Congestion Control Approaches for Multi-path Routing in Wireless Ad Hoc Networks

By

Rishitha Reddy Kallu (UFID: 20015890)
Manogna Sai Kolluri (UFID: 83231363)
Haritha Vannemreddi (UFID: 48876144)
Rakesh Gaini (UFID: 82662450)
Aalekya Reddy Chintala (UFID: 61983722)

Abstract

Wireless devices to one another without the standard network infrastructure equipment. It faces several problems and obstacles. In a WANET, congestion control is a difficult task to do. When there is more demand than the resources to meet it, congestion occurs. A variety of strategies have been suggested to get around the wireless ad hoc network's congestion. Multipath routing, in which data is transmitted over many pathways between source and destination, is one strategy for reducing congestion; nevertheless, congestion can occur if suitable strategies are not followed. Surveys on different congestion control approaches for multipath routing can improve network throughput and fairness. In this paper, we discuss existing methods, their advantages and disadvantages, and potential future work.

1. Introduction

1.1 Wireless Ad Hoc Networks

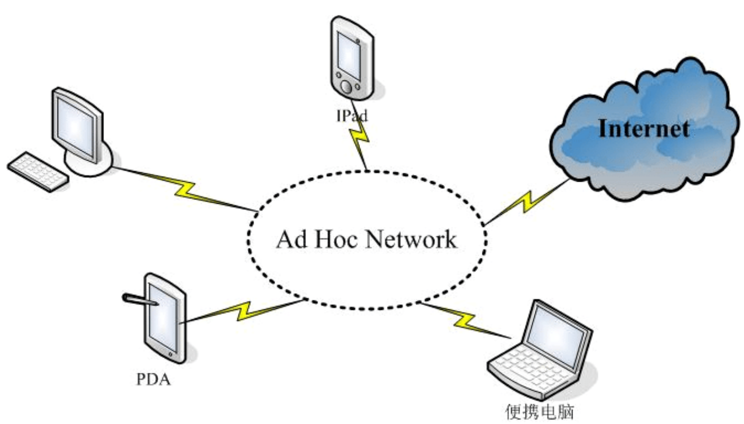


Figure 1: Wireless ad hoc network

Wireless ad hoc networks (WANET) are self-organizing wireless networks formed by several mobile devices or nodes that connect without a fixed infrastructure or centralized control. Each node in a WANET interacts with other nodes, transmits data packets, and carries out routing tasks. Each node in a WANET must carry out network administration tasks such as neighbor detection, routing table upkeep, and congestion control because there is no centralized control in a WANET. Due to the dynamic network topology of a WANET, where nodes can move or connect/leave the network at any moment, routing protocols for WANETs need to be robust and adaptable to endure frequent changes in the network. WANETs use different wireless communication technologies. These technologies' range, bandwidth, and power consumption vary, which can impact the network performance. WANETs have numerous applications, including emergency response, military operations, vehicular networks, sensor networks, and home automation. However, since the network structure is dynamic and there is no centralized control, WANETs face various challenges, such as security, scalability, reliability, and energy efficiency. Researchers are developing new protocols and algorithms to overcome these challenges and improve WANET's performance.

A type of WANET in which mobile devices form a temporary network without needing a fixed infrastructure is called a Mobile ad hoc network (MANET). It is a wireless, decentralized, unstructured network that relies on routing for communication. In a MANET, each device acts as a node and communicates with other nodes within the network to establish and maintain connectivity. Since nodes may move about freely and carry out various functions, including relaying and transferring data packets from a source to a destination node, the network topology can change rapidly. The communication between nodes in a MANET is typically performed using wireless technologies. It can be organized in different ways, like a mesh network, a peer-to-peer (P2P) network, or a hierarchical network. The subsequent sections give a survey on the WANET and MANET network's routing protocols, advantages, and challenges.

1.2 Routing in Wireless Ad Hoc Networks

The process of transmitting data packets from the source node to the destination node through a series of intermediary nodes is known as routing in WANET. Each node in a WANET is in charge of transmitting data packets to its neighbors, who in turn transmit the packets to their neighbors, and so on, until they reach the destination. Based on how they function, routing systems in WANETs can be categorized into three groups:

Proactive routing protocols: Even when there aren't any active data transactions, these protocols keep the routing information for each node in the network up to current. Proactive routing techniques include optimal link state routing (OLSR) [8] and destination-sequenced distance vector (DSDV) [24]. Proactive protocols are better suited for networks with high mobility and frequent topology changes.

Reactive routing protocols: These protocols, also called on-demand routing protocols, only create a route when necessary, that is when a source node needs to deliver data to a destination node. Ad hoc on-demand distance vector (AODV) [25] and dynamic source routing (DSR) [10] are two examples of reactive routing techniques. Networks with less mobility and irregular data flows are more suitable for reactive protocols.

Hybrid routing protocols: These protocols balance the overhead of keeping routing information and the latency of creating a new route by combining the benefits of proactive and reactive protocols. Zone routing protocol (ZRP) [11] and wireless routing protocol (WRP) [12] are two examples of hybrid routing protocols.

1.3 Congestion in Wireless Ad Hoc Networks

When the traffic demand for WANETs exceeds the network's capacity, congestion occurs, causing packet loss, longer delays, and reduced network performance. Congestion control becomes difficult since WANETs are decentralized, self-organizing networks without any fixed infrastructure or centralized control. Congestion results in packet losses, bandwidth degradation, and time and resources wasted on congestion recovery. WANET routing techniques may not be aware of congestion, which can result in a number of problems that can significantly degrade the network performance. Some of these issues include:

1.2.1 Increased packet loss: Network congestion can result in increased packet loss, which can decrease the network's quality of service (QoS).

1.2.2 Increased delay: Congestion can cause an increase in packet delay, resulting in increased end-to-end delay for data transmissions. This can lead to a decrease in the responsiveness of applications and overall network performance.

1.2.3 Decreased network throughput: Congestion can decrease network throughput due to increased contention for network resources, resulting in reduced network performance.

1.2.4 Routing loops: In the absence of congestion-aware routing protocols, congestion can lead to routing loops where packets are continually forwarded between nodes, resulting in increased network overhead and a decrease in overall network performance.

1.2.5 Energy inefficiency: Congestion can also lead to increased energy consumption by the network nodes, which can significantly impact the network nodes' battery life.

1.4 Congestion Control in Wireless Ad Hoc Networks

Congestion control mechanisms for multipath routing in WANETs are essential in improving network throughput and fairness. Congestion control aims to prevent the network from becoming overloaded with data traffic by regulating the rate at which data is transmitted. There are several approaches for congestion control in WANETs, including end-to-end congestion control and hop-by-hop congestion control. Overall, the goal of congestion control in WANETs is to ensure the efficient use of network resources while maintaining good network performance and avoiding congestion. This can be achieved through local and global mechanisms that allow each node to detect congestion and adjust its behavior accordingly.

1.5 Multipath Routing in Wireless Ad Hoc Networks

In WANETs, multipath routing refers to using numerous pathways between a source node and destination to improve communication reliability and efficiency. In classical routing, a single path transfers data from the source node to the destination node. However, the communication link quality in WANETs is unpredictable due to interference, fading, and other reasons. As a result, a single channel may not always be enough to provide consistent communication. Multipath addresses this issue by transmitting data through multiple paths simultaneously, providing redundancy and load balancing. This may lead to increased network throughput, decreased end-to-end delay, and improved network failure resilience. Wireless ad hoc networks benefit from multipath routing because it increases network capacity, reduces congestion, and improves network reliability. However, it has challenges, such as increased complexity, higher overhead, and increased power consumption. Overall, multipath routing is an essential technique for improving the efficiency and reliability of WANETs, and there has been extensive research in this area. Some of the algorithms and approaches proposed by several researchers over the past decade are discussed in section 3 of this paper.

2. Motivation

In an ever-expanding world, we need to transport data effectively and reliably, which includes transferring data in less time while eliminating data loss. With such criteria, we are attempting to wirelessly transfer massive volumes of data from one location to another. Wireless ad-hoc is a temporary network that does not depend on any irrelevant hardware and has a limited transmission range. Obstruction control and frequent changes in network topology can also occur. In such cases, more congestion issues may degrade the network's quality of service(QoS) and cause packet loss. As a result, it is critical to solve this issue. The most common strategy is multi-route routing, which sends data across various paths. Congestion control mechanisms for multipath routing in WANETs are significant because they aid in managing network traffic and avoiding network congestion. If the traffic load is not evenly distributed over the available pathways in a WANET, congestion may occur when several channels are used to transfer data. This is higher in wireless than wired networks because wireless networks have substantially lesser capacity than traditional links. Congestion can cause packet loss, increased latency, and decreased network throughput, influencing the overall network's performance and dependability. Congestion control mechanisms govern the traffic flow on each path and guarantee that the network is working within its capability to solve this problem.

3. Existing Algorithms:

3.1 <u>Ad hoc On-Demand Multi Route Distance Vector (AOMDV) in Mobile Ad Hoc Networks (2012)</u>

Wireless ad-hoc networking is a transient network that does not depend on irrelevant hardware and has a limited transmission range. Obstruction control and frequent network topology modifications are a problem in such networks. Ad-hoc networks randomly vary in network topology as well. Destination Sequenced Distance Vector Routing(DSDV)[24] can scale to small networks with fewer nodes, but Ad-hoc On-demand Distance Vector(AODV)[25] is preferred as it uses the bandwidth efficiently. The problem with the dynamic network changes might lead to fading and interference while the packet is transmitted. Lack of congestion control causes packet loss, delay in transmission, and high overhead. Low throughput and fairness problems are observed in networks with congestion.

In [23] an AODV protocol with wireless agent-based congestion control is proposed. These agents carry information of routing and the status of node congestion. They select a node with less load as its next hop and modify the routing table dynamically. Each node in the network has a routing table with up to k entries holding information about neighboring nodes. The final path is selected based on a metric called the congestion metric. This metric is calculated using two estimates: the estimation of Queue Length and the estimation of channel contention. The overall congestion metric is the product of the distribution of the channel's contention and the queue length estimate. However, this addresses the congestion control in single-path routing.

By considering multi-path routing, Soundararajan S and Bhuvaneswaran R.S. presented an adaptive approach in multi-path routing[14] to reduce congestion and accomplish load balancing in MANET networks. It employs Ad hoc On-Demand Multi Route Distance Vector (AOMDV), a reactive routing mechanism, to identify and maintain on-demand routes and provides these routes to intermediate nodes on the primary path. The significant criteria examined for the best fail-safe routes to the destination are

- The total energy spent by the path should be minimum
- The total residual battery powers of all nodes along the path should be maximum

Based on this criterion, the source selects and stores the best routes. Using these multiple paths, the data is transmitted from source to destination. To detect congestion, a path counter (PC) is maintained in each of the intermediate nodes to monitor the number of possible paths traveling via that node. If any other source wants to transmit the data using a route that was already used by another source, then the path counter gets increments by 1 for that node. If PC exceeds the threshold, contention increases, determining that congestion can occur in this path and transmission should be stopped. The node continuously sends the overloaded traffic value (total capacity of node – total load on the node) and sends this value as feedback to the respective source. Hence, the source will know the value of overloaded traffic if the PC reaches its threshold.

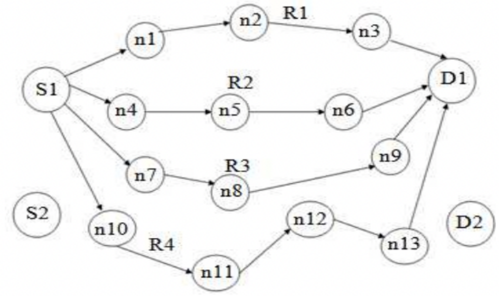


Figure 2: multi path route discovery

In figure 2, to reach S1 to D1, there are 4 paths i.e., R1, R2, R3 and R4. As discussed above, the total energy for every path E_{toti} is calculated using the equation below.

$$E_{tot_i} = E_i^{RTS} + E_i^{CTS} \quad i{=}1,2,3,4$$

$$\text{where} \quad E^{RTS} = \lambda \times d_M^R \times t_{RTS} \quad \text{and} \quad E^{CTS} = \lambda \times d_M^R \times t_{CTS}$$

In the above formula, R is the exponent of path loss, t_{CTS} and t_{RTS} are the RTS and CTS transmission times respectively. N_R are all the nodes used in the path.

The total residual battery for each path is measured by summing up the residue battery of each node as shown in the below formula.

$$b_i^r = \sum_{j=N_{R_j}^b} \quad where\ i{=}\ 1,2,3,4$$

Now the routes with minimum value of E_{toti} and maximum value of b^r_i are considered as the best routes for S1 to D1 data transmission. Now all the best routes have the path counter, if any source selects the same path, then PC of that will be incremented by 1. If the PC reaches a threshold, node sends a rate of overloaded traffic to inform the source about the congestion.

Advantages:

- As this chooses the efficient energy paths, transmission is reliable and stable
- If congestion is detected, then recovery is done quickly

Disadvantages:

- Each node in a mobile network has a limited amount of battery power.
- As the number of nodes increases, buffer management, and congestion control may become complex

3.2 Multicast Ad hoc On-demand distance vector using SGD-DLNN algorithm:

Congestion control's main objective is to reduce the overflow of the buffer and transmission delay caused by congestion while also improving network performance[30-32]. In the previous approach, we used the AOMDV protocol to decide the best route based on the energy and residual battery of the nodes. But here, the authors of this research paper[33] have developed a congestion control mechanism to resolve this issue in WANETs using MAODV along with SGD-DLNN, a machine algorithm.

In this protocol, firstly, the source node and destination node are initialized; the source node broadcasts a Route Request (RREQ) packet to find the route to the destination to its neighbors. If any node has found a route to the destination group, it responds by transmitting Route Reply

(RREP) message, allowing the multicast message to be forwarded to all nodes in the group along the path specified by the RREP message irrespective of the data transmission time.

It is important to include the congestion state of each node to avoid congestion. This model considers bandwidth, packet number and data rate as the 3 important metrics to understand about each node's congestion state. To achieve load balancing, authors have used the SGD-DLNN algorithm as part of the MAODV protocol to identify congestion state of every node based on different rules. If congestion is detected, this algorithm avoids the congested nodes and distributes traffic over alternate congestion-free paths until normal traffic conditions are achieved. For detecting the path which is optimal, this protocol utilizes the LF-BWO algorithm based on different criterias such as link cost, lifetime, route distance and residual energy.

$$F_{opmial\ path} = \begin{Bmatrix} max(L_f); & Maximum\ life\ time \\ max(E_R); & Maximum\ residual\ energy \\ min(L_c); & Minimum\ link\ cost \\ min(R_{dist}); & Mininum\ route\ distance \end{Bmatrix}$$

The suggested methodology is simulated in an NS2 simulator and results show that MAODV approach is far more effective in lowering network congestion in WANET as it has higher delivery ratio, higher reliability, low delay and energy consumption.

Advantages:

- The suggested method aids in balancing traffic loads over various paths, which helps in increasing overall network performance.
- Utilizing a machine learning-based method for congestion detection (SGD-DLNN) makes the system more adaptable to dynamic network changes.
- LF-BWO methodology has helped find optimal paths that are efficient, consistent, and shortest, enhancing network efficiency and lowering energy usage.

Disadvantages:

- The proposed methodology requires higher computational resources to implement the machine learning-based congestion detection mechanism, which cannot be possible for devices with constrained resources.
- The suggested technique may not be ideal for networks with a high number of nodes, as the route discovery process may take longer, which results in delays and inefficiencies in the network.

3.3 Fibonacci sequence based multipath load balancing approach for MANETS(FLMB)

The FLMB protocol proposed in the paper [15] mainly distributes packets to the multiple paths in mobile nodes based on the Fibonacci sequence. This process can decrease congestion by increasing the delivery ratio among the paths. This protocol mainly balances the transmission of packets over designated routes and sorts them based on hop count. This method uses the shortest paths more efficiently and reduces congestion. The Fibonacci sequence is shown below mathematically.

$$f_0 = 0$$
$$f_1 = 1$$
$$f_n = f_{n-2} + f_{n-1}; \quad n \geqslant 2.$$

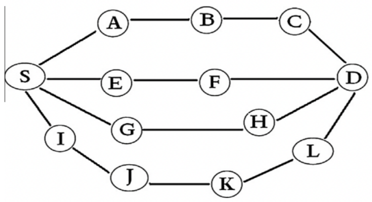


Fig 5: multiple routes between source and destination

Consider Figure 5, where S is the source, and D is the destination with four possible routes from S to D, i.e. (S->I->J->K->L->D),(S->E-> F->D), (S->A->B->C->D) and {S->G->H->D}. If the limit of the number of routes between S and D is 3, then the paths are selected in the ascending order of hops. Hence, {S->E->F->D}, {S->G->H->D} and {S->A->B->C->D} can be chosen, and {S-> I->J->K->L->D} can be ignored because it has five hops. Each route is assigned a weight depending on the hops count. Hence, the weight of {S->E->F->D}, {S->G->H->D} and {S->A->B->C->D} is Fibonacci (3), Fibonacci (2) and Fibonacci (1) respectively. S wants to send five packets; then two are sent over {S->E->F->D} because Fibonacci (3) is two by the above mathematical equation. Similarly, one packet is sent over {S->G->H->D} and {S->A->B->C->D}. The remaining packet is again sent over {S->E->F->D}. If there are k paths, then FMBL assigns the weights depending on hops count, and if the number of hops is the same for two routes, then the most recent one will be placed after the older one according to a sorted list. This way, all the packets get distributed in all the paths to maintain load balancing and reduce congestion.

Advantages:

- This protocol reduces the congestion by distributing the load over the several paths

Disadvantages:

- It has more E2E delay time.
- If more extensive networks are considered with many sources and destinations, this protocol might increase the load on any node as the congestion metric is not considered.

3.4 Multipath Load Balancing Congestion Control (MLBCC) based on path and link costs

There have been many methods for finding the efficient routing protocol path. Most of them focus on the shortest path routing. This can come with a problem where the nodes at the center can be congested as they carry more load when compared to the nodes on the border of the same network. This can lead to link breakage in a path leading to an increase in the packet loss rate, a decrease in the throughput, and path loss. A way to tackle this is to use a multipath routing protocol where multiple paths are selected to transfer the packets. If a node is heavily loaded, it might lead to a delay in the transfer and a reduction in quality of service.

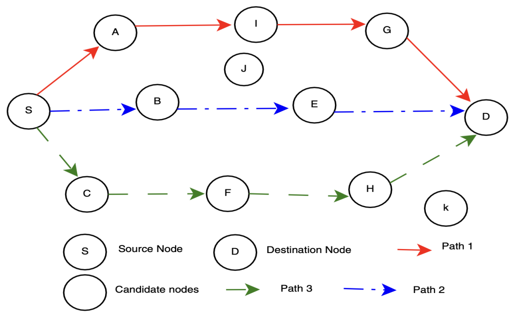
In [17], a protocol that handles congestion control by maintaining load balancing in multi-routing is proposed. Congestion is controlled by detecting congestion based on the arrival and leaving the rate at a specific time T. Load balancing is achieved using the gateway nodes(selected by computing path cost and link cost), the minimum cost is found, and the data transmission is done via these paths.

A node is said to be congested when the size of queue (QL) and length of queue(Lq) are equal (QL = Lq) or if the input rate is more at the node than its output rate($I_r > O_r$). If and when there is congestion, gateway nodes are utilized to discover other reliable paths. These paths are found by calculating the cost of path(P_C) and cost of link(L_C). The path cost is the sum of all link costs. Initially the cost of the path is zero and later it is calculated using the below formula.

$$P\_C = P\_C + L\_C$$

Sometimes, a single node can receive information from various sources, so each individual value is stored, as well as the path with the minimum value of P_C is selected. After the calculations, the top 3 paths with minimum P_Cs will be selected as alternate routes. This is because any less no.of routes will be similar to single path routing and any more can lead to a possibility of selecting the longest path. If there is any traffic from outside the nodes, the standard deviation of node availability degree $\delta(p_i)$ is utilized as a corrective factor.

Consider the network in figure a, where there are three paths from source(S) to destination(D). Assume at node ‘I’ the congestion is detected. Nodes E and B are selected as the gateway nodes and these nodes select 2 other paths for the transmission as in figure b.



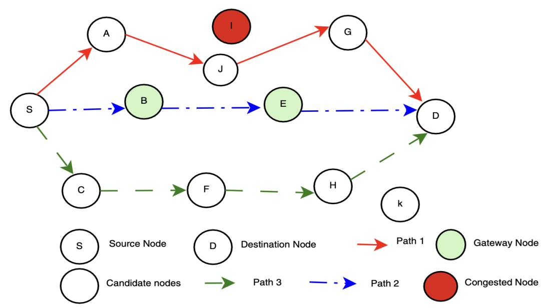


Fig. a multiple paths from S to D **Fig. b** Congestion control and gateway nodes selection

Advantages

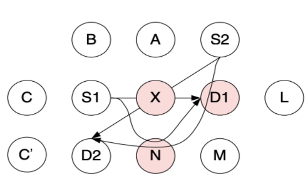
- This technique is compatible with existing multipath routing protocols.
- Efficient load balancing is done among multiple paths by calculating the cost based on energy and available bandwidth
- Improved network performance as a measure of reduced packet loss and delay

Disadvantages

- An additional overhead in the form of information about the available bandwidth of multiple paths is maintained by each node.
- Error correction techniques are not considered in this study, which can help recover packet losses that might be caused because of transmission failures.

3.5 Split Equal-cost Multipath Routing using congestion metric (SEMR) (2013)

The Split Multipath Routing protocol (SMR) on the basis of DSR is a prominent reactive multipath protocol used in WANETs where multiple paths are used between the nodes to improve performance. The main aim of SMR is to construct the maximal disjoint paths to maintain high fault tolerance. Here the destination chooses the first path as the shortest delay path and the second path as the maximal disjoint path. The main problem is that there is a high chance that one node can belong to two data sessions when the destination chooses the shortest delay path. Hence, SEMR is introduced in [14]. SEMR is an enhanced approach of SMR by introducing a unique measure called congestion path metric in the place of the shortest delay path (most minor hop path). This metric determines if the route has a bottleneck node; it can lead to the selection of alternate non-congested pathways while selecting the path.



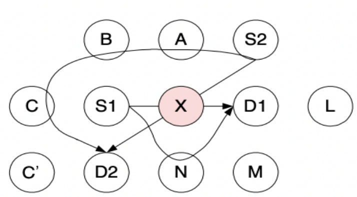


Fig 3: Path selection with SMR Fig 4: Path selection with SEMR

Consider Figure 3 and Figure 4, where two sessions are present S1->D1 and S2->D2. SMR and SEMR choose S1->X->D1 and S1->N->D1, as shown in fig1 and 2, respectively, for the initial data session. If the second data session is considered, SMR selects S2->X->D2 as first path and S2->D1->N->D2 as the second path, which ends up creating three congestion nodes, i.e., D1, X, and N. SEMR selects S2->A->B->C->D2 as a first path to reduce the involvement of congestion nodes instead of choosing a short delay path and the maximally disjoint route is selected as the second path, i.e., S2->X->D2. Now the congestion node is only one, i.e., X. Hence, the SEMR considers the congestion metric explained above and reduces the congestion. The path congestion (PC) with n intermediate nodes is calculated by using the formula below in SEMR.

$$PC = \sum_{i=1}^{n} NC_i$$

Here, Node Congestion (NC) refers to the processing data in each node. It can be estimated based on present and future time. NC_i is the congestion value of a node i.

Advantages:

- The fault tolerance and network efficiency are increased as the protocol chooses the path dynamically based on the congestion metric, and it also balances the load among the different paths. Hence load balancing is also achieved.

Disadvantages:

- Using congestion metrics to find the routes might make the attackers attack the network by manipulating the metric value.
- The issue of deciding on the traffic allocation scheme and scheduling scheme still needs to be solved.

<u>3.6 An Congestion Aware Multipath Routing Protocol using Oppositional Artificial Flora Algorithm in MANETS(2020)</u>

The paper [16] introduces a novel QoS congestion Aware multipath routing using the Oppositional Artificial Flora algorithm (OAF), known as QCMRP-OAF. It also uses a fitness function(FF) which uses the lifetime of the link, congestion, energy, and distance as parameters. This algorithm combines the oppositional-based learning (OBL) algorithm and FF to find the best routes in the network. The OBL is nothing but estimating the opposite population and also the recent population in the same generation to identify the best candidate. This technique is used in this algorithm to identify the best route. The fitness function is calculated using the below formula.

$$F_{fit} = \alpha[100 - f_{obj1}] + \beta[f_{obj2}]$$

Here, f_{obj1} and f_{obj2} are two objective functions and $\alpha=0.1$ and $\beta = 0.9$ which are the weighted constant variables.

Let's say there are k nodes between source S and destination D; initially new routes are produced using the OAF model. The discovered new paths are accessed using FF to select the best route. The provided FF is QoS aware, meaning that paths with the best QoS are selected as outstanding routes. This process stops once the optimum paths are found using discovered routes. Now the data is transmitted between the nodes which have high QoS, less congestion, and more link lifetime.

Advantages:

- This is one of the best algorithms by considering energy, delay, congestion, and packet loss while considering the path.

Disadvantages:

- The details were not exactly given in this paper on how FF includes the lifetime of the link, congestion, energy, and distance.
- The performance can also be improved, and it is stated as future work in this research.

3.7 Backbone based Multipath routing by selecting candidate nodes

Mobile Ad-hoc networks are wireless networks requiring no centralized administration or infrastructure. As a result, node mobility is great. The high node mobility causes difficulties in routing in the form of path failures which may lead to packet dropping. Path rediscovery adds overhead and causes packet losses at this moment. Different techniques address the issues, including proactive, reactive routing protocol(on-demand), and hybrid routing protocols.

In [22], a Stable Backbone Based Multipath Routing Protocol for MANET(SBMRP), a reactive routing mechanism, is proposed to find a stable path to transmit data packets. In the beginning, suitable nodes with high residual power, bandwidth, link quality, and low mobility are considered to be candidate nodes. This is done in two steps: (1) selection of candidate nodes based on the above parameters, and (2) Building of a routing backbone(backbone is a set of candidate nodes).

A HELLO message is sent by the source node, which finds the links to the neighboring nodes. Based on this message, each node identifies itself with the values; if the values of parameters satisfy the threshold requirements, the node is selected as a candidate node. Building a backbone routing involves the discovery of a route and maintaining it. When a node desires to transfer data, the node sends a route request packet to all the nodes in the network. Intermediate nodes will either reply with the destination path or send the request to neighbors. Route request format has a node state field that tells if a node is a candidate or a non-candidate node.

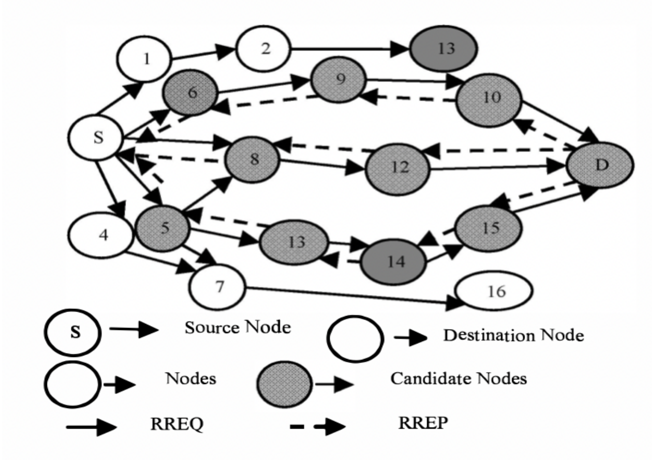


Fig: An example of backbone structure in a network

Multiple paths are established using candidate nodes, as shown in the figure. If any node is failed, it transmits a REER packet which triggers the process of finding alternate paths to the destination.

Advantages

- This technique minimizes the delay, overhead, and packet drop. This also increases packet delivery.
- The performance is enhanced because of the backbone routing protocol.

Disadvantages

- In the construction of a backbone, as the network grows, more resources and time will be required
- Selection of candidate nodes demands information which can be huge as the network is increasing

3.8 New Congestion Avoidance Method(NCAM) by using Ant Colony Optimization

Many congestion control techniques use the method of Ant Colony Optimization(ACO). ACO has been adopted to improve network performance in [18] and [19]. In [20], an NCAM was proposed using ACO. This technique was introduced to enhance the network'snetwork's performance by preventing congestion issues once the optimal route is found. In the next step, the data packets are split into a suboptimal path. They considered four types of ants: forward ants(FAs), backward ants(BAs), local forward ants(LFAs), and local backward ants(LBAs).

The algorithm is as follows: (1) An optimal path found by an agent is used for data transfer. If the path is detected to be congested, a suboptimal path is found. (2) Local forward and backward agents are used to find a sub-optimal path following the rules described in [21]. (3) The packets

are transferred through the newly found suboptimal path. (4) Steps 2 and 3 are repeated if congestion is detected.
If the routing protocol uses the same path, packet loss will occur and degrade the performance of the network [18]. So a threshold of 75% in queue space is used as a metric to find a new suboptimal path. Probabilities are assigned and updated, called pheromone values in the pheromone table. This probability is used for the packets to choose the desired path for data transfer. If congestion is detected in an optimal path, the pheromone value is decreased and is increased in the suboptimal path.

Advantages

- End-to-end delay and Packet loss are reduced using this mechanism
- Improved throughput is observed because of a reduction in retransmissions

Disadvantages

- The proposed technique may be vulnerable to security risks in the form of attacks
- Input rates higher than the capacity were not considered in the study

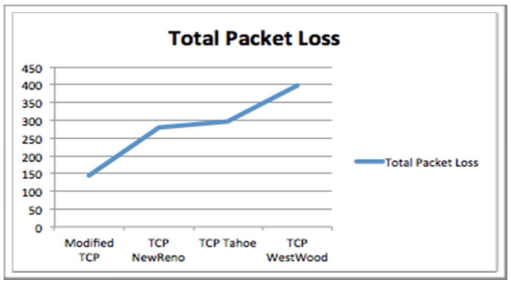
3.9 Cross-layer congestion control in TCP by modifying congestion window size in wireless mesh networks

TCP Protocol is one of the most widely used protocols for transmitting data across the internet. In wireless mesh networks, it was observed that the congestion control mechanism as part of TCP could not effectively control the packet sizes of the data transmitted over the network. This led to issues such as buffer overflow, packet loss, and inefficient utilization of the available network resources. To optimize the congestion control in TCP in such networks, the authors of this research paper[29] have proposed a cross-layer solution by including information from various layers of the protocol stack, which has improved TCP'sTCP's performance.
As Markov Chain steady transition state calculation helps analyze the current behavior and state of the TCP network protocol, the authors have used this technique to estimate the size of the congestion window (cWnd) during the Slow-Start or congestion avoidance stages of TCP protocol. The cross-layer architecture is also utilized to deliver packets over several pathways by monitoring the available bandwidth on every interface and path. This load balancing method divides incoming and outgoing loads among neighboring mesh node connections. The authors have modified the calculation of the size of the congestion window using Round Trip Time and Bandwidth Delay Product of the mesh network based on the TCP Reno algorithm as given below:

$$cWnd = BDP_{byte/sec} \times RTT_{sec}$$

The authors have implemented this solution in NS3 simulation by modifying the MeshL2HWMPProtocol and customizing the congestion window size in TCP. The modified protocol checks the routing table for the destination MAC address using Hybrid Wireless Mesh Protocol (HWMP) once it receives the packet. For those cases where it cannot find the MAC

Address, the authors suggest that assessing alternate mesh link paths with lower metrics to reach the destination can improve the overall routing efficiency. The NS3 simulation has shown that modified congestion window size calculation has reduced the packet loss and aided in better data transmission.



Advantages:

- The proposed methodology utilizes multi-path routing which increases the network capacity and improves the network performance.
- As the methodology modifies the congestion window size,it mitigates the congestion in the network.

Disadvantages:

- The suggested protocol relies on the availability of multiple alternate paths in the network, which might not be the case for a few wireless mesh networks.
- The modification of the protocol and TCP congestion window size will require additional overhead, which might impact the network performance and stability.

3.10 <u>Congestion Control methodology using Relative Traffic Link Matrix Routing in MANETS (2020)</u>

This paper [35] suggests a method that utilizes a link matrix to reduce congestion in MANETs by considering the distance of each selected transmission node before the signal becomes distorted. The technique selected has two key phases; first, point2point traffic matrices are generated using a time-slicing technique, and the end2end traffic matrices are created using various filtering methods. If there is a difference between these traffic matrices indicating a delay in flow rate, the source node establishes a new connection with the destination through a newly created intermediate node. To prevent traffic congestion, a disclosure node is established to keep a check on all potential network routes. Hence, this process is called traffic generation, which helps in congestion identification. To eliminate the congestion, this methodology uses a traffic link matrix constructor.

The algorithm is given as follows:

1. Firstly, the source transmits the data along the route information it gets from its neighbors' route reply messages.
2. The flow rate and latency of all active links that join the source and destination nodes through intermediate nodes are determined after the initial transmission. This is done by mapping the nodes in a 3x3 matrix and calculating the flow rate for each link.
3. If there is any difference between the incoming and outgoing flow, then it indicates that there is a delay. As delay means congestion, the proposed algorithm re-evaluates the 3x3 matrix to a 2x2 matrix which contains information about the congested links and the intermediate node. This helps the algorithm take action to reduce congestion and avoid delays in data transmission.

4. If a node is congested, the node is removed, and the corresponding field in the 3x3 matrix is changed to 0, indicating that a particular node is not in use.
5. After modifying the 2x2 matrix, the algorithm rechecks the flow rate in the modified route.
6. Segmented node is temporarily removed from the table whose value is changed to 0 in the actual matrix.
7. Source then transmits the data again to check the segmented matrix, and if it works, then the previously removed node is considered again, and the 3x3 matrix is restored.
8. If the 2x2 segmented matrix fails to meet the checks, the node is permanently removed by marking it as infinity.
9. After the checks, the source considers only those nodes in the primary matrix.
10. Once the algorithm considers the nodes with a stable flow rate, the link between the neighbors can be considered as constant paths.

This methodology is simulated in NS2, and it shows that RT-LMRA has a lower end-to-end delay, less cumulative overhead, better throughput, and higher packet delivery percentage when used along with DSDV and AODV protocols when compared to Capacity Optimized COoperative communication (COCO) methodology.

Advantages:

- The proposed methodology effectively controls congestion in MANETs by considering both congestion level and network topology.
- Using the relative traffic link matrix aids in distributing the traffic load equally among all the available paths by reducing the possibility of congestion.
- The methodology modifies depending upon the changes in the flow of traffic and topology of the network, which allows efficient and effective congestion control even in dynamic environments.

Disadvantages:

- The suggested methodology requires additional routing tables and matrices, which may increase overhead and complexity.
- The algorithm's performance may be affected by the accuracy of the traffic link matrix estimation and the selection of appropriate congestion threshold values.
- The methodology may not be appropriate for large-scale MANETs, as the computational and communication overheads can be high.

3.11 Optimized Link state routing(OLSR) based on channel and queue utilization:

The work proposed by [26] will reduce congestion-dependent wasted packet flooding and network congestion using explicit rate measurement techniques. This approach uses the OLSR approach while selecting the paths based on the intermediate node channel and queue utilization. For congestion detection and control, the following steps are followed:

Step 1: Estimation of channel consumption in percentage

Obtain the CU(t) [27] channel usage at time t using

$$\%CU = \left(\frac{Tc(t)}{10^6}\right) * 100$$

Step 2: Estimation of intermediate queue length

Long-term node traffic is defined as average queue size LQ [28], which is calculated as

$$L_Q = \psi * L_{Qold} + (1-\psi) * L_{Qc}$$

Where LQc is current queue length value

Step 3: Algorithm for detecting congestion

1. The source sends the data packets to the destination through the intermediate nodes.
2. Let L_{Qth} be the predefined threshold value of queue length.

Let % CU_{th} be the predefined threshold percentage channel utilization

Upon reception of the data packets, intermediate node verifies both the queue length and channel utilization

2.1 If $L_Q > L_{Qth}$ and $\%CU > \% CU_{th}$, Then

Set $C_b = 1$

End if

2.2 If $L_Q <= L_{Qth}$ and $\%CU <= \% CU_{th}$, Then

Set $C_b = 0$

End if

Advantages:

1. A node's excessive load on its neighbors is kept to a minimum.
2. Effectiveness is ensured along with robustness.
3. Reduces the number of packets lost due to queue overflow and end-to-end delay.
4. Efficient use of resources is enhanced.
5. The performance of the network is improved.
6. The route selected by dynamic channel estimation reduces collision.

Disadvantages:

1. When the buffer is full, certain packets may be discarded or fail to be transmitted by the router.
2. The extra information field is added in the packet header

5. Design tradeoffs:

In [24] the practical utilization of the routes is discussed which gives an overview of how many routes are actually used instead of other factors like defining optimal routing metrics etc. It focuses on practical utilization of each node on the network, i.e, if it is utilized to it's full potential or not. The findings of the paper showed that some of the routes in the multipath routing were not practically used at all. So based on the results of this paper, we can understand how to use the optimizing routing protocols to achieve higher routing optimization using AODV. This paper tells us how to use the nodes efficiently based on the practical utilization of the nodes but does not provide information on reducing the routing overhead, improved security, packet loss, etc for the existing nodes. In [26], there is a method suggested to reduce the routing overhead of the network. This paper proposes the OLSR routing mechanism for the mobile ad-hoc networks. It aims to avoid congestion with the help of the feedback messaging. This mechanism ensures successful data transfer with minimum overhead. This is done with the help of estimating the rate, limiting the queue and efficient utilization of Chanel. This design is effective for multiple paths for mobile ad-hoc networks. However, MANETs face other issues with respect to their design which this paper fails to address. These issues include, route fluctuation and packet loss, network attacks. [26] provides an efficient mechanism to resolve the congestion issues but does not involve any means to tackle the other mentioned issues. In [30], we see a new concept of trust based routing for MANETs, this mechanism can deal with the packet dropping issues for MANETs therefore providing an efficient routing algorithm with more throughput. Trust based algorithms are found to be an effective mechanism for reducing the packet dropping in networks. [30] proposes an Uncertainty Analysis Framework(UAF), which categorizes the network behavior based on different parameters. Then based on these parameters and AODV protocol, this model aims to reduce the uncertainty of the network by improving the trust in the network. Therefore, it provides a safe judgment for the security and performance of a network. However, This model is built on a number of assumptions like, while recommendation messages are being exchanged by nodes to discuss their observations, they assume that the integrity of these messages is maintained, which might not be the case in some situations where the integrity is compromised, then the whole judgment might be varied. This paper promises to explore more upon including better parameters for better judgements.

6. Conclusion

Congestion control is of major concern for wireless multipath networks. It increases the delay in the networks and reduces network performance and throughput. Therefore we have conducted an extensive study which includes techniques for congestion control in these networks. This study demonstrates the different algorithms which were proposed for the purpose of congestion control in the network. We have elaborately studied the research papers and have demonstrated our findings. We have also mentioned a few design flaws with the existing networks and how the techniques proposed in other papers could overcome these flaws. The papers cited in this study are over a span of a decade and include various different algorithms and mechanisms for congestion control in multi path Ad-hoc networks which are MANETs, WANETs.

7. Future Scope

Upon studying the different papers and understanding the algorithms, it is safe to say that we do not have a single algorithm that can tackle all the issues but a variety of different algorithms. Some of the papers studied include algorithms like the AODV, OLSR, SGD-DLNN, FLMB, etc. All of these algorithms achieve the objective that they are designed for. However, in order to obtain more optimality, we can make changes to these algorithms so that they can be used to design even better networks. We can use UAF proposed in [30] to be built using other mathematical models like the fuzzy theory etc to ensure better probability modeling. Fuzzy logic can be used for FLMB algorithm [15] as well in order to distribute the load in a dynamic manner over the multiple paths. In [17] we can include techniques for error correction like network coding or forward error correction for multi path routing to compensate for the packet loss occurring because of the transmission failures. For [28] we can use techniques that can provide security considering the dynamic nature of MANETs, because of node mobility it becomes difficult to secure the nodes but we can design an efficient technique that fits the purpose.

Machine learning technologies have taken over the industry because of their ability to provide accurate analysis using efficient algorithms in a way that mimics human intelligence. Hence, we propose a mechanism wherein we can use Machine learning for congestion control in multi path networks too. With the emergence of technologies like WiFi, 5G, wireless networks etc. The networks have become dynamic and it is harder to maintain the state of these networks. This is where we can use machine learning to keep track of the states for the multipath networks, develop a learning model which can be trained rigorously to provide optimal paths based on the various different outputs that the model would give and provide the best route that can minimize congestion, delay and increase network efficiency and performance. We know that training ML models is time taking in the networks, data flows at a much faster rate. To bridge this gap we can use some pre-trained models so that overtime they can adapt to the newer environments and give the best results.

8. References

[8] Clausen, Thomas, and Philippe Jacquet. "*Optimized link state routing protocol (OLSR)*". No. rfc3626. 2003.

[10] Hua, Wu, and Gong Jian. "Analysis of TCP BIC congestion control implementation." *2012 International Conference on Computer Science and Service System*. IEEE, 2012.

[11] Kumaran, T. Senthil, and V. Sankaranarayanan. "Congestion free routing in adhoc networks." *Journal of computer science* 8.6 (2012): 971.

[12] Khatkar, Avni, and Yudhvir Singh. "Performance evaluation of hybrid routing protocols in mobile ad hoc networks." *2012 Second International Conference on Advanced Computing & Communication Technologies*. IEEE, 2012.

[14] Soundararajan, S., and R. S. Bhuvaneswaran. "Adaptive multi-path routing for load balancing in mobile ad hoc networks." *Journal of computer science* 8.5 (2012): 648.

[15] Tashtoush, Yahya, Omar Darwish, and Mohammad Hayajneh. "Fibonacci sequence based multipath load balancing approach for mobile ad hoc networks." *Ad Hoc Networks* 16 (2014): 237-246.

[16] R., Jayaraj. "An Efficient Congestion Aware Multipath Routing Protocol Using Oppositional Artificial Flora Algorithm in Mobile Adhoc Networks." *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 9, no. 4, Aug. 2020, pp. 5121–27.

[17] Mallapur, Sujata V., Siddarama R. Patil, and Jayashree V. Agarkhed. "Load balancing technique for congestion control multipath routing protocol in MANETs." *Wireless Personal Communications* 92 (2017): 749-770.

[18] Grover, Payal, Paramjeet Singh, and Shaveta Rani. "Congestion reduction in wireless mesh networks." *International Journal of Computer Applications* 124.13 (2015): 41-45.

[19] Mani, Saranya, and Ranjana Ponraj. "Optimization With Congestion Aware Routing In Mesh Topology Optimization With Congestion Aware Routing In Mesh Topology."

[20] Pa, Son, and Satria Mandala. "A new method for congestion avoidance in wireless mesh networks." *Journal of Physics: Conference Series*. Vol. 1192. No. 1. IOP Publishing, 2019.

[21] Bokhari, Fawaz, and Gergely Zaruba. "On the use of smart ants for efficient routing in Wireless Mesh Networks." *arXiv preprint arXiv:1209.0550* (2012).

[22] Mallapur, Sujata V., and Siddarama R. Patil. "Stable backbone based multipath routing protocol for mobile ad-hoc networks." *2013 International Conference on Circuits, Power and Computing Technologies (ICCPCT)*. IEEE, 2013.

[23] Rajesh, M., and J. M. Gnanasekar. "Congestion control using aodv protocol scheme for wireless ad-hoc network." *Advances in Computer Science and Engineering* 16.1/2 (2016): 19.

[24] Mehic, Miralem, Peppino Fazio, and Miroslav Voznak. "Usability of destination-sequenced distance vector routing protocol routes." *2019 11th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*. IEEE, 2019.

[25] Singh, Meeta, and Sudeep Kumar. "A survey: Ad-hoc on demand distance vector (AODV) protocol." *International Journal of Computer Applications* 161.1 (2017): 38-44.

[26] Dwivedi, Alok Kumar, and Gaurishankar Prajapati. "Study of Congestion Control in Multi-Flow in MANET." *International Journal of Computer Applications* 122.14 (2015).

[27] Jardosh, Amit P., et al. "Understanding congestion in IEEE 802.11 b wireless networks." *Proceedings of the 5th ACM SIGCOMM conference on Internet Measurement*. 2005.

[28] Gao, Xuemei, et al. "Contention and Queue-aware routing protocol for mobile ad hoc networks." *2007 international conference on wireless communications, networking and mobile computing*. IEEE, 2007.

[29]Toprasert, Thongchai, and Woraphon Lilakiataskun. "Optimized congestion control in TCP with Multi-Path support over Wireless Mesh Network." *2016 13th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*. IEEE, 2016.

[30] Thorat, Sandeep A., and Prakash J. Kulkarni. "Uncertainty analysis framework for trust based routing in MANET." *Peer-to-Peer Networking and Applications* 10 (2017): 1101-1111.

[31]. Zhang, Tongguang, Shuai Zhao, and Bo Cheng. "Multipath routing and MPTCP-based data delivery over manets." *IEEE Access* 8 (2020): 32652-32673.

[32]. Kumaran, T. Senthil, and V. Sankaranarayanan. "Early congestion detection and adaptive routing in MANET." *Egyptian Informatics Journal* 12.3 (2011): 165-175.
[33]Kanthimathi, S., and Jhansi Rani Prathuri. "A novel congestion control approach for optimal routing in Wireless Adhoc Networks." INTERNATIONAL JOURNAL OF COMMUNICATION SYSTEMS 35.10 (2022).
[35]Krishnamoorthy, Devarajan, et al. "An effective congestion control scheme for MANET with relative traffic link matrix routing." Arabian Journal for Science and Engineering 45 (2020): 6171-6181.