Proceedings of the 2009 IEEE International Conference on Systems, Man, and Cybernetics
San Antonio, TX, USA - October 2009

Design and Implementation of Heterogeneous Wireless Gateway

Hung-Chi Chu, Shih-Lung Chang, Ying-Hsiang Liao, and Yan-Ting Pan
Department of Information and Communication Engineering
Chaoyang University of Technology
Taichung, 41349, Taiwan
{hcchu, s9630612, s9630619, s9730609} @cyut.edu.tw

***Abstract*—This study proposed a software-based heterogeneous wireless gateway (HWG) to achieve the integration of multiple heterogeneous wireless networks. In an HWG, received packet is temporarily saved with buffer. And then a packet format conversion mechanism is adopted to enable packet under different wireless network protocols be converted to appropriate formats. Therefore, when the transmission demand occurs, the source nodes and destination nodes at both ends of heterogeneous wireless network can mutually communicate information via this gateway without changing the original communication protocol of each network, based on the modulization design to support multiple communication interface and system extensibility.**

***Keywords*—Hetergeneous wireless gateway, IEEE 802.11, Bluetooth**

I. INTRODUCTION

In recent years, with the progress of wireless network communication technology, there are more and more wireless communication technologies, which can be divided from large to small ranges as Wireless Wide Area network (WWAN)[1], Wireless Local Area Network (WLAN)[2-4] and Wireless Personal Area Network (WPAN)[5,6]. Users demand the best wireless communication technology according to communication quality such as delay, bandwidth, throughput, and so on. Therefore, the study of heterogeneous network [7-10] has gradually become one of the important research subjects. Various wireless communication protocols are made by different international standard organization or Task Groups, so communication between different wireless technologies cannot be achieved easily. Therefore, how to convert the data format between different wireless communication technologies has become a very important research subject. A simple conversion concept is to utilize a gateway to convert transmission data. Gateway is a system having several wireless communication interfaces that can connect two or more different wireless networks. The gateway can bridge different wireless networks, and uses the mechanism of data analysis and format conversion to achieve the integration of heterogeneous wireless network and promote the network extensibility.

HWG allows the transmitted data from network A to match with those of network B, and transmits them to network B by analyzing data and treating packet data compilation (conversion) via Gateway, thus, integration can be achieved for two or more heterogeneous networks. Moreover, HWG features reduction of data transmission, avoiding network congestion and full utilization of bandwidth. Because traditional gateway cannot enable several wireless communications to be connected for data transmission at the same time, and it has to wait to transmit the data to destination before receiving all of the data, such operation way may cause the delay of data transmission. Therefore, in order to save the delay time for treating data (or buffering delay) when spanning different network environments, direct conversion of partial temporary data that received from source end is a feasible way. As shown in Figure 1, in a heterogeneous network, traditional gateway must wait the source end to complete the transmission of packet A_1, A_2 and A_3 before it converts the complete data into packet B_1, B_2, B_3 and B_4 to the destination (see Figure 1(a)). The HWG proposed in this paper can immediately treat packet B'_1 and B'_2, and send them to destination (see Figure 1(b)) at receiving packet A_1 from source end and judging the factors, such as packet correctness and forwarding route. Therefore, the transmission time of traditional gateway is higher than the proposed HWG. The design of HWG integrates the heterogeneous wireless networks that were difficult to be connected as a large-scale network system. In such environment, an appropriate router can be designed to avoid network congestion and increase bandwidth utilization.

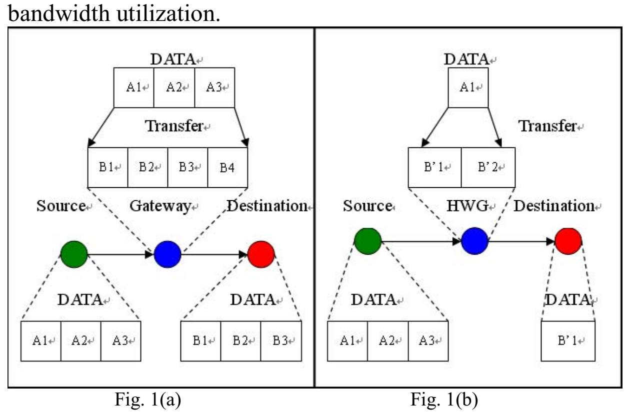

Fig. 1(a) Fig. 1(b)
Figure 1. (a) Traditional Gateway; (b) Heterogeneous Wireless Gateway

Therefore, this study integrated two wireless network technologies, IEEE 802.11 (Wi-Fi) and IEEE 802.15.1 (Bluetooth) [11-13], to make HWG. It also proposed the

978-1-4244-2794-9/09/$25.00 ©2009 IEEE

hardware framework and the software mechanism needed by HWG, and found that such design can effectively convert the transmitted packet as a suitable form for the network of receiving end and send them to the receiving end.

The remainder of this paper is organized as follows. Section 2 describes related works on heterogeneous network. Section 3 presents the designed HWG system framework and software mechanism. Section 4 discusses the result of practice and experiment. Section 5 gives the conclusions.

II. RELATED WORKS

According to the recently studies on HWG, it can be divided into two categories based on its design mechanism: (1) hardware mechanism and (2) software mechanism. The hardware mechanism refers to the redesign of hardware of gateway. The common method is to design two or more communication interfaces on the same hardware, so two or more networks can be connected at the same time (e.g. dual-mode wireless communication system or multi-mode wireless communication system). As a comparison, the software mechanism, by software simulation, has the system to simulate the desired environment according to user's needs. Therefore, under the software mechanism, users can enjoy the advantages of dual mode or multimode by updating the software only, without the need to change the hardware.

The advantages and disadvantages of the HWG of hardware mechanism and software mechanism are discussed as follows:

A. Hardware mechanism

The hardware design mechanism proposed by Cavalcanti, D. [9] is to redesign the two wireless communication protocols, Cellular and IEEE 802.11, and implement HWG in the same network interface. As shown in Figure 2, the hardware mechanism designs the Physical layer, Media Access Control (MAC) layer and Data Link Layer of the two mechanisms separately, while the Network layer, Transport layer and Application layer are integrated together to communicate with each other. Users send the packet to the gateway, via the Physical layer, after the MAC layer and Data Link Layer analysis, the data can be converted on the Network layer to be another communication protocol, and then the data is encapsulated in sequence of Data Link Layer, MAC layer and Physical layer and sent to the destination. The heterogeneous wireless networks can be integrated by this hardware mechanism. The advantages of hardware mechanism are that it can quickly convert the one data packet format into another one and the entire hardware system is relatively stable, but the disadvantages are: (1) not all communication protocols can use this mechanism; (2) the integration of multiple protocols is difficult and complicated; (3) the existing network equipments must be changed.

B. Software mechanism

The BlueStar software mechanism structure presented by Carlos De M. Cordeiero [10] is as shown in Figure 3. The stations in the BuleStar structure use Bluetooth wireless communication, and multiple stations similar to this form a BlueHoc network. And each BuleHoc network must contain a Bluetooth Wireless Gateway (BWG) [16]. The stations and BWG are interconnected by Bluetooth wireless communication. Moreover, the BWG and the Access Point (AP) are connected by IEEE 802.11. Such design can achieve the mutual communication between stations with Bluetooth interfaces and IEEE 802.11 (Wi-Fi) interfaces. The application of software mechanism is to convert the communication protocol in the BWG, that is, convert the Bluetooth protocol [14-15] to be IEEE 802.11 protocol.

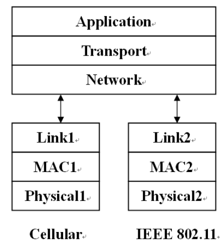

Figure 2. Network layer structure of hardware mechanism

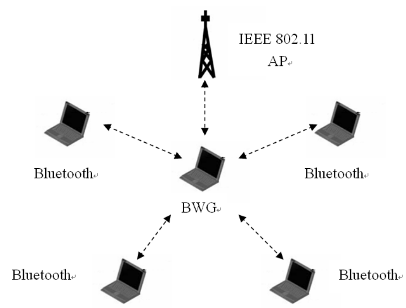

Figure 3. System structure of BlueStar

The BlueStar software mechanism is as shown in Figure 4. In the BWG, the software simulation design is done to individual layer of Physical layer and MAC layer of Bluetooth and IEEE 802.11 wireless networks, and two heterogeneous wireless protocols are integrated in the Internet Protocol layer as a bridge of communication between the two heterogeneous wireless networks. The advantages of the mechanism is that BWG can perform well by updating the software on the original hardware, but the disadvantage is that all stations are composed of Bluetooth communication interfaces, which restricts the maximum bandwidth and the network scalability by Bluetooth protocol.

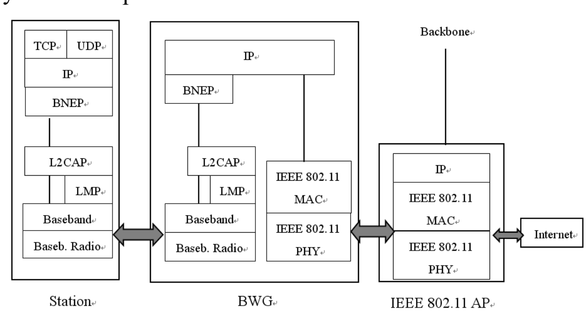

Figure 4. BlueStar software mechanism

III. SYSTEM FRAMEWORK

As stated above, this study designed an HWG at low cost and by relatively flexible software mechanism and integrated the currently widely-used Bluetooth protocol and IEEE 802.11 protocol to plan for the system structure, as shown in Figure 5.

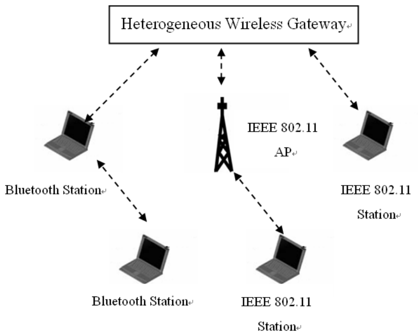

Figure 5. System structure of HWG

HWG acts as a bridge to connect the Bluetooth network and IEEE 802.11 wireless network. Users may use the Bluetooth stations via the HWG to communicate with the IEEE 802.11 stations and vice versa. Take Figure 5 as an example, the Bluetooth station adopts BlueHoc [17] technology, which indicates that in the Bluetooth network all stations can communicate with each other. This technology solves the problem of the Bluetooth with too short transmission distance. In addition, IEEE 802.11 station not only can employ the infrastructure mode and connect with the HWG through Access Point, but also can directly connect to the HWG using ad hoc mode. The IEEE 802.11 Access Point is set as bridge mode, so the signals received are transferred to the remote destination. Therefore, the IEEE 802.11 signals can be transmitted farther. The HWG can integrate the two heterogeneous wireless networks, which are Bluetooth and IEEE 802.11 wireless network, and expand the transmission distance of wireless network, so that users can obtain farther and better transmission quality.

Under the above hardware structure, this study proposed an HWG designed by software mechanism. The functions include: (1) *compatible to the original network*: user can connect to other heterogeneous networks without changing the network in use; (2) *multiple communication interfaces*: under the situations of more and more different communication protocols developed, the client will no longer have the single communication interface, so the gateway must be able to support multiple communication interfaces; (3) *system extensibility*: the network service develops fast, thus in order to support the network services in the future, the gateway must be able to be extended for the future new network services; (4) *unawareness connection*: it is unnecessary for users to deal with the connection of heterogeneous network, the mutual communication with the nodes in the heterogeneous network can be achieved by setting up the differences between communication protocols. To achieve the above functions, this study designed a software-based Protocol Stack for HWG, as shown in Figure 6.

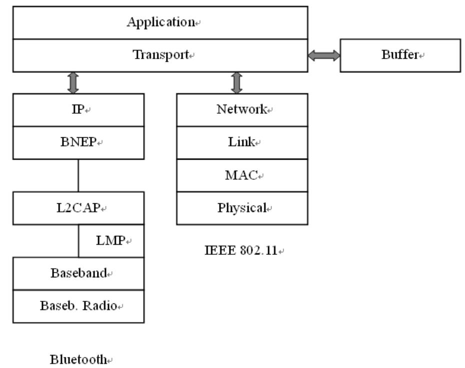

Figure 6. Protocol Stack of software-based HWG

The proposed HWG based on software mechanism can integrate various heterogeneous wireless networks by software simulation upon the network protocol layer. The original protocols of each communication protocol remain unchanged, so the original network can be fully compatible. When the other new communication interface is integrated, the corresponding simulation software of communication protocol is developed on the gateway, and then the capacity of the heterogeneous wireless network can be extended. The proposed method refers to establishing a large buffer in the transport layer in the gateway. When needed, after being analyzed by each communication protocol, it is sent to the buffer and temporarily stored; the communication protocols are converted by software mechanism and then it is transmitted to the destination end. The flowchart of proposed mechanism is shown in Figure 7.

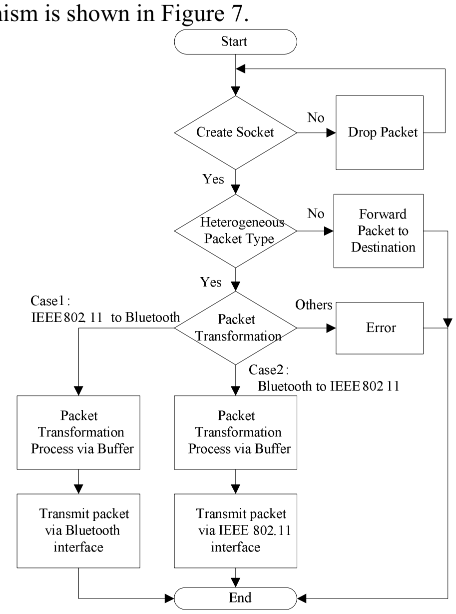

Figure 7. The flowchart of proposed mechanism

IV. SYSTEM IMPLEMENTATION

According to the proposed structure, this study implemented the HWG by software mechanism. The gateway includes Bluetooth version 2.0 and IEEE 802.11b wireless communication interfaces. The experiment of system was designed to determine whether the HWG exists during the data transmission and the transmission bottleneck. There were 4 simulation experiments: (1) Node A and Node B are connected by the ad hoc mode of IEEE 802.11 (Wi-Fi), and 100MB data is sent from Node A to Node B (see Figure 8); (2) Node A and Node B are connected by the BlueHoc mode of Bluetooth, and 100MB data is sent from Node A to Node B (see Figure 8); (3) Node A and HWG are connected by the ad hoc mode of IEEE 802.11 (Wi-Fi), Node B and HWG are connected by the BlueHoc mode, and 100MB data is sent from Node A to Node B (see Figure 9): (4) The structure is the same with (3), but 100MB data is sent from Node B to Node A.

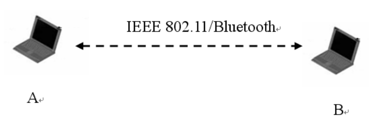

Figure 8. Transmission structure of homogeneous wireless network

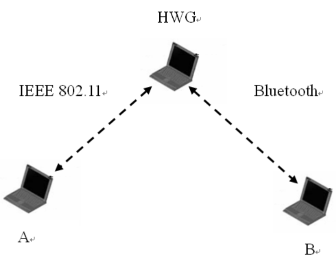

Figure 9. System structure of HWG

The hardware specifications of the experiment are as follows: Node A and Node B are ASUS F8SG notebook computer (CPU: Intel Core2Duo T7700, RAM: 2GB, WLAN network card: Intel 3945ABG, Bluetooth network card: ASUS BT-183); HWG is ASUS U6S notebook computer (CPU: Intel Core2Duo T7500, RAM: 2GB, WLAN network card: Intel 4965AGN, Bluetooth network card: ASUS BT-183). In addition, since the Bluetooth is WPAN, its transmission is effective only within several meters. Therefore, this experiment adjusted the distances between nodes (the distances between Node A and Node B, Node A and HWG, Node B and HWG) to be 0.5, 1, 1.5, 2, 2.5 and 3 meters respectively, and then observed the Round Trip Time (RTT) of packet and the throughput. The Wireshark software is installed on Node A, Node B and HWG to collect, record and analyze relevant data.

(1) Node A and Node B are connected by the ad hoc mode of IEEE802.11 (Wi-Fi). Node A is the Destination Node and Node B is the Source Node. A 100 MB file transfer is conducted to observe the average RTT of packet and the average throughput of IEEE 802.11 without using HWG. The experimental results are as shown in Figures 10 and 11. Under the IEEE 802.11 ad hoc mode and when the communication range is within 0.5~3 meters, the average RTT of packet is between 0.725ms and 0.77ms. Although the average RTT of packet varies somewhat, but variation is only 0.045ms, which is because the transmission range of IEEE 802.11 is approximately 100 meters and the distance variation is insufficient for influencing the RTT of packet. The experimental results are shown in Figure 11. The average throughput is between about 14.7Mbps and 15.9Mbps. Despite the throughput varies, the variation of 1.2Mbps is acceptable. This result is caused by is the transmission interference and signal fading.

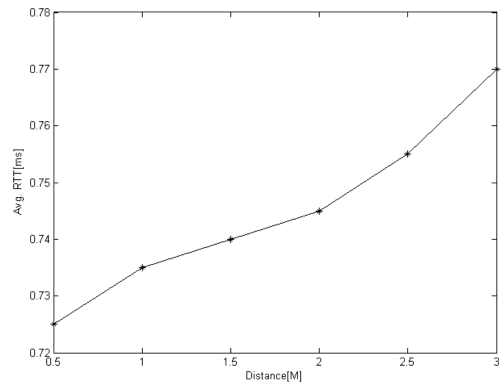

Figure 10. Average RTT of packet transmitted by IEEE 802.11 (ad hoc mode)

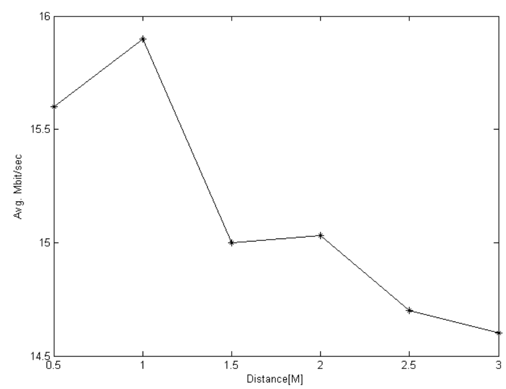

Figure 11. Average throughput of IEEE 802.11 transmission (ad hoc mode)

(2) Node A and Node B are connected by the BlueHoc mode of Bluetooth. Node A is the Destination Node and Node B is the Source Node. A 100 MB file transfer is conducted to observe the average RTT of packet and the average throughput of Bluetooth without using HWG. The experimental results are shown in Figures 12 and 13. The average RTT of packet transmitted by Bluetooth using BlueHoc mode increases with distance between nodes, and the average RTT of packet increases from 11.4ms to 14ms. The average RTT of packet varies serious which is because the affection of packet collision and signal fading in low speed communication is critical. Moreover, the experimental results in Figure 13 indicated that, the average throughput of Bluetooth using BlueHoc mode increases with the distance between nodes, and the average throughput increases from 1Mbps to 0.6Mbps.

(3) Node A and HWG are connected by the ad hoc mode of IEEE 802.11, Node B and HWG are connected by the BlueHoc mode of Bluetooth, and 100MB data is sent from Node A to Node B. The average RTT of packet from IEEE

802.11 to Bluetooth and the average throughput are observed. As shown in Figure 14, the average RTT of packet in Bluetooth with HWG increases with the distance between nodes, from 14.5ms to 22ms. Moreover, as shown in Figure 15, the average throughput of Bluetooth with HWG increases with the distances between nodes, and the average throughput declines from 1.2Mbit/s to 0.61Mbit/s. This experiment found that when the distances between nodes increase, the average RTT of packet increases and the average throughput falls off.

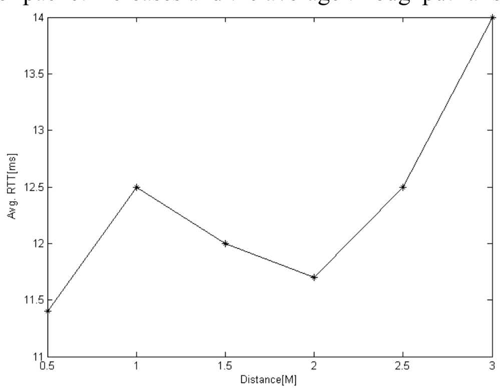

Figure 12. Average RTT of packet transmitted by Bluetooth (BlueHoc mode)

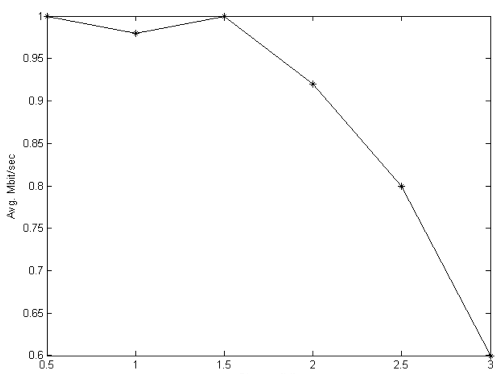

Figure 13. Average throughput of Bluetooth transmission (BlueHoc mode)

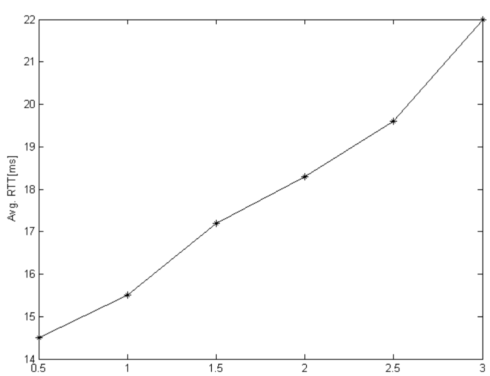

Figure 14. Average RTT of packet of Bluetooth with HWG

(4) Node A and HWG are connected by the ad hoc mode of IEEE 802.11, Node B and HWG are connected by the BlueHoc mode of Bluetooth, and 100MB data is sent from Node B to Node A. The average RTT of packet from Bluetooth to IEEE 802.11, the average throughput and the transmitted data are observed. As shown in Figure 16, the average RTT of packet in IEEE 802.11 with HWG increases with the distances between nodes, from 15ms to 29.1ms. As shown in Figure 17, the average throughput of IEEE 802.11 with HWG increases with the distances between nodes, falling off fro, 0.7Mbits/s to 0.41Mbits/s.

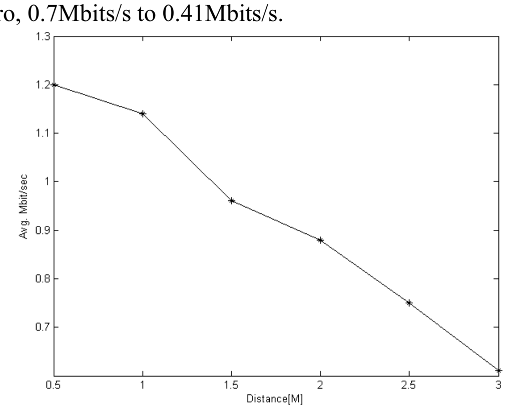

Figure 15. Average throughput of Bluetooth with HWG

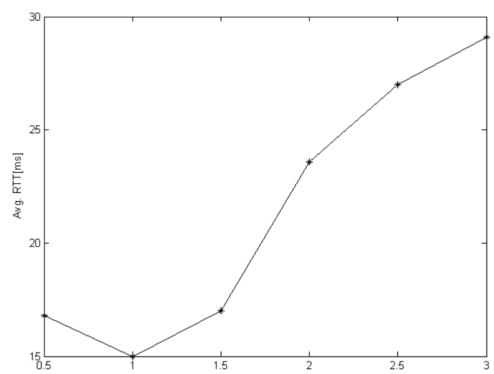

Figure 16. Average RTT of packet of IEEE 802.11 with HWG

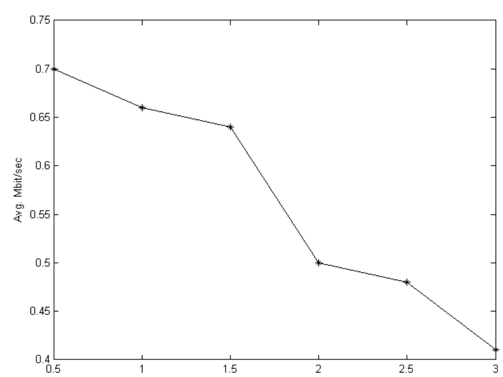

Figure 17. Average throughput of IEEE 802.11 with HWG

To sum up, the experimental data are listed in the Table 1. The results indicate that the efficiency of structure with

HWG lags behind the structure without HWG (comparing Experiment (1), (2) and Experiment (3), (4)), which is because the entire efficiency of the whole system reduces for the limitations of Bluetooth bandwidth. The bandwidth of currently used Bluetooth version 2.0 mechanism, and the protocols is far lower than IEEE 802.11. This problem can be solved after the standardization and the enhancement of bandwidth of the future Bluetooth version 3.0. In addition, Experiment (3) prevails over Experiment (4) because the transmission from IEEE 802.11 to HWG possess of the advantage of high bandwidth of WLAN, which enables HWG to convert the data format along with time and to cope with the communication of low-bandwidth Bluetooth. As far as the entire experiment concerned, if the influence of low bandwidth of Bluetooth is excluded, it is proved that the proposed method can effectively integrate the heterogeneous wireless network and the system efficiency is acceptable.

TABLE I. Experimental data

Wireless Protocol	Distance (meters)	Avg. RTT (ms)	Avg. Throughput (Mbit/s)
Experiment(1) IEEE 802.11	0.5	0.72	15.6
	1	0.73	15.9
	1.5	0.74	15
	2	0.74	15.03
	2.5	0.75	14.7
	3	0.77	14.6
Experiment(2) Bluetooth	0.5	11.4	1
	1	12.5	0.98
	1.5	12	1
	2	11.7	0.92
	2.5	12.5	0.8
	3	14	0.6
Experiment(3) IEEE 802.11 to Bluetooth	0.5	14.5	1.2
	1	15.5	1.14
	1.5	17.2	0.96
	2	18.3	0.88
	2.5	19.6	0.75
	3	22	0.61
Experiment(4) Bluetooth to IEEE 802.11	0.5	16.8	0.7
	1	15	0.66
	1.5	17	0.64
	2	23.6	0.5
	2.5	27	0.48
	3	29.1	0.41

V. CONCLUSIONS

This study used the software mechanism to design the HWG for integrating the heterogeneous wireless network, and supported multiple heterogeneous wireless communication protocols by the temporary storage mechanism in the buffer and the packet formation conversion function. The proposed HWG can integrate IEEE 802.11 and Bluetooth wireless communication protocols. The experiments proved that the HWG established by use of IEEE 802.11 and Bluetooth causes the delay of network transmission for slow transmission speed and short transmission distance of Bluetooth. As a result, with regard to this system, the bottleneck of the system efficiency may occur on the Bluetooth network with low bandwidth. If the system efficiency is to be increased, the improvement should be made accordingly. However, the proposed HWG can integrate the heterogeneous networks with the need to update the software functions of original devices, and it also has the advantage of low cost. In addition, the system extensibility can be achieved by adding other heterogeneous wireless communication interfaces through modularization, which allows this mechanism to have high compatibility.

REFERENCES

[1] D. Agrawal and Q.-A. Zeng, "Introduction to Wireless and Mobile Systems," Thomson-Engineering, 2002.

[2] IEEE Std. 802-11, "IEEE standard for wireless LAN medium access control (MAC) and physical layer (PHY) specification," Jun. 1997.

[3] IEEE 802.11, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," 1999 (reaff. 2003).

[4] IEEE 802.11 WG, "Amendment to Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Medium Access Control (MAC) Quality of Services Enhancements," P802.11e/D.13.0, Jan. 2005.

[5] Bluetooth SIG, "Bluetooth Specification," http://www.bluetooth.com

[6] C. Bisdikian, "An overview of the Bluetooth wireless technology," In: *Proceedings of IEEE Comm. Magazine*, Dec. 2001, pp. 86–94.

[7] J. Banos, C. Cardenas and C. Perez, "Testing of wireless heterogeneous networks," In: *Proceedings of IEEE MELECON* , May. 2006, pp. 676-679.

[8] A. Soomro and D. Cavalcanti, "Opportunities and Challenges in Using WPAN and WLAN Technologies in Medical Environments," *IEEE Communications Magazine*, Feb. 2007 , pp. 114-122.

[9] Cavalcanti, D. Agrawal, D. Cordeiro, C. Bin Xie Kumar, A. "Issues in Integrating Cellular Networks, WLANS, and MANETS: A Futuristic Heterogeneous Wireless Network," *IEEE Wireless Communications*, Jun. 2005, vol. 5, pp. 2926-2931.

[10] C. D. M. Cordeiro, S. Abhyankar, R. Toshiwal and D. P. Agrawal, "BlueStar: Enabling Efficient Integration between Bluetooth WPANs and IEEE 802.11 WLANs," *Mobile Networks and Applications*, 2004, vol. 9, pp.409-422.

[11] Mobilian, Mobilian TrueRadio, http://www.mobilian.com

[12] Possio, Possion PX20, http://www.possio.com.

[13] Red-M, Genos wirelessware, http://www.red-m.com.

[14] C. Cordeiro, D. Agrawal and D. Sadok, "Piconet interference modeling and performance evaluation of Bluetooth MAC protocol," In: *Proceedings of IEEE Transactions on Wireless Communications*, 2003, vol. 2, pp.1240-1246.

[15] Y. Kim, B. Zhen and K. Jang, "Hybrid of listen-before-talk and adaptive frequency hopping for coexistence of Bluetooth and IEEE 802.11 WLAN," In: *Proceedings of IEEE International Conference on Wireless LANs and Home Networks*, Dec. 2001.

[16] N. Rouhana and E. Horlait, "BWIG: Bluetooth web Internet gateway," In: *Proceedings of ISCC*, Jul. 2002.

[17] BlueHoc, IBM Bluetooth simulator, http://oss.software.ibm.com/developerworks/opensource/bluehoc/.