Applications and Performance Analysis of Bridging with L3 Forwarding on Wireless LANs

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Abstract

This paper presents an in-depth study of applying the bridging technology with layer-3 forwarding (L3F) in Wireless Local Area Networks (WLAN). It is a unique feature in Windows XP, and supports the Internet sharing of multiple workstations with a single wireless interface. We perform detailed analysis of the 802.11 protocol and discuss why L3F works over WLAN while the traditional layer-2 forwarding (L2F) does not work in this configuration. We also present the advantages of L3F over IP routing on WLAN. This paper also includes a thorough performance analysis using a high capability traffic generator and analyzer. Our results, as measured by throughput and latency, show that the L3F performance is comparable to L2F and significantly better than IP routing.

1 Introduction

Computer networking for home and Small Office and Home Office (SOHO) environment is a fast growing area where people usually have several computers at different places. The primary needs are to share the Internet connection and computing resources (such as printers, FAX, and storage devices) as illustrated in Fig. 1. In general, these computers are on multiple LAN segments[1] but on a single IP subnet. Note that the Wireless Access Point (WAP) in Fig. 1 is also an IP router and multi-port Ethernet switch. This device is commonly used at home and SOHO networks.

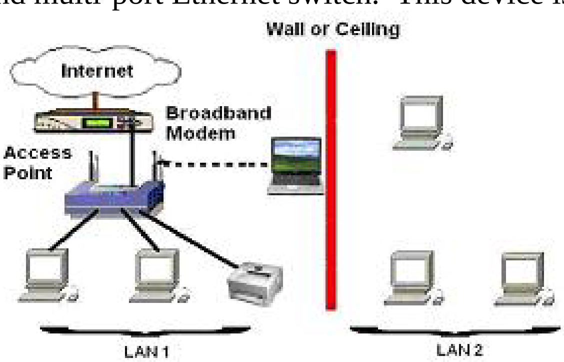


Fig. 1 SOHO network topology

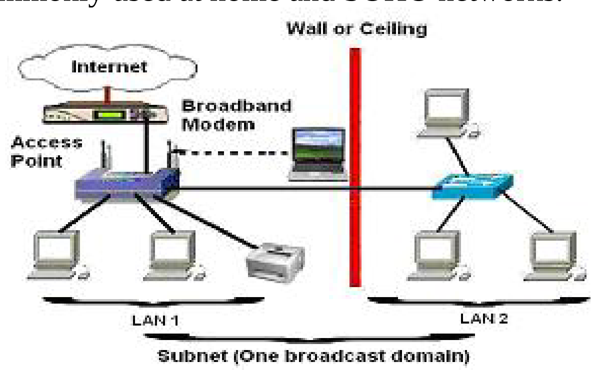


Fig. 2 SOHO network topology using bridge.

[1] A LAN segment is loosely defined as the group of computers connected to a single port of network device. The network device could be a switch or a router.

Traditionally, Ethernet switch/bridge is used to connect separate LAN segments into one IP subnet as illustrated in Fig. 2 [1]. One can also use an IP router for the connection and it creates multiple IP subnets. This configuration requires more complex routing design and more costly routing devices. A major issue with this *wired* configuration is the need of cabling inside the wall and requires a licensed professional to do the work. The solution to the cabling problem is to apply wireless network technology [2] as illustrated in Fig.3.

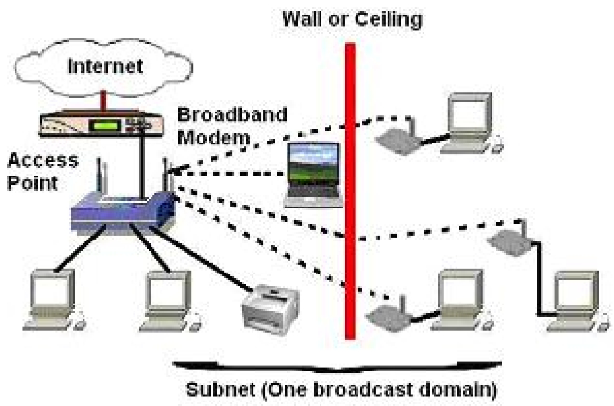


Fig. 3 SOHO wireless network topology.

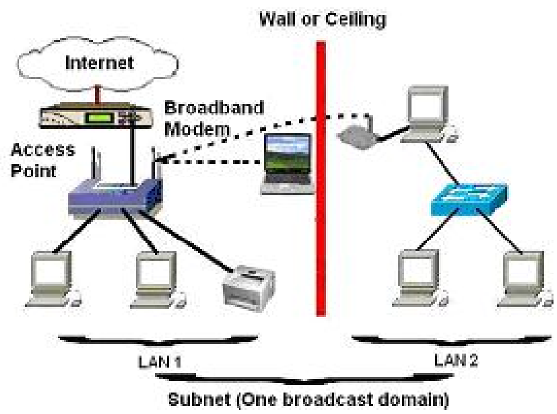


Fig. 4 SOHO Windows XP network topology.

One concern with this wireless configuration is the need of a wireless adapter for each workstation. Another issue is performance where all wireless workstations are competing for the shared Radio Frequency (RF) channel which could degrade the performance [3]. The third issue is workstation configuration where changes made to the WAP (such as the WEP security key) may require manual reconfiguration on every wireless workstation.

The objective of this study is to identify a *cost-effective* solution that supports the connection of multiple LAN segments over a single IP subnet on WLAN. We identified a unique bridge feature in Windows XP, called layer-3 forwarding (L3F). It supports the seamless connection between the wired and wireless networks as illustrated in Fig. 4, and its forwarding function is similar to the traditional Layer 2 forwarding (L2F) function as specified in IEEE 802.3 [4] and 802.1D [6]. As the name implies, L3F is based on the IP address, and not on the Medium Access Control (MAC) address. Unlike IP routing, LAN segments of L3F are on a single IP subnet which makes the configuration easier and performance better. Also shown in Fig. 4 is the need of only one wireless adapter. In this paper, we present why L2F is not working in this wireless configuration and the advantages of L3F over IP routing from the perspective of network performance and management in the SOHO environment.

2 Configurations of L2F, L3F, and ICS on Windows XP

The addressing scheme of 802.11 [7] is more complex than that of 802.3 where it requires four address fields in the 802.11 frame as described in Table 1. One should note that a typical wireless adapter supports only the first three modes, and WAP supports the 2^{nd} and 3^{rd} modes. Devices that supports the 4^{th} mode are called wireless repeater and they are a lot more expensive than WAP.

Table 1 802.11 Address scheme [5]

Mode/Case	Address 1	Address 2	Address 3	Address 4
WS=> WS (00)	DA	SA	BSSID	N/A
WAP=>WS (10)	DA	Sending WAP	SA	N/A
WS=>WAP (01)	Receiving WAP	SA	DA	N/A
WAP=>WAP (11)	Receiving WAP	Sending WAP	DA	SA

WS: Wireless Station
BSSID: Basic Service Set ID
DA: Destination Address
SA: Source Address
WAP: Wireless Access Point

2.1 Bridge with layer 2 forwarding (L2F)

Layer 2 forwarding (L2F) is the default operation mode of Windows XP bridge and it conforms to the IEEE 802.3 and 802.1D standards.

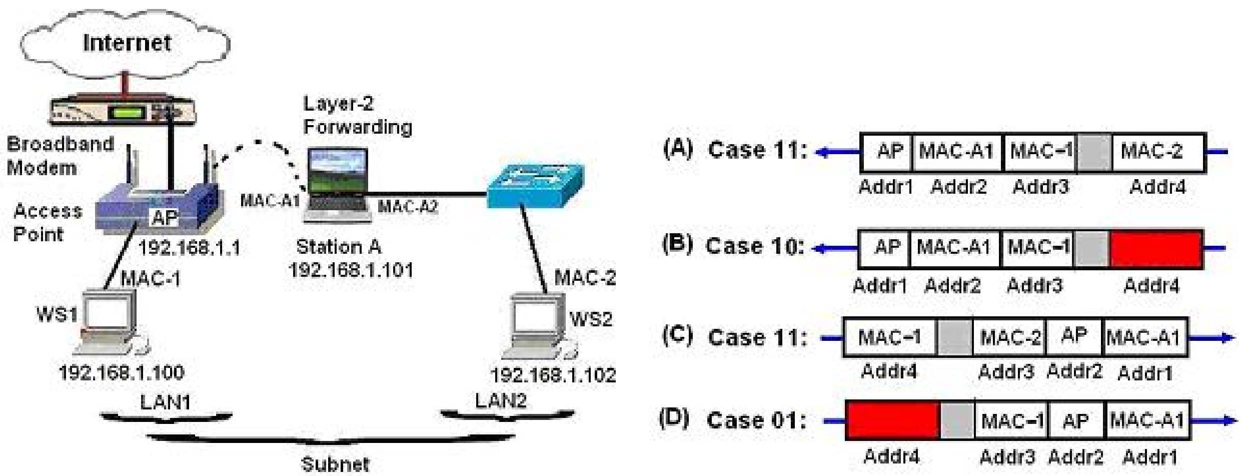


Fig.5 Windows XP L2F bridge address schemes.

Although L2F works well in the wired network, it does not work in the wireless network. If we configure L2F on Windows XP (Station A) as illustrated in Fig.5, we cannot send traffic from WS1 to WS2 or from WS2 to WS1 through the wireless connection. This is due to the implementation on most wireless adapters which do not support Case 11 in Table 1. When WS2 tries to communicate with WS1 through L2F via Station-A, the 802.11 addressing schemes between Station A and AP need to be Case 11 (Table 1 and Fig.5-A); however, Case 11 addressing scheme exists on *wireless repeater* only and is not supported on wireless adapter. Therefore, when WS2 sends packets to WS1, it uses Case 10 addressing schemes (Fig.5-B), and the source address (MAC-2) is lost during the wireless communication. In the same way, when WS1 tries to communication with WS2, it should adopt Case 11 (Fig.5-C) addressing scheme. Since wireless adapter does not support Case 11 addressing mechanism, AP sends out MAC frame to wireless station A using Case 01(Fig.5-D) addressing scheme, and the destination address of WS2 (MAC-2) is lost during the wireless communication. In summary, the communication between WS1 and WS2 fails under the L2F configuration illustrated in Fig.5.

2.2 Bridge with layer 3 forwarding (L3F)

Windows XP can also be configured as a bridge using Layer 3 forwarding (L3F) which performs the forwarding function based on the IP address. This feature supports wirelessly connection between two separate LAN segments as illustrated in Fig. 6. In this case, the Windows XP bridge functions like an ARP proxy, answering ARP requests from nodes on one LAN segment on behalf of nodes on another segment [8].

The implementation of L3F requires a forwarding table (Fig 6) based on the IP addresses. When WS1 sends data to Station A or WS2, it first tries to find their MAC addresses. If it cannot find the MAC address for 192.168.1.101/24 or 192.168.1.102/24, it broadcasts ARP requests to other nodes on the same subnet (192.168.1.0/24) with 192.168.1.101 or 192.168.1.102 as target IP address. After Windows XP bridge (Station A) receives this ARP request on its port 1, it checks its L3 forwarding table. If there is no entry for WS1 in its L3F table, it creates one entry with attributes of 192.168.1.100, port 1 and MAC-1 in the table. Then, it checks the target IP address of the received ARP request. If the target IP address belongs to itself; it simply sends back an ARP reply to WS1 with MAC-A1 as the target MAC address and 192.168.1.101 as target IP address. If the target IP address does not belong to itself, it checks the L3F table. If the target IP address (WS2) is in the L3F table, it sends back an ARP reply to WS1 with MAC-A1 as the target MAC address and 192.168.1.102 as the target IP address. If it does not have one entry for the target IP address, it sends its own ARP request messages out on all ports except the port on which the original ARP request is received [8]. When an ARP reply is received, it creates a new entry for WS2 in its forwarding table, and sends ARP reply to WS1 with MAC-A1 as the target MAC address and 192.168.1.102 as target IP address. Similar procedure is used when WS2 initiates communication with WS1. In the example of Fig. 6, there are two entries in its L3F table, one for WS1 and the other for WS2.

The procedure to build L3F table shows that Windows XP bridge knows both WS1 and WS2. For example, it knows that WS1 is on its interface of port 1; WS1 has one IP address of 192.168.1.100 and an MAC address of MAC-1. However, WS1 does not know WS2 and WS2 does not know WS1 as confirmed in the ARP tables of WS1 and WS2 (Table 2 and Table 3). Thus, Windows XP bridge with L3F forms one broadcast domain on both of its bridge interfaces.

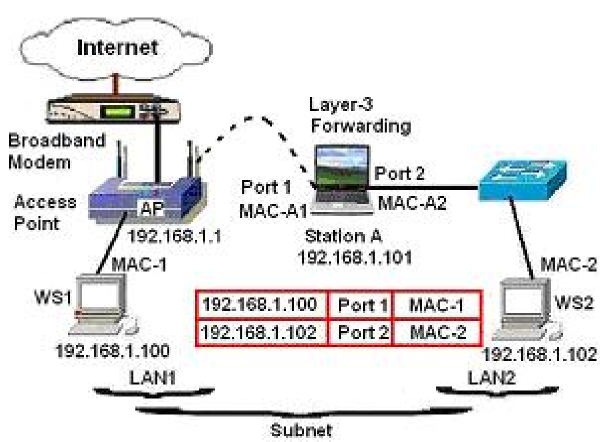


Fig. 6 Windows XP L3F bridge for LAN segments connection.

Table 2 ARP Table of 192.168.1.100 in FIG. 6.

IP Address	MAC Address
192.168.1.101	MAC-A1
192.168.1.102	MAC-A1

Table 3 ARP Table of 192.168.1.102 in FIG. 6.

IP Address	MAC Address
192.168.1.1	MAC-A2
192.168.1.100	MAC-A2
192.168.1.101	MAC-A2

With the L3F table, Windows XP bridge forwards packets between LAN1 and LAN2 (Fig.6). When WS1 communicates with WS2, it first sends the packets to MAC-A1. After station A receives packets from WS1, it checks the destination IP address (192.168.1.102) of the packets, and finds it in its L3F table with the information of outgoing port (port 2) and destination MAC address (MAC-2). The XP bridge then adds new Ethernet frame header with MAC-2 as the destination address and its own MAC address (MAC-A2) as the source address. This new Ethernet frame is exported via Port-2 to WS2. Packets from WS2 to WS1 are processed and forwarded in the same manner.

If the destination IP address of an incoming IP packet is to the Windows XP bridge itself, this packet is passed to the IP and upper layers for further processing. For broadcast IP packets, the XP bridge would forward them to all ports except the port on which the packet was received [8]. With L3F, both WS1 and WS2 can surf the Internet using AP as their default gateway. In summary, all computers are on a single IP subnet (Fig.6), and they can communicate with each other and share the computing and network resources.

2.3 Windows XP IP routing configuration

In Fig. 7, station A is configured as an IP router (a.k.a. Internet Connection Sharing) with a wireless adapter for the outside connection with an IP address of 192.168.1.101 and a wired adapter for the internal LAN connection with an IP address of 192.168.0.1. In this example, ICS router uses the AP as its default gateway to the Internet and other LAN segments. Workstations on the local LAN (LAN2) use the ICS router (192.168.0.1) as their default gateway to the Internet and other LAN segments.

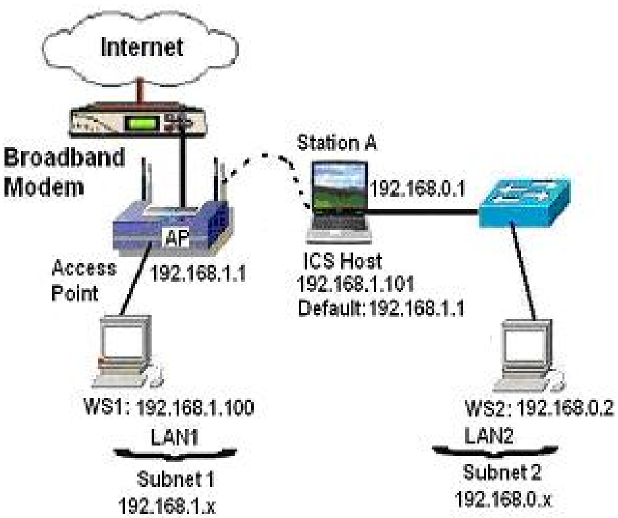


Fig. 7 Windows XP ICS host for LAN segments connection

Destination LAN IP	Subnet Mask	Default Gateway	Hop Count	Interface
0.0.0.0	0.0.0.0	140.192.35.120	1	WAN
140.192.35.0	255.255.255.128	0.0.0.0	1	WAN
192.168.0.0	255.255.255.0	192.168.1.101	1	LAN
192.168.1.0	255.255.255.0	0.0.0.0	1	LAN

Fg.8 Routing table of AP.

Our experiment shows that WS2 could surf the Internet and access any computer on LAN1 via the ICS router. However, computers on LAN1 could not access the computers on LAN2. We checked the routing table of AP router and found that there was no entry for 192.168.0.x/24. As a result, the traffic from 192.168.1.100 to 192.168.0.2 was routed to the internet, and dropped somewhere. With this finding, we manually created an entry for 192.168.0.0 in the routing table to route all the traffic with destination as 192.168.0.x to the wireless interface of the ICS router (Fig. 8). After inserting the new entry in the routing table of AP, we still cannot send Internet Control

Message Protocol (ICMP) traffic (ICMP request and reply) from 192.168.1.100 (outside) to 192.168.0.102 (inside). This is due to Network Address Translation (NAT) which forwards traffic initiated from LAN2 to LAN1. However, any traffic initiated from outside hosts cannot be forwarded to internal hosts. Therefore, hosts on LAN2 can use resources on LAN1, but hosts on LAN1 cannot use resources in LAN2. In summary, this configuration does not meet the typical home or SOHO networking requirements.

In conclusion, our analysis in section 2.1 shows that L2F cannot be used to support the wireless connection of the typical home and SOHO environments for local resource sharing and Internet connection. The ICS routing configuration supports the Internet sharing but does not support local resource sharing on different LAN segments. The L3F is the only configuration that supports the connection of multiple LAN segments into one subnet, where all workstations on different LAN segments can not only share the computing resources, but also use the same internet connection to the outside world.

3 Experiments

The purpose of the experiments is to measure the performance of L2F, L3F, and ICS based on the network configuration discussed earlier. Our experiments used multiple Windows XP laptop stations where some of them are equipped with built-in wireless adapters and others have Personal Computer Memory Card International Association (PCMCIA) wireless adapters. The access point used for this experiment is Linksys Wireless-G Broadband Router with 4 10/100 Mbps LAN ports and one 10/100 Mbps Internet port. The traffic generator and analyzer is the IXIA 1600 chassis with dual 1G ports for traffic generation and reception. We follow the RFC-2544 for the benchmark performance testing [9, 10]. The key measurements of the experiment are throughput and latency. We generated various traffic using layer-2 only frames, IP packets, and User Datagram Protocol (UDP) segments. The results presented in this paper are based on the UDP traffic. The network configuration for performance measurements is illustrated in Fig. 9.

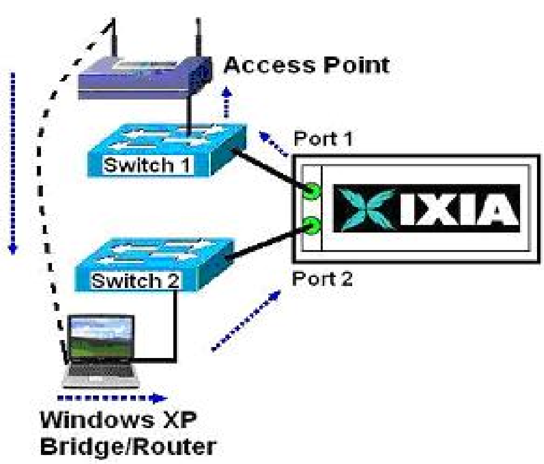


Fig. 9 Windows XP wireless bridge/ICS router configuration for performance measurement.

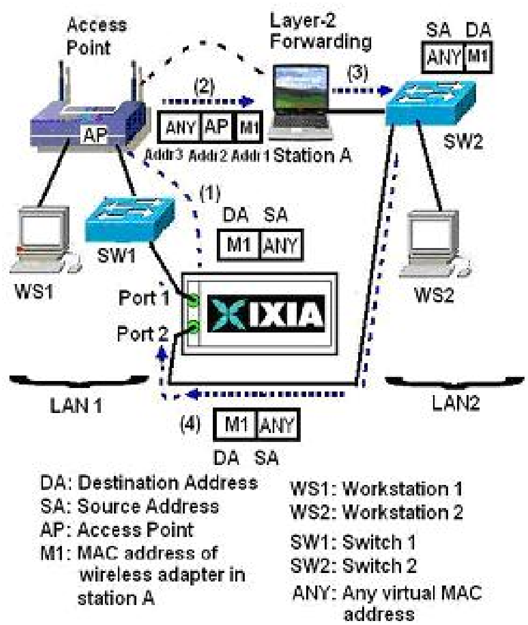


Fig.10 Configuration to measure performance of L2F wireless bridge.

The IXIA chassis has two 1G ports where port 1 is used for data transmission and port 2 is used for reception (Fig. 9). Each data frame has a time stamp used to calculate latency at the receiving port. The reason we need two Catalyst 2950 switches is to convert 1000BaseT traffic to 100BaseTX traffic to the AP or Windows XP bridge/router which does not have the 1000BaseT NIC. The traffic generator, on the other hand, supports 1000BaseT only. As we have demonstrated in [9], the Catalyst switch would not cause any congestion as long as the input rate is less than the physical link which is 100M bps.

Although L2F does not work in the wireless environment, we were able to create a special scenario to measure the L2F performance in a wireless environment. This is based on the broadcast nature of the 802.3 standard and the sniffing capability of the IXIA traffic analyzer.

Adapters of the XP bridge is configured in L2 promiscuous mode, where an adapter receives all frames on the shared medium, and not just the frames addressed to that adapter [11]. Network adapter drivers normally process only those frames containing the MAC address of the device. When the promiscuous mode is enabled, incoming frames of any destination MAC address are received and passed to all LAN ports in the same broadcast domain.

With the configuration shown in Fig. 10, we connected port 1 of IXIA box with LAN1 through switch1, and connected port 2 with LAN2 through switch 2. We generated the traffic on port 1 with the MAC address of the wireless adapter in station A as the destination MAC address, and used any virtual MAC address as source address (Fig. 10-1). These packets could be sent to the XP bridge through the wireless connection (Fig.10-2). Since the wireless adapter was in the promiscuous mode, all frames received by this wireless adapter were forwarded to all the ports of switch 2 through the wired link. These frames were then captured by port 2 of the IXIA box. In this way, we were able to measure the performance (throughput and latency) of L2F over the wireless link. The configuration and measurements for L3F and ICS follow the discussion of Section II of this paper.

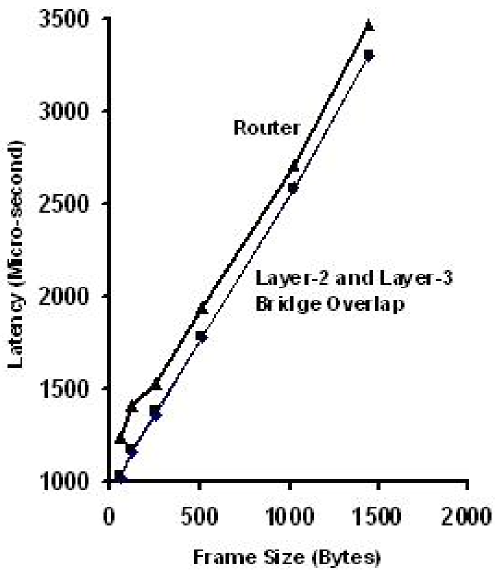
4 Performance results

In our first experiment, we have a Windows XP station with one 100BaseTX Ethernet adapter and one 802.11b wireless adapter (Fig. 6). We then configured the XP station as a L2F bridge, L3F bridge, and ICS router. The performance data is collected for each configuration. As recommended by the RFC 2544 standard, we collected the performance data using various frame sizes.

From Fig. 11, we can see that L2F and L3F have almost the same latency for each packet size. However, ICS routing has longer latency (5-10% longer) than both L2F and L3F. This confirms our understanding that IP routing involves more overhead in packet and routing processing.

Fig. 12 shows that L2F and L3F configurations could yield a maximum throughput of 7.2 Mbps at different input rates (1000 fps or 10,000 fps) with a packet size of 1500 bytes, which is close to those reported in the literatures [3, 12]. As the case of latency, the throughput of L3F is better than that of ICS routing, 7.2M bps vs. 6.1M bps or 15% higher throughput.

We also run an overload test for the frame size of 1500 bytes with input rate greater than the theoretical limit of 802.11b wireless adapter [3]. The result is given in Table 4.



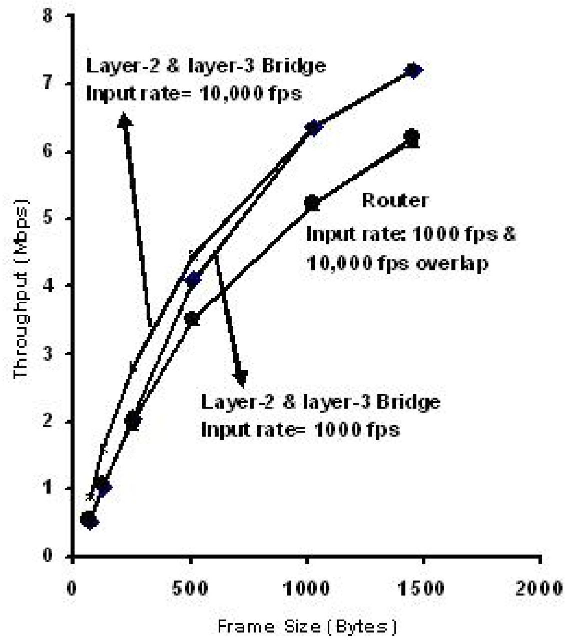


Fig.11 Latency test for Windows XP Wireless bridge/ ICS router at nominal input rate of 10 fps.

Fig.12 Wireless Windows XP bridge / route throughput at different frame sizes and different input rates.

Table 4 Windows XP bridge/router overload test (frame size =1450 bytes)

FPS	XMIT Rate (Mbps)	L2F Bridge		L3F Bridge		ICS Router	
		Latency (ms)	TPT (Mbps)	Latency (ms)	TPT (Mbps)	Latency (ms)	TPT (Mbps)
10	0.116	3.30	0.11	3.30	0.11	3.47	0.11
100	1.16	3.25	1.15	3.30	1.15	3.32	1.15
500	5.8	3.37	5.80	3.43	5.79	**161**	**5.80**
600	**6.96**	**4.90**	**6.90**	**4.95**	**6.94**	3,000	5.82
620	7.192	98.8	7.15	97.6	7.14	4,000	6.0
625	7.25	98.7	7.17	98.2	7.17	4,300	6.12
630	7.308	102.6	7.22	101.7	7.17	6,000	6.12
650	7.54	103.9	7.15	102.9	7.15	7,000	6.1
700	8.12	103.0	7.22	101.3	7.20	7,340	6.11
1000	11.6	100.9	7.19	102.0	7.21	9,345	6.14

XMIT Rate: Transmit Rate; TPT: Throughput; FPS: Frames per second

Table 4 shows that L2F and L3F configurations have similar performance. They reach the bottleneck at an input rate of 6.96 Mbps. At that point they have a throughput of 6.90 Mbps, and a latency of 4.9ms. If input rate continues increasing, network congestion occurs and latency increases by 2-3 orders of magnitude where throughput keeps unchanged. ICS routing, on the other hand, reaches bottleneck at a lower input rate of 5.8Mbps. If input rate continues increasing, the latency of ICS routing increases by 3-4 orders of magnitude. In summary, our performance study shows that L3F configuration has comparable performance to L2F configuration. The L3F performance is significantly better than that of ICS routing.

5 Factors affecting L3F performance

In addition to the Windows XP configurations, we are interested in another two factors that affect the WLAN performance:

- 802.11b vs. 802.11g standards, and
- 64-bits vs. 128 bits WEP encryption keys

The experiments to compare the above two factors are all conducted with the L3F configuration on the Windows XP bridge.

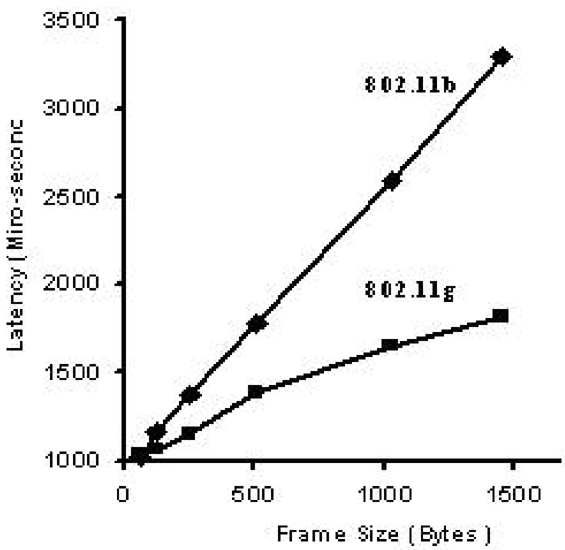


Fig.13 Influence of wireless standard on the latency of wireless L3F bridge.

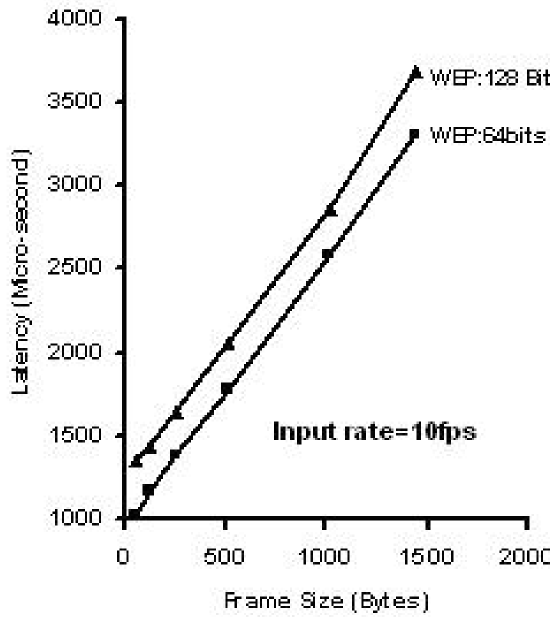


Fig.14 Influence of the length of WEP key on the latency of L3F wireless bridge.

Fig. 13 shows that the latency data for 802.11b and 802.11g is almost the same for *small* packets, which is about 1 ms. When the packet size increases, the latency for 802.11g is significantly shorter (or better) than 802.11b. This is due to the fact that 802.11g has a higher data transmission rate than 802.11b [12].

The latency of 128-bit WEP key is higher than that of 64-bit WEP key (Fig. 14). At the packet size of 1500 bytes, the latency for 40 bits is 3,300μs, and the latency for 128 bits is 3,680 μs. The results show that longer key encryption and decryption involves more computation and longer delay than the shorter one.

6 Conclusions

This study presents a new application of using bridging with layer-3 forwarding in a WLAN environment which could have a great potential for home and SOHO networking. We acknowledge that this configuration may not be suitable for the enterprise environment where multiple *wireless repeater* could meet the needs and provides a more scalable solution. For home and SOHO environment where the need is to connect a *small* number of workstations to share resources and the Internet connection, the L3F configuration is considered more cost-effective than a wireless repeater.

We performed detailed protocol analysis on the 802.11 addressing schemes with ARP, L2F, and L3F. We demonstrated that this wireless configuration cannot be supported by the traditional layer-2 forwarding due to the 802.11 addressing schemes implemented on most wireless adapters. We showed several issues with using the IP routing scheme to support this wireless configuration.

Our performance analysis shows that there is almost no additional overhead for L3F where its performance is the same as L2F as measured by throughput, latency, and congestion threshold. On the other hand, L3F shows significant performance advantages over IP routing based on the same performance metrics.

Currently, L3F is a unique feature found only on the Windows XP environment. Because of the significance of the application identified in this paper for home and SOHO environments, we propose the consideration of standardizing this Layer-3 forwarding feature. We also hope that this paper could bring more studies to explore more applications of layer-3 forwarding on different networking environments, and one of them is to use L3F to solve the problems related to bridging in multi-hop ad hoc networks of mobile hosts.

References

[1] Microsoft Corporation, "Network Bridge overview" *" http://www.microsoft.com/windowsxp/home/using/productdoc/en/default.asp?url=/windowsxp/ home/using/productdoc/en/hnw_understanding_bridge.asp"*

[2] Microsoft Corporation, "Home and Small Office Network Topologies" *http://www.microsoft.com/technet /prodtechnol/winxppro/plan/topology.mspx,* May, 2003.

[3] J. A. García-Macías, F. Rousseau, G. Berger-Sabbatel, L. Toumi, A. Duda "Quality of service and mobility for the wireless internet", *First ACM Wireless Mobile Internet Workshop '01 Rome, Italy*, 2001.

[4] IEEE 802.3 Standard, http://standards.ieee.org/getieee802/802.3.html.

[5] B. A. Forouzan, *Local area Networks*, McGraw-Hill, 2003.

[6] IEEE 802.1 Standard, http://standards.ieee.org/getieee802/802.1.html.

[7] IEEE 802.11 Standard, http://standards.ieee.org/getieee802/802.11.html.

[8] J. Davies, "How the Windows XP Network Bridge Works", http://www.microsoft.com/technet /community/columns/cableguy/cg0102.mspx, January 2002.

[9] J. T. Yu, "Performance Evaluation on Linux Bridge", *Telecommunications System Management Conference 2004, Louisville, Kentucky,* http://facweb.cti.depaul.edu/jyu/Publications/Yu-Linux-TSM2004.pdf, April, 2004.

[10] S. Bradner, J. McQuaid, "Benchmarking Methodology for Network Interconnect Devices", RFC-2544 , *http://www.faqs.org/rfcs/rfc2544.html*, 1999.

[11] Tom Sheldon, http://www.linktionary.com/p/promiscuous.html.

[12] Atheros Communications Inc. "802.11 Wireless LAN Performance" *http://www.atheros.com/pt/atheros_range_whitepaper.pdf,* 2003.