A Priority Gated Round Robin Polling Scheme for Bluetooth Piconets

Asmaa Ibrahim, Rawya Rizk, and Gamal Mahmoud
Electrical Engineering Department, Suez Canal University, Egypt

Abstract: *Bluetooth is a wireless access technology where polling is used to share bandwidth among the nodes. In this paper, a new polling scheme for intra-piconet scheduling in Bluetooth piconets, Priority Gated Round Robin, is proposed. The performance of this algorithm is analyzed via simulation in different cases such as different Segmentation And Reassembly algorithms, different packet sizes, and variable number of slaves and is compared with the traditional Gated Round Robin algorithm. Simulation results demonstrate that the new scheme achieves better performance over the existing Gated Round Robin scheme.*

Keywords: *Bluetooth, piconet, polling, Segmentation And Reassembly (SAR).*

Received October 10, 2006; accepted February 25, 2007

1. Introduction

A wireless replacement for cables connecting electronic devices, bluetooth, is an emerging standard for Wireless Personal Area Networks (WPANs). Bluetooth is a short range, small size, low cost, and low power wireless access technology operating in the Industrial Scientific Medical (ISM) frequency band at 2.4 GHz [1, 5].

Bluetooth provides two types of services. First, Synchronous Connection-Oriented (SCO) connections provide a circuit-switching service with constant bandwidth based on a fixed and periodic allocation of slots. The SCO link aims to carry real-time delay-sensitive traffic such as voice. It uses a slot reservation mechanism which allows the periodic transmission of SCO data with guaranteed delay and bandwidth. Second, Asynchronous Connection-Less (ACL) connections provide a packet-switching service. The ACL links are classified based on the data rates they carry, namely High Data rate packets (DH packets) and Medium Data rate packets (DM packets). The packets are also classified into three types based on their lengths that include the 1-slot, 3-slots and 5-slots long packets [4]. The combination of these two classifications gives rise to six packet types as reported in Table1.

Segmentation And Reassembly (SAR) mechanisms are used to improve efficiency by supporting a maximum transmission unit size. This reduces overheads by spreading the packets used by higher layer protocols over several baseband packets. In this paper, two cases are used. First case uses one packet size and then higher layer packet divides on a fixed packet size according to its type. Second case is Best Fit (BF) algorithm [3], which aims to reduce the wasted bandwidth. The higher layer packet is divided to 5-slot packet(s), and the remainder is divided to 3-slot packet(s), and 1-slot packet; respectively. So the packet type in this case is either DHx or DMx that combine (DH1/DH3/DH5) or (DM1/DM3/DM5); respectively.

The smallest network unit in bluetooth is a piconet, which consists of one master and up to seven slaves. A piconet owns one frequency-hopping channel, which is controlled by the master in a Time-Division Duplex (TDD) manner with 625 μs time slots. The master fully controls the traffic in the piconet. A slave is allowed to start transmission in a given slot if the master has addressed it in the previous slot. The master addresses a slave by sending a 1-slot POLL packet which has data to be send or not. Then, the slave must respond by sending a data packet or, if it has nothing to send, a 1-slot NULL packet. The master-to-slave communication is called as *downlink* and the slave-to-master communication is called as *uplink*. Master-to-slave transmission always start in an even-numbered time slot, while the slave-to-master transmission always start in an odd-numbered time slot. There are no direct connections between slaves, data packets from one slave to another are first send to the master [11]. The ways used to arrange transmission between nodes are called polling schemes.

Table 1. Packet characteristics for ACL links.

Packet Type	Slot Occupancy	Header (bytes)	Max. Payload (bytes)	FEC Encoding Rate	Maximum Data Rate (kbps)
DM1	1	1	17	2/3	108.8
DM3	3	2	121	2/3	387.2
DM5	5	2	221	2/3	477.8
DH1	1	1	27	----	172.8
DH3	3	2	183	----	585.6
DH5	5	2	339	----	732.2

The rest of the paper is organized as follows. Section 2 introduces different types of polling algorithms. Section 3 describes in details the proposed Priority Gated Round Robin (PGRR) polling algorithm. Section 4 discusses the simulation model used to study the proposed algorithm in different cases. Section 5 presents the simulation results of the proposed PGRR algorithm, and compares it with the existing Gated Round Robin (GRR) polling algorithm. Finally, concluding remarks are summarized in Section 6.

2. Related Works

The choice of the polling scheme is the main determinant of transmission performance in bluetooth piconets. Several polling schemes have been proposed and developed in the recent years. The original polling scheme in bluetooth piconet is the Pure Round Robin (PRR). In PRR, the master visits each slave for exactly one frame, and then moves on to the next slave. The sequence of slaves is fixed and does not change [16]. In Exhaustive Round Robin (ERR) polling, the master stays with the slave until both the master and slave queues are empty [10, 13]. Under the Limited Round Robin (LRR) polling scheme, the master stays with a slave for a fixed number of frames [13]. In GRR polling scheme, only the packets buffered at the station when it gets the token are served, while the packets that arrive during the service time are set aside to be served at the next cycle [12]. Limited and Weighted Round Robin (LWRR) scheme adopts a cycle-weighted round robin algorithm with the weights dynamically changed according to the observed queue status [7, 8]. A similar idea is used in the Fair Exhaustive Polling (FEP) scheme, where a pool of active slaves is maintained by the master. The sequence of active slaves in the original FEP is fixed. The scheme can be modified so that this sequence is dynamically determined in each cycle, according to the decreasing length of downlink queues. This modified scheme is referred to as the FEP Longest Downlink Queue First (LDQF) scheme [2].

Under the Exhaustive Pseudo-cyclic Master (EPM) queue length scheme, each slave is visited exactly once per cycle. At the beginning of each cycle, the slaves are reordered according to the decreasing length of downlink queues [9]. Master Slave Queue-State-Dependent Packet Scheduling Policies use reserved bits of transmission packets to inform their own queue state to a master. It has two models of policies: Priority Policy (PP) and K-Fairness Policy (KFP). In the PP, higher priority (higher number of slots) is given to the master-slave connections when both have data to send. While in KFP, Round Robin Scheduling (RRS) is performed among all master-slave pairs. A lower priority pair is sacrificed to a higher priority pair until certain threshold. Once this threshold value is reached, the Round Robin (RR) scheme is resumed leading to degraded performance [6, 14].

Several comparisons between polling schemes have been discussed [2, 12]. It is shown that the conventional scheduling policy PRR is not efficient, since it has to poll the idle slaves with much frequency as the slaves that have data to exchange with the master. In [12], it is proved that both GRR and ERR policies out perform basic PRR when the traffic load is strongly unbalanced which is a likely situation in the WPANs environment. The GRR shows good performance in terms of both fairness and channel utilization, but the average delay increases dramatically as the system approaches stability limit. In order to avoid performance degradation of KFP policy and the increase in the average delay in GRR scheme in addition to achieving fairness among all master-slave connections, the Priority Gated Round Robin (PGRR) scheme is proposed.

3. The Priority Gated Round Robin Scheme

The proposed PGRR scheme develops the existing GRR polling scheme in order to implement the priority among master-slave connections. It classifies the master-slave connections into three classes according to the presence or absence of data in each pair of corresponding master-slave queues. It takes into account downstream queue as well as upstream queue. The status of all slaves' queues is re-examined after each cycle. The PGRR has the following steps:

1. *At the beginning of each cycle, master sends a POLL packet to all slaves in order, asking about the queue size of each slave.*
2. *Slaves respond in order, by either NULL packet if it hasn’t data to send, or a data packet contents the slave's queue size.*
3. *The master classifies the master-slave connections into three classes based on the presence or absence of data at both the Slave Queue (QS) and the respective Master Queue (QM). The state QM or QS denotes that either the master or the slave; respectively has data to transmit and the state* $\overline{QM}$ *or* $\overline{QS}$ *represents the case where there is no data to transmit in either the master or the slave; respectively. The three classes are defined in Table 2.*
4. *The master rearranges the master-slave connections from higher priority to lower priority according to their classes and then, at each class according to the amount of data in each master-slave connection (QM+QS). Mater-salve connections that classified as Class 3 are discarded from this cycle.*
5. *The master polls the slaves in the new order.*
6. *At each master-slave connection, only the buffered packets are serviced, while the new arriving packets wait to the next cycle as in the case of GRR*

algorithm.

The overall algorithm for the PGRR is displayed in Figure 1.

Table 2. Priority classes of master-slave connections.

Priority Classes	**Master-slave connections status**	**Description**
Class 1 (Highest priority)	$QM - QS$	Both the master and the corresponding slave have data to send.
Class 2	$QM - \overline{QS}$ or $\overline{QM} - QS$	Either the master or the corresponding slave has data to send.
Class 3 (Lowest priority)	$\overline{QM} - \overline{QS}$	Both the master and the corresponding slave have no data to send. This class is discarded to avoid the wasted time resulting in polling the idle slaves.

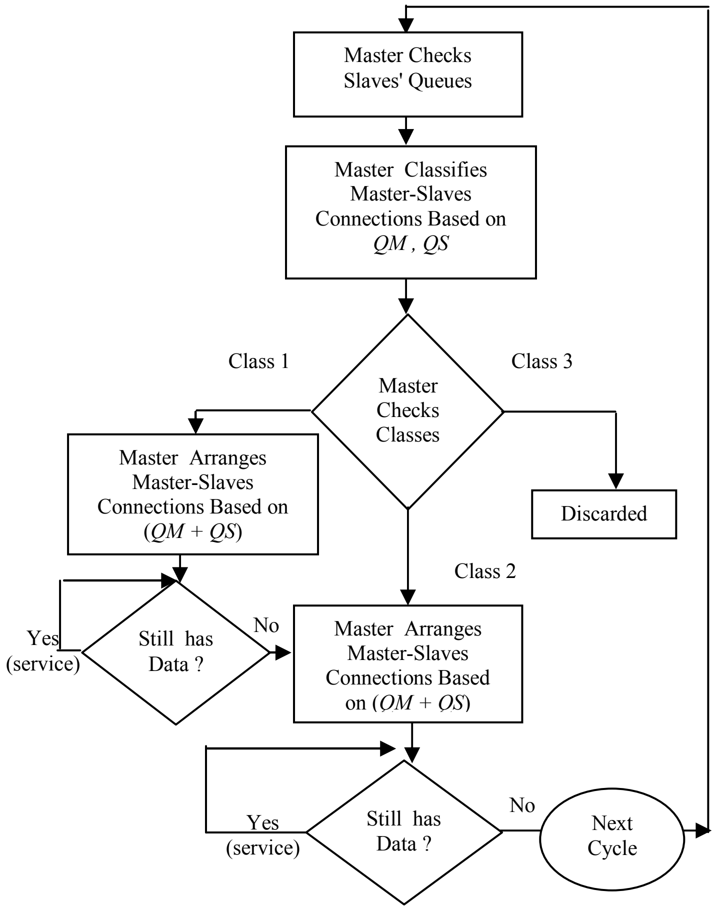


Figure 1. The algorithm for the PGRR.

4. The Simulation Model

Consider an isolated piconet with one master and *N* active slaves, where *N* is varying from one to seven. Master has *N* queues corresponding to the *N* active slaves, and each slave has one queue (consider infinite queues). ACL links only are considered. They are used to transmit data. Data traffic is generated independently for each master-slave connection according to a Poisson process since that it is the most unpredictable processes with respect of the packets arrival times [15]. The six possible packet types which differ for both data rate (either DH or DM) and packet length (1, 3 and 5 time slots) are used. The simulation assumed different number of slaves ranges from piconet has one master and one slave to piconet has one master and seven slaves. Two SAR mechanisms are considered: the traditional mechanism that uses fixed packet length and the best fit mechanism that first divides the total size into the greatest packet length (5 slots), then the remainder into (3 slots) up to (1 slot) packet length. The simulation is performed using MATLAB. It is run 10^6 time slots. The time slot is the bluetooth time slot (625 μs).

When testing different polling algorithms, the main performance issues to take into account as required by bluetooth are total packet delay, wasted time, channel utilization, and fairness. The total packet delay is the time needed for a pair of nodes (master, and slave) to transmit all data packets they have. The wasted time is the idle time slots wasted during transmission. The channel utilization (%) is the ratio of the total number of data packets sent and its transmission time in slots. The fairness can be intended in two ways [12]: a network can be fair in terms of bandwidth allocated to each user or in terms of the time delay each master-slave connection spent until its service is complete.

Focusing on the delay since it has the most importance in real networks, the system is fair if the time which master spent at each slave is approximately equal.

5. Simulation Results

In this section, the performance of the proposed PGRR algorithm is evaluated and compared with the traditional GRR algorithm in the different situations. As it is difficult to distinguish between the all results of the two cases in the Figures since they are too much, tables are used to report the simulation results of the two cases. Table 3 records the simulation results of the delay for both PGRR and GRR. Also, Tables 4 and 5 describe the wasted time and channel utilization; respectively. In all cases, the comparison confirms that the PGRR achieves an improvement in the performance.

Clearly, within the scope of the results, the proposed PGRR scheme is capable of achieving high utilization of the piconet bandwidth in addition to low the tables that Best Fit SAR algorithm (DHx or DMx) always gives better performance than the traditional SAR algorithm (DH1, DH3, DH5 or DM1, DM3, DM5) since it adapts the packet lengths according to the traffic length. Some cases of the packet delay and wasted time. It is also cleared from simulation results are chosen to be presented in the Figures in order to clarify the improvement in the performance over the traditional GRR.

Figure 2 shows the total packet delay for both PGRR and GRR versus load at different number of slaves (3, 5 and 7 slaves) at DH5. It can be clearly observed that the PGRR performs better than GRR, improving the total packet delay with about 30 ms at the case of 3 slaves and 1.2 sec. at 7-number of slaves. The total packet delay is represented for different SAR algorithms in 4 slaves' piconet at Figures 3 and 4. Since that there are many results, some examples of the different SAR algorithms are chosen to be presented in the Figures. Figure 3 displays the cases of DH3 and DHx and Figure 4 displays the cases of DM1 and DM5. It is shown that, the proposed PGRR highly reduces the total packet delay than GRR in all cases of SAR algorithms. This improvement in the delay becomes more noticeable as the load increases.

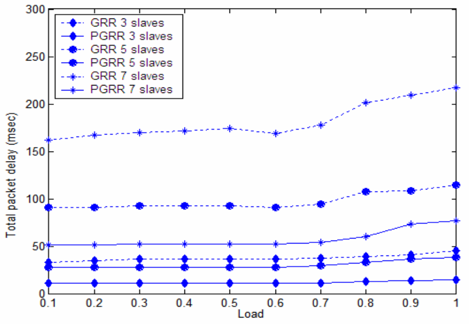


Figure 2. Total packet delay vs. load at 3, 5 and 7 slaves' piconets in DH5.

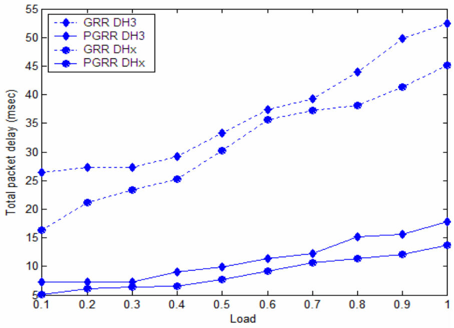


Figure 3. Total packet delay vs. load at DH3 and DHx in 4 slaves' piconet.

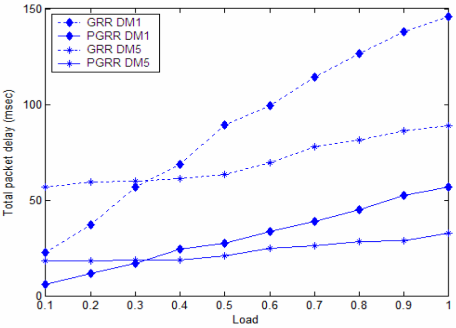


Figure 4. Total packet delay vs. load at DM1 and DM5 in 4 slaves' piconet.

Figure 5 shows the wasted time versus load for both PGRR and GRR algorithms at DM3 and DMx in 4 slaves' piconet. As mentioned above in Table3, the Best Fit SAR algorithm (represented by DMx) causes less wasted time than the traditional SAR algorithm (represented by DM3) since it avoids the waste in the packet lengths. It is also observed that the proposed PGRR algorithm wasted less time than the existing GRR algorithm.

Figure 6 represents the channel utilization for both PGRR and GRR algorithms versus load at different number of slaves' piconet (4 and 6) in DHx. It is noticed that PGRR performs well for both piconets. It achieves channel utilization about 95% as opposed to only 80% for GRR (for 4 slaves' piconet under a load of 0.6) and 88% as opposed to 76% for GRR (for 6 slaves' piconet under the same load). Figure 7 shows the channel utilization versus load at different SAR algorithms (DH3, DH5 and DHx) in 7 slaves' piconet for both PGRR and GRR schemes. It is clear from the figure that the proposed PGRR scheme improves the channel utilization than the GRR scheme. For example, in the case of DMx at load 0.6, the channel utilization is increased from 84% for GRR to 92% for PGRR.

The fairness in both PGRR and GRR algorithms at DH5 is illustrated in Figure 8. The Figure confirms the previous results reported on total packet delay and channel utilization for the two polling schemes PGRR and GRR. It is observed that how PGRR achieves fairness among the 7 slaves. While using GRR scheme may cause an unfair sharing of capacity between slaves.

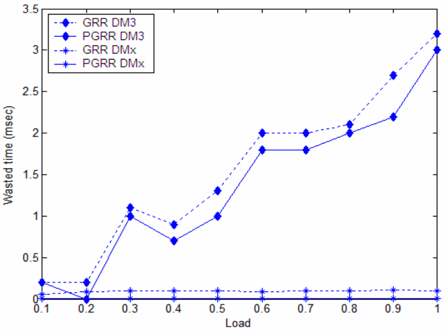


Figure 5. Wasted time vs. load at DM3 and DMx in 4 slaves' piconet.

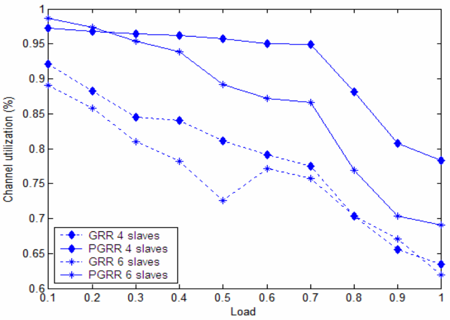


Figure 6. Channel utilization vs. load at 4 and 6 slaves' piconets in DHx.

6. Conclusion and Future Work

In this paper, a new efficient polling scheme called PGRR algorithm is proposed. This scheme develops the existing GRR polling scheme in order to implement the priority among master-slave connections.

Table 3. Total packet delay for both PGRR and GRR algorithms at different packet types at load 0.7.

Total Packet Delay (msec)	**1 slave**		**2 slaves**		**3 slaves**		**4 slaves**		**5 slaves**		**6 slaves**		**7 slaves**	
	GRR	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***
DH1	6.36	1.89	20.06	7.13	43.76	15.11	76.97	24.9	112.77	38.51	159.56	53.77	206.46	72.86
DH3	3.66	1.11	10.55	3.53	23.36	7.21	39.32	12.25	60.61	19.26	85.42	26.87	112.04	35.46
DH5	2.84	1.89	17.75	5.65	37.09	11.17	62.8	18.8	94.44	29.61	131.77	41.25	177.51	53.52
DHx	1.68	0.36	9.49	2.76	14.17	3.28	29.02	10.36	55.8	13.11	70.22	19.66	80.18	26.48
DM1	8.61	4.21	31.1	11.98	64.46	23.66	114.1	38.62	174.91	59.91	242.32	79	325.41	109.06
DM3	5.16	1.29	15.05	4.47	30.39	10.49	51.1	16.2	80.04	25.24	110.96	37.3	154.64	49.31
DM5	7.26	2.38	22.48	7.83	44.62	14.92	77.99	26.3	117.72	40.3	167.78	53.03	220.26	74
DMx	3.97	0.71	9.59	3.02	20.24	6.46	41.64	12.51	63.66	15.26	92.06	20.78	99.72	45.75

Table 4. Waste Time for both PGRR and GRR algorithms in different packet types at load 0.7.

Waste time (msec)	**1 slave**		**2 slaves**		**3 slaves**		**4 slaves**		**5 slaves**		**6 slaves**		**7 slaves**	
	GRR	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***
DH1	1.9	0.2	5.4	4.9	9.9	6.6	10.6	7.1	13.1	12.6	16.9	14.2	17.0	15.8
DH3	0.188	0.013	0.9	0.6	0.9	0.1	1.1	0.9	1.6	1.3	1.8	1.5	2.1	1.7
DH5	0.063	0	0.5	0.125	0.187	0.063	0.2	0.2	0.21	0.20	0.25	0.23	0.4	0.3
DHx	0.003	0.001	0.046	0.031	0.079	0.038	0.011	0.007	0.013	0.007	0.016	0.008	0.017	0.009
DM1	2.3	1.4	8.5	8.2	14.6	14.3	16.3	16.0	18.9	16.4	28.8	27.7	29.4	28.1
DM3	0.5	0.313	1.2	1.1	1.4	1.8	2.0	1.8	2.1	2.0	3.2	3.1	4.1	3.4
DM5	0.375	0.063	0.8	0.438	0.9	0.1	1.1	1.0	1.1	1.0	1.6	1.3	2.6	2.0
DMx	0.003	0.001	0.061	0.044	0.081	0.046	0.090	0.050	0.129	0.062	0.164	0.079	0.207	0.115

Table 5. Channel utilization for both PGRR and GRR algorithms in different packet types at load 0.7.

Channel Utilization (%)	**1 slave**		**2 slaves**		**3 slaves**		**4 slaves**		**5 slaves**		**6 slaves**		**7 slaves**	
	GRR	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***	***GRR***	***PGRR***
DH1	0.6974	0.7071	0.6550	0.7627	0.6983	0.7349	0.6820	0.8326	0.7005	0.7657	0.6829	0.7837	0.6976	0.7690
DH3	0.2643	0.3150	0.2578	0.3156	0.2600	0.3134	0.2600	0.3162	0.2583	0.3151	0.2585	0.3136	0.2578	0.3126
DH5	0.1176	0.1343	0.1176	0.1339	0.1187	0.1343	0.1184	0.1336	0.1189	0.1341	0.1187	0.1344	0.1190	0.1344
DHx	0.7921	0.8846	0.7425	0.8345	0.7761	0.8394	0.7750	0.9491	0.8688	0.8643	0.7571	0.8662	0.7844	0.8468
DM1	0.7416	0.7636	0.7062	0.8038	0.7326	0.7814	0.7175	0.7495	0.7110	0.7634	0.6952	0.7761	0.7001	0.7470
DM3	0.2771	0.3084	0.2640	0.3084	0.2695	0.3089	0.2653	0.3090	0.2715	0.3069	0.2651	0.3086	0.2707	0.3134
DM5	0.1217	0.1381	0.1270	0.1367	0.1256	0.1376	0.1262	0.1378	0.1254	0.1376	0.1258	0.1395	0.1252	0.1377
DMx	0.8039	0.8528	0.8282	0.9451	0.8021	0.8059	0.8435	0.8732	0.8443	0.8836	0.7220	0.8536	0.8194	0.8949

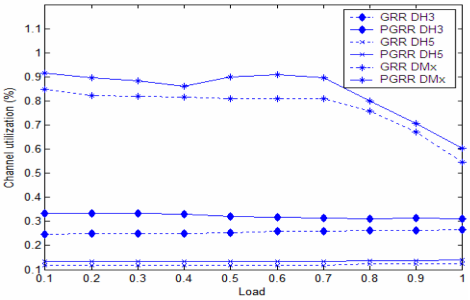
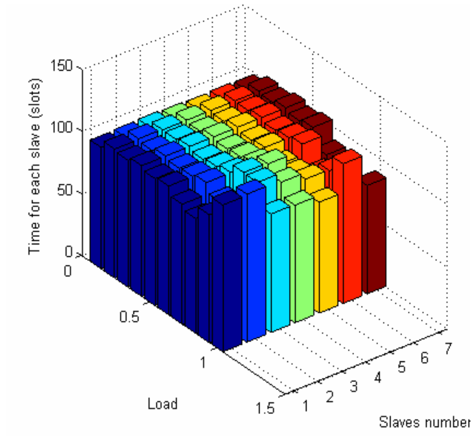
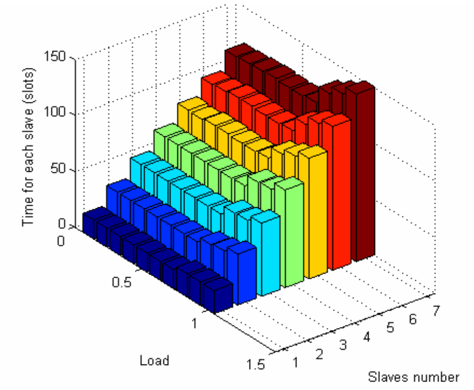


Figure 7. Channel utilization vs. load at DH3, DH5 and DMx in 7 slaves' piconet.

It classifies the master-slave connections into three classes according to the presence or absence of data in each pair of corresponding master-slave queues. Then, it also arranges master-slave connections in each class based on the amount of data in each master-slave connection. The simulation results prove that the proposed PGRR scheme is fair and capable of achieving high utilization of the piconet bandwidth in addition to low packet delay and wasted time. The simulation results also show a highly improvement in the performance over the traditional GRR algorithm. Subject seems to be of great interest for future work is using this scheme to transmit voice over different types of ACL links.



(a) PGRR algorithm.



(b) GRR algorithm.

Figure 8. Fairness in both PGRR and GRR algorithms at DH5.

References

[1] Chakrabarti S., Vuong S., Sinha A., and Paul R., "Convergence in Bluetooth and 802.11 Networks," *in Proceedings of IEEE Conference on Software, Telecommunications, and Computer Networks (SoftCOM)*, Croatia and Italy, 2004.

[2] Chan K., Mišić V., and Mišić J., "Efficient Polling Schemes for Bluetooth Picocells Revisited," *in Proceedings of the 37th Hawaii International Conference on System Sciences*, 2004.

[3] Das A., Ghose A., Razdan A., Saran H., and Shorey R., "Enhancing Performance of Asynchronous Data Traffic over the Bluetooth Wireless Ad-Hoc Network," *in Proceedings of IEEE INFOCOM'01*, 2001.

[4] Haartsen J., "The Bluetooth Radio System," *in Proceedings of IEEE Personal Communications Magazine*, vol. 7, no. 1, pp. 28-36, 2000.

[5] Jahansson P., Kazantzidis M., Kapoor R., and Gerla M., "Bluetooth: An Enabler for Personal Area Networking," *in Proceedings of IEEE Network*, pp. 28-37, 2001.

[6] Kalvala J. and Zaruba G., "Differentiated Priority Scheduling and Adaptive Segmentation for Bluetooth Piconets," *in Proceedings of the 39th Hawaii International Conference on System Sciences*, 2006.

[7] Kapoor R., Zanella A., and Gerla M., "A Fair and Traffic Dependent Polling Scheme for Bluetooth," *in Proceedings of the Joint IEEE Conferences ICWLHN'2002 and ICN'2002 Atlanta*, USA, pp. 26-29, August 2002.

[8] Lee Y., Kapoor R., and Gerla M., "An Efficient and Fair Polling Scheme for Bluetooth," *in Proceedings of the MILCOM'2002*, vol. 2, pp. 1062-1062, 2002.

[9] Lin T., Tseng Y., and Lu Y., "An Efficient Link Polling Policy by Pattern Matching for Bluetooth Piconets," *in Proceedings of the 36th Hawaii International Conference on System Sciences*, 2003.

[10] Mercier A., Minet P., and George L., "A Class-Based EDF Scheduling for Bluetooth Piconet," *Ad Hoc & Sensor Wireless Networks*, vol. 1, pp. 343-364, 2005.

[11] Miller B., and Bisdikian C., *Bluetooth Revealed: The Insider's Guide to an Open Specification for Global Wireless Communications*, Prentice Hall, 2001.

[12] Miorandi D., Zanella A., and Pierobon G., "Performance Evaluation of Bluetooth Polling Schemes: An Analytical Approach," *Mobile Networks and Applications MONET*, vol. 9, no. 1, pp. 63-72, 2004.

[13] Mišić V. and Mišić J., "Modeling Bluetooth Piconet Performance," *in Proceedings of IEEE Communications Letters*, vol. 7, no. 1, 2003.

[14] Oh J., Joo Y., Kwon O., Kim Y., Lee T., and Tchah K., "Differentiated Fairness Guaranteeing Scheduling Policies for Bluetooth," *in Proceedings of IEEE*, pp. 923-926, 2002.

[15] Saidane L., Minet P., Ayed S., and Mercier A., "Deterministic and Probabilistic QoS Guarantees in a Bluetooth Piconet with 1-RR/FIFO Scheduling," *in Proceedings of the Advanced International Conference on Telecommunications and International Conference on Internet and Web Applications and Services (AICT/ICIW)*, 2006.

[16] Zussman G., Yechiali U., and Segall A., "Exact Probabilistic Analysis of the Limited Scheduling Algorithm for Symmetrical Bluetooth Piconets," *IFIP TC6 PWC 2003, LNCS 2775*, pp. 276-290, 2003.

Asmaa Ibrahim is a staff member in Electrical Engineering Department in Suez Canal University, Egypt. She received a BSc degree in computer and control engineering in 2003. She is currently a MS candidate in wireless computer networks.

Rawya Rizk is an assistant professor in Electrical Engineering Department, Suez Canal University, Egypt. She received her BS degree, MS degree, and PhD degree in computer and control engineering, Suez Canal University, in 1991, 1996 and 2001; respectively. Her research interests are in the area of computer networking, including mobile networking, ATM, QoS, traffic and congestion control, and handoffs.

Gamal Mahmoud is an associate professor in Electrical Engineering Department, Suez Canal University and a Vice Dean at The Higher Institute of Management and Computer, Port-Said, Egypt. He received his BS degree and MS degree in electrical power engineering from the Suez Canal University, Egypt in 1976 and 1980; respectively. He received his PhD degree from the University of New Castle Upon Tyne, England in 1986. During 1990 he was a post doctor visiting in the Department of Electrical Engineering, Iowa State University, USA. His research interests include computer applications in electrical power systems, power system stability, and catastrophe theory and its applications in electrical power systems.