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Quality-of-Service in IP Services over Bluetooth Ad-Hoc Networks

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Abstract. Along with the development of multimedia and wireless networking technologies, mobile multimedia applications are playing more important roles in information access. Quality of Service (*QoS*) is a critical issue in providing guaranteed service in a low bandwidth wireless environment. To provide Bluetooth-IP services with differentiated quality requirements, a *QoS*-centric cascading mechanism is proposed in this paper. This innovative mechanism, composed of intra-piconet resource allocation, inter-piconet handoff and Bluetooth-IP access modules, is based on the Bluetooth Network Encapsulation Protocol (BNEP) operation scenario. From our simulations the handoff connection time for a Bluetooth device is up to 11.84 s and the maximum average transmission delay is up to 4e-05 s when seven devices join a piconet simultaneously. Increasing the queue length for the Bluetooth-IP access system will decrease the traffic loss rate by 0.02 per 1000 IP packets at the expense of a small delay performance.

Keywords: quality of service, Bluetooth-IP access system, BNEP protocol, handoff, resource allocation

1. Introduction

Wireless communications have evolved rapidly over the past few years. Much attention has been given to research and development in wireless networking and personal mobile computing [10,17]. The number of computing and telecommunications devices is increasing and consequently, portable computing and communications devices like cellular phones, personal digital assistants, tablet PCs and home appliances are used widely. Wireless communication technologies will offer the subscriber greater flexibility and capability than ever before [14].

In February 1998, mobile telephony and computing leaders – Ericsson, Nokia, IBM, Toshiba, and Intel – formed a Special Interest Group (SIG) to create a standard radio interface named Bluetooth [13]. The main aim of Bluetooth has been the development of a wireless replacement for cables between electronic devices via a universal radio link in the globally available and unlicensed 2.4 GHz Industrial Scientific and Medical (ISM) frequency band [9]. Bluetooth technologies have the potential to ensure that the best services, system resources and quality are delivered and used efficiently. However, global services will embrace all types of networks. Therefore, bluetooth-based service networks will interconnect with IPv4/v6 existing networks to provide wide area network connectivity and Internet access to and between, individuals and devices [7]. In Reference [2], the BLUEPAC (BLUEtooth Public ACcess) concepts presented ideas for enabling mobile Bluetooth devices to access local area networks in public areas, such as airports, train stations and supermarkets.

The Bluetooth specification defined how Bluetooth-enabled devices (BT) can access IP network services using the IETF Point-to-Point Protocol (PPP) and the Bluetooth Network Encapsulation Protocol (BNEP) [12,19,20]. By mapping IP addresses on the corresponding BT addresses (BD_ADDR), common access across networks is enabled [3]. This means that devices from different networks are allowed to discover and use one another's services without the need for service translation or user interaction. To support communications between all Bluetooth-based home appliances and the existing IP world, IPv6 over Bluetooth (6overBT) technology was proposed [8]. The 6overBT technology suggested that no additional link layer or encapsulation protocol headers be used. However, the development of 6overBT technology is still in progress. The BNEP protocol was referred to as the key technology in our research.

What with the development of applications and wireless networking technologies, mobile multimedia applications are playing more important roles in information access [21]. To provide responsive multimedia services (high *QoS*) in a Bluetooth-IP mobile environment, a pre-requisite for our discussion is seamless data transmission. A cascading system with fair resource allocation scheme, seamless handoff strategy, and transparent bridging system that provides a way of integrating IP networks and Bluetooth-based service networks to relay multimedia applications within residual and enterprise is thus inevitable [6].

The rest of this paper is organized as follows. The following section describes Bluetooth background information, including the piconet, scatternet, IP over Bluetooth service architecture. Section 3 presents the proposed QoS-centric cascading mechanism, including the intra-piconet resource allocation, inter-piconet handoff, and Bluetooth-IP access system. The simulation model and performance analysis of the queue length, loss rate, average delay, are introduced in section 4. Section 5 presents our concluding remarks.

2. Bluetooth-IP services

Figure 1 is a Bluetooth-IP service network environment. When a BT user wants to receive a networked video stored on a remote video server, the BT (maybe a slave in a picocell) will initiate a connection procedure with the picocell master. The master initiates a connection procedure with the video server through the Bluetooth-IP access system. During the connection state, the video stream will be fed through the access system, master to BT user (the dotted line of figure 1).

2.1. Piconet

When two BTs establish a connection, one BT will act as master and the other as the slave. More BTs can join the piconet. A single piconet can accommodate up to seven active slaves. If a slave does not need to participate in the channel, it should still be frequency-hop synchronized and switch to a low-power Park mode. The master can also request that the slave enter the Park mode so the master can communicate more than seven slave BTs. The master determines the frequency-hop sequence, the timing and the scheduling of all packets in the piconet.

Within a piconet, the master initiates the connection procedure, although the application may necessitate that the master and slave roles be exchanged. For instance, such an exchange is necessary when a BT receives network services through Bluetooth-IP access systems. In this circumstance, the access system provides an IP service that may be used by many other BTs. This situation requires that the access system be the master of the piconet and the other BTs to act as slaves. However, when the device is initially activated and looks for an access system, it may be the device initiating the connection. This will make the device the master and the access system the slave [1].

2.2. Scatternet

Several piconets can be established and linked together to form an ad-hoc network. This is called a scatternet. A BT can participate in two or more overlaying piconets by applying time multiplexing. To participate on the proper channel, the BT should use the associated master device address and proper clock offset to obtain the correct phase. A BT can act as a slave in several piconets, but only as a master in a sin-

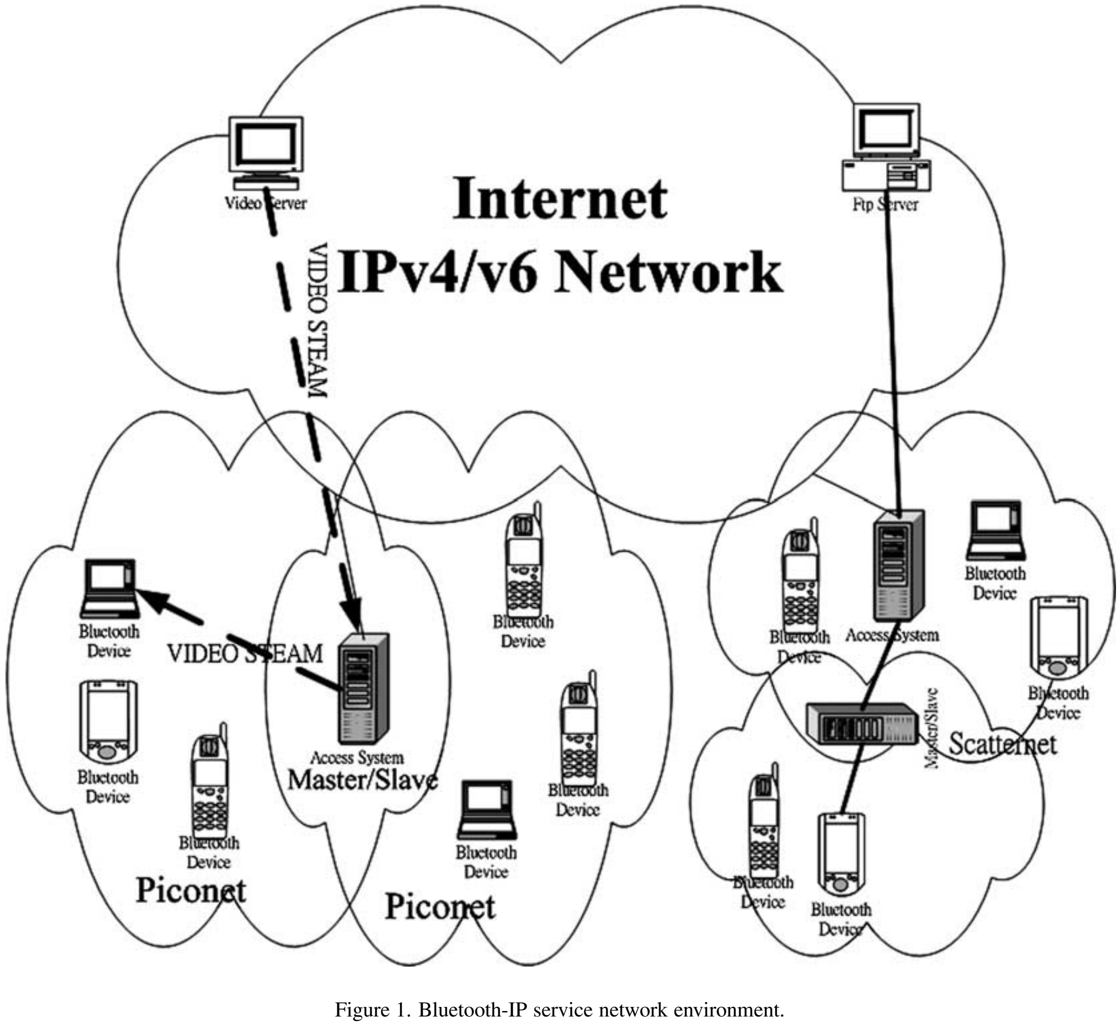

Figure 1. Bluetooth-IP service network environment.

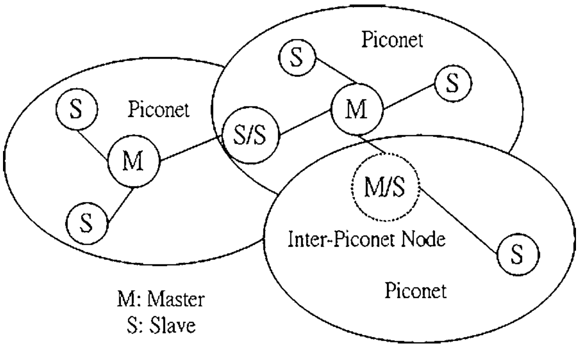

Figure 2. An inter-piconet node in the scatternet.

gle piconet: because two piconets with the same master are synchronous and use the same hopping sequence. This synchronization makes them one and the same piconet.

Time multiplexing must be used to switch between piconets. In figure 2, an inter-piconet node is capable of time-sharing between multiple piconets. This allows the traffic to flow within and between the piconets [18]. In the case of data links only, a BT can request to enter the Hold or Park mode in the current piconet during which time it may join another piconet by just changing the channel parameters. BTs in the Sniff mode may have sufficient time to visit another piconet in between the Sniff slots. If audio links are established, other piconets can only be visited in the non-reserved slots.

2.3. IP networking

The LAN Access profile defines IP service access using PPP over RFCOMM. TCP/IP runs on the PPP protocol. BTs can receive IP services using the PPP protocol [20]. When a BT wants to receive IP service, it will find a LAN Access Point (LAP) within radio range through inquiry and paging. After the data links have been setup, the LMP (Link_Manager Protocol) will process the master/slave switch and the L2CAP/RFCOMM/PPP connection will then be established. A suitable IP address is negotiated between devices in the PPP layer. The BT can forward IP packets through the LAP.

Encapsulating an Ethernet packet inside a PPP packet is not an efficient solution. Moreover PPP is not sufficient for ad-hoc networks that contain multiple wireless hops. The best way of providing networking would be to Ethernet over the L2CAP layer. The Bluetooth Network Encapsulation Protocol (BNEP) was pursued by the Bluetooth SIG PAN working group to provide an Ethernet-like interface to IP services [19], as depicted in figure 3.

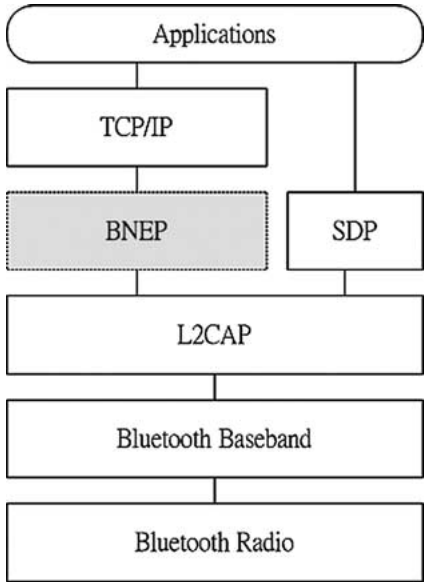

Figure 3. BNEP protocol stack.

3. QoS-centric cascading mechanism

From figure 1, a BT that accesses multimedia services on the Internet may do so through a piconet or scatternet. QoS is critical in transmitting of different network segments. To provide Bluetooth-IP services with differentiated quality requirements, a QoS-centric cascading mechanism is proposed in our research to tunnel the guaranteed applications. The operational modules are illustrated in figure 4. The innovative mechanism consists of three modules: intra-piconet resource allocation, inter-piconet handoff and Bluetooth-IP access system. These modules were developed based on the BNEP operation scenarios.

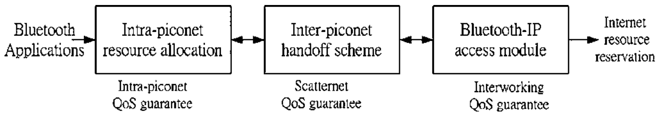

Figure 4. The proposed QoS-centric cascading modules.

3.1. Intra-piconet resource allocation

Two service types: Synchronous Connection Oriented (SCO) and Asynchronous Connectionless Link (ACL) were defined in the Bluetooth service environment. Through the QoS setup, the ACL link can be configured to provide QoS requirements. The ACL link can be configured with the Flush Timeout setting, which prevents re-transmission when it is no longer useful. Acknowledgement can be received within 1.25 ms. This makes the delay small and it is possible to perform re-transmission for real-time applications. The ACL link also supports variable and asymmetrical bandwidth requirement applications.

Currently, the IP QoS architecture is based purely on IP-layer decision making, packet buffering and scheduling through a single link-layer service access point. The mechanism in the link layer has better understanding of the communications medium status. However, simplicity has been important design objective for the Bluetooth interface and the number of IP-based protocols is becoming increasingly more complex. As depicted in figure 5, QoS architecture at the network layer such as differentiated and integrated services provides different services to applications. These services at

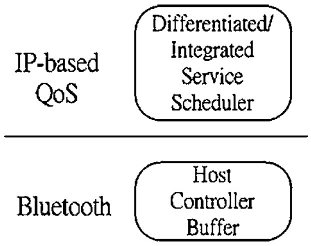

Figure 5. Bluetooth IP QoS mechanism.

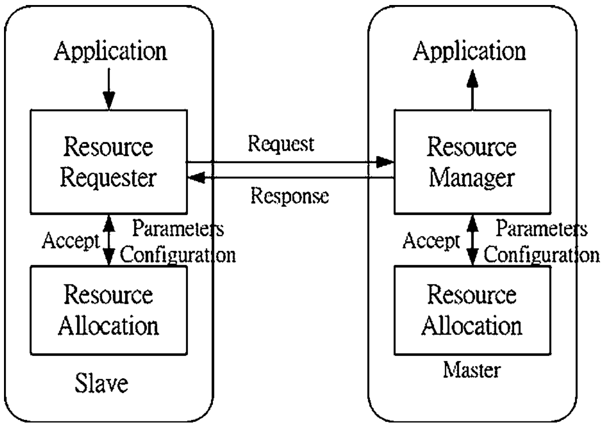

Figure 6. General QoS framework.

the high layer are sufficient depending on the particular scenario. With shared bandwidth and a re-transmission scheme, the Host Controller (HC) buffering will invoke delays. The HC buffer size can be decreased to reduce the buffer delay.

In bluetooth-based service layer, the L2CAP layer informs the remote side of the non-default parameters and sends a Configuration Request. The remote L2CAP-side responds to the Configuration Response that agrees or disagrees with these requirements. If the Configuration Response disagrees, the local side sends other parameters to re-negotiate or stop the connection. The Link Manager uses the poll interval and repetitions for broadcast packets to support QoS. The poll interval, which is defined as the maximum time between subsequent transmissions from the master to a particular slave on the ACL link, is used to support bandwidth allocation and latency control. Figure 6 depicts the general framework, which defines the basic functions required to support QoS.

In figure 6, the traffic and QoS requirements for the QoS flow from the high layer sends the request to the Resource Requester (RR). Based on this request, the RR generates a resource request to the Resource Manager (RM). When the RM accepts the request the RR configures parameters to the local Resource Allocation (RA) entity. The RA actually reserves resources to satisfy the QoS requirements. The QoS is satisfied by the application that receives the appropriate resource.

In our scheme, bluetooth-based operation identifies the following functions and procedures to determine the amount of resources assigned to a traffic flow. A polling algorithm determines which slave is polled next and bandwidth is assigned to that slave. The slave uses the air-interface scheduler to determine which data to send when it is polled. An inter-piconet scheduling algorithm is used by the inter-piconet node to efficiently control the traffic flow between two piconets. Bluetooth also uses the Flush Timeout setting to determine the maximum delay involved with re-transmissions. The Link Manager module in the master selects the baseband packet type for transmission in the single, three and five time slots [4].

3.2. Inter-piconet handoff

The inter-piconet environment suffers many challenges. First, the formation of Bluetooth networks is spontaneous and the problem of scatternet formation has not been defined in the Bluetooth specification [16]. Some researches have addressed these issues in the formation of an efficient scatternet [5,22]. The data sent forward between nodes must been sent via the master. Sometimes this data will traffic through multiple hops in the scatternet. Efficient routing protocols are needed for Bluetooth. The inter-piconet node as the bridge over which a piconet controls communications between piconets. Smarter traffic control is needed to coordinate with these masters. Different data rates exist in each link in different scenarios. The inter-piconet node becomes the bottleneck for the scatternet.

In a piconet, the master controls all of the slaves in the piconet. The inter-piconet node joins more than two piconets, but it is only active in one piconet at a time. To efficiently move traffic between different piconets scheduling is needed to coordinate the inter-piconet and the master. In Reference [11], inter-piconet (IPS) and intra-piconet scheduling (IPRS) were presented to interact with one another to provide an efficient scatternet scheduler, as illustrated in figure 2. The IPS and IPRS must coordinate with one another to schedule when the inter-piconet node belongs to which piconet and how and when to transfer data packets between the different masters.

Bluetooth connection progress includes two steps: the inquiry progress and the paging progress. This causes the bottleneck in the handoff. Two situations were discussed in BLUEPAC. When the Access Point is the master, the mobile node joins the piconet as a slave. The Access Point can efficiently control the traffic to the Internet. However, the disadvantage is that the Access Point must periodically enter the inquiry stage to find the newly arrived mobile node. This will interrupt the Access Point transfer a packet to the Internet. In a situation in which the BT is the master, the Access Point involves itself in multiple piconets. The BT can actively inquire the Access Point when it wants to connect to the Access Point. However, the traffic control becomes difficult and complex when the Access Point must switch between various piconets.

The scheduler is still not supported for seamless handoffs in real time applications. To solve this problem, reference [15] proposes the Next Hop Handoff Protocol (NHHP) to support fast handoffs. The major focus is on reducing the connection time in the strategy. A scheme that passes the inquiry information to the next Access Point was used to avoid wasting time in the inquiry stage. The disadvantage is that the Access Points are divided into two categories: Entry Points which constantly make inquiries to the new BT and pass information to the Access Points in the internal regions have the responsibility in the handoff. If a newly arrived BT is initiated in an internal region, the scheme doesn't work.

To resolve the above problem, a fast handoff scheme was proposed. This scheme assumes Bluetooth service environment is a micro-cellular network architecture. However, it also adapts Bluetooth as a macro-cellular network. Based on the fast handoff mission, the major focus is reducing the connection procedure that causes significant delay. We assumed the following conditions; the Access Point and mobile BT periodically scan for page attempts and inquiry requests. To obtain seamless and efficient handoff support, the Access Point RF range should cover the nearby Access Point. The neighborhood set records all Access Point locations.

3.2.1. Connection procedure

As depicted in figure 7, when the mobile BT accesses the Internet it initiates an inquiry to the Access Point and makes a connection. The Access Point passes the BT addresses and clock information to the nearest Access Point according to the neighborhood set. The nearest Access Point uses this information to page the BT and form the piconets. These piconets form the scatternet and the BT becomes the inter-piconet node between them. The BT depends on the received signal strength indicator (RSSI) to determine which Access Point to use to access the Internet. The BT is a dedicated Access Point only in the connection state. The remaining piconets are all in the Hold state.

3.2.2. Handoff

The BT periodically monitors the RSSI and bit error rate. When the RSSI decreases to the lower threshold a handoff may take place. To know where the mobile BT moves, the BT detects which RSSI becomes stronger. It then informs the Access Points and Foreign Agent that a handoff is imminent (figure 8(A)). The BT leaves the Hold state to the connection state in the piconet that contains the coming Access Point (AP0 in figure 8(B)). The routing path also changes to a new path. Additional caches may be needed in the Access Point to avoid packet losses. The new nearest Access Point (APa in figure 8(C)) in accordance with the neighbor set is notified that the mobile BT is within range to receive BT information. It begins to page the BT and enter the Hold state with the BT. The original connection state also turns into the Hold state in the piconet that contains the original access (AP1 in figure 8(D)).

When the BT does not seek access service from the Access Point it should inform the Access Point that it no longer wants a connection. A connection could break down without prior warning. In the Bluetooth specification, both the master and slave use the link supervision time to supervise the loss. The supervision timeout period is chosen so that the value is longer than the hold periods.

For simplicity of discussion we assumed that the Bluetooth AP is the application sender and divided the architecture into two parts, wired parts: the correspondent node (CN) to the Bluetooth AP and wireless part: the Bluetooth AP to the mobile BT device. The wired part is the same as the current general mechanism. We will only discuss the mechanism that combines the wireless part and our handoff mechanism in the Bluetooth environment. After making a connection and switching roles as mentioned earlier, the Bluetooth AP becomes a master. As illustrated in figure 9, the Bluetooth AP1 sends an active PATH message to the BT in figure 9(1). After the BT receives the PATH message, if the BT needs RSVP

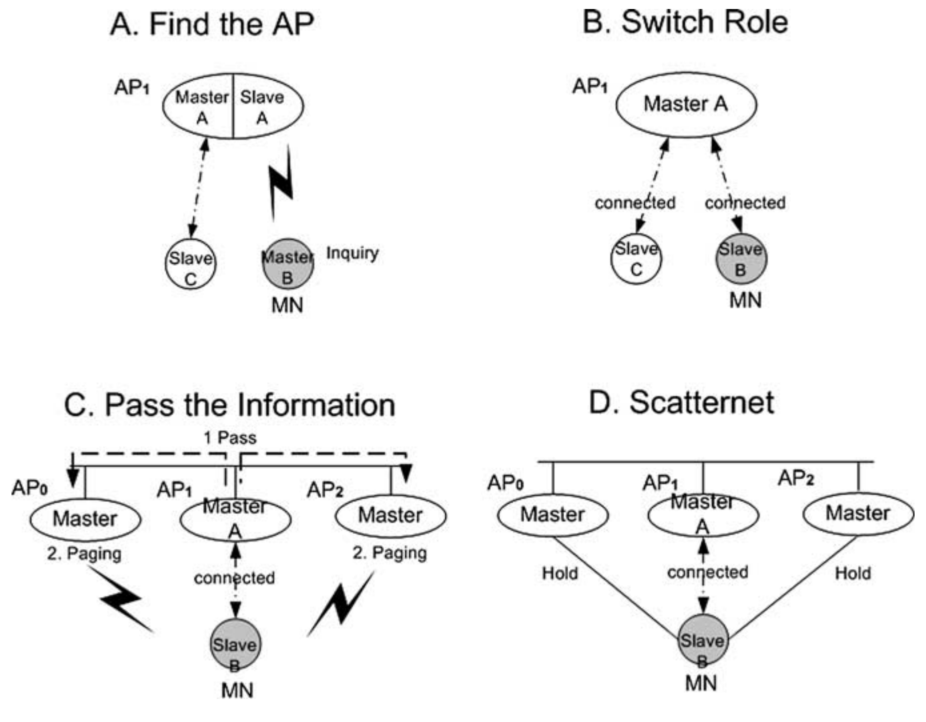

Figure 7. Connection procedures.

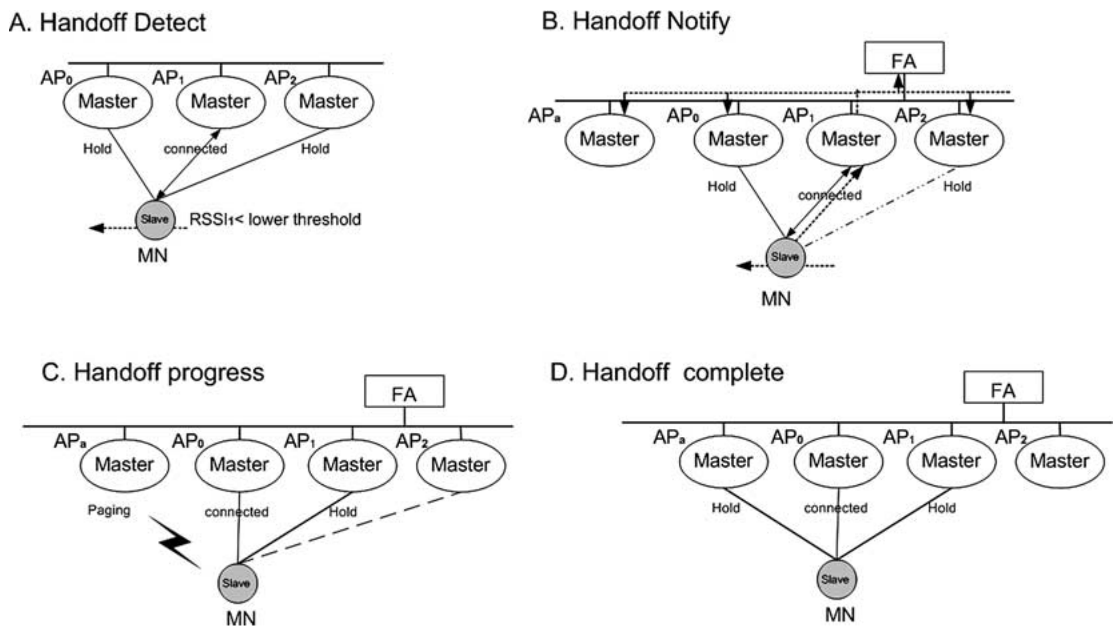

Figure 8. Handoff procedures.

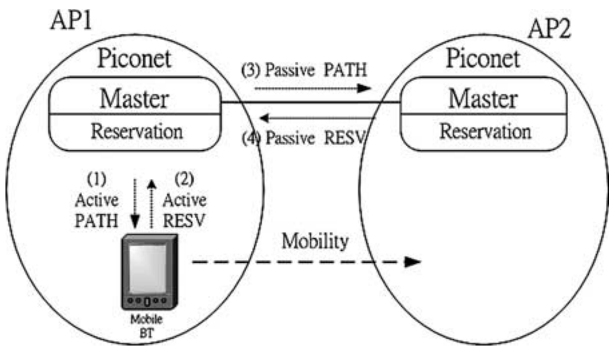

Figure 9. RSVP messages for bluetooth resource reservation.

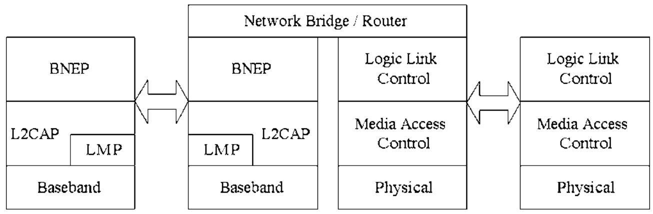

Figure 10. The protocol stack for Bluetooth-IP interworking.

support, it sends a resource reservation request with a RESV message to the AP1 in figure 9(2). When the traffic specification contains a RSVP message, the traffic and QoS requirements for the QoS flow from the high layer sends a request to the Resource Requester (RR). The Bluetooth low levels will thus coordinate with one another.

Once the Bluetooth AP1 accepts the request, the reservation along the flow between the AP1 and BT is made. After this point, the Bluetooth AP1 must have reservations in the neighboring APs. The resource reservation request is the same as an active reservation. The current AP1 sends a *Passive PATH* message to the neighboring AP2. The AP2 responds with a *Passive RESV* message and reserves the resources that the BT may need. Because Bluetooth can have only seven active slaves in a piconet at the same time, the resources must be used efficiently. One way is adding more Bluetooth devices in an AP. This can be easily achieved by modifying the application layer.

As discussed before, to support seamless handoffs, information about the BT is sent to the AP2 after the RSVP process is performed. The Hold state is maintained between the BT and AP2. However, if the BT does not need a QoS guarantee, the QoS mechanism is not added. After supporting the end-to-end QoS using the RSVP protocol, the packet classification and scheduler can be used to control the traffic.

3.3. *Bluetooth-IP access system*

Th difference between existing Bluetooth piconets and IP LANs is the communication protocol stack illustrated in figure 10. From figure 10, these differences are shown in the lower OSI seven layers. The lower layers are responsible for connection and addressing. We therefore focused on the connection management and address resolution issues in our research.

The access function allows connections to be established without requiring any particular knowledge or interaction. The Bluetooth-IP access system plays the role of bridging/routing multimedia traffic between the various LANs and piconets. Their operational scenario is illustrated in figure 11.

When different piconet devices are connected directly to the access system, the access system function is referred to as a bridge (piconet Master and Slave role). If a LAN host (piconet BT) communicates with a piconet BT (LAN host) through the access system, because of the different protocol stacks between the piconet and LAN networks, two issues, addressing and connection must be resolved in the design.

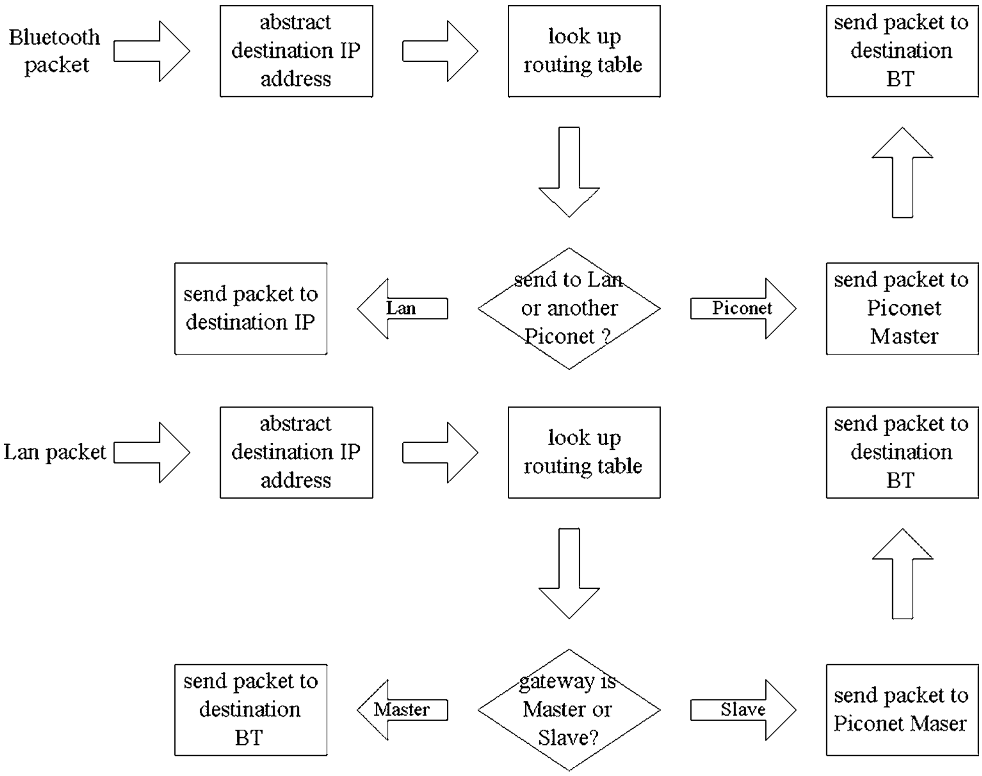

Figure 11. Bluetooth-IP interworking operational scenario.

3.3.1. Address resolution

To achieve the interconnection function in a Bluetooth-IP environment, the access system must refer to both the piconet and LAN networks as members. Thus, two different protocol stacks must be combined to form a new communication protocol stack suitable as a routing server. The combined protocol stack is shown in figure 10. Using the protocol stack specifications, a scenario for addressing is identified as follows:

Step 1: Each LAN host assigns an IP address. Each host thus possesses two addresses; an IP address and a MAC address.

Step 2: Each piconet BT acquires two addresses, a BT address (BD_ADDR) and an IP address.

Step 3: A routing table must be built for interconnection in the access system. A lookup for destination addresses is needed to find the corresponding outbound BD_ADDR or MAC address to which the packet must be forwarded.

3.3.2. Connection management

Because the existing LAN is a packet switching service and BT connections are made on an ad hoc basis, interconnection is very difficult. To solve this problem, a mechanism based on IP services over Bluetooth was proposed in the Bluetooth specification. The system is as follows:

Step 1: Bluetooth adapters and an Ethernet card are embedded into a desktop computer. These adapters and card are referred to as network attachment units (wired or radio). Each port in the interface is directly attached to different networks (see figure 12).

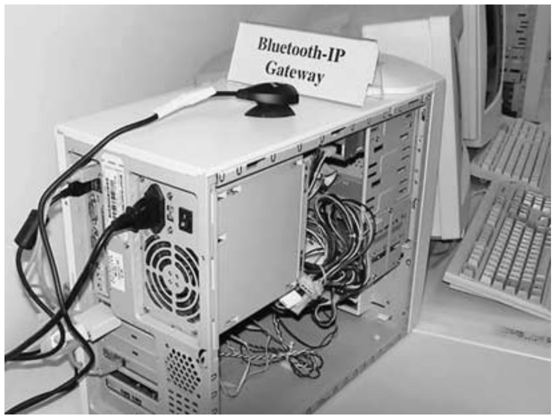

Figure 12. The Bluetooth-IP access system.

Step 2: The API of the Bluetooth adapter and the Ethernet packet driver are used to design an access system. The operational procedures for this system follow the scenario in figure 11.

4. Performance analysis

4.1. Simulation environment

The Bluehoc toolkit was used to simulate the various scenarios in the Bluetooth-IP service environment. As depicted in figure 13, the data is dumped from the L2CA_DataWrite

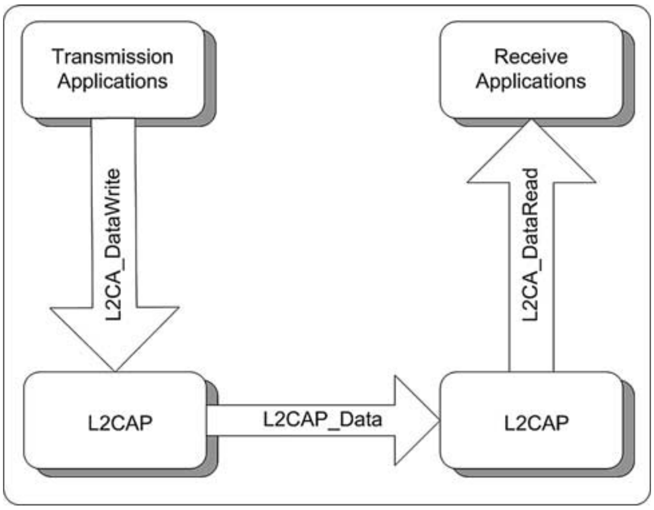

Figure 13. L2CAP packet flow.

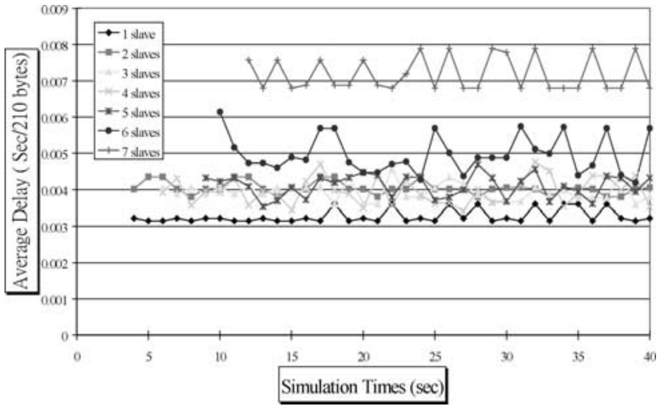

Figure 14. Average delay with voice services.

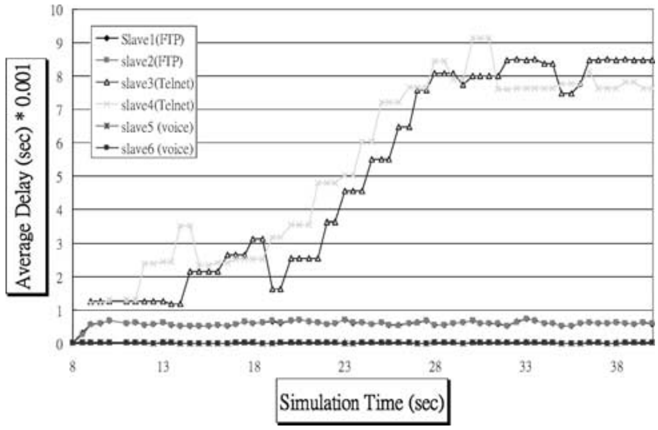

Figure 15. Average delay in the mixed traffic.

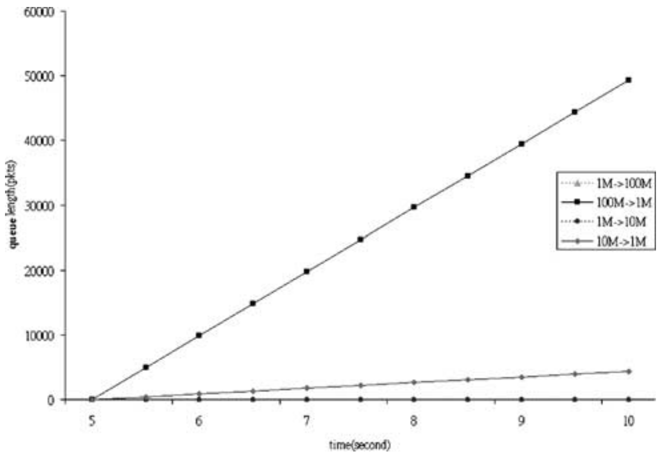

Figure 16. Queue length analysis.

and L2CA_DataRead into the connection state. The L2CA_DataWrite and L2CA_DataRead events are the upper-Layer to the L2CAP events. The L2CA_DataRead is the event that requests transfer for received data from the L2CAP entity to the upper layer. The L2CA_DataWrite is the event that requests data transfer from the upper layer to the L2CAP entity for transmission over an open channel.

In the Bluehoc toolkit the connection procedures such as inquiry and paging are simulated according to the Bluetooth specifications. The master sends the QoS parameters, which depend on the application. QoS parameters are then passed to the Deficit Round Robin (DRR) based scheduler that determines if the connection can be accepted by the LMP. The DRR-based scheduler finds the appropriate ACL link baseband packet type (DM1, DM3, DM5, DH1, DH3 and DH5) depending upon the application level MTU and loss sensitivity. The simulation applications include packetized voice, Telnet and FTP.

4.2. Simulation results

In figure 14 the average delay for various numbers of slaves using packetized voice in a piconet is shown. The voice application is real time and would be sensitive to a loss of several consecutive small packets. Figure 15 shows the average delay in the mixed traffic source. The short-packet delay, such as telnet applications, are significantly increased by the long-packet in the DRR-based scheduler. An efficient and simple scheme that does not add to the Bluetooth load is important.

4.2.1. Queue length analysis

The queue length analysis was based on the access system queue size. We observed the variations in queue length using specified traffic levels. In figure 16, the queue length of the traffic from 100 M LAN to 1 M piconet increases very fast. It reaches 50000 packets within 10 s. The queue length for the traffic from 10 M LAN to 1 M piconet increases more smoothly and the queue length of the traffic from 1 M piconet to 100 M or 10 M LANs is almost zero.

4.2.2. Loss rate analysis

In the loss rate analysis the queue length was changed to observe the variations in the loss rate. In figure 17, when the queue length is smaller than 1000 packets, the loss rate is close to 0.9. When the queue length increases to 5000 packets, the loss rate decreases to 0.8. Therefore, increasing the queue length will decrease the traffic loss rate. The loss rate from 100M LAN to 1 M piconet is a little more than that for 10 M LAN to 1 M piconet because of the difference in the LAN transport speed.

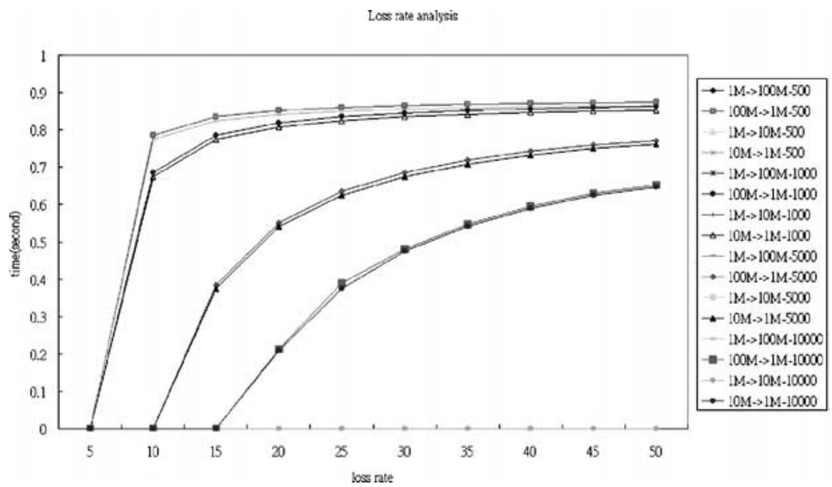

Figure 17. Loss rate analysis.

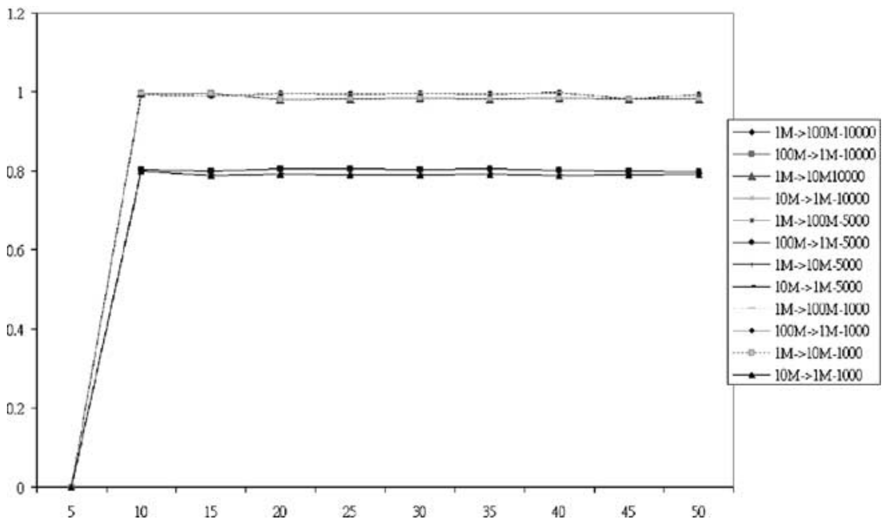

Figure 18. Throughput analysis.

4.2.3. Throughput analysis

From figure 18, increasing the queue length has no effect on improving the throughput. The throughput is smooth in both the LAN to piconet and piconet to LAN traffic.

4.2.4. Delay analysis

From figure 19, when the queue length is 500 packets, the delay is about 0.0005 seconds per bit. If the queue length increases to 1000 packets, the delay becomes almost double. When the queue length reaches 5000 packets, the delay is close to 0.003 seconds per bit. The transfer delay has no obvious change when the queue length increases to 10000 packets.

5. Conclusions

In a wireless environment the QoS guarantee provision becomes more important. The frequent mobility of a host increases the service disruption in real-time applications. Even though efficient RSVP enhances the resource reservation ability and allows for requesting a specific QoS from the network, these mechanisms do not have enough QoS guarantee to prevent service disruption during handoff. In this paper a cascading mechanism for QoS guarantee in a Bluetooth-IP environment was proposed. A fast and efficient handoff scheme that supports BT roaming handoffs between different Access Points was proposed. Concepts for the mobile RSVP issues in Bluetooth networks were presented with our fast handoff mechanism. The Bluetooth-IP access system can be implemented using available technology such as Network Addressing Translation (NAT) and Linux Bluetooth Stack to connect Bluetooth piconets and LAN. In our simulations Bluetooth required a long time to process the inquiry and paging procedures. These results show that the connection time is up to 11.84 sec when seven slaves join a piconet at the same time. Moreover, the access system queue length increases by about 10000 packets per second in a 100 Mbps LAN and about 1000 packets per second in a 10 Mbps LAN when the traffic load is 80%. In the loss rate analysis, the loss rate was close to 90% when the queue length was less than 1000 packets. However, when the queue length increased to 10000 packets the

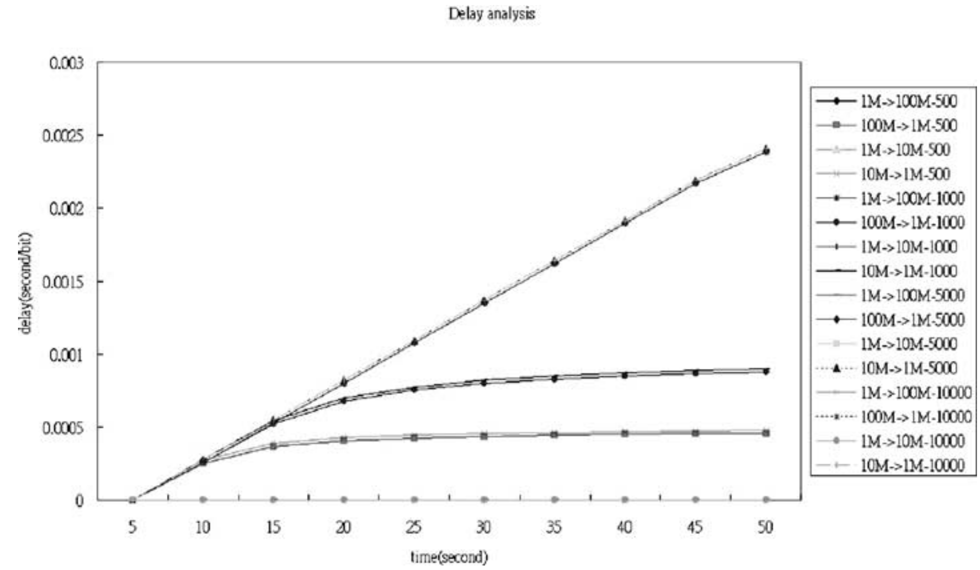

Figure 19. Delay analysis.

loss rate decreased to 70%. In the delay analysis, the delay was about 0.000045 seconds per bit when the queue length was 500 packets. The delay doubles when the queue length doubles. However, when the queue length is more than 5000 packets the delay has no obvious variance.

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