An InfiniBand-Based Mechanism to Enhance QoS in Multipath Routing Protocols in MANETs

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Abstract **— Mobile Ad-hoc Networks (MANETs) usually suffer from high packet loss and high link failure rates. These challenges usually increase congestion on some links while other links are almost free. In this paper, we propose a novel mechanism to enhance QoS in multipath routing protocols in MANETs based on the InfiniBand (IB) QoS architecture. The basic idea of our approach is to enhance the load balancing and thus reduce congestion on overloaded links. This mechanism has enabled us to (1) give critical applications higher priority when routing their packets across the network, (2) effectively manage frequent connections and disconnections and thus reduce link failures and packet loss rates, and (3) reduce the overall power consumption as a consequence of the previous gains. We have tested the scheme on the (IBsim) simulator and achieved significant improvements in QoS parameters compared to two well-known routing protocols: AODV and AOMDV.**

Keywords— MANET; InfiniBand; QoS; Multipath Routing, Simulation; Network Performance; Efficiency; Pathbits; VLANs;

I. INTRODUCTION

Existing routing protocols for Mobile Ad Hoc Networks (MANETs) can be either based on single-path or multiple-paths mechanisms. In a single path routing, there is a dedicated path between the source and the destination, in which the packet header contains the complete path with all hops' information until the destination is reached. On the other hand, multipath routing schemes build multiple paths from a source to a destination, and thus, can achieve better performance, and can resolve many of the single path performance issues such as scalability, security and network lifetime by using alternative paths [1-3].

InfiniBand (IB) mechanism was introduced to provide a high-performance computing with QoS and load balancing as core features. IB is a centralized network model which combines managers and agents collaborating to provide the best network performance that regular Internet protocols cannot reach [4,5]. By adapting the IB multipath (Pathbits) with Virtual Lanes (VLs) the network performance can be increased [6,7].

In this paper, we propose an InfiniBand-based mechanism to enhance QoS in multipath routing protocols in MANETs. To test the proposed approach, we have chosen the (Ad hoc On-demand Multipath Distance Vector Routing algorithm—AOMDV); We picked this algorithm since it is considered as one of core and most generic reactive routing algorithms for MANETs, and one can claim that most of the recent reactive routing algorithms are based on it. In addition, incorporating VLs into IB architecture is independent of the underlying routing algorithm [7]. Thus, in our work we study the effect of applying the VLs and other IB components to the AOMDV routing algorithm.

The remaining of the paper is structured as follows: relevant work is revised in Section II. A detailed discussion of the proposed system architecture is presented in Section III. Section IV summarizes the simulation testbed environment and the different parameters used with their values. The simulation results, discussions and the main findings are given in Section V. Finally, in Section VI we derive the main conclusions and shed light on planned future work.

II. RELATED WORK

Routing in MANETs is one of the most challenging issues cited by the computer networking research community [6,8]. This is due to continuous changes in topologies and nodes' locations and their neighborhoods in such networks. In this section, we review some of the most relevant research efforts addressing the routing problem in recent years, and mainly focus on those that are related to the work proposed in this paper. Vidwans *et al*. [8] proposed a congestion control mechanism for Ad hoc On-demand Multipath Distance Vector Routing (AOMDV). The mechanism uses rate base data sending scheme and queue base congestion control to improve the performance. The results have shown that packet delivery and control overhead are enhanced. Lou, W. *et al*. [9] proposed a methodology to enhance the QoS based on Node-Disjoint Multipath Routing (NDMR) using multiple node-disjoint paths to assign packets to paths in the best possible way, and handle some limitations in MANETs. Devi P. *et al.* [10] proposed an approach to increase packet delivery ratio by forwarding a smaller number of control packets to maintain route discovery and route failure, and thus managed to reduce control overhead. Ardagna, D. *et al.* [11] proposed an adaptive load balancing routing algorithm. Unlike other works, this algorithm has relied on the forwarding statistics, nodes distribution, and load status to achieve load balancing in the discovery stage. Yeng-Zhong L. *et al*. [12] proposed a QoS architecture that is suitable for large scale networks. This architecture was established with the help of Landmark

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TABLE 1. TESTBED SIMULATION PARAMETERS.

Simulator Parameter	Description
Simulation time	3000
Number of simulations run	Up to 255
Number of nodes	Up to 512
Node mobility pattern	Random
Topology	100mx 100m
Transmission range	Up to 25 m
Transmission power	31 mW
Queue length	100 packets
Routing Protocol	AOMDV
MTU	Up to 5x256
Link Width	Up to 4
Link Speed	Up to10Mb
LMC	Up to 7
packet-life	Up to 10s

Routing (LANMAR); a scalable routing algorithm to push the work into the source nodes and limit the work being performed in the intermediate nodes without the need for any state information. Venkatasubramanian S. *et al.* [13] presented a load balancing mechanism that is useful for increasing reliability and network throughput. Their approach relied on the modification of Ad hoc On-Demand Distance Vector Routing (AODV) protocol via an extension to utilize the node's resolvable load information and fairly distribute the load across the network. Fujian Q. *et al.* [14] introduced an algorithm based on Dynamic Source Routing (DSR) discovery and maintenance mechanism to deal with route failures and enhance the load balancing without incurring network overhead. Their simulation results have shown that packet delivery ratio was high. Pradeep B. *et al.* [15] proposed a detailed packet-layer model in which the physical layer and Media Access Control (MAC) address are used to study the traffic performance of both the AODV and the QoS-AODV protocols. Francisco *et al.* [6] compared the QoS results after using VLs as a part of QoS mechanism. The result has shown that using VLs gave better results, especially for big topologies. J. Pelissier [7] described the use of the IB mechanism in enhancing QoS, and showed that IB-based QoS mechanisms provide better performance measures over traditional QoS mechanisms. Ryan E. *et al.* [16] introduced the QoS main features for socket-based communication over IB networks, and concluded that IB can provide the opportunity to enact service differentiation for traditional socket-based applications over high-performance networks. The contribution presented in this paper is different from these previous works; it considers a new and novel strategy towards enhancing the efficiency of the routing process in MANETs by incorporating the InfiniBand mechanism into the routing process.

III. THE PROPOSED SYSTEM ARCHITECTURE

A. InfiniBand Overview

IB is a network model that is extensively used in high performance networks, and it has many applications in High Performance Computers (HPC) and Large-Scale Database Management Systems (DBMS) such as `Google`, `Facebook` [17] and `NASA` [18].

Since IB is a centralized network model that is controlled by managers and agents, it is completely opposite to MANET's nature, since it provides high performance in a completely organized fashion and thus, can be used to help organizing and managing chaotic networks like MANETs. Because of the inherent inclusion of QoS in the base layer in IB standard specification, there are two levels for QoS implementation: (1) QoS mechanisms that are inherently built into the basic service delivery mechanism supported by the hardware; and (2) the queuing services and management for prioritizing flows and guaranteeing service levels or bandwidths [18]. The number of Pathbits for any node (a) can be calculated using the following equation: $Pathbits\ (a) = 2^{LMC(a)}$, and the total number of paths between two nodes, *i.e.,* node (a) to node (b) can be calculated as follows: $total\_paths_{a\_to\_b} = Pathbits(a) * Pathbits(b)$.

```
//initiate paths
INIT = 1
ARMNED = 2
ACTIVE = 3
DISABLED = 4
num_paths= pow(2, lmc)
for num_path in range(num_paths):
    path = new(path)
    path.id = num_path
    path.state = INIT
for path in paths:
    switch (path.state){
        case INIT:
            if calculate(path):
                path.state = ARMED
            else:
                path.state = DISABLED
        case ARMED:
            try:
                if data:
                    path.state = ACTIVE
                    start_transmit(data)
            Except error:
                    path.state = DISABLED
        case ACTIVE:
            try:
                while data:
                    transmit(data)
                path.state = ARMED
            Except error:
                path.state = DISABLED
        case DOWN:
            if time_out == 0:
                path.state = INIT
```

Figure 1. The Load-Balancing Algorithm.

B. The Proposed Load Balancing Algorithm

Figure 1 shows the proposed load balancing algorithm that incorporates the IB features (QoS and multipath) into MANETs routing protocols. It consists of five states: *INIT, ACTIVE, ARMED, DISABLED,* and *ERROR*. The algorithm works as follows: At the beginning, all of the node's paths will be in the *DISABLED state* since we have a data to send out, but we do not have a path yet. The sending node floods a discovery routing packet and builds the routing table for a target destination using AOMDV, and sets valid paths state to *INIT*. Some of the paths in the *INIT* state will have QoS characteristics (not all paths can serve the QoS rule), only those paths are marked under the *ARMED* state. All *ARMED* paths can transmit, but only those that have data to transmit will change state to *ACTIVE*, but if the transmission failed for any reason, the failed path will change its state to *DISABLED*. Each of them use same concept with minor differences. In this paper, we will compare each one with traditional routing algorithms: Ad hoc on-demand multipath routing, which provides QoS support AOMDV. One scenario to map IB's *Minihop* into a MANET can go as follows: each node that wants to send data first calculates the LMC that determines how many maximum paths will be needed to reach the destination node. Each node floods the network to discover the paths between itself as a source and the destination node (depends on the routing algorithm). The paths that match the QoS requirements are marked and given lowest LMC, while other paths are given higher LMCs.

There are two types of paths: (1) paths for sending, and (2) paths for forwarding. The sending paths apply the QoS properties while the forwarding paths do not interfere with QoS characteristics and they are kept as provided by the sending node. If the QoS level cannot be maintained, an ERR_PATH_NOT_MATCH_QOS is sent to a source.

In IB, QoS is supported via *Virtual Lanes* (VLs); these VLs are separate logic communication links (in the Data Link Layer) which share the same physical link. Each physical link has 16 VLs from VL_0 to VL_{15}, such that VL_{15} is reserved for management to transmit control packets such as routing information and has the highest priority. Therefore, the applications can use VL_0 to VL_{14} to send their data. A *Service Level* (SL) for a link is defined to ensure its QoS level. Each link along a given path can have a different VL, and the SL defines the desired priority of communication. Each switch/router has an SL to VL mapping table that is set by the subnet manager to keep the proper priority with the number of VLs supported on each link. Therefore, the IB architecture can ensure end-to-end QoS through switches, routers and over the long-haul trunks [6, 19]. In this regard, each VL is assigned to a specific SL since the relationship between them can be presented by many-to-one relation; which means that each VL can be bound to one SL and/or many VLs can be bound to a single SL – this mapping is stored in a table called the SL/ VL table [18,19]. At each node, when a packet is received, it looks at the SL/VL table, if it has VL_{15} it is processed immediately, otherwise, it is inserted into the VL queues to be forwarded to the next hop according to the QoS rules specification.

There are many possible measures that can be used to test the performance of the VLs. Only some of them will be considered here. Let's assume that D_i represents the delay induced in the VL by the i[th] packet, and W_i represents the waiting time for the same packet, and S_i represents the service level. Then, we can calculate W_i as follows: $W_i = D_i + S_i\, Q(t)$. Furthermore, if we assume that the number of packets processed in time t is α, the number of packets in the network at time t is $L(t)$, and the number for all VLs in all Nodes is $Q(t)$. Then, $L(t)$ can be calculated as: $L(t) = Q(t) + \alpha$. Furthermore, to calculate the capacity of VL (d), and the weight of VL in the network (w), we can sum all values for the delay and waiting time in any VL over the number of nodes (n) as follows:

$$d = \lim_{x\to\infty} \frac{\sum_{i=1}^{i=\infty} Di}{n} \qquad w = \lim_{x\to\infty} \frac{\sum_{i=1}^{i=\infty} Wi}{n}$$

Similarly, to calculate the average delay and the average waiting time in the VL. we use the following equations:

$$Q = \lim_{t\to\infty} \frac{1}{T} \int_0^T Q(t).\,dt$$

$$L = \lim_{t\to\infty} \frac{1}{T} \int_0^T L(t).\,dt$$

Finally, if VL15 has some packets to consider, and considering that VL15 will block all other VLs from sending packets, the relationship the delay and waiting time will be liner and can be present as: $Q = L + E(S)$.

IV. Simulation Testbed

We have used two main simulators; namely: IBMGTSim [20] and IBSim [21]. IBMGTSim was used as the main simulator due to its flexibility in designing a dynamic topology and its ability to run in different states. The second simulator (IBSim) was used to collect the results at the network steady state. Furthermore, we have used the Poisson distribution method for allocating the nodes across the simulated area; this function has been used extensively by the research community and is considered the most suitable probability density function to describe the traffic in such systems – as the network traffic in our case can be described as "bursty traffic". Table 1 shows the different simulation parameters and their values. It is worth mentioning that some values were chosen based on the standard IB values found in the literature.

V. Simulation Results

We compared our IB-AOMDV approach with traditional routing protocols (AODV and AOMDV) while running the same QoS rules while adding the Virtual Lanes (VLs) setup at IB-AOMDV to serve the QoS rules. We varied the number of nodes from 10 to 100 and changed the transmission rate (R) by changing Link Speed (LS) and Link Width (LW) from

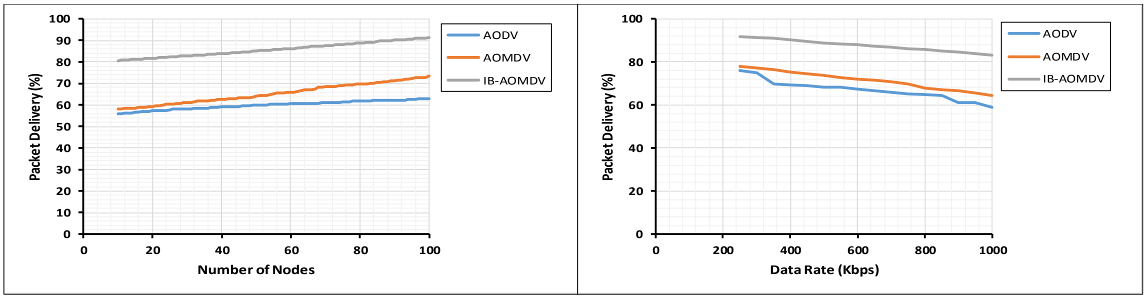

Figure 2. Packet delivery ratio vs. number of nodes (Part A) and data rate (Part B).

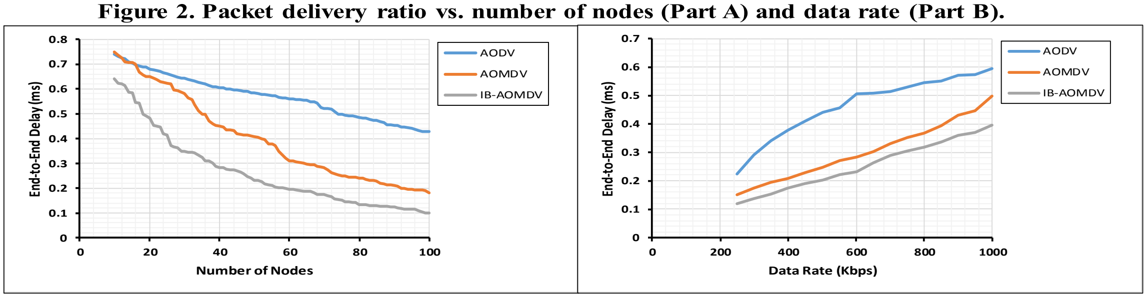

Figure 3. End-to-end delay vs. number of nodes and data rate.

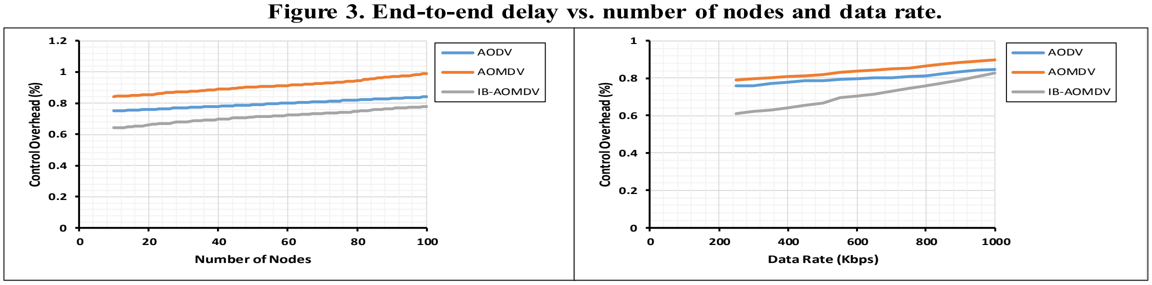

Figure 4. Control overhead vs. number of nodes and data rate.

20KBps to 100KBps and collected the average of all nodes of the following performance matrices: *End-to-End delay; Packet Delivery Ratio;* and *Control overhe*ad.

A. Packet Delivery Ratio

Figure 2 (Part A) shows the packet delivery ratio vs. the number of nodes, and Part (B) shows the same matric vs. the data rate. The packet delivery ratio is defined as the ratio of delivered packets to the total number of packets. From these two plots, we extract the following findings: (1) As Part (A) shows, the enhanced version of the AOMDV protocol (IB-AOMDV) outperforms both AODV and AOMDV in terms of the number of packets successfully delivered to their destinations, then comes AOMDV and AODV, in that order. In average, IB-AOMDV had achieved about 85.5% packets delivery ratio, 65.5% for AOMDV, and 60% for AODV. This means that the packet delivery ratio has increased by about 24% compared to AOMDV and 30% compared to AODV; (2) As the number of nodes increases, the packet delivery ratio increases as well, and in all three protocols the graph increasing almost linearly. In IB-AOMDV, when the number of nodes increases, the packet delivery ratio increases linearly, and the same for all protocols, but for AODV the increased value will be smaller after 60 nodes; (3) in Part (B) we have measured the same matric by changing the data rate and fixed the topology to 50 nodes. IB-AOMDV gives the best results with about 87.6%, then comes AOMDV with about 71.5%, and 70% for the AODV protocol. We conclude that the packet delivery ratio for IB-AOMDV is enhanced by 18% and 20% when compared to both AOMDV and AODV respectively. Furthermore, (4) as the data rate increases the performance of the IB-AOMDV is still higher than the others which gives a strong indication of higher scalability and sustainability of the new method. It is worth noting that we got these significant improvements due to using VLs; there are 15 independent queues that are filled with packets from several QoS levels. The VLs that contain highly important traffic send more packets than the VLs with lower priority, and thus, can find independent paths that are suitable for each QoS rule. Therefore, we managed to increase the delivery rate between important nodes and keep less priority traffic low without affecting important traffic.

B. End-to-End Delay

The second matric we present here is the end-to-end delay, which can be defined as the average time of all traffic from source to destination. Figure 3 shows the simulation results for both cases; increasing the number of nodes and increasing the data rate. Our main findings in this metric can be summarized as follows: (1) As shown in Part (A), IB-AOMDV gave the best results among the others in terms of end-to-end delay. On average, IB-AOMDV achieved about 0.26 ms delay, AOMDV gave 0.4 ms, and AODV gave 0.57 ms. This means that we have achieved an enhancement over the other two protocols by 35% and 54.3% respectively; (2) in Part (B) – increasing the data rate – the behavior of the three protocols is still the same. It is obvious that as the data rate increases the end-to-end delay will be increased as well. By taking the average of all values, we obtained 0.25 ms, 0.3 ms, and 0.46 ms for IB-AOMDV, AOMDV, and AODV, respectively. Thus, we achieved a significant enhancement of 16% and 45.6% compared to AOMDV and AODV, respectively.

C. Control Overhead

Figure 4 shows the simulation results of the third matric considered in this research that is control overhead. It is defined as ratio of routing packet though VL15 in IB-AOMDV to the total number of packets. As we can see IB-AOMDV outperforms the others and gives the smallest overhead regardless the number of nodes. In average, 71.4% for IB-AOMDV, 91.1% for AOMDV, and 79.5% for AODV. This means that the overall performance enhancement of the control overhead that was achieved when considering the InfiniBand mechanism has increased by 21.6% and 10.2% compared to AOMDV and AODV, respectively. In Part (B) the same finding is also valid here. This means IB-AOMDV comes first, then come AOMDV and AODV, respectively. The average values are 71%, 84%, and 80%, with about 15.5% and 11.3% enhancement.

VI. Conclusions and Future Work

In this paper, we have suggested a new mechanism based on the InfiniBand architecture to enhance QoS of multipath routing protocols in MANETs. The simulation results of three QoS performance metrics have shown that our proposed mechanism outperforms both AOMDV and AODV and gave better performance measures. In average, we have achieved 26% enhancement in packets delivery, 45% in end-to-end delay, and about 15% reduction in control overhead. In future work, we will try to adapt routing features and investigate their effect on the entire network while transmitting data; we will especially investigate the case if part of the nodes cannot deliver data and find alternative paths without affecting the QoS rules from source to destination, avoiding the extra work of the source recalculating a damaged path.

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