Abstract—A proactive routing protocol CL-OLSR (cross-layer based optimized link state routing) by using a brand-new routing metric CLM (cross-layer metric) is proposed. CL-OLSR takes into account four link quality impact factors in route calculation through the cross-layer operation mechanism: the node available bandwidth, the node load, the link delivery rate, and the link interference, and thus the effect of route selection is optimized greatly. The simulation results show that the proposed CL-OLSR protocol can not only improve the network throughput to a large extent, but also reduce the end-to-end delay, while achieving load balance route results.

Index Terms—Cross-layer design, proactive routing, routing protocol, wireless mesh network.

1. Introduction

Wireless mesh network (WMN) is a novel kind of distributed broadband network architecture, of which the key idea is that every node in the network can be the access point and the router at the same time[1]. WMN has excellent scalability, robustness, and self-organization, which can support rapid deployment and installation, achieve high-speed routing and high-bandwidth transmission, and be applied to wideband local area networks, transport medical system networks, metropolitan area networks, and other scenes. At present, many domestic and foreign research institutions and related companies are carrying on extensive researches about the WMN technology, and the relevant standards are actively being customized.

Traditional hierarchical network design approach is not effective for WMN. Due to the openness of the wireless channel and time-variability of channel parameters, the hierarchical design method can not guarantee the utilization of network resources and quality of service (QoS) requirements of users. The traditional minimum hop based routing protocol[2] has the flaws that it can not effectively control congestion, has poor fairness, and can not realize load balance. Therefore, using the cross-layer idea to implement new routing protocols and improve the performance of WMN is the main point of this paper. The new protocol can meet the requirements of load balance and fault tolerant routing, and increase the network capacity while providing a certain QoS guarantee.

The rest of the paper is organized as follows. Section 2 points out the main research issues and ideas of this paper on the basis of the current research situation of related works. Section 3 proposes a route metric—cross-layer metric (CLM), makes performance analysis about it, and describes the cross-layer based optimized link state routing (CL-OLSR) protocol in more detail. In Section 4, the performance of CL-OLSR route protocol is analyzed and the simulation results are presented. Finally, this paper is concluded and the future research work is proposed in Section 5.

2. Related Works

In recent years, the research approach of integrating cross-layer idea into the WMN routing protocol design has made obvious progress, which can increase the utilization of network resources to a large extent and enhance the QoS guarantee to users. This approach has obtained the recognition of a growing number of scholars and research institutions. Reference [3] proposed a capacity-aware routing (CAR) protocol, which adopted a routing metric called bottleneck link capacity (BLC). This metric can increase the network throughput and reduce the end-to-end delay to a certain degree by the cross-layer operation of considering the link interference, the link load, and other link quality information. Reference [4] proposed a QoS-aware routing with a congestion control and load balancing protocol (QRCCCLB), which, by introducing the cross-layer operation, takes dynamic source routing protocol in an Ad hoc network as the prototype and can make the network traffic bypass the network’s business
hotspot, thus achieve the effect of congestion control and load balance. In [5], a wireless fidelity Ad hoc on-demand distance vector (WiFi-AODV) routing protocol was proposed, which fully exploits the adaptive rate switching mechanism of IEEE802.11 by introducing the cross-layer mechanism, in which nodes use the data transmission rate of the physical layer as a metric and are able to establish a route with a high data rate and low transmission delay. Reference [6] proposed an integrated metrics based extended dynamic source routing method (EDSR), which uses the cross-layer design to provide the frame delivery rate, extra bandwidth, and the node load of the media access control (MAC) layer for the network layer routing algorithm, thus improving the throughput rate and load balance capability of the network and satisfying users’ QoS requirements by promoting the network’s overall performance. These routing protocols are all proposed based on existing on-demand routing protocols of Ad hoc network, such as dynamic source routing, and Ad hoc on-demand distance vector routing. But for WMN, the network node is relatively fixed. Only node failures, as well as joining, leaving, and the uncertainty of wireless links will result in changes in the network topology. The change rate of network topology is far below the arrival rate of the data flow and the main business in WMN is the Internet business with certain delay requirements. These routing protocols have jumped out of the traditional route of taking the minimum hop as the routing metric and introduced the idea of cross-layer design. But there is a lack of systemic knowledge for the cross-layer design of WMN, in which the implementation process is complex and the practicality is low.

3. CL-OLSR Scheme

3.1 Fundamental Idea

This paper designs a CL-OLSR protocol for WMN based on optimized link state routing (OLSR) protocol. CL-OLSR based on [6] refines the idea of cross-layer design, and proposes a brand-new routing metric CLM applicable to WMN. This routing metric[7] takes into account four cross-layer factors: node available bandwidth, node balance, link delivery rate, and link interference by introducing the cross-layer operation mechanism. Through considering these four factors, the route selection is optimized to a large extent, the network throughput is improved and the goal of load balance is achieved. Compared with the on-demand routing, CL-OLSR is a proactive routing protocol[8] of hop-by-hop forwarding, which is more suitable for approximately static topological properties of WMN, and satisfies the requirements of low delay of the traffic flow. Moreover, the algorithm is relatively simple and practical.

3.2 Protocol Implementation

CL-OLSR senses the information of the node available bandwidth, node balance, link delivery rate, link interference, and node state, and switches node state through the distribution method. CL-OLSR exchanges sensed information through the distributed cooperative mechanism in the neighbor discovery phase. CL-OLSR makes inferences about the link state through this information, then completes route calculation and optimizes selection according to the inference results, thus realizing the load balance.

A. Node State Aware

First the network model is given: consider a WMN consisting of N wireless access points, in order to simplify the model, when considering the routing problems, treat a super gateway (SGW) as an ordinary mesh access point and ignore its gateway role. According to the graph theory, this WMN can be denoted by a directed graph G(V, E), where V is the set of vertices in the graph, \( \forall v_i \in V \) denotes a mesh access point (MAP) in a network, E is the set of direct edges, and \( \forall e_{ij} \in E \) denotes that there is a directed path from \( v_i \) to \( v_j \). We make the following assumptions:

1) The network topology is carefully designed and the MAPs no longer moves after deployment.

2) Each MAP is homogeneous, equipped with multiple wireless adapters, and can communicate in multiple channels simultaneously. Channel allocation scheme can remain stationary in a significant period of time.

3) Each MAP has two additional cross-layer modules, as shown in Fig. 1. The data acquisition module is responsible for collecting the information about the quality of links from this node to other adjacent nodes on the data link layer, including the node available bandwidth, the node balance, the link delivery rate, and the link interference. The parameter called module is responsible for providing data interface with various statistics information for network layer routing protocols.

![Fig. 1. CL-OLSR cross-layer module.](image-url)
B. Route Optimization Selection

For \( \forall v_i \in V \), consider the following two performance parameters: the node available bandwidth and the node load. For \( \forall e_{i,j} \in E \), consider these two performance parameters: the link delivery rate and the link interference. This algorithm integrates performance parameters of a node into performance parameters of the downstream edge on its path. For \( \forall e_{i,j} \in E \), there are four performance parameters:

1) \( B_{w_e} \) denotes the node available bandwidth of an upstream node \( v_i \) of a direct edge \( e_{i,j} \), where the subscript \( e \) is used instead of \( e_{i,j} \). Following is similar.

2) Load, denotes the node load of an upstream node \( v_i \) of a direct edge \( e_{i,j} \).

3) PDR, denotes the link delivery rate from a node \( v_i \) to another node \( v_j \) on direct edge \( e_{i,j} \).

4) LI, denotes the link interference of a direct edge \( e_{i,j} \).

These four performance parameters can be obtained through the cross-layer mechanism, of which the definition is as follows.

Definition 1. \( B_{w_e} \) represents the bandwidth surplus extent of an upstream node \( v_i \) of a direct edge \( e_{i,j} \). According to assumption 2), all MAP are homogeneous, so their basic data bandwidth is same as

\[
B_{w_e} = \frac{B_{w_{available}}(i)}{B_{w_{basic}}} \tag{1}
\]

where \( B_{w_{available}}(i) \) denotes the available bandwidth of \( v_i \) and \( B_{w_{basic}} \) denotes the basic data bandwidth of an MAP. In practical application, if the basic data bandwidth of an MAP is different, then \( B_{w_e} \) should be multiplied by a weighting factor to reflect the basic data bandwidth situation. For more details about the available bandwidth estimation methods, we can refer to [9] and [10].

Definition 2. \( \text{Load}_e \) represents the busy degree of an upstream node \( v_i \) of a direct edge \( e_{i,j} \).

\[
\text{Load}_e = \frac{Q_{sent}(i)}{Q_{max}(i)} \tag{2}
\]

where \( Q_{sent}(i) \) denotes the number of data packets waiting to be sent in a sending queue, and \( Q_{max}(i) \) denotes the maximum length of the wait queue. In practical application scenarios, representational contents of the node load should be made appropriate adjustments according to specific circumstances.

Definition 3. \( \text{PDR}_e \) represents the data transmission efficiency of a direct edge \( e_{i,j} \) defined as the frame delivery rate from node \( v_i \) to node \( v_j \) on the edge \( e_{i,j} \) of the MAC layer, expressed as

\[
\text{PDR}_e = \frac{F_{\text{rev}}(j)}{F_{\text{sent}}(i)} \tag{3}
\]

where \( F_{\text{rev}}(j) \) denotes the number of frames successfully received by \( v_j \), and \( F_{\text{sent}}(i) \) denotes the number of overall frames sent by \( v_i \). Here, only when the MAC layer perfectly receives frames sent by the neighbor nodes, a frame is defined as successfully received. If a complete frame can not be correctly received due to collision or the wrong checksum of a received frame, then a frame is called lost.

Definition 4. \( \text{LI}_e \) represents the interference extent of a direct edge \( e_{i,j} \) to its surrounding nodes,

\[
\text{LI}_e = \frac{|\text{IS}(e)|}{\text{ISN}} \tag{4}
\]

where \( |\text{IS}(e)| \) denotes the node set in the network, which may have interference with wireless transmission on the direct edge \( e_{i,j} \), and \( |\text{IS}(e)| \) denotes the number of nodes in this set. In this paper, each node in the network monitors the surrounding network in its own channel and records the node set using the current channel to transmit in a period of time. \( \text{IS}(e) \) is the intersection of the node sets recorded by \( v_i \) and \( v_j \) corresponding to the channel used by the direct edge \( e_{i,j} \). Intersection set number (ISN) denotes the number of nodes contained by the largest \( \text{IS}(e) \) set in the network, of which the value can be estimated through the specific network environment according to [11] and [12].

According to Definition 1 to Definition 4, CLM is defined as follows.

Definition 5. For any directed edge \( e_{i,j} \) in graph:

\[
\text{CLM}(e) = \alpha (1 - B_{w_e}) + \beta \text{Load}_e + \gamma (1 - \text{PDR}_e) + \delta \text{LI}_e \tag{5}
\]

where \( \alpha \), \( \beta \), \( \gamma \), and \( \delta \) are the weighting factors and satisfy \( |\alpha| + |\beta| + |\gamma| + |\delta| = 1 \). The value of \( \alpha \), \( \beta \), \( \gamma \), and \( \delta \) are decided by specific network environment and applications.

It can be seen from Definition 5 that CLM integrates the effect of four factors on link quality: the node available bandwidth, the node load, the link delivery rate, and the link interference. The smaller the value, the better the overall quality of the directed link denoted by direct edge \( e_{i,j} \) is. In practical applications, the exponentially weighted moving average method is used to smooth the weight of CLM:

\[
\text{CLM}(e) = \theta \text{CLM}(e)_{previous} + (1 - \theta) \text{CLM}(e)_{current} \tag{6}
\]

where \( \text{CLM}(e)_{previous} \) denotes the CLM(e) calculated in the last round and \( \text{CLM}(e)_{current} \) denotes the CLM(e) calculated currently. The value of \( \theta \) is decided by specific network environment and applications. This can reduce the sensitivity of CLM weight change, which to some extent weakens the route flapping phenomenon induced by the load-sensitive routing metric.

Definition 6. For any directed path \( r \) in graph, the CLM weight of \( r \) is the sum CLM of all directed edges on \( r \) expressed as

\[
\text{CLM}(r) = \sum_{e_{i,j}} \text{CLM}(e) \tag{7}
\]
A cross-layer based proactive routing protocol CL-OLSR based on OLSR routing protocol for WMN is proposed in this paper. This protocol exploits a brand-new routing metric called CLM, which takes into account four impact factors: the node available bandwidth, the node load, the link delivery rate, and the link interference, through the cross-layer operation mechanism in route calculation. Thus the effect of route selection is optimized. Simulation
experiment results demonstrate that CL-OLSR dramatically improves the network performance, efficiently increases the network throughput, reduces the end-to-end average delay, and achieves load balancing route results to some extent. The determination of the feasible weight of these factors in route selection integrated metrics is our future research focus.

References


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