Design of a bluetooth-based interactive control network

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Abstract : Bluetooth technology is essentially a method for wireless connection of a diverse set of devices ranging from PDAs, mobile phone, notebook computers, to another equipments. The bluetooth system supports both point-to-point connection and point-to-multipoint connections. In point-to-multipoint connection, the channel is shared among several bluetooth devices. Two or more devices sharing the same channel form a piconet. There is one master device and up to seven active slave devices in a piconet. The radio operates in the unlicensed 2.45GHz ISM band. This allows users who travel world-wide to use bluetooth equipments anywhere. Since the link is based on frequency-hop spread spectrum, multiple channels can exist at the same time. The Bluetooth standard has been suggested that Bluetooth equipments can be used in the short-range, maximum 100 meters . It has been defined that the time takes to setup and establish a bluetooth connection among devices is 10 seconds. It is a long time and may be a cause to lose a chance of finding other non-fixed devices. We propose a routing protocols for scatternets which can be used to control a mobile units(MUs) in this network. The proposed routing protocol is composed of two kinds of bluetooth information, access point(AP) and MU.

Keywords: Bluetooth, control network, routing , mobile unit,

1. INTRODUCTION

Currently, IEEE 802.11 becomes the most widely used standard for wireless data communication. This technology has a benefit of fast speed about public user and can be applied to local area network(LAN) using medium access control(MAC) protocol. However, it is known that IEEE 802.11 has a problem in the mobile wireless network like Ad hoc, recently [1]. IEEE 802.11 cannot solve the problem of the hidden terminal and exposed terminal. These problems arise from simultaneous common channel usage by medium access control. The newly developed Bluetooth technology provides a good example to solve the medium access problem. Inside each piconet, polling and time-division duplex(TDD) are utilized for sequential data transform and different piconets employ different frequency hopping code-division multiple access (FH-CDMA) channels to prevent mutual interferences.

The limitation of range is solved using scatternet which combine piconets[1,5,6] and the long time delay much higher values of 10 seconds is different from the value of actual experiments. Some results have shown that the time of inquiry can be reduced until 2 seconds[4]. The other distinguishing features of scatternets is their interconnection. Scatternets and wireless LANs, for example, differ in terms of their communication capabilities. Two Bluetooth nodes cannot hear from each other unless they form a master-slave pair. This is in contrast to the wireless LANs where any two nodes within proximity can hear each other's transmissions.

The purpose of this paper is to design routing method for scatternets and to control a mobile unit in this network. The proposed routing method is considered as a method for finding mobile unit in the network. Users within network area can send control packets to the robot and receive data from the robot.

2. BLUETOOTH SPECIFICATION

Bluetooth devices form piconets and communicate with each other in a master/slave configuration. A piconet consists of a single master device and up to seven slave devices.The time division duplex (TDD) frequency hopping (FH) channel is divided into 625 us time slots that each contain a baseband transmission. Table 1 presents a Bluetooth transform packet types distinguished from time slot occupancy and a available max time slot is five.

Table 1 Packet type

Type	Slot occupancy	Payload (bytes)	Symmetric Max. Rate (Kb/s)
DM1	1	0-17	108.8
DH1	1	0-27	172.8
DM3	3	0-121	258.1
DH3	3	0-183	390.4
DM5	5	0-224	286.7
DH5	5	0-339	433.9

Here p is the packet size of packet type and the transmission of a single packet with the size of l costs m time slots. The t_f is the cost of time slot, 625 us. We can derive the maximum throughput expression of data transmission.

$$\frac{p\times l}{(2\times p\times m)\times t_f} \quad (1)$$

The Bluetooth master device always starts the transmission in the even-numbered slots whereas the salves start their transmission in the odd-numbered slot. This means that the timing of the master and the slaves is shifted by one slot. In case of multi-slaves operation, the maximum data throughput is divided by slaves. The reason is that the limited channel capacity and time slot based data transmission. Fig. 1 shows the time slot based data transmission in multi-slaves, only a TX or RX is arising in terms of a time slot.

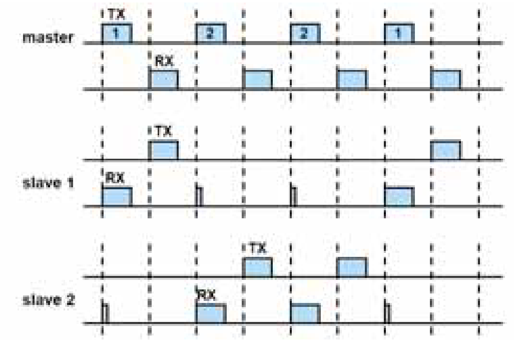


Fig.1 RX/TX timing in multi-slave configuration

Let us $M(k)$ denote the each slaves data transmission rate, we can fulfill the equation using eq.(1)

$$M(k) = \frac{w_k \times p \times l}{(2 \times p \times m) \times t_f} \quad , (k = 0,1,...,6) \qquad (2)$$

$$\sum_{k=0}^{6} w_k = 1$$

where w_n is the weight of transmission occupancy. Control of this value is the method of the proper usage for channel capacity. Without control of channel capacity is difficult to transfer various size of data at same time. Fig. 2 shows the maximum throughput with same weighted n-slaves.

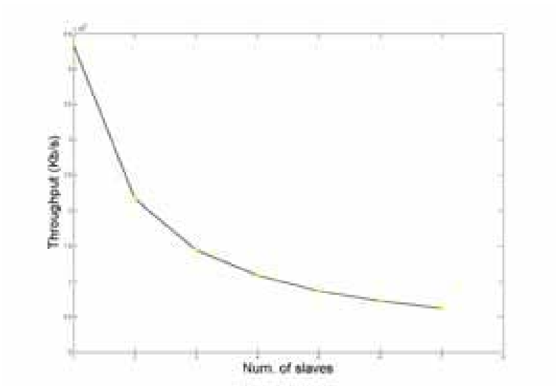


Fig.2 Maximum throughput (w/ same weight)

3. ROUTING METHOD

The constraints of control network using Bluetooth scatternet are listed below:

C1. All Bluetooth devices know the adjacent Bluetooth device address.

C2. A access point can be connected up to seven access point.

Follow these constraints, we propose a routing method of Random Access Sequence Spread(RASS).

3.1 Random Access Sequence Spread

It is possible that fast path decision from user to mobile units in the control network using RASS. A identification number(ID) is given to Bluetooth access points as sequence of connection request. At first, the Bluetooth access point of connection request is numbered in origin point:a start point of Bluetooth access point. And the Bluetooth access point of connection request is numbered in next of sum up prior step from smallest numbered access point. In this procedure, each access point has a number of adjacent access point.

F(K,N) (3)
K : Kth access point
N : Number of Neighbors

Over a process, the information of neighbors, each access point has, is transferred to origin point and assembled to a rout table. Table 2. shows the result of RASS process.

Table 2. A result of RASS

$(0, N_0)$ (Origin point)
$(1, N_1)$
…
(K, N_K)

The size of memory for this table in each access point is about $ceil(\log 2(K \times 2^3)) \times K$ bits. If one thousand access point exist, each access point need to have a memory of 1.6Kbytes. The next lists procedure of path selection:

a) PICONET : Is the source and destination in same piconet?
b) IF not, find a path from the source to origin point
c) Find a path from the destination to origin point.
d) From C1, decrease the path length with a manner of comparison the path of step 2 between step 3.

A rout path from source to origin is (src, R_{s0} , R_{s1} ,…,origin) and destination to origin is (des, R_{d0} , R_{d1} ,…,origin). Combining of this two path, we can get total path from source to destination, (src, R_{s0} , R_{s1} ,…,origin,…, R_{d1} , R_{d0} ,des). A $R_{(s,d)n}$ can be calculated by

```
IF ~Piconet(src,des)
    WHILE( R_{(s,d)n+1} != origin)
        IF ( R_{(s,d)n} ≤ Σ_{i=0}^{K} N_i )
            R_{(s,d)n+1} = K,
            IF ( K = des(src))
                END,
    END
    FOR i = 0:Sn,
        FOR j = 0:Dn,
            IF PICONET( R_{si} , R_{di} )
                SelecetNewPath;
```

A simple operation of RASS leads to fast rout selection. Fig 3. shows the numbered access point and table for RASS.

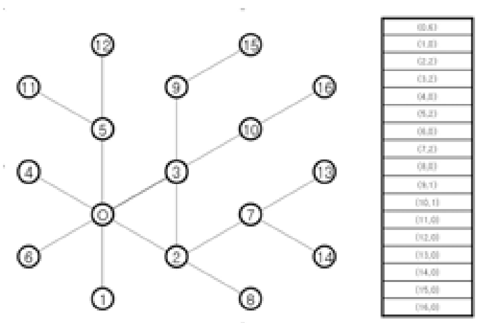


Fig 3. Example of RASS

In Fig.3, a path selection using couples of source and destination shows below:

```
Case 1: 11 -> 8
        (11,5,0)
        (8,2,0)
        No Path Change
        Result -(11,5,0,2,8)
Case 2: 6 -> 1
        Piconet(6,1)
        Result -(6,1)
Case 3: 8 -> 13
        (8-2-0)
        (13,7,2,0)
        Path Change -Piconet(8-7)
        Result -(8,7,13)
```

The RASS determines the path by random sequence. In spite of no address and position information, it can find the path using only connection request. This means that RASS can be applied to Bluetooth standard process, inquiry, connection without C1.

4. CONTROL NETWORK

As shown Fig. 2, since multi-slave operation decrease the maximum throughput, all access point which has to connect at least two other access points cannot transfer data in maximum rate. And the time slot based data transmission is caused to transmission delay. The delay time t_d about transmission hop is simply expressed

$$t_d = (2 \times h - 1) \times t_f + t_p \times h \quad (4)$$

In Eq.(4), t_p is the process time delay. The process time delay is concerned with transmission HCI packets between HOST and Bluetooth module. Lower ability of HOST leads to more process delay.

4.1 Control packet

Bluetooth data propagation method is based on the type of packets. Since it has to need packet to control of mobile units, we define the control packet. It is composed of devices, command, data length and data field. In the control packet, device field has 3 bits and it is possible to control up to eight devices. For example, the robot itself, sensors, pan/tilt equipment and *etc.* are combined in one system. Command field has 5 bits. This means that each device can be controlled in 32 ways. The size of packet is changed from several bytes to hundreds bytes. The reason is that the kind of data is not fixed. Fig.4 shows the proposed packet.

Figure 4. Control Packet

Fore define packet can reduce packet size and be used in the multi-slave operation with low throughputs. But, as mentioned, since the size of data is changed, we should be control weight value.

4.2 Bluetooth Access Point

In case of the knowledge about the other Bluetooth, it can create connection without inquiry process. The inquiry process is used to discover the existence of neighboring devices and to collect their information(link address, clock, etc). According to the Bluetooth specification, the master device has to stay at the inquiry state for 10.24s. The inquiry state time delay leads to eventually lost chance which find connection in moving. So, from C1,it can connect another Bluetooth devices whenever it need.

Our hardware testbed of MCU for HOST and Bluetooth module is shown Fig. 5. This board is used to access point and has a fixed location. The ability of Bluetooth access point is the medium between user and mobile unit and operation of RASS.

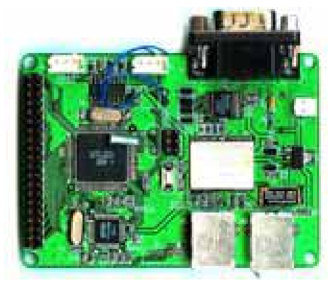


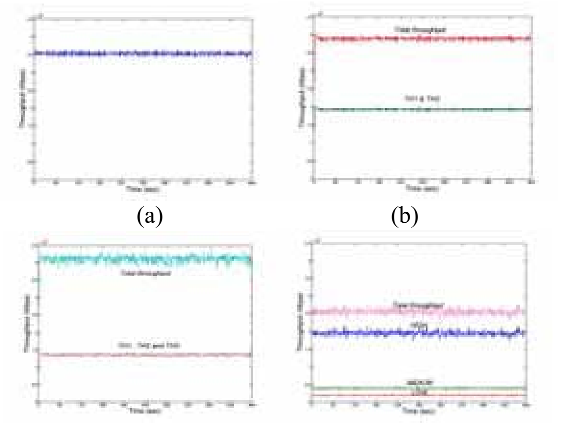
Figure 5. Bluetooth access point

4.3 Sequence of Data transmission

When the mobile unit connect to control network, it send a fore-defined unit type to origin point and receive a information of all neighboring Bluetooth access points from first connected access point. Users who connect to control network, receive a information of mobile units(unit type) from origin point and select a path using RASS and start transmission. If users cannot transfer data in this connection because of various reason, the Bluetooth device of users attempt to establish connection as the information of all neighboring devices. After create connection, it select a new path using RASS, repeatedly.

5. EXPERIMENTAL RESULTS

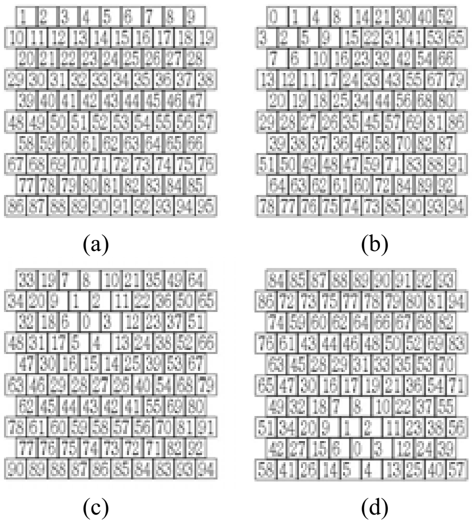
Fig. 6 shows the maximum throughput in case of a master and multi-slave. In Fig. 6(a), one master and one slave are used. In Fig. 6(a~c), all slaves have a same weight factor for channel capacity. In Fig. 6(d), each slaves have different weight. Fig. 6(d) shows that the control network can transfer various size of data in multi-access point environment. The data from simple control packet to enormous image data exists. The Control network should support some kinds of data which control mobile unit.



(a) (b) (c) (d)

Figure 6. Max Throughput in multi salves

We implement our routing method using virtual access point like in Fig. 7. In Fig. 7(a), it shows the arrangement of 95 access points before RASS. After RASS, Fig. 7(b~d) show the result of identifying as change of origin points.



(a) (b) (c) (d)

Fig. 7. RASS examples

Table 3. Rout table for Fig.7 (c) using RASS

(0,6)	(19,1)	(38,1)	(57,1)	(76,1)
(1,3)	(20,1)	(39,1)	(58,1)	(77,1)
(2,2)	(21,1)	(40,1)	(59,1)	(78,0)
(3,2)	(22,1)	(41,2)	(60,1)	(79,0)
(4,2)	(23,2)	(42,1)	(61,2)	(80,1)
(5,2)	(24,1)	(43,1)	(62,0)	(81,1)
(6,1)	(25,1)	(44,1)	(63,0)	(82,1)
(7,1)	(26,2)	(45,2)	(64,0)	(83,0)
(8,0)	(27,1)	(46,1)	(65,0)	(84,0)
(9,1)	(28,1)	(47,0)	(66,0)	(85,0)
(10,1)	(29,2)	(48,0)	(67,1)	(86,0)
(11,1)	(30,1)	(49,1)	(68,1)	(87,0)
(12,2)	(31,1)	(50,1)	(69,1)	(88,0)
(13,1)	(32,0)	(51,1)	(70,1)	(89,0)
(14,2)	(33,0)	(52,1)	(71,2)	(90,0)
(15,1)	(34,0)	(53,1)	(72,1)	(91,0)
(16,2)	(35,1)	(54,1)	(73,1)	(92,1)
(17,1)	(36,1)	(55,1)	(74,1)	(93,0)
(18,1)	(37,2)	(56,2)	(75,1)	(94,0)

In Fig. 7(c), the origin point is the 23 numbered access point and a rout table is shown Table 3.

Table 4. Path selection using RASS in Fig. 7(c)

no	Src	Des	Hop	Elapsed Time(ms)
	Path			
1	33	4	5	2.7
	(33,19,7,1,0,4)			
2	1	2	1	0.2
	(1,2)			
3	33	94	13	3.2
	(33,19,7,1,0,3,12,24,39,54,69,81,92,94)			
4	4	43	3	3.2
	(4,14,27,43)			
5	43	4	3	3.2
	(43,27,14,4)			
6	0	85	7	3.5
	(0,4,14,26,41,56,72,85)			
7	64	90	13	3.1
	(64,49,35,21,10,2,0,5,16,29,45,61,77,90)			
8	45	65	10	3.3
	(45,29,16,5,0,2,11,22,36,50,65)			
9	60	65	11	3.5
	(60,44,28,15,4,0,2,11,22,36,50,65)			

Table 4 shows the path and elapsed time about different source and destination. From this result, we can get the idea that the path selection elapsed time is within 4ms. It is assumed that mobile unit is in the access point of 45 and transfer data to access point of 65. And then, mobile unit lost connection to 45 and newly establish the connection to 60. After that mobile unit can find new path to 65 during 4ms.

6. CONCLUSION

We can control the mobile units in the Bluetooth control network based scatternet. Using RASS can get the time reduction of change access point and the chance increase. According to the Bluetooth specification of time slot based transmission, the channel interference problem may be solved. But, time delay is derived from multi-slave operation and non-optimized path selection. The further research will mainly focus on optimizing path with position.

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