Performance Analysis of Bluetooth Piconet

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Design and Implementation of the Interconnection circuits with recovery mode

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Abstract

In this paper, a performance of Bluetooth piconet is analyzed. Average cycle time, average waiting time, average transfer delay and average queue length are used for measure of performance (MOP). Simple round robin (RR) scheduling policy with exhaustive service is used for the analysis. Packet loss is considered because of noise environments of wireless communication. Numerical results have been presented. Simulation is performed to validate the correctness of analysis.y and its maximum operating frequency is 800MHz.

I. Introduction

Recently, a new universal radio interface, Bluetooth, has been developed enabling electronic devices to communicate wirelessly via short-range ad-hoc radio connections[1]. The Bluetooth technology eliminates the need of wires, cables and the corresponding connectors between phones, head-sets, personal digital assistants (PDAs), computers, notebooks, printers, projectors, etc. This network concept is one of personal area network (PAN), which is standardized by the IEEE 802.15, PAN. Bluetooth is assigned to the IEEE 802.15. 1 standard.

Piconet is the smallest network in Bluetooth which consists of one master and several slaves. Up to seven slaves can be active in one piconet. Polling is used in the piconet for the channel access. To describe the operation of polling networks, there are some important parameters such as cycle time, average queue length, average waiting time and average transfer delay. The total time required to poll each station and return to the starting station in the polling sequence is called the cycle time, T_C. The average waiting time, W, is the time that packets must wait in the station buffer before being transmitted. The total time required from entry into the station buffer to delivery to the destination station is defined as the average transfer delay, T. The average queue length, N is obtained from the average transfer delay by Little's theorem. In this paper, those parameters are adopted as measures of performance (MOPs). The analyses of those parameters are necessary to understand the operation of the piconet.

There are some results about the performance of single Bluetooth piconet[2,3,4].

They focused on new scheduling policy within a single piconet, because the scheduling policy is not defined yet in the current Bluetooth specification [1]. Obviously, the scheduling policy affects the performance of the piconet. However, those papers are based on the simulation result only. In [5,6], the cycle time and the average transfer delay of the piconet is analyzed using M/G/1 with vacations under the exhaustive and limited service. However, there are no considerations about packet errors and packet retransmissions. Because the noise environments of wireless communication such as interference, path loss, fast fading and shadowing, the packet error is inevitable. Therefore, ignoring the packet error is unrealistic assumption.

In addition, the master is assumed not to generate any traffic. Because the master has more computational power, it usually acts as LAN access point(LAP) in one piconet. In that case, the master generates traffic to relay packets from external traffic source such as Internet.

In this paper, the average cycle time, the average waiting time, the average transfer delay and the average queue length of the piconet polling system are analyzed. Because the wireless channel is error-prone, the packet error must be considered. For the packet error, forward error correction (FEC) and automatic repeat request (ARQ) are considered. Also, the traffic of the master is generated. For the analytic simplicity, a round robin scheduling with exhaustive service is applied for the piconet polling system. In the exhaustive service, the master polls the same slave as long as there are packets to be transmitted to and/or from that slave and moves to the next slave only when both queues are empty

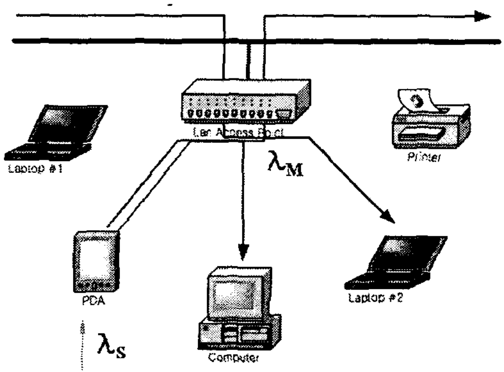
This paper is organized as follows. In Section 2, the polling model of single Bluetooth piconet is described. The average cycle time, the average waiting time, the average transfer delay and the average queue length in the piconet polling system are analyzed in Section 3. In Section 4, numerical results and simulation results are shown. Finally, this paper is concluded.

II. Performance Analysis

Assume that the arrival rate of each slave is λ_S . The arrival rate of the master, λ_M, consists of two traffics. One is the traffic generated outside of the piconet for example traffic from Internet. The other is the traffic generated inside of the piconet, which is exchanged information between two slaves.

Bluetooth uses time-driven duplex (TDD) for channel access. Piconet master controls medium access control (MAC) and packet transmission. The master sends packet to each slave and slave transmits packets. This TDD scheme is different from conventional polling scheme because there can be exchange of information between master and slave.

Each Bluetooth packet consists of an access-code, packet header, and user payload.



Then, the model is shown like Figfure 1. The access-code is used for the signaling. The receiver correlates and triggers when a threshold is excceeded, providing a robust signaling. So, in this paper, the error in the access-code is ignored when calculating the packet error probability. The following notations are used for the analysis. Let the P_H be the error probability of packet header, and the P_P, the error probability of payload. Bit error rate (BER) is defined as b. In the Bluetooth systems, data transmission consists of sending data and receiving acknowledgement (ACK). Let S(n,m) denote the sending side and R(n,m) is receiving side, where n is success flag of the packet header and m is success flag of the packet payload. The n value and m value of a set {s,f,x}, where s is the initial character of success, f is the initial character of failure and x means don't care. Let us consider about the number of Bluetooth packet transmission cases with imperfect feedback channel as shown in Table 1.

Table 1: Bluetooth packet transmission cases

Case	Process	Meaning
Case 1	$S(s,s)$, $R(s,s)$	success
Case 2	$S(s,s)$, $R(s,f)$	success
Case 3	$S(s,s)$, $R(f,x)$	failure
Case 4	$S(s,f)$, $R(s,s)$	failure
Case 5	$S(s,f)$, $R(s,f)$	failure
Case 6	$S(s,f)$, $R(s,x)$	failure
Case 7	$S(f,x)$, $R(x,x)$	failure

In the Table 1, only the Case 1 and the Case 2 mean successful packet transmissions with $(1-P_H)^2\cdot(1-P_P)$, where P_H is

$$P_H = 1 - \left[\sum_{x=0}^{1}\binom{3}{x} b^x (1-b)^{3-x}\right]^{18}$$

and P_P is $P_P = 1-(1-b)^{240}$. Assume that packets arrive with Poisson, we can get these resulting equations for the average waiting time, average transfer delay and average queue length. (M:Master,S:Slave)

(1) Average cycle time

$$T_C = \frac{2(N-1)P_S \cdot T_S}{D}$$

where

$$D = P_S - 2T_S\cdot[\lambda_M\{1-(1-P_H)\cdot(2-P_P-P_S)\}+(N-1)\lambda_S]$$

(2) Average waiting time

(2-1) Master

$W_M = W_{M1} + W_{M2}$ where $W_{M1} = \frac{T_C}{2} - \frac{\lambda_M T_C T_S}{(N-1)P_S}$

$$W_{M2} = \frac{4\lambda_M T_S^2(2-P_S)}{\{(N-1)P_S - 2\lambda_M T_S\}P_S}$$,

(2-2) Slave

$W_S = W_{S1} + W_{S2}$ where

$$W_{S1} = \frac{T_C - T_{S-M}}{2} - \frac{E_S[n](T_{M-S} - T_{S-M})}{2(N-1)\lambda_S T_C}$$,

$$W_{S2} = \frac{2\lambda_S T_S^2(2-P_S)}{P_S(P_S - 2\lambda_S T_S)}$$

(3) Average transfer delay

$T_M = W_M + d_{tr}$ $T_S = W_S + d_{tr}$ where

$$d_{tr} = \frac{2T_s(1-P_E)}{P_E} + T_D$$

(4) Average queue length

$$N_M = \frac{\lambda_M}{(N-1)}W_M,\ N_S = \lambda_S W_S$$

III. Results

In this section, both analytic results and simulation results are shown. The polling model of single Bluetooth piconet is simulated using OPNET V9.1. In both the analysis results (ANAL) and the simulation results (SIM), the size of each packet arrival packet is assumed to be identical to the DH1 payload size, 240 bits long.

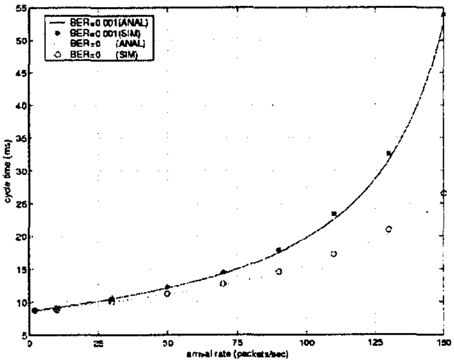


Figure2. Cycle Time

In Figure 2, the cycle time is given as a function of arrival rate,λ, with two BER cases. The packet arrival rate of the master and the slave are defined as λ_M = 0.75 λ, λ_S = 0.5 λ, respectively. As the arrival rate increases, the cycle time increases exponentially. Because the arrival rate increases, the amount of packet to be transmitted also increased, in other words, the average duty cycle increased. During the increased duty cycle, more packets arrive at the master and the slaves. Therefore, the cycle time increases exponentially. The result of 0.1% BER is compared to no error case. Transmission error means the required time to transmit packet arrived within the cycle time is increased. Also during the increased cycle time, more packets could be arrived. Therefore, the cycle time increases exponentially. Table 2 shows the impact of the slave numbers on the cycle time where λ_M =60, λ_S =40, respectively.

	BER = 0		BER =0.001	
Slaves	ANAL	SIM	ANAL	SIM
1	1.3158	1.3150	1.3349	1.3340
2	2.7778	2.7820	2.8642	2.8444
3	4.4118	4.4310	4.6338	4.4584
4	6.2500	6.2946	6.7052	6.5706
5	8.3333	8.3980	9.1026	8.9266
6	10.714	10.813	12.125	11.720
7	13.462	13.650	15.767	15.050

Table 2: Cycle time(ms) Vs Numer of slaves

As the number of slaves increases, the cycle time of single piconet increases. As you can see, the simulation results is in accordance with the analytic results. For λ=80 packets/sec with 7 slaves, 0.1% BER, the throughput of the master is 14.4 kbps and that of each slave is 9.6 kbps. Then the total throughput of sing piconet is 81.6 kbps.

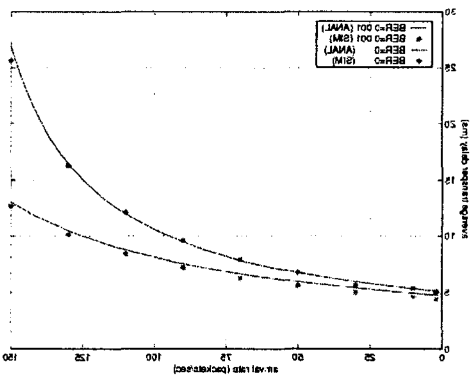


Figure 3. Master-to-slave average transfer delay

IV. Conclustions

In this paper, the performance of the piconet polling network is analyzed under imperfect channel environments. The average cycle time, waiting time, transfer delay and queue length are used for the measure of performance (MOP). Stop&wait ARQ and FEC, error control mechanisms adopted in Bluetooth, are taken into considerations. For the simplified analysis, round robin with exhaustive service is used. By introducing the intra-piconet and the inter-piconet traffics, more realistic network model is suggested. Simulation is performed to prove the correctness of the analysis. This paper analyzes the performance of the piconet considering the packet error. and the traffic of the master. Therefore, the performance analysis of this paper shows more realistic results for the single piconet. This paper can show some information to design the Bluetooth piconet and its applications.

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