On the Method of A Configurable Blueweb Routing Protocol

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Abstract—**Blueweb is a self-organizing Bluetooth-based multihop network equipped with a scatternet formation algorithm and a hybrid routing protocol. The routing protocol combines the reactive method globally and the proactive method locally to discover the optimal path for packet transmission. In Blueweb, the route master maintains the global topology information and each master maintains its own N-tier routing information. In this paper, a tier number decision algorithm is used in Blueweb to determine the optimal number of tiers for all the other masters. Our computer simulation results show that this algorithm can efficiently improve the routing performance and reduce the routing maintenance cost for Blueweb routing protocol.**

Keywords—**Bluetooth, scatternet formation, routing protocol**

1. INTRODUCTION

Bluetooth is emerging as a potential technology for short-range wireless ad hoc network [1]. This technology enables the design of low power, low cost, and short-range radio [2] that can be embedded in existing portable devices. Initially, Bluetooth technology is designed as a cable replacement solution among portable and fixed electronic devices. Today, people tend to use a number of mobile devices such as cellular phones, PDA's, digital cameras, laptop computers, and so on. Consequently, there exists a strong demand for connecting these devices into networks. As a result, Bluetooth becomes an ideal candidate for the construction of ad hoc personal area networks.

Until now, a number of routing protocols have been proposed for Bluetooth multihop networks [3]-[5]. In the proactive approach, such as in the Bluetree [3], each master node maintains a routing table. The main problem here is the overhead in routing information exchanges, although little delay is involved in determining a route. In the reactive approach [4], a flooding method is usually used to search for the optimal path from a source node to a destination node and this will incur a certain amount of delay. However, the reactive approach provides better network scalability. In [5], the performance of a hybrid routing protocol is presented for Bluetooth scatternets and it consumes small amount of storage, low routing overhead, and low route discovery latency. Nevertheless, the paper did not try to construct and optimize this hybrid routing protocol for Bluetooth scatternet to achieve its excellent routing performance. Blueweb [6][7] proposes a hybrid routing protocol in which we use the reactive approach globally in the router master and the proactive approach locally in the master to discover the optimal path for source routing.

In this paper, a tier number decision algorithm is used in the route master to determine optimal tier number for all the other masters. In addition, a uniform end-to-end traffic model is used to simulate and demonstrate the routing performance of Blueweb. Our computer simulation results show that this algorithm can determine the efficient configuration for Blueweb routing protocol.

The rest of this paper is organized as follows: In Section 2, we review the scatternet formation algorithm and the routing protocol of Blueweb. In Section 3, we describe the detailed operation of the tier number decision algorithm. In Section 4, computer simulations are used to verify the system performance improvement of the Blueweb network. Finally, a conclusion is drawn in Section 5.

2. A REVIEW ON BLUEWEB

2.1. Scatternet Formation Process

In Blueweb, the scatternet formation process includes two phases. In the first phase, a designated root starts to create a tree-shaped topology and in the second phase the tree-shaped topology is converted into a web-shaped topology.

A role exchange mechanism is used in the first phase to make slaves function as relays. In the second phase, a return connection mechanism is used to generate more connection paths among nodes.

Fig. 1 is an example to review the Blueweb scatternet formation process [6]. In the beginning of the first phase, the designated root initiates the scatternet formation procedure by paging up to 7 neighboring slaves, and forms the first piconet, as shown in Fig. 1(a). The slaves then switch their roles to masters (called S/M nodes). Each S/M node pages only one additional neighboring slave, as shown in Fig. 1(b). After these S/M nodes connect to their slaves, a role exchange mechanism is executed such that the S/M nodes switch their roles to relays (called S/S nodes) and their slaves switch their roles to masters, then the new masters begin to page up to 7 neighboring slaves, as shown in Fig. 1(c). This procedure is operated iteratively until the leaf nodes of the tree are reached.

In the second phase, each leaf node will request either itself (if it is a master) or its immediate upstream master to function as a returning master and start a return connection procedure. A returning master will page any available neighboring slave and connect with it. If this new link is established, the slave switches its role to a relay (S/S node), as shown in Fig. 1(d). Then the returning master will ask its immediate upstream master to function as the next returning master. This return connection procedure is operated iteratively in the upstream direction until the designated root is reached. As a result, the designated root can manage the whole scatternet with global topology information.

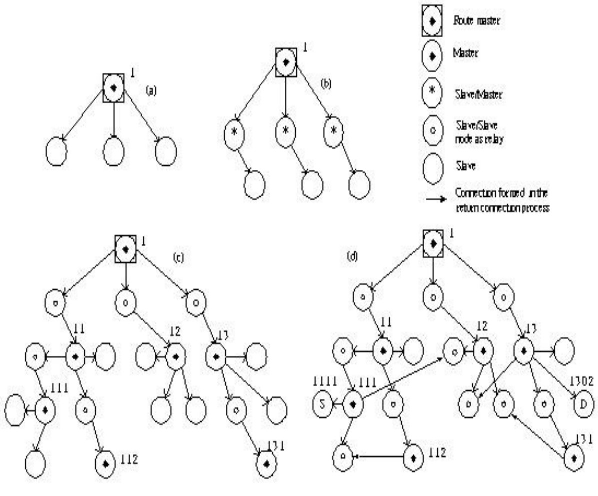

Fig. 1 Blueweb scatternet formation proess

2.2. Routing Protocol

In the Blueweb scatternet formation period, some routing information can be exchanged among masters. In the first phase of scatternet formation, each master keeps a record of its directly connected upstream master. As a result, a query path can be easily formed by connecting all the masters in the upstream direction to the route master.

In the second phase of scatternet formation, each returning master will pass its own piconet information together with a list of its directly connected masters to the route master via its upstream masters. At the same time, each returning master including the route master will pass its own piconet information to its directly connected masters. Here, we define the directly connected neighboring piconets within its neighboring N tiers of a master as the N-tier piconets of the master. The associated N-tier piconet information will be stored in the master's N-tier piconet table. In addition, those masters affected by the return connection mechanism will update their N-tier piconet table via relays. As a result, each master will keep its own piconet information and its N-tier piconet information. This information is used locally when a node inquires the master for a path to deliver packets.

After finishing the second phase of scatternet formation, the route master will have the routing information of all nodes and store it in a piconet list table. This table contains a list of all the masters and their associated slaves. Meanwhile, the route master will compute the shortest path for any two-piconet pair using the all-pairs shortest path algorithm. This shortest path information is stored in a scatternet routing table and is used when any node inquires the route master for routing information to deliver packets.

In order to implement this routing protocol, a piconet-layer addressing scheme can be used. This scheme combines the Bluetooth active member address (AM_ADDR) with piconet identification (PID) to address each Bluetooth device throughout the whole scatternet. In a piconet, each slave is assigned a 3-bit AM_ADDR by its master. In addition, the PID is used to distinguish different piconets in the scatternet.

The PID's are assigned on a layer-by-layer basis in the downstream direction during the first phase of scatternet formation. For example, the route master is the only layer 1 node and uses 1 as its PID. Its first attached master is assigned 1.1 as its PID, the second attached master is assigned

1.2 as its PID, and so on. In this way, a layer 3 master will be assigned a PID of 1.a2.a3. We refer this addressing method as a piconet-layer addressing scheme. This addressing scheme can be applied to Blueweb architecture directly. An example of this scatternet addressing scheme for Blueweb is shown in Fig. 1.

Based on the routing information collected by all the masters including the route master, a modified source routing protocol is developed. This is a hybrid routing protocol and operates in two phases. In the first phase, an optimal path from source to destination is searched. In the second phase, the optimal path is used to transmit the packets.

Besides, a packet format is also designed for implementing our routing protocol. This packet format is similar to RVM (Routing Vector Method) [4] and is shown in Fig. 2. The SRC field contains the address of the source node according to the piconet-layer addressing scheme. The DST field contains either the 48-bit Bluetooth address for a query packet or the address of the destination node for a reply packet or a data packet. The PATH field contains either the address of the route master for a query packet or a sequence of PID's according to the piconet-layer addressing scheme for a reply packet or a data packet.

2.3. Routing Example

For example in Fig. 1, when the node S with address 1.1.1.1 sends a packet to the destination node D, the node S will query its affiliated master with a query packet for routing information. If the master node has the node D information in its N-tier piconet table, the master will reply the routing path to the slave node directly. Then, the source node will embed the routing path in the PATH field and transmit the packet. Otherwise, the queried master 1.1.1 will forward this query message directly to the route master 1 via its upstream master 1.1. In this scenario, the header fields for a sequence of query packets are shown in Table 1.

When the route master receives the query packet, it will first look up in its piconet list table for the associated piconet addresses and then look up in the scatternet routing table for the optimal path. The route master then sends back the optimal routing path to the source node via the downstream master nodes according to the piconet address of SRC field. The optimal path contains a sequence of PID's in the PATH field. The header fields for a sequence of reply packets are shown in Table 2.

In the packet transmission phase, when a master receives a packet from another node, it strips off its PID in the PATH field and forwards this packet to the next piconet according to the next PID in the PATH field. In this way, the packet will finally reach the destination node D. The header fields for a sequence of data packets are listed in Table 3.

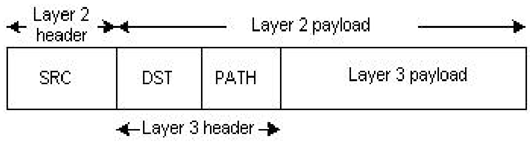

Fig. 2 Blueweb packet format

Table 1
Header fields for a sequence of query packets

Query packet sequence	SRC	DST	PATH
Node S queries its master	1.1.1.1	D's Bluetooth address	1
Queried master forwards to its upstream master	1.1.1.1	D's Bluetooth address	1
Upstream master forwards to the route master	1.1.1.1	D's Bluetooth address	1

Table 2
Header fields for a sequence of reply packets

Reply packet sequence	SRC	DST	PATH
Route master sends routing path to downstream master	1.1.1.1	1.3.0.2	1.1.1;1.2;1.3
Downstream master passes this information to the queried master	1.1.1.1	1.3.0.2	1.1.1;1.2;1.3
The queried master passes this information to the query node S	1.1.1.1	1.3.0.2	1.1.1;1.2;1.3

Table 3
Header fields for a sequence of data packets

Packet transmission sequence	SRC	DST	PATH
Node S sends packet to destination node D	1.1.1.1	1.3.0.2	1.1.1;1.2;1.3
The master of node S forwards to the next piconet	1.1.1.1	1.3.0.2	1.2;1.3
The immediate master forwards this data packet to the master node of destination	1.1.1.1	1.3.0.2	1.3
The packet reaches the destination node D	1.1.1.1	1.3.0.2	0

3. TIER NUMBER DECISION ALGORITHM

In Blueweb, each master (including the route master) maintains its N-tier piconet information. The larger N-tier improves the routing performance but generates more routing overhead in terms of maintenance cost. There is a trade-off between routing performance and maintenance cost for this hybrid routing protocol. In order to achieve the configurable routing performance, a tier number decision algorithm is used in the route master to compute the optimal number of tiers for all the other masters.

The tier number decision algorithm is described as follows. After route master collects the overall topology information, the N-tier delay performance of the Blueweb routing protocol can be found through computer simulation. By computing the delay performance of I-tier and (I+1)-tier iteratively, the optimal *n*-tier can be determined and this algorithm will be terminated. Where the computation sequence for I is varied from 1 to N.

An example of simulated delay performances for different number of tiers is shown in Fig. 3. The delay threshold *S* is a predefined system QoS parameter for tier number decision in Blueweb network.

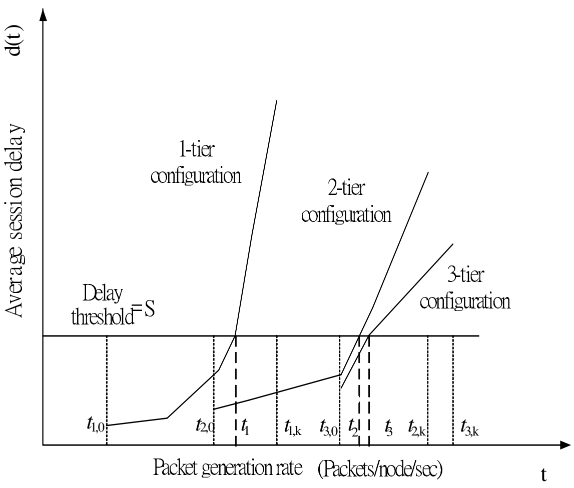

Fig. 3. Three tiers example of Blueweb delay performance

The simulated delay performances can be used to find out the achievable packet generation rate t_I at the predefined delay thresholds in the *Ith*-tier case. In the 1-tier case, we start from an initial packet generation rate $t_{1,0}$ and increase it in a step size of α to simulate the average packet delay. When the simulated average packet delay is larger than the delay threshold S, the packet generation rate $t_{1,k}$ is recorded. Then we start from $t_{1,k}$ and decrease it in a step size of δ ($\delta < \alpha$) to run the simulation backward until the simulated average packet delay is smaller than the delay threshold S. At this point, the packet generation rate cross point t_1 in the 1-tier case can be determined by interpolation between $t_{1,i}$ and $t_{1,i} + \delta$, for which the average packet delay for $t_{1,i}$ is smaller than S and that for $t_{1,i} + \delta$ is larger than S.

In the 2-tier case, the packet generation rate starts from $t_{2,0} = t_{1,k} - \alpha$ and is increased in a step size of α to simulate the average packet delay. When the simulated average packet delay is larger than the delay threshold S, the packet generation rate $t_{2,k}$ is recorded. Then, $t_{2,k}$ is decreased in a step size of δ to determine t_2 with the same method as in the 1-tier case. In the same way, t_3 in the 3-tier case can also be determined.

When the system performance improvement ratio t_{I+1} / t_I is below the other predefined threshold *T*, the configuration of *I* tiers will be selected as the optimal *n*-tier and the algorithm stops here.

After determining the efficient configuration of Blueweb routing protocol, the route master passes the tier number *n* to its immediate downstream masters. Then, each master passes this *n* to its immediate downstream masters until the leaf masters are reached. Finally, each master exchanges and maintains its optimal *n*-tier routing information to reduce the overall routing maintenance cost.

4. System Performance Simulation

In this section, we simulate and evaluate the system performance for Blueweb with the N-tier routing protocol. The performance evaluations are based on a uniform end-to-end traffic model to demonstrate the system performance of Blueweb. A simulation program is written to evaluate the system performance.

4.1. Simulation Model and System Parameters

In our simulation scenario, the scatternet topologies simulated were constructed by using the scatternet formation algorithms as described in Section 2. Overall, we simulated ten topologies each with 40 nodes randomly distributed in the same geographical area.

Table 4. The simulation parameters

Simulation time (seconds)	20
Number of nodes	40
N-tier in each master	4
Traffic pattern	Poisson arrival
Scheduling scheme	Round robin
Routing protocols	Modified source routing
FIFO buffer size	400 packets
Source-destination pair	Randomly selected
Query or reply packet	1 time slot
Data packet (for each routing session)	5 time slots
Each routing session	1 data packet
Predefined delay threshold	1600 time slots
Performance improvement ratio	1.1

For data transmission, packets were generated in each node according to a Poisson arrival pattern. Here, we assumed only a single packet was sent in each routing session. Each data packet was assumed to last five time slots. Each route query packet and each route reply packet were assumed to last one time slot. Each node was provided a FIFO queue with a length of 400 packets. The source-destination pair in each routing session was selected randomly and packets were forwarded by using the Blueweb routing protocol. To evaluate the system performance, we calculated some selected performance metrics over twenty seconds of simulation time for each topology. Table 4 summarized the simulation parameters.

4.2. Routing Performance

4.2.1 Average Packet Delay

The average packet delay metric is defined as the average packet transmission time from the first transmitted bit at the source node to the last received bit at the destination node for every routing packet. In addition, our simulation adopts the Poisson arrival traffic pattern, the round robin scheduling algorithm, and the modified source routing protocol to evaluate this performance metric in a uniform end-to-end traffic model.

Fig. 4 shows the average packet delay performance of Blueweb. The average packet delay increases as the packet generation rate increases. In addition, the larger number of tiers achieves better delay performance than the smaller number of tiers and the 4-tier case generates the smallest average delay.

With the tier number decision algorithm, we simulated the delay performance for the above four configurations and the results are shown in Fig. 3. The predefined delay threshold S was set to be 1600 time slots. In the first configuration case, the session generation rate starts from $t_{1,0}$=1.0 and is increased in a step size of α=1.0 to simulate the average session delay. When the average session delay is larger than the delay threshold S, the session generation rate $t_{1,k}$ is recorded and $t_{1,k}$ is decreased in a step size of δ=0.1 to run the simulation until the average session delay is smaller than S. Then, the t_1 can be determined by interpolation. In a similar method, t_2, t_3, and t_4 can be found. The four session generation rates t_1, t_2, t_3, and t_4 are found to be 6.48, 7.18, 7.99, and 8.34. As a result, the optimal tier number is 3 for this 40-no de simulated case.

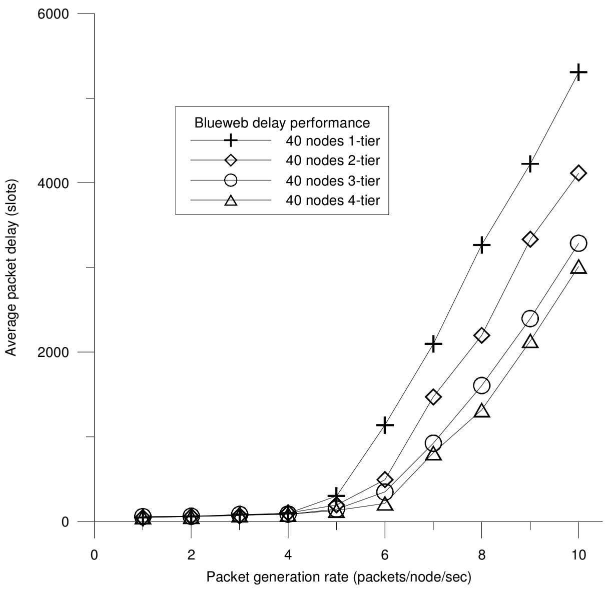

Fig. 4 Average packet delay

4.2.2 Average Packet Query Time

The average packet query time is defined as the average transmission time of query packet to discover a path from either the piconet master or the route master. The query time to the piconet master is defined as the local query time, and the query time to the route master is defined as the global query time.

Fig. 5 shows the average route query time performance (including both the local and global query time) represents about three-fourths of the overall average packet delay time. In addition, the larger number of tiers achieves better packet query time performance in terms of routing performance than the smaller number of tiers and the 3-tier case is reduced significantly from the 1-tier cases. Because the local query with a larger local routing table effectively shares the working load of global query.

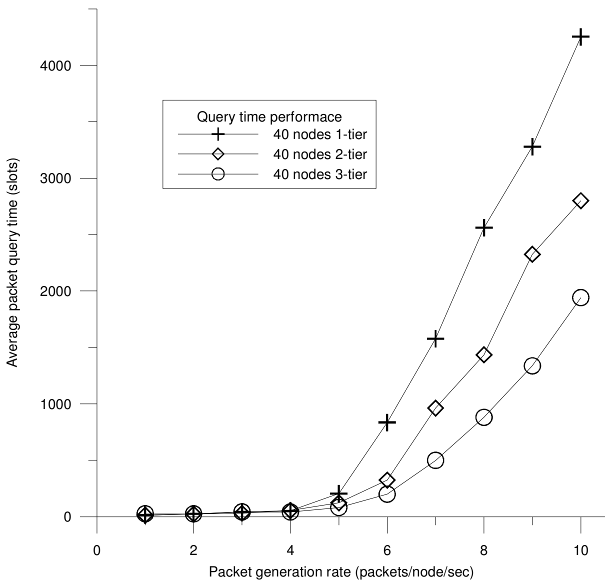

Fig. 5 Average packet query time

5. CONCLUSIONS

In this paper, the Blueweb hybrid routing protocol with a tier number decision algorithm is proposed. This algorithm can be used to determine the efficient configuration for this hybrid routing protocol. In the tier number decision algorithm, the average delay performance is evaluated with uniform end-to-end traffic models in the route master to find out the optimal n-tier for all other masters. Computer simulation results also show that this algorithm works well and efficiently improves the routing performance at a least network maintenance cost.

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