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Network Coding-Based Priority-Packet Scheduler Multipath Routing in MANET using Fuzzy Controllers

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Abstract

A Mobile Ad Hoc Network (MANET) is a dynamic wireless network that can be formed without the need for any pre-existing infrastructure in which each node can act as a router. Due to bandwidth constraint and dynamic topology of mobile ad hoc networks, multipath supported routing is a very important research issue. This paper proposes a Network Coding-based Priority-packet Scheduler Multipath routing in MANET using fuzzy controllers (NC-PSM). Specifically, differentiated packet scheme with feedback preference information (FPI) is studied in detail to illustrate the implement of the new approach. Simulation shows that the approach is efficient, promising and applicable in MANETs. The performance of the NC-PSM is studied using NS2 and evaluated in terms of the packet delivery ratio, packet overhead, and average end-to-end delay when a packet is transmitted. Simulation shows that the approach is efficient, promising and applicable in MANETs.

Keywords: *MANET; network coding; fuzzy controllers; multipath routing algorithm*

1. Introduction

A mobile ad hoc network (MANET) is a collection of distributed mobile nodes without any fixed infrastructure (such as access points and base stations) or any form of centralized administration. MANETs are defined as the category of wireless networks that utilize multi-hop radio relaying and are generally capable of operating without the support of any fixed-line infrastructure [1-8]. Each node has the capability to communicate directly with other nodes, acting not only as a mobile wireless host but also as a router, forwarding data packets to other nodes. In other words, such networks are self-creating, self-organizing and self-administrating. Key application areas for these types of networks include: conference networking, disaster relief, military networks and sensor networks.

For robust delivery of packets, multipath routing [4-8] is very important because the routes in MANETs are easily fragile. The dense deployment of nodes in a MANET makes multipath routing a suitable and cheap technique to cope with the frequent topological changes and consequently unreliable communication services. Several multipath routing protocols were proposed for MANETs [4-8]. The main objectives of multipath routing protocols are to provide reliable communication and to ensure load balancing of ad hoc and mobile networks. Other goals of multipath routing protocols are to improve delay, to reduce overhead and to maximize network life time.

In their pioneering work [9], Ahlswede *et al.*, showed that if network coding is permitted over the nodes of a network, the communication rate can be improved over that obtainable by

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routing alone. Li *et al*., [10] showed that linear coding is sufficient for solving multicast network coding problems. The authors also proposed a distributed coding-aware routing (DCAR) scheme in [11], with which available paths and potential coding opportunities can be discovered. Yao *et al*., [12] presented a high efficient multipacket decoding approach for network coding (EMDNC) in wireless networks, EMDNC can improve the efficiency of decoding and reduce the number of retransmission and transmission delay. Kagi *et al*., [13] proposed an efficient and reliable packet transmission method by using multipath routing constructs from multiple node disjoint routes, and by applying network coding which allows packet encoding at a relay node.

In [14], Yan *et al*., proposed the use of fuzzy logic controllers for the dynamic reconfiguration of edge and core routers. This reconfiguration allows for adjusting the network provisioning according to the incoming traffic and the QoS level achieved. The fuzzy logic is used to the uncertainty associated with ingress traffic estimation and to the non-linearity. Lack of mathematical models is able to estimate this traffic. A fuzzy controller is specified by fuzzy sets definition (membership function) and a set of rules (rule base). Din *et al*., [15] proposed a token bucket fuzzy logic bandwidth predictor for real time variable bit rate traffic class. The fuzzy logic bandwidth predictor facilitates bandwidth predicting and dynamic policing based on the class based packet aggregates. Chen *et al.*, [16] presented a technique based on fuzzy logic to solve the uncertain measurement error by multipath propagation. Several works make use of controllers based on fuzzy logic. Zarandi *et al.*, [17] develop expert systems for diagnosis of asthma disease by the method of Fuzzy Logic. The knowledge acquisition process is done by using a semantic network. Knowledge representation is done with the production rules. Fuzzy inference method used is the Mamdani method and the method used is defuzzification centric method.

Without scheduling, the packets will be processed in FIFO (First In First Out) manner and hence there is more chance that more packets may be either dropped or not meet the network coding. A scheduler should schedule the packets to reach the destination quickly, which are at the verge of expiry. In this paper, we propose a fuzzy based Scheduler for scheduling the packets based on its priority index. The priority index for each packet is determined based on number of hops the packet has suffered and the buffer size [18]. It is found that the proposed fuzzy scheduler provides improved packet delivery ratio, reduced average end-to-end delay and increased throughput, when tested under various mobility conditions.

This paper proposes a Network Coding-based Priority-packet Scheduler Multipath routing in MANET using fuzzy controllers (NC-PSM). Specifically, differentiated packet scheme with feedback preference information (FPI) is studied in more detail to illustrate the implement of the new approach. It is typically proposed in order to increase the reliability of data transmission, by applying network coding which allows packet encoding at a relay node. Because the network coding packet is generated by a relay node, the source node does not need to encode the packets but to send only data packets to each route. Thus, the packets transmitted by the source node are not increased.

The rest of the paper is organized as follows. In Section 2, we introduce multipath routing and network coding in MANETs. Section 3 presents network coding method in MANETs. Section 4 shows the fuzzy scheduler controller of network coding packets. Some simulating results are provided in Section 5. Finally, the paper concludes in Section 6.

2. Related Work

Ad hoc On-demand Distance Vector (AODV) routing protocol [5] is an on-demand variation of the distance vector routing protocol. Route discovery: When a source node desires to send a message to a certain destination node to which it does not have a valid route, it initiates a route discovery process. The source node broadcasts an RREQ (Route REQuest) message to its neighbors, which then forward the request to their neighbors, and so on, until either the destination or an intermediate node with a route to the destination in its routing table is reached. Route maintenance: When a source node moves, it has to reinitiate the route discovery protocol to find a new route to the destination. On the other hand, when an intermediate node along with the route moves, its upstream neighbor will notice route breakage due to the movement and propagate an RERR (Route ERRor) message to each of its active upstream neighbors.

Many routing protocols preserve a caching mechanism by which multiple routing paths to the same destination are stored. Multipath routing is essential for load balancing and offering quality of service. Ad hoc On-demand Multipath Distance Vector (AOMDV) [6] is an extension to the AODV protocol for computing multiple loop-free and link-disjoint paths. The protocol computes multiple loop-free and link-disjoint paths. The Scalable Multipath On-demand Routing (SMORT) is proposed in [7], which establishes fail-safe paths between intermediate nodes and the destination node, reducing the delay and routing overhead, while achieving higher packet delivery ratios. Figure 1 shows multipath routing mobile ad hoc network.

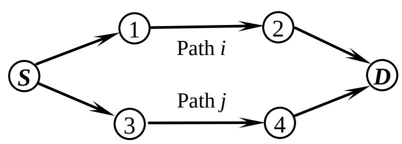

Figure 1. Two Routes with Different Route Quality between *S* and *D*

For example, a wireless network coding scheme depicted in Figure 2. In this example, two wireless nodes need to exchange packets *a* and *b* through a relay node. However, the network coding approach uses a store code and forward approach in which the two packets from the clients are combined by means of an XOR operation at the relay and broadcast to both clients simultaneously. The clients can then decode this coded packet to obtain the packets they need.

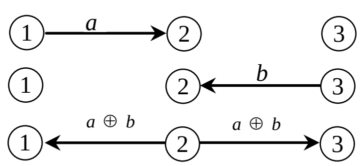

Figure 2. Wireless Network Coding

The binary symbol $a \oplus b$ is a mathematical function of *a* and *b*. Calculation of a function from received data is called coding. This shows the merit of mixed coding among multiple messages at an intermediate node. This is called network coding (NC). In algebra, $a \oplus b$ is called the binary sum of *a* and *b*. Interpreting in more general terms of linear algebra, this is the linear sum $1 \cdot a + 1 \cdot b$ over the binary field. Thus, the calculation of $a \oplus b$ not only is a form of coding but also belongs to the more restricted form of linear coding.

3. Network Coding and Multipath

In our proposed method, multiple link-disjoint paths are constructed, and then the source node sends packets to a neighbor node on each path. The neighbor node generates an encoded packet when it receives the necessary data packets for encoding, then the neighbor node sends the encoded packet [13].

3.1. Basic Model

In our proposed method, network coding (NC), multiple link-disjoint routes are constructed. Figure 3 shows an example of two link-disjoint routes.

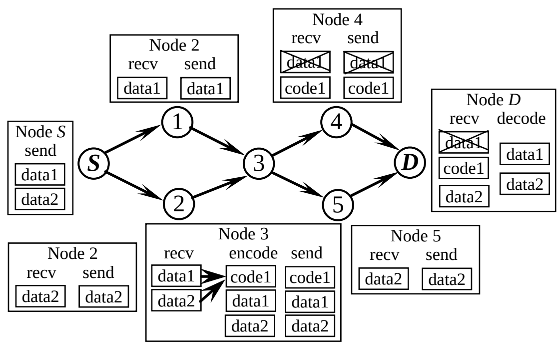

Figure 3. Sample Model using NC

We assume the following two routes are constructed.

Primary path: (*S*, 1, 3, 4, *D*).

Secondary path: (*S*, 2, 3, 5, *D*).

Even if the data packets are lost, the destination node decodes the coded packets and successfully retrieves the data packets.

As shown in Figure 3, first, source node *S* sends a data packet named data1 to node 1. Node 1 receives data1 then forwards it to the next node, Node 3. Node 2 receives data2 then forwards it to the next node, Node 3. Node 3 receives data1 then buffers data1. Next, Source node *S* sends a data packet named data2. Again, node 2 receives data2 then forwards it to the next node, Node 3. Node 3 receives data2, and then generates the encoded packet code1 by encoding from data1, which is buffered, and data2. The node 4, 5 forward the packets on their respective routes.

For example, let us assume data1 is dropped between nodes 3 and 4. However, destination node *D* receives code1 and the data 2, and so data1 can be decoded from these packets. Therefore, the number of transmissions does not need to be increased, and reliability can be improved because the encoded packet can be forwarded to destination node *D*.

3.2. Construction of Multiple Routes

We use AOMDV [6] protocol to construct the multiple link-disjoint routes. AOMDV has the best performance for multipath routing [8]. The AOMDV computes the multiple paths with minimal additional overhead, contrary to other multipath routing protocols. If multiple link-disjoint routes are not constructed, the network coding will not be used and all nodes will send only the data packets. Similarly, all nodes send data packets when a single route is constructed.

Based on the distance vector concept, AOMDV shares several characteristics with AODV, using hop-by-hop routing approach. Moreover, AOMDV also finds routes on demand using a route discovery procedure. In AOMDV, RREQ propagation from the source towards the destination establishes multiple reverse paths both at intermediate nodes and at the destination. Multiple RREPs traverse these reverse paths back to form multiple forward paths to the destination at the source and intermediate nodes.

The core of the AOMDV protocol lies in ensuring that multiple paths discovered are loop-free and link-disjoint, and in efficiently finding such paths using a flood-based route discovery. AOMDV route update rules, applied locally at each node, play a key role in maintaining loop-freedom and disjoint properties. The simulation study conducted on AOMDV shows that there is a reduction, on the whole, of overhead in the network.

3.3. Network Coding Method

The network coding idea was introduced by Ahlswede *et al*., [9]. Usually, the routers or relay nodes just forward and duplicate the packets in the networks. However, network coding permits routers or relay nodes to encode the packets.

In this paper, we use a linear network coding scheme [10]. The linear network coding scheme is an encoding method such that coding vector $g_i = (g_{i1}, g_{i2},\ldots, g_{iN})$ is given, and input packet $M = (M_1, M_2,\ldots, M_N)$ is converted into output packet P_i by the following expression [13].

$$P_i = \sum_{j=1}^{N} g_{ij} M_j \tag{1}$$

The destination node can decode input packets because the coding vector $G = (g_1, g_2, \ldots, g_N)$ and output packet data $P = (P_1, P_2, \ldots, P_N)$ are obtained from the received packets, and an inverse matrix exists in G.

4. Fuzzy Controller

4.1. FPI Scheme

Two bits are used as a Different Priority Packet Point (DPPP) to select the per-hop behavior a packet experiences at each node whereas two bits are Currently Unused (CU). Table 1 shows the different priority byte structure.

Table 1. The Different Priority Byte Structure

0 1	3 4
DPPP	CU

The different priority bytes in the feedback preference information (FPI) theme are shown in Table 2. According to this table, one can understand that bit 0 at a different priority byte indicates if the packet is network code packet, and bit 1 indicates if it is a non-network code packet.

Table 2. The DPPP Allocation in the FPI Scheme

Priority Class	Code point space	Type of Service
0	00XX	Network code packet
1	11XX	Non-network code packet

4.2. Different Priority Controller Architecture

The controllable elements in the different priority architecture are shown in Figure 4. In this architecture, all nodes have a separate queue for each service class; a classifier places the packets into the respective queue and the scheduler selects packets from these queues for transmission in the output links. In addition to these elements, the edge nodes contain a marker that (re)-marks each packet, and a police that keeps the ingress traffic on edge node as contracted. The proposed architecture implements two controllers: one that controls the queues and scheduler, which is used in the core and edge nodes, and the other that controls the police, which is only used on the edge nodes.

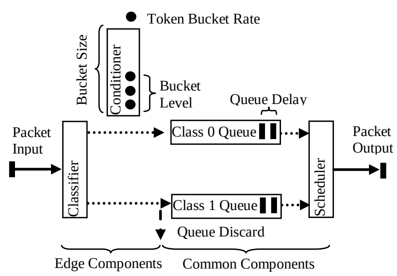

Figure 4. Different Priority Controllable Architecture

4.3. Rule Base and Inference

Rule base is an IF-THEN rule group with fuzzy sets that represents the desired behavior of a fuzzy system. It can be defined in agreement with the administrative policy.

1) Scheduler controller. A synthesis of the scheduler controller rule base is presented below:

a) If the delay in DPPP queue is medium, then the queue weight is increased by one level; *e.g.*, if the weight was low it goes to medium. And if DPPP delay is high the queue weight is increased by one level.

b) If the delay in DPPP queue is low and the packet discard rate in effort traffic queue is medium, then queue weight is reduced by one level. And if effort traffic packet discard rate is high the queue weight is reduced by one level.

2) Police controller. A synthesis of the police controller rule base is presented below:

a) If the DPPP queue delay in core node is medium, then the police rate is reduced by one level. If DPPP queue delay in core nodes is high, the police rate is reduced by one level.

b) If the packet discard rate of effort traffic class in edge node is high and DPPP queue delay in core nodes is low, then the police rate is increased by one level. If packet discard rate of effort traffic class in edge node is high and DPPP queue delay is low, the police rate is increased by one level.

5. Simulation Experiments

5.1. Simulation Model

To conduct the simulation studies, we have used randomly generated networks on which the algorithms were executed [19]. This ensures that the simulation results are independent of the characteristics of any particular network topology.

The results of the simulation are positive with respect to performance. We use the NS-2 simulator [20] to evaluate the NC-PSM in Diff-Packet Scheduler using Fuzzy Controllers. It is particularly popular in the MANET community, and many protocols used in MANETs have been implemented, including IEEE 802.11, the standard wireless LAN MAC protocol.

To effectively evaluate with NC-PSM scheduler's performance, we compare with fuzzy controller scheduler and without fuzzy controller scheduler for cost to control information, average link-connect time, the success rate to find the path and the feature of data transmission. A mobile ad hoc network is generated as follows: there are 100 nodes in the network and they are confined in a square area of 1000 m × 1000 m; the radio transmission range of a node is 250 m and channel capacity of 2 Mbps is chosen. There were no network partitions throughout the simulation. Each simulation is executed for 600 seconds of simulation time. In the beginning, the nodes are randomly placed in the area. Each node remains stationary for a pause time, which is exponentially distributed with a mean of 10 seconds. The considered bit rate here is 20 packet/s. The node chooses a random point in the area as its destination and starts to move towards it and moves according to Random Way Point model. By increasing the speed, the mobility will also increase. For randomized simulations, the speed is varied between the interval of 0 and 20 m/s. A speed of 0 m/s corresponds to a static network, whereas a speed of 20 m/s corresponds to move speed, which represents high mobility.

5.2. Performance Metrics

We will compare the performance of NC-PSM and without fuzzy controller or network coding scheduler multipath routing methods under the same movement models and communication models. We primarily consider the following four performance metrics.

1. Packet overhead — the total number of protocol overhead packets over transmitted data packets and encoded packets.

2. Average end-to-end delay of data packets — it represents the average value of the time that the received data packets take to reach the destination from their origin.

3. Packet delivery ratio — Packet delivery ratio is the ratio of the number of data packets actually delivered to the destinations to the number of data packets supposed to be received. The packet delivery ratio shows the transmission efficiency of the network with the given protocol.

4. Packet loss — the failure of one or more transmitted packets to arrive at their destination.

The performance of the network with the NC-PSM's scheduler and without the fuzzy controller or network coding scheduler is studied under various conditions such as variation in network size, mobility of the nodes and the routing protocols used in the simulator.

5.3. Simulation Results

Figure 5 shows the packet overhead as a function of the node's mobility speed for each protocol. The packet overhead increases as the packet loss rate increases because the node's mobility speed increases. The NC-PSM scheduler, which sends both the data packets and network coding packets, has lower packet overhead than without fuzzy controller or network coding scheduler does, because without fuzzy controller or network coding scheduler sends only the data packets. Figure 5 shows a comparison of packet overhead. For the this simulation factors, the network coding-based multipath routing in diff-packet scheduler using fuzzy controllers have smaller routing overhead than the without fuzzy controller or network coding scheduler. On the average fuzzy controller scheduler reduces the routing overhead by 30-40% as compared to without fuzzy controller or network coding scheduler.

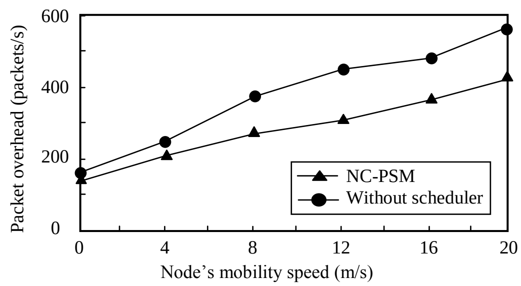

Figure 5. Routing Packet Overhead with Varying Mobility

The average end-to-end delay includes all possible delays from the instant the packet is generated to the instant it is received by the destination node. Figure 6 depicts the comparison of average end-to-end delay under total of network nodes for both protocols. The increase of movement speed induces more frequent topology change and therefore the probability of broken links grows. Broken links may cause additional route recovery process and route discovery process. Because of this reason, the average end-to-end delay of packet increases as node speed increases. From the Figure 6 we can see that when the node's mobility speed increases, the NC-PSM scheduler average end-to-end delay is lower than that of without fuzzy controller or network coding scheduler.

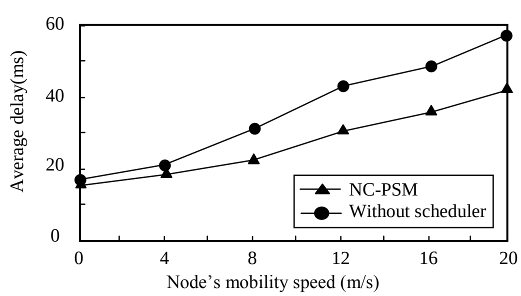

Figure 6. Average end-to-end delay with Varying Mobility

From the simulation results we obtained, we can conclude that, compared to without fuzzy controller or network coding scheduler, NC-PSM scheduler has almost the same performance with low mobility and low network load. However, when the speed of the nodes or the network load increases, NC-PSM scheduler has a better delivery ratio and a shorter delay than without fuzzy controller or network coding scheduler, without fuzzy controller or network coding scheduler has due to the ability to distribute the packets through different paths.

Packet delivery ratio is a key metric as it shows the loss rate, which in turn affects the maximum throughput of the network. With regard to the network coding when a byte of data is transmitted, Figure 7 shows the simulation results of the NC-PSM scheduler routing protocol, and without fuzzy controller or network coding scheduler. Figure 7 shows the packet delivery ratio of routing methods according to the increase of node's maximum speed. As the nodes maximum speed increase, a packet delivery ratio of methods decreases. It is mainly due to the fact that not only the higher node mobility induces more frequent link breakage but also the larger number of connections increases the probability of link breakage. That is, diff-packet scheduler using NC-PSM is much more robust than without fuzzy controller or network coding scheduler in harsh operation environments.

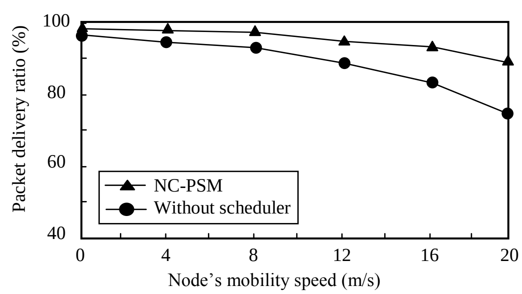

Figure 7. Packet Delivery Ratio with Varying Mobility

Packet loss mechanisms are much more complicated in MANETs because wireless links are subject to transmission errors and the network topology changes dynamically. Packet loss for the two schemes is shown in Figure 8, NC-PSM scheduler has the lower packet loss, a consequence of lower route discovery latency. Packet loss takes into account packet drops at the MAC and the network layer. Packet losses follow increases in mobility because the protocol is sending RREQ packets on a broken route that it still considers being valid and, thus packets in node buffers are dropped because of congestion and timeouts. Packet loss in NC-PSM scheduler is lower simply as a consequence of better link fault tolerance when compared with the other schemes.

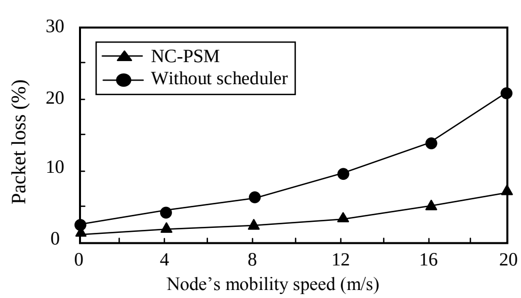

Figure 8. Packet Loss with Varying Mobility

6. Conclusion

This paper discusses multpath routing problem, which may deal with the network coding model for researching the MANET multpath routing problem. It presents a Network Coding-Based Priority Packet Scheduler Multipath Routing in MANET using Fuzzy Controllers. It is typically proposed in order to increase the reliability of data transmission, by applying network coding which allows packet encoding at a relay node. Because the encoding packet is generated by a relay node, the source node does not need to encode the packets but to send only data packets to each route.

A possible future work is to apply the network coding scheme to other routing protocols for MANETs, so network coding scheme can provide more robust and scalable routing paths. Our future work includes the exploration of a new multipath routing protocol for MANETs with asymmetric links as well, which should be a very challenging work.

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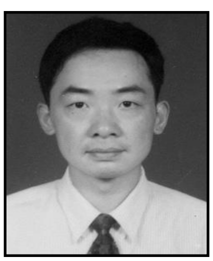

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