

# A Two-Level Framework of Internetworking Bluetooth Scatternets with Internet

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**Abstract** - Bluetooth is a low-cost, short-range wireless technology. Since Bluetooth devices may move around in the Scatternet, the access points and gateways are required for the devices to access the Internet. First, this paper investigates the features of the infrastructures that interconnect Bluetooth scatternet and Internet. Though some frameworks of internetworking Bluetooth scatternet and Internet were proposed. The framework for the large-scale network is not yet investigated. Thus, a two-level infrastructure that consists of the core network and the access network is proposed in this paper. And several possible structures for the core network are investigated. These structures include single-star, multi-star, tree, master/slave ring (MSR), slave/slave ring (even/odd) (SSRe and SSRo). The future study may include the performance evaluation of the framework with various structures.

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

## 1. INTRODUCTION

Bluetooth is a low-cost, short-range wireless technology, which can be employed for realizing Personal Area Network (PAN). It operates in industrial, scientific and medical (ISM) band at 2.4GHz and adopts Frequency Hopping (FH) to avoid radio interference [1]. For Bluetooth technology, the ISM band is divided into 79 channels, the bandwidth of each channel is 1 MHz. The hopping rate of a Bluetooth device is 1600 hops/sec. In addition, it adopts Time Division Duplex (TDD) technology for data transmission. The length of a time slot for TDD technique is 625  $\mu$ s and the length of a data packet may be 1, 3, or 5 time slot(s).

The basic topology of the Bluetooth network is piconet. When two Bluetooth devices come into each other's communication range, one Bluetooth device can act as master and the other acts as a slave. Thus, the single-hop network, which is called a piconet, is formed. A piconet contains one master device and up to seven active slave devices. Moreover, two or more piconets use the bridge node to interconnect with each other to form a larger Bluetooth network called Scatternet. The scatternet has different types of topologies [2], such as mesh, tree, ring, etc. The scatternet of mesh topology can be optimized to support less routing and traffic transmission time. For a

tree topology, the data packet can be transmitted quickly through the scatternet, because the average routing length is shorter than those of other topologies. For ring topology, the bottleneck problem, which the root node in a scatternet may suffer from traffic jam, can be alleviated. Besides, mobile devices that move in a Bluetooth network can be characterized by either low mobility or high mobility. To deal with the device mobility, the efficient handoff procedure is required, so that the devices can connect to the different access points as soon as possible when they move in a scatternet.

For internetworking Bluetooth scatternet with Internet, the Bluetooth gateway is employed. So, the piconet and the scatternet can connect to the Internet to access versatile services. When one mobile host enters the area of a scatternet, the device could quickly connect to the access point (AP) in the vicinity and transmit data packets to the Internet. 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 the literature, a lot of scatternet formation approaches for Bluetooth networks were proposed, but a few works discuss the mobile Bluetooth devices access to Internet via scatternet. In [3], an approach of forming a scatternet as a tree topology and connecting all APs to a central access point (CAP) server for Internet access was proposed. Moreover, to extend the coverage of Bluetooth, the Bluetooth Wireless Gateways (BWGs) [4], which manage the wireless local area network (WLAN) and Bluetooth interface in a BlueStar architecture, is employed to interconnect Bluetooth networks to WLANs. Besides, BLUEtooth Public ACcess (BLUEPAC) [5] makes use of the Mobile IP and Cellular IP for mobile Bluetooth devices to access Internet services.

In this paper, a variety of frameworks for internetworking Bluetooth scatternet with Internet were studied. Furthermore, this paper proposes an efficient framework that makes use of less APs and improves 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. Moreover,

the core network with respect to different topologies are explored.

The rest of the paper is organized as follows. Section 2 discusses the related work. Section 3 presents the important feature of the framework, i.e., the number of the required access points. Section 4 addresses the proposed two-level infrastructure, and Section 5 concludes the paper.

## 2. RELATED WORK

In this Section, the various scatternet topologies are discussed and, then, the related work on frameworks of internetworking Bluetooth scatternet and Internet are presented. The related work includes the scatternet with infrastructure support [3], the Bluetooth wireless gateway [4], and the BLUEPAC [5].

### 2.1 Scatternet Topologies

Bluetooth scatternet can be formed by executing various formation algorithms [6,7,8], which may construct the scatternets with different topologies. The topologies include mesh, tree, ring, etc.

For the scatternet of mesh topology, it can be optimized to support less routing and traffic transmission time. However, the drawback is that it is more complex than other scatternets with different topologies. For the mesh topology, there are two alternatives as shown in Fig. 1. One is the Master/Slave Mesh (MSM) and the other is the Slave/Slave Mesh (SSM). Obviously, the SSM scatternet makes use of Slave/Slave (SS) bridges to interconnect piconets. On the other hand, the MSM scatternet makes use of either Master/Slave (MS) or Slave/Slave (SS) bridges to interconnect piconets. Thus, MSM scatternet is more flexible than SSM scatternet.

A tree topology consists of a root node, many intermediate nodes and more leaf nodes. Tree hierarchy (TH) topology can be used for constructing a scatternet as shown in Fig. 1. For TH topology, the data packet can be

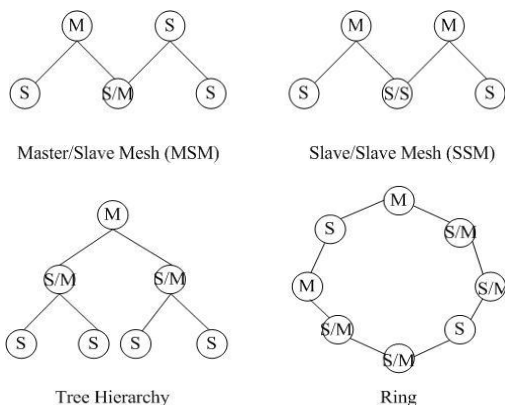


Fig. 1 Scatternet topologies

transmitted quickly through the tree-structure scatternet, because the average route length in a tree topology is shorter than those of other topologies. Besides, TH topology can simplify routing in a scatternet. However, the main disadvantage of tree topology is that the bottleneck for data transmission in the scatternet may occur on the root node.

For the ring topology (see Fig. 1), the characteristics of the ring topology are opposite to those of the tree topology. The ring topology can be used to alleviate bottleneck problems in the TH topology. However, the partition problem and longer average path length are two disadvantages of the ring topology.

In the literature, Persson *et al.* [2] propose several criteria for constructing an optimal scatternet. We also propose some criteria for constructing a framework of internetworking Bluetooth scatternet with Internet. These criteria include (i) minimized the number of hops, (ii) minimized average route length, (iii) minimized scatternet construction time, and (iv) maximized probability of access to Internet.

### 2.2 Scatternet with Infrastructure Support

Madsen *et al.* proposed formation algorithms [3] for Bluetooth scatternet, which consists of infrastructure and ad hoc parts. The proposed scatternet structure can extend coverage and enable access of a larger number of users. And the formation algorithms can resolve the synchronization problem for creation of a height- and width-balanced tree topology.

To extend the coverage of network and enable access of large number of clients, access points are interconnected into a scatternet, which is formed in a tree topology as shown in Fig. 2. The central access point (CAP) is an access point that directly connects to the server. The authors refer to this topology as master-slave separated tree topology.

The CAP acts as a master and APs act as slave/master with respect to CAP/clients as shown in Fig. 2. The client may move around the coverage area of the network and connects to different APs. Moreover, the client can

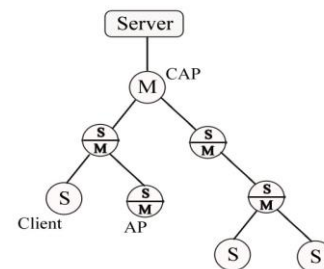


Fig. 2 Master-slave separated tree

communicate with other clients by transmitting packets through APs and CAP, and accessing application service via the server. A problem, which is inherent from the tree topology, is the bottleneck at CAP since a large volume of packets are transferred through the root node, i.e., CAP. Besides, the other problem is that the tree may not keep balanced, so that the CAP adopts a level synchronization mechanism to create a balanced tree.

### 2.3 Bluetooth Wireless Gateway

Cordeiro *et al.* proposed a novel Bluetooth architecture, BlueStar [4], which can support Bluetooth devices with uninterrupted access to the Internet. The architecture employs a Bluetooth device that is IEEE 802.11 enabled to be the Bluetooth Wireless Gateway (BWG), which serves as the access point to/from Internet via WLAN. A Bluetooth device may transmit data packets to BWG in the piconet, the BWG sends the data packet to Internet through local WLAN. Figure 3 illustrates a BlueStar architecture in which two BWGs are employed to realize uninterrupted access to the Internet.

Since a BWG should be equipped with both Bluetooth interface and WLAN interface, the cost of BWG is higher and may dominate the total cost of the system. The maximum number of BWGs required in a scatternet, which consists of  $n$  piconets, is  $\lceil \frac{7n}{2} \rceil - 2\lfloor 4\sqrt{n} - 4 \rfloor$ .

### 2.4 BLUEPAC

In [5], the protocol, which is called Bluetooth Public Access (BLUEPAC) IP, for an extension of IP for mobility issues in Bluetooth scatternet is proposed. By making use of the protocol, access to the Internet in public areas, e.g., airplane, trains, museums, etc., can be achieved. BLUEPAC IP is based on IP protocol and additionally adopts Mobile IP and Cellular IP technologies to facilitate IP assignment, routing, and handoff [9, 10, 11].

Figure 4 shows the BLUEPAC reference network architecture. The main element of the BLUEPAC Local Area

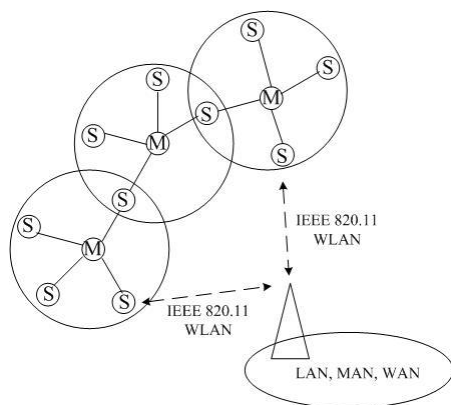


Fig. 3 The architecture of BlueStar

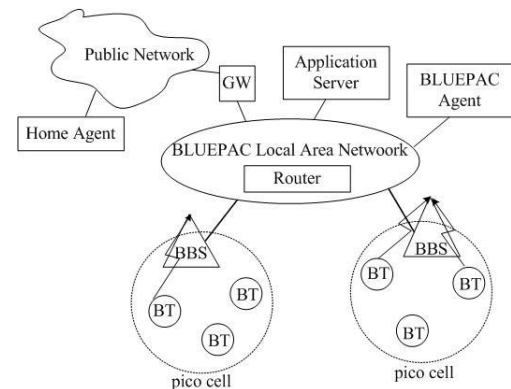


Fig. 4 BLUEPAC architecture

Network is a wired LAN to which the BT devices can gain access. Moreover, a gateway (GW) connects the BLUEPAC LAN to public networks, e.g., Internet, or PSTN. And several BLUEPAC Base Stations (BBSs), which is a LAN access point, are directly attached to the BLUEPAC LAN.

When a Bluetooth device is within the range of a BLUEPAC Base Station, it will get an allocated IP address from the BLUEPAC Agent. If the BT device owns its IP address, the BLUEPAC Agent will accept the address. The purpose of a BLUEPAC Agent is to be an assignment of IP address and the authentication of the connection devices. The application server provides location-based information services. When a BT device leaves the original BT pico-cell, the BLUEPAC Agent will break off the present connection and establishes a new connection in the other BT pico-cell where a BT device enters. Moreover, some BLUEPAC routers exist between servers and BBSs, and a routing mechanism is designed to achieve routing decisions and accommodate devices in motion, changing position within the network all the time.

### 3. NUMBER OF THE REQUIRED ACCESS POINTS

To determine the number of access points in a scatternet to support high connectivity for mobile nodes is a tradeoff between total cost of the access points and the connectivity of the mobile nodes. In this Section, some metric that can be used to measure the connectivity of a scatternet with mobile nodes are addressed. These metrics include (i) density of access points, (ii) the minimum number of access points required, and (iii) the maximum number of access points required.

Suppose that there are  $n$  access points to be regularly arranged on a scatternet and the coverage area of each access point is a square area with 10-meter width. Firstly, we define the density of access points as follows.

**Definition (Density of Access Points):** Let  $n$  access point be regularly arranged in the area of  $a \times a \text{ m}^2$ . We define the density of access point,  $D$ , as follows.

$$D = \frac{n}{a \times a} \dots\dots\dots(1)$$

Moreover, when a mobile node enters a square area of  $a \times a m^2$ , it must be capable of connecting to at least one access point. Therefore, the lower bound of access points required is  $\left(\left\lceil \frac{a}{10} \right\rceil\right)^2$ .

**Definition (Lower Bound of Access Points Required):**  
The lower bound of the number of access points,  $N_{ap}^{min}$ , in a square area of  $a \times a m^2$  is defined as follows.

$$N_{ap}^{min} \left(\left\lceil \frac{a}{10} \right\rceil\right)^2 \dots\dots\dots(2)$$

Furthermore, if a mobile node can connect to two access points anywhere, the number of access points is the upper bound of the number of access points. If a mobile node connects to more than two access points anywhere, it means that there are too many redundant access points in the area. Therefore, the upper bound of the number of access points can be defined as follows.

**Definition (Upper Bound of Access Points Required):**  
The upper bound of the number of access points required,  $N_{ap}^{max}$ , in a square area of  $a \times a m^2$  is defined as follows.

$$N_{ap}^{max} \left(\left\lceil \frac{a}{10} \right\rceil + 1\right)^2 \left(\left\lceil \frac{a}{10} \right\rceil\right)^2 \dots\dots\dots(3)$$

So far, the related works were reviewed and some metric that can be used to measure the connectivity of a scatternet with mobile nodes were briefly discussed. In the following Section, a framework for Bluetooth scatternet that supports seamless connection to Internet are proposed.

### 4. THE PROPOSED FRAMEWORK

The proposed framework of internetworking Bluetooth scatternet with Internet, adopts a two-level infrastructure. The proposed framework is on the basis of the two-level infrastructure.

#### 4.1 Two-Level Infrastructure

A two-level infrastructure for internetworking Bluetooth scatternet and Internet consists of the core network (the first level) and the access network (the second level) as shown in Fig. 5. A mobile node can connect and transmit data packets to the Base Station (BS), and the BS gets and forwards them to the Base Station Leader (BSL) or the Base Station Bridge (BSB). The data packets are finally transmitted to Internet through the Base Station Control (BSC). The core network consists of BSLs and BSCs. On the other hand, the access network consists of the BSs.

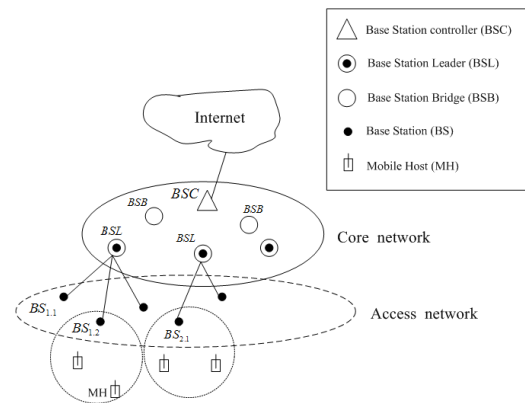


Fig. 5 Two-level infrastructure

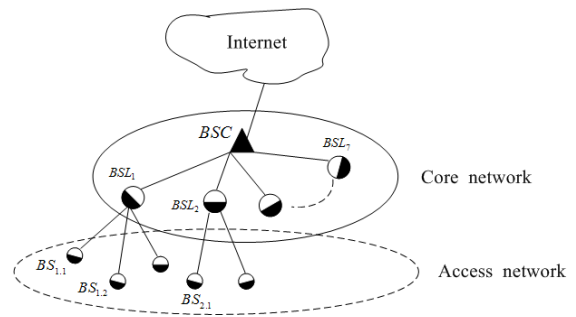


Fig. 6 The single-star architecture

The construction of the proposed framework, which consists of the core network and the access network, is presented as follows.

#### 4.2 The Access and Core Networks

In the access network, each BS 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.

The BS is responsible for transmitting data packets of the MNs to Internet through the core network. Thus, the topology of the core network is critical to the performance of internetworking Bluetooth scatternet and the Internet. In this paper, three types of topologies (i.e., star, tree, and ring) are considered for the core network.

1) Single Star: Figure 6 shows the single star topology for the core network. The BSC is a gateway for internetworking the Bluetooth scatternet with Internet, and the BSC connects to the BSLs in a tree topology.

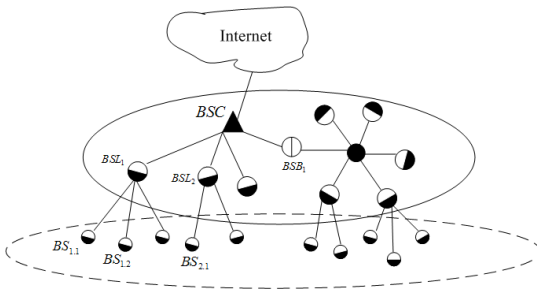


Fig. 7 Multi-star architecture

2) Multiple Stars: The architecture of multiple-star core network is shown in Fig. 7. Unlike the single star, architecture is horizontally expanded to form a multi-star core network. The BSC directly connects to six BSLs at most and connects to another BSL that acts as the bridge to connect to another star network. However, the master node of a star network could connect only five BSLs because it needs to connect two bridge nodes to extend the core network.

3) Tree: When many mobile devices are dispersed in a wide area, tree architecture can interconnect lots of BSs to support these mobile devices connecting to Internet. One of the characteristics of tree architecture is that the average path length is a logarithmic value of the total number of nodes. However, an inherent problem is that the root node is a bottleneck for traffic. In this paper, only the binary tree is considered. The BSC acts as the master role and the BSLs play the Master/Slave role as shown in Fig. 8.

4) Master/Slave Ring (MSR): For the ring architecture,

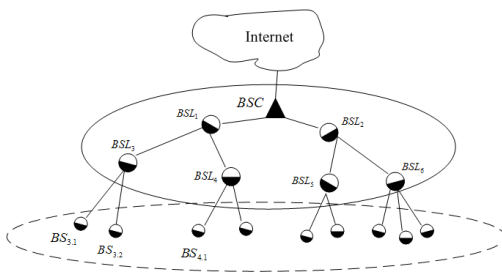


Fig. 8 Tree architecture

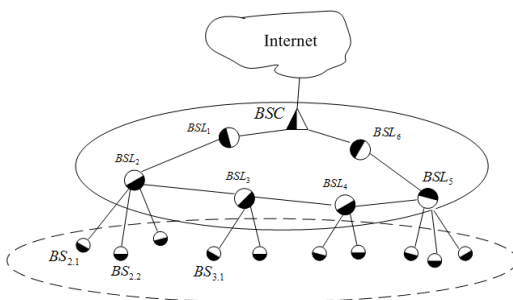


Fig. 9 MSR architecture

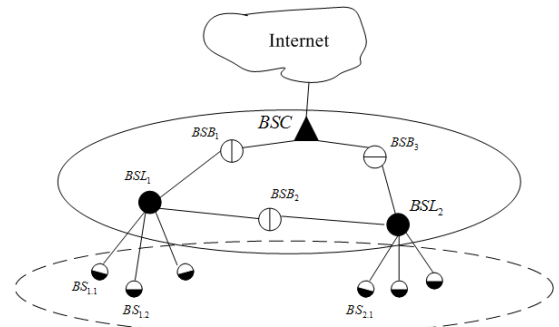


Fig. 10 The SSRe architecture

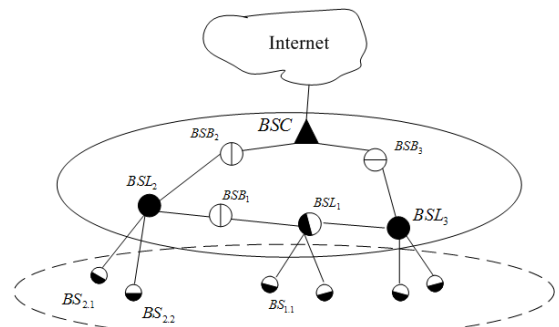


Fig. 11 The SSRo architecture

each BSL can transmit the data packet to the BSC through two different paths. Because the number of BSLs is not limited, the average path length increases as the number of BSLs gets large. The ring architecture can be classified into two types according to the roles of nodes. If the BSLs act as Master/Slave role, it is a master/slave ring (MSR). When a BSL receives a data packet from a mobile node, the data packet will be transmitted to the next BSL. Moreover, each BSL can connect to six BSs at most. Figure 9 illustrates the MSR.

5) Slave/Slave Ring (SSR): On the other hand, the slave/slave ring architecture is a ring architecture that the BSL acts as the slave role. The total number of both the BSL and the BSB would affect the slave/slave ring. When the total number of nodes in the core network is even, the BSL nodes must act as the master roles and transmit packets to the BSC through the BSB nodes. So, one BSL node can connect to five BS nodes. We refer to this architecture as the Slave/Slave Ring-even (SSRe) architecture as shown in Fig. 10.

On the other hand, we refer to the architecture that consists of odd number of nodes in the core network as the Slave/Slave Ring-odd (SSRo) architecture as shown in Fig. 11. Because the number of both the BSL and the BSB is even, there is a BSL node that will act as the Master/Slave node in all BSL nodes, so it would connect to six BS nodes.

Finally, the comparison of these architectures is shown in Table 1.

**Table 1** Comparison of architecture

structure	advantage	disadvantage
Single-Star	Shorter transmission path	Limited number of BSL
	Shorter transmission time	Poor scalability
Multi-Star	Good scalability	Bottleneck at bridge
Tree	No limit on number of BSL	Longer transmission path
	Good scalability	Bottleneck at root node
Ring	Two alternative paths	Longer transmission path
	No limit on number of BSL	Poor scalability

## 5. CONCLUSIONS

Most of the Bluetooth devices are portable and may move around on the Scatternet. To access the Internet the Bluetooth devices must connect to the access point and gateway. Thus, to develop an efficient infrastructure for internetworking Bluetooth scatternet and Internet is becoming a crucial issue. In this paper, a two-level infrastructure that consists of the core network (the first level) and the access network (the second level) was proposed. In this infrastructure, the access network consists of the MHs and the BSs, and the core network comprises of the BSLs and the BSC (i.e., gateway). Several structures for the core network were investigated. These structures include single-star, multi-star, binary tree, MSR, SSR<sub>e</sub>, and SSR<sub>o</sub>. For the future study, the performance of the infrastructure with different structures of core network may be evaluated.

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