International Journal of Emerging Trends & Technology in Computer Science (IJETTCS)
Web Site: www.ijettcs.org Email: editor@ijettcs.org, editorijettcs@gmail.com
Volume 7, Issue 3, May - June 2018 ISSN 2278-6856

A Mobility Model and Dynamic Scatternet Formation for Wireless Personal Area Networks with Portable Bluetooth Devices

Chorng-Horng Yang* **and Yi-Sheng Chen**

Department of Information Management, I-Shou University
No. 1, Sec. 1, Syuecheng Rd., Dashu District, Kaohsiung City 84001, Taiwan R.O.C.
**Corresponding author*

Abstract: ***Bluetooth is a mature technology for a variety of personal computing devices, which are interconnected to form a wireless personal area networks (WPANs). The topology of the WPAN is known as scatternet, which consists of the portable Bluetooth devices. This paper presents a proposed mobility model for the portable Bluetooth devices. Based on the mobility model a dynamic scatternet formation is developed for WPANs that interconnects portable Bluetooth devices. The proposed approach constructs a scatternet within three phases: scatternet backbone formation, device movement detection, and scatternet reformation. Finally, the paper demonstrates the approach with a practical case and then discusses the topics for further study.***

Keywords: WPAN, scatternet, mobility, Bluetooth.

1. INTRODUCTION

Bluetooth [1] is a promising technology that provides wireless interconnection between electronic devices for wireless personal area networks (WPANs). A piconet is the basic block for constructing WPANs. In a piconet, one device should act as the master and the other devices are slaves. The number of active slaves in a piconet can be up to seven. Devices in a piconet share the same hopping channels, which the channel is selected from the 79 hopping channels according to the FH sequence. The identity and system clock of the master determines the FH sequence. Each device selects the same hopping channel, and there creates a unique channel in a piconet. Moreover, a number of piconets can interconnect by using the bridge devices to form a scatternet.

There are few papers discuss the mobility of Bluetooth devices in the literature. We proposed a mobility model for Bluetooth PANs in [2]. On the other hand, many researchers propose the scatternet formation protocols [3-8]. The existing scatternet formation protocols do not deal with the device mobility. Thus, we develop a dynamic scatternet formation protocol that takes the device mobility into account and can format the scatternet in three phases: (i) constructing a backbone, (ii) detecting the device mobility for joining/leaving the scatternet, and (iii) reformatting the scatternet.

The rest of this paper is organized as follows. Section 2 introduces the related work. Section 3 presents the device mobility. In Section 4, we propose the scatternet formation protocol. Section 5 summarizes this paper.

2. RELATED WORK

Many scatternet formation protocols were proposed in the literature. These protocols can be classified into two types. One is the big-scatternet formation protocol, which constructs a big scatternet and makes the Bluetooth devices always connect to the scatternet. The big-scatternet formation protocols include the distributed formation [3], tree scatternet formation (TSF) [4], MIT Scatternet Formation Algorithm [5], BlueStars [6], Loop scatternet [7], etc.

The other one is the scatternet-route structure [8], which constructs a control scatternet (i.e., a backbone) and establishes a route on demand. The scatternet-route structure does not maintain a big scatternet, so that the number of control messages for maintaining the scatternet can be reduced and the power can be saved. Since most of the Bluetooth devices are battery-driven, operating these devices in a power-efficient mode is essential. Thus, many researchers investigate the related issues of the scatternet-route structure in recent years.

In [9], we have studied the performance of scatternet routes. Moreover, most of the Bluetooth devices are portable and mobile, and the users of these Bluetooth devices may take with these devices and walk (roam) among (in) offices. Thus, a scatternet formation protocol has to take not only the power consumption but also the device mobility into account. Unfortunately, there are few papers that deal with the mobility issue in the literature. We have proposed a mobility model for Bluetooth PANs in [2]. On basis of the proposed mobility model, we can further develop the dynamic scatternet formation protocol to cope with both the power consumption and the device mobility issues. In the following Section, we briefly introduce the proposed mobility model.

3 PROPOSED MOBILITY MODEL

The mobility model [2] for Bluetooth scatternets in the wireless PAN includes topology model, movement model, residence time model, and call arrival model. We describe these models as follows.

3.1 Model of Topology Change

In the literature, there are many kinds of scatternet topologies be proposed. These topologies include star, ring, loop, tree, and scatternet-route [3-8]. The topology model presents the possible topology changes due to devices movement in a scatternet. We summarize the possible topology changes in Table 1.

From the topology model shown in Table 1, the number of device(s) that move(s) to cause topology change can be either single device or multiple devices. For the single device movement and the moved device is a slave, the topology changes only occur in the two piconets (see Fig. 1-(a)), which one piconet is the device moves from and the other piconet is the device moves to. However, if a device whose role is either a master or a bridge moves in the scatternet, the topology of the scatternet would change. To deal with such a scatternet topology change, the scatternet formation procedure must be run to select another device to replace the moved master/bridge, so that not only the piconet topology but also the scatternet topology changes. We refer to such a topology change as a scatternet topology change. Note that when a Bluetooth device uses up its battery energy the device would lose its connection to other devices. We also regard such an event as a single device movement.

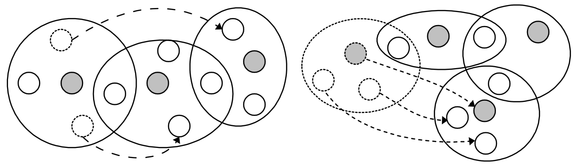
For the movement of multiple devices, there are two possible cases. One is that the moved devices are all slaves, so that the masters and bridges within the scatternet remain unchanged and the topology changes occur only at piconets. The other case is that the moved devices constitute a piconet and such a piconet topology must be retained after devices moving. We refer to such multiple devices movement as piconet movement (see Fig. 1-(b)). Obviously, the scatternet topology would change if a piconet moves. From the point of view of users, the piconet movement may occur frequently. For example, one may bring a cell phone (master), a headset (slave) and a PDA (slave) together and moves to a meeting room. And she/he would like to retain such a piconet topology after moving to the meeting room. Note that there is another case that multiple devices which include masters or bridges but do not form a piconet move in a scatternet. Such movements of multiple devices can be regarded as many single-device movements occur simultaneously.

Table 1. Topology model

Number of devices moved	Types of device moving	Types of topology change
Single device	single slave	piconets
	Master or bridge	scatternet
Multiple devices	multiple slaves	piconets
	a piconet	scatternet

3.2 Model of Device Movement

Movement model describes the patterns of Bluetooth device movements. We distinguish the movement of



(a) Piconet topology change (b) Scatternet topology change

Figure 1. Mobility of Bluetooth devices

Bluetooth devices into low mobility and high mobility scenarios. Table 2 summarizes the movement model. Low mobility scenario describes that a device moves within a small area in an indoor environment. For example, one brings Bluetooth devices and moves between offices on the same floor. High mobility scenario represents the movement pattern that devices move faster in a larger area. For example, one brings Bluetooth devices walking between several buildings or moving in a factory by riding on a low-speed car.

Moreover, we classify the moving behaviors into tree patterns: (i) enter/leave a scatternet, (ii) roam among the piconets that connect to a scatternet, and (iii) turn off the device temporarily. For the enter/leave pattern, users may bring Bluetooth devices to enter/leave to/from a scatternet during rush hours. Such a movement may usually be a piconet movement and pass through a particular entrance/exit point (or a particular piconet in the scatternet). The movement pattern of roaming among offices describes that users bring Bluetooth devices and roam among the offices during office hours. For this pattern, users usually move to another piconet to stay there for a while and then return to the home piconet. For example, users move from their offices to the meeting room and return to their offices after the meeting. The pattern of turning off device temporarily represents the event that a device runs out battery power or be turned off by users. We propose the associated characteristics for each movement pattern in Table 2. These characteristics are number of moved devices, residence time (i.e., residence time model), and geographical range of the movement. The length of residence time and distance of movement range we propose in Table 2 are considered for the academy in Taiwan.

3.3 Model of Device Residence Time

The residence time is an important parameter to identify mobility characteristics. It anticipates the time that a Bluetooth device resides in a piconet. We further define two parameters for residence time model: (i) T_p : The piconet residence time represents the length of time that a Bluetooth device resides in a piconet. (ii) T_x : The transition time represents the length of the time period from a Bluetooth device leaving a piconet to the device settling down in a new piconet. The distributions of T_p and T_x are dependent on many factors, such as mobility patterns, etc. The generalized Gamma distribution can provide the best

Table 2. Movement model

Movement patterns		Characteristic		
		Number of devices	Resid. time	Movement range
Low mobility	Enter/leave	Multiple	Long 3~8 hrs	Within 100m
	Roam among offices	Single / Multiple	Medium 1~3 hrs	Within 100m
	Turn off device temporarily	Single	Short <30mins	Within 100m
High mobility	Enter/leave	Multiple	Long 3~8 hrs	Within 2000m
	Roam among offices	Single / Multiple	Medium 1~3 hrs	Within 2000m
	Turn off device temporarily	Single	Short <30mins	Within 2000m

approximation for residence time in cellular networks. However, it is for further study to validate the distribution for Bluetooth scatternets.

3.4 Model of Device Call Arrival

In this paper, Call arrival model gives the probability of having incoming calls during the time that a Bluetooth device resides in a piconet. The Poisson distribution is often used to model the calls. Thus, we can also employ Poisson distribution to model call arrivals in a Bluetooth scatternet. Given a rate of λ , the call arrival is then defined by

$$C(t) = \lambda e^{-\lambda t} \qquad (1)$$

4 DYNAMIC SCATTERNET FORMATION

The proposed dynamic scatternet formation involves three procedures: (i) backbone formation, (ii) device movement detection, and (iii) scatternet reformation. Figure 2 depicts the flow of the proposed dynamic scatternet formation.

The first step is to construct the scatternet backbone, which consists of the masters and the bridges of the piconets that connect to the scatternet. After the backbone formation, the procedure of the device movement detection is responsible for searching the nearby Bluetooth device that would like to join the scatternet and detecting any device that has already connected to the scatternet but now loses its connection to the scatternet. If a new device or a leaving device is detected, the procedure of scatternet reformation starts dealing with the topology change, which is either a piconet topology change or a scatternet topology change. After the scatternet reformation, the status of the scatternet can be a scatternet, a scatternet with backbone partitioned, or a vanished scatternet. If the scatternet is maintained well, the flow goes to device movement detection. However, if the backbone is partitioned, the flow goes to backbone formation procedure. Finally, if the scatternet vanishes, the procedure goes to the end. In the following subsections, we describe the three main procedures, backbone formation, device movement detection, and scatternet reformation, as follows.

4.1 Formation of Scatternet Backbone

In the literature, there are lots of papers that present their approaches of scatternet backbone formation. In this paper, we propose an approach that is similar to the approach proposed in [8], which does not provide the details of their approach. During formatting the backbone, the state of the Bluetooth device may be in one of the following states. We describe these states as follows.

(i) *Inquiry (Discovering) and Inquiry Scan States*: A Bluetooth device that tries to find other nearby devices is known as an inquiring device. It can actively send inquiry requests and waits for the responses from other devices. On the other hand, the Bluetooth device that is available to be found is known as a discoverable device. It listens to the inquiry request and sends the response back to the inquiring device. Moreover, a pair of Bluetooth devices that one successfully inquires the other one can form the simplest piconet, which consists of a master and a slave.

(ii) *Page (Connecting) and Page Scan States*: After discovering the nearby devices, the master can execute the paging procedure for creating connections. The procedure is asymmetrical and requires that one Bluetooth device carries out the page (connection) procedure while the other Bluetooth device is connectable, in other words, in page scanning state.

(iii) *Connected State*: After a successful connection procedure, the devices are physically connected to each other within a piconet.

Suppose that the Bluetooth devices are brought to offices in an ad-hoc fashion. Each active device runs the above procedures to join a piconet to be either a master or a slave. After the piconets forming, the scatternet is constructed by several piconets that interconnect by bridge devices. The bridge device can be either a slave or a master/slave (double-role) device. In a scatternet, different piconets share a common bridge device. The bridge device then alternates its participation to the two interconnected piconets. After creating a scatternet in such a distributed manner, the scatternet backbone can be further constructed.

Figure 3 depicts a scatternet that can be further constructed as the backbone.

After connecting the piconets together to form a scatternet, each master in the scatternet has to gather the information of the backbone for routing. The master first creates a *piconet topology table*, which stores the physical addresses and roles (i.e., master, bridge, and slave) of the devices in the piconet. Then, the master sends its piconet topology table to its bridge(s), which further send(s) the piconet topology table to the other master(s) that it connects to. A master receives the piconet topology tables of other piconets in the scatternet from the bridges, and then constructs a *scatternet topology table*, which links all the piconet topology tables together to provide the master with the complete information of the scatternet.

Table 3 shows the scatternet topology table for the scatternet of Fig. 3. (Note that the items in the table represent both the physical addresses and the roles of the Bluetooth devices in the scatternet. And the piconet address (e.g., p1) is the same as the physical address of the master (e.g., m1). In order to maintain the scatternet topology table, the master periodically sends its piconet topology table to other masters. Generally speaking, since the Bluetooth PAN naturally consists of a few piconets (e.g., 3 or 4 piconets), such a topology information exchange can be done quickly. And the topology information can be maintained correctly and consistently.

By employing the scatternet topology table, an on-demand route can be established easily and quickly. We demonstrate an example by using the scatternet shown in Fig. 3. If s1.1 wants to connect to s4.2, the device of s1.1 sends a Route Discovery Protocol (RDP) packet [8] to its master m1. The master m1 looks up its scatternet topology table and finds that there are four possible paths to s4.2. Then, the master m1 sends the RDP packets to bridges b1 and b2. When the RDP packets finally arrive at the master of piconet 4, i.e., m4, the master m4 obtains the permission of establishing connection from the slave s4.2, and then selects a route and sends back a Route Reply Protocol (RRP) packet [8] to the master m1. When the master m1 receives the RRP packet from m4, the master m1 informs the slave s1.1 and starts data transmission.

In general, the above proposed scatternet backbone can successfully support on-demand routing for a static scatternet, in which the Bluetooth devices do not move frequently. In order to cope with the device mobility in the Bluetooth PANs, the device movement detection is required. We describe the device movement detection as follows.

4.2 Device Movement Detection

The device movement detection is responsible for searching a new device that would like to join the scatternet and detecting the device that loses connection to the scatternet due to movement or power off. For searching a new device, the masters in the scatternet could periodically transmit the inquiry control message to find a new device as discussed in the previous subsection. The new device that joins to an existing scatternet has to be a slave in a piconet. After joining the scatternet as a slave, the new device may change its role to be a bridge or a master during the scatternet reformation.

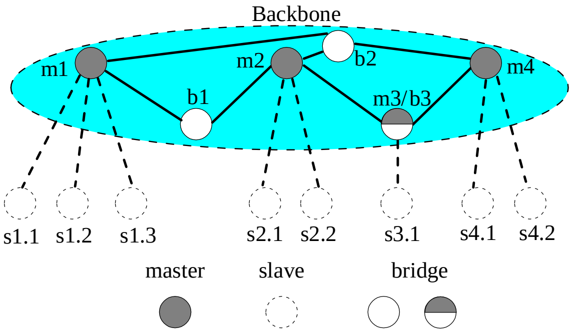


Figure 3. Scatternet backbone

For detecting a leaving device, there are two possible approaches. One is an active approach, which the device actively reports the leaving (in this case, leaving means a device with low power [2]), and the other one is the passive approach, which the scatternet detects the device movement (i.e., users bring the devices out of the range of the piconet and/or the scatternet [2]). For the active approach, a Bluetooth device that is either a slave or a bridge can be configured to report its low power status to the master. After receiving such a leaving report from the slave or bridge, the master can activate the scatternet reformation procedure to resolve such a device movement. We discuss the scatternet reformation in the following subsection. If the master would like to leave due to low power, the master can activate the scatternet reformation by itself to deal with the master movement.

For the passive approach of detecting device movement, we discuss according to the role of the device in the scatternet as follows.

(i) Slave or bridge: The master periodically polls the slave and bridge in the piconet not only for data transmission but also for status report. Let the period of the master polling any device in the piconet be T_{poll} seconds, and the master waits for the response from the slave or bridge for T_w seconds. If a slave or a bridge does not respond to the master's poll for consecutive k times,

Table 3. Scatternet topology table

p1	m1	s1.1, s1.2, s1.3, b1, b2	
	b1: p2	b2: p4	
p2	m2	s2.1, s2.2, b1, b2, b3	
	b1: p1	b2: p4	b3: p3
p3	m3	s3.1, b3	
	b3: p2, p3		
p4	m4	s4.1, s4.2, b2, b3	
	b2: p1, p2	b3: p3	

the master decide that the slave or bridge has moved out of the range of the piconet/scatternet or powered off. Thus, we can calculate the average time (T_d) of detecting a slave or a bridge moving as follows.

$$T_d = \frac{1}{2} T_{poll} + k \cdot T_w \quad (2)$$

(ii) Master: Similarly, if a slave or a bridge waits for the master polling and does not receive any poll from the master for T_{idle} seconds, the slave or bridge knows that the master has moved or powered off. Note that the value of T_{idle} can be set to the value that satisfies $T_{idle} > n \cdot T_{poll}$.

The average time required to detect the device movement depends on the above parameters. For different device mobility, we can adjust the values of the parameters to detect the device movement quickly. However, setting improper values for the above parameters may lead to wrong decision on device movement. Thus, the adaptive approach for setting the values of the parameters is important for the scatternet with the devices that have varying mobility. After detecting the device movement, the scatternet reformation is activated to deal with the device movement. We discuss the scatternet reformation in the following subsection.

4.3 Scatternet Reformation

In the proposed mobility model [2], two types of mobility are proposed: one is the single device movement and the other one is the moving of a group of devices. In this paper, we focus on the single device movement and the group mobility issue is for further study. We discuss the scatternet reformation according to the role of the moved device.

(i) Slave: When a slave moves (either be powered off or actually moves) and be detected by its master, the master updates its piconet topology table and then sends the piconet topology update to the bridge(s). Such a piconet topology update will propagate to the other piconets in the scatternet. As discussed in the previous subsection, the number of piconets in a scatternet is a few. Thus, such a piconet topology update can take effect quickly.

(ii) Bridge: For the case that a bridge moves and be detected by its masters, the master with the smallest value of the addresses is responsible for searching an existing device to replace the moved bridge. There are three possible outcomes of executing the scatternet reformation. (1) The new bridge completely replaces the moved one. In other words, all piconets that the moved bridge connects to are connected by the new bridge. (2) A new bridge is found but not all of the piconets that the moved bridge connects to are connected by the new bridge. In such a case, the scatternet reformation will activate the backbone formation, if the backbone is partitioned. On the other hand, if the backbone is not partitioned, the scatternet reformation is done. (3) The last case is the worst one that no device can be a new bridge. Thus, the scatternet reformation can activate the backbone formation if the backbone is partitioned due to the bridge moving. Similarly, such a topology update has to be sent to the other piconets by the master. So, the on-demand routing still works successfully.

(iii) Master: When a master will move due to the low power, the master can select one of its slaves to be a new master. After role switching [1], the master can leave successfully and the piconet topology update can be sent to the other piconets by the new master through the bridges. However, if a master actually moves out of the range of the scatternet, one of the slaves or bridges will first detect the movement. There are two possible solutions for resolving the master moving: one is local reformation and the other one is globally backbone formation. For the local reformation, the first device that detects the master moving can be a new master and inquire the devices that lose their master to join its new piconet. After local reformation, the new master has to send the new piconet topology table to the other piconets for updating their scatternet topology tables. Such a local reformation may fail and the (globally) backbone formation is activated to resolve such an issue.

4.4 Performance Evaluation

Refer to the simulation model proposed in [10]. A simulation study was conducted to evaluate the performance of scatternet formation. The area is a 50 meters x 50 meters square for the simulation study. The number of nodes is from 25 to 55. The other parameters are as follows. T_{poll} is set to 0.5s, and T_w is set to 0.75s as well as k is set to 3. The generalized Gamma distribution is employed to provide the best approximation for residence time. The performance is evaluated with respect to the ratio of the number of nodes connected to the scatternet to the total number of nodes. The simulation result is shown in Fig. 4.

For the case of fixed devices, the ratio is higher than 0.96. For the case of low-mobility devices, the ratio is higher than 0.91. However, for the case of high-mobility devices, the ratio is lower than 0.86. Besides, the ratio

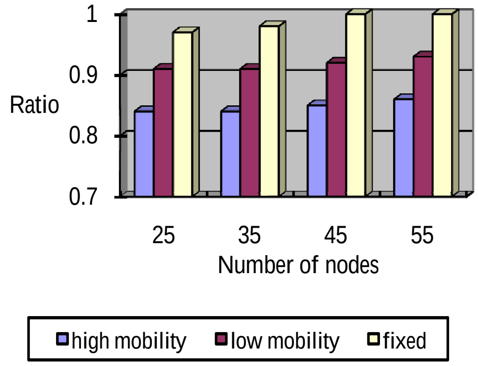


Figure 4. Simulation result

increases as the number of nodes increases. It is obvious since the density of nodes could increase the connectivity of the scatternet. Based on the above performance evaluation, the high-mobility devices may lose their connections to scatternet. Thus, more sophisticated approach should be developed for detecting device movement and reconnecting device to scatternet.

5 SUMMARY

In this paper, the proposed mobility model for the Bluetooth WPANs was presented. The mobility model consists of the topology model, movement model, residence time model, and call arrival model. The mobility model can represent the behavior of the portable Bluetooth devices. With the proposed mobility model, a dynamic scatternet formation approach was developed and presented. The approach includes three major procedures: backbone formation, device movement detection, and scatternet reformation. Moreover, a practical case study was employed for demonstrating the proposed approach. For further study, the following topics are interesting. Firstly the adaptive device-movement detection can facilitate the device movement detection. Secondly, the performance of the proposed dynamic scatternet formation can be evaluated on basis of the proposed mobility model. Finally, the scatternet reformation must be further refined for resolving the movement of a group of devices that would like to retain their roles.

References

[1] Bluetooth SIG, *Specification of the Bluetooth System-Core v1.2*, 2003 (www.bluetooth.com).

[2] C.-H. Yang, Y.-S. Chen, J.-W. Ruan, and W.-P. Ho, "A Mobility Model for Bluetooth Scatternets in Wireless Personal Area Networks," in *Proc. Int'l Conf. on Wireless Networks (WNET 2004)*, pp. 140-143, June, 2004.

[3] V. Verma and A. Chandak, "Distributed Bluetooth Scatternet Formation Algorithm," in *Proc. IEEE Global Telecommunications Conference (GLOBECOM '03)*, vol. 3, pp.1274-1278, December, 2003.

[4] G. Zaruba, S. Basagni, and I. Chlamtac, "Bluetrees-Scatternet Formation to Enable Bluetooth Based Ad Hoc Networks," in *Proc. IEEE Int'l. Conf. on Communications (ICC '01)*, vol. 1, pp.273-277, June, 2001.

[5] C. Law and K.-Y. Siu, "A Bluetooth Scatternet Formation Algorithm," in *Proc. IEEE GLOBECOM '01*, vol. 5, pp. 2864-2869, 2001.

[6] C. Petriol, S. Basagni, and I. Chlamtac, "Configuring BlueStars: Multihop Scatternet Formation for Bluetooth Networks," *IEEE Transactions on Computers*, vol. 52, no. 6, pp.779-790, June, 2003.

[7] H. Zhang, J. Hou, and L. Sha, "A Bluetooth Loop Scatternet Formation Algorithm," in *Proc. IEEE Int'l. Conf. on Communications (ICC '03)*, vol. 2, pp.1174-1180, June, 2003.

[8] Y. Liu, M. Lee, and T. Saadawi, "A Bluetooth Scatternet-Route Structure for Multihop Ad Hoc Networks," *IEEE J. on Sel. Areas in Commu.*, vol. 21, no. 2, pp. 229-239, Feb., 2003.

[9] C.-H. Yang, S.-C. Hsu, and H.-J. Tsai, "Performance Study on Scatternet Routes in Bluetooth Personal Area Networks," in *Proc. IASTED Int'l Multi-Conf. on Wireless and Optical Communications*, pp. 656-661, July, 2004.

[10] E. M. Arpitha and T. M. Ramesh, "Performance Analysis of Low Rate WPAN Topologies," *Int'l J. of Innovative Research in Computer and Communication Engineering*, pp. 4283-4288, May 2014.

AUTHOR

Chorng-Horng Yang received the B.S. degree in Electrical Engineering in 1992 from National Taiwan University of Science and Technology, and M.S. and Ph.D. degrees in Electrical Engineering from National Chung Cheng University, Taiwan, in 1994 and 2001, respectively. In 1999, he was a visiting scholar at the Ohio State University, USA; and from 2005 to 2007 he was the Chief of Networking Section of Computer Center in I-Shou University, Taiwan. He is currently an assistant professor at the Department of Information Management, I-Shou University. His research interests include information systems, wireless networks, performance analysis, and protocols.

Yi-Sheng Chen had graduated from the Department of Information Management, I-Shou University, Taiwan.