Performance Evaluation of a Framework for Internetworking Bluetooth Scatternets with Internet

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Abstract – *This paper evaluates the performance of a proposed framework that inter connect Bluetooth scatter net and Internet. The proposed framework consists of the core network and the access network, and several possible structures are considered for the core network. These structures include single-star, multi-star, binary tree, master/slave ring (MSR), slave/slave ring-even (SSRe), and slave/slave ring-odd (SSRo). The performance for the framework was analyzed and evaluated. The results of the performance evaluation show that the core networks for the framework have almost the same number of BSLs and BSBs except for the SSRo and SSRe. However, the numbers of hops for these infrastructures are diverse. And the SSRe and SSRo could balance the traffic load well. The future work may include developing an approach to choosing the BSL and BSB nodes and refining the proposed two-level framework.*

Key Words: Performance, Bluetooth, Framework, Scatternet, Internet.

1. INTRODUCTION

Bluetooth [1] is a promising wireless technology, which can be employed for realizing Personal Area Network (PAN). The basic topology of the Bluetooth network is the piconet. Two or more piconets use the bridge node to interconnect each other to form a larger Bluetooth network called Scatternet. The scatternet has different types of topologies [2-8], such as mesh, tree, ring, etc. Besides, mobile devices that move in a Bluetooth network can be characterized by either low mobility or high mobility [9-12]. To deal with the device mobility, the efficient handoff procedure [13-15] is required, so that the devices can connect to the different access points as soon as possible when they move in a scatternet [16-17]. For internetworking Bluetooth scatternet with Internet, the Bluetooth gateway is employed. So, the piconet and the scatternet can connect to Internet for accessing versatile services. Therefore, how to establish a scatternet in which a Bluetooth device can efficiently connect to the AP and maintain the connection to Internet is becoming a crucial issue.

In [2] a framework for internetworking Bluetooth scatternet with Internet was proposed. The framework makes use of Access Points (APs) to improve service accessibility. The proposed framework consists of two levels. The first level is a core network, which is composed of the Base Station Bridge (BSB), the Base Station Leader (BSL) and the Base Station Controller (BSC). The second level is the access network, which consists of APs. The AP receives data packets from the mobile host and forwards them to BSC through BSB and BSL.

This paper evaluates the performance of the proposed framework which adopts various types of core networks. The rest of the paper is organized as follows. Section 2 introduces the proposed framework. Section 3 presents the analysis of the framework. Section 4 addresses the performance evaluation, and Section 5 concludes the paper.

2. THE PROPOSED FRAMEWORK

The proposed two-level framework for internetworking Bluetooth scatternet and Internet consists of the core network and the access network. As shown in Fig. 1 a mobile node may connect and transmit data packets to the Base Station (BS). Then the packets are forwarded to the Base Station Leader (BSL) or the Base Station Bridge (BSB). These data packets finally reach Internet through the Base Station Control (BSC).

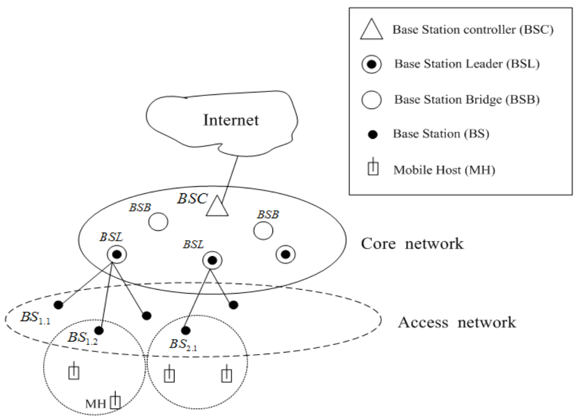

Fig -1: The proposed framework.

In the framework, the core network consists of BSLs, BSBs and BSCs. The access network consists of BSs. Each BS in the access network can connect to the mobile node which is in the vicinity. Therefore, a BS can connect to seven mobile nodes to form a piconet. Besides, the BS can connect to its corresponding BSL. The number of BSs that can connect to the BSL is different according to the different architecture in the core network.

To evaluate the performance of internetworking Bluetooth scatternet and Internet the topology of the core network is a critical factor. Several types of topologies are considered in this study. They are star (single-star and multiple-star), tree, and ring (MSR: master/slave ring, SSRo: slave/slave ring-odd, and SSRe: slave/slave ring-even). The details of the core networks are presented in [2]. Table 1 summarizes and compares the different core networks.

Table -1: Summary of core networks

Core	Advantages	Disadvantages
Single-Star	Shorter transmission path and shorter transmission time	Limited number of BSL, Poor scalability
Multi-Star	Good scalability	Bottleneck at bridge
Tree	No limit on number of BSL, Good scalability	Longer transmission path, Bottleneck at root node
Ring	Two alternative paths, No limit on number of BSL	Longer transmission path, Poor scalability

3. ANALYSIS OF THE PROPOSED FRAMEWORK

The number of mobile hosts is an important factor that affects the number of the required BSLs and the required BSBs in the different core networks. The relationship between the number of hops from MH to BSC and the number of the required BSLs and the required BSBs is discussed. Moreover, the congestion of the traffic load in the different core networks is also investigated.

Firstly, the total number of BSL and BSB according to the number of MHs is figured out. Suppose that the total number of the MHs is k. Each BSL could connect to the maximum number of BSs, and the BS also connects to the maximum number of MHs. Besides, each MH delivers λ packets per second and the BSC can process $k\lambda$ packets per second. So, there are $k\lambda$ total number of packets per second in the core network.

3.1 Number of Hops

The number of hops that the packet goes through from MHs to BSC is investigated as follows. First, because the MHs transmit packets to the BSLs through the BSs, the number of hops is 2 from MHs to BSL for these core networks except the multi-star infrastructure. Afterward the hop counts from BSLs to BSC in the core network is figured out.

Since the Single-Star core network is a hierarchical structure, the number of hops is a logarithmic value in the core network, and the number of hops is 2 from MHs to BSL. Therefore, $\left\lceil \frac{k}{49} \right\rceil$ BSLs are required when there are k MHs and the number of hops is as follows.

$$N_{Sstar}^{hop} = 2 + \left\lceil log_7 \left\lceil \frac{k}{49} \right\rceil \right\rceil \quad (1)$$

For the multi-star core network, there are three hops when the MHs deliver packets to BSL. However, the structure consists of many piconets. Thus, the number of hops would be double when the master BSL connects to another master BSL through the BSB node. Hence, the number of hops from the MHs to the BSC is:

$$N_{Mstar}^{hop} = 3 + N_{BS}^{B} \times 2 \quad (2)$$

The number of hops with the BSLs is logarithmic value because the core network is a hierarchical binary tree. The BSC node should be considered when calculating the number of hops in the core network. So, the number of BSLs is increased by one and the number of hops is 2 from MHs to BSL. Hence, the number of hops is as follows.

$$N_{Tree}^{hop} = 2 + \lfloor log_2 (N_{Tree}^{sum} + 1) \rfloor \quad (3)$$

The MSR core network consists of N_{MSR}^{sum} BSLs and one BSC. Packets are transmitted from the BSL to the BSC. Thus, the minimized number of hops is 1 and the maximize hop number is N_{MSR}^{sum}. Then, the average hop number is as follows.

$$\left\lceil \frac{N_{MSR}^{sum}+1}{2} \right\rceil \quad (4)$$

Besides, the number of hops is 2, from MHs to BSL. Hence, the hop number of the MSR infrastructure is:

$$N_{MSR}^{hop} = 2 + \left\lceil \frac{N_{MSR}^{sum}+1}{2} \right\rceil \quad (5)$$

The hop counts of the SSRe and SSRo are like that of the MSR. The total number of BSLs and BSBs are denoted as $N_{SS\,Re/o}^{sum}$, and the average number of hops is as follows.

$$\left\lceil \frac{N_{SS\,Re/o}^{sum}+1}{2} \right\rceil \quad (6)$$

And the number of hops is 2, from MHs to BSL. Therefore, the SSRe/o have the number of hops as follows.

$$N_{SSRe/o}^{hop} = 2 + \left\lceil \frac{N_{SS\,Re/o}^{sum}+1}{2} \right\rceil \quad (7)$$

3.2 The Average Number of Packets Arrived at BSLs

The average number of packets arrived at the BSL is investigated in this Subsection. Suppose that the total number of MHs is k, and each MH delivers the packets with the rate of λ packets per second. Then, the BSC node will receive $k\lambda$ packets per second and the total number of packets is $k\lambda$. So, the average number of packets arrived at BSLs is the total number of packets divided by the number of BSLs.

The average number of packets arrived at BSLs with the Single-Star infrastructure is as follows.

$$N_{Sstar}^{PBSL} = \frac{k\lambda}{\sum_{i=1}^{n}\left\lceil \frac{\left\lceil \frac{k}{49} \right\rceil}{7^{i-1}} \right\rceil} \qquad (8)$$

The average number of packets arrived at BSLs with the multi-star core network is as follows.

$$N_{Mstar}^{PBSL} = \frac{k\lambda}{\left\lceil \frac{k}{49} \right\rceil + \left\lceil \frac{\left\lceil \frac{k}{49} \right\rceil - 6}{5} \right\rceil} \qquad (9)$$

The average number of packets arrived at BSLs with the tree core network is as follows.

$$N_{Tree}^{PBSL} = \frac{k\lambda}{\sum_{i=1}^{n} 2^i + \left\lceil \frac{k - (35\sum_{i=1}^{n} 2^i)}{49} \right\rceil} \qquad (10)$$

The average number of packets arrived at BSLs with the MSR core network is as follows.

$$N_{MSR}^{PBSL} = \frac{k\lambda}{\left\lceil \frac{k}{42} \right\rceil} \qquad (11)$$

The average number of packets arrived at BSLs with the SSRe core network is as follows.

$$N_{SSRe}^{PBSL} \frac{k\lambda}{\left\lceil \frac{k}{35} \right\rceil} \qquad (12)$$

The average number of packets arrived at BSLs with the SSRo core network is as follows.

$$N_{SSRo}^{PBSL} = \frac{k\lambda}{\left(1 + \left\lceil \frac{k-42}{35} \right\rceil\right)} \qquad (13)$$

4. PERFORMANCE EVALUATION

4.1 The Minimum Number of BSLs and BSBs

Figure 2 shows the minimum number of BSLs and BSBs. It is obvious that all the core networks need more BSLs and BSBs if the number of MH is increased. And the SSRe and SSRo need more BSLs and BSBs than others as shown in Fig. 2. The SSRe and SSRo adopt the slave/slave ring, which needs more BSBs in the infrastructure. Moreover, the number of BSLs and BSBs increases, the cost also rises.

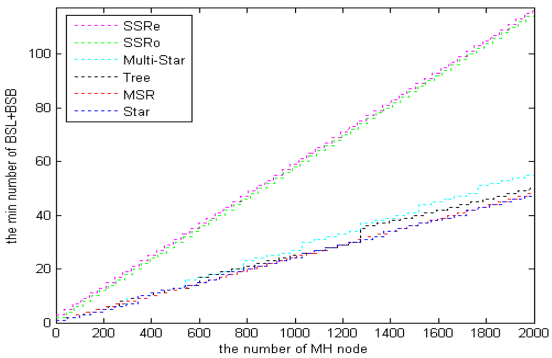

Fig -2: The minimum number of BSLs and BSBs.

4.2 The Number of Hops from MH to BSC

Figure 3 depicts the number of hops that the packet traverses from the MH to the BSC. The result shows that the number of hops for SSRe and SSRo are higher than those of others, and the single star has the lowest value for the number of hops. According to the results shown in Fig. 2, these approaches have very different structures. Thus, the numbers of hops from MH to BSC for these approaches are also diverse. For short, the number of hops is denoted as n_p. This factor n_p would dominate the efficiency of transmitting packets in these core networks. If the value of n_p is smaller, the transmission delay from MH to BSC is shorter. Because the Single-Star infrastructure is hierarchical, each BSL can connect to seven BSL/BS nodes. So, the BS collects the packets and transmits them to the BSC through the BSLs quickly when there are many MH nodes. On the contrary, there are more BSLs and BSBs for the SSRe and SSRo approaches. The packets traverse through these BSLs and BSBs, so that the factors n_p for these infrastructures are larger and the transmission delay is longer.

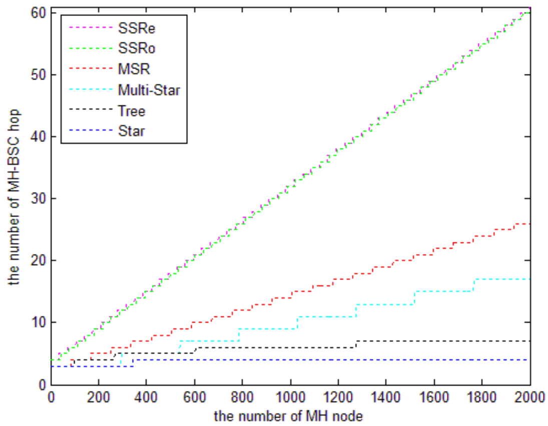

Fig -3: The number of hops from MH to BSC.

4.3 The Average Number of Packets Received By BSL

Suppose that the light loading is that each MH generates and transmits one packet per second. Under light loading (for short, T_L) conditions, the average number of packets arriving at BSL for all core networks are investigated. Figure 4 shows the performance for T_L. Moreover, the heavy loading is denoted as T_H, which means a MH generating and transmitting ten packets per second. And Figure 5 shows the performance of T_H. From the results shown in Fig. 4 and Fig. 5, the performance oscillates seriously when the number of MHs is smaller. As the number of MHs increases, oscillation is alleviated and the curves become more smoothly. When the number of MHs is smaller, the MHs could connect to BSL exactly and, thus, the average number of packets at BSL would attain at the maximum value. However, when the number of MHs increases, the core network is also expanded by adding more BSL to connect these MHs. Thus, the average number of packets at BSL would decrease. Therefore, the curves may oscillate as the number of MHs increases. The BSLs in the single-star, MSR and multi-star would receive more packets than other infrastructures do. But the average numbers of packets received at BSLs for the SSRo and SSRe are smaller. And the average number of packets at BSL in a tree core network is a middle value among these results. For the SSRo and SSRe, each BSL only connects to five BSs except for one BSL in SSRo connecting to six BSs. Thus, the BSL receives less packets and the average number of packets is smaller. On the other hand, the BSLs in the single-star, MSR and multi-star connect to more BSs and, thus, receive more packets. Hence, the average numbers of packets at the BSL for these infrastructures are larger.

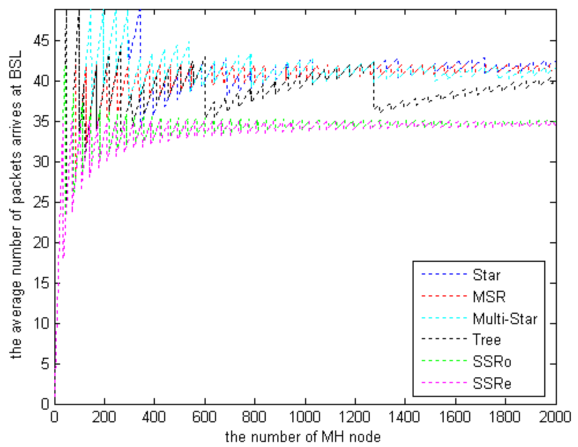

Fig -4: The avg. no. of packets at BSL (light loading).

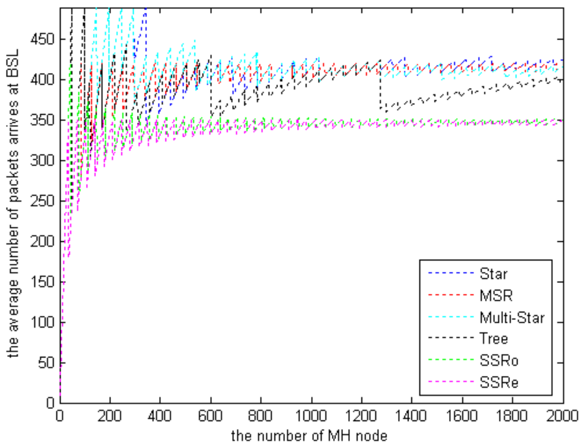

Fig -5: The avg. no. of packets at BSL (heavy loading).

5. CONCLUSIONS

Most of the Bluetooth devices are portable and may move around on the Scatternet. To access Internet the Bluetooth devices must connect to the access point and gateway. Thus, to develop an efficient framework for internetworking Bluetooth scatternet and Internet is becoming a crucial issue. A two-level framework that consists of the core network and the access network was proposed. The access network consists of the MHs and the BSs, and the core network comprises of the BSLs and the BSC (i.e., gateway). Different structures for the core network include single-star, multi-star, binary tree, MSR, SSRe, and SSRo. This paper analyzes the proposed framework and evaluates the performance of the framework. The results of our performance evaluation show that these core networks have almost the same number of BSLs and BSBs except for the SSRo and SSRe. However, the numbers of hops for these core networks are diverse, since different structures in the core network may cause a variation of the number of hops. Besides, the SSRe and SSRo have a smaller average number of packets received at the BSL and BSB. In other words, the SSRe and SSRo could balance the traffic load. The future work may include developing an approach to choosing the BSL and BSB nodes, employing the mobile IP (i.e., home agent, foreign agent) and exploring the routing mechanisms for the framework.

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