Traffic Scheduling in Bluetooth Network

Vanicha Sangvornvetphan[1] and Tapio Erke[2]

[1]Mobile Operations, Sonera Corporation
P.O. Box 040 SONERA, Helsinki, Finland, Email: vanicha.sangvornvetphan@sonera.com
[2]Telecommunications Program, Asian Institute of Technology
P.O. Box 4 Klong Luang, Pathumthani 12120, Thailand, Email: erke@ait.ac.th

Abstract

Bluetooth is a wireless ad-hoc network concept using a universal short-range radio link for communicating electronic devices in a small area. The Bluetooth radio nodes form piconets and provide slotted Time Division Duplex (TDD) scheme in which each slot is 0.625 ms long. This work studies traffic performance in a piconet focusing on "Mean Packet Delay" and "Probability of Packet Loss" of data traffic. A mix of data and voice traffic is used in the simulation where data traffic streams are modeled by Interrupted Bernoulli Process. The Priority, Round Robin, and "Alternating Priority" scheduling schemes are studied and compared. Alternating Priority scheme turns out to be a fair and efficient scheme and it has almost as good overall performance as in Priority scheme.

1. Introduction

Bluetooth technology is developed for replacing cables between electronic devices and for communicating in a small area network. It uses a combination of circuit and packet switching protocol. Performance of Bluetooth network has been studied in case of a mixture of data and voice traffic [3], [4], and [8]. Two types of transmission links, Synchronous Connection Oriented (SCO) and Asynchronous Connectionless (ACL) links, are used. SCO link is a symmetric point to point link supporting time-bounded voice traffic. SCO packets are transmitted over reserved intervals without being polled. ACL link is a point to multipoint link between master and all slaves on the piconet and can use all the remaining slots of the channel not used for SCO link. Both link types use a Time Division Duplex (TDD) scheme for full-duplex transmission. The media access scheme is based on polling algorithm controlled by the master for allocating the bandwidth.

This paper presents the results of a simulation study of three channel access methods (Priority, Round Robin, Alternating Priority) used by the slaves in a Bluetooth piconet. Mean packet delay and probability of packet loss of the schemes are compared.

2. Simulation Model

2.1. Network Model

The network is modeled as a star configuration (Figure 1). It includes one laptop as a master, two laptops as data traffic sources, one headset for voice traffic, and one WLAN access point. Master controls traffic from slaves to WLAN access point. Voice traffic has the highest priority. SCO link is reserved for voice and synchronous services whereas ACL links are used primarily for data traffic and asynchronous services.

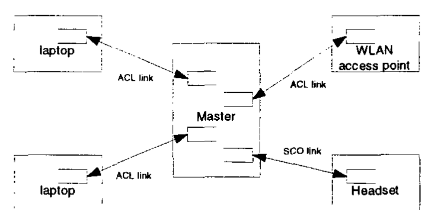

Figure 1. Simulated Network

2.2. Traffic Model

Data packets are generated according to Interrupted Bernoulli Process (IBP), which enables bursty traffic characteristics [8]. The squared coefficient of variation of the packet inter-arrival time, C^2, describes burstiness of IBP traffic (Equation 1). "p" and "q" are state transition probabilities from OFF to ON and from ON to OFF states.

$$C^2 = \frac{2q - pq - q^2}{(p+q)^2} \qquad (1)$$

The voice source generates 2 packets every 30 ms thus using 2 slots of a 24-slot Bluetooth-frame [3]. These packets are placed on (ACL) slots 2 and 5 in the 24-slot frame.

2.3. Traffic Frame Format

Bluetooth frame format here has 24 time slots with 1.25 ms slot lengths including up-link and down-link directions. 8 SCO slots are reserved for voice traffic and 16 ACL slots are reserved for data traffic as shown in Figure 2. The first ACL slot after SCO slot is reserved if there is voice traffic in SCO and the second ACL slot is assigned for data packet.

2.4. Channel Assignment Scheme

ACL slots for data traffic are allocated based on 3-slot cycles by using three different scheduling schemes: Priority (PR), "Alternating Priority" (AP), and Round Robin schemes (RR), Table 1.

In Priority Scheme (PR), voice has the highest, data1 the second highest, and data2 the lowest priority. In "Alternating Priority" Scheme (AP), slots are reserved for both data traffic components in Round Robin manner but the unused slots can be used by the other data traffic. Round Robin Scheme (RR) uses 3-slot cycles.

2.5. Study Cases

The mean delay and loss of data packets in presence of 1 or 2 data traffics is studied for all three polling algorithms. Offered traffic loads, traffic burstiness, and buffer capacities are varied, Table 2.

3. Simulation Results

3.1. Single Data Traffic Behavior

The queue length behavior in the case of infinite buffer, and only one data source is studied by varying burstiness and load of offered data1 traffic. Characteristic temporal queue length behavior of 0.1 Erl and 0.6 Erl offered data traffic with squared coefficient of variation 1 and 100 is demonstrated.

It can be seen in the Figures 3 and 4, as expected, that queue length grows when load grows. High burstiness (C^2=100) of packet inter arrival times increases the length of ON and OFF cycles thus having a dramatic impact on queue length. For low traffic long ON cycles come seldom causing high occupation peaks in most of the time empty queue, whereas for high traffic long ON cycles come frequently, and queue occupation reaches very high values, Figure 4.

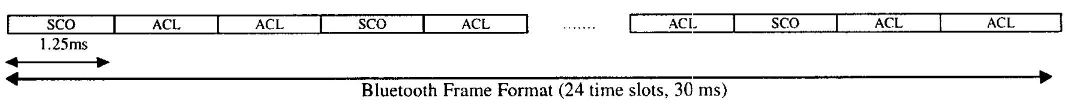

Figure 2. Bluetooth Frame Format

Table 1. Channel Assignment Schemes

	Cycle 1			Cycle 2				Cycle 8		
Scheme	S1 SCO	S2 ACL	S3 ACL	S4 SCO	S5 ACL	S6 ACL	...	S22 SCO	S23 ACL	S24 ACL
Priority (PR)	V	V/D1/D2	D1/D2	V	V/D1/D2	D1/D2	...	V	V/D1/D2	D1/D2
Round Robin (RR)	V	V/D1	D1	V	V/D2	D2		V	V/D2	D2
Alternating Priority (AP)	V	V/D1/D2	D1/D2	V	V/D2/D1	D2/D1	...	V	V/D2/D1	D2/D1

V: Voice D1: Data1 D2: Data2

Table 2. Study and Performance Measurement Cases

Parameter	Varied Parameter	1 Voice 1 Data	And Sources	1 Voice	Source	and	2	Data	Sources
				P	R	A	P	R	R
		FQ	IQ	FQ	IQ	FQ	IQ	FQ	IQ
Delay	C^2	(X)	(X)	X	(X)	X	(X)	X	(X)
	T	(X)	(X)	X	(X)	X	(X)	X	(X)
	Buffer	(X)		X		X		X	
Loss	C^2	(X)		X		X		X	
	T	(X)		X		X		X	
	Buffer	(X)		X		X		X	

C^2: Burstiness, T: Offered Traffic, Buffer: Buffer Size, FQ: Finite Queue, IQ: Infinite Queue, X: Study case, (X): Not presented in this paper

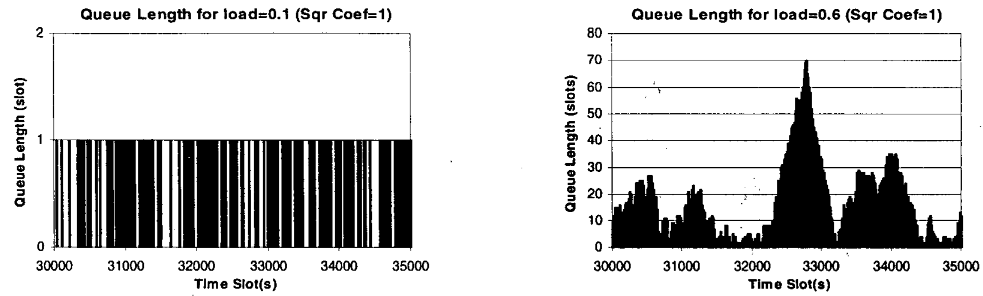

Figure 3. Queue Length as a Function of Time, Squared Coefficient of Variation $C^2= 1$

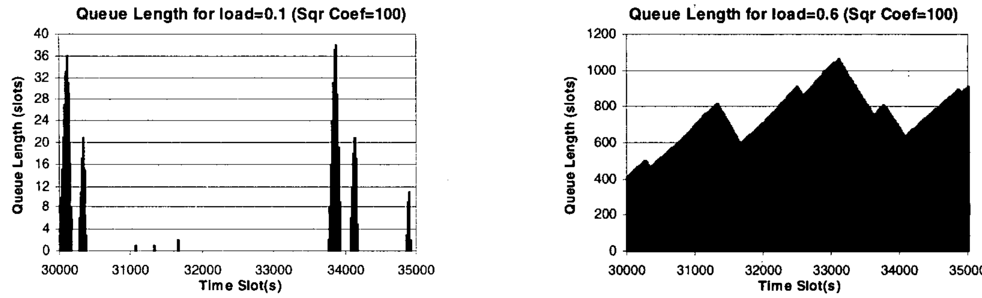

Figure 4. Queue Length as a Function of Time, Squared Coefficient of Variation $C^2= 100$

3.2. Mean Packet Delay and Packet Loss

In this section three scheduling schemes are studied and compared. Two data traffic generators (data1 and data2) both offer equal traffic load varied from 0.1 Erl to 0.4 Erl. Three buffer sizes, Q=50 slots, Q=100 slots, and Q=1000 slots, are considered. First the squared coefficient of variation is fixed at C^2=50. Figures 5, 6, and 7 show the relationship between mean packet delay and probability of packet loss in Priority, Alternating Priority, and Round Robin schemes.

When total load is less than maximum available ACL capacity (0.6389 Erl [8]), both data1 and data2 can be served by all three scheduling strategies. The higher priority data1 in Priority procedure (Figure 5) has the lowest mean packet delay and probability of packet loss among all studied schemes and traffic cases.

The delay and loss performance of Alternating Priority and Round Robin schemes are similar but the numerical values in Round Robin are higher, because the slots in RR are always assigned for a specific type of traffic, Figure 6 and Figure 7. In these two schemes, data1 and data2 have equal loss and delay performance because of their fair polling rules.

In Priority scheme even with 0.8 Erl total load which exceeds the available capacity with 25%, probability of packet loss of higher priority traffic data1 is zero for queue capacity Q=1000, and about 2% for Q=100, but the lower priority data2 has 38% packet loss for Q=1000, and 48% for Q=100. Mean delays vary depending on queue capacity from 45 to 80 slots for data1 and about from 200 to 4000 for data2. In two other schemes, both data traffics are served with equal probability, resulting nearly equal loss and delay performance. Alternating Priority has better overall performance than Round Robin, as can be seen e.g. in 0.8 Erl overload case, where in AP scheme for buffer sizes Q=50, 100, and 1000 loss values are 16%, 23%, and 29%, and delays are 100, 200, and 3000 slots respectively. In RR scheme these values are for loss 17%, 28%, and 36%, and for delay 120, 300, and 3000.

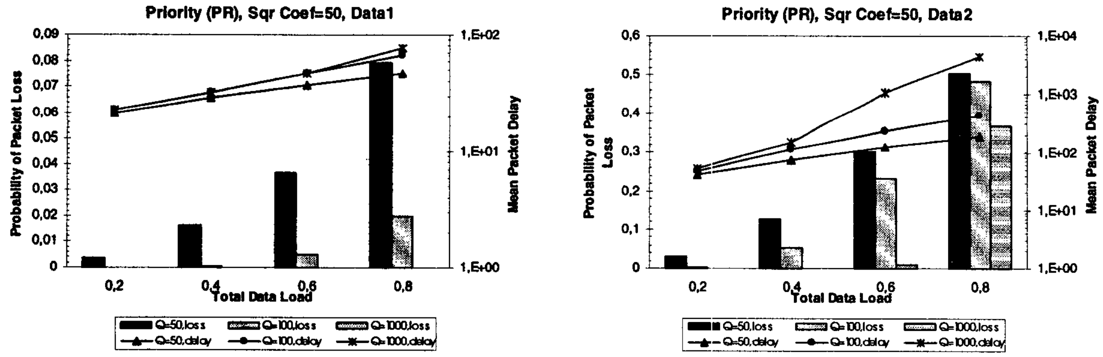

Figure 5. Packet Delay and Loss in Priority Scheme

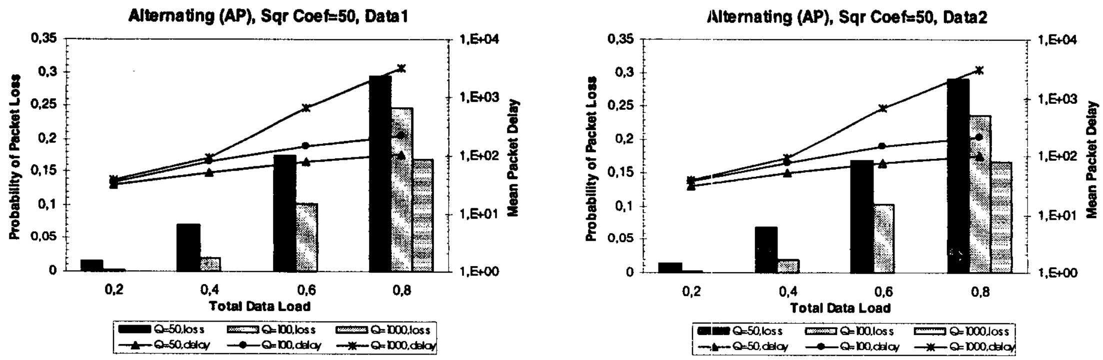

Figure 6. Packet Delay and Loss in Alternating Priority Scheme

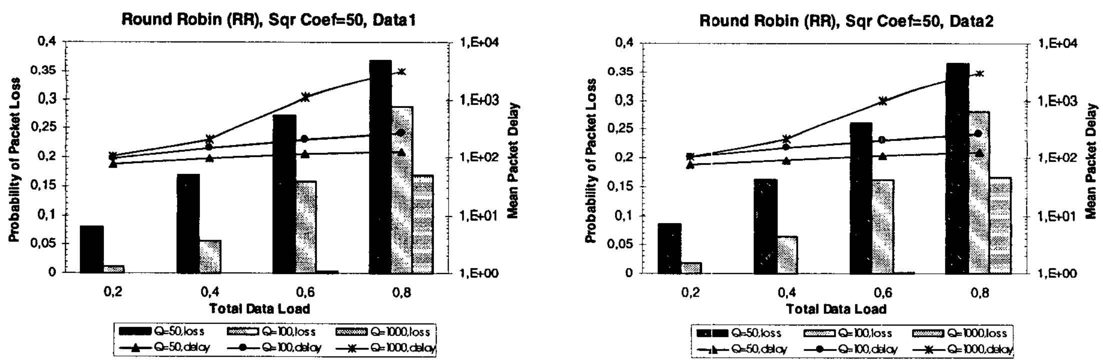

Figure 7. Packet Delay and Loss in Round Robin Scheme

Mean packet delay and probability of packet loss are studied when the buffer size is fixed at Q=50 packets and data1 and data2 both generate 0.3 Erl. Three scheduling algorithms are compared. Values C^2=5, C^2=50, and C^2=150 of squared coefficient of variation, are used to study the influence of burstiness of data traffic. The results are shown in Figure 8 and Figure 9.

In Figure 8 probability of packet loss increases when burstiness increases. Higher priority data1 in Priority scheme is almost fully served when burstiness is low. Data1 packet loss is 15%, data2 loss is 43%, and total loss is 29% if C^2=150. Priority scheme has the lowest overall probability of packet loss in all schemes. Total probability of packet loss of Round Robin is the highest (46% for C^2=150) because of its polling manner. Priority and

Alternating Priority schemes have nearly equal total probability of packet loss (in AP about 30% if C^2=150).

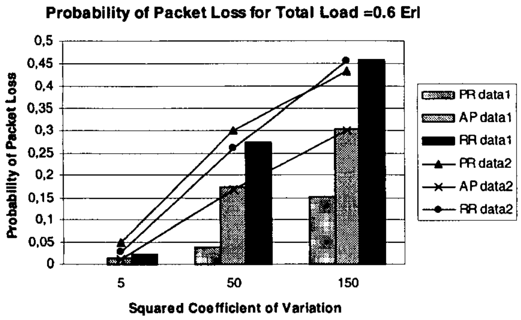

Figure 8. Packet Loss for 0.6 Erl Data Load, Q=50

According to Figure 9 mean delay increases when burstiness increases. Obviously delay of high priority data1 in Priority scheme is the lowest (e.g. 60 for C^2=150) in all schemes, and delay of lower priority data2 is the highest (140 for C^2=150) in all schemes. Delay in Round Robin scheme is almost as high (135 for C^2=150). Overall performance of Alternating Priority scheme is the best, delay for data1 and data2 is e.g. about 88 if C^2=150.

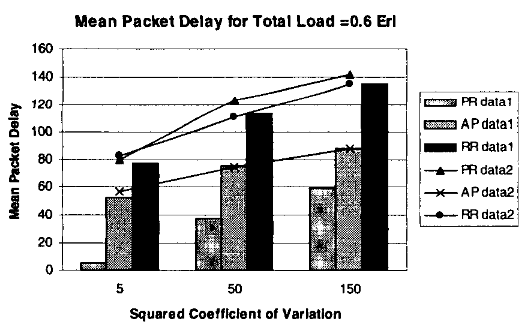

Figure 9. Packet Delay for 0.6 Erl Data Load, Q=50

4. Conclusions

In the simulation, performance of Priority, Alternating Priority, and Round Robin traffic scheduling methods are studied by varying traffic load and burstiness of offered data traffic streams and varying the queue capacity. The results show in infinite queue case that queue length grows dramatically when offered load and burstiness are high because of existence of very long and frequent "ON" periods, and long "OFF" periods.

In all three scheduling schemes queue capacity has essential impact on loss and delay performance of all studied traffic cases. A suitable buffer size reduces loss but increases delay. When for example with queue capacity of 1000 data traffic burstiness is 50 and total offered load is 0.6 Erl, which offers 96.1% occupation to the studied Bluetooth frame, loss can be fully eliminated except in Priority scheme where the lower priority traffic loss has about 1% loss, and in Round Robin loss is less than 0.5%. The cost is long average delay of about 50 and 1000 in Priority, 600 in Alternating Priority, and 1000 in Round Robin. With offered traffic 0.2 Erl corresponding delays are 20 and 50 (PR), 30 (AP), and 80 (RR).

Among three studied polling algorithms the overall performance of Round Robin is the weakest, while Priority and Alternating Priority schemes have approximately equal probability of packet loss.

The proposed "Alternating Priority" scheme proves to be a fair and efficient scheme and it has almost as good overall performance as in Priority scheme.

5. References

[1] Bluetooth SIG, "Specification of the Bluetooth System Version 1.0B", *Specification Volume 1&2, December 1St 1999.*

[2] Haartsen, J. C., "The Bluetooth Radio System", *IEEE Personal Communication, February 2000, Vol.71, pp. 28-36.*

[3] Johansson, P., Johansson, N., and Körner, U., "Performance Evaluation of Scheduling Algorithms for Bluetooth", *IFIP Broadband Communications, Hong Kong, Nov 1999.*

[4] Johansson, P., Johansson, N., Körner, U., and Elg, J., "Short Range Radio Based Ad-hoc Networking: Performance and Properties", *IEEE International Conference on Communication, June 1999, Vol3, pp.1414-1420, Vancouver, Canada.*

[5] Kalia, M., Bansal, D., and Shorey,R., "MAC Scheduling and SAR Policies for Bluetooth: A Master Driven TDD Pico-Cellular Wireless System", *6 th International Workshop on Mobile Multimedia Communications, Nov 15-17, 1999, Hyatt Islandia, San Diego's Mission Bay, pp.384-388.*

[6] Schwartz, M., "Broadband Integrated Networks", *Prentice Hall PTR, 1996, pp.26-32.*

[7] Sangvornvetphan, V., "Traffic Control and QOS in Bluetooth Network," *A thesis for the degree of Master of Engineering, Asian Institute of Technology, Thailand, Dec. 2000.*

[8] Sangvornvetphan, V., Erke, T., "Traffic Control and QOS in Bluetooth Network," *Advances In Communication Conference 2001, July 2001, Rhodes, Greece.*

[9] Stefan, Z., Wolfgang, S., Kirsten, M., and Jaap, H., "Radio Network Performance of Bluetooth", *IEEE International Conference on Communication, 2000, Vol.3, pp.1563-1567.*