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On The Method and Performance Evaluation of A Hybrid Mesh-Tree Topology

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Abstract: In this paper, a hybrid mesh-tree topology construction for Bluetooth ad hoc network is proposed. The hybrid mesh-tree constructs a mesh-shaped topology in one dense area that is extended by tree-shaped topology to the other sparse areas. First, a designated root constructs a tree-shaped subnet, and then propagates a constant k in its downstream direction to determine new roots. Each new root asks its upstream master to start a return connection to convert the first tree-shaped subnet into a mesh-shaped subnet. At the same time, each new root repeats the same procedure as the root to build its own tree-shaped subnet until the whole scatternet is formed. As a result, the mesh subnet size can be controlled by appropriated selecting the k parameter. Simulation results show that the hybrid mesh-tree achieves better network performance than blueHRT does. As a result, the optimal k value can be determined, and the hybrid mesh-tree generates an efficient scatternet configuration.

Keywords: Bluetooth, Ad-hoc networks, Scatternet formation.

1 Introduction

Bluetooth is emerging as a potential technology for short-range wireless ad hoc network. This technology enables the design of low power, low cost, and short-range radio that can be 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 might become an ideal candidate for the construction of ad hoc personal area networks.

A Bluetooth-based multihop ad hoc network brings a number of challenges. In addition to the methods of device discovery for a node to participate in multiple piconets, the scatternet formation algorithm is a major technical issue. The scatternet formation algorithm deals with the problem of how to construct individual piconets and connect them together into a scatternet.

Depending on the purpose of a scatternet, a number of different topology models [1] can be generated. These scatternet topology models are shown in Figure 1, and can be generally classified as the tree hierarchy (TH) [2]-[4], the master/slave mesh (MSM) [5]-[6], the master/slave ring (MSR) [7]-[9], and the slave/slave ring.

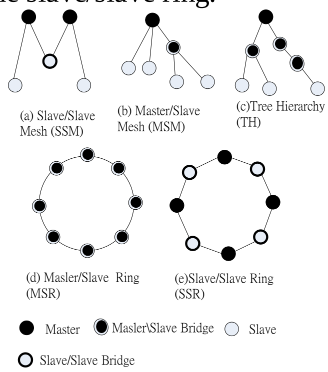

Figure 1: Scatternet topology models of Bluetooth networks

Bluetree [2] is the first scatternet formation protocol to build a tree hierarchy (TH) for Bluetooth ad hoc network. It adopts one or a few root nodes to start the formation of a scatternet. The resulting topology is tree-shaped and it uses master/slave nodes to serve as relays throughout the whole scatternet. Although its spanning tree architecture achieves a minimum number of connection links between any two nodes, its tree-shaped topology is not reliable under dynamic topological changes [11]. In addition, the algorithm can be implemented easily but the root node is likely to become the bottleneck.

Bluenet [10] and Bluestar [11][12] are good master/slave mesh (MSM) examples. Bluenet sets up a scatternet in a distributed fashion and it shows that a mesh-like architecture achieves higher information-carrying capacity than a tree-shaped one. In BlueStars, each node initially executes an inquiry procedure in a distributed fashion to discover its neighboring devices, then a number of masters are selected based on the number of their neighbors, and finally a number of gateways are selected by these masters and a mesh-like scatternet is formed. The MSM model may use master/slave or slave/slave nodes as relays to increase scatternet performance with additional protocol complexity.

In [13], a blueHRT is proposed to combine both the tree hierarchy (TH) and ring topology. The hybrid ring tree (blueHRT) is composed of three algorithms: discovery, role assignment and connection algorithms, which form Bluetooth networks. During the inquiry phase, a discovery algorithm compares the addresses of all Bluetooth devices and selects a root as a leader with the largest amount of addresses. In the role assignment algorithm, the root assigns master nodes and slave/slave bridges in the ring area, as well as master/slave nodes for the tree topology. In the connection phase, all master and master/slave nodes start to page their slaves and connect the scatternet to a hybrid ring tree topology.

To retain the advantages while combating the limitations of both mesh-shaped and tree-shaped topology, a hybrid mesh-tree formation method is proposed. This method uses a designated root to propagate constant k in its downstream direction in order to construct the mesh-shaped topology and determine the new roots for its descendant TH nodes. Then, each new root starts to build its own tree subnet until the entire scatternet is formed. As a result, the mesh subnet size can be controlled by the appropriate selection of the k parameter.

2 Hybrid Mesh-Tree Method

The hybrid mesh-tree assumes that a set of Bluetooth nodes is randomly distributed in a specific geographical area and all nodes are not necessary within the radio range. In order to construct a multihop scatternet, two additional assumptions are made. One is that every node is aware of the number and the identity of its neighbors upon completing the boot procedure. The other assumption is that there is at least one path between any two nodes in the network.

At the beginning, a new root selection process is designed in the designated root to determine new roots on a tier-by-tier basis in the downstream direction (out from the designated root) during scatternet formation. Then, each new root constructs and coordinates its own local tree-shaped subnet. In addition, a return connection algorithm is used for the first root to convert its tree-shaped subnet into the mesh-shaped subnet. The hybrid mesh-tree scatternet formation algorithm is described as follows.

With a new root selection process, the designated root sets constant k as a parameter. With the k parameter, the first root pages up to seven neighboring slaves to form a piconet. The detail flow diagram of master is shown in Figure 2. Then each slave then switches its role to master (called M/S node) and pages additional slaves. These new masters decrease k by 1 and continue to propagate the k parameter in the downstream direction. Afterwards, the new masters begin to page up to seven neighboring slaves and connect their slaves to form their own piconets. Finally, each new master will switch to return mode and wait for the return signal notification.

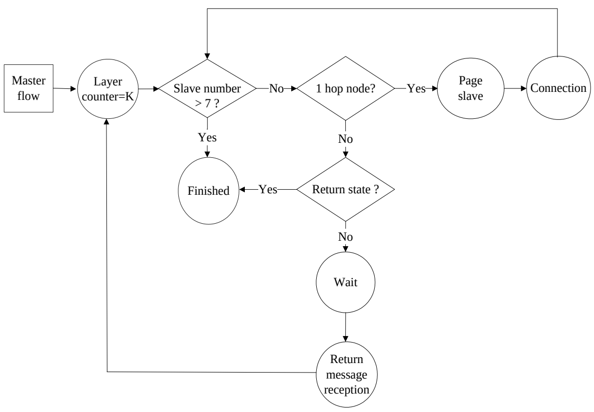

Figure 2: The master flow diagram

In this method, when the (k)th master is reached, k=0. The master becomes a new root and the k propagating process stops here. The root selection process continues until all new roots are selected. Then, the tree-shaped subnet of the designated root is created. The detail flow diagram of slave is shown in Figure 3.

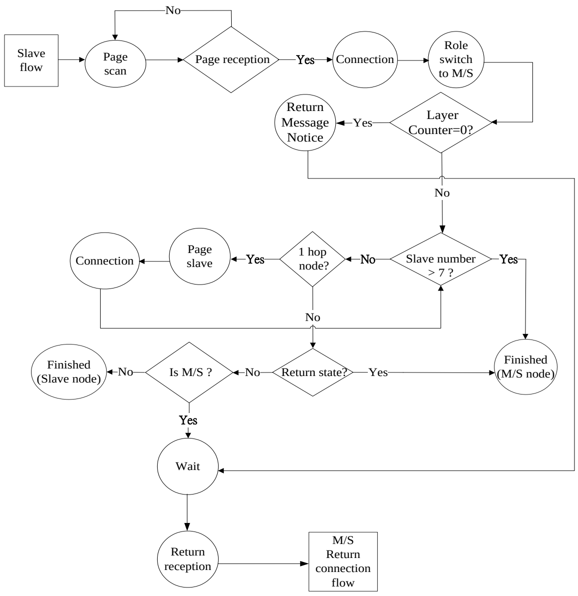

Figure 3: The slave flow diagram

After each new root is determined, it notifies its upstream masters to start a return connection procedure to connect with additional master/slave (M/S) nodes. During the return connection procedure, each returning M/S node alternately switches its state between page and page scan activities to connect with the other M/S nodes. This procedure is operated iteratively until the designated root is reached. The detail flow diagram of M/S return connection is shown in Figure 4. As a result, the tree-shaped subnet of the designated root is converted into a mesh-shaped subnet.

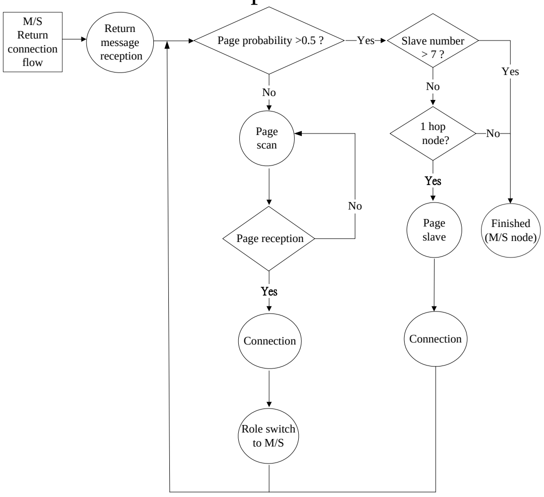

Figure 4: The M/S return connection flow diagram

At the same time, the new roots start to page and connect up to seven neighboring slave nodes to form their piconets. Then, the paged slaves switch their roles to master (called M/S nodes). Afterwards, the new masters begin to page up to seven neighboring slaves and connect their slaves to form their own piconets. This procedure is operated iteratively until the leaf nodes of the tree are reached. When the leaf nodes of M/S cannot page and connect any other slave nodes, the M/S nodes change their role to slave nodes and the algorithm stops here. As a result, the mesh-shaped topology of the designated root is formed and each new root manages its own tree-shaped subnet.

It is assumed that when two or more masters try to connect with a slave, this slave node will be affiliated with the master node whose page signal reaches it first. After finishing the scatternet formation, a hybrid mesh-tree architecture is formed, the immediate master/slave (M/S) nodes function as relays, and only the leaf nodes play the role of slave.

Here, k=2 was used in Figure 5 as an example to describe the hybrid mesh-tree scatternet formation process. At the beginning, the designated root R1 connects with the first tier masters, as shown in Figure 5(a). Then the first tier masters decrease k by one and continue to connect with their downstream masters. When the second tier masters are reached and the counter limit k=0, these masters become new roots, as shown in Figure 5(b). The tree-shaped subnet of the designated root is created.

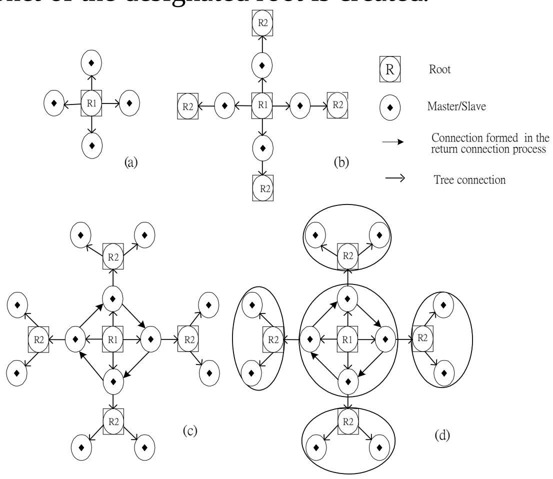

Figure 5: Scatternet formation process of hybrid mesh-tree

These new roots ask their upstream masters to start the return connection procedure until R1 is reached. The topology of the designated root is finished and generates a mesh-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 Figure 5(c), to build their own tree-shaped subnets. Finally, the mesh-shaped topology of the designated root is formed and each new root manages its own tree-shaped subnet, as shown in Figure 5(d).

3 Scatternet Performance

In this section we simulate and compare the performance of the scatternet formation algorithms for hybrid mesh-tree and blueHRT. The comparisons are based on a set of metrics which we use to measure scatternet performance. A simulation program is written to evaluate the scatternet performance.

The performance of scatternet formation algorithms is simulated and compared with both the hybrid mesh-tree and blueHRT. The ring-shaped topology of blueHRT contains only 3 nodes in the ring structure and the tree-shaped topology is extended by all the other nodes. In the scatternet performance simulation, it is assumed that Bluetooth nodes are randomly located within a rectangular area of 40 x 40 , while a radio transmission range of 10 m is assumed, and the number of simulated nodes ranges from 40 to 160. A set of performance metrics is calculated by averaging over 50 randomly generated topologies for each simulated node number. The scatternet performance metrics include: the average number of nodes in a piconet, the average path length and the total link connections. The simulation results for both hybrid mesh-tree and blueHRT are shown as follows.

Figure 6 shows the piconet efficiency (average number of slave nodes in a piconet) of the hybrid mesh-tree and blueHRT. With blueHRT, the piconet efficiency is less than two, since all nodes except the leaf nodes play the M/S role. With the same spanning tree topology, the hybrid mesh-tree achieves better piconet efficiency than blueHRT does, since each piconet can connect with more M/S nodes as its slaves during the return connection.

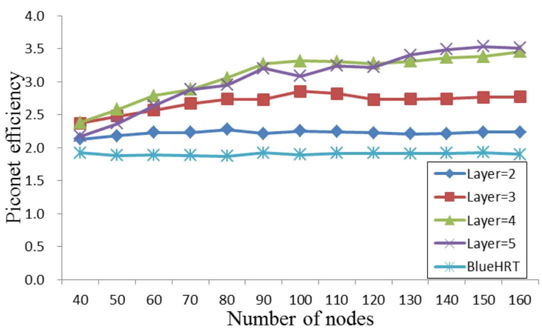

Figure 6: Average number of slave nodes in a piconet

An average hop length between any two nodes is also calculated for these networks. A larger average hop length implies that it will take more time to deliver a packet. This metric usually provides a coarse estimation of the average packet transmission delay of the scatternet.

In Figure 7, it can be seen that the hybrid mesh-tree achieves significant performance improvements in regard to the average hop length, compared to that of blueHRT. More return links can be connected among the M/S nodes as parameter k increases, thus the average path length among nodes can be reduced. In the hybrid mesh-tree, k=4 achieves the lowest hop length when the number of nodes ranges from 40 to 120, and k=5 achieves the best performance when the number of nodes is greater than 130. As a result, the optimum k value with the lowest average hop length varies according to the size of the network.

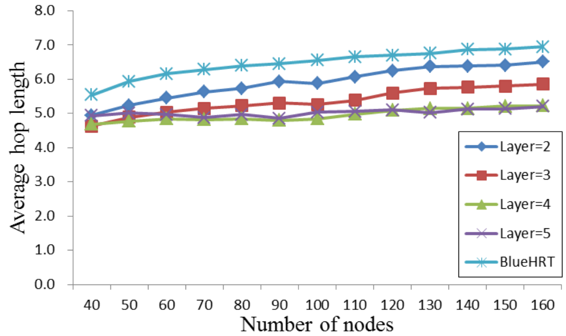

Figure 7: Average path length in a scatternet

The formation packets are counted as the total number of page packets in terms of the number of connecting links during scatternet formation. The link connections represent the aggregated connections, including the spanning tree links and return links of the network to improve the scatternet efficiency. In Figure 8, the hybrid mesh-tree spends more control packet overhead as a formation cost than blueHRT does. However, this control overhead is only generated during the scatternet formation phase.

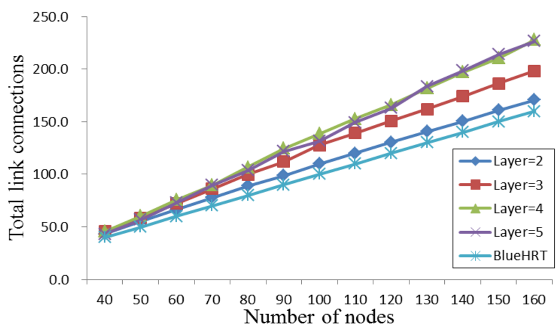

Figure 8: Average number of formation packets

4 Conclusion

To retain the advantages while combating the limitations of both mesh-shaped and tree-shaped topology, a hybrid mesh-tree formation method is proposed. The hybrid mesh-tree constructs a mesh-shaped topology in one dense area that is extended by tree-shaped topology to the other sparse areas. This method uses a designated root to propagate constant k in its downstream direction in order to construct the mesh-shaped topology and determine the new roots for its descendant TH nodes. Then, each new root starts to build its own tree subnet until the entire scatternet is formed. Simulation results show that the hybrid mesh-tree achieves better network performance than blueHRT does. As a result, the mesh subnet size can be controlled by the appropriate selection of the k parameter and the hybrid mesh-tree generates an efficient scatternet configuration.

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References

[1] K. Persson, D. Manivannan, and M. Singhal, Bluetooth Scatternet Formation: Criteria, Models, and Classification. IEEE Consumer Communications and Networking Conference, (2004), 59-64.

[2] Zaruba, G.V., Basagni, S.and Chlamtac, I. Bluetrees-scatternet formation to enable Bluetooth-based ad hoc networks. IEEE International Conference on communications, vol.1, (2001), 273-277.

[3] G. Tan, A. Miu, J. Guttag and H. Balakrishnan, Forming scatternets from Bluetooth personal area networks, MIT Technical Report, MIT-LCS-TR-826, (2001), 1-11.

[4] Liu, Chung-Hsin and Zeng, Wen-Yan, The study for the extension of Bluetooth Tree network. International Conference on Information Sciences and Interaction Sciences, (2010), 392-397.

[5] Chih-Min Yu, Shiang-Jiun Lin, and Chia-Chi Huang, On the Architecture and Performance of Blueweb: A Bluetooth-based Multihop Ad Hoc Network. IEICE Transaction on Communication, vol. E89-B, No. 2, (2006), 482-489.

[6] Chih-Min Yu and Chia-Chi Huang, On the Architecture Design and Performance Evaluation of A Configurable Blueweb Network. IEICE Transaction on Communication, vol. E96-B, No. 2, (2007), 1104-1111.

[7] T. lin, Y. Tseng, K. Chang, and C. Tu, Formation, Routing, and Maintenance Protocols for the BlueRing Scattemet of Bluetooths. International Conference on System Sciences, (2003), 313-322.

[8] T. Hassan, Ring of Masters (ROM) A New Ring Structure for Bluetooth Scattemets. Master's thesis, (2004), 1279-1282.

[9] Liu, Chung-Hsin and Shi-Wei Dai, The study for the extension of Bluetooth Ring network. International Conference on Multimedia and Information Technology, (2010), 127-130.

[10] Zhifang Wang; Thomas, R.J.; and Haas, Z., Bluenet – A New Scatternet Formation Scheme. Proceedings of the 35th Annual Hawaii International Conference on System Sciences, (2001), 779-787.

[11] Stefano Basagni and Chiara Petrioli, Multihop Scatternet Formation for Bluetooth Networks. IEEE 55th Vehicular Technology Conference, Vol.1, (2002), 424-428.

[12] Chiara Petrioli, Stefano Basagni, and Imrich Chlamtac, Configuring BlueStars: Multihop Scatternet Formation for Bluetooth Networks. IEEE Transaction on Computers, vol. 52, no.6, (2003), 779-790.

[13] I. AI-Kassem, S. Sharafeddine, and Z. Dawy, BlueHRT: Hybrid Ring Tree Scatternet Formation in Bluetooth Networks. IEEE Symposium on Computers and Communications, (2009), 165-169.

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