Routing Protocols for Improving Survivability of Scatternet Routes

Chorng-Horng Yang[*] and Chia-Wen Wang

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 one of the popular short-range wireless communication technologies, and most of the portable Bluetooth devices are battery-driven. Thus, the survivability of routes in a Bluetooth scatternet is becoming a crucial issue. The survivability of a scatternet route depends on not only the residual energy of the battery of the Bluetooth device but also the mobility of the Bluetooth devices on the route. In this paper, the survivability of a scatternet route on basis of the energy and mobility of Bluetooth devices are explored. Moreover, a quality measure, Q-value, for the Bluetooth device is proposed for evaluating the impact of a device onto the survivability of a scatternet route. Then, based on the quality measure, three approaches that can establish highly survivable scatternet routes are proposed. Finally, the simulation study was conducted to evaluate the performance of the three approaches. The simulation results show that the three approaches can improve survivability of scatternet routes with the cost of computing overhead during route establishment.***

Keywords: survivability, Bluetooth, scatternet, routing.

1. INTRODUCTION

Bluetooth [1] is a promising low-power, low-cost, short-range radio-based technology that was developed to replace cables between electronic devices. Bluetooth operates in the 2.4 GHz license-free Industrial, Scientific and Medical (ISM) band. A Bluetooth enabled device can establish a communication link with other device within its radio range. The maximum data transmission rate can reach 723.2 kbps.

A Bluetooth piconet consists of at most eight active devices, including one master and maximum up to seven slaves. Each piconet utilizes the frequency hopping (FH) scheme and its master monitors the scheduling of the data transmission with its slaves. Besides, several piconets can co-exist in a common area, and can be interconnected via some bridge nodes to form an ad-hoc network known as the scatternet. In [2], we have studied the performance of scatternet formation. Moreover, the Bluetooth device is mobile and the users may take with Bluetooth devices and roam in offices [3]. In [4], we have studied the routing protocol, which can detect device movement and establish routes in a mobile scatternet. In a wireless network, power is used for transmitting and receiving data, battery constrained the wireless network lifetime [5]-[8]. Network survivability is an essential aspect of reliable communication services [9]-[11]. Survivability is the capability of a mobile wireless networks to fulfill its mission in a timely method. Thus, a scatternet route protocol has to take not only the power consumption but also the device mobility into account.

In the literatures, there are a lot of papers that address the various issues of Bluetooth networks, such as the scatternet formation and routing mechanisms. For studying the survivability of scatternet routes, we investigate a variety of scatternet formation protocols, which include Bluetree, BlueMesh, and Bluestar. Furthermore, we study the routing protocols for Bluetooth networks. These routing protocols are dynamic source routing, Ad hoc On-Demand Distance Vector (AODV), and node-disjoint routing.

The rest of the paper is organized as follows. Section 2 presents the proposed quality measure, Q-value, for the Bluetooth device. In Section 3, we present the proposed approaches, MMinQ, MavgQ, and HybridQ for improving route survivability. Section 4 addresses the simulation study. Section 5 summarizes this paper.

2. PRELIMINARY

2.1 Scatternet Routes

The following notations are used in this paper.

m_i : the master of the i-th piconet in the scatternet

b_i : the i-th bridge in the scatternet

$s_{i,j}$: the j-th slave in the i-th piconet

P_i : the i-th piconet in the scatternet

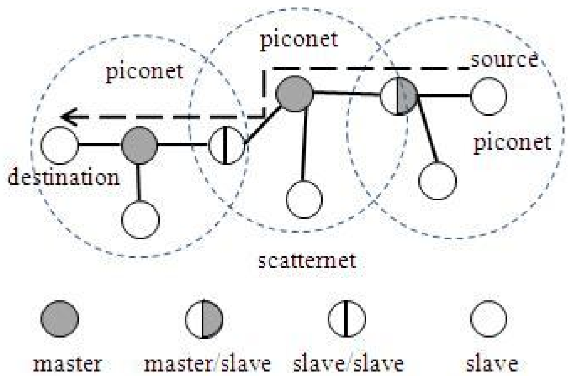


Fig. 1. Piconet and scatternet

B : the backbone of the scatternet
S : the scatternet
n_i : i -th node in scatternet

As shown in Fig. 1, a scatternet S consists of several piconets and each piconet includes a master device and up to seven active slaves as well as the bridge(s). Each device includes mobility and energy parameters.

2.2 Quality Measure for Survivability

We propose a quality measure, Q value, for Bluetooth devices, which are with two internal parameters, residual energy of the battery and mobility .The Q-value of a Bluetooth device can be used to evaluate the contribution of the device to the survivability of a scatternet route. Then, we analyze the survivability issues of the scatternet route and propose three approaches that can establish highly survivable scatternet routes. The following notations are used for defining the quality measure.

E_i :residual energy of n_i

e_i : energy consuming by node n_i per second

$T(n_i)=\frac{E_i}{e_i}$: lifetime of n_i

$L(n_i)=\frac{T(n_i)}{\max_{j=1}^{m}(T(n_j))}$, *where* $0<L(n_i)\le 1$: the normalized lifetime of n_i (2)

$M(n_i)$: mobility of n_i , where $0<M(n_i)\le 1$

$q(n_i)=\frac{L(n_i)+(1-M(n_i))}{2}$: quality measure of n_i (3)

$r_i=\bigcup_{j=1}^{k} n_{i,j}^{r}$: i -th route in scatternet

$n_{i,j}^{r}$: the j -th node on the i -th route in scatternet ; $j=1...k$

Q_{r_i} :Quality measure of i -th route in scatternet, where $i=1...p$

$$\overline{Q}^{\min}=\frac{1}{p}\sum_{i=1}^{p} Q_{r_i}^{\min}; i=1...p \quad (4)$$

$$R^{\min}=\{r_x \mid r_x \ \textit{satisfies}\ Q_{r_x}^{\min}\ge \overline{Q}^{\min}, r_x\in R\}$$

When the destination device receives the Route Discovery Protocol (RDP) packets from source through alternative routes, we describe the set of these routes as follows.

$$R=\{r_1,r_2,...,r_p\};$$

Then, how can we select a route from R to establish a highly survivable route for data transmission is an issue for our study. We present the proposed approaches as follows. We describe the proposed approaches that can establish highly survivable scatternet routes as follows.

3 Proposed Approaches For Establishing Survivable Routes

We describe the proposed approaches that can establish highly survivable scatternet routes as follows.

3.1 MMinQ Approach

In this section, we present the *MMinQ* approach, which selects the route that the minimum Q-value of the devices on the route is the maximum value among the corresponding values of the other routes. We define a parameter, $Q_{r_i}^{\min}$, as follows.

$$Q_{r_i}^{\min}=\min_{j=1}^{k} q\left(n_{i,j}^{r}\right);\ j=1...k \quad (5)$$

Thus, the value of $Q_{r_i}^{\min}$ for route r_i is the minimum value of the $q(n_{i,j}^{r})$ of devices on route r_i . Note that the q -value of each device on a route is recorded in the Route Discovery Protocol (RDP) packet that traverses from source node to the destination node. When the destination node receives multiple RDP packet(s) from source node, the destination node select the route that has the (1) maximum value of $Q_{r_i}^{\min}$. Then, the destination replies a Route Reply Protocol (RRP) packet back to the source device along the route. The pseudo-code of the *MMinQ* approach is shown

Proc. $MMinQR(S,D)$
{
Suppose there exist $r_1,r_2,...,r_p$ routes from S to D in scatternet.
Choose r_x , where r_x satisfies $Q_{r_x}^{\min}\ge Q_{r_i}^{\min}, i=1,2,..., p$
return r_x
}

(a) MMinQ approach

Proc. $MAvgQR(S,D)$
{
Suppose there exist $r_1,r_2,...,r_p$ routes from S to D.
Choose r_x , where r_x satisfies $Q_{r_x}^{avg}\ge Q_{r_i}^{avg}, i=1,2,..., p$
return r_x
}

(b) MAvgQ approach

Proc. $HybQR(S,D)$
{
Suppose there exist $r_1,r_2,...,r_p$ routes from S to D.
Choose r_x , where r_x satisfies
$r_x\in R^{\min}$ and r_x satisfies $Q_{r_x}^{avg}\ge Q_{r_i}^{avg}; \forall r_i\in R^{\min}$
return r_x
}

(c) Hybrid approach

Fig. 2. The proposed approaches.

in Fig. 2(a).

3.2 MAvgQ Approach

Moreover, we propose the *MAvgQ* approach that selects the route with the average q-value of all devices on the route to be greater than the corresponding values of the other routes. The destination node may receive multiple RDP packets from the source node and then calculates the average q-value of all devices on a route. Thereafter, the destination node chooses the route that has the maximum average q-value from the routes. And, the destination node replies a RRP packet back to the source node along the selected route. We define the parameter $Q^{avg}_{r_i}$ as follows.

$$Q^{avg}_{r_i} = \frac{1}{k}\sum_{j=1}^{k} Q(n^{r}_{i,j})\ ;\ j = 1...k \quad (6)$$

Then, the pseudo-code of the *MAvgQ* approach is shown in Fig. 2(b).

3.3 HybridQ APPROACH

We propose the *HybridQ* approach that combines both of the *MMinQ* approach and the *MAvgQ* approach. We define the following notations.

$$\overline{Q}^{min} = \frac{1}{p}\sum_{i=1}^{p} Q^{min}_{r_i} ; i = 1...p \quad (7)$$

$$R^{min} = \{r_x \mid r_x \text{ satisfies } Q^{min}_{r_x} \ge \overline{Q}^{min}, r_x \in R\}$$

Where $R = \{r_1,...,r_p\}$ is the set of routes from source node to destination node.

The destination node receives multiple RDP packets from source node and calculates the $Q^{min}_{r_i}$ for each route in R. Then, it further figures out the value of $\overline{Q}^{min}$ and finds the set of routes that belong to R^{min}. Finally, the approach selects a route from R^{min} according to the *MAvgQ* approach. Then, the destination node replies a RRP packet back to the source node along the selected route. Figure 2(c) shows the *HybridQ* approach.

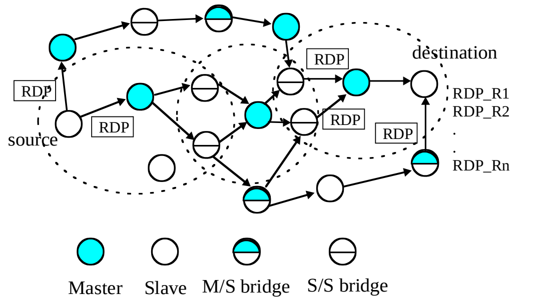
3.4 Partially Disjoint Backup Routes

In this paper, we also propose an approach that establishes partially disjoint routes to be the backup route for an existing route for further improving the survivability of a route. We refer to the proposed approach as PDR approach, and discuss the PDR approach as follows. The PDR approach consists of three procedures:

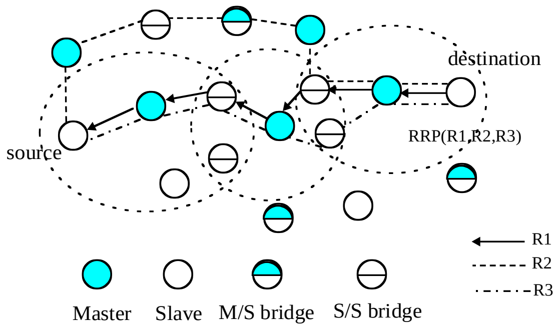
(a) *Route discovery:* When a mobile node wants to start the communication, it initiates the route discovery process by broadcasting the RDP packets toward the destination. It is possible that several RDP packets finally reach the destination if there are several routes that exist in the scatternet (see Fig. 3(a)).

(b) *Route selection:* The destination node, upon receiving the RDPs, can select a route according to the routing policy. Furthermore, after selecting a route, the destination node uses the route information carried in all RDP packets from the source to generate two partially disjoint routes against to the route it selected. The purpose of choosing some overlapping routes is to increase the connectivity of the network. Then, the destination sends back a RRP packet, in which carries the information of the three routes (R1, R2, R3), to the source as shown in Fig. 3(b).

(c) *Route restoration:* When the source communicates with the destination by exchanging data packets through the route, an intermediate node on the route may move out of the piconet and the route will be disconnected. For a node on the route detecting its downstream node movement, the node has to send out a *route error (RERR)* packet back toward the source node to stop data transmission at the source node. Moreover, when the route disconnection occurs and is detected by the downstream node, the downstream node also sends out a RERR packet to the destination node. When a node that is on the route receives an RERR packet from its upstream, it sets a timer (T_s) and waits for the *route request confirmation (RRC)* packet from its downstream [12]. If no RRC packet is received after time period T_s, it would release the network resource that is reserved for this route. After transmitting the RERR packet, the node that is the upstream node of the moved node will look up the cache of routing table that records backup routes and selects one of the backup routes in which the moved node is not on-route node (see Fig. 4).



(a) Source sends RDP to destination



(b) Destination sends back RRP_R1.R2,R3 packet.

Fig. 3. Backup routes establishment.

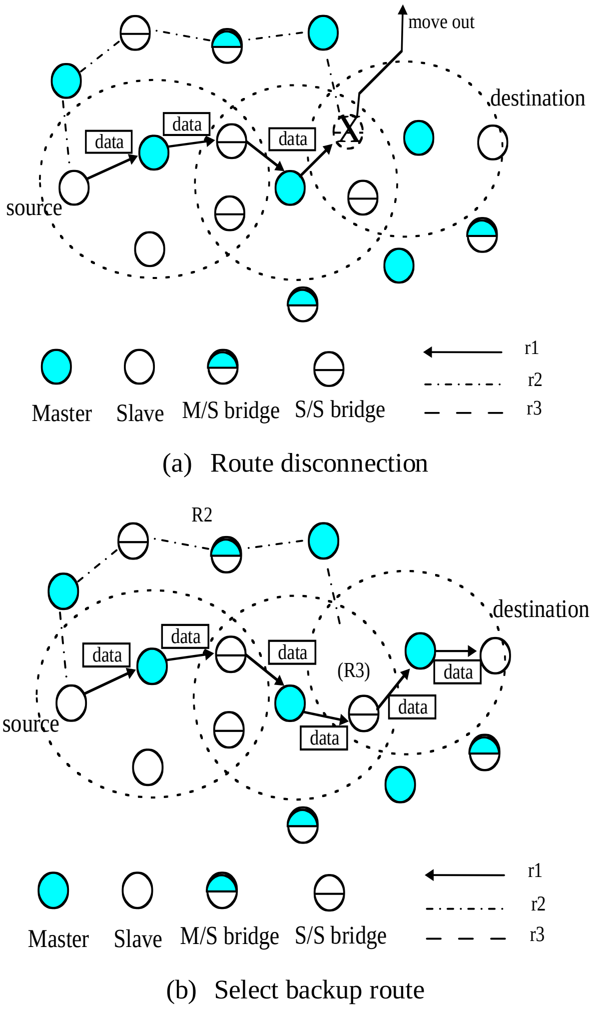


Fig. 4. Backup route establishment.

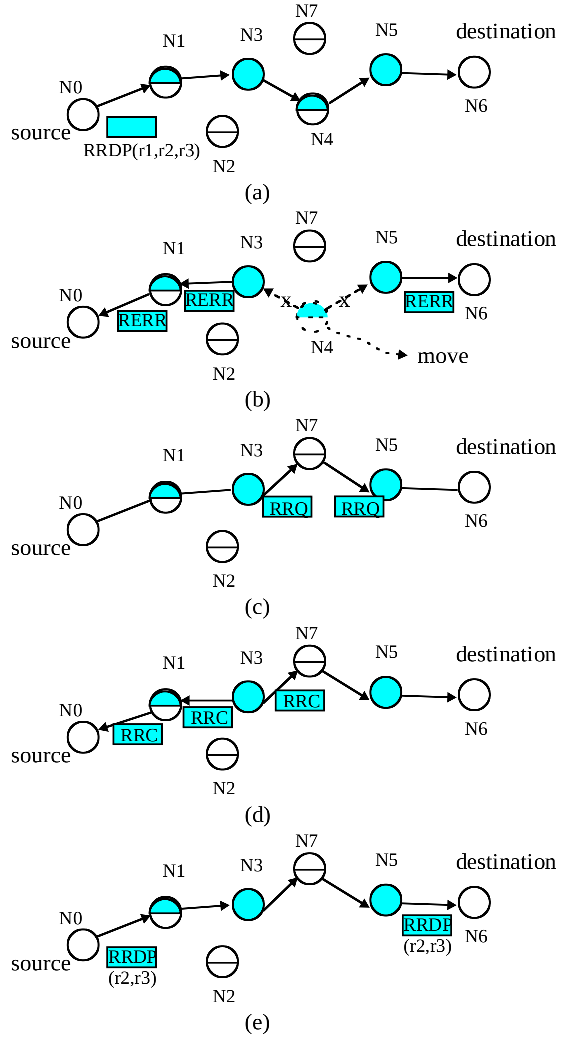


Fig. 5. Example of route backup process.

We illustrate the backup route as shown in Fig. 5. In Fig. 5, the nodes on a route are N_0 (source), N_1, N_3, N_4, N_5 and N_6 (destination). During the data transmission phase, the node N_4 moves out and the route is broken. After N_3 and N_5 detecting the moving of N_4, they would send out the RERR packets to the source and destination nodes along the route (see Fig. 5(b)). After sending out the RERR packet, the node N_3 would execute the route backup procedure. It sends back a RRQ packet through the backbone to source (see Fig. 5(c)). When N_3 receive the RRQ packet from the backbone, it finds that there is an existing route (the original route) to the destination.

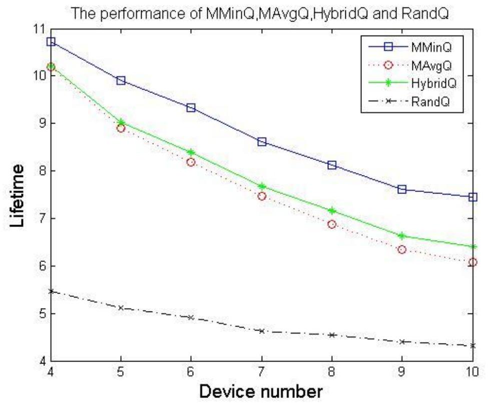
Thereafter, the node N_3 sends out the RRC packets to the upstream and downstream nodes. And the RRC packets finally reach to the source and the destination. Assume that the source selects the R2 route and resends the RRDP (RRDP_R2) packet. The source node N_0 would resume the data transmission after received the RRC packet. The nodes on the restored route are N_0 (source), N_1, N_3, N_7, N_5 and N_6 (destination).

4 Simulation Study

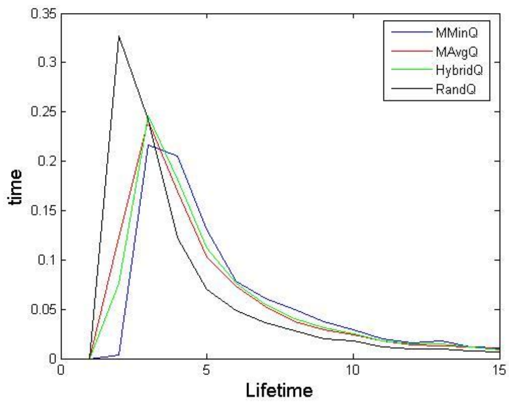
4.1 Assumptions

In order to compare and evaluate performances of the three methods (*MMinQ*, *MAvgQ* and *HybridQ*) in Bluetooth network, we make the following assumptions for our simulation study. (i)We suppose that the device only moves out and does not move in the Bluetooth scatternet during the route establishing and restoration. (ii) Each device in the scatternet is with the different mobility and power consumption of Q-value. (iii) We conduct the simulation study on both of the regular Bluetooth scatternet and irregular Bluetooth scatternet. (iv) We assume that the Q-value of Bluetooth device is between 0.2 to 0.9 and the power consumption is between 0.19 to 0.01on the regular Bluetooth scatternet. The number of Bluetooth devices on a route is from 4 to 10. Each simulation is conducted randomly for 10000 times, and total number of routes in the scatternet is 50. (v) All nodes are in radio visibility of each other in an area of 40m×40m square area for the irregular Bluetooth scatternet, so that

the route length may vary. We assume that the Q-value of the Bluetooth device is random number from 0.1 to 0.9.
(vi) We conduct the simulation experiments for the PDR approach on a regular Bluetooth scatternet as shown in Fig.10. And, we conduct simulation experiments on scatternets with different sizes, 3×3, 3×4, 3×5, 5×3, 5×4 and 5×5 piconets.



(a) Lifetime



(b) Distribution of lifetime

Fig. 6. Comparison of three approaches.

4.2 Simulation Results

(a) *Comparison of three approaches:* Figure 6(a) shows the lifetime of the four approaches with respect to the length of the route in terms of number of nodes. And Fig. 6(b) shows the distribution of route lifetime for the four approaches on a regular Bluetooth scatternet with route length of 10 nodes. The MMinQ approach has the largest average of route lifetime, and the approach of randomly selecting has the worst performance. Thus, the proposed three approaches can improve the route lifetime with the computing overhead at destination, which selects the route according to the three approaches.

(b) *Computing overhead of the approaches:* The computing overhead of the *MAvgQ* approach is more complex than those of the other methods as shown in Fig. 7.

(c) *Performance of the PDR approach:* Figure 8 shows the simulation results of the PDR approach on the regular Bluetooth scatternet with different sizes, 3×3, 3×4, 3×5, 5×3, 5×4 and 5×5 piconets. The backup route can successfully replace the broken route for the different scatternets. For 5x5 scatternet the performance of the PDR approach is the best among the different scatternets. On the other hand, the PDR approach has the worst performance on a small scatternet with the size of 3x3 piconets. It is nature that a larger scatternet has more possible backup routes. Thus, the PDR approach performs well on a large scatternet.

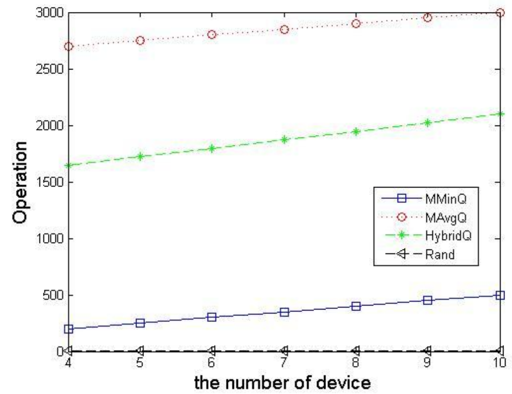


Fig. 7. Computing overhead.

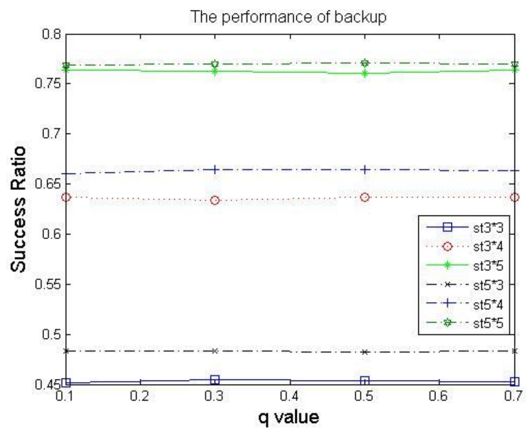


Fig. 8. Performance of the PDR.

5 SUMMARY

Most of the portable Bluetooth devices are battery-driven and may be carried by users to roam in a Bluetooth scatternet. Thus, the survivability of a scatternet route is crucial and constructing a survivable Bluetooth network is becoming an interesting topic. The survivability of a scatternet route depends on both the residual battery energy and the mobility of the Bluetooth devices on the route.

Based on the residual battery energy and the mobility of the Bluetooth device, a quality measure, q value, was proposed for evaluation of the contribution of a Bluetooth device to the survivability of a route. And, three approaches, MMinQ, MAvgQ, and HybridQ, which can establish highly survivable scatternet route with the cost of computing overhead were proposed in this paper. The data transmission could be interrupted when any on-route node moves out the piconet. Thus, a local rerouting mechanism, which can resolve the device movement during route establishment by establishing a partially disjoint route, was developed. To validate and evaluate the proposed approaches, we conducted simulation experiments. The simulation results show that the three approaches can improve survivability of scatternet routes with the cost of computing overhead during route establishment.

References

[1] The Bluetooth SIG, The Bluetooth Core and Specifications, the Bluetooth SIG, v1.2, http://www.bluetooth.com.

[2] Chorng-Horng Yang, Jian-Wei Ruan, and Chia-Wen Wang (2006), "Rerouting and Restoration of Scatternet Routes for Survivable Bluetooth Networks", in Proc. Of the 3rd 3rd IEEE VTS Asia Pacific Wireless Communications Symposium (APWCS '06), August 24-25, 2006. The 3rd IEEE VTS Asia Pacific Wireless Communications.

[3] Chorng-Horng Yang and Yi-Sheng Chen(2005), "Bluetooth scatterent formation for supporting device mobility", in Proc. of the 3rd International Conference on Information Technology Research and Education (ITRE '05), June, 27-30, 2005.

[4] C.-H. Yang, Y.-S. Chen, J.-W. Ruan, and W.-P. Ho(2004), "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.

[5] Chorng-Horng Yang and Jian-Wei Ruan (2005), "On-demand Routing for Bluetooth Scatternet Subject to Device Mobility," in Proc. of the First International Workshop on Information Networking and Application ,INA'2005, March, 2005.

[6] F. Cuomo, T. Melodia, and I. F. Akyildiz (2004), "Distributed self-healing and variable topology optimization algorithms for QoS provisioning in scatternets," in IEEE J. of Commu. on Sel. Areas, vol. 22 , pp.1220 - 1236, Sept. 2004.

[7] Jian Tang and Guoling Xue (2004), "Node-Disjoint Path Routing in Wireless Networks: Tradeoff between Path Llifetime and Total Energy," in Proc. IEEE International Conference on Communications, vol. 7, pp. 3812 – 3816, June, 2004.

[8] James P. G. Sterbenz, Rajesh Krishnan, Regina Rosales Hain, Alden W. Jackson, David Levin, Ram Ramanathan and John Zao (2002), "Survivable mobile wireless networks: issues, challenges, and research directions," in Proc. of the ACM workshop on Wireless security, pp. 31-40, 2002.

[9] Romdhani, L.; Bonnet, C. (2004), "Energy Consumption Speed-Based Routing for Mobile Ad Hoc Networks," in Proc. 24th International Conference on Distributed Computing Systems Workshops, pp. 729 – 734, 2004.

[10] Robert Poor, Cliff Bowman, Charlotte Burgess Auburn, and Ember Corporation (2003), "Self-Healing Networks," in Proc. of Annual ACM Queue vol. 1, May 2003

[11] Senouci, S.-M.; Pujolle, G. (2004), "Energy Efficient Routing in Wireless Ad Hoc Nnetworks," in Proc. IEEE International Conference on Communications, vol. 7, pp. 4057 – 4061, June, 2004.

[12] Xin Zhang; Riley, G.F. (2005), "Energy-Aware On-Demand Scatternet Formation and Routing for Bluetooth-Based Wireless Sensor Networks," IEEE Communications Magazine, vol. 43, pp. 126 – 133, July, 2005.

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.

Chia-Wen Wang had graduated from the Department of Information Management, I-Shou University, Taiwan.