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Virtual Scatternet Formation for Supporting Multicast in Bluetooth Networks

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***Abstract*—Bluetooth is a wireless, short-range, low-cost communication technology. The multicast communication is an efficient way of distributing a data packet to a group of receivers. This paper presents a formation approach that generates a virtual scatternet (VSm) for realizing the multicast communication mechanism in Bluetooth networks. The proposed VSm scheme can construct a multi-source multicast tree based on the core-based tree concept. Moreover, simulations were conducted to evaluate the performance of the VSm scheme regarding to several critical factors, such as network size and packet arrival rate. The simulation results show that the virtual scatternet has a smaller tree depth and shorter transmission delay than the traditional flooding scheme. However, the traffic loading at the core node is heavy and the lifetime of the multicast tree is critical.**

***Index Terms*—Bluetooth, multicast, protocol, scatternet.**

I. Introduction

Bluetooth [1] is a low-cost, short-range, wireless communication technology that can be used for cable replacement among electronic devices. Bluetooth is a universal standard and operates in 2.45 GHz Industrial, Scientific, and Medical (ISM) band. It adopts frequency-hopping spread spectrum (FHSS) technique to avoid interference with other techniques in the same band. For the Bluetooth network, a piconet consists of a master device and up to seven active slave devices. A device that joins two or more piconets is called as bridge. Thus, the bridge plays two roles, which are either slave/slave or master/slave roles. Moreover, one piconet may connect with other piconets by using bridges to form a scatternet. Figure 1 illustrates the Bluetooth piconet and scatternet.

Multicast is an efficient way of distributing a data packet from the source to a group of receivers. It can make use of the bandwidth efficiently and reduce the communication cost. Thus, supporting multicast transmission in a Bluetooth scatternet is important. The multicasting in Bluetooth networks can be achieved intuitively by employing multiple unicast or piconet-wide broadcast. However, such two approaches are not efficient and flexible. Therefore, an efficient multicast mechanism for Bluetooth scatternets should be explored, so that the transmission of data in a scatternet can be more efficient and the lifetime of the scatternet can be lengthened.

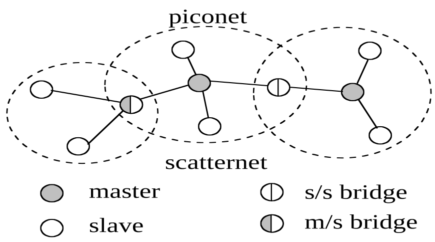

Fig. 1. Bluetooth network.

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In the literatures, there are few papers that addressed the multicast in a Bluetooth network. Ryu et al. proposed a distributed clustering scheme [2] for realizing multicast by varying transmission power of the masters. However, it still makes use of the piconet-wide broadcast to achieve multicast instead of constructing a multicast tree. Cordeiro et al. studied the dynamic slot assignment [3] for realizing multicast-like communication in Bluetooth piconet. This study focuses on the slot assignment in a piconet but not construction of multicast group in a scatternet. On the other hand, Chang, et al. proposed a power-aware multicast protocol (PAMP) [4], which can construct a multicast tree that consists of the multicast members only. The PAMP adopts the role switching operation and member collection procedure to construct a multicast tree. Moreover, Wang addressed a scheme [5] that constructs a shared tree and adopts slot scheduling to achieve multicast in a scatternet.

In this paper, we propose a protocol that can construct a virtual scatternet, on basis of an underlying physical scatternet, for supporting efficient multicast with the following features. (i) The multicast tree consists of multicast members and a few key non-members only. (ii) Each of the member nodes in the multicast tree may be the source for multicasting a data packet to the group. The rest of the paper is organized as follows. Section 2 presents the proposed approaches, and Section 3 discusses performance evaluation. Finally, Section 4 concludes the paper.

II. Proposed Virtual Scatternet for Multicast (VSm) Approach

In this Section, we present the proposed virtual scatternet for multicast (VSm) approach that can construct a general multicast tree over Bluetooth networks. Firstly, we discuss the design considerations as follows.

A. Design Considerations

On designing the VSm, we consider the following factors. (i) The VSm must support general multicasting, which can provide multiple sources to distribute data packets to the group simultaneously, instead of the single source multicast, which is used for delivering streaming data from the single source to a group of receivers. (ii) The multicast group may be created logically and dynamically, so that the VSm

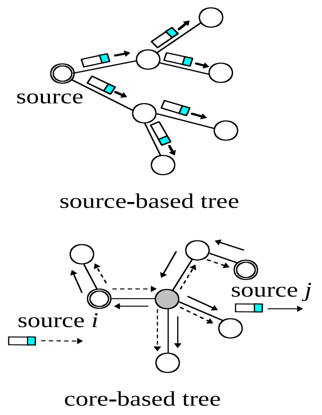

Fig. 2. Two types of multicast trees.

protocol must be very efficient and lightweight. In other words, it must ensure the effectiveness of the multicast tree for data transmission under the environment of dynamic node grouping.

In general, there are two kinds of multicast trees. One is the source-based tree and the other is a center-based tree. For the source-based tree, the source node is the root node and the other nodes are invited to join into the tree according to the minimum distance rule. On the other hand, the center-based tree is based on a core. Then, the core node collects the other nodes to construct a minimum distance tree with respect to the multicast groups. In this paper we consider the core-based tree (CBT)[6], in which each member may be the source and can distribute packets to the members. The reasons we choose core-based tree for Bluetooth scatternet is that the multicast tree must be efficient to reduce power consumption and could support multi-source multicast communications. On the other hand, the source-based tree is preferred for the single-source multicast. Figure 2 illustrates the source-based tree and the core-based tree.

B. *Construction of Virtual Scatternet*

The proposed virtual scatternet for multicast (VSm) approach can construct a virtual structure over underlying physical scatternet. The VSm approach includes two main procedures: (i) selecting a core node that is located at the center of the scatternet according to the core-based tree concept [6] and (ii) constructing the virtual scatternet for the multi-source multicast. We address the required control packets for the VSm protocol as follows.

There are several control packets that are used by the VSm approach. These control packets can be carried by the Bluetooth ACL packet [1] as shown in Fig. 3, and the whole control packet is filled into the payload data field whose length is 0-2712 bits. We briefly discuss these control packets

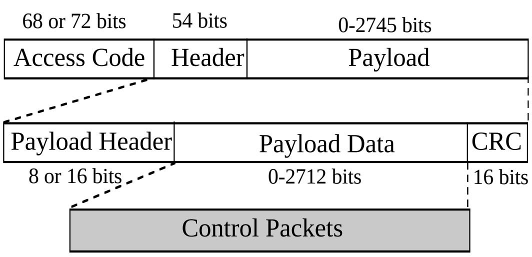

Fig. 3. ACL packet for control functions.

Table 1 Control Packet Format

Type	Source address	Searching path	Hop of members	Hop of nodes	Destination address	Relationship of nodes

Table 2 Description of Fields

Type	Type of control packet (0: Hello, 1: JOIN_REQ, 2: JOIN_ACK)
Source address	Address of source node
Searching path	List of nodes of the searching packet passed by in sequence
Hop of members	Hop count of multicast members that searching packet passed by
Hop of nodes	Hop count of the nodes that searching packet passed by
Destination address	Address of destination node
Relationship of nodes	Relationships between child nodes and the parent nodes

as follows.

i. HELLO packet: The core node periodically broadcasts HELLO packet to all multicast members in order to ensure the existence of members for maintenance.

ii. JOIN_REQUEST packet: A designated master node in the original underlying scatternet broadcasts JOIN_REQUEST packet to member or non-member devices to invite the members to join the multicast tree. In this paper we use JOIN_REQUEST packet or searching packet interchangeably, because the JOIN_REQUEST packet is employed for searching the multicast member.

iii. JOIN_ACK: Multicast members who receive the JOIN_REQUEST packet will reply a JOIN_ACK to the master.

The format of the control packet is shown in Table 1. The fields include type, source and destination address, searching path, hop count of member nodes, hop count of non-member nodes and relationship of nodes. We omit the discussion of the packet format and summarize the descriptions of the fields of the control packet in Table 2.

Figure 4 shows the procedure of the proposed VSm approach. Firstly, we summarize the notations used in the algorithm in Table 3 and, then, address the VSm construction algorithm (see Fig. 4). Moreover, we define the maximum hop count of the member node, c_m^{max}, as follows.

$$c_m^{\max} = \max_{\forall v_i \in G_m} (c_m \text{ of } v_i) \quad (1)$$

As shown in Fig. 4, the algorithm firstly selects a master node $\boldsymbol{v_o}$ that broadcasts the P_s to the nodes in S. The P_s

Proc. VS_Construction (S , G_m){
  v_o ←select a master node in S
  v_o broadcasts P_s to all $v_i \in S$
  While any v_i receives P_s {
    if ($v_i \in G_m$) then
      { v_i increases c_m and updates $\Re$ in P_s,
      forwards P_s to v_{i+1} and replies P_a to v_o .}
    else /* $v_i \notin G_m$ */
      { v_i increases c_n and updates $\Re$ in P_s, and
      forwards P_s to v_{i+1} }
    if all $v_i \in S$ receive P_s, then break }
  v_o summarizes all P_a from $\forall v_i \in G_m$,
  selects the node whose $c_m \cong c_m^{\max}/2$ to be core,
  construct VS by sending (V_m, E_m) to $\forall v_i \in G_m$
}

Fig. 4. Algorithm of VSm.

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Table 3 Notations

S	Underlying scatternet	P_s	Join_Request (searching) packet
G_m	Multicast group	P_a	Join_Ack packet
V_m	Set of nodes in G_m	c_m	Hop count of a node $v_i \in G_m$
E_m	Set of links in G_m	c_n	Hop count of a node $v_i \in S$
v_i	i-th node in S	$\Re$	Vector of node relationships
P_h	Hello packet	c_m^{max}	Maximum hop count

contains several fields to store the required information for constructing the virtual scatternet, such as the hop counts, path, $\Re$, etc. When a node $v_i \in G_m$ receives P_s, it must increase the hop count of member nodes and update the path and $\Re$. Then, it replies a P_a to $\boldsymbol{v_o}$ and forwards P_s to the next node. On the other hand, if a node $v_i \notin G_m$ receives P_s, it just increases the hop count of non-member nodes and updates the path and $\Re$. Then, the P_s is forwarded to the next node.

When all the nodes in S have received and reply the P_a, the $\boldsymbol{v_o}$ will summarize the information in P_a and select a node whose c_m is equal to or near to $c_m^{max}/2$ to be the core. Moreover, v_o also figures out the virtual scatternet topology, (V_m, E_m). Then, it sends (V_m, E_m) to all member nodes, which autonomously connect to their adjacent member nodes or non-member nodes if they are essential to the virtual scatternet. Thus, the virtual scatternet is achieved. Figure 5 illustrates the construction of a virtual scatternet, in which two sources send packets to the multicast group simultaneously via the core node.

III. Performance Evaluation

A. A Model for Performance Evaluation

In order to validate and evaluate the proposed VSm scheme, we make use of a model for evaluating the performance of a simplified system that adopts the VSm scheme against to the traditional flooding approach. Figure 6 illustrates the model for the performance evaluation. The input parameters of the model include network size, the total number of nodes in the network and the packet arrival rate of the source node for the multicast group. The output parameters (i.e., the performance metric), which we are

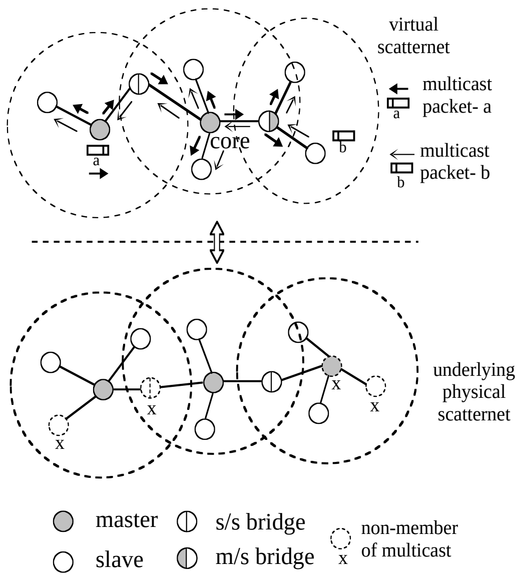

Fig. 5. Construction of a virtual scatternet.

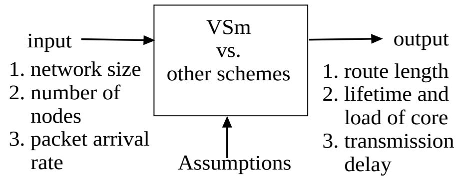

Fig. 6. Simulation model.

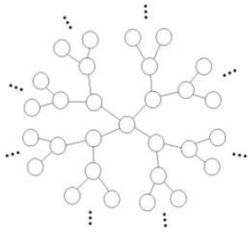

Fig. 7. Regular topology.

interested in, are route length, traffic loading/lifetime of the core, and the transmission delay.

Moreover, we make some assumptions in order to simplify this study. The assumptions include the regular topology for the underlying scatternet as shown in Fig. 7, a bounded network size, and an ideal communication range for each node. With the above model, we can evaluate the performance and compare the proposed VSm scheme with the flooding scheme. We present the results of performance evaluation as follows.

B. Results of Performance Evaluation

1) *Depth of the multicast trees*: Figure 8 shows the depth of the flooding and VSm multicast trees. Let r denote the ratio of the number of multicast member nodes to the number of all nodes in the scatternet. As the total number of nodes increases, the depth of the flooding scheme increases rapidly but the depth of the VSm tree increases slowly. Moreover, the stair-wise curve with larger value of r rises quickly than that with smaller value of r does.

2) *The average depths of the Flooding and VSm trees*: Figure 9 presents the average depths of the flooding and VSm trees, if the total number of nodes varies in a range from 10 to 300. The average depth of the flooding scheme is 5.45, and the average depth of the VSm tree with $r = 0.3$ is 3.84. The above results show that the VSm tree can construct a smaller size and more efficient multicast tree. However, the penalty of the VSm tree is the extra cost for constructing and maintaining the VSm multicast tree.

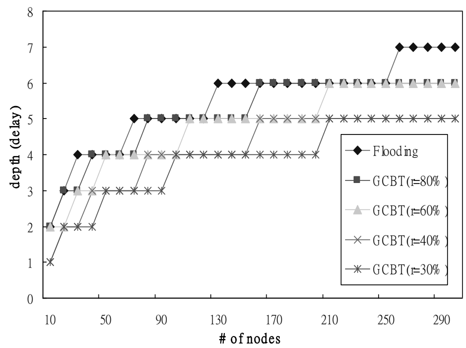

Fig. 8. Depths of trees.

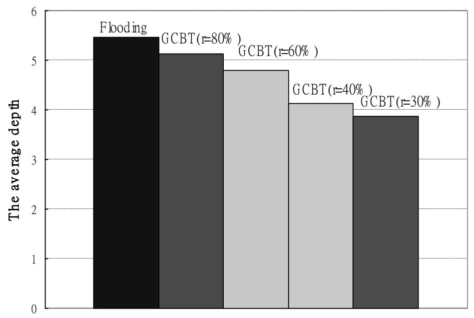

Fig. 9 The average depths of trees.

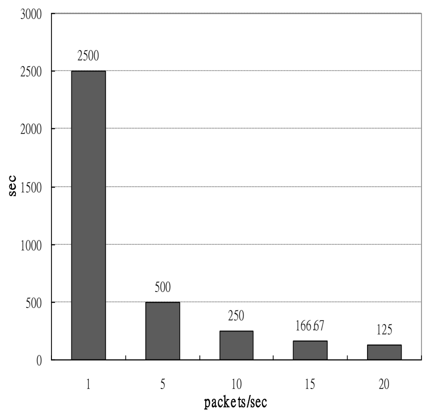

Fig. 10 Lifetime of core device.

3) *Lifetime of multicast core device*: Figure 10 presents the lifetime of the multicast core device. We make some assumptions. (i) The power of the core node can support transmitting or receiving 10000 packets. (ii) Each source node may generate n packets per second, where n is set to be 1, 5, 10, 15, or 20 for this study. The results show that the lifetime of the core may be reduced dramatically as the rate of generating packets at source nodes increases linearly. Thus, the short lifetime of the core is a drawback of the VSm scheme. To resolve this drawback, one may select a powerful node to be the core and equips the core device with uninterruptible power supply but the penalty is the high cost.
4) *Core traffic loading vs. network size*: We explore the traffic loading at the core as the network size increases. Suppose that every node of the VSm network transmit one packet to the core node and the network size is extended from one-hop tree (i.e., 4 nodes) to 7-hop tree (i.e., 253 nodes). Figure 11 shows the core traffic loading versus the network size. The results show that the traffic loading of core arises quickly as the network size is becoming large. Thus, the VSm scheme would perform well for a small multicast group.
5) *Transmission delay vs. network size*: Figure 12 shows the analysis results for the transmission delay versus network size. We assume that the transmission delay between two nodes that are located in the two adjacent levels is different. For example, the delay of transmitting a packet from a node at level one to the core is 800 ms due to the heavy traffic, but the delay of transmitting a packet from a node at level two to the node at level one is only 400 ms because the traffic loading is less heavy. The analysis results show that the transmission delay increases slowly even though the network size is becoming very large. Thus, the VSm scheme can support real-time

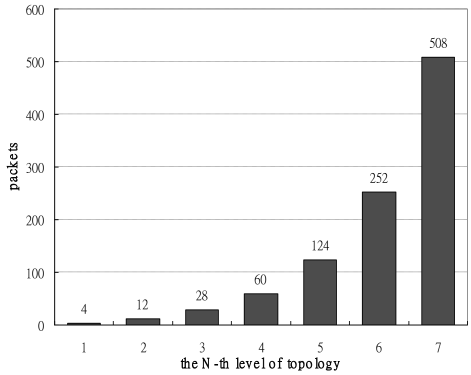

Fig. 11 Core traffic vs. network size.

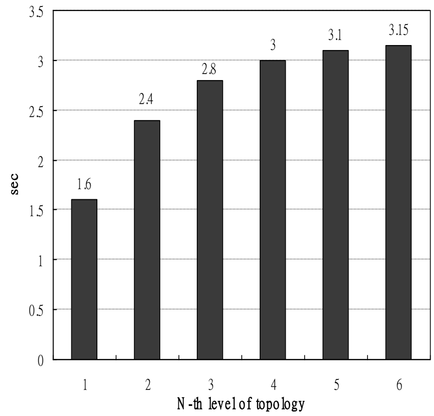

Fig. 12 Delay vs. network size.

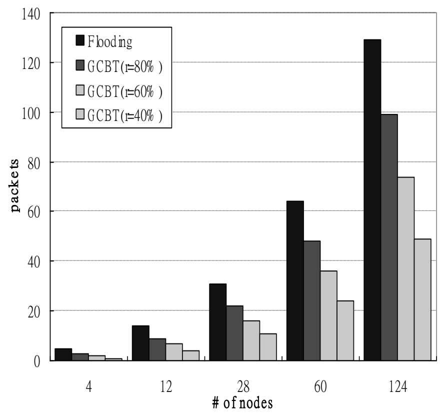

Fig. 13 Core traffic load.

transmission.

6) *Core traffic loading for different schemes*: We assume that the total number of the nodes in the network is 4, 12, 28, 60, or 124 and the values of r is 0.8, 0.6, or 0.4. Figure 13 shows the analysis results. The results show that the traffic loadings of the core for the different networks decrease proportionally with respect to the value of r and the difference of the traffic loadings for different networks increases as the total number of nodes increases. Thus, not only the VSm scheme but also the other schemes may suffer from the core traffic loading.

IV. Conclusion

Bluetooth is a short-range, low-cost, wireless communication technology. Multicast is an efficient way of distributing a data packet to a group of receivers. In this paper, we propose a virtual scatternet for multicast (VSm) scheme that constructs a multi-source multicast tree based on the core-based tree concept. Moreover, we make use of a model for evaluating the performance of the VSm approach. The results show that the VSm tree has a smaller tree depth and shorter transmission delay. However, the traffic loading at the core node is heavy and, thus, the lifetime of the core may be reduced as sending a large number of packets. Thus the VSm multicast is more suitable for the multicast group that is smaller and for transmitting real-time traffic. Ongoing research may include investigating the performance of the irregular multicast tree with diverse mobility nodes.

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