LETTER *IEICE/IEEE Joint Special Section on Autonomous Decentralized Systems Theories and Application Deployments*

Introduction to Blueweb: A Decentralized Scatternet Formation Algorithm for Bluetooth Ad Hoc Networks*

Chih-Min YU[†a)], ***Member and*** **Chia-Chi HUANG**[††], ***Nonmember***

SUMMARY In this letter, a decentralized scatternet formation algorithm called Bluelayer is proposed. First, Bluelayer uses a designated root to construct a tree-shaped subnet and propagates an integer variable $k1$ called counter limit as well as a constant k in its downstream direction to determine new roots. Then each new root asks its upstream master to start a return connection procedure to convert the tree-shaped subnet into a web-shaped subnet for its immediate upstream root. At the same time, each new root repeats the same procedure as the root to build its own subnet until the whole scatternet is formed. Simulation results show that Bluelayer achieves good network scalability and generates an efficient scatternet configuration for various sizes of Bluetooth ad hoc network.

key words: *Bluetooth, ad hoc network, scatternet formation, network scalability*

1. Introduction

Bluetooth is emerging as a potential technology for short-range ad hoc wireless networks. This technology enables the design of low power, low cost, and short-range radio which is embedded in existing portable devices. Initially, Bluetooth technology is designed as a cable replacement solution among portable and fixed electronic devices. Today, people tend to use a number of mobile devices such as cellular phones, PDA's, digital cameras, laptop computers, and so on. Consequently, there exists a strong demand for connecting these devices into networks. As a result, Bluetooth becomes an ideal candidate for the construction of ad hoc personal area networks.

Until now, many decentralized scatternet formation algorithms for constructing a Bluetooth ad hoc network have been proposed [1]–[4]. In [1], a node which has complete knowledge of all the nodes is elected as the leader of the scatternet. Then, this leader partitions the entire scatternet topology by a predefined formula. In [2] and [3], multiple leaders each with the largest number of neighbors in its local neighborhood are elected as root nodes to form piconets. The leaders instruct their slaves to page specific neighbors in order to form gateways to neighboring piconets.

In a Distributed Bluetree algorithm [4], two phases including the subtree formation and scatternet formation phases are designed to form a scatternet. In the first phase, multiple init nodes, each with the highest ID in its local neighborhood during the inquiry mode, are selected as root nodes (root selection process). Then each root pages its neighboring slaves to form piconets and builds its own subtree topology. In the second phase, the subtree topologies are merged into a single scatternet. Finally, Distributed Bluetree designates one of the subtree topologies as the root of the scatternet.

To simplify the root selection process and make the scatternet topology controllable, a decentralized scatternet formation algorithm called Bluelayer is proposed in this letter. This method uses a designated root to propagate an integer variable $k1$, the counter limit, and a constant k in its downstream (outward) direction to determine new roots as well as build their associated subnets. The new roots are determined locally without exchanging information among nodes. With this method, the subnet size can be also controlled by appropriately selecting the constant k and each root manages its own subnet.

This letter is organized as follows: In Sect. 2, we describe the scatternet formation algorithm of the Bluelayer. In Sect. 3, we use computer simulations to verify the system performance of Bluelayer. Finally, a conclusion is drawn in Sect. 4.

2. Bluelayer Scatternet Formation Algorithm

At the beginning, a particular node is given as the designated root to set a counter limit $k1 = k$, where $k1$ is an integer variable and k is the constant. With these two parameters, the first root inquires and pages up to 7 neighboring slaves, and forms its own piconet. Each slave then switches its role to master (called S/M node) to inquire and page one additional slave. After each S/M node connects to its slave, a role exchange mechanism is executed to make the S/M node function as a relay and make the slave function as a master. Then, these new masters decrease $k1$ by 1 and continue to propagate the two parameters in the downstream direction.

In this way, when the ($k1$)th master is reached, $k1 = 0$. The master becomes a new root and the counter limit $k1$ is reset to k. The tree-shaped subnet of the designated root is created. Then this new root asks its upstream masters to start the return connection procedure and tries to connect with one additional slave until its immediate upstream root is reached. As a result, the tree-shaped subnet of the designated root is converted into the web-shaped subnet.

Manuscript received January 12, 2008.
Manuscript revised April 18, 2008.

[†]The author is with the Department of Computer and Communication Engineering, Asia University, Taichung County, Taiwan.
[††]The author is with the Department of Communication Engineering, National Chiao Tung University, Hsinchu, Taiwan.

*This work is supported by the National Science Council, Taiwan (NSC97-2218-E-468-006).

a) E-mail: hankycm@ms47.hinet.net

DOI: 10.1093/ietcom/e91–b.9.2873

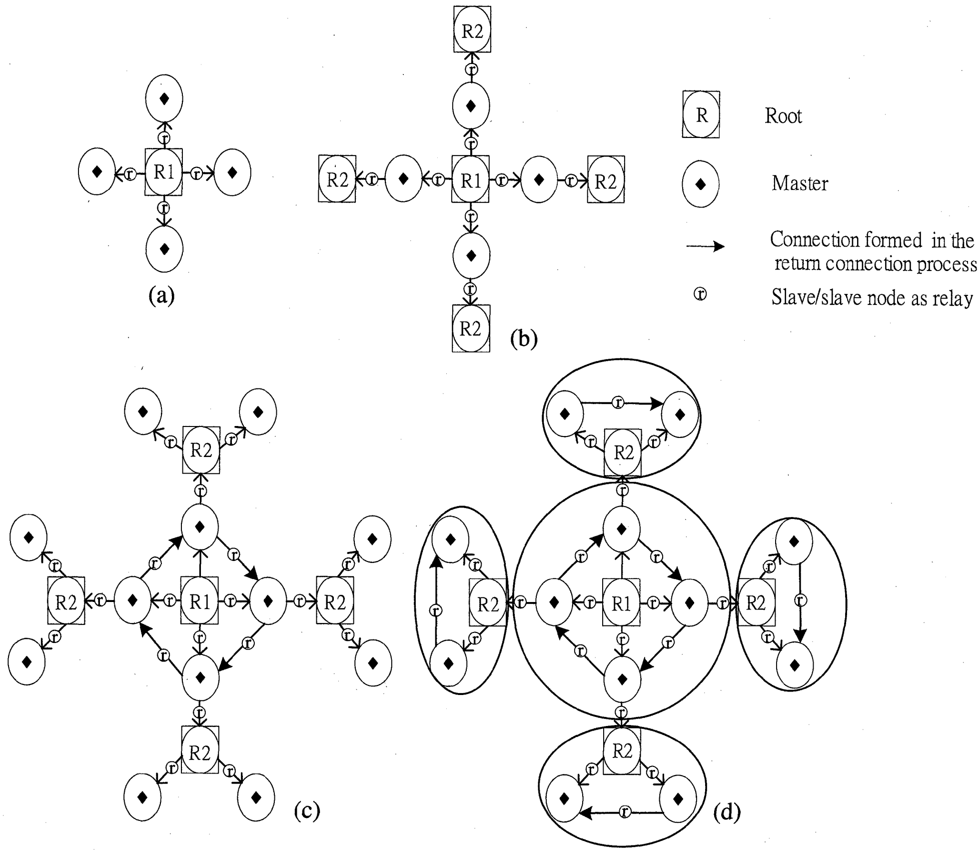

Fig. 1 The Bluelayer scatternet formation process.

At the same time, the new root repeats the same procedure as the designated root to build its own subnet and propagates the two parameters to determine new roots. This procedure is continued until the leaf nodes are reached. All the leaf nodes will request their immediate upstream masters to conduct the return connection procedure until its immediate upstream root is reached, and the whole scatternet is formed. Finally, each root manages its own web-shaped subnet.

Here, we use $k = 2$ in Fig. 1 as an example to describe the Bluelayer scatternet formation process. Initially, the designated root R1 inquires and pages slaves to form its piconets. Each slave then switches its role to master (called S/M node) to inquire and page one additional slave. After each S/M node connects to its slave, a role exchange mechanism is executed to make the S/M node function as a relay and make the slave function as a master. As a result, the R1 connects with the first tier masters, as shown in Fig. 1(a). There is a relay (slave/slave node) between R1 and its immediate downstream masters.

The first tier masters decrease $k1$ by 1 and continue to connect with their downstream masters. When the second tier masters are reached and the counter limit $k1 = 0$, these masters become new roots and reset $k1$ to k, as shown in Fig. 1(b). The tree-shaped subnet of the designated root is created. These new roots ask their upstream masters to start the return connection procedure and connect with one additional slave until its immediate upstream root R1 is reached. The topology of the designated root is finished and it generates a web-shaped subnet. At the same time, these new roots start to page new slaves and connect with their immediate downstream masters (leafs in this example), as shown in Fig. 1(c), to build their own tree-shaped subnets.

When the leaf masters are reached, these masters start the return connection procedure until their immediate upstream roots R2's are reached, and the scatternet formation process is terminated. Finally, all roots have their corresponding web-shaped subnet, as shown in Fig. 1(d).

3. Bluelayer System Performance Simulation

3.1 Simulation Model and System Parameters

A simulation program is written to evaluate the system performance. First, we assume that the Bluetooth nodes are uniformly located on a rectangular lattice and the number of neighboring nodes which can be reached by each node is between 2 and 4. The simulated node number ranges from 60, 70, 80,, to 150. Two performance metrics, including the average number of roots and the average subnet size, are calculated by averaging over 100 randomly generated topologies for each simulated node number. The constant k is varied from 1, 2, 3, to 4 and the simulation results of Bluelayer are shown as follows.

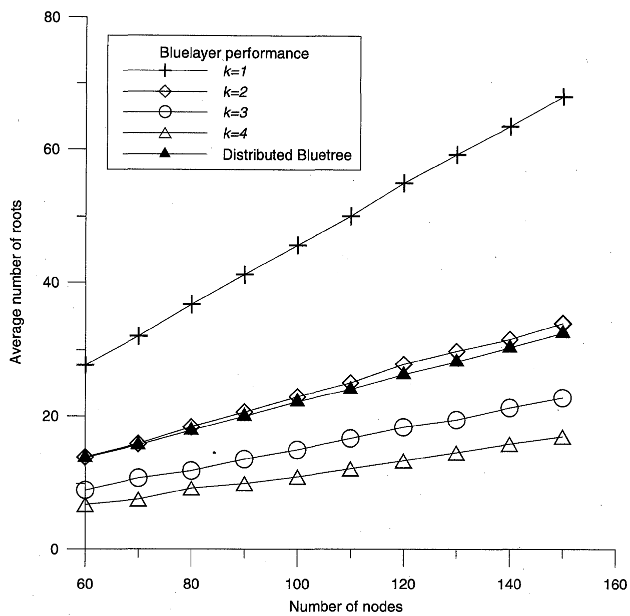

Fig. 2 Average number of roots in a scatternet.

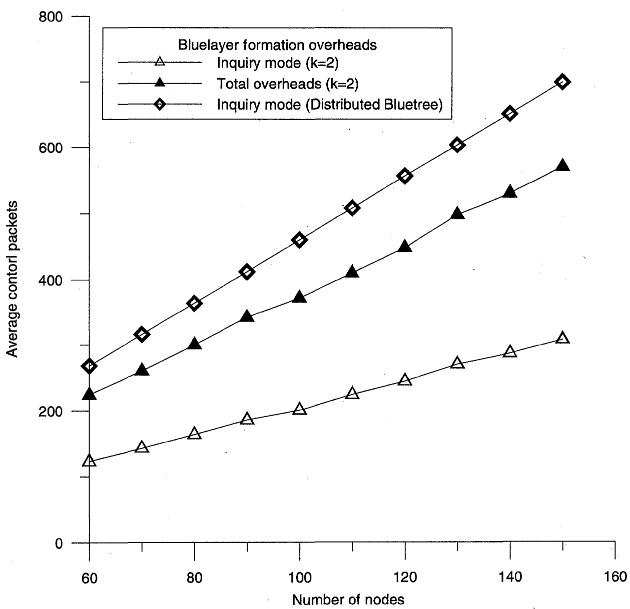

Fig. 3 Average control packets of scatternet formation.

3.2 Performance Results

Figure 2 shows the performance on average numbers of roots for both Bluelayer and Distributed Bluetree. The average number of roots increases as the number of nodes increases and the average subnet size is defined as the number of nodes divided by the average number of roots. In Bluelayer, we observe that the number of roots decreases as k increases and the $k = 4$ case produces the smallest number of roots in terms of the largest average subnet size. There is a performance tradeoff among the value of k, the average number of roots, and the average subnet size. In addition, the $k = 2$ case produces almost the same performance as the Distributed Bluetree. As a result, the number of roots can be easily controlled for various subnet size by selecting an appropriate k value in Bluelayer.

Figure 3 shows the scatternet formation overheads of Bluelayer with $k = 2$ case. The total overheads are calculated by the number of average control packets for both inquiry and page mode during scatternet formation. In the inquiry mode, the average control packets are calculated by the number of packets to execute the function of inquiry, inquiry response and return connection. In our simulation, each inquiry cycle of the master is counted as one inquiry packet. In the page mode, the average control packets are calculated by the number of packets to perform the function of page, return page and role exchange.

Figure 3 also shows that Bluelayer spends much less on control overheads than Distributed Bluetree in electing a root. This is because Bluelayer determines the root node only with its connected nodes instead of all neighboring nodes. As a result, Bluelayer not only reduces the root selection overheads but also simplifies the root selection process of scatternet formation compared to Distributed Bluetree.

4. Conclusion

Bluelayer is a tier-based method of generating new roots and spontaneously constructing their own subnets locally, until the whole scatternet is formed. By selecting an appropriate k value, we can achieve good network scalability for various size of Bluetooth scatternet. In addition, the proposed new root selection process is more efficient than Distributed Bluetree because it generates lower control overheads in electing new roots. Simulation results show that Bluelayer achieves better network scalability by selecting k value appropriately. As a result, Bluelayer generates an efficient scatternet configuration for various sizes of Bluetooth scatternet.

References

[1] T. Salonidis, P. Bhagwat, L. Tassiulas, and R. LaMaire, "Distributed topology construction of Bluetooth personal area networks," IEEE J. Sel. Areas Commun., vol.23, pp.633–643, March 2005.

[2] C. Petrioli and S. Basagni, "Degree-constrained multihop scatternet formation for bluetooth networks," Proc. IEEE Globecom 2002, vol.1, pp.222–226, Taipei, Taiwan, Nov. 2002.

[3] C. Petrioli, S. Basagni, and I. Chlamtac, "Configuring BlueStars: Multihop scatternet formation for Bluetooth networks," IEEE Trans. Comput., vol.52, no.6, pp.779–790, June 2003.

[4] G.V. Zaruba, S. Basagni, and I. Chlamtac, "Bluetrees-scatternet formation to enable Bluetooth-based ad hoc networks," IEEE International Conference on Communications, vol.1, pp.273–277, June 2001.