A QoS Routing Framework on Bluetooth Networking

Chao Liu
Waseda University, Japan

Bo Huang
Waseda University, Japan

Takaaki Baba
Waseda University, Japan

INTRODUCTION

Bluetooth (2001) is one of the low-bandwidth, energy-efficient wireless technologies designed for mobile devices. As the technology spreads widely in various applications, more and more services and functions are brought to the front, so different types of devices may be equipped with the Bluetooth module and appear in the same area. However, when nodes for different services come together, the need for forming a network comes out.

Actually in Bluetooth technology, there is a kind of basic form of network structure, which is called *piconet.* In a piconet of several nodes, there needs to be a master node and up to seven slave nodes, and all nodes form a star topology centered by the master node. Thus, the piconet is limited by the node number of eight and the communication range of area centered with the master node. To extend the piconet, the scatternet is proposed. In the scatternet, some slave nodes are proposed to serve more than one master. So it can act as a bridge between piconets.

However, the piconet and the scatternet is just the link layer structure. To transmit data between different piconets, in the network layer, a routing protocol is necessary. In addition, the *quality of service* (QoS) is another issue to be solved (Wang & Crowcroft, 1996), because those nodes that are equipped with a Bluetooth module could vary quite differently. Some may be multimedia data, some may be emergency data, and some may be best effort data. When all these services share the same network, the priority shall be different. For this reason, we try to propose some QoS mechanisms in the Bluetooth network.

Bluetooth has a quite unique protocol stack, which has some core layers and the other layers are left to be flexibly customized. To multiplex all above possible services, the QoS routing is proposed to be inserted directly above the core layers of Bluetooth, as shown in Figure 1.

Why shall we propose an improvement to the protocol architecture? It is one of the key points of this article. One of the reasons is as addressed above, to multiplex and not to be bypassed by upper layers. Another reason is that it can utilize the *energy efficiency* function better, which is provided by the under core layers of Bluetooth.

BLUETOOTH FEATURES AND CHALLENGES

Bluetooth is designed to be the industry standard for low-power mobile devices. Highly integrated chipsets are being developed that provide RF circuitry and protocol processing on a single chip. Current Bluetooth only supports simple services, such as human interfacing, audio/video transmitting, and home network controlling. Most of the cases are one-step communication or the last step to the wired network. Therefore, the Bluetooth network is just as simple as a star topology consisting of a master and several slaves or less. The network range is just the radio transmission range, about 30 feet. In each piconet, the master is limited to have no more than seven active slaves.

To extend the network a little bit further, a multi-hop relay is necessary. Although in Bluetooth, the *scatternet* is designed specially to build the connections between multiple piconets, it is simply a concept of link layer and physics layer, which means it offers the ability to transmit data between piconets but it does not offer the routing function. We need routing algorithms. The general routing algorithms in the wired network or the routing algorithms proposed for the mobile ad hoc networks are not efficient for the Bluetooth scatternet. The power efficiency consideration is necessary.

Bluetooth technology is designed to support 2Mbps at a range of 30 feet. The 2Mbps bandwidth is shared by all the slaves in the piconet. If several slaves try to communicate with the master, the master may share equal opportunity with each slave and the bandwidth is split. If several piconets are overlapped with each other, they will share the same radio spectrum resources as well. Therefore, in each piconet, the

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available bandwidth also becomes less. In either case above, each link connection of the multi-hop path is trying to compete for the bandwidth with each other. Thus, if any streaming service runs over the Bluetooth network, the available end-to-end bandwidth will be quite critical. From this viewpoint, a quality of service routing is necessary.

Comparing to others, such as IEEE Standard 802.11 (1997), HyperLan (Z002), HomeRF (Chinitz, 2001), ZigBee (ZigBee Alliance, 2002), and so forth, the advantage of Bluetooth technology is that it offers the power efficiency at a low cost and relatively enough bandwidth. The Bluetooth offers the function of power efficiency by several modes of operation, which is hold mode, sniff mode, and park mode, besides the connection mode. The four modes of operation consume different amounts of energy in different activity states. The sniff mode and the hold mode are not generic device modes. Here we simply consider the connection mode and the parked mode. The connection mode is the mode that the device is working actively, while the parked mode is the mode where the device almost does not work (actually still receiving some messages from the master by a specific channel) and consumes less energy. Normally mobile ad hoc network routing protocols require that all the nodes be in the connection mode. Therefore, the advantage of Bluetooth cannot be explored. We need a routing protocol that can manage the mode of operation to save the energy by sleeping the unused nodes.

NETWORK MODELING

In this section, we compare different applications and different choices of the network model. As a result, it is found that routing on the L2CAP layer is the best choice.

A typical example of the Bluetooth protocol stack is shown in Figure 1. The Bluetooth radio and the baseband consist of the physical layer of the Bluetooth which is implemented by hardware chipsets. The LMP and the L2CAP layer represent the Media Access Control layer of the Bluetooth. The LMP deals with the power management and offers the ACL (Asynchronous Connectionless Link) channel for the communication. The L2CAP layer takes responsibility to multiplex logic transports into the physical channels. By these means, the upper layers can share the bandwidth. Up to the L2CAP layer, the protocols are usually integrated in the hardware. Those protocols built above the L2CAP layer are usually left to be flexibly configured according to the need. The RFCOMM (RFCOMM with TS 07.10, 1999) is protocol emulation to the serial ports. The Bluetooth Network Encapsulation Protocol (BNEP) (Bluetooth Special Interest Group, 2001) is a protocol specifically designed for the Bluetooth to emulate the Ethernet. The PPP (Simpson, 1994) is the simple and useful point-to-point protocol. According to different applications, the choice of these logic link layer protocols varies greatly.

The network model of supporting IP services over Bluetooth has been a warmly discussed issue. The possible network model can be [IP over ACL], [IP over L2CAP], [IP over [BNEP over L2CAP]], [IP over [PPP over RFCOMM]], and [IP over [PPP over L2CAP]].

The L2CAP layer has the segmentation and reassembly (SAR) function and maximum transmission unit (MTU) negotiation, which is done by hardware. Because the SAR function is an unavoidable part in the whole process, hardware implementation of course is better than additional software. Thus we prefer the [IP over L2CAP] to the [IP over ACL] network model. The other three models introduce much overhead and a lot of unnecessary things, although it can improve the compatibility to support many widely used protocols.

Figure 1. Bluetooth protocol stack