

A Survey of Multipath Load Balancing Based on Network Stochastic Model in MANET

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Abstract— Mobile Ad Hoc Network (MANET) is a special kind of network that differs from traditional communication network. It consists of multiple wireless nodes within an area, with each device assuming responsibility for assisting in forwarding packets and being free to move around the area to change the wireless connection at any time. The network's wireless topology may change rapidly and unpredictably, and MANET has no centralized control for distribution of load properly, so load balancing becomes one of the most important issue in MANET. When a network transmits a large number of packets, if there is no load balancing, the network's life and performance will be affected due to congestion, high latency and data loss caused by overloading the network. Load balancing can improve network life and performance by distributing the load on a per-node basis. With development of the research, multi-path routing protocols are more popular than single-path routing protocols, and multi-path routing protocols have shown superiority in their ability to improve packet rates, increase transmission reliability, and handle network congestion and busy traffic on time. This paper examines some multi-path load-balanced routing schemes in MANET networks and provides the relative advantages and disadvantages of the protocols so that we can identify future directions for research.

Keywords— MANET, Multi-path, Single-path, Load balancing, Routing protocol

I. INTRODUCTION

Mobile Ad Hoc Network (MANET) is a special kind of network that combines mobile communication and computer networks, and consists of a group of wireless mobile nodes. Traditional wireless cellular communication networks require the support of fixed network equipment such as base stations for data forwarding and user service control. However, the mobile ad hoc network does not need to rely on a fixed network architecture, there is no centralized server for scheduling, wireless mobile nodes can automatically complete the establishment of the entire network structure through a variety of communication protocols and communication mechanisms, relying on the nodes themselves for organization, management and configuration. Each node is equivalent to a terminal, all terminals are connected to each other to form a link for communication. When a node or link fails, the node will dynamically change the network topology. This type of network breaks through the limitations of traditional wireless

communication networks and realizes faster, more convenient and efficient deployment.

Mobile Ad Hoc Network (MANET) has the characteristics of no center, self-organization, dynamic topology, multi-hop routing, and easy deployment. In recent years, there has been an increase in the content and form of information about mobile services, and mobile data services have accounted for an increasing share of communications, so mobile self-organizing networks are used in a variety of scenarios. For example, emergency mobile communications, smart home connectivity, warrior-only combat systems, field work, and medical monitoring systems.

With the in-depth research on MANET, the goal of MANET routing protocol is to maximize network life, improve energy efficiency, network throughput, and minimize delay. In order to achieve these goals, more and more protocols have been developed and used. These protocols can be divided into multi-path and single-path routing protocols from the perspective of data packet transmission, and they can be divided into active routing protocols, on-demand routing protocols and hybrid routing protocols from the perspective of usage.

The rest of this article is organized as follows, the second part summarizes the routing protocol; the third part describes the load balancing; the fourth part presents the two models proposed for load balancing; the fifth part introduces the related work that has been done in this field; the sixth part outlines the performance of routing protocols and the last part summarizes the article.

II. ROUTING PROTOCOL IN MANET

MANET is greatly help to mobile communications, changes in the network topology caused by the movement of nodes have also brought many problems to MANET, such as network congestion, packet loss, and high delays. The key challenge in Mobile Ad Hoc Network is to design effective routing protocols to improve network lifetime and performance, and a number of available routing protocols have been developed. The protocols in MANET are generally divided into three types: active routing protocols (table-driven routing), on-demand routing protocols (reactive routing protocols) and hybrid routing protocols.

A. Active routing protocol

Active routing protocol is also called table-driven protocol. In active routing, each wireless node maintains multiple routing tables and each table entry contains routing information to all nodes in the network, including the next hop address to the destination node and routing cost. Each node periodically broadcasts routing information with neighboring nodes, and the node that received the information updates the information in the routing table. However, because the node maintains the routing information of the entire network in the routing table for a long time and periodically broadcasts its connection status which can result in significant overhead. So active routing protocols are not suitable for large networks. The classic active routing protocol is Destination Sequenced Distance Vector (DSDV)^[1].

B. On-demand routing protocol

The on-demand routing protocol is also called reactive routing protocol, which is specifically proposed for the MANET environment. This type of protocol does not generate routes in advance Unlike active routing protocols. If a node wants to send data to another node, this protocol performs the route discovery process in the network. The routing information is stored in the routing table after the connection is established and it is only part of the overall network topology. When the transmission is completed the information in the routing table is discarded. The classic on-demand routing protocols include Ad Hoc On-Demand Distance Vector Routing (AODV)^[2]and Dynamic Source Routing (DSR)^[3].

C. Hybrid routing protocol

Hybrid routing protocol is a combination of active routing protocol and on-demand routing protocol, usually used to provide hierarchical routing. The active routing protocol is used in a local area to save routing information within a certain range, which can reduce the scope of routing control information propagation. When the target node is far away, the on-demand routing protocol is executed. A typical hybrid routing protocol is Zone Routing Protocol (ZRP)^[4].

III. LOAD BALANCING IN MANET

Since wireless applications have increasingly high requirements for wireless network speed and bandwidth, and the capacity of wireless links is much lower than that of finite links, they are more likely to cause network congestion and reduce network performance, which is the biggest challenge in Mobile Ad Hoc Network. As the battery power of the mobile node gradually decreases, the processing capacity will gradually decrease. If a node is under heavy load for a long time, the battery will be exhausted quickly resulting in link failure, data packet loss, and increased end-to-end delay.

Due to the existence of these problems, load balancing plays a vital role in prolonging network life and improving network performance, which is an important work in MANET network research. In order to cope with multiple contingencies

in the network, multi-path load balancing protocols are created. Multi-path routing enables the existence of multiple routing paths between the source and destination nodes, thus providing alternative routes, which can be immediately transmitted using another path while one of the nodes and links fails on one path. When the number of data packets is large, multiple paths can be used for transmission to reduce the load on a single path, thereby reducing the overall end-to-end delay, increasing the packet transmission rate, and better load balancing.

IV. PROPOSED WORK

A. Stochastic network model

Due to the mobility of nodes and the dynamic topology of the network, as shown in Figure 1, we can see the MANET model is generally stochastic. $G(N, E)$ is defined as a group of MANET with N vertices and E edges, $n_i \in N$ is the node in the network, $i = 1, 2, 3, 4 \dots n$; $(n_i, n_{i+1}) \in E$ is the effective link from node n_i to node n_{i+1} in the network, which is randomly established during the route discovery process.

$P_i(S, D)$ is a path from the source node S to the destination node D , and $N(P_i(S, D))$ represents the node on one path i from S to D . The path is expressed by the following formula:

$$S, n_i, n_{i+1} \dots n_r, D \in N(P_i(S, D)), i, r = 1, 2, 3, 4 \dots n \quad (1)$$

$$P_i(S, D) = (S, n_i) \cup (n_i, n_{i+1}) \cup \dots \cup (n_r, D) \quad (2)$$

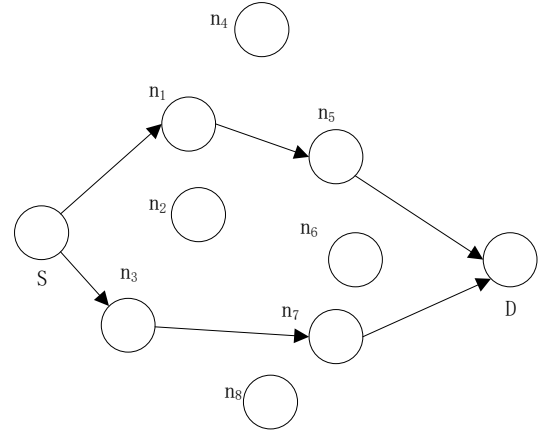


Figure 1. Stochastic network model

As shown in the figure above, the nodes are randomly distributed in the area. When the source node S wants to send data to the destination node D , the route discovery process finds two paths $P_1(S, D)$ and $P_2(S, D)$:

$$P_1(S, D) = (S, n_1) \cup (n_1, n_5) \cup (n_5, D) \quad (3)$$

$$P_2(S, D) = (S, n_3) \cup (n_3, n_7) \cup (n_7, D) \quad (4)$$

Then send the data packet from S to D through two paths.

B. Load balancing model

The Physicist Bak et al. used the sand pile model to illustrate the formation and characteristics of self-organizing

critical states^[5]. When sand is poured into a location, the initial amount of sand is small, and the sand fall has little effect on the entire pile, which will slowly spread out around it. As the amount of sand increases, it will accumulate higher and higher, and after reaching the critical point, increasing the amount of sand may lead to the collapse of the pile.

Both the sand stack model and multi-path load balancing have similarities which can be used to understand load balancing. The network architecture uses the random network model defined in the previous section, using θ_i to represent the threshold of each node, $i=1,2,3,4\cdots n$. μ_i represents the number of data packets on path i , η_i represents the threshold on a path i from the source node S to the destination node D , $i=1,2,3,4\cdots n$, defined as:

$$\eta_i = \min(\theta_i), i=1,2,3,4\cdots n \text{ and } \theta_i \in N(P_i(S,D)) \quad (5)$$

Multipath load balancing can be expressed using the following steps:

1) Set the network topology and the initial threshold of each node θ_i , then initialize μ_i .

2) Perform the route discovery process to find the path. It is assumed that the three paths found are $P_1(S,D)$, $P_2(S,D)$, $P_3(S,D)$, and the threshold on the path is calculated as η_1 , η_2 , η_3 .

3) When $\mu_i \geq \eta_i$ on path i , and $\mu_j \leq \eta_j$ on path j , then:

$$\begin{cases} \square = \mu_i - \eta_i \\ \mu_i = \mu_i - \square \\ \mu_j = \mu_j + \square \end{cases} \quad (6)$$

4) By analogy, step 3 is performed for each path until the number of packets on all paths does not exceed the threshold η_i on that path, and the entire network reaches a load balance state.

V. RELATED WORK

This chapter describes the work that has been done in this area.

Siuli Roy et al.^[6] proposed the use of directional antenna multi-path routing to achieve load balancing in mobile ad hoc networks, which can improve end-to-end delay. Route coupling, occurs in wireless medium when two routes are located physically close enough to interfere with each other during data communication. In this article, the correlation factor η is used to measure the impact of routing coupling. Experimental results show that using directional antennas instead of omnidirectional antennas on mobile nodes and using proper load balancing can significantly reduce end-to-end latency as well as improve the performance of multi-path routing.

Djemili, F et al.^[7] proposed the AODV-LB protocol by considering the node capacity of the relay node to enhance the AODV protocol for data packet transmission. The defined node capacity includes the workload and remaining energy of the node. The consumption model is proposed in the article as follows:

$$E_{tx} = \frac{P_{tx} \times k}{Bandwidth} \quad (7)$$

$$E_{rx} = \frac{P_{rx} \times k}{Bandwidth} \quad (8)$$

$$E_{mx} = F \times d_{t-1}, t \quad (9)$$

E_{tx} and E_{rx} represent the energy consumed by the send or receive k -bit packet, the P_{tx} and P_{rx} are the send or receive power, and the E_{mx} is the energy consumed by node movement.

The AODV-LB protocol adds an auxiliary message to the RREQ and RREP packets for route selection. The average queue length and the neighbor node queue length are used in the route discovery process to calculate the workload of this node. The remaining capacity is calculated based on the energy consumption model and used to find the highest quality route. From the experimental results, as the simulation time increases, the AODV-LB protocol is superior to the AODV protocol and the E^2AODV protocol in terms of energy consumption and data packet transmission rate.

Malviya, L.K et al.^[8] modified the Dynamic Source Routing Protocol (DSR) to Load Balanced Multi-Path Dynamic Source Routing Protocol (LMR-DSR). Two data structures are introduced in the new protocol: route cache and load table. The route cache looks for a route to the destination node but only maintains five routes at most, and the load table maintains the amount of data on a given route. Experimental results show that LMR-DSR is better than DSR and AOMDV in terms of throughput and packet transmission rate, and it is better than DSR but worse than AOMDV in terms of end-to-end delay. In this paper, the single-path routing protocol is modified to a multi-path routing protocol, but the appropriate load distribution strategy is not used, resulting in poor performance.

Monika Malik, P.Y et al.^[9] have improved an Load Balancing Algorithm with AOMDV (LBA-AOMDV) protocol based on the AOMDV protocol. The protocol analyzes the load of the neighbor nodes of the current node through different parameters such as loss rate, communication rate and delay. Neighboring nodes are assigned high, medium, and low priority by comparing them to a predefined threshold, and the node with the highest priority is selected as the path to reach the destination. Although the LBA-AODV protocol has obvious improvements in packet loss rate, end-to-end delay and throughput compared with the AOMDV protocol, it can also use an appropriate load distribution protocol to further improve performance.

This article^[10] proposed a combination of active and passive loss recovery mechanism in response to packet loss in the data transmission process of mobile ad hoc networks, consisting of an active part of the network coding mechanism and a reactive ARQ protocol. The sender encodes the data packet, the intermediate node processes the encoded data packet, then the receiver decodes it after receiving it. When the data packet is found to be lost, the active mechanism is used to recover the data packet. When the active mechanism cannot recover the lost data packet, the response mechanism

composed of the ARQ protocol is adopted, and the receiver sends an ACK to the sender for retransmission. The simulation results prove that this mechanism reduces data packet loss and improves throughput and data packet transmission rate.

This article^[11] proposed a Multipath Load Balancing Technique For Congestion Control (MLBCC), which uses the arrival rate and the egress rate within a specific time period to detect congestion. The link cost and path cost are used to select the gateway node. When the default path is congested, the gateway node selects other paths for traffic distribution. The data packets are segmented and evenly distributed on other paths and sent in a circular manner. The MLBCC protocol has better performance than the FMLB and AOMDV protocols.

Selvi, P.F.A et al.^[12] proposed an Ant Based Multipath Backbone Routing for Load Balancing Protocol (AMBRBL) in MANET, which estimates path preference probability based on next hop availability, delay and bandwidth when the source is trying to transmit data to the destination, and use the colony-based ant colony optimization (ACO) technology to select multiple routes with the greatest path preference probability. During route discovery, failed nodes are identified and relevant paths are skipped, then each backbone node is indexed to balance the network load on the route in order to evenly distribute data traffic over the link from the source to the destination for transmission, reducing the network load to improve performance.

This article^[13] focuses on the research of load balancing solutions based on battery life to improve network performance. When the remaining energy of node 1 is reduced to 40% from the default value, 50% of the incoming traffic is transferred to node 2. When the remaining traffic of node 1 is less than 20%, all incoming traffic is forwarded to node 2, and Node 1 becomes passive. Although this article reduces the network load by transferring the load from low-energy nodes to high-energy nodes, multiple paths can be used for data transmission to further improve network performance.

This article^[14] proposed a Traffic-aware Load Balancing AOMDV protocol (TALB-AOMDV) based on the AOMDV protocol. Since AOMDV saves multiple paths for data transfer, using only one path can lead to high overhead and waste resources on a single path. The proposed method adds the queue length field to the RREQ packet, takes the queue length and the number of hops as the metric for path selection. After path selection, the data is evenly distributed between the paths to obtain more Good resource utilization, extending network life. However, this paper can further improve network performance using appropriate traffic allocation.

Aouiz, A.A et al.^[15] proposed a Channel Busyness Multipath Load Balancing Protocol (CBMLB). A new parameter is defined to measure the centrality of the network based on the busyness of the channel. The centrality of each node m and path p is defined as:

$$C(m) = \frac{\sum \text{Transmission} + \sum \text{busyness}}{\sum \text{Transmission} + \sum \text{busyness} + \sum \text{idle}} \quad (10)$$

$$C(P) = \frac{1}{n} \sum_{m=1}^n C(m) \quad (11)$$

The node centrality is defined as the node's perceived busy time plus transmission time divide node's perceived busy time plus the transmission time plus the idle time. The path centrality is the average of the centralities of all nodes on the path p , and the source node selects the least busy path for data transmission. If this protocol uses multiple paths for data transmission, better performance will be obtained.

Zhang, X.B et al.^[16] proposed a Load Balancing For Multipath DSR Protocol (LBMDSR) in order to monitor the current and predict future congestion of the active path. The protocol uses multiple detection and cyclic mechanisms to update alternate routes, using the number of packets buffered in the interface and the number of RREPs in the path as the main route selection criteria. The current congested data packet field (CCP) and the future congested data packet field (FCP) are added to the RREQ data packet. CCP is the load situation in the interface queue and FCP predicts based on the number of RREP packets received. Select the least congested path for data transmission by calculating the total number of congested data packets (TNCP) on the path:

$$TNCP_i = CCP_i + \omega \times FCP_i \quad 0 < \omega < 1 \quad (12)$$

However, the protocol uses an equal distribution for traffic distribution. If different traffic distributions are used for paths with different congestion levels, the performance of the network will be further improved.

Naseem, M et al.^[17] proposed a Congestion Aware Fibonacci Queue Based Multipath Routing Protocol (Congestion-aware FMLB). The multiple paths found in the route discovery process are sorted according to the round-trip time of the packet request and reply. Then, the Fibonacci sequence is used to distribute the data and the weight based on the round-trip time is assigned to each path. The weight is set according to the Fibonacci sequence number. The Fibonacci calculation method is as follows:

$$\begin{aligned} fib(0) &= 1 \\ fib(1) &= 1 \\ &\vdots \\ fib(n) &= fib(n-2) + fib(n-1) \end{aligned} \quad (13)$$

This article^[18] proposed a Load Balancing Maximal Minimal Nodal Residual Energy ad hoc on-demand multipath distance vector routing protocol (LBMMRE-AOMDV). The protocol monitors the residual energy of each node, uses the minimum node residual energy on the path as the path's residual energy, then sorts by residual energy and sets the path with the minimum path residual energy as an alternate path and uses the rest of the path to transmit data. Calculating the number of data packets which can be transmitted on the active path based on the remaining energy and then send the data cyclically.

Naseem, M et al.^[19] proposed a queue-based multipath load balancing routing protocol (QMLB), which finds multiple disjoint paths from the source node to the destination node. The minimum queue length of a path is defined as the minimum value of the queue length of all nodes on the active path and the minimum path queue length is found for a single path, and then the paths are sorted by comparing the minimum

path queue length and data packets are forwarded to achieve the purpose of improving network performance.

Bhattacharya, A et al.^[20] proposed a new routing protocol called the Least Common Multiple based Routing (LCMR) for load balancing. The protocol finds multiple paths from the source node to the destination node, records the round-trip time for sorting, and then uses the round-trip time to calculate the least common multiple. The number of packets transmitted in each path is called n_k , which is the least common multiple divided by the round-trip time, and packets sent in less than one cycle are sent proportionally. For example, there are k paths, n is the total number of data packets sent in each cycle, and the previous p_n data packets are sent cyclically along k paths. If there are remaining r data packets ($r < n$), they are calculated ratio for each path by using $\frac{r}{k} \times n_k$ then sent.

VI. COMPARISON

The following Table 1 shows the comparison of existing load balancing techniques in the different parameters like packet delivery ratio(PDR), delay and throughput.

1) Packet delivery ratio(PDR): it is the ratio of total data packets received at the destination node to the total data packet sent by the source node.

2) delay: The difference in the time it takes for a sent packet to reach the destination. The lower value of end to end delay means the better performance of the protocol.

3) throughput: Throughput is obtained by calculating how many packets are received at the destination from the source during a specified time interval (kbps).

TABLE 1. COMPARISON OF THE EXISTING LOAD BALANCING TECHNIQUES

Protocol	Delay	PDR	Throughput	Comparison Protocol
Directional Antenna ^[6]	Low	-	-	Multi-omni-eta, Multi-omni-gamma, Multi-dir-gamma, single path
AODV-LB ^[7]	-	High	-	AODV, E^2 AODV
LMP-DSR ^[8]	High	Moderate	High	DSR, AODV, AOMDV
LBA-AOMDV ^[9]	Moderate	High	Low	AOMDV
HLRMLB ^[10]	Low	Low	High	MCR
MLBCC ^[11]	Low	High	-	FMLB, AOMDV
AMBR ^[12]	Low	Moderate	High	QAMR, MC-AOMDV
M-EALBM ^[13]	Low	High	High	EALBM
TALB-AOMDV ^[14]	Low	Moderate	Moderate	AOMDV
CBMLB ^[15]	Moderate	High	-	AODV, AOMDV, QMLB
LBMDSR ^[16]	Low	High	-	MRDSR, DSR
Con-gestion-aware FMLB ^[17]	Moderate	High	-	AODV, FLMB, Linear
LBMRE-AOMDV ^[18]	Moderate	Moderate	-	MMRE-AOMDV, AOMDV
QMLB ^[19]	Low	High	-	AODV, FMLB
LCMR ^[20]	Moderate	-	-	MAODVHC, MAODVRT, FLMBHC, FMLBRT

VII. CONCLUSIONS

There is no centralized control in MANET, and nodes can move freely and self-organize to form a network topology. Since node resources in the network such as battery power, bandwidth, buffer size, etc. are limited, balancing the load in MANET is a very important issue. In order to improve performance in the MANET network, it is important to distribute traffic correctly among mobile nodes using load balancing to maximize node lifetime, packet-to-packet ratio and minimize traffic congestion. This paper discusses a part of different load balancing methods in this field and points out the limitations of them, which provides a direction for further development of future research work.

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