

Performance of Bluetooth Ad-hoc Network with SAW-ARQ Scheme

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Abstract - Addressed in this paper is a simulation performance of ARQ scheme for Bluetooth ad-hoc network for high data rate services and real time web applications in multi-path Rayleigh fading channel. To overcoming the channel errors in the Bluetooth asynchronous connectionless link (ACL), we propose Stop & Wait ARQ scheme that limited the retransmission within the threshold time. Simulation results show that the proposed ARQ strategy significantly improves the throughput and packet error rate (PER) performance compare to conventional retransmission scheme that do not take the channel conditions into account.

Keywords: Bluetooth ad-hoc, ACL packet format, SAW-ARQ, Throughput, PER.

1 Introduction

Bluetooth is a short-range wireless technology that operates in 2.4 GHz ISM band. It can be used as an access point, a cable replacement, and a wireless ad-hoc network between electronic devices [1]-[7]. The critical issue in Bluetooth ad-hoc network is the efficient throughput and packet error rate of high rate data to ensure correctness in the presence of AWGN and multi-path fading. Therefore, Bluetooth provides automatic repeat request (ARQ) scheme to handle the radio link transmission errors [8],[9]. Prior research closest to our paper is that of [10]. In the paper the performance of Bluetooth codec is examined to support a transparent mode for video application in Rayleigh fading channel.

Recently, it is possible to connect everything without any wire including phones, PDAs, PC devices, etc. This has become feasible by the emerging Bluetooth ad-hoc wireless networks concept. Bluetooth is an open technological specification for short-range wireless connectivity between electronic devices. It has been chosen as the baseline for the IEEE 802.15.1 standard for personal area networks (PANs), which can support both synchronous traffic such as voice, and asynchronous data communications.

The Bluetooth standard operates at the 2.4-GHz ISM band and offers the advantage of establishing ad hoc networks, called piconets. This eliminates any need for

having wires between personal devices such as computers, keyboards, printers, mobile phones, LANs, etc, located within a small distance (up to 10 m), hence offering added flexibility for a new range of applications. Up to eight devices constitute a piconet, with a master device coordinating access by a polling scheme. A given device may participate in more than one piconet, leading to an overlapped piconet configuration, also known as a scatternet (Fig. 1). As can be seen from the specifications [1], the Bluetooth design implies that all piconets use the same ISM frequency band and even though they use a different frequency hopping sequence, there could be interference among independent neighboring piconets. Attempts have been made to minimize the effects of inter-piconet interference on throughput by either introducing an interference aware packet scheduling algorithm or by packet segmentation. Interference has also been taken into account when analyzing different scatternet structures. In this paper, we consider the impact of such wireless channel on piconet performance and it can be said to serve as a basis for future work in this area.

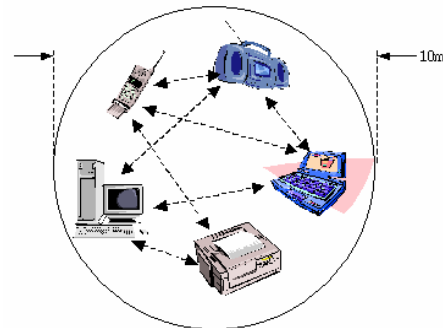


Fig. 1 Bluetooth network model.

The aim of this paper is to investigate the QoS of ACL packet using the retransmission limited stop & wait ARQ (SAW-ARQ) scheme in multi-path fading channel. The simulation block is modeled using the Bluetooth air interface standard, which recommends the ARQ scheme to overcome the wireless channel errors in the high rate data packets. However, conventional ARQ scheme is unsuitable for real time applications. Therefore, the retransmission limited SAW-ARQ scheme is proposed in this paper, which does limit the number of retransmission of erroneous

packets before the threshold time. This scheme is shown to be superior to a conventional ARQ scheme. The work confirms that proposed error recovery scheme for Bluetooth ad-hoc network should support a packet mode for real-time applications.

This paper is organized as follows. Section II introduces the features of Bluetooth system, Bluetooth signal, Bluetooth simulation model, with special emphasis on its SAW-ARQ protocol. Section III outlines the parameters for the analytical and simulation and covers the packet error rate (PER) and throughput for Bluetooth ad-hoc network in multi-path Rayleigh fading channel. Finally, Section IV gives concluding remarks.

2 System Model And Proposed SAW-ARQ Scheme

2.1 Features of Bluetooth System

Bluetooth system defines multiple channels for communication, and each channel is defined by a different frequency hopping sequence. A group of devices, which share a common channel, is called piconet. One of the devices is master unit, which selects a frequency hopping sequence for the piconet and controls access to the channel. Other devices, members of the piconet, are known as slave units. The slave units are synchronized to the hopping sequence of the piconet master. Such piconets are suitable for any of mentioned electronic device to communicate with any other such electronic device without prior set up. It is ad-hoc networking technique for communication between different devices within few meters to a maximum 100 meters. IEEE and Bluetooth Special Interest Group (SIG) defined IEEE802.15 standard [1]. This working group is also developed a Wireless Personal Area Network (WAN) standard. Bluetooth is low power radio system that operates in the range from 2.4 GHz to 2.4835 GHz and use license free ISM (Industrial, Scientific, Medical) band.

The frequency hopped spread spectrum (FHSS) technique is used in the Bluetooth standard as the medium access control protocol. The frequency band is divided into 1 MHz spaced channels. Data rate of the each channel is 1 Mb/s. The channel is represented by a pseudorandom hopping sequence that is cycling through 79 hop channels at 1600 hop/sec. The specified standard supports transmission rate of up 1 Mb/s for half duplex link.

Between master and slave units can be established different types of links: Synchronous Connection Oriented (SCO) link and Asynchronous ConnectionLess (ACL) link. The SCO link is a symmetric, point-to-point link between the master and a specific slave. This type of link typically is reserved for voice. The ACL link provides a packet-switched connection between master and all active slaves participating in the piconet. In the slots not reserved for SCO links, the master can set up ACL links. The packets, which aren't addressed to a specific slave, are considered as broadcast packets and are available to every slave.

2.2 Bluetooth Signal

Bluetooth operates at a channel bit rate of 1 Mbit/sec. The modulation is Gaussian frequency shift keying (GFSK) with a nominal modulation index of $h_f = 0.33$ and a normalized bandwidth of $B_b T = 0.5$, where B_b is the 3 dB Bandwidth of the transmitter's Gaussian low pass filter, and T is the bit period [11],[12]. The Bluetooth radio employs a frequency hopping scheme in order to mitigate the effect of interference and multi-path fading. There are a total of 79 hopping channels, each separated by 1 MHz, and the hopping frequency is changed on a packet by packet basis.

The GFSK signal can be represented by

$$s(t, a) = \sqrt{\frac{2E_b}{T}} \cos(2\pi f_c t + \phi(t, a)), \quad (1)$$

where E_b is the energy per data bit, f_c is the carrier frequency, and a is the random input stream, comprised of the data bits α_i ; $\phi(t, a)$ is the output phase deviation, given by

$$\phi(t, a) = 2\pi h_f \sum_{i=n-L_b+1}^n \alpha_i q(t - iT) + \pi h_f \sum_{i=-\infty}^{n-L_b} \alpha_i \quad (2)$$

$$q(t) = \int g(\tau) d\tau \quad (3)$$

$$g(\tau) = \sqrt{\frac{2\pi}{\ln 2}} B_b \exp\left(-\left(\frac{2\pi^2}{\ln 2}\right)(B_b \tau)^2\right) \quad (4)$$

The second sum of eq(2) is the accumulated phase of all previous symbols, and it is called the phase state. $g(t)$ is the impulse response of a Gaussian filter, and L_b is the length of $g(t)$ in bit periods. For Bluetooth with $B_b T = 0.5$, we have $L_b = 2$.

The complex low-pass equivalent impulse response of a multi-path fading channel can be written as

$$h_j(t) = \sum_{l=0}^{L_p-1} \alpha_{j,l}(t) \delta[t - \tau_{j,l}(t)] e^{j\theta_{j,l}(t)} \quad (5)$$

where L_p ($L_p \geq 1$) is the number of resolvable propagation paths. For the sake of simple notation, it is assumed that all bluetooth users have the same number of multi-paths. $\alpha_{j,l}(t) e^{j\theta_{j,l}(t)}$ and $\tau_{j,l}(t)$ are the complex fading factor and propagation delay of the l -th path of the j -th bluetooth user, respectively, and $\alpha_{j,l}(t)$ is frequency selective Nakagami-distributed in wireless channel model. All random variables in (5) are assumed independent for j and l . The amplitude fading in each path is assumed to be Nakagami distributed since the Nakagami distribution is more versatile and more adequate to describe different fading situations. For example, Nakagami fading can closely represent Rayleigh and Rician fading under appropriate parameters. The multi-path intensity Nakagami fading pdf of ζ is given by

$$f(\zeta) = \left(\frac{m_T}{\Omega_T} \right)^{m_T} \frac{\zeta^{-m_T-1}}{\Gamma(m_T)} \exp\left(-\frac{m_T \zeta}{\Omega_T} \right) \quad (6)$$

where $\Omega_T = \sum_{i=0}^{N_R-1} \Omega_o e^{-i\delta}$, $m_T = \sum_{i=0}^{N_R-1} m_i$, and δ is the exponential decay ratio of the multi-path intensity profile (MIP).

2.3 Bluetooth Simulation Model

Bluetooth uses a short-range radio link for carrying voice and data traffic. Up to eight devices can be connected in an ad-hoc network. Bluetooth ad-hoc forms a piconet with one unit acting as a master and the other(s) as slave(s). Figure 2 shows the simulation model for Bluetooth ad-hoc network using error recovery scheme.

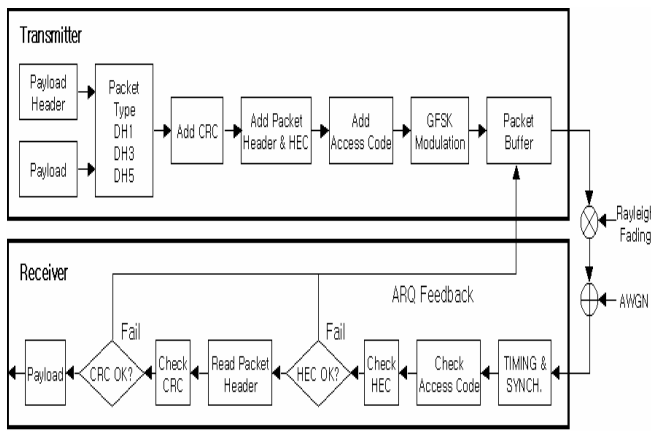


Fig. 2 Simulation model for Bluetooth ad-hoc network using ARQ scheme.

The simulation model is consist of transmitter, wireless channel, receiver, and feedback path for ARQ. In the transmitter, ACL packet is formed according to the figure 3.

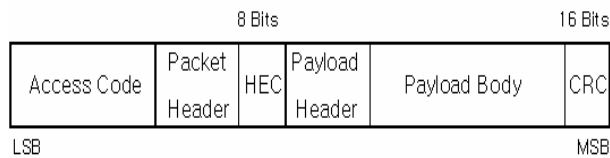


Fig. 3 ACL packet format.

The incoming binary data stream is added with a 1 or 2 bytes payload header. The payload header contains information about the logical channel and the payload length. And, the payload header is preceded with packet header, which contains link control information and active member addresses. Bluetooth uses a time-slotted channel with a slot length of $625 \mu s$. The duty cycle of a standard packet is $366 \mu s$, and a packet can be extended to occupy 3 or 5 slots. A summary of the various packet types and the corresponding packet specifications are listed in table 1.

Table 1 Simulation parameters for Bluetooth ACL Packet.

Link Type	Packet Type	Payload Header (bytes)	User Payload (bytes)	FEC	CRC	Occupied Slots
ACL	DH1	1	27	No	Yes	1
	DH3	2	183	No	Yes	3
	DH5	2	339	No	Yes	5

After the entire packet has been formed, the binary data is mapped to antipodal pulses at 1 Mbps. They are then passed through a Gaussian filter. In practice, the GFSK signal can be digitally produced by modulating the integrated phase as I and Q signal onto the 2.4 GHz frequency. However, in this paper, an equivalent baseband GFSK modulation signal can be used for simulation purposes.

Bluetooth is a frequency-hopping system. There are 79 channels available in Europe's ISM band. This corresponds to 79 hop frequencies. Each packet is transmitted on a different hop frequency. In the case of combined packets which consisting of 3 or 5 slots, the hop frequency remains fixed until the end of the packet. In this simulation, Rayleigh fading channel is assumed for every packet transmission. During the transmission of a single packet, the connected Bluetooth terminals will remain stationary channel state. Hence, a static Rayleigh distributed fading channel is considered. Rayleigh fading represents the worst possible scenario for the Bluetooth propagation channel.

2.4 Concepts of Proposed SAW-ARQ Scheme

Typically Bluetooth radio channel provides the error rates of around 10^{-2} due to multipath fading channel [2]. In addition to the poor channel quality, the design of Bluetooth systems is complicated by the rapidly changing quality of the radio channel. Therefore, an ARQ scheme is used to inform the source of the success or failure of transfer of payload. Generally, the baseband packet is retransmitted till a positive acknowledgement (ACK) is returned or until threshold time for retransmission is exceeded. Although ARQ achieves reasonable throughput levels if the error rates are not very large, it leads to variable delays time that are not acceptable for real-time applications. Therefore, we quantify this threshold time by *thresh_time* and limit the number of retransmissions of an ACL packet. In the case of real-time video traffic, the value of *thresh_time* must be low whereas higher values of *thresh_time* can be used without strict delay constraints, but requiring reliable data transfer. Figure 4 shows the procedure of SAW-ARQ scheme to limit the number of retransmission according to the channel conditions and delay constraints.

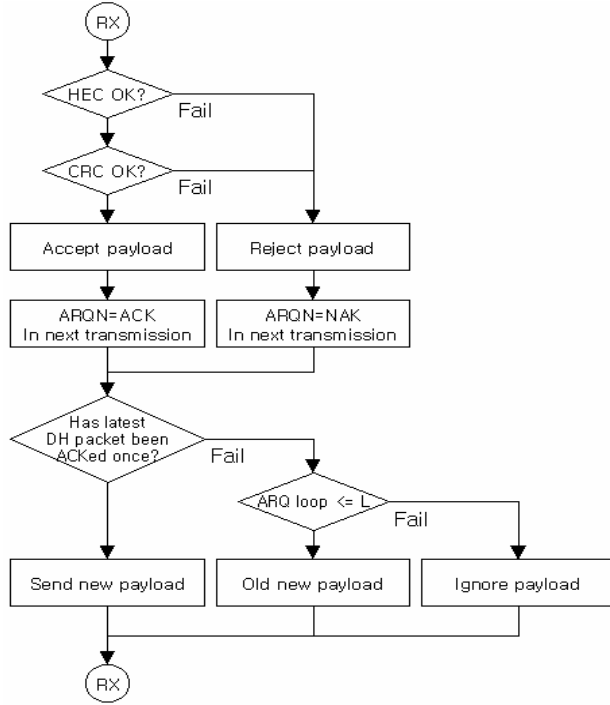


Fig. 4 Proposed ARQ scheme.

The number of retransmissions in the proposed SAW-ARQ scheme is also varied based on the negotiated QoS requirements and an optimum value for this parameter can be obtained. Using the proposed scheme, we investigate the throughput and PER performance by varying the number of retransmissions and find a reasonable value for L under different Bluetooth packet types and channel conditions.

3 Simulation Results

The performance evaluation in a Rayleigh fading channel can be used to characterize the worst possible situation for the Bluetooth system. Therefore, the effects of packet error rate and throughput performance of DH type packets (DH1, DH3, DH5) were simulated and the results are plotted in figure 5 and figure 6, respectively. Figure 5 shows the PER of the DH types for Bluetooth system with ARQ scheme in a Rayleigh fading channel. Using an ARQ ($L = 10$), the PER of Bluetooth system indicate that there is a difference of 10 dB between DH 1 and DH 3 and 4 dB between DH 3 and DH 5 at a packet error probability of 10^{-3} . At same packet error rate, the difference between the DH 1 and DH 5 is approximately 14 dB. And, L increases from 10 to 20, the PER of DH packet type is decreases. Also, it can be seen that the PER performance of all DH packet type is very close to 0 till $E_b/N_o = 17dB$ but beyond that all DH packet type exhibit a difference PER according to the E_b/N_o and L .

Figure 6 shows the throughput versus the E_b/N_o , for the DH packet types and the number of retransmission (L). The length of the packet has a considerable affect on the packet error probability. Longer packets have less chance of passing the CRC check as compared to shorter packets. This can be confirmed from figure 5. Therefore, the throughput with small slots is greater than that with large slots for a given E_b/N_o . As the number of ARQ loop (L) increases from 10 to 20, the throughput becomes more increased which consequently reduces the channel error.

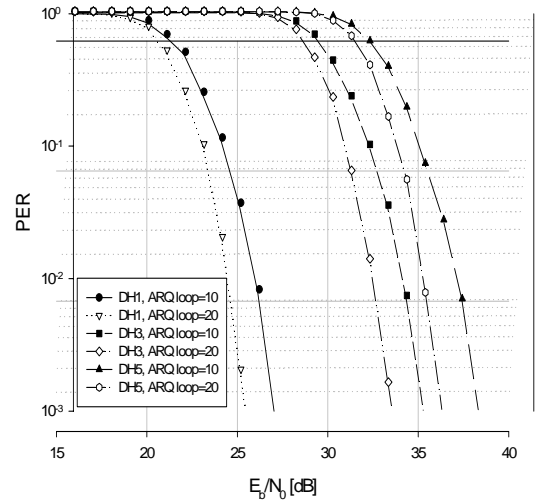


Fig. 5 PER for Bluetooth ad-hoc network in Rayleigh fading channel.

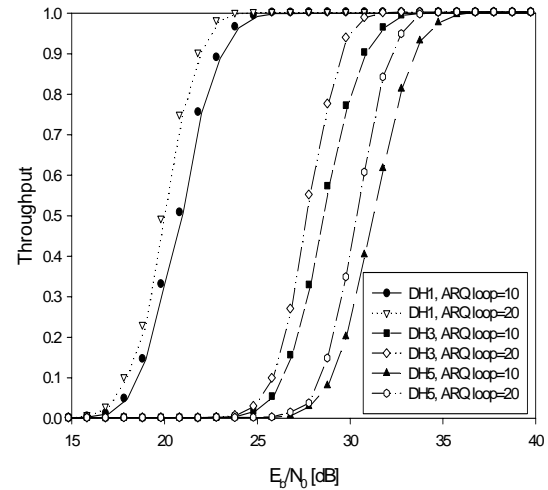


Fig. 6 Throughput for Bluetooth ad-hoc network in Rayleigh fading channel.

4 Conclusions

The Bluetooth technology represents an attractive approach to enable short distance wireless connectivity. The massive-spread of Bluetooth implementation in consumer products opens up a wide arena for new short range wireless networking applications. Bluetooth works in the 2.4 GHz unlicensed ISM band, which is also shared by other communication systems including 802.11 wireless local area networks. The primary range of operation is 10 meters, but it can be extended up to 100 meters. This paper's main contribution is to evaluate the Bluetooth performance in hostile environments. Two scenarios are considered: (1) PER performance in wireless channel, and (2) throughput performance in multi-path Rayleigh fading channel environment. This paper has developed a baseband simulator for the Bluetooth ad-hoc network in multi-path Rayleigh fading. The packet error rate and throughput performance of Bluetooth ad-hoc network using the proposed SAW-ARQ have been investigated. The length of the DH packet has a considerable affect on the packet error rate in fading channel. And the throughput of the DH packet with small slots is greater than that with large slots for a given E_b / N_o . As the number of retransmission (L) increases, the throughput becomes more increased in a multi-path Rayleigh fading channel.

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5 References

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