Available Online at www.ijcsmc.com

International Journal of Computer Science and Mobile Computing

A Monthly Journal of Computer Science and Information Technology

ISSN 2320–088X

IJCSMC, Vol. 3, Issue. 12, December 2014, pg.474 – 481

SURVEY ARTICLE

A Survey On Bluetooth Scatternet Scheduling Research Trends

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Abstract— Bluetooth is a promising new technology for short range wireless connectivity between mobile devices. By constructing a piconet, Bluetooth device establishes link and communicates with other devices in a master–slave manner. The piconets are combined to form the Scatternet and communicate through the Relay /bridge node. So the performance of the Scatternet highly depends on the relays and its degree and mobility. This paper describes the issue of piconet interconnection for Bluetooth technology. These larger networks, known as scatternets, have the potential to increase networking flexibility and facilitate new applications .In this survey many research papers were collected concerning various fields in Bluetooth scatternet scheduling and discussed each and categorized them under the few mechanisms and the trends were interpreted based on the area of research and applications.

Keywords— Scatter net, Bridge/Relay node, Bridge Scheduling, Relay reduction, Load balancing, Route breakage, Signal Strength

I. INTRODUCTION

The wireless technology can be classified as infrastructure and Infrastructure less (Adhoc) network. Bluetooth is an Adhoc networking technology aimed at Low-powered, short range applications. Bluetooth operates in the 2.4 GHz Industrial, Scientific, Medical (ISM) frequency band[9]. It works on the principle of frequency hop spread spectrum (FHSS). There are 79 hop carriers defined for Bluetooth, with 1 MHz spacing, in the ISM band. The basic network of Bluetooth is known as the Piconet. It contains maximum of eight nodes, one master and others are slaves. Each piconet master determines a frequency hopping spreading sequence that the slaves must follow in order to stay synchronized to the piconet channel. . The Time Division Duplex (TDD) frequency hopping (FH) channel is divided into 625μs time slots.

A Bluetooth device identifies other devices through their Bluetooth Device Address (BD_Addr) and clock [9]. Initially, Blue- tooth device is in the standby mode and not associated to any device. The master of the piconet performs the inquiry operation to find the new devices within its range by broadcasting the ID packets. Each device enters to inquiry scan (listen to the master) mode to connect the master if it already exists in its range. In the second phase, the page and page scan procedure is used to get the Bluetooth address clock and device class for synchronization. The master allocates the AM Addr to slave; it range is from 1 to 7 [9]. As connection is then established allowing both the devices to start communication using a Time Division Duplex (TDD) mechanism.

The Bluetooth uses the different types of packets like, control (ID, NULL, POLL, FHS), voice (HV1, HV2,HV3, DV), and data (DH1, DH3, DH5, DM1, DM3,DM5) packets. Bluetooth supports 1, 3 and 5 slots packets, each higher slot packet consumes more time as compared to lower slot packet. A master sends packets to in an even-number of slots, while the slave to the master in subsequent slots (odd). If master has no data for slave it sends a POLL packet; and in response if slave also has no data to send to master, it sends a NULL packet to master. A master generally visits all its active slaves in a cycle fashion using a Round-robin scheduling technique [8].

If many devices exist in a co-located area and exceed the limit of piconet, a larger network will be formed that has multiple piconet known as Scatternet. Bluetooth Scatternet has some special characteristics in comparison with general Adhoc networks [5]. In order to communicate between piconets there should be a bridge node that listen both piconet. This shared device is called as relay. The relay is synchronized to two piconets using the bridge scheduling algorithms [8]. The Scatternet performance highly depends on relay degree, mobility and the number of relays.

A relay can only serve one piconet at one time; therefore other piconets' communication is blocked. Once the relay has finished its service time in the current piconet, it switches to the next piconet, which causes delay and decreases network performance. This issue is known as an inter-piconet scheduling problem. There have been many protocols developed for inter-piconet communications, but only the two most significant related protocols are considered as basis for the proposed protocol. The relay reduction with disjoint route construction protocol (LORP) [4] reduces the relay without considering the traffic load. The dynamic relay management protocol(DRM) [2] does the relay reduction with load balancing. But DRM does not consider the node mobility, so the proposed protocol predicts the link disconnection due to mobility and the alternate path is selected before the link disconnection. The prediction is done using the signal strength measurement.

A lot of researches have been done in Scatternet formation and inter piconet communication. The Bluetooth devices are connected through inquiry and paging procedures to form the piconet. Within a piconet the routing is controlled by the master node. The piconet combines together to form the Scatternet with one node as a bridge known as relay node[10][6]. In case of inter piconet that is Scatternet scheduling the relay node plays the important role. The relay node synchronize with its connected masters using bridge scheduling algorithms, which depends on fixed time instances called rendezvous points, for which the bridge remains in the piconet in order to exchange the data with its master[9]. The large number of relays will have to be reduced to optimum number without compromising the Scatternet performance. The traffic load should also take into consideration to avoid congestion [5][3]. The link disconnection occurs due the frequent movement of the relay node. So breakage prediction is done based on the received signal strength

II. LITERATURE SURVEY

A. BLUETOOTH SPECIFICATION

Paper [9] Whitaker et al, 2004explains the fundamentals of the Bluetooth technology. The Bluetooth specification includes the Radio layer-hooping sequences, baseband, device admission, link type and packet types etc. At the lowest level, the radio layer of the core specification defines the wireless interface. Spread spectrum frequency-hopping occurs in the 2.4GHz ISM band using either 79 radio frequencies A fast hopping rate of 1600 hops per second occurs, using pseudorandom hopping sequences, which provide an automatic method for controlling interference from other sources in the unregulated ISM band. These frequencies are located at (2402 + a) MHz, for a = 0, 1, . . , 78.
The baseband specifies how the radio layer should be employed to facilitate communication between Bluetooth devices. This layer defines the concept of a piconet, which is Bluetooth's fundamental logical topology for organizing group-wise communication. At this point, homogeneous devices are distinguished by their Bluetooth device address which is a unique 48-bit address, and each device holds a free-running clock which ticks every half time-slot for a hopping rate of 1600 hops per second. Exchange of clocks and Bluetooth addresses is fundamental to the formation of a piconet. This is defined as a group of devices that share the same communication channel. Each piconet consists of exactly one device whose role is the master, and at most seven other active devices whose roles are slaves. It is the master who defines the communication channel used by all members of the piconet. The first device to initiate the formation of a piconet becomes the master. Every other device in range is assigned a locally unique active member address. These take up the role of the slave within

the master's piconet. At most seven active slaves participate in each piconet, but additional slaves can be registered with the master and sustain the parked mode. Devices outside of any piconet sustain the stand-by mode.

The master may communicate with any member of the piconet, but slaves in the piconet may only communicate with the master. This means that the communication between slaves may only occur via the master. The principle role of the master is maintenance of synchronization. This is organized by referencing slots in piconets as odd or even, according to the second least significant bit of the clock of the master. To determine the frequency hopping sequence in a piconet, slaves maintain the offset time between their clock and that of the master, using a slot dwell time of 625 μs, and apply pseudo-random sequencing of frequencies. Uplink and downlink between master and slave occurs using time division duplex, with the master only communicating in even numbered slots, and slaves in odd numbered slots. Prior to commencing communication in a piconet, the slaves need to identify the address and clock of the master, and similarly the master needs to know the identity of slaves. This is organized by inquiry and paging phases defined at the baseband layer. The inquiry process is used to discover other devices and paging is used to establish connection with them, via invitation. The scan process is used by idle devices which periodically become active and listen for devices trying to make a connection. Every time a device wakes up, a different hop carrier is scanned for a period of approximately 10 ms. The hop carrier scanned is defined by the wake-up sequence. This is a cyclic sequence of 32 hops, in a pseudo-random order defined uniquely for each device. Here there is a trade-off between power consumption and response time.

Two types of link can be supported. A single asynchronous connectionless link (ACL) is supported between a master and a slave, for services such as bursty data traffic. Additionally, up to three synchronous connection-oriented (SCO) links may be supported in a piconet, for services such as voice traffic. Four control packets are defined. These are the identification packet, consisting of only the access code and used for signaling; the null packet which contains the access code and a packet header, being sent only to convey link control information; the poll packet, sent by the master to force a response from the slaves; and the synchronization packet, used to exchange real-time clock and identity information between devices.

Benefits

This paper [10] explains clearly the fundamentals of the Bluetooth technology and piconet formation procedure .It also explains the communication within the piconet.

B. Scatternet Formation

Paper [5] Persson et al, 2004 discusses the criteria for different types of Scatternet and establish general models of Scatternet topologies. A scatternet topology is formed by interconnecting piconets. Since each piconet has a unique frequency hopping sequence, piconet interconnections are done by allowing some nodes to participate in more than one piconet. These, so called bridge nodes, divide their time between piconets by switching between FH channels and synchronizing to the piconet's master. As of now, Bluetooth specification does not provide any solution for Scatternet formation. However, there are six different approaches to scatternet topology formation as described below:

- **Single Piconet Model (SPM):** One piconet is created and devices are managed in active and park mode according to the demand.

- **Slave/Slave Mesh (SSM)**: The devices those are shared (relay) are slaves among the piconets where they participate and provide multiple paths among nodes. This topology allows only SS bridges. Generally, this increases Scatternet performance at the cost of additional protocol complexity.

- **Master/Slave Mesh (MSM)**: A relay device is master in one and slave in other piconet that creates a mesh structure. The piconets are interconnected through MS or SS bridge. An MSM is the most non restrictive Scatternet model, since it allows any type of piconet interconnection to be formed. But this structure put extra load on master to do the Inter piconet routing besides the intra piconet communication.

- **Tree Hierarchy (TH):** They have a single root node and descendant tree nodes. The main advantage of TH topologies over the preceding models is that they have logarithmic average path length and simplify Scatternet routing. On the other hand, the root node is a bottleneck point and node disconnections close to the root node can partition the Scatternet and substantially reduce node availability.

- **Master/Slave Ring (MSR**): Different nodes are arranged in ring with given master slave roles consequently.

- **Slave/Slave Ring (SSR):** It is same like Master/Slave ring the main difference is that both devices are salve.

The main reason to form a ring topology is to alleviate the bottleneck problems in TH topologies while maintaining simple Scatternet routing .However, ring models suffer from partitioning problems and significantly longer average path lengths and mean access delays.

C. Polling and Bridge Scheduling Algorithms

Paper [8] Vojislav et al 2003 describes the intra-piconet polling schemes and bridge scheduling algorithms for Bluetooth Scatternet. The main performance measure is the end to end packet delay, lowest delay indicate the high performance. Other measures are fairness that is the master should give equal preference to all the slaves and the polling scheme should be simple in terms of computational and memory requirements since Bluetooth devices are having limited resources. There are mainly three categories of the polling scheme: Traditional polling scheme, dynamic reordering of slaves, adaptive bandwidth allocation.
The traditional polling schemes use fixed ordering of the slaves and fixed bandwidth allocation per slave. The only variable is the duration of master's visit. Mainly there are three types for the traditional polling scheme[8]:

- **Limited service polling**: Master visits each slave for exactly one frame, in a round robin fashion. If there is no data packets then empty (POLL, NULL) packets are sent.

- **Exhaustive service polling**: Master will stay with client until there is no more packets is to sent .The absence of packets are detected by the POLL-NULL frame.

- **E-limited service polling:** Master will stay with the slave until no more packet to exchange or for a fixed number M of frames(M>1),whichever comes first. This scheme is also known as the Limited Round robin. Of these schemes the limited service polling performs better under high load.

Better results can be obtained using the so called Stochastically Largest Queue (SLQ) policy that is the master should always poll the slave for which the sum of uplink and downlink queue is the highest. But it is not possible in Bluetooth because there is no way for the master to know the uplink status of its slaves. So the possible approach is to dynamically reorder the polling schemes according to the length of downlink queues at the master. This reordering may be done once in each piconet cycle or the master will always poll the slave with longest downlink queue. In both the cases the polling scheme used is limited or exhausted or E-limited service polling schemes. One problem with dynamic reordering is that the fairness among slaves cannot be guaranteed when if the reordering is done for every poll.

The duration of visit to each slave can be adjusted according to the current or historical traffic information. There are two approaches for doing this: give high preference to the slave which have high traffic or give less preference to slave with less or no traffic. So the master will stay longer with slave having more packets to sent and ignore the slaves for some piconet cycles which is having less traffic. There exist many variations of the adaptive schemes like limited and weighted round robin, air exhaustive polling, adaptive E-limited polling etc.

The bridge scheduling algorithms are based on the concept of Rendezvous points, which are time instants at which the bridge stay in a piconet for exchanging the data with its master. These time instants are fixed before the actual data transfer or for the entire Scatternet life time or can be negotiated as necessary between the piconet masters and bridges. These algorithms use global scheduling of rendezvous points, fixed in advance, on the basis of the traffic requirements of the individual devices.

There exist also the adaptive Rendezvous points, in which the schedule of the rendezvous points are calculated locally, on per piconet or per bridge basis and dynamically adjusted to the current traffic conditions. The scheduling of the bridge can also be done without rendezvous points. In this the bridge node will synchronize with each master according to its on will. This approach is known as the walk in approach. In this master will poll the bridge device also, and the packet transfer occurs if and only if the bridge is synchronized with the master, otherwise the polling is wasted.

Benefits

This paper [8] provides a clear idea of the polling schemes and bridge scheduling algorithms. The round robin polling scheme is used to poll the slave nodes and bridge scheduling algorithm uses rendezvous points to schedule the bridge device.

D .Relay Reduction

Paper [4] Yung et al, 2005 presents an effective protocol that can dynamically adjust the network topology by reducing the unnecessary relays. In a Scatternet, each relay r sends the Relay Information Collection (RIC) message to each of its masters. On receiving the RIC message, master mi collects information of relays belonging to piconet Pi and the connection information of neighboring masters. Once the relay r receives the information provided by the masters the relay connects to, each relay creates a Connection Table (CT), where,

$$CT(r_c^k, m_j) = \begin{cases} 1, r_c^k \text{ connects } m_j \\ \text{Null}, r_c^k \text{ does not connects } m_j \end{cases}$$

for each r_c^k in first column and each m_j in first row. After the CT is constructed, each relay examines the CT and determines whether to change the role from a relay to a pure slave. According to the CT, relay r_i checks whether any other relay has a larger degree, and also connects to the masters which are connected by the relay r_i. If such relay exists, the role change of relay r_i from relay to pure slave does not cause the disconnection of the piconets and relay r_i should determine the piconet in which to participate as a pure slave according to balance consideration. All relays that simultaneously execute the same relay reduction procedure will minimize the number of relays and guarantee that the restructured Scatternet is connected.

Reducing the number of relays not only decreases the guard time cost for relay switching among piconets, but also reduces the probability of packet loss and improves the transmission efficiency. The relay nodes update the CT in the following two situations. First, the relay nodes use the received polling messages from masters to check the link validity and update the CT. Second, the relay node updates the CT table when routes create new links. Therefore, the relay nodes update or refresh their CTs dynamically based on the two cases mentioned above.

Drawbacks

The relay reduction is done on higher degree relays, relays with same degree are not considered. The reduction is done without considering the traffic load so congestion occurs by reducing the high traffic relay.

E. Route Breakage Prediction

Paper [6] Tahir et al 2012proposes a Route Breakage Prediction (RBP) Protocol for Bluetooth network recovery that predicts the route breakage on the basis of signal strength before the link breaks. Each master device and bridge device maintains a table. The master device makes the Master Record Table (MRT) that contains the record of all connected slaves whereas the bridge device makes a Bridge Record Table (BRT) that contains the record of all connected masters in the Bluetooth network. The master device selects the Fall-Back Master (FBM) from its connected slaves and each bridge selects a Fall- Back Bridge (FBB). The master device can easily select the FBM from its slaves; the slave device which is within the radio range of all other slaves is selected as the FBM. The bridge device selects the FBB if there is any other bridge device. In case there is no other bridge device, then the research protocol performs the role switch operation for the FBB.

A threshold value is defined for the signal strength. If the threshold value of the master or bridge device is going to decrease then the master device will send a request to its FBM to become a new master and inform the other slave devices. The bridge device will send the request to its FBB to become a new bridge and inform the other master devices. Any device which will become a new master or bridge device will first maintain its table.

Benefits

The main advantage with this technique is that as it predicts the route breakage before the link failure and repairs it, this protocol overcomes the problem of data packet loss and the problem of delay.

F. Signal Strength Threshold

Paper[7] Thapa et al 2003 proposed a method for positioning the Bluetooth device using the metrics such as the RSSI (Received Signal Strength Indicator), time difference etc[8]. The Host Controller Interface (HCI) layer provides several HCI services that have potential value in supporting a positioning service. Specifically, the following HCI services are of interest:

- **Get_Link_Quality**: This HCI command returns measure of the quality of a link between the local module and a remote Bluetooth device. The link quality is scaled to a value of 0-255.

- **Read_RSSI**: This HCI command returns a measure of the received signal strength indication of a link between the local module and a remote Bluetooth device. The returned value provides a relative measure of the RSSI and the "Golden Receive Power Range." This golden receive power is defined as a range with a lower and higher threshold levels and a high limit. The lower threshold level corresponds to a received power between -56 dBm and+6 dB above the actual sensitivity of the receiver. The upper threshold level is 20 dB above the lower threshold level to an accuracy of +/- 6 dB. This command returns a negative measure if the RSSI is too low, zero if the RSSI is within the golden range and a positive measure if the RSSI is too high.

- **Read_Transmit_Power_Level**: This HCI command returns the current transmit power level of a link between the local module and a remote Bluetooth device.

If the Read_RSSI command returns a value of 0 then the device has only limited information pertaining to signal strength. However, this information will still provide useful localization information. Perhaps the value indicates that the device is between 1 and 10 meters from the transmitting device. This single point of information can be combined with similar data from another Bluetooth device to help eliminate the inherent error. Even if the second device results in another Read_RSSI value of 0, the position is now known to be within the intersection of two regions, each bounded by a minimum radius of 1 meter and a maximum radius of 10 meter.

Paper [1] Almuala et al 2006describe the Bluetooth Triangulator, an experiment combining hardware and software design to allow Bluetooth devices to communicate with each other and determine the position of other Bluetooth devices using signal strength readings. The physical setup will consist
of 3 master nodes, each collecting RSSI measurements from a slave mobile device. One of the 3 master nodes acts as a server that will collect measurements from the two client master nodes. Before sending a message packet to the server master node, a client master node will collect the RSSI readings four times for each discovered Bluetooth device. Then, the slave will pack the message packet as shown below and send it to the host for further processing. The reason to have multiple RSSI readings is twofold. First of all, RSSI reading tends to fluctuate greatly. Multiple sampling points can be used to normalize the fluctuation. Secondly, instead of sending a message packet each time a RSSI read is executed, one packet containing multiple RSSI readings for all known devices greatly reduces network overhead.

Benefits

These papers explain the positioning of Bluetooth devices using signal strength measurements.

G. The Dynamic Relay Management

The Dynamic Relay Management (DRM) protocol adjusts optimally the number of relays according to the traffic load. It contains two basic procedures: First, it changes the role of unnecessary relays, including relays of the same degree, with less control overheads. Second, the DRM monitors the traffic load on each relay, and if a relay creates a bottleneck, a master shares its traffic load through the creation and activation of backup relays, i.e. a load balancing process [9]. Initially all Bluetooth devices will be in the standby mode. The nodes enter into the inquiry and inquiry scan mode, in which some node send ID packets and others listens and replys. In the next phase, the master enters into the page state, while the salve enters into the page scan state, for receiving page messages from the master node.

When a new connection is established, each relay sends its information (remaining battery, piconet Id and number of connections) to all connected masters. When a master receives a message from the relay, it stores the received information in the relay connection table. Once, the connection activation procedure ends, each master checks the traffic load. If traffic load is low, the master performs the relay reduction. Each master finds the higher degree relays to assign them the relay role, while the lower degree node is assigned a backup relay role. After the higher degree of relay selection, the master checks the same degree of relay. Where the master compares the remaining power of the same degree of relays, and assigns backup relay roles to lower remaining battery relays.

In a predefined time interval, the master records incoming and outgoing traffic in the Flow Analysis Matrix (FAM). A master compares the traffic load with the threshold, if the delay is greater than, the master finds a backup relay to share the load. A master of a piconet calls a function (Decision Maker) that checks for backup a relay node to share the load. The DM decides on a backup relay; it sends a role_switch request to the backup relay and the neighboring piconet master. The DM compares the TLD (Total Link Delay) with θ (threshold delay).The θ value is fixed and it is analyzed that $\theta = 1.5$ s [8] gives optimum results. If the TLD is greater than θ the master searches for a backup relay.

If multiple backup relays exist, a higher degree node is selected as the relay because it can be used to avoid bottlenecks from other piconets as well. The master sends a role_switch request to the BR and sets the FAM values to zero after completing the backup relay operation. It is assumed that the BR remains active until the end of the communication. All the masters perform the same steps when the number of connections passing through a relay exceeds more than two or after a time interval T. The master node will go for relay reduction if low traffic otherwise it will do load balancing through the backup relay. For doing relay reduction the master compares the degree and remaining battery power. The load balancing is done by calling the decision maker function, which selects the backup relay or slave through role switch operation.

Limitations

Analytically, the DRM has reduced relay-reduction overhead. The Simulation results show that this protocol outperforms other already existing approaches. But this system has not addressed the relay node mobility that will cause frequent link disconnection.

III. CONCLUSION

The previous works and researches on the Bluetooth Scatternet formation is inter piconet routing, relay reduction and route breakage prediction etc are explored .The Scatternet is formed through the inquiry and paging procedures. The routing is done through the Scatternet by discovering the route though the relays, which are scheduled using the bridge scheduling algorithms. Some of the relays are reduced to backup relay without Scatternet disconnection. The Dynamic Relay Management protocol changes the role of active relays to backup relays according to the degree and battery power measures. It will also take care of the traffic and avoid bottleneck by switching the backup relay to active relay. Then the link disconnection occurs due to the node movement .This is predicted by measuring the received signal strength. These works have benefits and drawbacks, which motivated to research to find the new protocol called R^3BP protocol which stands for Relay Reduction Route Breakage Prediction protocol.

ACKNOWLEDGEMENT

I would like to express my deep sense of gratitude with sincerity to my guide Mrs. A.Nirmala, Assistant Professor , Department of Computer Applications, who provided her valuable suggestions and precious time in accomplishing this paper. I thank all those who had contributed directly and indirectly towards the success of my research.

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