Proceedings of the 5th WSEAS Int. Conf. on APPLIED INFORMATICS and COMMUNICATIONS, Malta, September 15-17, 2005 (pp204-208)

Optimizing Packet Size via Maximizing Throughput Efficiency of ARQ on Bluetooth ACL Data Communication Link

LI XIANG, KALUM PRIYANATH UDAGEPOLA, YANG XIAO ZONG
School of Computer Science and Technology
Harbin Institute of Technology
No.92, West Da-Zhi Street, Harbin, Heilongjiang
PR CHINA

Abstract: Based on the acknowledgement history of the most recently transmitted packets, an estimate of the channel bit error rate is made, based on which an optimal packet size can be selected through maximizing the expected throughput efficiency of ARQ protocol on Bluetooth ACL data communication link. Simulation results show that this method works very well even with a short observation history.

Key words: Bluetooth; ARQ; ACL; SCO; Throughput Efficiency; BER

1 Introduction

Bluetooth (BT)[1,2,3] is a short-range radio link intended to be a cable replacement between portable and/or fixed electronic devices. 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 in the piconet and can use all the remaining slots of the channel not used for SCO link. Bluetooth is a frequency hopping system which can support multiple communication channels in a common area (each channel is defined by a unique frequency hopping sequence). Frequency hopping is used in such a way that the radio is turned to the same frequency for the entire duration of the packet, but then changes to a different frequency each time it transmits a new packet or retransmits an erroneous packet. Since the fading and interference in the new frequency channel will be significantly different than that of the previous one, the use of frequency hopping with ARQ provides an effective method of diversity.

Automatic Repeat Request (ARQ) protocols are designed to remove transmission errors from data communications systems. When used over relatively high bit-error rate links (e.g., 10^{-5} or higher) such as wireless or satellite links, their performance is sensitive to the packet size used in the transmission. When too large a packet size is employed, there is an increased need for retransmissions, while too small a packet size is inefficient because of the fixed overhead required per packet. When an ARQ scheme is to be used at the link layer over a relatively high error-rate link, the packet size should be chosen based on the error-rate.

In this paper, we concern with choosing optimal packet payload length on the Bluetooth ACL data communication links, in terms of maximizing the throughput efficiency of ARQ protocol based on the acknowledgement history of the most recently transmitted packets. That is, given the number of packets that required retransmission, an estimate of the channel bit error rate is made, based on which a packet size is chosen to maximizes the expected throughput efficiency of the data link protocol.

2 Bluetooth Data Packets

In Bluetooth, the data on the piconet channel is conveyed in packets. The general packet format is shown in Figure 1. Each packet consists of 3 entities: the access code, the header, and the payload. In fig.1, the number of bits per entity is indicated.

Access Code(72)	Header(54)	Payload(0-2745)

Fig.1 Standard Packet Format

The access code and header are of fixed size: 72 bits and 54 bits respectively. The payload length can range from zero to a maximum of 2745 bits. Different packet types have been defined. Packets may consist of the (shortened) access code only, of the access code − header, or of the access code − header − payload.

Data in Bluetooth can be transmitted asynchronously using ACL packets. In this paper, we mainly focus on ACL packets data transfer used in asynchronously connections, such as summarized in Tab.1, seven ACL packet types are defined in the Bluetooth. DM stands for Data-Medium rate, and DH for Data-High rate. DM packets are all 2/3-FEC encoded to tolerate possible transmission errors. Not encoded by FEC, DH packets are more error-vulnerable, but it can carry more information. Among seven packets all but one of these packet types (AUX1) use a cyclic redundancy check (CRC) code and automatic repeat request (ARQ) for error control. The AUX1 packet is similar to DH1, but it has no CRC code and can’t be re retransmitted, so we don’t take the AUX1 packet into consideration.

Table 1 Summary of Bluetooth ACL data packets

Type	Payload Header(bytes)	User Payload(bytes)	CRC (bits)	FEC
DM1	1	0-17	16	2/3
DH1	1	0-27	16	no
DM3	2	0-121	16	2/3
DH3	2	0-183	16	no
DM5	2	0-224	16	2/3
DH5	2	0-339	16	no
AUX1	1	0-29	no	no

Then, the six ACL packet types have total maximum payload length as follows: DM1:240、DH1:240、DM3:1500、DH3:1496、DM5:2745、DH5:2744.

3 Selecting Optimal Packet Size

3.1 Throughput Efficiency of ARQ Protocol

A protocol performance is usually characterized by many parameters which are defined by the communication system requirements. The most important parameters are the probability of receiving a message without errors and the protocol throughput efficiency. There are several definitions of the protocol throughput efficiency. Most frequently it is defined as the ratio of the mean number of information bits successfully accepted by the receiver to the number of bits that could have been transmitted during the same time interval[4]. To do so we must first derive an expression for the throughput efficiency of the ARQ protocol. The expressions derived in this section assume the use of an “optimal” ARQ protocol in that only packets containing errors are retransmitted. The throughput efficiency of ARQ scheme that uses packets having n bits of information bits k is determined by[5]:

$$\eta = (\frac{k}{n})/\overline{R} \qquad (1)$$

where, the first term k/n of the above expression represents the ratio of information bits to total bits in a packet, and $\overline{R}$ represents the average number of transmission attempts per packet.

Assuming that the ARQ scheme retransmits a packet until the acknowledgement of a successful reception, the average number of attempts, $\overline{R}$, needed to successfully transmit one packet is given by[6]:

$$\overline{R} = 1\times(1\text{-}p)+2\times p\times(1\text{-}p)+3\times p\times p\times(1\text{-}p)+\ldots$$

$$\Rightarrow \overline{R} = \frac{1}{1-p} \qquad (2)$$

where, p is the packet error rate.

So, for a given p, the throughput efficiency of ARQ that uses packets having n bits of information bits k is given by:

$$\eta = (\frac{k}{n})(1\text{-}p) \qquad (3)$$

3.2 Choosing Packet Size based on History of Transmitted Packets

In Bluetooth wireless connection, in order to guarantee reliable transmission an automatic repeat request (ARQ) mechanism is adopted. That is, the receiving side sends back special control frame as the acknowledgement or negative acknowledgement (ACK/NACK) to the input. In case of losing frame or acknowledgement message, the timer will send out timeout signal when the timer has expired, and to remind other side that some problems have happened and this frame must be retransmitted. At the same time, receiver must be capable of distinguishing between retransmitted and new frame. With an automatic repeat request scheme in Bluetooth specification, DM, DH and the data field of DV packets are transmitted and retransmitted until acknowledgement of a successful reception is returned by the destination (or timeout is exceeded). The acknowledgement information is included in the header of the return packet, so-called piggy-backing. To determine whether the payload is correct or not, a cyclic redundancy check (CRC) code is added to the packet. The ARQ scheme only works on the payload in the packet (only that payload which has a CRC). The packet header and the voice payload are not protected by the ARQ scheme.

Supposed the BER(bit error rate) is b, and *R*, the number of retransmission requests out of the last *M* packet transmissions, and k' is the payload size used in the previous M transmissions. The expected throughput efficiency $\eta_R(k)$ of ARQ protocol packets is given by[7]:

$$\eta_R(k) = \int_b \frac{k(1-p)}{n} \times \frac{\binom{M}{R}(p')^R(1-p')^{M-R}}{\int_b \binom{M}{R}(p')^R(1-p')^{M-R}} \qquad (4)$$

where p' is the packet error rate of *M* packets transmission.

The packet error rate, *p*, for DH packets is[6,8]:

$$p = 1-(1-b)^k \qquad (5)$$

Recalling that DM packets are protected by a (15,10) Hamming code (encoded with a 2/3 block FEC), i.e., in every block, 15 bits are used to encode 10 bits of data, which is capable of correcting one bit error per 15 bit code block. The payload is correctly decoded provided that all code blocks contain one or fewer errors. The packet error rate, *p*, for DM packets can be approximated as:

$$p = 1-((1-b)^{15} + 15b(1-b)^{14})^{k/15} \qquad (6)$$

Combining equations (4)–(6), we can get $\eta_R(k)$ for DH and DM packets respectively as:

$$\eta_R(k) = \int_b \left[\frac{k(1-b)^k}{n} \times \frac{\binom{M}{R}(1-(1-b)^{k'})^R(1-b)^{k'(M-R)}}{\int_b \binom{M}{R}(1-(1-b)^{k'})^R(1-b)^{k'(M-R)}}\right] \qquad (7)$$

$$\eta_R(k) = \int_b \left[\frac{k((1-b)^{15}+15b(1-b)^{14})^{k/15}}{n} \times \frac{\binom{M}{R}(1-((1-b)^{15}+15b(1-b)^{14})^{k'/15})^R((1-b)^{15}+15b(1-b)^{14})^{k'(M-R)/15}}{\int_b \binom{M}{R}(1-((1-b)^{15}+15b(1-b)^{14})^{k'/15})^R((1-b)^{15}+15b(1-b)^{14})^{k'(M-R)/15}}\right] \qquad (8)$$

where, n=k+126.

It is now possible to choose the value of *k*, the payload length to be used in future transmissions, so that the throughput efficiency of the ARQ protocol is maximized. This can be done by choosing the value of *k* that maximizes equation (7) or (8) for a value of *R* that is equal to the number of retransmission requests that occurred during the previous *M* transmissions using the payload size k'.

4 Simulation Results

Usually, the solution way of the maximization problem for $\eta_R(k)$ in equation (7) or (8) is difficult; However, for specific values of *M*, *R* and k' equation (7) or (8) can be solved numerically. An optimal value for *k* can now be found using numerical search algorithms. Since the numerical evaluation of this integral is very intensive, a comprehensive search for the optimal value of *k* is not practical. Instead, a restricted search using select values for *k* can be performed. Such a search, for example, can consider values of *k* that are a multiple of 100; thereby significantly reducing the complexity of the search. Such a restricted search has little impact on the performance of the protocol since values of *k* that are within 100 bits of the optimal block size should result in near-optimal performance.

In figure 2, we plot the optimal payload size when a history of 50 previously transmitted 1500 bit packets payload is considered. As can be seen from the fig.2 (a), for DH packets transmission, when the previous fifty transmissions resulted in no errors the payload length can be maximized to 2744 bits (the maximization throughput efficiency can be gotten at payload length of 3200 bits). When one and two errors occurred the payload length can be increased to 2100 and 1700 bits respectively. When three errors occurred the payload length can be kept at 1500 bits and when more than three errors occur the payload length is reduced. As depicted in fig.2 (b), for DM packets transmission, when the previous fifty transmissions resulted in no errors the payload length can be maximized to be 2745 bits (the maximization throughput efficiency can be gotten at packet payload length of 4400 bits). When one, two and three errors occurred the payload length can be increased to 2500, 1900 and 1600 bits respectively and when more than three errors occur the payload length is reduced.

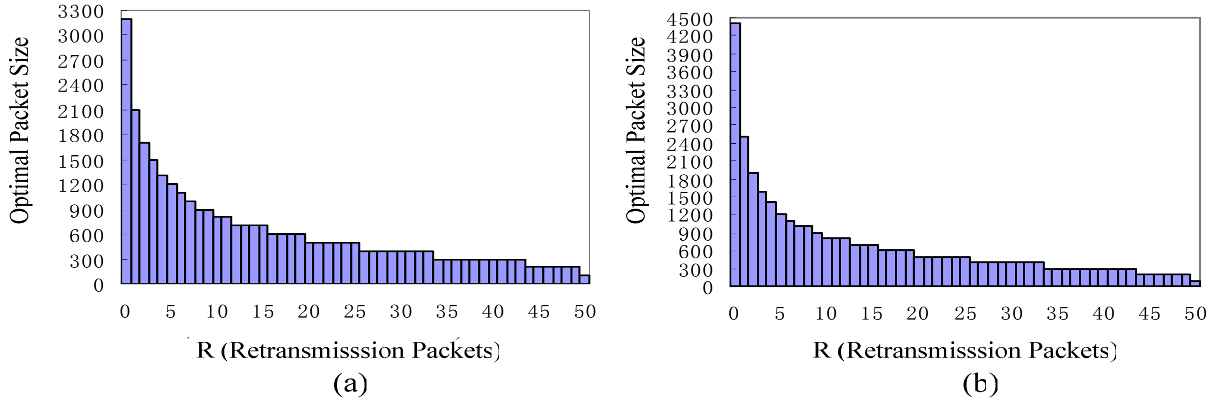

Fig.2 Optimal packet size based on retransmission history of the 50 previous 1500 bit packets transfer. (a) DH packet. (b) DM packet.

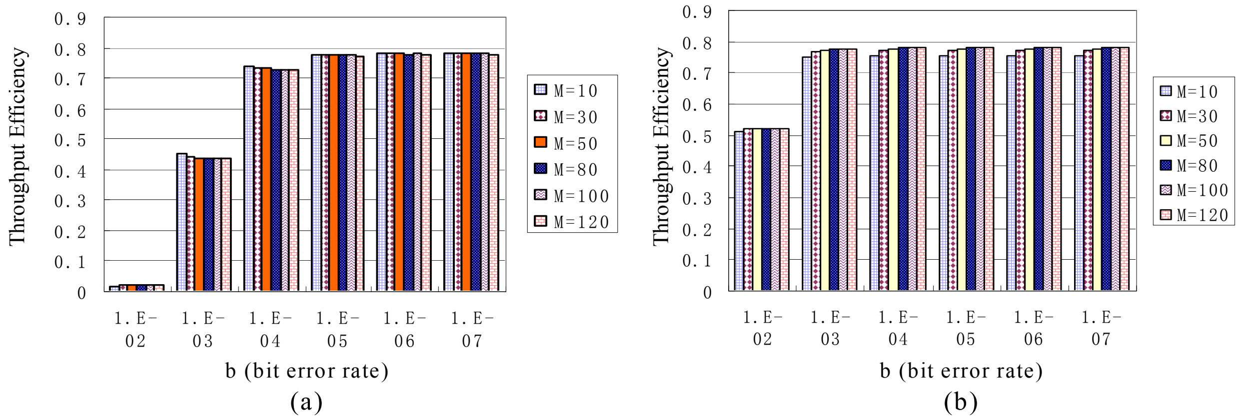

Fig.3 Mean throughput efficiency of algorithm for various b. (a)DH packet. (b)DM packet.

Let $k_{opt}(R)$ be the optimal value of k chosen for a given value of R out of the last M packet transmissions. The efficiency of the ARQ protocol with that value of k can be computed according to equation (3) combined with equation (5) or (6). Then it can be averaged over the distribution of R given b to yield the performance of ARQ for a given value of b. Fig.3 shows the mean throughput efficiency of ARQ with various values of M and b, and a previous packet payload length of 1500 bits. As can be seen from the figure, whether it is DM or DM packets transmission, good performance is obtained with a history of just 7500 bits payload size (50 packets at packet payload size of 1500 bits). When b is higher than 10^{-5}, more of history is required to obtain a reasonable estimate of throughput efficiency for DM packets transmission; but for DH packets transmission, the situation is quite different, only few or the least history of packets transfer is required to obtain high throughput efficiency.

In the previous fifty packets transmission with payload length of 1500 bits, select optimizing packet size under different retransmission packets, fig.4 compares mean throughout efficiency of ARQ during DH and DM packets transmission for various b. It is important to note that the performance of ARQ is much more vulnerable to DH packets when b is high. That is, when b is high the use of DH or DM packet type can have a disastrous effect on the throughput efficiency, and DM packets transfer can produce higher throughput efficiency than DH packets. When b is low, small variations in the throughput efficiency from the different bit error rate b, packet types (DH/DM). So in a high error rate environment, it is better to take DM packets as data transmission, which accords with the capability of DM to tolerate high transmission error rate. Oppositely, in a low error rate environment, it is better to take DH packets as data transmission, it is because not decoded by 2/3-FEC DH packets have relatively higher data transfer rate than DM packets data transmission.

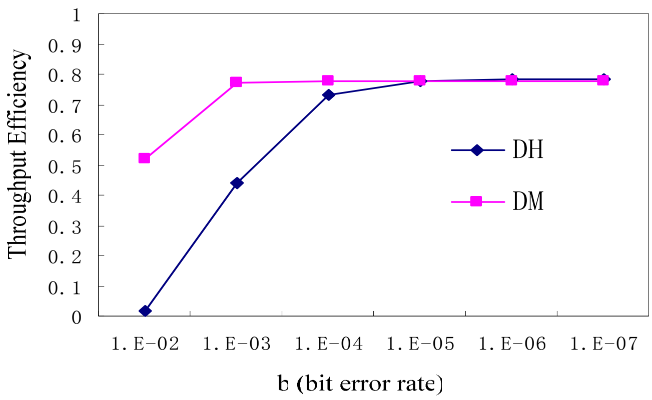

Fig.4 Comparing mean throughput efficiency of DH and DM packets transmission

5 Conclusion

This paper introduces a method to select the optimal packet payload length used by Bluetooth ACL data link layer. The throughput efficiency of ARQ protocol is given based on retransmission history. So, given packet transmission record we can choose the packet size such that the expected throughput efficiency of the ARQ protocol is maximized under different channel BERs (bit error rates). Simulation results show that the method works very well even with a short observation history (50 packets at size of 1500 bits payload, total 7500 bits payload transfer). In a high error rate environment, it is better to take DM packets as data transmission; but in a low error rate environment, it is better to take DH packets as data transmission to improve the data transfer rate.

References:

[1] Bluetooth SIG, Specification of the Bluetooh System, version 1.1, Feb.2001.

[2] J.Harrtsen, *The bluetooth radio system,* IEEE Personal Communicatios, Feb.2000, 7(1): 28-36.

[3] X. Li, X.Z. Yang, *eBlueScatter: an Energy-Efficient Ad Hoc Network Formation Algorithm over Bluetooth,* WSEAS Transactions on Information Science and Applications, 2005, 8(2), pp.1034-1045.

[4] W. Turin, *Throughput analysis of the Go-Back-N protocol in fading radio channels*. IEEE Journal on Selected Areas in Communications, 1999, 17(5), pp. 881-887.

[5] V.P. Pribylov and G.A. Chernetsky, *Throughput efficiency of automatic repeat request algorithm with selective reject in communication links with great signal propagation delay,* in: Proc. of the 3-rd IEEE-Russia Conferences Microwave Electronics: Measurements, Identification (MEMIA'2001), Novosibirsk, Russia, 2001, pp. 202-205.

[6] L.J. Chen, R. Kapoor, M.Y. Sanadidi, M. Gerla, *Enhancing bluetooth TCP throughput via link layer packet adaptation,* in: Proc. of the 2004 IEEE International Conference on Communications (ICC 2004), Paris, France, 2004.

[7] E. Modiano, *An adaptive algorithm for optimizing the packet size used in wireless ARQ protocols*. Wireless Networks, 1999, 5: 279-286.

[8] M.C. Valenti, M. Robert, and J. H. Reed, *On the throughput of bluetooth data transmissions,* in: Proc. of the IEEE Wireless Commun. and Networking Conf., Orlando, USA, 2002, 119-123.