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TARP:A Traffic-Aware Restructuring Protocol for Bluetooth Radio Networks

Chih-Yung Chang*, Chao-Tsun Chang+, Shih-Chieh Lee*, Sheng-Wen Chang*, Chih-Hsiung Tseng*

*Tamkang University, Tamsui, Taipei, Taiwan,
+ National Central University, Chung-Li, Taiwan,
cychang@mail.tku.edu.tw, cctas@tcts.seed.net.tw

Abstract—**Bluetooth is a well-known wireless technology designed for Wireless Personal Area Networks (WPAN). The Bluetooth device randomly searches and connects with other devices using the inquiry/inquiry scan and the page/page scan operations, resulting an uncontrolled scatternet topoloty. The unpredictable scatternet topology usually raises the problem of redundant traffic and causes inefficient communications. A Traffic-Aware Restructuring Protocol (TARP) is presented for partially restructuring a piconet or neighboring piconets by applying role switch mechanism. According to the recent routes and their traffic pattern, the TARP adjusts piconet structure by selecting the proper master from devices of a piconet and switches proper devices of neighboring piconets to reduce the route length and thus improve the power and bandwidth consumptions and transmission delay. Performance results show that TARP significantly improves network performance by reducing traffic load and power consumptions.**

Keywords- scatternet; piconet; role switch; restrucuring protocol.

I. INTRODUCTION

Bluetooth [1] is a low cost, low power, and short-range wireless communication technology. It randomly searches and connects with other Bluetooth devices using the inquiry/inquiry scan and the page/page scan operations to link an uncontrolled connection. The unpredictable topology of scatternet usually raises the problem of redundant traffic caused by long routing path, guard time delay for relay switching among piconets, unnecessary energy consumption for forwarding packets, and high rate of packet lost, resulting inefficient communications. Previous works [2, 3, 5, 6, 7] are proposed to achieve connected scatternet and preset an average case of communicating topology for improving the network performance. However, the formatted scatternet is not usually sufficient to support the real traffic need.

Communication in Bluetooth is categorized as intra-piconet and inter-piconet. In an intra-piconet, performance highly relies on the role assignment based on traffic pattern. Previous works [2, 3] arrange role of master and slaves during link construction stage to form a connected scatternet and decrease the number of piconets, reducing the rate of packet lost. Proper role assignment will improve the structure of piconet or scatternet, improving the network performance. Role switch mechanism enables two devices to exchange roles very rapidly, rather than reconnecting by executing the time-consuming inquiry and inquiry scanning processes, reducing the overhead of topology restructuring. Pervious study [4] has shown that a slave with heavy traffic for communicating with another slave will consume master's bandwidth for relaying data, causing traffic overhead and energy consumption. In scatternet (or inter-piconet), when two devices of different piconets intend to communicate with each other, they must establish a routing path, subsequently using masters and relays to forward the information. Protocols in [5, 6, 7] are proposed to achieve connected scatternet and enable master to manage its neighboring relays for improving the communication efficiency. But the protocols are proposed for scatternet formation, thus no traffic pattern is taken into consideration. Protocols proposed in [8, 9] constructs a routing path between two devices in different piconets. However, route established by the protocols highly relies on the existing scatternet topology. Thus an improper topology of scatternet usually results inefficient routes with problems of long routing path and guard time delay for switching relay between piconets, increasing power consumption and packet lost rate.

This paper proposes a Traffic-Aware Restructuring Protocol (TARP) for scatternet using role switch operations to dynamically adjust the role of devices and restructure the topology of a given scatternet. According to the recent routes and their traffic load information, TARP dynamically adjusts piconet structure by selecting the proper master from devices of a piconet or switching proper devices of neighboring piconets. Performance results reveal that the proposed restructuring protocol reduces path length of recent routes and traffic load in scatternet and saves power consumption, thus significantly improves the network performance for a given connected scatternet.

The rest of this work is organized as follows Section 2 introduces some backgrounds and basic concepts of this study. Section 3 details the intra-piconet and inter-piconet restructuring protocols of TARP through examples. Section 4 discusses experiments on TARP and their results, and finally, a brief conclusion is presented in Section 5.

II. BACKGROUND AND BASIC CONCEPTS

This section introduces the basic role switch operations which have been adopted in the proposed TARP. Role switch operations enable two Bluetooth device exchange their roles very rapidly. Proper role assignment will improve the structure of piconet or scatternet, improving the network performance.

In the restructuring process of TARP, three role switch operations are utilized as basic functions which are introduced in detail in below.

Piconet takeover operation

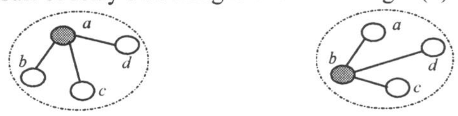
As defined in Bluetooth spec. [1], *TakeOver* operation enables a slave to take over all slaves of a piconet. Function *Piconet_TakeOver*(s, m) enables slave s to take over all slaves of a master m. Figure 1 is used to illustrate the detail of the role switch operation *Piconet_TakeOver*(b, a). As shown in Fig. 1(b), device b takes over all resource of master a, playing a master role in the restructuring piconet.

Member-Switch operation

Member-Switch is another role switch operation adopted in TARP. Let m_1 and m_2 be masters of two neighboring piconets. Let s be a slave connecting to m_2. The *Member-Switch* operation *Member_Switch*(m_1, m_2, s) allows that slave s connects to m_1 and disconnects with m_2. Taken Fig. 2(a) as an example, executing role switch operation *Member_Switch*(*f*, *a*, *b*), slave device s switches from Piconet P_1 to P_2, connecting with master f and disconnecting with master a. The result of member switching is showed in Fig. 2(b).

Relay Switch operation

Relay Switch operation enables relay and slave devices to exchange their roles. Let m_1 and m_2 be two masters of neighboring piconets. Let device s be a slave connecting to master m_2 and relay r connecting with the two masters m_1 and m_2. The relay switch operation *Relay_Switch*(m_1, m_2, s, r) exchanges the roles of relay and slave, making device r playing a slave role and device s playing a relay role. Taken Fig. 3(a) as an example of executing *Relay_Switch*(*a*, *c*, *d*, *b*) the result of relay switching is showed in Fig. 3(b).



(a) (b)

Figure 1: (a) Topology before executing *Piconet_TakeOver(b, a)*. (b) Topology after executing *Piconet_TakeOver(b, a)*.

(a) (b)

Figure 2: (a) Topology before executing *Member_Switch*(*f*, *a*, *b*). (b) Topology after executing *Member_Switch*(*f*, *a*, *b*).

(a) (b)

Figure 3: (a) Topology before executing *Relay_Switch*(*a*, *c*, *d*, *b*). (b) Topology after executing *Relay_Switch*(*a*, *c*, *d*, *b*).

III. THE TARP PROTOCOL

This section details a novel traffic-aware restructuring protocol to adjust intra-piconet or inter-piconet. TARP consists of intra-piconet restructuring protocol and inter-piconet restructuring protocol. Each of restructuring protocols consists of perceiving and restructuring phases. In perceiving phase, the master and relay are responsible for monitoring the traffic pattern in a predefined time interval. Then the collected traffic patterns will be used to evaluate the traffic load of a piconet or neighboring piconets. TARP will initiate operations defined in the restructuring phase in case of heavy traffic and inefficient communications. In the restructuring phase, TARP will analyze the traffic pattern, derive an optimal topology on which the efficient communication will be performed, and evaluate the benefit of executing intra-piconet or inter-piconet restructuring protocol. Then TARP applies role switch operations to restructure the topology of piconet or neighboring piconets in case that the evaluated benefit obtained from restructuring the current topology exceeds a predefined threshold. The following describes first the intra-piconet restructuring protocol then inter-piconet restructuring protocol.

3.1 Intra-piconet restructuring protocol

The intra-piconet restructuring protocol aims at selecting a proper master from slaves according to recent traffic pattern and applying *Piconet TakeOver* operation to restructure the piconet topology. A Flow Matrix is defined in below as a data structure for representing the recent traffic pattern among devices of a piconet.

***Definition* : *Flow Matrix:* FM_{intra}**

Assume there are n devices, d_1, …, d_{n-1} and d_n existed in a piconet, $n \le 8$. The data flow volume between devices in a predefined time interval, say T, is recorded in a *Flow Matrix*, $FM_{intra} = [f_{ij}]_{n \times n}$, where the element of *Flow Matrix*, f_{ij}, represents the data flow volume sent from d_i to d_j and the diagonal element f_{ii} is zero for all $1 \le i \le n$. □

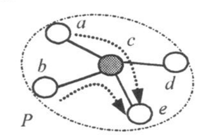
Let symbols t_m and f_k respectively denote the traffic volume that passes through master m and the total flow volume sent or received at device k for a duration T. The *total flow volume at device* d_k can be derived by

$$f_k = \sum_j f_{kj} + \sum_i f_{ik} .$$

To reduce the traffic overhead in a piconet, a device with maximal data volume will be selected to play a master role. In the perceiving process, the master collects traffic patterns of recent duration T and determines whether or not to initiate the restructuring phase. Two procedures, the evaluation procedure and role switch procedure, are included in design of restructuring phase. The evaluation procedure derives an optimal topology according to the recent traffic pattern, evaluates the benefit of piconet restructuring, and determines whether or not to restructure the piconet topology. If the evaluated benefit larger than a predefined benefit threshold, the role switch procedure then applies role switch operation to restructure the piconet topology.

Perceiving Phase

In the perceiving phase, the master, say m, collects the traffic patterns for a duration T and records them with the FM_{intra}. Then master m derives the values t_m and f_m. If t_m is smaller is smaller than the predefined restructuring threshold, δ , the master resets the elements of FM_{intra} to zeros and begins the next duration of perceiving phase. Otherwise, the master initiates the restructuring phase. The piconet whose master initiates the restructuring phase is called a *restructuring piconet*. The master is an *initiator* and all devices in the restructuring piconet are *restructuring devices*.



Route Paths (data flow volume)
1. Path *ae* : *a-c-e* (8 units) 2. Path *be* : *b-c-e* (6 units)

(a) The example of intra-piconet restructuring and the traffic patterns in duration T.

f_{ij}	a	b	c	d	e
a	0	0	0	0	8
b	0	0	0	0	6
c	0	0	0	0	0
d	0	0	0	0	0
e	0	0	0	0	0

(b) FM_{intra} recorded in restructuring master c.

Figure 4: The example of restructuring piconet and the FM_{intra} recorded by master c.

To facilitate the details of intra-piconet restructuring protocol, example shown in Fig. 4 will be used throughout this subsection. In Fig. 4 (a), the threshold value δ is assumed to be 6 units and there are five devices a, b, c, d and e in piconet P. The recent traffic flow volume of two routes, Paths *ae* and *be*, for duration T are recorded in the FM_{intra} by master c as shown in Fig. 4 (b). After the predefined duration time, the traffic volume that passes through master c, t_c, is evaluated by $t_c = f_{ae} + f_{be} = 14$. Due to the t_c is greater than the threshold, $\delta = 6$ units, the master c becomes an initiator and initiates the restructuring phase.

Restructuring Phase

To detail the evaluation and role switch procedures, the following terms are defined.

Definition : *Hops$_{old}$(s, t)* and *Hops$_{new}$(s, t)*

Let s and t be any two devices of a restructuring piconet. $Hops_{old}(s, t)$ and $Hops_{new}(s, t)$ respectively denotes the number of hops of path connecting devices s and t before and after executing the intra-piconet restructuring protocol. □

Assume an Intra-piconet Flow Matrix $FM_{intra}=[\,f_{ij}\,]_{nxn}$ is given. Let notations L_{old} and L_{new} respectively represent the traffic load of the piconet before and after applying intra-piconet restructuring protocol. We have

$$L_{old} = \sum_{\forall\ path}\sum_{ij} f_{ij}\cdot Hops_{old}(i,j) \text{ and } L_{new} = \sum_{\forall\ path}\sum_{ij} f_{ij}\cdot Hops_{new}(i,j).$$

Therefore, the restructuring benefit, B_R, can be obtained with the computation: $B_R = 1 - (L_{new} / L_{old})$.

Following the example of Fig. 4 (a) and previous results, master c executes the evaluation procedure and the benefit threshold value Δ is assumed to be 0.1. Firstly, master c computes the total flow volume at each device based on the FM_{intra} and the sum of traffic load, L_{old} is equal to 28. Device e is selected as a master due to its maximum total flow volume. Then master c computes the traffic load in considering the change of master from device c to device e. The sum of new traffic load, L_{new}, is equal to 14. Finally, the restructuring benefit of intra-piconet is determined by evaluation: $B_R = 1-(L_{new}/L_{old}) = 0.5$. Due to the restructuring benefit, B_R, is larger than the benefit threshold, Δ, master c executes the role switch procedure. This implies that the intra-piconet restructuring will increase 50% of network performance.

According to the selected master in evaluation procedure, the role switch procedure uses *Take Over* operation to change master and thus restructures the piconet topology. First, the master sends a control message to the restructuring devices to reserve sufficient time slots for role switch. If the new master is not original master c, master c executes the *Piconet_Takeover*(e, c), resulting the new piconet as shown in Fig. 5. Otherwise, no role switch operation will be down. After that, the master e resets the elements of FM_{intra} to zeros and returns to the Perceiving Phase and begins the next monitoring duration.

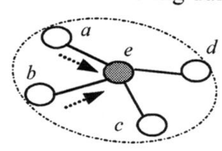


Figure 5: The restructuring topology after executing the intra-piconet restructuring for the example in Fig. 4.(a).

3.2 The inter-piconet restructuring protocol

For two neighboring piconets, TARP collects source and destination devices that have heavy traffic between them into the same piconet reducing the route length and therefore decreasing the cross-piconet traffic. Similar to intra-piconet restructuring protocol, the inter-piconet restructuring protocol consists of perceiving phase and restructuring phase. In the perceiving phase, the relay of two neighboring piconets collects traffic patterns for a predefined duration T and determines whether or not to initiate the restructuring phase. Two procedures, the evaluation procedure and role switch procedure, are included in design of restructuring phase. The evaluation procedure derives an optimal topology according to the recent traffic pattern, evaluates the benefit of inter-piconet restructuring, and determines whether or not to restructure the neighboring piconets topology. If the evaluated benefit larger than a predefined benefit threshold, the role switch procedure will be initiated. The role switch procedure then applies role switch operations to restructure the neighboring piconets topology.

The inter-piconet restructuring protocol first groups proper devices of two neighboring piconets into same piconet, then selects the proper slaves to play the master and relay roles according to recent traffic patterns, and finally applies *Piconet TakeOver*, *Member-Switch* and *Relay Switch* operations to restructure the neighboring piconets topology. A Flow Matrix is defined in below as a data structure for representing the recent traffic pattern among devices of two neighboring piconets.

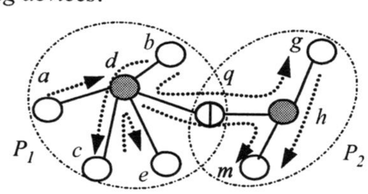
Definition : *Inter-piconet Flow Matrix: FM$_{inter}$*

Assume there are n devices, $d_1, \ldots, d_{n-1}$ and d_n existed in two neighboring piconets, $n \le 16$. The data flow volume between devices for a predefined time interval, say T, is recorded in an *Inter-piconet Flow Matrix*, $FM_{inter}=[\,f_{ij}\,]_{nxn}$, where the element of Flow Matrix, f_{ij}, represents the data flow volume sent from d_i to d_j and the diagonal element f_{ii} is zero for all $1 \le i \le n$. □

Let symbols t_r and f_k respectively denote the traffic volume passes through the relay r and the total flow volume sent or received at device k for a duration T. The *total flow volume at device k* can be derived by $f_k = \sum_j f_{kj} + \sum_i f_{ik}$.

Perceiving Phase

In the perceiving phase, relay r counts t_r at itself and then records the across-piconets traffic flow. If t_r is smaller than the predefined restructuring threshold, δ, the relay resets the elements of FM_{inter} to zeros and begins the next duration of perceiving phase. Otherwise, the relay r integrates the whole traffic patterns of the two piconets into FM_{inter} by integrating two Intra-piconet Flow Matrixes that are maintained by the two masters it connects. Then relay r initiates the *Restructuring Phase*. The two neighboring piconets whose relay initiates the *Restructuring Phase* are called a *restructuring piconet-pair*. The relay is an *initiator* and all devices in the restructuring piconet-pair are *restructuring devices*.



Existing paths (data flow volume)

1. Path bc : b-d-c (5)
2. Path bg : b-d-q-h-g (4)
3. Path ce : c-d-e (2)
4. Path ad : a-d (3)
5. Path gm : g-h-m (7)
6. Path dm : d-q-h-m (4)

Figure 6 : The example of inter-piconet restructuring and the traffic patterns in duration T.

To facilitate details of the inter-piconet restructuring protocol, example shown in Fig. 6 will be used throughout this subsection. In Fig. 6, the threshold value δ is assumed to be 6 units and there are nine devices a, b, c, d, e, q, g, h and m in restructuring piconet-pair P_1 and P_2. The recent traffic flow volume of two routes, Paths bg and dm are recorded in the FM_{inter} by relay q as shown in Fig. 7 (a). The traffic volume that passes through relay, t_q, for a duration T, is evaluated by $t_q = f_{bg} + f_{dm} = 8$.

Due to t_q is greater than the threshold value, $\delta = 6$ units, the relay q becomes an initiator and requests the masters d

and h to transfer their recorded traffic patterns to it. While the traffic patterns recorded in the masters d and h are received by initiator q, the initiator q integrates the whole traffic patterns of the restructuring piconet-pair into its FM_{inter} and initiates the restructuring phase. The FM_{inter} are recorded by initiator q as shown in Fig. 7 (b).

Restructuring Phase

The evaluation procedure in inter-piconet restructuring mainly consists of three processes, namely *grouping*, *master and relay selection* and *benefit evaluation* processes. First, the grouping process aims at grouping the restructuring devices into two groups each intends to form a new piconet in the future. Then, the master and relay selection process is used to choose the master candidate for each new piconet and the proper relay of the two neighboring piconets from slaves according to recent traffic patterns. Finally, the restructuring benefit is estimated in the benefit evaluation process. If the restructuring benefit is smaller than the predefined benefit threshold, Δ, the initiator q resets the elements of FM_{inter} to zeros, returns to the perceiving phase and begins to monitor the traffic pattern for the next duration T. Otherwise, the initiator executes the Role Switch Procedure.

f_{ij}	a	b	c	d	e	q	g	h	m
a	0	0	0	0	0	0	0	0	0
b	0	0	0	0	0	0	4	0	0
c	0	0	0	0	0	0	0	0	0
d	0	0	0	0	0	0	0	0	3
e	0	0	0	0	0	0	0	0	0
q	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	0	0	0	0
h	0	0	0	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0

(a) The FM_{inter} recorded by relay q.

f_{ij}	a	b	c	d	e	q	g	h	m
a	0	0	0	3	0	0	0	0	0
b	0	0	5	0	0	0	4	0	0
c	0	0	0	0	2	0	0	0	0
d	0	0	0	0	0	0	0	0	3
e	0	0	0	0	0	0	0	0	0
q	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	0	0	0	7
h	0	0	0	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0

(b) The FM_{inter} recorded by initiator q.

Figure 7: The *Flow Matrixes* respectively are recorded in relay q and initiator q in the example of Fig. 6.

During the *Grouping process*, devices that have heavy traffic among them will be grouped, intending to form a piconet to reduce the across-piconets traffic load. To detail the operation of *Grouping Process*, we define *Group* and *Group Flow Matrix* in below. Let X be a set of restructuring devices. Group G_X denotes the group containing all devices in set X. Initially, each restructuring device itself forms a group. For example, device a forms the group $G_{\{a\}}$. Then two groups that have largest total flow volume between them will be grouped into one in the *Grouping Process*. The *Grouping Process* is operated based on the computation of Group Flow Matrix which is defined in below.

***Definition* : Group Flow Matrix: GFM**

Assume there are n groups, G_1, ..., G_{n-1} and G_n containing restructuring devices, $n \le 16$. The data flow volume between groups for a predefined time interval, say T, is recorded in a *Group Flow Matrix*, GFM_{nxn}, where the element $GFM_{nxn}(I, J)$ represents the data flow volume sent from G_I to G_J and is derived based on the Inter-piconet Flow Matrix, $FM_{inter}=[f_{ij}]_{nxn}$, by

$$GFM_{nxn}(G_I, G_J) = \sum_a \sum_b f_{ab}\text{ , where } a \in G_I \text{ and } b \in G_J.$$

The diagonal element $GFM_{nxn}(G_I, G_I)$ is zero for all $1 \le I \le n$. □

***Definition* : Grouping(G_X, G_Y)**

From the set relation point of view, *Grouping*(G_X, G_Y) denotes that groups G_X and G_Y are combined as a new group, $G_{X \cup Y}$. Corresponding to each grouping operation *Grouping*(G_X, G_Y), the Group Flow Matrix will be transferred from GFM_{nxn} to $GFM_{(n-1)x(n-1)}$. Let S be the set of groups involved in the GFM_{nxn}, the resultant Group Flow Matrix $GFM_{(n-1)x(n-1)}$ will include the set of groups $(S - \{G_X, G_Y\}) \cup G_{X \cup Y}$ after executing *Grouping*(G_X, G_Y). □

Following the previous results of example shown in Fig. 6, the initiator q executes the *Evaluation Procedure*. Herein the benefit threshold value Δ is assumed to be 0.1. Initially, each restructuring device individually forms a group and therefore the *Group Flow Matrix*, GFM_{nxn}, is equivalent to FM_{inter}. In each grouping progress, the groups G_X and G_Y will be selected to combined into a new group if element $GFM(G_x, G_y)$ has the largest value in the matrix. If the device number of the combined group $G_{X \cup Y}$ is not greater than one half of the number of restructuring devices, the groups G_X and G_Y are combined as a new group, $G_{X \cup Y}$, by executing *Grouping*(G_X, G_Y) and the next grouping operation is initiated. Otherwise, the *Grouping process* is finished and the master and relay selection process is initiated. Then the remainder devices, not included in $X \cup Y$, are collected into another group.

Let G_1 and G_2 respectively denote the two groups obtained from the *Grouping process*. After *Grouping process*, initiator q will select proper devices to play the master role for each new group and the relay role for the two groups according to FM_{inter}. Similar to the mechanism of selecting master in intra-piconet restructuring protocol, the masters m_1 and m_2 are respectively selected from the two groups due to the two devices have the maximal total flow volume in their groups. The remaining work is the selection of device to play the relay role. The *total across-piconets data volume at device* $k \in G_1 \cup G_2$ is the total traffic volume between device k and those devices that belong to another group with device k. More specifically, the *total across-piconets data volume* S_k *at device* k, can be evaluated according to the FM_{inter} as following.

$$S_k = \begin{cases} \sum_{y \in G_2} (f_{yk} + f_{ky}) & ,if \quad k \in G_1 \\ \sum_{y \in G_1} (f_{yk} + f_{ky}) & ,if \quad k \in G_2 \end{cases}$$

Device x will be selected to play the relay role if it satisfies the following criteria

$S_x = \max\{ S_k |$ for each device $k \in (G_1 \cup G_2) - \{m_1, m_2\} \}$.

That is, device x that has the maximal total across-piconets data volume will be selected to play the relay role for Groups G_1 and G_2. Since relay is the device that has the shortest path to those devices in the neighboring piconet, the relay selection according to the above criteria will minimize the traffic load that crosses picoents. Following the previous results of example shown in Fig. 6, devices a and g will be selected to play the new masters and devices d or m will be selected to play the relay role since they have maximal total across-piconets data volume. Figure 8 shows the new restructuring topology evaluated by initiator q.

The benefit of restructuring neighboring piconets can be evaluated by the traffic load that has been eliminated by applying the inter-piconet restructuring protocol. Given a Flow Matrix $FM_{inter}=[f_{ij}]_{nxn}$, the total traffic load of the two neighboring piconets before and after restructuring can be defined similarly as L_{old} and L_{new} in the intra-piconet restructuring. Hence we have

$L_{old} = \sum_{\forall path_{ij}} f_{ij} \cdot Hops_{old}(i, j)$ and $L_{new} = \sum_{\forall path_{ij}} f_{ij} \cdot Hops_{new}(i, j)$.

Therefore, the restructuring benefit, B_R, can be obtained with the computation: $B_R = 1 - (L_{new} / L_{old})$.

The following takes example shown in Fig. 6 by constructing the two new piconets, the initiator q computes the traffic loads, L_{old} = 56 and L_{new} = 38, based on the FM_{inter}. The restructuring benefit of inter-piconet is obtained by evaluation: B_R = 1-(38/56) = 0.32. Due to the restructuring benefit is greater than the benefit threshold, Δ =0.1, initiator q executes the *Role Switch Procedure*. This implies the inter-piconet restructuring procedure will increase 32% of network performance.

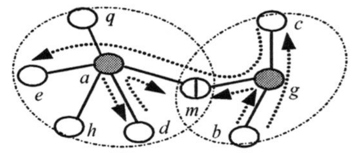


Figure 8 : The restructuring topology evaluated by initiator q.

IV. PERFORMANCE STUDY

This section discusses the performance study of TARP. The environment is set as follows. A scatternet is randomly constructed by containing devices ranging form 6 to 14. The duration time of TARP is set by 2000 slots; the threshold value, δ , is selected by 500 packets, and the threshold, Δ , is set by 0.1. Setting δ value by a large value will result in difficulty of initiating TARP whereas setting δ value by a small value will result in poor performance of TARP, creating too much overhead in executing restructuring protocol. Different value of δ will effect the performance of TARP. The heuristic value of the δ can be observed and selected at 500 packets, according to the performance study shown in Fig. 9.

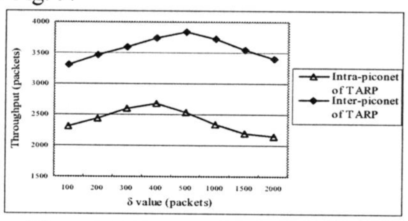


Figure 9: Effects of δ value on TARP.

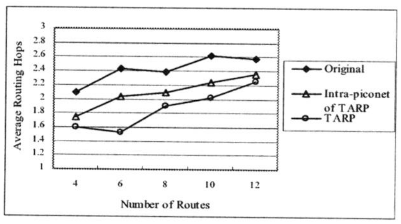


Figure 10: Average traffic load reduced after execution of TARP.

Figures 9 to 12 show the effects for changing stochastically produced routing path numbers to respectively execute Putting devices of scatternet having mutually large traffic load together in the same piconet can reduce the routing length; this can lower the average traffic load during packet transmission as shown in Figs. 10. Reducing the average number of routing hops reduces the average delay time wasted for congestion, packet transmission and guard time of bridging. Figure 11 shows that TARP significantly saves delay time.

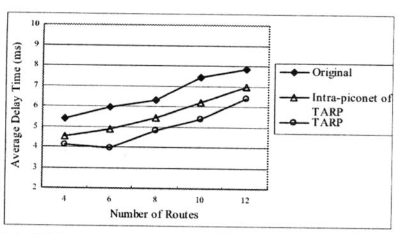


Figure 11: Effects on delay time after execution of TARP.

Effectively changing the role of restructuring devices and switching the restructuring devices between neighboring restructuring piconets will clearly improve the performance of intra-piconet or inter-piconet restructuring. Figure 12 shows the number of routes in duration T affects the average restructuring benefit of TARP.

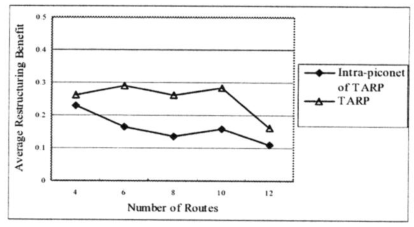


Figure 12: Effects on average restructuring benefit after the execution of TARP.

V. Conclusion

The unpredictable topology of Bluetooth scatternet usually raises the problem of redundant traffic and causes inefficient communications. According to the recent traffic pattern, this paper proposes an efficient traffic-aware restructuring protocol to dynamically adjust the structure of piconet or two neighboring piconets by using role switch operations. TARP mainly consists of two restructuring protocols, namely the intra-piconet and inter-piconet restructuring protocols. Performance results reveal that the proposed protocol reduces the path length and traffic load and saves transmission delay and power consumption, therefore significantly improves the network performance.

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