PAMP: A Power-Aware Multicast Protocol for Bluetooth Radio Systems

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Abstract–**Bluetooth is a low power, low cost, and short-range wireless technology. A piconet consists of a master and ups to seven slaves. Devices that desire for receiving data from the same source will construct a multicast group, sharing multicast communication services. A piconet may consist of member and non-member devices of a multicast group, causing non-member devices consuming power for overhearing the multicast message. For those members that belong to different Piconets, a multi-hop communication path is required, hence increases the delay time of multicast service and causes more non-member devices to participate the multicast tree. This paper develops a Power-Aware Multicast Protocol (PAMP) for constructing an efficient multicast tree. By collecting members into same piconet, the constructed multicast tree has characteristics of least non-member devices, smallest tree level, and proper role assignments to members. Experiment results show that PAMP provides efficient multicast service with low power consumption and small delay.**

Keywords: Bluetooth, piconet; multicast; procotol; role switching; location aware.

I. INTRODUCTION

Bluetooth is a low cost, low power, and short-range wireless communication technology. In a Bluetooth network, Piconet is a basic networking element that consists of a master and ups to seven slaves. According to master's 48-bit Bluetooth address, a hopping sequence could be derived for the Piconet. Different Piconets will adopt different hopping sequences, enabling data communication of multiple piconets in different channels at the same time. In a Piconet, all members apply the master's hopping sequence and thus prevent the co-channel interference fromother Piconets.

Mobile device that participates in two or more piconets is defined as *bridge*. An S/S (or Slave/Slave) bridge simultaneously participates more than one piconets and alternatively play role of slave in the participated piconets. An M/S (or Master/Slave) bridge is a bridge device that plays master role in at least one piconet. Figure 1 displays a scatternet where an S/S bridge connects piconets P_a and P_b and an M/S bridge connects piconets P_b and P_c. A bridge can deliver messages among piconets so that the data transmission service can be provided over scatternet.

In a Bluetooth scatternet, the multicast service provides data transmission from source Bluetooth device to multiple multicast member devices, which may belong to different piconets. An efficient multicast protocol is required to construct efficient communication paths over scatternet from source to all destinations. An RVM routing protocol[8] has been developed for constructing a route from single source to single destination in Bluetooth scatternet. However, separately applying the existing routing protocol to construct a multicast tree from source to each destination will not only create a large amount of control packets but also construct an inefficient multicast tree. To guarantee the multicast service has small delay, an efficient multicast tree should guarantee shortest path and few forwarding nodes. In addition, common links sharing in multicast tree also reduces bandwidth consumption.

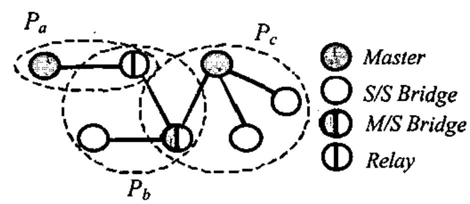
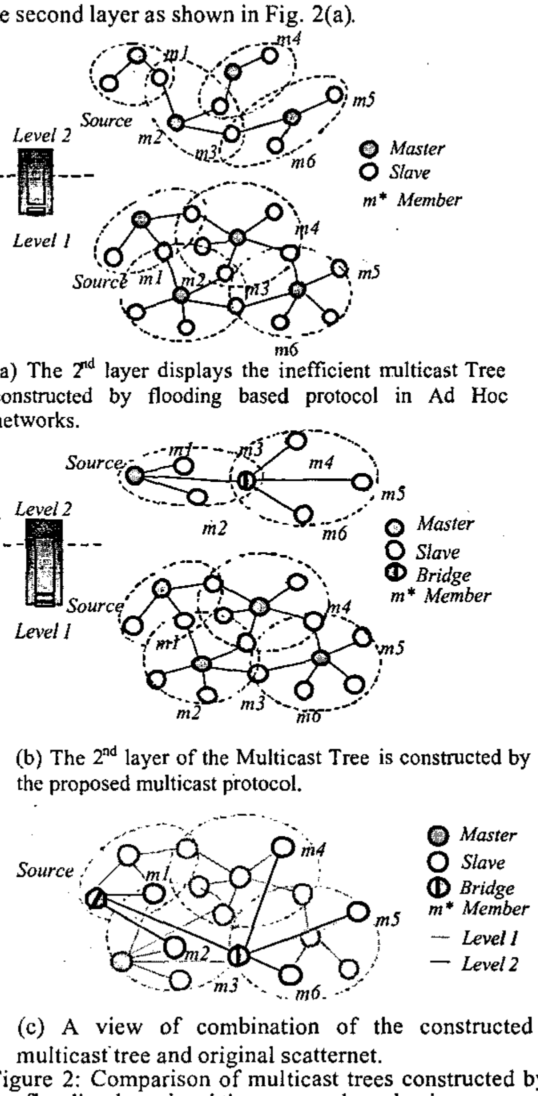


Figure 1: A scatternet consists of three piconets. An S/S bridge connects piconets P_a and P_b and an M/S bridge connects piconets P_b and P_c.

A number of multicast protocols[2][3] have been proposed for wireless ad hoc networks, based on 802.11 radio system. Previous study[2][3] proposes shared tree scheme to reduce the bandwidth consumption. However, the radio characteristics are different between 802.11 and Bluetooth radios. Applying the existing multicast protocols on Bluetooth scatternet cannot create an efficient multicast tree. This paper proposes a multicast protocol to construct an efficient multicast tree in Bluetooth Scatternet. The *role switch* mechanism is adopted herein to temporarily change the improper role of members so that multicast service can be provided with the least impact on other communication services. The constructed multicast tree remains links of the original scatternet topology so that there is no effect on other communication services in the original scatternet. The proposed protocol intends to collect multicast members into the same piconet to reduce the tree height and thus minimizes the transmission delay from source to each destination.

II. BACKGROUND AND BASIC CONCEPTS

Due to that channel management policies of 802.11 and Bluetooth networks are different, multicast protocols developed for 802.11 Ad Hoc networks cannot be efficiently applied on Bluetooth networks. Figure 2(a) depicts an example of inefficient multicast tree constructed by applying flooding mechanism which is widely used in 802.11-based Ad Hoc networks. Given a connected scatternet shown as Figure 2(a), the source device uses flooding mechanism to broadcast a request for tree construction over scatternet. On receiving the request message, bridge device alternatively switches to another piconet and forwards the message to the master, until all the unvisited masters have received the request message. A master will broadcast the request message as it received the message from one bridge and discard those messages it has broadcasted previously. As the multicast member receives the request message, it constructs a path from itself to the previous member along the path the request message passing through. The multicast tree thus can be constructed on the second layer as shown in Fig. 2(a).



(a) The 2nd layer displays the inefficient multicast Tree constructed by flooding based protocol in Ad Hoc networks.

(b) The 2nd layer of the Multicast Tree is constructed by the proposed multicast protocol.

(c) A view of combination of the constructed multicast tree and original scatternet.

Figure 2: Comparison of multicast trees constructed by the flooding-based and the proposed mechanisms.

However, the multicast tree constructed by flooding mechanism includes a lot of nonmember devices. As shown in Fig. 2(a), there are 11 devices participating the multicast tree where only 7 devices are multicast members. Four nonmember devices participating the multicast tree will not only consume their power and bandwidth of their piconets but also increase the tree height, increasing the end-to-end delay of multicast service. Figure 2(b) shows an efficient multicast tree that is constructed by applying the proposed protocol. The constructed tree contains 7 devices that are all multicast members. The eliminating of nonmember devices reduces the bandwidth and power consumptions. Since the tree height is reduced from 6 to 2, the transmission delay from source to destination has been largely reduced. In addition, the role of bridge device in the multicast tree has been changed to Slave/Master (or S/M in short), which is beneficial to multicast service. On receiving a multicast message, the S/M bridge can immediately switch to another piconet, change its role to master, and use broadcast operation by setting AM_Addr to value 000 to forward the multicast message to all its members. Compared with the multicast tree shown in Fig. 2(a), the constructed tree in Fig. 2(b) gains more benefits. Figure 2(c) gives a combination view of the original scatternet and the new constructed multicast tree. The details of the proposed multicast protocol will be described in the next section.

This paper proposes an efficient multicast protocol so that the constructed multicast tree will have the following good properties: (1)Devices that participate the multicast tree are all multicast member. (2)Geographical neighbors will participate the same piconet in the multicast tree, reducing the communication distance and saving the power consumptions. (3)Utilize the broadcast channel (AM_ADDR=000) to transmit the multicast message to all multicast members in the same piconet. (4)The protocol is capable of supporting multicast service whose multicast members are possible located in an area larger than 10 meters range. The properties can be found in the constructed tree shown in Fig. 2(b) which is constructed by applying the proposed PAMP protocol.

III. CONSTRUCTING THE MULTICAST TREE

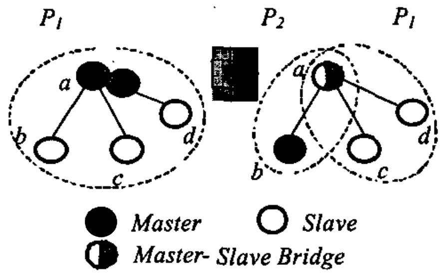
Given a scatternet and a set of multicast members, how to construct an efficient multicast tree is the main purpose of this paper. This paper applies the role switching operations to construct an efficient multicast tree. The following introduces the basic operation of role switching and its three application usages.

A. Basic operation of Role Switch

Role switching enables two devices to exchange roles very quickly, rather then reconnecting by executing the time-consuming inquiry and inquiry scanning processes. Two basic role switching operations used in this paper are introduced in below.

1) Piconet Combining

As presented in Fig. 3(a), devices *b* and *a* act as master and slave, respectively. Device *b* may initiate a piconet combining request and send a role switching request to device a so that it can play a slave role in piconet P_1. The role switching operation will combine two piconets P_1 and P_2 into a single piconet P_1, as shown in Fig. 3(b).



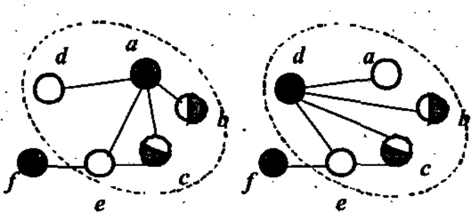
(a) (b)

Figure 3: (a) Topology before executing *Piconet Splitting* operation. (b) Topology after executing *Piconet Splitting* operation.

2) Piconet Splitting

A role switching operation can also split a piconet into two piconets. As depicted in Fig. 3(b), in piconet P_1, slave device b intends to create a new piconet P_2, where device b is the master. Device b accordingly initiates a role switching request to device a. As depicted in Fig. 3(a), device b creates a new piconet P_2 and plays a master role in P_2. Device a then alternatively participates in two piconets P_1 and P_2 and plays master and slave roles, respectively.

This paper proposes a multicast protocol to construct an efficient multicast tree on the second layer of scatternet. The two types of role switching operations are dynamically utilized for establishing a new link, collecting geographically neighboring members into same piconet, reducing the number of piconets, modifying the role to a better one, as well as reducing the tree height.



(a) Device a plays a master role in the original scatternet.

(b) Device a executes role switching operation.

Figure 4: *Master source case*: Role switching changes the role of device a so that it can play master role in the second layer.

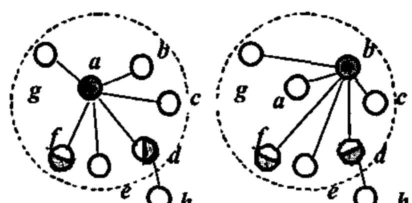
B. Role Switching Usage Cases

1) Master source case

In a piconet, only device that plays the master role can use AM_ADDR=000 to broadcast a multicast message to all slaves. To speed up the message delivery to all slaves in a piconet, a root (or multicast source) of multicast tree should play the master role. In case that the source device of a multicast service is a master in the original Scatternet, the device can not play the master role in multicast tree on the second layer. The proposed protocol uses role switching operation to change the device's role in the original scatternet. Consider Fig. 4(a). Device a is a source device of multicast group, but yet it also plays master role in the original scatternet. To construct an efficient multicast tree, source device a will initiate a role switching operation with device d which is the slave device with minimal traffic load. As shown in Fig. 4(b), device a plays a slave role in original scatternet after executing role switching with device d. After that, device a will construct a multicast tree on the second layer and play the master role in the multicast tree.

2) S/M bridge case

An S/M bridge node in multicast tree is responsible to play a slave role for receiving the multicast message from its parent and then to switch to child piconet to play the master role for broadcasting the received message to all its children. If the bridge node also plays the master role in the original scatternet, then the bridge device will have an invalid role since a device can not simultaneously play the master role in more than one piconets. For example, consider Fig. 5(a). During the construction of multicast tree, device a is selected to be the S/M bridge in the second layer. However, device a plays a master role in original scatternet. Thus, a role switching operation will be initiated by device a so that its role can be changed from master to slave in the original scatternet. In this case, device b that has lowest traffic load will switch its role with device a.



(a) Device a plays a master role in the original scatternet.

(b) Device a executes role switching operation with device b.

Figure 5: Device a is selected as an S/M bridge node in the second layer but it plays master role in the first layer. Role switching is applied between devices a and b.

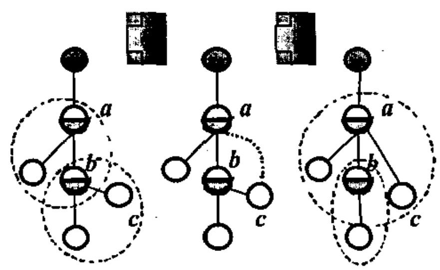


Figure 6: *Member collection case*: Device a invites device c, which originally belongs to its child piconet, to participate device a's piconet, collecting 7 members as possible.

3) Member collection case

One of the good properties of a Bluetooth multicast tree is that each piconet has seven member slaves so that the master can use broadcast operation to achieve the multicast service, as well as the tree height can be reduced. Taken Fig. 6 as an example, devices a and b be the masters of piconets P_a and P_b and a is the parent of b in the multicast tree. Since the number of slaves in P_a is less than 7, master b may remove one of its slaves, say c, to piconet P_a. To achieve this, the master a should transmit its information about BD_ADDR and clock offset to master b and then enter the Page Scan state. As master b receives the packet, it forwards this information to slave c. On receiving the BD_ADDR and clock offset information of device a, slave c enters page state, constructing a link with master by sending a response packet to device a. Then device c breaks its link in P_b and creates a new link in P_a.

C. Protocol for Constructing an efficient Multicast Tree

There are two phases in constructing the Multicast Tree in the second layer. In phase I, a multicast tree will be constructed in the second layer of scatternet. Phase II uses role switching techniques to reorganize the multicast tree so that member devices can be collected in the same Piconet from lower level to higher level and adapt the structure of multicast tree can be reorganized by collecting members that are located in subtrees into the same piconet.

1) Phase I: Multicast Tree construction

The purpose of the phase I is to construct a multicast tree in the second layer, of scatternet.

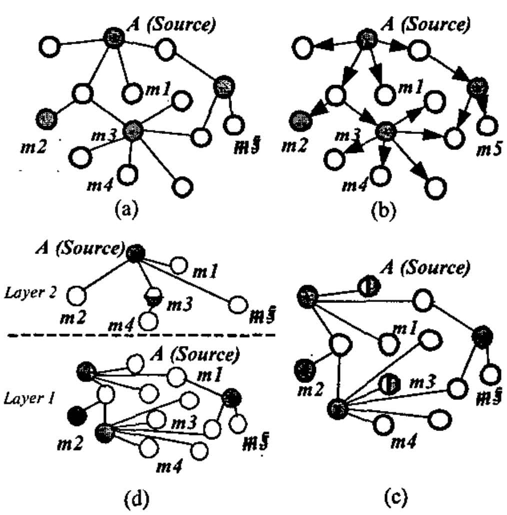


Figure 7: Example of Phase I of multicast protocol.

Take Fig. 7 as an example. Given a scatternet as shown in Fig. 7(a), assume the multicast group is {A, $m1$, $m2$, $m3$, $m4$, $m5$} where device A is the source device. In this phase, source device firstly broadcasts a search packet over the scatternet, and then stays in Page state. Figure 7(b) exhibits the search packet flooded over the scatternet. The search packet contains BD_ADDR and clock information of source. Because that device A plays the roles of master in original scatternet and the multicast source simultaneously, firstly it changes the role to a slave in the original scatternet before entering the Page state, as shown in Fig. 7(c). In addition, on receiving the search packet, device m_3 also changes its role to slave by executing the role switching operation, since it is a multicast member but has heavy traffic in the original scatternet.

On receiving the search message, the nonmember device will forward the message. When the member device m_3 receives the packet, it updates the BD_ADDR, clock offset, with its own information and then broadcasts the updated packet to its neighbors. Member device m_3 then enters the Page state and tries to construct a link with the device A whose information has been recorded in the received packet. After constructing a link with device A, device m_3 executes a role switching operation with device A, resulting devices A and m_3 playing the roles of master and slave, respectively. Then, device m_3 enters the Page Scan state, trying to construct a link with the next child member. On receiving the search packet, device m_4 will execute the similar procedure.

As far as all devices complete the procedure mentioned above, each member' s has created a link in the multicast tree. The operations of Phase I is completed, as shown in Fig. 7(d).

2) Phase II: Parent–Child Reorganization

After executing Phase I, a multicast tree has been constructed. In this phase, role switching operations are applied to reorganize the structure of multicast tree in a dynamic and distributed manner. All masters in the tree will then execute the role switching operation by examining the cases including *S/M bridge case* and *member collection case*, as illustrated in previous subsection. The examination of these cases will be executed in a distributed manner. Figure 2(c) display the resultant two-layer scatternet that contains an efficient multicast tree. In the next section, performance study will depict the efficiency of the proposed multicast protocol.

IV. PERFORMANCE STUDY

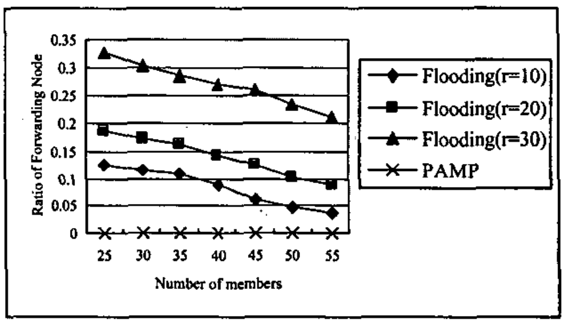


Figure 8: Comparisons of the number of forwarding nodes in the constructed tree. The region size is set at r*r, where r=10, 20, or 30.

This section proposes the performance investigation of PARM protocol. The environment is set as follows. The size of experimental region is set at 10*10, 20*20, or 30*30 units, while the maximal radio transmission distance of a Bluetooth device is set at a constant 10 units. Performance measures considered herein include the number of forwarding nodes, the power consumption, the length of multicast tree, and the propagation delay of multicast services. The number of Bluetooth devices is set at 80 whereas the number of members varies ranging from 25 to 55, and their locations are randomly determined.

Figure 8 compares the number of nonmembers that participate in the multicast tree. The rate of forwarding node is the ratio of the number of nonmember nodes to the number of all nodes in scatternet. The proposed PAMP does not have any forwarding nodes since a parent member always can find a son member within its transmission range (10 units) as the number of member nodes larger than 25.

Figure 9 presents the overhead associated with power consumptions. The power consumption increases with the multicast data transmission rate. Since PAMP increases a fewer number of nonmembers in the constructed multicast tree and tries to collect those members that are geographically closed to each other into one piconet, PAMP has lower power consumption than flooding scheme in cases that multicast data transmission rate is 5K bits or 10K bits. Figure 10 compares the flooding scheme and the PAMP scheme in the average length of constructed multicast tree. In general, the length of multicast tree increases with the number of piconets and the number of members. The PAMP tries to collect seven members into same Piconet, thus reduces the tree length. As shown in Figure 10, since the multicast tree constructed by flooding scheme highly depends on the original topology of scatternet, the length of multicast tree increases fast with the number of piconets and members. This phenomenon can be found in Figure 11.

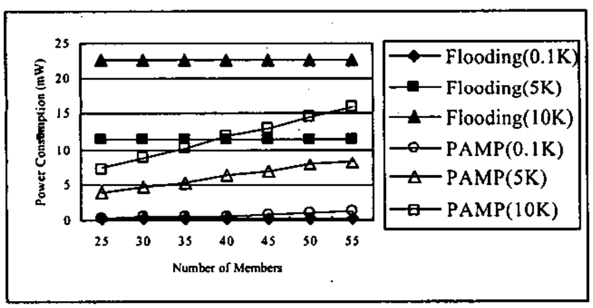


Figure 9: Comparison in power consumptions associated with various data transmission rates.

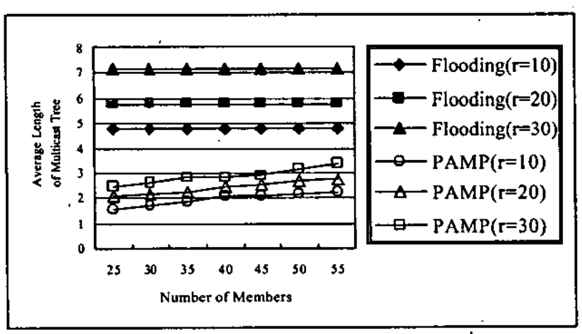


Figure 10: The average length of multicast tree constructed by PAMP and flooding.

The multicast protocol employed in this study constructs an efficient multicast tree. By applying the role switching operations, closed multicast members are collected in the same piconet and are assigned with proper role. The multicast tree constructed by PAMP has good properties including small tree length, few forwarding node, and proper role assignment for each node in tree. Performance investigation shows that PAMP is performance well in low power consumption and short transmission delay.

V. CONCLUSION

This paper purposes an efficient power-aware multicast protocol. According to the signal strength, the proposed protocol constructs the multicast tree on the second layer, reducing the impacts of improper topology of original scatternet. The proposal protocol also applies the role switching operations on the constructed tree so that the improper role can be changed. The constructed tree collects multicast members into same piconet so that the broadcast operation can be utilized to achieve the multicast service, thus saving power and bandwidth consumptions. Simulation results show that the proposed multicast tree reduces the power consumptions and transmission delay. Multicast services thus can be performed well in Bluetooth radio networks.

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