ADAPTIVE PACKET SELECTION ALGORITHM FOR BLUETOOTH DATA PACKETS

RADOSVETA SOKULLU AND ENGIN KARATEPE
Department of Electrical and Electronics Engineering
Ege University
35100 Bornova, Izmir, Turkey

Abstract **-** In this paper we present a Matlab-Simulink model for performance evaluation of Bluetooth DHx data packets. The simulation model developed takes into account channel quality, distance and interference in the Bluetooth frequency band. We propose a new adaptive algorithm for packet selection based on the number of retransmissions until successful packet reception under current environment conditions. The results obtained using the simulation model have proved the increase in performance provided by this algorithm.

Key words: - Modeling Bluetooth ACL packets, adaptive packet selection, Matlab-Simulink.

1. Introduction

Even though Bluetooth is already a well established short range wireless technology due to its very low price, easy implementation, versatility and great user convenience it provides, increasing its throughput and performance is still an open research issue. Simulation models play a great role in this process because they allow multifaceted parameter and performance evaluation, testing and optimization because they allow for reducing the price and risks of hardware implementation. Research groups have dealt with simulating voice packets, investigating performance under different channel conditions and suggested algorithms for choosing best performing packet types.

In [Dogan K. et al. 2004] the authors have tested Bluetooth performance for different BER and according to the results provided estimation for most suitable packet type selection in a certain BER range. In [Valenti 2002] the authors suggest a dynamic selection scheme based on measurements for SNR. In [Golmie 2003] a detailed OPNET Bluetooth model is developed and the mutual interference of Bluetooth and 802.11b system is evaluated. In [Ju M-C 2002] behavior of different packets is examined a link management scheme is suggested based on a set of rules analytically derived from channel quality measurements. In another article [Floren 2004] the authors give an analytical expression for the throughput as a function of the number of frequency channels used for frequency hopping and the duration of the packet types. [Golmie 2003] suggests two schemes for dynamic transmission scheduling based on classifying the frequencies as “good” or “bad” depending on the registered packet loss, called BIAS (Bluetooth Interference Aware Scheduling) and AFH (Adaptive Frequency Hopping). Even though they give quite good results they are quite complex to realize. Another drawback of most models is the fact they concentrate either on the physical or link layer only. Matlab-Simulink is an integrated simulating environment which allows both very precise physical layer description as well as system level description. This is also supported by the fact that the new version of Matlab 7.0 has included and example of simulating Bluetooth SCL packets. In a previous work [Sokullu 2005] we have developed and tested simulation models for the DMx packets. In this work we provide models for the DHx packets and incorporate all data packet types in a Matlab-Simulink model.Further on we simulate the performance of a new, simple to implement adaptive packet selection algorithm based on counting the number of retransmissions required until a packet is received successfully under different environment conditions including both interference and variable distance between the devices.

From here on the paper is organized as follows. In the next part we present a brief review of Bluetooth and the structure of different packet types. In part 3 we discuss our simulation model and in part 4 the suggested adaptive packet selection algorithm. Following that we present simulation results and conclude the paper.

2. Bluetooth ACL Packets Structure

Bluetooth is a short distance (10 to 100 m) wireless technology in the ISM (2.40-248 GHz) band based on FHSS. Communication is carried out according to a master slave model. A master and max of 7 active slaves form a piconet using TDD and transmission is divided into time slots of 625 μs duration. Information, both voice and data is carried in packets. The Bluetooth standard specifies different structure for voice, data, and control packets. Data packets are divided into DMx and DHx types. The DM packets carry control and data information protected by FEC and were envisaged for noisy channels, while the DHx type packets carry more data without FEC. All packets are divided into tree subtypes – DM1/DH1, DM3/DH3 and DM5/DH5 depending on the number of time slots they occupy. After the master addresses a slave in one slot the active slave has to respond in the next slot with either a 1-slot (DM1/DH1), 3-slot (DM3/DH3) or 5-slot (DM5/DH5). The selection of the suitable packet to be used is very important and highly depends on the channel and interference at a certain moment in time. DM1 carry least information but are suitable for worst conditions, while DH5 packets carry most information which is least protected against errors. Selecting the most suitable packet type is a major factor in ensuring highest throughput under specific channel conditions.

As in general the practically achievable data rates are quite low (despite the theoretical 1 Mbps a practical max is about 700 kbps) implementing a suitable packet type selection algorithm is of utmost importance. Such an algorithm has to be easy to implement and simple to operate in order to meet the performance requirements. The decision of our simulating tools, models and environment has been governed by the need to precisely reflect the specifics of both physical and data link layer functions. In all previous work known to us either one or other aspect has been favored depending on the specifics of the simulation tool used.

2.1 Structure of the ACL packet types

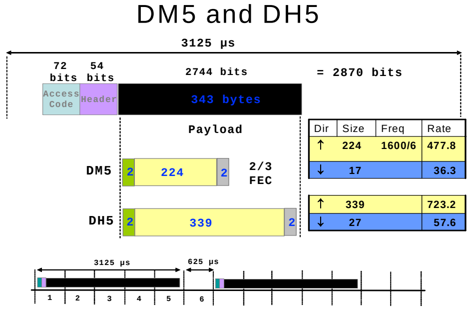
The Asynchronous Connectionless Link (ACL) is a point-to-point connection between a master and active slaves in the piconet. An automatic Repeat Request (ARQ) is applied to ACL packets and they are repeated until a positive ACK is received. The positive ACK is piggy-backed in the header if the returned packet. The ARQN is set to 1 or 0 depending on whether or not the previous packet was successfully received. Packets consist of three major parts: a 72-bit Access Code, a 54-bit Header and a variable length Payload, which has is own header data part and CRC. The first bit from the packet that is transmitted is the LSB. In our simulation this is represented by the first bit of the Access code. The payload field varies depending on the packet type from 0 to a max of 2745 bits. The difference between the user information carrying possibilities are clearly seen if we compare the payload fields: for DM1 the data payload is max 17 bytes, compared to DH1 – 27 bytes; for DM3, which occupies 3 slots, it has a value 121 bytes compared to 183 for DH3; and for DM5 – 224 versus 339 for the DH3 packet type.

Achievable throughput in kbps for different packet types are given in TABLE 1 and an example of the DH5 packet structure and comparison with the DM5 packet type is given in Figure.1

TABLE 1

ACL PACKET TYPES USING ARQ

Packet Type	Duration (slots)	Payload data length (Bytes)	Hamming FEC code?	Peak throughput
DM1	1	17	Yes	108.8 kbps
DH1	1	27	No	172.8 kbps
DM3	3	121	Yes	387.2 kbps
DH3	3	183	No	585.6 kbps
DM5	5	224	Yes	477.9 kbps
DH5	5	339	No	723.2 kbps

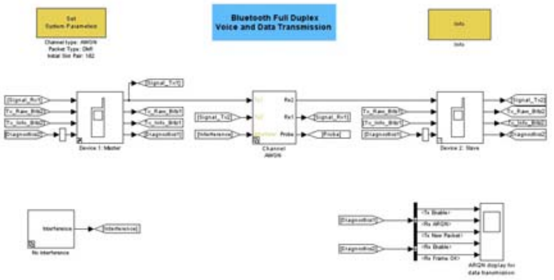


Figures 1: Structure and comparison of the DM5 and DH5 packet types

As defined in the Bluetooth standard, […], the DH1 payload itself consists of 1 byte header, 27 bytes data and 2 bytes CRC. Accordingly the DH3 and DH5 payloads carry 183 and 339 bytes data, accompanied by a 2 byte header and 2 byte CRC.

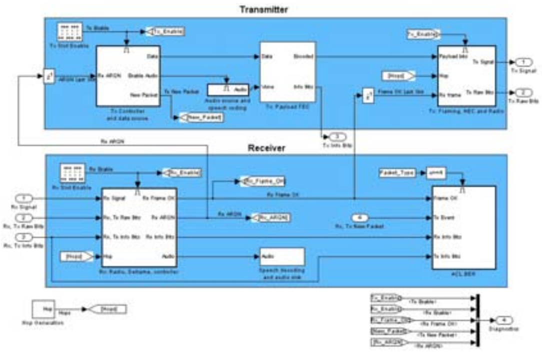
2.2 Simulation model description

We have based our simulation model on the IEEE 802.15.1 and the Bluetooth standard ver.1.2 and realized it using Matlab ver.7.0. The model consists of 4 major building blocks: master, slave, channel and interference. Figure 2 gives the main, top level window of the simulation program.



Figures 2: Main program window

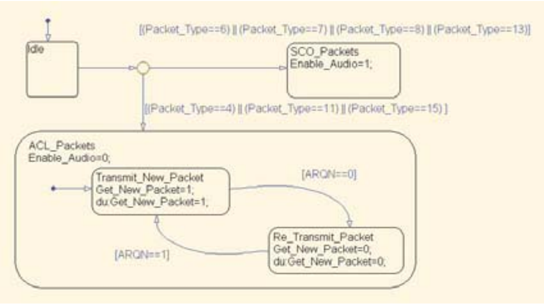
In general each Bluetooth device can function either as a master or a slave depending on the creation of the piconet. The detailed functional structure of our master/slave simulation model is presented in Figure 3. The Bluetooth hopping pattern is implemented using a pseudo-random generator.



Figures 3: Structure of the simulation model of the master/slave

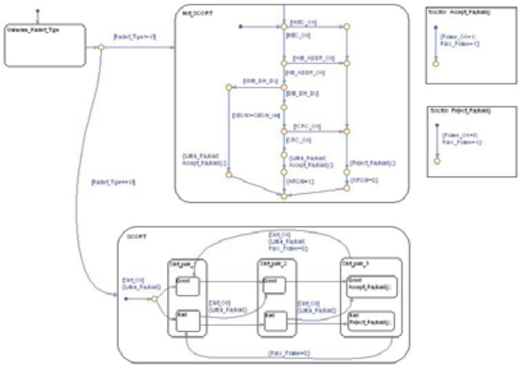
The transmitter block shown in Figure 3 realizes the functions of formatting the data payload, including its header and CRC and incorporating it with the required Access Code and Packet Header. Another major function incorporated here is the selection of a suitable packet type. The decision mechanism has to be embedded in the transmitter part. We assume asymmetric transmission. Besides this the transmitter has an encoder part, while the receiver has a filter part responsible for decoding the incoming data based on the understanding of the packet type. The receiver part contains also the performance metrics evaluation block.

Referring to the OSI Data Link Layer model the functions of data error and flow control are realized using Simulink. An example of the realized data flow model and error correction mechanism is given in Figure 4.



Figures 4: ACL packets data flow control diagram

As seen in Figure 4. This is an asynchronous type transmission and an ARQN=1 requests a new packet to be transmitted while in the opposite case the packet has to be retransmitted. In more detail, at the receiver side the first operation is checking the received packet for errors in the CRC. If the output is a Frame_OK the rest of the packet parts are checked and finally the packet is accepted. In the opposite case the packet is discarded and the ARQN is set to 0. A more detailed receiver side control flowchart is represented in Figure 5. It should be noted that there are differences in the master and slave decision mechanism which for simplicity are not included here.

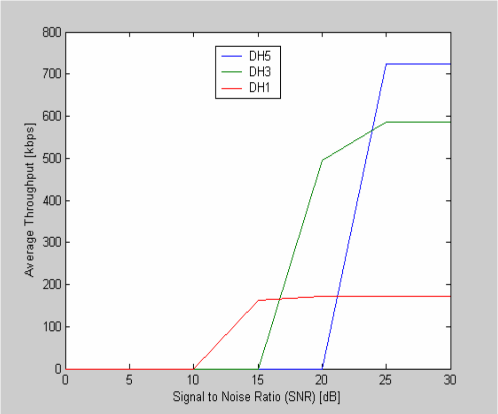


Figures 5: Details of ACL packets data flow control

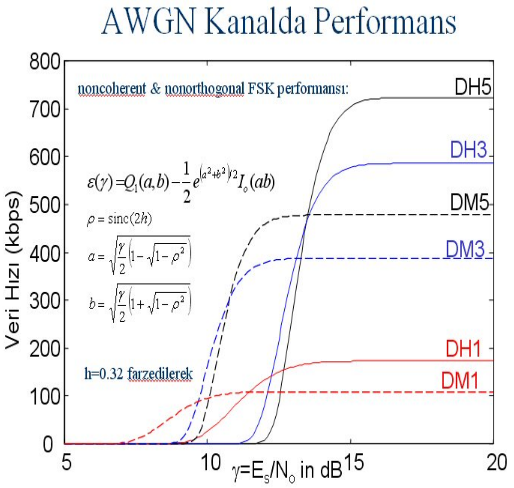
As far as the channel and interference block is concerned we have considered an AWGn channel and 802.11b interference as well as the effect of distance between the master slave pair and interference sources.

2.3 Simulation results

In Figure 6 we present results for the throughput as a function of EsNo achieved with different DH1, DH3 and DH5 packet types for a noiseless channel using model presented in detail in the previous subsection. It has been verified against the analytical model from [VAlenti 2002.] given for reference in Figure 7.



Figures 6: Throughput against Es/No for DH1, DH3 and DH5 packet types



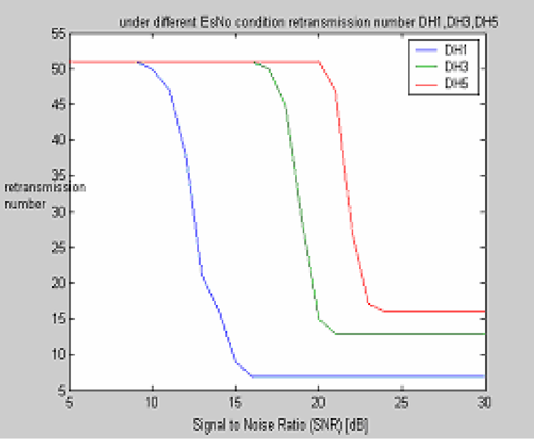
Figures 7: Analytical model from [Valenti 2002]

3. Adaptive Packet Selection Algorithm

Main objective of the ACL packets in the Bluetooth technology is carrying asynchronous data with min error and max throughput independent of the environment with a limited predetermined power levels. Frequency hopping allows for continuous change of the transmission frequency which leads to reducing effects of interference in certain bands. In some work elaborate frequency selection schemes have been proposed to increase mitigate the interference. [4,6]. The disadvantage of these schemes is their complexity in realization and the fact that they require major changes in the radio layer which is undesired by chip producers. Including FEC is an additional measure for ensuring min error rate. But it has also the disadvantage of reducing the user data rate.

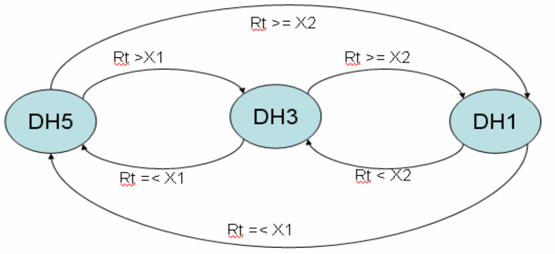
As a measure, specific to Bluetooth different packet types have defined with the aim to select the most suitable one for the given transmission conditions. The standard has left open the details of how these packets will be selected. Most of the suggested schemes are based on measurements and calculations using the LQI which means that they still require changes in the lower layer of the stack. Another group of studies are based on calculating the bit error rate and changing the packet type accordingly. Researchers have provided heuristic algorithms for specific data rate/EsNo combinations [..]

Based on the simulation model we have developed we have investigated the relation between the number of retransmission required until the successful reception of a packet in different noise conditions. The results are given in Figure 8.



Figures 8: Required number of retransmissions for different DH packet types.

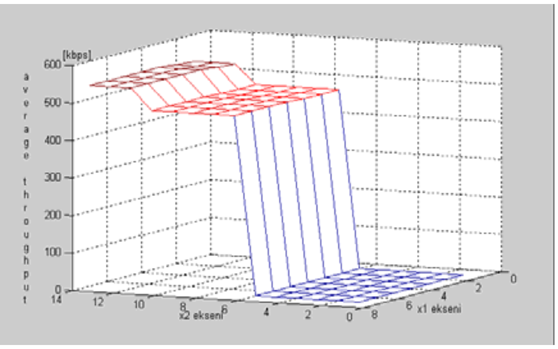
As it can be seen there are distinctive thresholds for different packets and different EsNo. Based on this we have simulated an algorithm for adaptively changing the packet type when a threshold is reached. The decision mechanism is incorporated in the sender side. The state diagram is presented in Figure 9.



Figures 9: State diagram of the suggested algorithm

The decision mechanism is based on two parameters X1 and X2 which reflect the number of retransmissions recorded by the sender. Results (Figure 10) show gradual reduction of the average throughput with worsening channel conditions and easy adaptability to changes independent of the factors causing them.

In another [Sokullu 2006] work we have implemented this algorithm using only changes in the software stack and preliminary results have supported the simulation results presented above. In our experimental setup we have also observed that allowing fragmentation and encapsulation of large used frames using simultaneously two packet types, for example DH3 and DH5 increases the throughput with some10% more.



Figures 10: Results of throughput changes as a function of Es/No using adaptive packet selection.

4. Conclusion

In this paper we describe the model developed for simulating Bluetooth ACL data packets and link management functions using Matlab. We discuss its details and advantages compared to other existing simulation models. Further on we describe and show simulation results for an adaptive selection algorithm for ACL packets. It is fast and simple to realize in software without requiring major changes in the Bluetooth radio. We believe that our work is a contribution to the efforts of the research community to increase with min possible changes in the hardware and firmware of Bluetooth chips the data throughput under changing environmental conditions.

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