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PERFORMANCE EVALUATION OF AN ALTERNATIVE CONTROLLER FOR BLUETOOTH SERVICE DISCOVERY

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Abstract

Bluetooth is a short range radio technology to form a small wireless system. It is used in low –cost, low power ad-hoc networks and it suffers from long service discovery delay and high power consumption. Bluetooth employs the 2.4 GHz ISM band, sharing the same bandwidth with the wireless LAN implementing the IEEE 802.11 standards. Thus it causes significantly lower interference. For improving the efficiency of SDP, we present an implementation of Bluetooth 2.1 in the NS-2 simulator, discuss the IEEE 802.11b as a Bluetooth controller and propose a new alternative Bluetooth Controller based on Adaptive Frequency Hopping techniques using Amplifier Power. The resulting approach significantly reduces the service discovery time, thereby lowering power consumption and increasing the throughput. We present the benefits of our new approach and compare it with existing approach using NS-2 Simulations and we have presented the comparison graphs in support of our approach.

Keywords:
NS-2 -BT2.1+EDR, 802.11b, Interference, Node Delay, Energy Efficiency

1. INTRODUCTION

Bluetooth is a low-power, open standard for implementing PANs [1][2]. It is a popular protocol with 40 million Bluetooth-enabled phones shipped worldwide and over 1,000 new Bluetooth products being developed by more than 2,000 companies [3]. It uses a slow hop frequency hopping spread spectrum scheme with 79 1-MHz frequency slots (23 in some countries) in the 2.4 GHz band. Members of a Bluetooth piconet hop together among the 79 frequencies (numbered 0-78) with a sequence that is a function of the master's free-running counter (*CLK*) and the first 28 bits of the master's 48 bit address. Service Discovery Protocol (SDP) [4] is the basis for discovery of services on all bluetooth devices. This is essential for all bluetooth models. Using the SDP device information, services and the characteristics of the services can be queried and after that a connection between two or more bluetooth devices may be established. SDP uses a request/response model where each transaction consists of one request PDU and one response PDU. Only one SDP request per L2CAP connection to a given SDP server is allowed at a given instant until a response is received. Some requests may however require responses that are larger than what can fit in a single response PDU. To extend the response to more than a single response PDU, the SDP server generates a partial response along with a continuation state parameter. All SDP communications use only the BR/EDR controller.

The current SDP is defined for operation between two devices only. Moreover, the SDP does not maintain historical information. Hence, a fresh SDP request for each service invocation. The current SDP does not provide a proactive mechanism to inform devices of availability of newly available services. A Bluetooth device needs to query every other device irrespective of whether the device hosts the desired service(s) or not. As devices need to periodically search for desired services, it leads to higher overheads. In addition, a Bluetooth device needs to establish a separate SDP connection with every-other Bluetooth device. While this is fine for two device environments, it imposes a heavy overhead for larger networks. To improve performance in these environment, a technique known as Adaptive Frequency Hopping has been introduced by Bluetooth SIG to reduce the impact of interference in WLAN and similar environments. When there are transmitters, there must be RF power amplifiers. People rate the performance of an RF power amplifier in terms of the power gain, the efficiency and the linearity. Also, the basic underlying principles of operations of different power amplifier modes should be thoroughly understood before an improved circuit topology can be designed. Therefore, understanding the language used in the world of power amplifiers and the basic operating principle of different modes of power amplifier is required.

2. BLUETOOTH ADAPTIVE FREQUENCY HOPPING

We describe the Bluetooth frequency hopping sequence defined in the Bluetooth specifications [4], then we present an AFH algorithm that modifies it in order to mitigate interference. Adaptive frequency hopping is a method for avoidance of fixed frequency interferers. AFH for Bluetooth can be broken down into four main components:

- **Channel Classification** – A method of detecting an interfering source on a channel-by-channel basis (each channel equals 1 MHz)
- **Link Management** – Coordination and distribution of the AFH information to the rest of the members of the Bluetooth network (accomplished via LMP commands)
- **Hop Sequence Modification** – Avoiding the interferer by selectively reducing the number of hopping channels
- **Channel Maintenance** – A method for periodically re-evaluating the channels

Frequency hopping in Bluetooth is achieved as follows. Frequencies are sorted into a list of even and odd frequencies in the 2.402-2.480 GHz range. A segment consisting of the first 32 frequencies in the sorted list is chosen. After all 32 frequencies in that window are visited once in a random order, a new window is set including 16 frequencies of the previous window and 16 new frequencies in the sorted list. From the many AFH algorithms possible, here is an implementation that eliminates “bad” frequencies in the sequence. Given a segment of 32 “good” and “bad” frequencies, the algorithm visits each “good” frequency exactly once. Each “bad” frequency in the segment is replaced with a “good” frequency selected from outside the original segment of 32.Thus, the difference between AFH and the original Bluetooth hopping sequence algorithm is in the selection of only “good” frequencies in order to fill up the segment size. Some additional constraints can be imposed on the maximum number of “bad” frequencies to eliminate if a minimum number of different frequencies is to be kept in the sequence. In their most recent ruling the FCC recommends using at least 15 different frequencies.

2.1 BENEFITS OF AFH

AFH for Bluetooth is targeted toward easing the congestion of the rapidly crowding ISM band. AFH is specifically tailored to combat the interference of fixed frequency interfering devices such as 802.11b, some cordless telephones, microwave ovens, and others. Avoiding occupied spectrum enables the Bluetooth link to operate at a higher throughput and reliability translating directly into improved quality of service (QOS). The benefits extend beyond that of just Bluetooth systems. The avoided system will experience higher throughput (e.g., 802.11b) or greater voice quality (e.g., cordless telephones). This is called Bluetooth’s good neighbor policy and is due to the fact that (from their perspective) the interfering Bluetooth device is no longer hopping in their desired frequency band. AFH allows for the coexistence between a Bluetooth system and another system (also occupying the ISM band) by having both systems avoid each other in frequency. Since both technologies will have less collisions, they will both experience lower latency due to a fewer number of retransmissions. The fewer retransmissions for both technologies also means there will be less overall interfering power generated within the ISM band.

2.2 AMPLIFIER POWER

Concerning service discovery, the main drawback of this is necessity of a permanently connected piconet infrastructure with increased power consumption for connection maintenance. To avoid this when there are transmitters, there must be RF power amplifiers. People rate the performance of an RF power amplifier in terms of the power gain, the efficiency and the linearity. Whenever an RF power amplifier is discussed, people are interested in its power gain, power-added efficiency (PAE), the drain efficiency (DE) and the linearity. The RF power amplifier consumes most of the power inside a transceiver. To preserve the battery lifetime, the power amplifier should be effective in converting DC power to RF power. PAE and DE are the parameters to characterize the effectiveness of power conversion. where P_{out} is the output power at the desired frequency, P_{DC} is the DC supply power and P_{in} is the input power at the frequency of interest. PAE includes information on the driving power for a power amplifier, so PAE is commonly used instead of DE.

$$\text{Power Gain}=\frac{\text{Power delivered to the Load}}{\text{Power available at the input port}}=\frac{P_{out}}{P_{in}} \quad (1)$$

3. INTERFERENCE ANALYSIS

As Wi-Fi uses a fixed frequency band of 22 MHz while Bluetooth hops between 79 bands each of 1 MHz, there is a probability of 22/79 that a Bluetooth packet hops in the Wi-Fi fixed frequency band leading to a collision. Coexistence between Wi-Fi and Bluetooth was studied in [3, 5]. It was found in[3] that Wi-Fi packets suffer most from the 1-slot Bluetooth packets then 3 and 5 slots packets, so 5-slot packets are recommended when Bluetooth coexist with Wi-Fi as this would lead to a reduction in the Bluetooth hop rate, thus increasing the chances for a successful Wi-Fi packet reception. Though, if Bluetooth hops to the Wi-Fi channel during back-off period, there is no effect on Bluetooth packets. Regarding the Wi-Fi data rates, it was found in [3] that with a small number of Bluetooth nodes Wi-Fi high data rates can be used, but when Bluetooth piconets increase, Wi-Fi high data rate modes have to be abandoned. In [5], it was found that using Bluetooth voice traffic might be the worst of all interference cases causing a 65% packet loss for the Wi-Fi with a severe impact on the Bluetooth voice leading to a packet loss of 8%. Coexistence between narrow band technologies and UWB was studied in [6]. The authors used high power IR-UWB transmitters that greatly exceed the FCC radiation regulations. It was found that both Wi-Fi and Bluetooth networks will slightly suffer only at high proximity from the UWB signals (less than 10 cm) [8]. Packet selection and scheduling scheme based on channel state and queue state by round robin packet scheduling scheme are studied in interference environment [7].

4. PERFOMANCE EVALUATION

In this paper we are using an alternative controller in Bluetooth 2.1. To get understanding about the issues of switching between the controllers, to compare controllers and contribute to the research, we have developed the UWB [9] OPNET simulation model in NS-2 Simulator in BT2.1+EDR.

4.1 SIMULATION MODEL

Interference based Service Discovery (ISDP) was developed to provide an accurate modeling of the AODV and DSDV protocol and communication channels over the different controllers and to provide an interface to easy the operation of adding other controllers for future research. For the alternative 802.11 MAC/PHY, NS-2 802.11b model was used. The L2CAP component was also modified to establish logical links over the 802.11 MAC using the 802.11 PAL and over the BT2.1+EDR MAC. Finally, the 802.11 and BT2.1+EDR models were integrated, creating a simulation model for high speed bluetooth over IEEE802.11b or BT2.1+EDR.

4.2 SIMULATION ENVIRONMENT

A number of simulation scenarios were built to compare the performance of IEEE 802.11b and BT2.1+EDR in terms of node delay, throughput and energy efficiency versus number of connections and packet size. In this analysis the BluetoothV2.1+EDR performance was used as a benchmark. Each scenario was run ten times. The simulation runs according to the following cases,

Case 1: By Increasing No. of Nodes

In this case, increasing the no of devices and keeping the backoff limit value and packet size as constant, we are finding the node delay, energy and Throughput

Table.1. Node Delay

No. of Nodes	Existing (802.11b)	Proposed-(IBT2.1+EDR)
10	0.0072776208389	0.0070195731999
20	0.0152245628045	0.0103235113328
30	0.0210823208483	0.0163846374112
40	0.0355142272220	0.0239032935361
50	0.0441974719310	0.0343920850603

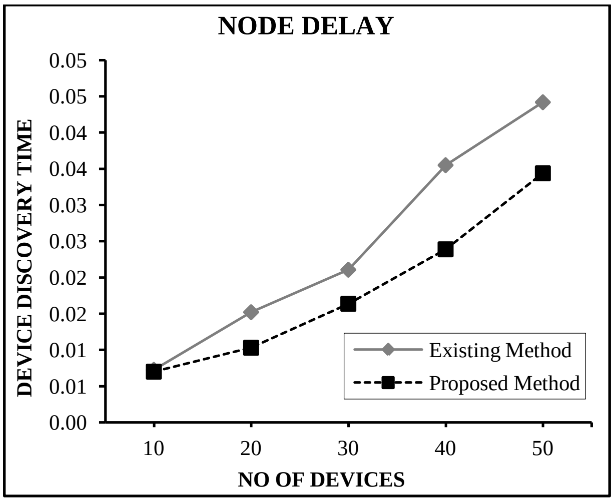

Fig.1. Node delay of 802.11b controller and BT2.1+EDR

Table.2. Node-Energy

No. of Nodes	Existing(802.11b)	Proposed(BT2.1+EDR)
10	0.0106742263941	0.0066367231713
20	0.0117599738032	0.0066095409355
30	0.0119683495049	0.0063823128359
40	0.0126923495337	0.0068138496717
50	0.0127075299329	0.0055588317798

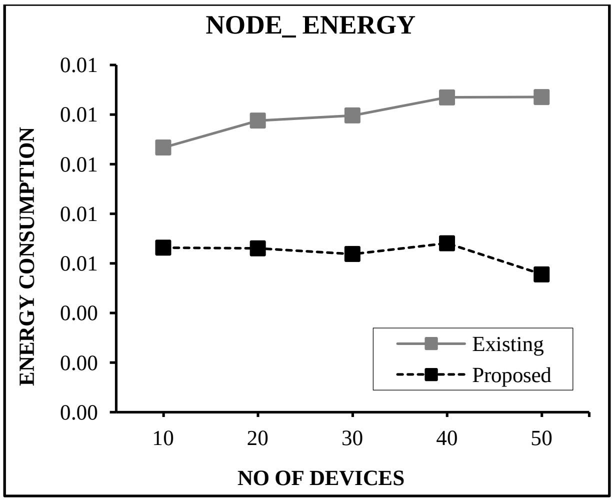

Fig.2. Node Energy of 802.11b controller and BT2.1+EDR

Table.3. Node-Energy

No. of Nodes	Existing(802.11b)	Proposed(BT2.1+EDR)
10	1.646315602	1.663469006282
20	1.211643169	1.357008330468
30	0.940703598	1.117988765506
40	0.747156256	0.892234606352
50	0.651767858	0.739023963660

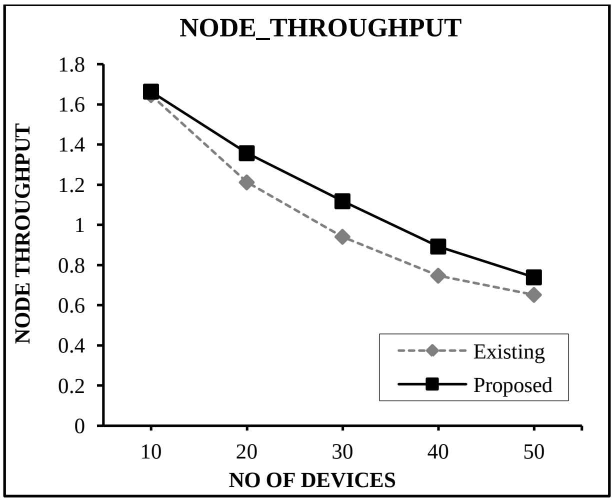

Fig.3. Node Throughput of 802.11b controller and BT2.1+EDR

Case 2: By Increasing Packet_Size

In this case, increasing the packet size and keeping the backoff limit value-1000 and No. of Node-10 as constant, we are finding the node delay, energy and Throughput

Table.4. Packet-Delay

Packet-Size	Existing(802.11b)	Proposed(BT2.1+EDR)
1000	0.0060444164079	0.0056226685413
3000	0.0072779671859	0.0070167653814
6000	0.0072779671859	0.0070184736838
9000	0.0073835619537	0.0070162993891
12000	0.0072779671859	0.0070180060157

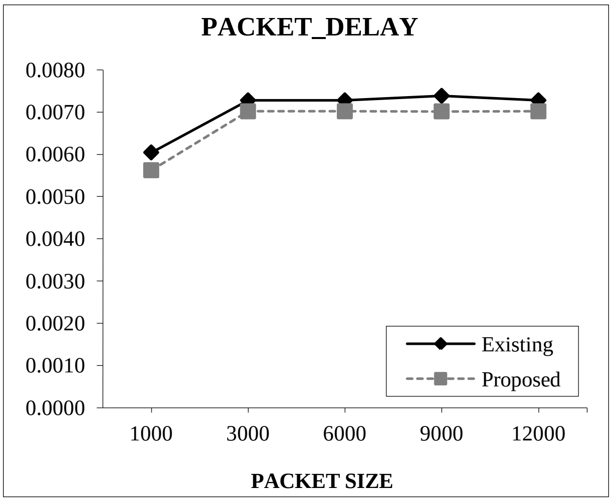

Fig.4. Packet Delay of 802.11b controller and BT2.1+EDR

Table.5. Packet-Energy

Packet-Size	Existing(802.11b)	Proposed(BT2.1+EDR)
1000	0.0114954423219	0.0071160048056
3000	0.0106748677274	0.0066343548935
6000	0.0106748677274	0.0066367690602
9000	0.0106615482830	0.0066324160046
12000	0.0106748677274	0.0066352135046

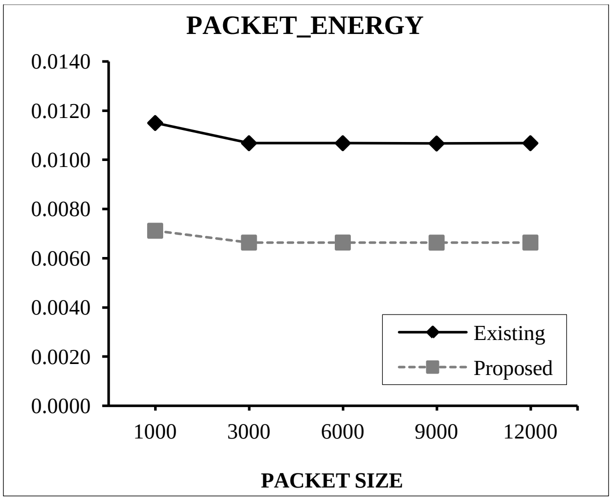

Fig.5. Packet energy of 802.11b controller and BT2.1+EDR

Table.6. Packet-Throughput

Packet-Size	Existing(802.11b)	Proposed(BT2.1+EDR)
1000	1.3709076748188	1.4094106353279
3000	1.6464091753605	1.6635906062824
6000	1.6464091753605	1.6628498103745
9000	1.6340562943288	1.6628180886353
12000	1.6464091753605	1.6628498103745

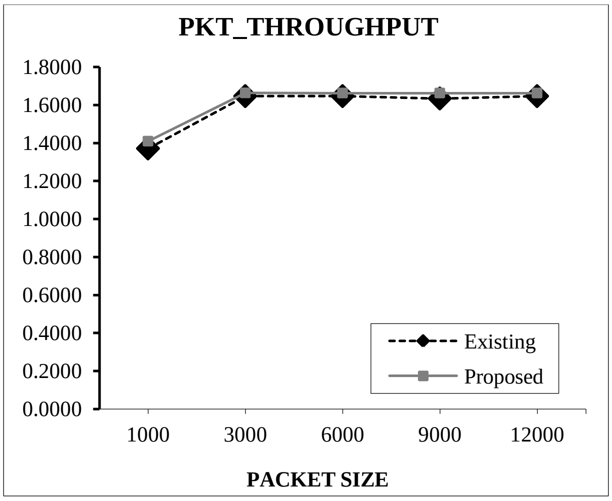

Fig.6. Packet Throughput of 802.11b controller and BT2.1+EDR

Table.7. Simulation Parameters

Parameter	Values
Propagation Model	Radio energy model
Initial energy (Wh)	3
Number of connections	1,2,4,6,8
Number of nodes	Twice the number of connections
Alternative controller	IEEE802.11b , BT2.1+EDR
Transport layer agent	UDP
Transport layer packet size (Bytes)	1500
Distance	1,3,6,10

5. RESULTS AND ANALYSIS

5.1 NODE DELAY

The average end-to-end delay is yet another quantitative metric considered in the evaluation process. Having a constant or near constant metric value indicates that a technology would suites applications that can’t tolerate jitter. The average delay is obtained by computing the sum of the total delay encountered by all the nodes in the network divided by their number as given in Eq.(2)

$$\textbf{Average delay} = \frac{\sum_{\forall \text{Nodes}} \dfrac{\sum_{\forall \text{Packets}} \textbf{Arrival Time} - \textbf{TransmissionTime}}{\textbf{Number\_of\_Packets}}}{\textbf{Number\_of\_Nodes}} \quad (2)$$

Table.8. Relationship between Node delay Existing and their Node delay Proposed

Node delay Existing	**Correlation value**	**Statistical inference**
Node delay Proposed	.987(**)	P <0.01 significant

** Correlation is significant at the 0.01 level

Statistical test: Karl Pearson coefficient correlation test

The above table indicates that there is a highly significant relationship between Node delay Existing and their Node delay Proposed. Hence, the calculated value less than table value.

Table.9. Relationship between PKT delay existing and their PKT delay Proposed

PKT delay Existing	**Correlation value**	**Statistical inference**
PKT delay proposed	.997(**)	P < 0.01 Significant

** Correlation is significant at the 0.01 level

Statistical test: Karl Pearson coefficient correlation test

The above table indicates that there is a highly significant relationship between PKT energy existing and their PKT energy Proposed. Hence, the calculated value less than table value.

5.2 ENERGY CONSUMPTION PER BIT

The other key quantitative metrics considered in the evaluation process is the average network energy consumption per bit. Average network energy consumption per bit is calculated by dividing the total amount of energy consumed to send and receive the data by the amount of data received. Average network energy consumption per bit is obtained using Eq.(3).

$$\text{Average Network Energy Consumption per bit} = \frac{\sum_{j=0}^{\text{Number\_of\_Nodes}} E_j}{\sum_{i=0}^{\text{Number\_of\_Connections}} R_i} \tag{3}$$

Table.10. Relationship between Node energy Existing and their Node energy Proposed

Node energy Existing	**Correlation value**	**Statistical inference**
Node energy Proposed	-.407	P > 0.05 Not significant

Statistical test: Karl Pearson coefficient correlation test

The above table indicates that there is no significant relationship between Node energy Existing and their Node energy Proposed. Hence, the calculated value greater than table value.

Table.11. Relationship between PKT energy existing and their PKT energy Proposed

PKT energy existing	**Correlation value**	**Statistical inference**
PKT energy proposed	1.000(**)	P < 0.01 Significant

** Correlation is significant at the 0.01 level

Statistical test: Karl Pearson coefficient correlation test

The above table indicates that there is a highly significant relationship between PKT energy existing and their PKT energy Proposed. Hence, the calculated value less than table value.

5.3 THROUGHPUT

Average network throughput is one of the key quantitative metrics considered in the evaluation process. This metric gives an indication of the capability of a technology in handling high rate applications and mitigating interfering sources effects. Higher metric value indicates that a technology is more capable in handling more traffic. Having a constant or near constant value for this metric with different number of interfering sources represents a good indication that a technology can work in a crowded environment. Average network throughput is calculated by averaging the connections throughput using Eq.(4).

$$\text{Average Network Throughput} = \frac{\sum_{i=0}^{\text{Number\_of\_Connections}} R_i / \left(T(\text{Last})_i - T(\text{First})_i \right)}{\text{Number\_of\_Connections}} \tag{4}$$

where: R*i* is the total number of bits received at connection *i* destination node.

T(Last)i is the arrival time of the last data bit for connection *i*.

T(First)i is the arrival time of the first data bit for connection *i*.

Table.12. Relationship between node throughput existing and their node throughput Proposed

Node throughput existing	**Correlation value**	**Statistical inference**
Node throughput proposed	.990(**)	P < 0.01 Significant

** Correlation is significant at the 0.01 level

Statistical test: Karl Pearson coefficient correlation test

The above table indicates that there is a highly significant relationship between node throughput existing and their node throughput Proposed. Hence, the calculated value less than table value.

Table.13. Relationship between PKT throughput existing and their PKT throughput Proposed

PKT throughput existing	**Correlation value**	**Statistical inference**
PKT throughput proposed	.999(**)	P < 0.01 Significant

** Correlation is significant at the 0.01 level

Statistical test: Karl Pearson coefficient correlation test

The above table indicates that there is a highly significant relationship between PKT throughput existing and their PKT throughput Proposed. Hence, the calculated value less than table value.

6. CONCLUSION

In this study we proposed the use of BT2.1+EDR as an alternative controller for proposed scheme and IEEE 802.11b for existing scheme. The two alternative controllers are then evaluated by means of [NS-2] simulations in terms of node delay, energy efficiency and throughput for 25 devices [say 50 nodes]. The simulation results reveal that BT2.1+EDR have better efficiency than the current or existing approaches. Analyzing the data from the graphs and tables we can see that the proposed approach is having a much lower average end to end node delay and reduces the average network energy consumption per bit. It is also shown that the proposed approach provides better network throughput compared to the existing one. These features make it suitable for networks requiring high transfer rates and at the same time reducing energy consumption and node delay. On the other hand, the existing scheme is not suitable for all wireless technologies, whereas the proposed model is suitable for all wireless technologies and in future, we plan to extend this model to support single-hop clustering and multi-hop clustering in bluetooth network using Max-Min D-Cluster formation [10].

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