A Caching-List based Fast Handoff Mechanism in Wireless Mesh Networks

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***Abstract*—It is critical for time-sensitive applications to realize seamless connectivity with bounded data transmission delay in wireless mesh networks (WMNs). This paper presents a caching-list based fast handoff mechanism (CLH) which includes two parts: first, the client needs to keep a list of available access points; second, when the client needs to handoff, it will send an authentication request frame rather than probe request frame in active scanning. We evaluate the benefits of CLH in a real network which only needs to modify the wireless driver (madwifi) in the client side. Our result shows that CLH improves the availability and results in reducing the handoff latency.**

***Index Terms*—Caching-list, Fast handoff, Madwifi, WMN**

I. INTRODUCTION

A wireless mesh network(WMN) is a communication network made up of radio nodes organized in a mesh topology which is a distributed network with high capacity and high rate. The WMN is different from traditional wireless networks and can be regarded as the integration of WLANs and mobile Ad hoc networks. WMN is a promising wireless technology for numerous applications, like home networking, community networking and enterprise networking. The WMN has many advantages including cost-effective, easy deployment and high reliability[1].

However, most wireless mesh networks today require specially modified clients in order to transfer connectivity from one access point to the next. Others, even if they give the appearance of continuous connectivity to a roaming client, provide connections that are in fact interrupted when a client transfers from one access point to the next, with delays that can be as long as several seconds[12]. For some applications (*e.g.* transferring files), this delay is acceptable; however, it is far too long for real-time traffic such as interactive Voice over IP or video conferencing.

In order to alleviate this problem, extensive research work on fast handoff in wireless mesh network has been done and the performance of such protocols gets good ascension [2-14].

Pack[2] proposed Proactive Neighbor Caching(PNC) accepted by IEEE as a standard. The paper also proposed a selective neighbor caching mechanism in which stations's information would be transmitted to partial APs according to AP's frequency. In addition, selection of neighbor nodes was optimized in the paper.

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To solve the optimal channel assignment (CA) problem in multi-radio wireless mesh networks, Rezguia[3] proposed a multi-objective optimization model that, besides maximizing throughput, improved fairness and handoff experience of mesh clients. This model used the Jain's index to maximize users' fairness and allows same-channel assignments to links involved in the same high handoff traffic, thus reducing handoff-triggered re-routing characterized by its high latency. Then, the author proposed a centralized variable neighborhood search and a Tabu search heuristics to efficiently solve their model as an off-line CA process. Moreover, in order to adapt to traffic dynamics caused especially by user handoffs, the author proposed an on-line CA scheme that carefully re-assigns channels to interfaces with the purpose of continuously minimizing the re-routing overhead/latency during user handoffs.

Hsieh[6] proposed a complete handoff procedure in 802.11 wireless networks. It first accomplished AP selection by choosing an AP with the lowest channel utilization and smaller number of associated users. Next, it performed CAC and IP address pre-fetch simultaneously through the simplified DHCP procedure. The simulation results demonstrated the integrated approach is effective, and the overall disconnection time due to handoff can be reduced. Leua[4] proposed a corona-oriented multi-channel assignment system(COMAS) as a metropolitan scale system which coordinated channel usage for wireless networks to mitigate radio interference among APs and nodes so as to improve network throughput and efficiency. In the COMAS, APs were deployed as concentric circles named coronas, channels were grouped and then allocated to coronas. They also clustered APs into groups and scheduled available channels to avoid radio interference and multi-channel hidden terminal problems among adjacent AP groups and among APs in a group.

Lin[5] proposed a channel management protocol for multi-channel, single-radio 802.11-based wireless mesh networks. This paper described a cost-effective solution for some problems of WMNs by using multiple channels. Here, most existing multi-channel solutions involved a channel assignment scheme and a scheduling scheme to determine nodes' behaviors at different time.

Wang[7] proposed a dynamic association mechanism considering load balancing, link quality and association oscillation avoidance. It introduced oscillation avoidance schemes to avoid association oscillation. The metric measured the real-time traffic load and considered dynamic re-association.

Zhang[8] proposed a hybrid routing protocol for forwarding packets. Intra-domain and inter-domain mobility management were designed. During intra-domain handoff, gratuitous ARP messages were used to provide new routing information, thus avoiding re-routing and location update. For inter-domain handoff, redundant tunnels were removed in order to minimize forwarding latency.

Li[9] proposed a channel splitting strategy to reduce the channel access delay of handoff. They designed the handoff procedures and two transmission strategies for scheduling the delivery of handoff signaling packets. Simulation results showed that the handoff delay requirement in WMNs can be guaranteed regardless of the background data traffic, and the channel throughput can also be improved.

Omheni[10] proposed an efficient Mac Layer handoff management scheme for WMNs. First, they described a new method to reduce discovery delay based on handoff prediction when mobile stations roamed across different Wireless Mesh Routers (WMRs). Then they selected the optimal target WMR using the minimum airtime cost as a metric.

Sarddar[11] proposed Neighbor Graphs (NG) pre-scanning mechanisms to reduce handoff latency for IEEE 802.11 wireless networks. They designed an algorithm scanning the channels 1, 6 and 11 which do not mutually overlap firstly. They also introduced pre-authentication mechanism which will reduce the message processing delay effectively.

In this paper, we present a caching-list based fast handoff mechanism (CLH) which includes two parts: first, the client needs to keep a list of available access points; second, when the client needs to handoff, it will send an authentication request frame rather than probe request frame in active scanning. In order to evaluate the performance of CLH, we set up a test bed which uses 3 laptops installed with Madwifi wireless driver as mesh nodes and 1 laptop as client. The client implements handoff during different mesh nodes, by doing so, we calculate the handoff delay. The results show that the minimum handoff delay is only 10ms under no load. The CLH can provide faster handoff comparing to traditional handoff method's 104ms delay. At the same time, we measured the handoff delay under 10Mbps and 20Mbps load. The results show that the delay will increase along with the load's increasing. We can explain the phenomenon easily, the load increases, then the round trip time increases, so the delay increases.

The rest of the paper is organized as follows: Section II analyses the handoff phases in wireless mesh network. Section III deeply describes the caching-list based fast handoff mechanism in WMN. The performance emulations and analysis of CLH are shown in section IV. In the last section, we present conclusions and directions for future work.

II. Handoff analysis in WMN

A. *Handoff phases in WMN*

The Wireless Mesh Network Switching is majorly for completing the message interactive process among MH(Mobile Host), nAP(new AP) and cAP(current AP). The Switching can be divided into three phases in general. They are Channel-Probing Phase(Channel-Scanning Phase), Authentication Phase and Re-association Phase. Each phase has its own handoff latency, and the probe delay contributes more than 90% of the handoff latency.

Channel-Probing phase, also called Channel-Scanning Phase. When the RSSI (Receive Signal Strength Indicator) of the cAP in MH or the SNR(Signal to Noise Ratio) reaches certain threshold, the handoff process will be invoked. Channel-Probing phase is the first phase to find out all neighboring APs of MH. It has active and passive two scanning modes. Passive scanning mode is not beneficial for fast-scanning. Because MH should have to wait for the beacon frame from AP on certain channel, but time is not easy to control. And the worst situation is scanning all the channels. If there are 11 optional channels, the cost time will be 1.1s (a period of waiting beacon's default value is 100ms). Active scanning mode is initiated by MH. MH will broadcast probe request frame positively on every channel by turns, and will keep waiting for the probe response from AP. Active scanning time depends on the *MinChannelTime* and the *MaxChannelTime*. When there is no probe response message during the *MinChannelTime*, MH will automatically switch to the next channel to continuing scanning. Otherwise, MH will receive and deal with the probe response message in the *MaxChannelTime*. But in general situations, MH will terminate the probing process when finding the first AP in order to reduce the handoff latency.

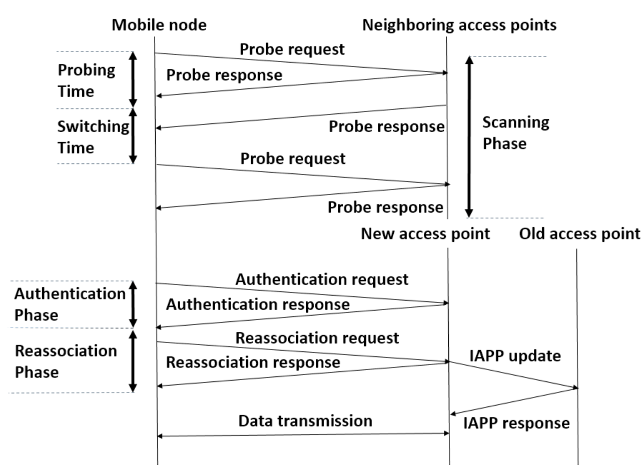

Fig. 1: Wireless Mesh Network handoff method

Authentication Phase mainly relies on the security mechanism between MH and nAP, such as open authentication mechanism, shared key authentication mechanism and other technical encryption mechanism. Open authentication mechanism only has a simple frame authentication between MH and

TABLE I: Caching List Based Handoff Latency

	Passive Scanning	Active Scanning
Handoff Trigger delay	0	$\frac{1}{2}RTT$
Authentication delay	$M \times (\frac{1}{2}RTT) + RTT$	$M \times (\frac{1}{2}RTT) + RTT$
Association delay	$2RTT$	$2RTT$

AP. When using WEP(Wired Equivalent Privacy) encryption mechanism on AP, it needs to exchange WEP key or other information between MH and AP. 802.11i security mechanism's authentication frame will be empty, and the security authentication will be initiated through 802.11x authentication interface after having association with AP.

During Association Phase and Re-association Phase, MH will send Association Request to AP, and then AP sends an Association Response to notify MH success or not of the association.

B. The trigger principle of handoff

The handoff is triggered by the movement of station and the weakness of signal strength. Generally, this process is triggered by different AP's signal strength in IEEE 802.11 WLAN.

As shown in Fig. 1, signal-to-noise ratio (SNR) changes while the station moves from AP1 to AP2. When the station moves from AP1's range to AP2's range, SNR received from AP1 becomes smaller and SNR received from AP2 becomes bigger. $S_1(x)$ represents SNR of AP1 in point x and $S_2(x)$ represents SNR of AP2 in point x. There are 2 positive arguments for reference during the handoff process, handoff threshold Y_h and hysteresis threshold Z. In any point x, the station's current AP is AP1, only if the following two formulas are established at the same time, the station triggers handoff from AP1 to AP2.

$$S_1(x) < Y_h \tag{1}$$

$$S_2(x) - S_1(x) > Z \tag{2}$$

In the Fig. 2, when $Y_h = Y_1$, STA will trigger handoff process at the point X_1. The handoff threshold can avoid unnecessary handoff, and putting off the threshold can avoid the ping-pong effect during the handoff process.

III. CACHING-LIST BASED FAST HANDOFF MECHANISM IN WMN

A. Handoff mechanism of CLH

As mentioned above, Mishra[12] mentioned that the probe delay contributed to 90% of the handoff latency while authentication delay and re-association delay cannot be improved in the current IEEE 802.11 standard. So the handoff process can be divided into two parts, discovery phase in which available APs or mesh nodes are discovered; execution phase includes authentication and re-association phase.

Thus, we propose a caching-list based method to improve delay in the discovery phase. The method is based on preloading the table containing available mesh nodes around. And

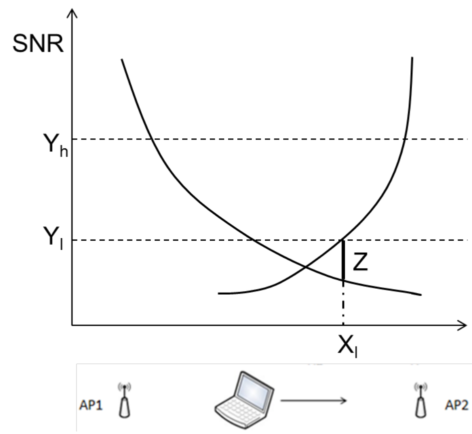

Fig. 2: Handoff principle

the table is stored in the client side, the client will unicast authentication request frame to find out which mesh node to switch to when the handoff is necessary. By doing so, active and passive scanning to discover available mesh nodes are avoided.

Table I shows how the handoff latency is measured and the delay of every step about active and passive scanning. Passive scanning is triggered by the disconnected frame sending by the mesh nodes current connected. Active scanning is triggered by the disconnected frame which the client sending to the current connected mesh nodes without ACK. Formula 3 refers to passive scanning and formula 4 refers to active scanning. M is the number of sending authentication request frame. *ChannelSwitchTime* is the time of the network interface card cost to switch one channel to another. The best situation is the first node in the list happens to be the node needs to be re-associated. In this situation, passive scanning delay is 3RTT/2, and active scanning delay is 4RTT. The worst situation is no available mesh nodes available, thus, the mobile clients have to perform active scanning.

$$M \times (\frac{1}{2}RTT) + 3RTT + (M-1) \times ChannelSwitchTime \tag{3}$$

$$M \times (\frac{1}{2}RTT) + \frac{3}{2}RTT + (M-1) \times ChannelSwitchTime \tag{4}$$

RTT (Round Trip Time) is the time of probe request frame and the ACK response frame's transmission between two nodes. We should have the information of four time points to calculate the RTT as Formula 5:

$$RTT = (T_{21} - T_{11}) + (T_{12} - T_{22}) \tag{5}$$

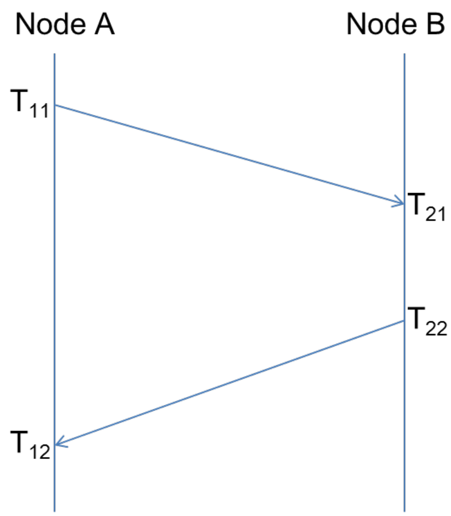

Fig. 3: Round Trip Time

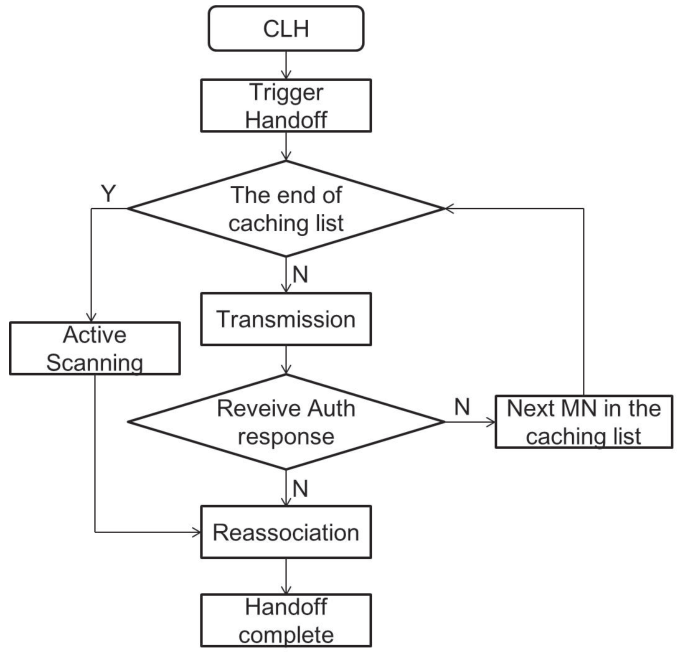

Fig. 4: Caching List Based Fast Handoff Method

In this paper, we define RTT as Fig. 3. (T_{11} refers to the time of probe request frame sent by Node A. T_{21} refers to the time of the same probe request frame received by Node B. T_{12}, T_{22} is the same as T_{11}, T_{12}). RTT is related with a series of factors, such as network load, interference and contention.

Passive scanning's delay costs a lot, since clients have to monitor every channel by turns in order to find next associated AP.

Active scanning's delay mainly depends on *MinChannelTime* and *MaxChannelTime*. They are all measured in a 1024 microseconds time slot. *MinChannelTime* is the shortest time scanning a channel and *MaxChannelTime* represents the longest time. The 802.11 standard does not specify their value. But we can infer their values based on our experience:

$$MinChannelTime = DIFS + (aCW_{min} \times aSlotTime) \quad (6)$$

(*MinChannelTime* is defined in a time slot, so the size of *MinChannelTime* is a time slot. DIFS is 50 microseconds and a CWmin is 31 microseconds. A Slot Time in 802.11b/g is 20 microseconds, in 802.11a is 9 microseconds.)

$$MaxChannelTime = 15 microseconds \quad (7)$$

There are some other hardware delays, such as handoff latency between channel and interface. But we ignore these delays and these factors in analysis, since they vary with the different manufacturers.

B. Fast handoff process of CLH

The fast handoff can be divided into two steps. Firstly, mobile clients get the information of the available neighboring mesh nodes. Then, client sends authentication request frame to every other client in the list to perform handoff by means of unicast.

The caching list is used for storing the information of mesh nodes and managing them. One mesh node's position in the list is based on its Received Signal Strength Indicator (RSSI). Obviously, mesh nodes with the highest signal strength will be in the top of the caching list so that fast handoff can be provided in time.

When a client is added to the wireless mesh networks for the first time, information of the mesh nodes can be stored into the client side easily. We can monitor all mesh nodes' frame information to get their receive signal strength. And the CLH scheme method doesn't produce any additional cost or change the protocol and also doesn't need to update the hardware.

In our handoff strategy, the process of CLH is described as Fig. 4, the mobile client sends authentication request frame one by one when the handoff is necessary. If the authentication response frame is received, the client will connect with this mesh node instead of continuing sending authentication request frame to the rest of mesh nodes in the list. However, if all the mesh nodes in the list don't response to authentication request frame, the client will implement active scanning to find available wireless network.

IV. Performance Evaluation and Analysis

In order to test the performance of CLH, we build a test bed, and our wireless driver is madwifi(the trunk snapshot) through which we change the code to realize our caching list.

In the experiment, we use 3 laptops installed with madwifi wireless driver as mesh nodes naming MN1, MN2 and MN3, and use 1 laptop as client. The client implements handoff during different mesh nodes, by doing so, we calculate the handoff latency. The topology of the wireless test bed we use in our experiments is shown in Fig. 5.

All the MNs and client are installed with Madwifi wireless driver. The client is in the managed mode and the MNs are in

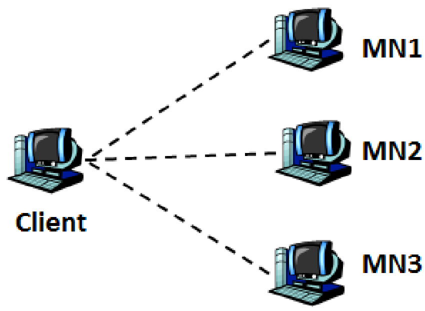

Fig. 5: Topology of the test bed

master mode. The platform is Ubuntu 10.04 on Intel Celeron 1.7GHz, with 2G memory.

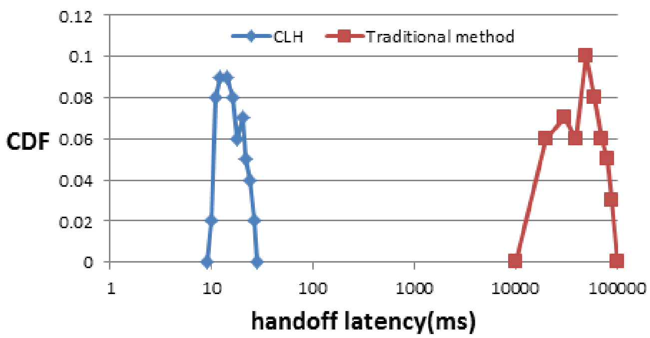

Fig. 6: Handoff latency of CLH and traditional method

From Fig. 6 we can see the traditional fast handoff method and the fast handoff method based on the caching list. The abscissa represents time with the unit millisecond. The ordinate represents frequency at a time point. The dark line represents the handoff latency of the traditional method. The light line represents the handoff latency of CLH.

As shown in Fig. 6, we can see that the handoff latency of traditional method fluctuates between 10^4ms and 10^5ms and has several peaks, which shows the result is on random and corresponding to our randomly handoff experiment method. Handoff delay is so high that can't provide fast handoff that we want. Moreover, we cannot use real-time application like VoIP when performing handoff.

We can see that the delay of CLH is about 10ms to 50ms and even lower than 10ms. So the CLH greatly improves the handoff speed and reduces the handoff latency. In the experiment, we get the node information manually. The nodes' number is limited. And network has no load. So all mentioned above illustrate that our method is efficient and can even provide seamless handoff.

Because our experiment is conducted in the ideal case, without any load, so the experiment is not convincing. Then we test the handoff latency with 10Mbps and 20Mbps load respectively. According to our idea, the delay should increase along with load increasing.

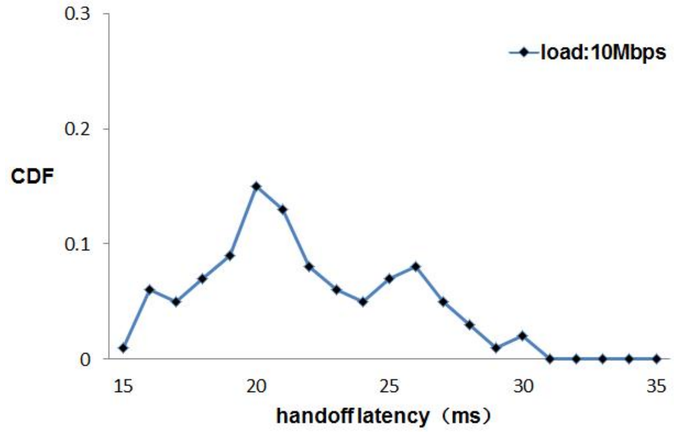

Fig. 7: Handoff latency with 10 Mbps

We use D-ITG(Distributed Internet Traffic Generator) to control our link load. As shown in Fig. 7, this is an experiment with 10Mbps load. The abscissa is the latency value with the unit millisecond. The ordinate is frequency at a time point.

In Fig. 7, we can see CLH with the 10Mbps load still can make fast handoff. The minimum latency is less than 20ms and most are completed in 30ms. The minimum handoff delay is about 10ms without load. So the handoff latency with load increases as expected. Because of the network interference and load, the handoff latency increases along with the increase of RTT.

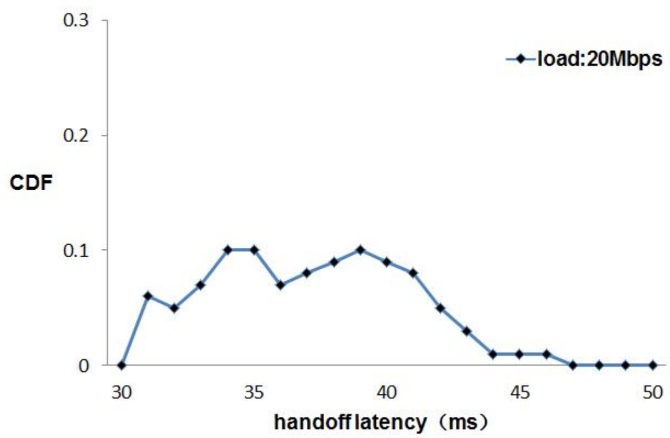

Fig. 8: Handoff latency with 20 Mbps

In order to make our experimental data more convincing, we also tested the handoff latency with 20Mbps load as shown in Fig. 8. The handoff latency of CLH with 20Mbps load fluctuates between 30ms and 45ms. Furthermore, we can know that the handoff latency with 20Mbps is larger than that with 10Mbps and that without load, which corresponding to the discovery that RRT increases along with increase of the network load.

When switching delay is greater than the packet inter-arrival time, the packet will be lost, as the switching delay increases, the packet loss increases, the packet loss ratio is equal to the ratio of handoff latency and packet arrival interval. Besides of the signal strength of the mobile generated and packet forwarding routing problems, the moving speed of the terminal equipment will also affect the packet loss. In this experiment, at the same speed, the link layer handoff latency reduction makes the total switching delay smaller than the traditional switching mechanism. Therefore, the switching delay and packet loss in traditional switching mechanism is also reduced. Fig. 9 shows packet loss between the two access points during handoff process.

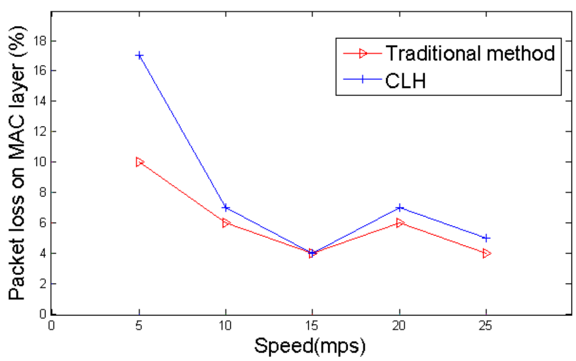

Fig. 9: Packet loss of handoff in these APs

We can see that, our CLH's packet loss ratio is larger than the traditional method. When the speed is between 5mps and 15mps, the packet loss becomes smaller as the speed increases. And as the moving speed increases larger than 15mps, packet loss does not show much volatility, generally in a relatively stable trend.

V. Conclusion

This paper mainly focuses on the fast handoff in WMN with deep analysis. Based on detailed analysis of the handoff phases, we introduce a caching-list based fast handoff mechanism (CLH) in order to decrease the handoff latency. And through our experiment, we can find that CLH can work in the real network environment.

In the future, we will test the performance of the CLH from various aspects, such as testing the protocol performance under different signal, testing CLH with different mobile nodes, testing performance under different upper service (such as TCP service).

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