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# An Efficient QOS-Oriented Distributed Routing Protocol for Hybrid Wireless Networks

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***Abstract*— It has been observed that, from last few decades wireless technology is gaining popularity in the communication world. In these days, a person sitting at one place can communicate and access the resources of another place with the help of wireless technology. Recent advances in portable computing and wireless technologies are opening up exciting possibilities for the wireless hybrid networks. A hybrid wireless network combines a mobile wireless ad hoc network (MANET) and an infrastructure wireless network. Hybrid wireless networks are a viable networking way to fight with the limitations of infrastructured wireless networks and provide Internet connectivity to ad hoc networks and these hybrid wireless networks has been proven to be a better alternative for the next generation wireless networks. But how to guarantee the QoS in hybrid networks remains an open issue. So an Efficient QoS-Oriented Distributed routing protocol (QOD) is proposed to enhance the QoS support capability of hybrid wireless networks. This protocol incorporates the following algorithms: 1) a QoS-guaranteed neighbour node selection algorithm to meet the transmission delay demand and for choosing qualifies neighbours, 2) a Distributed packet scheduling algorithm for data packet routing and to further reduce transmission delay, 3) a mobility based packet resizing algorithm that adaptively adjusts size of the data segment as per the node mobility in order to decrease transmission time 4) a traffic redundant elimination algorithm to increase the transmission throughput of the system, and 5) a data redundancy elimination algorithm to discard the redundant data to further enhance the transmission QoS. The results are shown using simulations on NS-3.***
***Keywords*— Hybrid Wireless Networks; MANET; Wireless Infrastructure Networks; Quality of Service (QoS), Routing.***

## I. INTRODUCTION

Wireless technology is gaining popularity day by day as it support various real-time wireless applications. Today, with the help of wireless technology people sitting at either ends of the country can communicate with each other. Wireless networks are established with various wireless applications that have been used in the areas such as commerce, military, emergency and educational fields. The evolution and the anticipating future of real time mobile multimedia streaming services are extensively flourished and has grown vigorously, so the networks require high Quality of Service (QoS) to support the wireless and mobile networking environment. The QoS support reduces end-to-end transmission delay and enhances throughput to guarantee the seamless communication between mobile devices and wireless infrastructures. Also, with the advent and growth of wireless technology, a wide number of modern services are expected to be aided including appealing services that currently exist in the wired systems. Also, the resource restraints in wireless networking environment may render difficulty to realizing all the desirable wireless services. So, a system with improved data rate is indispensable to complement the resource constraints and to act as anchor points linking mobile nodes to other fixed networks as the Internet. Infrastructure wireless networks and ad hoc networks are two popular types of wireless networks. But these two types of networks suffer from some limitations. So hybrid wireless networks have come out as a promising solution which is a viable networking solution to combat the limitations of infrastructure wireless networks and provide Internet connectivity to ad hoc wireless networks. Hybrid networks fuses infrastructure networks and MANETs to support each other. In a hybrid network, infrastructure networks enhance the scalability of MANETs, while MANETs themselves form self-organizing networks, stretching the coverage area of the infrastructure networks. Hybrid wireless networks can help to tackle the stringent end-to-end QoS requirements of different applications. Figure 1 shows a hybrid wireless network.

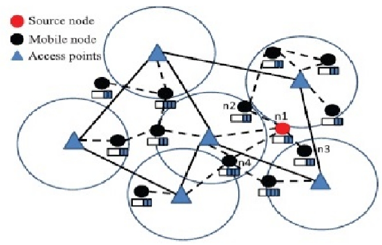


Fig. 1. The network model of the hybrid wireless

But how to ensure QoS in hybrid wireless networks with high mobility still remains an open problem. In the wireless infrastructure networks, QoS provision (e.g., Intserv [2], RSVP [3]) has been proposed for QoS routing, which often requires negotiation of node, admission control, reservation of resources, and scheduling of packets priority wise [4]. Nevertheless, it is much harder to attain QoS in MANETs due to their unique features like mobility of nodes, channel errors, and bandwidth limitation. So the QoS remedies for infrastructure wireless networks cannot incorporated be into MANETs. Various reservation-based QoS routing protocols have been proposed for MANETs [5], [6], [7], [8] that makes routes created by nodes and links that reserve their resources to fulfil the QoS conditions. However, not much effort has been made to enhance QoS routing in hybrid wireless networks. Most of the present works in hybrid networks [9], [10], [11], [12], [13] concentrate on increasing network capacity or routing reliability but cannot provide QoS-oriented services. If the reservation-based QoS routing protocols of MANETs are directly applied into hybrid networks, they may experience problems like invalid reservation and race condition problems. Invalid reservation problem is that if the data transmission path between a source node and a destination node breaks, the set aside resources become useless. Race condition issue implies allocating the same resource to two separate QoS paths. So it is important to inquire new routing methods that can provide QoS routing and can better adapt to the hybrid wireless networks with different traffic composition and application requisite. So an efficient QoS Oriented Distributed (QOD) routing protocol is proposed to provide QoS routing in wireless hybrid networks. QOD routing protocol aims at minimizing end-to-end transmission delay and increasing network throughput. This paper is organized as follows: Section II exposes a study of the related work, Section III explains the QOD routing protocol and Section IV discusses the simulation results for the system. Finally, the conclusions are detailed in Section V.

## II. RELATED WORKS

### *A. Wireless Infrastructure Networks*

As the internet evolves into a global communication system, there is an increasing need to support more sophisticated services (e.g., traffic management, QoS) than the traditional best effort service. Two classes of solution emerge: the scheme which is maintaining the stateless property of the original IP architecture, and the scheme which is requiring a new stateful architecture. Examples of stateless solutions are RED for congestion control and Differentiated Service (Diffserv) for QoS. The corresponding examples of stateful solutions are Fair Queuing for congestion control and Integrated service (Intserv) for QoS. In general, stateful solutions can provide more powerful and flexible services. IntServ provides per-flow QoS assurance in which routers have four basic functions: RSVP, admission control routing, packet scheduler and classifier. These functions create high control overhead and consume power, which is limited in ad hoc networks. The DiffServ affords a limited number of aggregated classes. It uses fine grained mechanism to manage traffic in the network [14]. But the packet dropping ratio and bandwidth cannot be minimized. So it fails to fulfil QoS.

### *B. Wireless Ad hoc Networks*

An ad hoc wireless network (AWN) is a collection of mobile nodes forming an impermanent network, without using any fixed infrastructure. Characteristics of Ad-hoc Networks such as lack of central coordination, host mobility, dynamically changing network topology, and limited handiness of resources make QoS provisioning very challenging in such networks. The Mobile Ad hoc Networks working group of the Internet Engineering Task Force (IETF) has been actively evaluating and standardizing several routing protocols, e.g. Ad hoc On-demand Distance Vector (AODV) Routing, Dynamic Source Routing (DSR), Topology Dissemination based on Reverse-Path Forwarding (TBRPF) Routing and Optimized Link State Routing (OLSR).However, most routing solutions only provide best-effort routes which do not satisfy the QoS requirements of growing multimedia applications in ad hoc networks, such as delay and bandwidth constraints. Perkins [15] proposed AODV protocol which is a distance vector routing protocol and it is the most popular routing protocol for ad hoc networks, and has been investigated widely by many researchers for a large number of network topologies and environments. AODV protocol is a pure on demand routing protocol in which a route is only discovered when it is required by a source node. In AODV, there is a frequent link break down between the source node the Destination node. So, it will degrade the network performance. The Dynamic Source Routing Protocol (DSR) [16] is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile hosts. DSR makes the network to be fully self-organizing and self-configuring, without the requirement of any existing network infrastructure or administration. But it does not consider the transmission delay.

### *C. Hybrid Wireless Networks*

Routing is the main research issue in the development of hybrid wireless networks. Most of the techniques used for routing focus on improving network capacity and routing reliability. A Unified Cellular and Ad Hoc Network Architecture (UCAN) is proposed by Luo et al [17]. In UCAN, the 3G BS forwards packets in a hybrid manner only for destination clients with poor channel quality and it improves network throughput. But it's hardware is complex which may cause MNs to quickly run out of battery. An integrated cellular and ad hoc relaying (iCAR) system [18] is proposed that enables a cellular network to achieve a throughput closer to its theoretical capacity. But it has some limitations like signalling overhead, non-optimal routes and hardware complexity. Many of the routing approaches for hybrid networks have been borrowed from mobile ad hoc networks (MANETs) to achieve routing solutions in these networks but are not ideal or optimal and cannot provide QoS routing. So it is necessary to define new routing schemes with QoS routing guarantee which can better adapt to the hybrid wireless networks.

## III.THE QOD PROTOCOL

In order to improve the QoS support capability of hybrid networks, a QoS-Oriented Distributed routing protocol (QOD) is proposed. Usually, a hybrid wireless network has widespread base stations. The QOD protocol converts the packet routing problem into a dynamic resource scheduling problem. The main objective of QOD is to reduce transmission time and increase the network capacity based on queuing condition, channel condition and user mobility. In QOD routing protocol, if a source node is not within the transmission range of an AP, a source node chooses the nearby neighbour nodes that can provide QoS services to forward its packets to the APs in a distributed fashion. The source node schedules the data packet streams to the neighbouring nodes based on their queuing status, channel state, and mobility, with an objective to decrease transmission time and improve network capacity. The neighbouring nodes then forward these packets to AP, which further forward these packets to the destination node. The QoS assured transmission in QOD routing protocol is achieved through five algorithms which includes a QoS-guaranteed neighbour node selection algorithm for reducing the transmission delay, a distributed packet scheduling algorithm for packet routing which reduces the total transmission time, a mobility dependent packet resizing algorithm which further reduces the transmission time, a Soft-deadline-based forwarding and scheduling algorithm for improving network throughput and a data redundancy elimination algorithm for improving the QoS of the packet transmission.

### A. *Overview Of QOD*

The source node generates the data packet periodically. The source node transmits the packet directly to the destination node if the source node is within the coverage area of access points. Otherwise the source node has to send the request message to adjacent neighbour nodes to reach the destination. The neighbour node compares the space utility ($U_s$) with the threshold and reply to the source node. Then a neighbour node $n_i$ having space utility Us less than a threshold value replies to the source node after receiving a forward request message from that source node. Based on the replies from the neighbour nodes the source node computes the queuing delay ($T_w$) and packet size ($S_p(i)$) and then finds the qualified neighbour nodes. The neighbour nodes get sorted in the descending order based on the queuing delay ($T_w$). Depending upon the workload of neighbour nodes the source node chooses the excellent neighbour. Then workload rate $A_i$ is calculated for each sorted intermediate neighbour node and send packets to $n_i$ with the transmission interval $S_p(i)$/ $A_i$ from the source node.

### *B. Applicability Of The QOD Routing Protocol*

The QOD routing algorithm is developed based on the assumption that the neighbouring nodes in the hybrid wireless network have different channel utilities and workloads using the protocol IEEE 802.11. If not, there is no need for packet scheduling in data packet routing, since all neighbouring nodes make comparative delay for packet forwarding. In order to avoid medium access contention, hidden terminal problem and exposed terminal problem, IEEE 802.11 uses the MAC protocol CSMA/CA. Before a node sends out packets, it sends a Request To Send (RTS) message to the next hop node indicating the duration time required for the subsequent data transmission. The destination node then reply with a Clear To Send (CTS) message to establish a connection with the source node. The neighbour nodes overhearing these RTS and/ or CTS messages set their Virtual Carrier Sense indicator or Network Allocation Vector (NAV) to the message's transmission time, so that it can avoid transmitting data into the channel within the time duration. Channel utility is defined as the fraction of time a channel is busy over a unit time. Assume $\overline{T}$ is a constant time interval used for channel utility updating, by referring to NAV and update interval $\overline{T}$, each node $n_i$ can statistically calculate its channel utility by $U_c(i) = T_{NAV}/\overline{T}$, where $T_{NAV}$ is the number of time units that $n_i$ is interfered which is recorded by NAV. The available bandwidth for $n_i$ is $W_i = (1-U_c(i)).C_i$, where $C_i$ is the transmission link capacity of node $n_i$. The workload of a node is defined as the accumulated number of packets received by the node through the entire simulation period.

### *C. QoS-Guaranteed Neighbour Node Selection Algorithm*

Since short delay is the major real-time QoS requirement for transmission of data traffic, QOD incorporates the Earliest Deadline First scheduling algorithm (EDF) [19], which is a deadline driven scheduling algorithm for data traffic scheduling in intermediate nodes. As per this algorithm, an intermediate node gives the highest priority to the data packet with the closest deadline and forwards the packet with the highest priority first. Let $S_p(i)$ denote the size of the packet steam from node $n_i$, $W_i$ denote the bandwidth of node i, and $T_a(i)$ denote the packet arrival interval from node $n_i$. The QoS of the packets going through node $n_i$ can be satisfied if

$$\frac{Sp(1)}{Ta(1)} + \frac{Sp(j)}{Ta(j)} + \cdots + \frac{Sp(m)}{Ta(m)} \leq Wi \quad (1)$$

Similar to the random early detection (RED) algorithm [20], in which a queue length threshold is set to avoid queuing congestion, a space utility threshold $T_{Us}$ is set up for each node as a safety line to make the queue scheduling feasible. Let $U_{as}(i)$ denote the available space utility and $U_{as}(i) = T_{Us} - U_{s(i)}$. In QOD, after receiving a forward request message from a source node, an intermediate node $n_i$ with space utility less than threshold $T_{Us}$ replies the source node. The replied node $n_i$ informs the source node about its available workload rate $U_{as}(i) * W_i$, and the necessary information to calculate the queuing delay of the packets from the source node. Based on the calculated queuing delay, the source node then selects the replied neighbour nodes that can meet its QoS deadline for packet forwarding. After the source node determines the qualified nodes that can satisfy the deadline requirement, the source node needs to distribute its packets to these qualified nodes based on their available workload rate $U_{as}(i) * W_i$ to make the scheduling feasible in each of the adjacent nodes. Consider the packet generating rate of the source node is $W_g$ kb/s, the number of QoS qualified neighbours is $N_q$ , the available workload rate of the intermediate node $i$ is $U_{as}(i) * W_i$, and the workload rate allocation from source node to immediate node i is $A_i = (S_p(i))/T_a(i)$, where $0 < i < n$. Then, the following equations is solved to get an allocation set $A$:

$$A = \begin{cases} Wg = \sum_{i=1}^{Nq} Ai \\ Ai \leq Uas(i) * Wi. \end{cases} \quad (2)$$

Any results that satisfy this equation can be used by the source node.

### *D. Distributed Packet Scheduling Algorithm For Data Packet Routing*

The distributed packet scheduling algorithm for packet routing is proposed to further decrease the transmission delay. This algorithm assigns previously generated packets to forwarders with higher queuing delays and scheduling feasibility, while assigns more lately generated packets to forwarders with lower queuing delays and scheduling feasibility, so that the transmission time of an entire packet stream can be reduced. Let us use $t$ to denote the time when a packet is generated, and use $T_{QoS}$ to denote the delay QoS requirement. Let $W_s$ and $W_I$ denote the bandwidth of a source node and an intermediate node respectively, $T_{S\rightarrow I} = S_p/W_s$ represents the transmission delay between a source node and an intermediate node, and $T_{I\rightarrow D} = S_p/W_I$ represents the transmission delay between an intermediate node and an AP. Let $T_w$ represents the packet queuing time and $T_w(i)$ denotes the packet queuing time of $n_i$. Then, the queuing delay requirement is computed as $T_w < T_{QoS} - T_{S\rightarrow I} - T_{I\rightarrow D}$. As the values of $T_{QoS}$, $T_{S\rightarrow I}$, and $T_{I\rightarrow D}$ are already known, the source node is required to calculate $T_w$ of each intermediate node to select intermediate nodes that can send its packets by the deadline, i.e., the nodes that can satisfy the condition $T_w < T_{QoS} - T_{S\rightarrow I} - T_{I\rightarrow D}$.

An intermediate node can find the priorities of its data packets based on their deadlines $D_p$. A packet with a lesser priority value x has a higher priority. The queuing time $T_w^{(x)}$ of a packet with priority x is estimated as

$$T_w^{(x)} = \sum_{j=1}^{x-1} (T_{I\rightarrow D}^{(j)} \cdot \lceil T_w^{(x)} / T_a^{(j)} \rceil) \; (0 < j < x) \quad (3)$$

where x denotes a packet with the xth priority in the queue, and $T_{I\rightarrow D}^{(j)}$ and $T_a^{(j)}$ respectively denote the transmission delay and arrival interval of a packet with the *j*th priority. $\lceil T_w^{(x)} / T_a^{(j)} \rceil$ is the number of packets arriving during the packet's queuing time $T_w^{(x)}$, which are sent out from the queue before this data packet.

After receiving the reply messages from neighbouring nodes along with the scheduling information of all flows in their queues, the source node computes the queuing time $T_w$ of its packets in each intermediate node and then chooses the intermediate node $n_i$ that meets the condition $T_w(i) < T_{QoS} - T_{S\rightarrow I} - T_{I\rightarrow D}$. After scheduling data packets to qualified intermediate nodes based on equation (3), the previously generated packet from source node is transmitted to a node with longer queuing delay but still within the deadline bound. Taking advantage of the different values of $T_w$ in different neighbouring nodes, the entire traffic stream transmission time can be decreased by making the queuing of previously generated packets and the generation of new packets be conducted in parallel.

### *E. Mobility Dependent Packet Resizing Algorithm*

In a highly dynamic mobile wireless networking environment, the transmission link between two nodes breaks frequently. This may lead to delay in packet transmission due to the re-transmission of data packets. The delay generated may degrade the QoS of the transmission of a data packet flow. On the other hand, a node in a highly fluctuating network has higher probability to meet different mobile nodes and APs, which is an advantage for resource scheduling. The space utility of an intermediate node that is used for forwarding a packet p is $\frac{Sp}{WI * Ta}$. That is, reduced packet size can improve the scheduling feasibility of an intermediate node and reduces packet dropping probability. However, it is not possible to make the size of the packet too small as it generates more packets to be transmitted, producing higher packet overhead. So a mobility dependent packet resizing algorithm is proposed for QOD. The basic idea is that the bigger sized packets are assigned to lower mobility intermediate nodes and smaller sized packets are assigned to higher mobility intermediate nodes that ensure the QoS- guaranteed packet transmissions. Specifically, in a QOD routing protocol implemented system, as the mobility of a node step up, the size of a packet $S_p$ sent from a node to its neighbour nodes i decreases as following:

$$Sp(new) = \gamma / vi \; Sp(unit) \quad (4)$$

where $\gamma$ is a scaling parameter and $vi$ is the relative mobility speed of the source node and intermediate node and Sp(unit) = 1 kb.

### *F. Soft-Deadline-Based Forwarding And Scheduling Algorithm*

As per the EDF algorithm, an intermediate node first send the data packets with the earliest deadlines and then forwards the data packets with the farthest deadlines. If an intermediate node has no problem to meet deadlines of all packets in forwarding, that is, if all of the packets are scheduling feasible, the EDF algorithm works satisfactorily. However, when an intermediate node has large number of packets to forward out and the deadlines of some packets must be missed, EDF forwards out the packets with the earliest deadlines but may delay the data packets with the farthest deadlines. Therefore, EDF is suitable for hard-deadline driven applications (e.g., online conferences) where packets must be forwarded before their deadlines but may not be fair to all the incoming packets in soft-deadline driven applications (e.g., online TV), where the deadline missing is sometimes allowed.

The Least slack first scheduling (LSF) algorithm is used for soft-dead line driven applications for achieving fairness in the packet forwarding. The slack time of a packet can be computed by $D_p - t - c'$, where $D_p$ is the packet deadline, t is the current time of the packet and $c'$ is the remaining packet transmission time for a packet. An intermediate node computes the slack time at regular intervals for each node and forwards the least slack time data packet. The packet would be chosen randomly if all packets have the same slack time. The LSF does not aim at transmitting the packet before deadlines are met. Rather, it aims to make delays and the sizes of delayed part in the delayed packets of different packet flows almost the same. In this algorithm fairness in data packet forwarding and scheduling can be achieved. Based on the nature of applications, QOD chooses EDF or LSF algorithm.

*G. Data Redundancy Elimination Algorithm*

In a mobile wireless networking environment, the mobile nodes set their NAV values based on the overhearing message's transmission duration. A large NAV leads to a small available bandwidth and a small scheduling possibility of the mobile nodes. Therefore, if the NAV value is lowered, the scheduling possibility of the intermediate nodes can be increased and it will sequentially increase the QoS of the data packet transmission. Because of the broadcasting feature of the wireless networks, in a hybrid wireless network, the APs and mobile nodes can overhear and cache packets. Based on this property, an end-to-end traffic redundancy elimination (TRE) algorithm [21] is proposed to eliminate the redundancy data to improve the QoS of the packet transmission in QOD. TRE algorithm uses a chunking scheme to find the boundary of the chunks in a stream of data packets. The data packet which is sent out by the source node is saved in its cache and the receiver node also caches its received data. In QOD with TRE, the AP and mobile nodes can overhear and cache data packets. As a result of overhearing, the nodes can know who have received the packets. When a source node begins to send packets, it scans the content for duplicated chunks in the cache memory of the source node. If the sender node notice a duplicated chunk in its cache and it knows that the AP receiver has received this chunk before, then it replaces this chunk with its signature (i.e., SHA-1 hash value). When the AP receives the signature, it searches for the signature in its local cache memory. If the AP has the data chunk associated with the signature, the AP sends a confirmation message to the sender and replaces the signature with the corresponding data chunk. Otherwise, the AP requests the data chunk associated with the signature from the sender.

## IV. PERFORMANCE EVALUATION

This section compares the performance of QOD with that of EAODV and AODV through simulations on NS3. E-AODV is Extended Ad-hoc On Demand Distance Vector routing protocol. This protocol extends AODV routing protocol by appending additional information such as maximum delay and minimum available bandwidth of each neighbour nodes in their respective routing tables. AODV is Ad-hoc On Demand Distance Vector routing protocol which is the most popular routing protocol for wireless ad hoc networks. Here the scenario considered is the networks with different number of source nodes. Then, the parameters like throughput, packet delivery ratio and delay is calculated for the networks with different number of source nodes. Throughput is defined as the total number of data packets which are successfully transmitted per unit time. Delay is defined as the entire time duration for transmitting the data packet from the source node to the destination node. Packet delivery ratio is defined as the number of packets that are successfully received to the number of packets that are sent by the source node. From the simulation results as shown in the figures 2, 3 and 4, it is clear that the network with QOD as the routing protocol has the highest throughput, improved packet delivery ratio and minimum transmission delay compared to the networks with EAODV and AODV as the routing protocols. Figure 2 represents the comparison of throughput of three networks which is implemented with QOD, EAODV and AODV routing protocol respectively. Figure 3 represents the comparison of packet delivery ratio of three networks which is implemented with QOD, EAODV and AODV routing protocol respectively. Similarly, figure 4 represents the comparison of transmission delay of three networks which is implemented with QOD, EAODV and AODV routing protocol respectively.

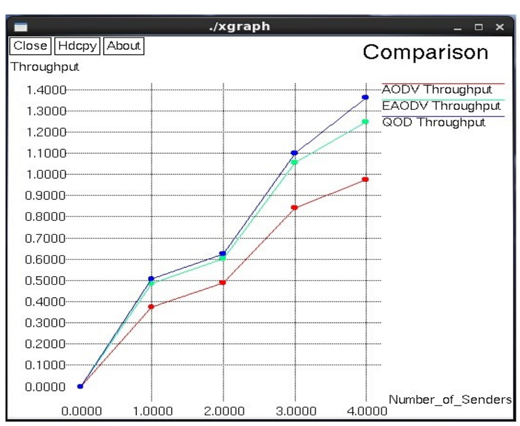


Fig. 2. Comparison of throughput of different

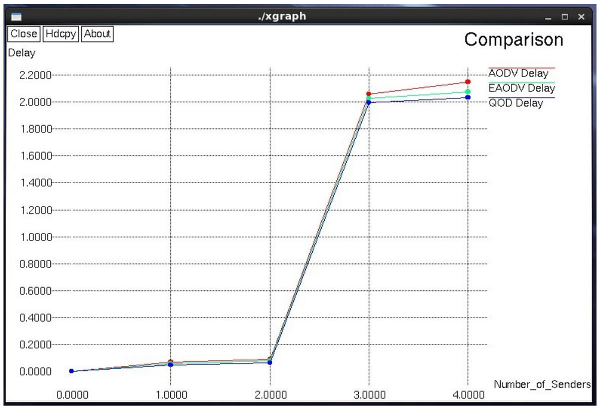


Fig. 4. Comparison of transmission delay of different networks

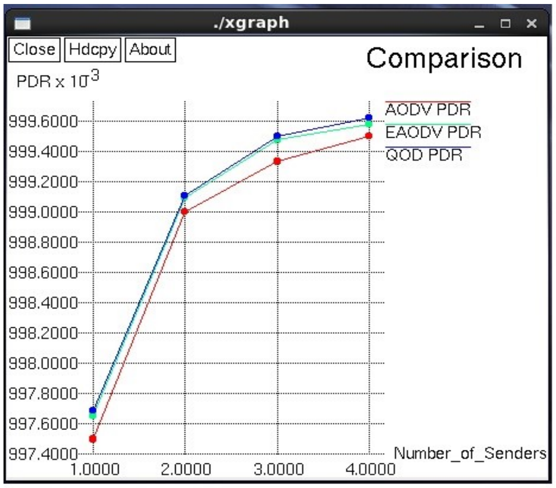


Fig. 3. Comparison of packet delivery ratio of different networks

## V. CONCLUSIONS

Hybrid wireless networks that unite MANETs and infrastructure wireless networks have proven to be a better network pattern for the next generation wireless networks. However, not much effort has been done to enhance QoS routing in hybrid wireless networks. Also, the direct application of the QoS routing techniques of MANETs into hybrid networks causes their drawbacks. So a QoS oriented distributed routing protocol (QOD) is proposed for hybrid networks to provide QoS services in a highly dynamic scenario. Specifically, QOD uses five algorithms. The QoS-guaranteed neighbour node selection algorithm chooses qualified neighbours for data packet forwarding and reducing delay. The distributed packet scheduling algorithm for packet routing which schedules the packet transmission to further decrease the packet transmission time. The mobility-dependent packet resizing algorithm that resizes packets and assigns smaller packets to nodes with faster mobility to guarantee the routing QoS in a highly mobile environment. The soft-deadline-based forwarding and scheduling algorithm achieves fairness in packet forwarding and scheduling and can further increase the transmission throughput. The data redundancy elimination algorithm to discard the redundant data to further enhance the transmission QoS. Experimental results show that QOD can achieve high mobility-resilience, scalability, and contention reduction. In future, the performance of QOD can be improved by allocating double channel.

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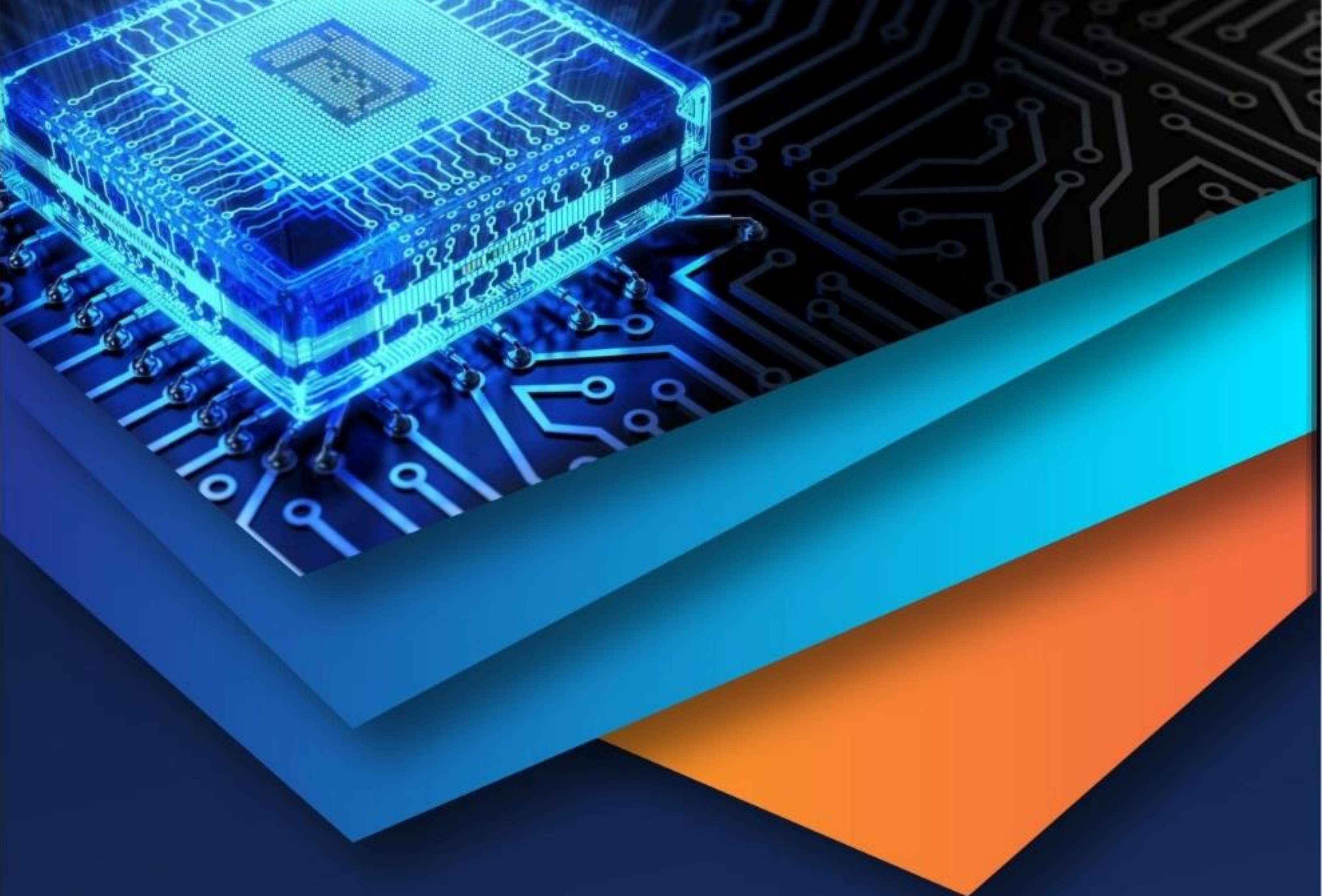

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