An Efficient Polling Strategy for Bluetooth Piconets using Channel State Information

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Abstract **- Bluetooth is an emerging technology for personal wireless communications and is being applied in many scenarios. In this paper we investigate the data scheduling policy for Bluetooth piconets. In general the performance evaluation of most piconet scheduling algorithms recently proposed do not consider the packet losses in the wireless channel. However in environments with high interference or mobility, the channel conditions can mitigate the performance of the polling strategies. In this work we propose a new piconet scheduling algorithm based on the estimated channel state information. The channel is modeled using the Nakagami-m distribution. The channel quality estimation is based on the received signal-to-noise ratio and on the Nakagami fading parameter m. These two metrics are used by the scheduling algorithm to define the best polling strategy. Simulation results demonstrate the good algorithm performance for different traffic conditions.**

Keywords — ***Bluetooth, Nakagami-m fading, scheduling, wireless networks.***

I. INTRODUCTION

Bluetooth is emerging as an important standard [1] for short range and low-power wireless communications. It operates in the 2.4 GHz ISM (Industrial, Scientific and Medical) band employing a frequency-hopping spread spectrum technique. The transmission rate is up to 1 Mbps, using GFSK (Gaussian Frequency Shift Keying) modulation. The Bluetooth MAC protocol is designed to facilitate the construction of ad hoc networks. The devices can communicate with each other forming a network with up to eight nodes, called *piconet*. Within a piconet, one device is assigned as a master node and the others devices act as slave nodes. Devices in different piconets can communicate using a structure called scatternet. The channel is divided in time slots of 625 μs. A time-division duplex (TDD) scheme is used for full-duplex operation.

For data transmission Bluetooth employs seven asynchronous packet types. Each packet may occupy 1, 3 or 5 time slots. The throughput of Bluetooth links using asynchronous packets was investigated in [2] for the additive white Gaussian noise (AWGN) channel and for the Rayleigh fading channel. In [3], we extended the results presented in [2] looking into the performance of Bluetooth links in Nakagami-*m* fading channels. The Nakagami-*m* distribution [4] allows a better characterization of real channels because it spans, via the parameter *m*, the widest range of multipath fading distributions. For m=1 we get the Rayleigh distribution. Using m<1 or m>1 we obtain fading intensities more and less severe than Rayleigh, respectively. The packet error rates (PER) of the asynchronous packets for different values of *m* and signal-to-noise ratios are derived in [3]. In this work we apply the channel modeling derived in [3] for the Nakagami fading channel in order to study the new proposed scheduling algorithm, which uses the channel quality information in the scheduling policy.

This paper is structured as follows: in Section 2 some issues about piconet scheduling and related works are presented. In Section 3 we draw some considerations about channel state estimation. Section 4 proposes a new strategy based on channel quality estimation and Section 5 shows the simulation results for different scenarios. Finally, conclusions are drawn in Section 6.

II. RELATED WORK ON PICONET SCHEDULING

In a Bluetooth piconet, the channel access is controlled by the master. A slave can send a packet only if it receives a polling packet from the master. The master transmits packets to the slave in even slots while the slave transmits packets to the master in odd slots. Thus, Bluetooth is a master driven TDD standard and this poses several challenges in scheduling algorithms since there could be a waste of slots if only the master or the slave has data to send. Recently, many schemes have been proposed in the literature for piconet and scatternet scheduling.

In [5], several polling schemes are compared. In the round robin scheme a fixed cyclic order is defined and a single chance to transmit is given to each master-slave queue pair. The exhaustive round robin (ERR) also uses a fixed order but the master does not switch to the next slave until both the master and the slave queues are empty. The main disadvantage of the ERR is that the channel can be captured by stations generating traffic higher than the system capacity. A limited round robin (LRR) scheme that limits the number *t* of transmissions can solves this problem. A new scheme called LWRR (limited and weighted round robin) with weights dynamically changed according to the observed queue status is also presented in [5]. Other works about piconet scheduling consider QoS issues in Bluetooth, such as [6] and [7]. The results in [5], [6] and [7] do not consider any loss model for the wireless channels.

In [8], a scheduling policy based on slave and master queues is shown. The master-slave pairs are distinguished based on the size of the Head-of-the-Line (HOL) packets at the master and slave queues. Then, the pairs are classified in three classes according to slot waste. This information is used in the HOL K-fairness policy (HOL-KFP) [12]. When the authors introduced channel errors, the HOL-KFP had its performance reduced. An extension for HOL-KFP called wireless adapted-KFP (WAKFP) was proposed and the results indicate that a better performance is achieved in the presence of channel errors [12].

In [9] an algorithm called Bluetooth Interference Aware Scheduling (BIAS) is presented that uses a channel estimation procedure in order to detect the presence of other wireless devices in the same band (such as other Bluetooth or IEEE 802.11b devices). The scheduling algorithm will avoid packet transmission in frequencies that have a high bit error rate (BER), called bad frequencies. This fact reduces the packet loss due to interference of other near devices.

Few of the scheduling schemes presented here consider a loss model for the wireless channel. The works in [8] and [9] use a simple error model. In this paper we use the Nakagami fading for the transmission channel and propose a new scheduling algorithm based on channel state information.

III. Channel State Information

In order to obtain the channel state information, two parameters need to be estimated: the average received signal-to-noise ratio (SNR) and the Nakagami fading parameter *m*. In [10] is proposed an online SNR estimator for generalized fading channels, which does not require the transmission of known training symbols. It is based on a block observation of the demodulated symbols. The values of SNR had a good accuracy for an analyzed block size of 5000 bits and a reasonable accuracy for 1000 bits. This technique could be as well applied to the Bluetooth link SNR estimation with a low computational cost.

Also many estimators have been proposed in the literature for the parameter *m*. In [11], Cheng and Beaulieu proposed a family of new moment-based estimators, using both integer and non-integer sample moments. These estimators are efficient for moderate number of samples and are suitable for implementations of low complexity. The received SNR and the Nakagami *m* parameter can be jointly estimated using the above described strategies. We consider these two metrics for use in the polling strategy.

IV. Proposed Scheduling Algorithm

Therefore, the condition of the channel can affect the performance of the piconet and the polling strategy. In mobile environments, the status of the wireless channel changes very rapidly and this means that a better performance will be achieved if a node is polled at the moment it has a good channel condition and not polled when the conditions are bad. Since Bluetooth is a technology designed for WPANs (Wireless Personal Area Networks), channels errors due to mobility and interference of other devices are very common. A good scheduling algorithm must consider these issues.

We propose an algorithm – called Bluetooth Channel State Scheduling (BCSS) algorithm – that uses the channel state information for piconet scheduling. The values of the fading parameter *m* and the SNR can be easily estimated as discussed in Section 3. The master will carry out the estimations using the data packets exchanged with the slaves. Every time a master receives a packet, the values of *m* and SNR for that link will be updated. Since this task does not require extra information to be exchanged between the master and the slaves, no extra time is added to the scheduling policy. The estimation accuracy of *m* and SNR will be low at the beginning of the transmission, when few packets were exchanged and the amount of bits to be analyzed is not significant. However after a few time slots transmission, the estimated values will quickly converge to the true values. In the new scheduling policy, the master will poll only the slaves that are above a certain threshold for *m* and SNR, indicating a good channel state. The slaves that are below the threshold, indicating that they are at a bad channel state, will be jumped for at most t_j times. It can be seen that if the channel state is always good the algorithm is reduced to a round robin policy.

V. Simulation Results

We developed an event driven simulator in C++ to compare the BCSS algorithm with round robin and ERR strategies. The effects of Nakagami fading are simulated using the models described in [3]. A Poisson traffic source was assumed for the traffic generation in each piconet node. This model can simulate various applications of Bluetooth. In the first simulation scenario we investigate the influence of the fading parameter *m* in a round robin scheduling. It consists of a piconet with a master and 7 slaves separated by a distance *d*. The parameter λ is the mean arrival rate in packets per time slot. Fig. 1 shows the average delay for this scenario for three different values of *m*, using DM1 packets. In this scenario all nodes have the same traffic conditions. We can observe that the state of the channel has great influence in the average delay of the piconet, affecting the performance of the network.

In the second simulation scenario a piconet with the master and 4 slaves is considered. Fig. 2 and 3 compare the average delay for different traffic conditions and DM1 packets using round robin, ERR and BCSS algorithm, for distances of seven and ten meters. In the BCSS algorithm we choose t_j=6 and a threshold *m*=1. This means that only the slaves with *m* greater than one will be polled, and the others will be jumped for at most six times. The traffic is the same in the master and the slave queues. In the simulation we assume that the channel conditions are changing every two rounds of the polling scheme. We also consider this scenario with *d*=10m for different traffic conditions in the master and slave links, as defined in Table 1. The results are shown in Fig. 4. The simulation results show that the BCSS algorithm improves its performance when the traffic is high. For low traffic, ERR has the best performance. In [5] and [12] was also concluded that the exhaustive service (ERR) does not have good performance under high traffic.

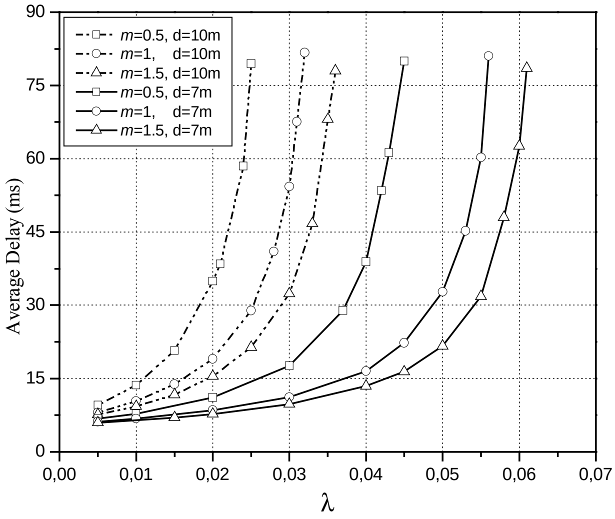

Fig. 1. Average delay for different values of *m*

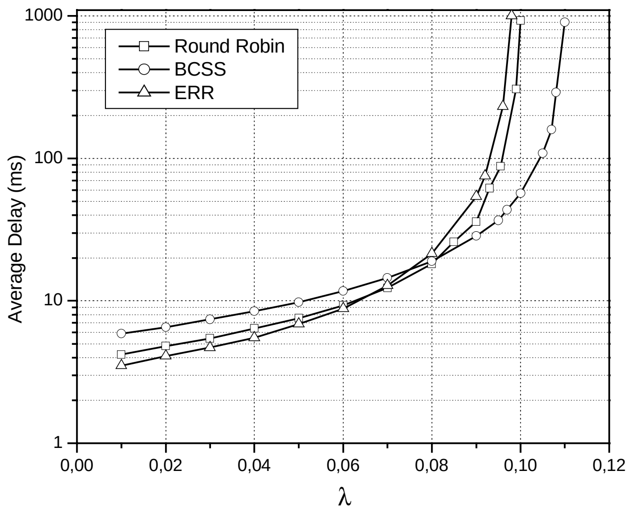

Fig. 2. Average delay for *d* = 7m

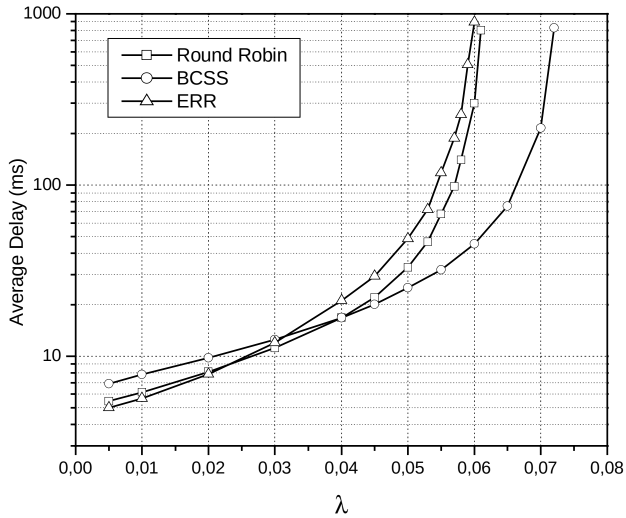

Fig. 3. Average delay for *d* = 10m

TABLE I - TRAFFIC CONDITIONS FOR MASTER-SLAVE LINKS

Traffic Scenario	λ_1 (master-slave 1)	λ_2 (master-slave 2)	λ_3 (master-slave 3)	λ_4 (master-slave 4)
1	0,01	0,01	0,02	0,02
2	0,01	0,01	0,04	0,04
3	0,03	0,05	0,03	0,05
4	0,03	0,03	0,06	0,06

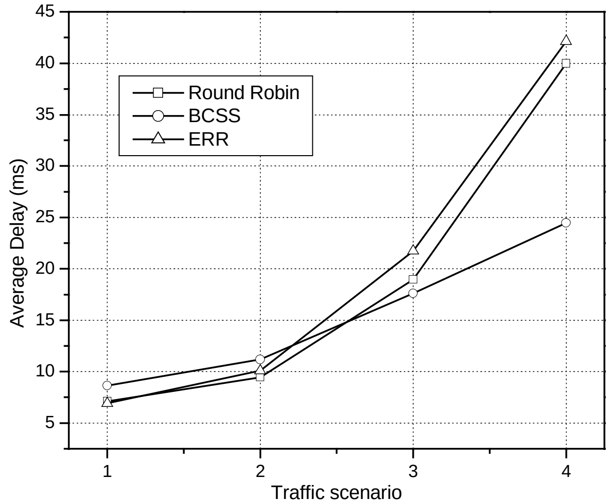

Fig. 4. Average delay for different traffic scenarios

VI. CONCLUDING REMARKS

This paper studied scheduling algorithms in the presence of errors and presented a piconet scheduling algorithm based on the estimation of the channel state using the signal-to-noise ratio and the Nakagami fading parameter *m*. The BCSS algorithm is considerably efficient for high traffic loads if the channel conditions change frequently. These variations in channel conditions are present in many applications of Bluetooth in environments with interference and mobility. The BCSS algorithm can be combined to other scheduling policies to improve their performance. This work can be extended to evaluate the performance of the proposed algorithm with different traffic sources, such as FTP, HTTP and voice.

Our future works include improvements to the intra-piconet scheduling policy and implementation of an inter-piconet scheduling scheme for scatternets. The parameter *m* and the SNR can also be used for other important issues in Bluetooth, like scatternet formation, routing and energy saving techniques.

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