DSR Based Bluetooth Scatternet

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Abstract: Bluetooth technology of cable replacement and infrastructure access is verified enough to be commercialized as goods. But there are a lot of works to implement ad-hoc Bluetooth radio network. For this, scatternet must be formed. We propose routing layer, packet format and link formation schemes for scatternet. The page procedure of the route request and the route reply page eliminates the procedure of the inquiry and the master-slave role switching. The route discovery time could be lower than 50msec within the distance of 50m. Proposed link formation scheme lets master, slave and bridge establish connection automatically and offers active ad-hoc environment. Devices that adopt Bluetooth module of 10m transmission range can communicate with other devices far away without any intervention of users.

1. Introduction

Bluetooth is a specification designed to replace cables and enable wireless communication between small mobile devices. Stability is ensured by implementing a frequency hopping spread spectrum scheme which makes Bluetooth robust against interference from other piconets[1].

Current Bluetooth specification version 1.1 describes inquiry, page, connection, low-power state and piconet in detail. A few companies developed Bluetooth chip and software protocol stack. But scatternet for constructing multi hop ad-hoc network topology is not specified enough to implement it. The packet format and whole scheme is not defined either. Scatternet is the general concept of network consisted of more than two piconets and means that a sender unit can transmit a packet to the destination unit through several hops. The current Bluetooth piconet specifies the communication only between master and slaves[2]. This limits the usage model of the original Bluetooth.

2. Scatternet in Current Bluetooth

If multiple piconets cover the same area, a unit can participate in two or more overlaying piconets by applying time multiplexing. To participate on the proper channel, it should use the associated master Bluetooth address and proper clock offset to obtain the correct phase. A Bluetooth unit can act as a slave in several piconets, but only as a master in a single piconet: since two piconets with the same master are synchronized and use the same hopping sequence, they are one and the same piconet. A group of piconets in which connections consists between different piconets is called a scatternet.

A master or slave can become a slave in another piconet by being paged by the master of this other piconet. On the other hand, a unit participating in one piconet can page the master or slave of another piconet. Since the paging unit always starts out as master, a master-slave role exchange is required if a slave role is desired.

Time multiplexing must be used to switch between piconets. In case of ACL(Asynchronous Connection-Less link) links only, a unit can request to enter the low power state as hold or park in the current piconet during which time it may join another piconet by just changing the channel parameters.

3. Blueroute Network Layer

Bluetooth specification does not have any multi-hop routing layer for scatternet. Blueroute layer enable the routing for scatternet. During initial inquiry and page procedure, Blueroute layer is not used. The layer operates actively when a sender wants to find a routing path and deliver the data through several hops. Baseband checks whether the received packet is for routing or not and propagates it to Blueroute layer if the packet is for routing. After then Blueroute layer manipulates the packet.

Blueroute layer is located between L2CAP(Logical Link Control and Adaptation Protocol) and HCI(Host Controller Interface)[1]. If the packet is for route discovery, Blueroute layer processes the jobs such as adding a unit's Bluetooth address to Routing path field and propagates it to HCI.

When the packet is for data delivery and finds its destination, Blueroute layer propagates it to L2CAP for SAR(segmentation and reassembly). Blueroute layer is derived from DSR(Dynamic Source Routing)[3] and adjusted to fit Bluetooth own characteristics.

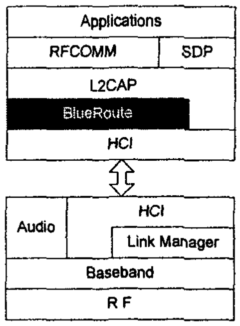

Figure 1. Stack including Blueroute layer

DSR is used as network layer in Ad-hoc and processes route discovery protocol. Generally Bluetooth supports ad-hoc but there is no instance to implement scatternet. Bluetooth has different characteristics compared with general ad-hoc because it operates on the group communication of the piconet and delivers the data through master-slave. Blueroute layer plays a role of routing and manages RREQ(Route Request), RREP(Route Reply), RERR(Route Error) and Cache. Each unit adds own BD_ADDR(Bluetooth Address) into RREQ Route discovery packet and checks cache whether it has destination's route. The Bluetooth unit floods the packet to the neighbors when it is not the packet's destination and doesn't have cache. The unit that received the packet adds its cached route to RREP and backwards the packet when it has the cache of the destination route.

4. Link Procedure

Sender delivers a RREQ page packet to find the destination. The destination unit reverses the RREP packet. Link formation and the determination of the master-slave role are established while the RREP packet propagates reversely. Determination of the master-slave depends on the number of the bridge. The procedure of the role determination is processed to minimize the bridge number.

Destination unit appoints each unit as either master or slave after it receives the RREQ packet. Each unit knows whether each unit is master or slave after the RREP packet passes through. This scheme can eliminate inquiry process and the time of master-slave role switching and can reduce the link formation time.

In Figure 2, U is the acronym of the unit. The number of the end of U is numbering to distinguish units. We suppose that U1 is a sender unit, U7 is a destination unit, and dot line means transmission scope without any piconet connection.

Suppose that U1-U0-U8-U6-U7 is selected as a shortest routing path, U7 determines that U6 and U0 are masters, so the route path can minimize the number of the bridge (U8). When a RREP packet arrives at a sender, unit's page and link formation is completed as in Figure 3. The numbers of the end of M and S are for piconet discrimination and

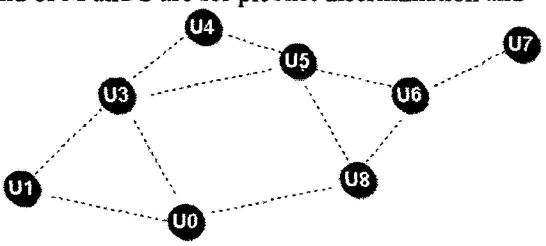

Figure 2. The location of non piconet unit

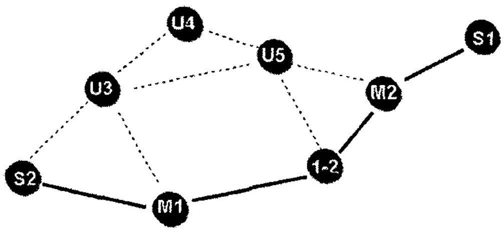

Figure 3. Scatternet link formation

AM_ADDR (Active Member Address) that a master endows to a slave. In Figure 3, "1" of 1-2 unit indicates that AM_ADDR for M1 is 1, and "2" indicates that 1-2 unit's AM_ADDR of M2 is 2.

U8 establishes the connection with U0, and U7 does with U6. Then U8 connects with U6, and U1 does with U0 by the page process of the Bluetooth specification.

U6 waits a FHS(Frequency Hopping Synchronization) packet from U7 after U6 sends a RREP page packet. U0 waits for a FHS packet from U8 after it delivers a RREP page packet. The FHS packet includes the information so that U6 and U7 may page and respond. After the RREQ page, the remaining procedures are the same as the current Bluetooth specification. Connection establishment occurs simultaneously among several units, so it can reduce the link formation time extremely.

5. Route Discovery

5.1 Route discovery in stand-by mode.

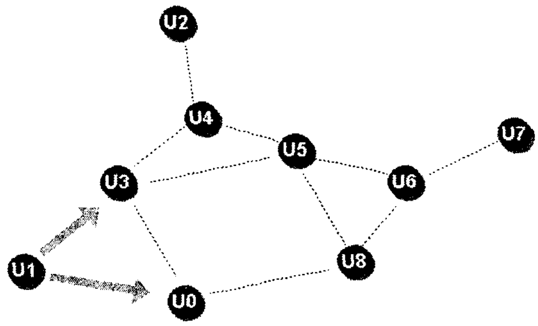

Figure 4. Route discovery model in stand-by mode

DSR reduces the packet flooding and uses cache and error handling packet. So DSR is proper to be applied to discover a routing path in Bluetooth scatternet.

There are two paths from U1 to U6, U1-U0-U8-U6 and U1-U3-U5-U6. Packet collision probability is high in U6, so back-off delay is applied. Although having already received a packet from U1, U3 may receive the same packet from U0. U3 investigates the source address, the destination address and the sequence number. And then U3 ignores the packet from U0 if its SEQN(Sequential Number) is equal to one from U1. Every unit inserts its own Bluetooth address to the packet during the routing process.

Route discovery packet is delivered to the destination U7, and then U7 transmits a response packet. U7 unit regards the route of the first received packet as a shortest routing path. The same packets that have different routing paths are ignored. The response packet reverses the forward routing path with establishing piconet and scatternet. After the route discovery procedure is completed, data transmission packets are routed through the discovered routing path that consists of 3 bit AM_ADDRs. That will be discussed in the next section in detail.

Forwarding packet and response packet correspond to each RREQ and RREP of DSR. Each unit caches the routing path while the response packet is reversed. The cached path can be used in a newly appeared unit. Also the route discovery packet includes TTL(Time to Live) that can prevent flooding storm.

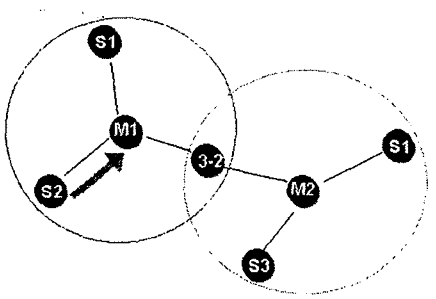

Figure 5. Route discovery model in connection mode

In stand-by mode, a unit sends a RREQ page packet for route discovery. Current Bluetooth protocol drops the received packet if the destination of the packet is not itself and waits another packet. But in our scheme, the unit that receives the packet does not ignore but forwards it although the unit is not the destination of the packet. For this algorithm Bluetooth Baseband should know that the packet is for routing and hands over it to the upper layer. Of course, the receiver unit must be in a page scan state while forwarding unit pages the packet. During flooding the RREQ packet, the forwarding unit does not hop. We propose that only one frequency is used for RREQ page.

This algorithm has the advantage of eliminating the inquiry procedure. During RREQ procedure, the procedure of determining master or slave is not needed because it may not be shortest path. A piconet is formed during reversing the packet through the determined routing path. So the time for discovering the routing path can be shortened.

For RREQ page, single and multi-slot packets are used. Every RREQ page is fixed to one frequency, so enough random back-off delay (RND_BOD) should be applied.

5.2 Route discovery in connection mode.

M and S mean master and slave respectively. We suppose the S2 of piconet 1 is a sender, the S1 of piconet 2 is a destination unit and 3-2 unit plays the role of piconet bridge in figure 5. In this case, packet collision does not happen because Bluetooth uses master driven TDMA/TDD scheme. Route discovery packet includes the Bluetooth address of the sender unit, destination Bluetooth address and TTL.

Slave S2 sends a packet to M1. M1 floods it to S1 and 3-2 bridge unit. 3-2 bridge unit sends it to M2. But M2 doesn't send it to S1 because S1 is M2's slave, so M2 already knows that S1 is the destination unit. M2 sends a response packet.

Each unit inserts its own AM_ADDR to the routing path field of packet while route discovery packet is flooded[4]. The use of the AM_ADDR instead of the Bluetooth address improves packet efficiency. But there are some problems that bridge does not know where the bridge should forward the packet when the bridge has the same AM_ADDRs for different piconets. To solve this problem, the bridge has the intelligent function that is adding 3 bits automatically to distinguish piconets.

5.3 Route discovery in mixed mode

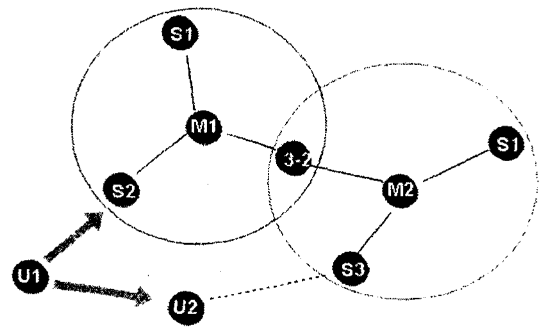

Figure 6. Route discovery model in hybrid mode

U1 is a sender unit. U2 is non piconet unit and is in page scan state. U1 floods a route discovery packet to S2 and U2 by RREQ page. S2 send it to M1, and U2 floods it to S3 by page. S3 sends the RREQ packet to M2 through TDMA/TDD.

In figure 6 we suppose that U1-U2-S3-M2-S1 is selected as routing path because it is short path. U1 and U2 insert their 24 bit LAP(Lower Address Part) of Bluetooth addresses into the RREQ packet, but S3 inserts its AM_ADDR. M2 inserts S1's AM_ADDR.

At this time if S3 of M2 is connected with another master, it should know where route discovery packet comes from. This means that S3 should remember how the RREQ packet was delivered by either page or piconet master.

6. Packet Formats for Routing

Current Bluetooth specification classifies packet formats with the 4bit Type field. 14 of 16 formats are being used. Two Types (1100 and 1101) are undefined. In Figure 7, colored fields among packet fields are proposed parts.

Routing type indicates packet's usage: route request, route reply, route error and data transmission. Packet is not discarded although it has the same destination and source address with the previous packet due to different sequence number. *RP Len* field has the length information of *ROUTING PATH* field that includes 24 bit Bluetooth LAPs and 3 bit AM_ADDRs. *Master/Slave* field is added to determine the role of Bluetooth units and is used only while the RREP packet reverses the found routing path.

Bluetooth unit refers to *TTL* in order to find the bit of *Master/Slave* field corresponding to itself. When the filed is 1, the unit becomes a master. Otherwise it becomes a slave. When the slave unit is not a sender or a destination unit, it becomes a bridge.

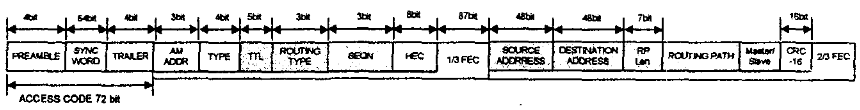

Figure 7. Packet for route discovery

7. Simulation

We simulated the proposed schemes and verified the performance of the route discovery time with Bluenario[5] program that includes Blueroute layer.

7.1 Program parameter and simulation setting

Senders, destinations, and masters are located randomly. We assume that Bluetooth transmission range is 10m of the class 2 module.

Each unit loops the check routine of the program to investigate that new packet arrived. When a packet arrived, it reduces the TTL value. After then if TTL is 0, the packet is dropped. In the next procedure, the routing field is checked whether the packet is RREQ or RREP. If RREQ, the packet is checked whether it is a new packet or a loop backed packet.

If the packet is new one, the unit examines that the destination of the packet is itself. If not, the unit investigates its cache to check whether it has routing path of the destination. If not, the unit adds its Bluetooth address to routing path field. After then it estimates the time delay, and it waits random back-off delay time. Finally the unit forwards the packet to its neighbors.

7.2 Packet collision for back-off delay

RREQ page doesn't hop the frequencies but uses one fixed frequency, so the RREQ page packet may not be forwarded due to packet collision.

The probability of packet collsion depends on RND_BOD. The larger RND_BOD is, the lower the probability is. But the large RND_BOD results in long route discovery time.

Figure8 shows the packet collision rate on the routing path when RND_BOD is selected from 0 to 6250 *u*sec for varying the number of piconets. Result shows that the probability of packet collision is lower then 3% after 2500*u*sec.

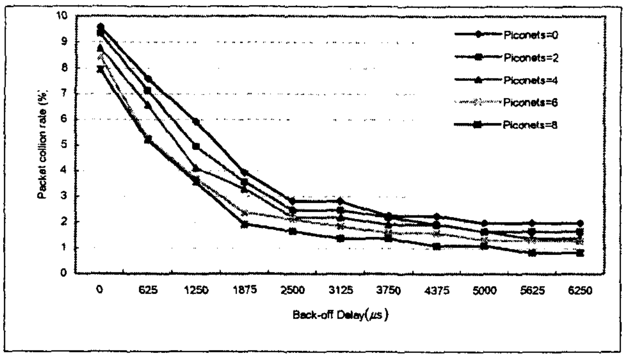

Figure 8. Packet collision probability vs. back-off delay

7.3 Route discovery time

RND_BOD is 6250*u*sec, and the master uses simple round-robin scheduling.

In figure 9, the result shows that route discovery time is less than 50 msec within the distance of 50m. This means that the proposed scheme is faster a few hundred times than the current Bluetooth scheme because the proposed scheme eliminates the procedures of initial inquiry and master-slave role switching. When the number of piconets increases, the delivery time inreases.

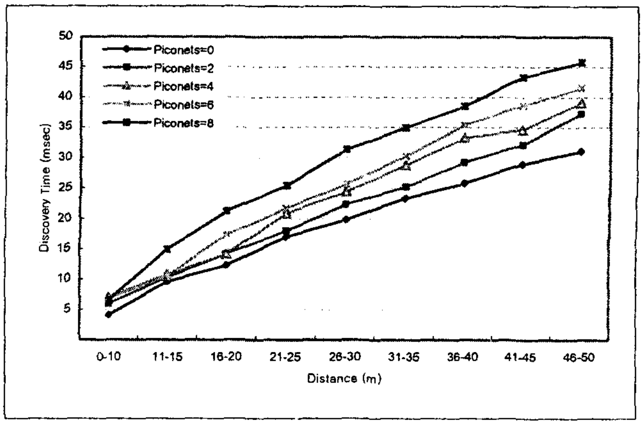

Figure 9. Route discovery time vs. distance between sender and destination

8. Conclusion

The link formation time of Current Bluetooth specification is too long for mobile devices. There is no enough scheme for scatternet, either. We proposed new schemes for the Bluetooth scatternet. For routing, we introduced the new packet format and the network layer.

The route discovery scheme by RREQ page packet reduces the time of initial start-up procedure. So proposed scheme achieves the fast route discovery. Route discovery time could be less than 50msec within the distance of 50m, so it ensures the mobile environment of Bluetooth devices.

Proposed link formation scheme provides the user with convenience because link formation among master, slave, and bridge is established automatically. User's intervention is not needed.

References

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