibits higher throughput, minimum packet loss and deadline miss ratio for real time data (RTD). In addition, it ensures maximum possible packet delivery for NRT data without violating QoS demands and deadline sensitive transmission.

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