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Performance of Sequential Monte Carlo Receiver in Presence of IEEE 802.11 Interference

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Abstract

Performance consequence analysis of IEEE 802.11b interferer block for the sequential Monte Carlo (SMC) receiver has been accomplished to decide the receiver's robustness as a GFSK receiver. The performance evaluation was conducted at the physical and system layers using MATLAB/Simulink as a simulation tool. Frame error rate (FER) and Bit error rate (BER) were used to quantify the SIR receiver. Two scenarios were performed at the physical layer: 1) A 50% interference rate affecting the Bluetooth system, 2) A 100% interference rate affecting the Bluetooth system. At the system layer, the packet drop rate caused by the interference was measured to determine the system robustness, while the BER evaluation measures the quality of processed packets. The results of the SIR receiver's performance were compared to the limiter discriminator integrator (LDI) receiver, and to the Viterbi receiver. The analysis proved that at the physical layer and while having a 100% interference rate, the SIR receiver outperformed the LDI receiver by approximately 17 dB, and outperformed Viterbi receiver by nearly 12 dB in terms of BER. At the system layer and by experiencing the same conditions, the SIR receiver proved to have nearly 14 dB improvement over the LDI receiver and about 7 dB improvement over the Viterbi receiver in terms of FER. In addition, the assessment also showed that when the SIR receiver is affected by a 50% interferer signal, the SIR receiver exposed significant improvements over both referenced receivers. The SMC receiver has a significant capability of managing major networks interferences that are within proximity of GFSK network. All of the results validate the robustness of the SMC receiver. The receiver proved to have a substantial performance perfection compared to other existing receivers.

Keywords: Bluetooth Receiver, IEEE802.11b Interference, Gaussian Frequency Shift keying (GFSK), Sequential Monte Carlo, Sequential Importance Resampling.

1. INTRODUCTION

The non–coherent GFSK demodulation by employing the sequential Monte Carlo technique was implemented under the presence of additive white Gaussian noise (AWGN) for a Bluetooth system [1], [2]. The sequential importance resampling (SIR) filtering theory processed the received modulated GFSK signal, then aided with a low complex bit detection algorithm to retrieve the originally transmitted bits [1]. The SIR receiver was assessed and analyzed with respect to the bit and frame error rates (BER, and FER) evaluations at the physical layer [1]. Conversely, the increasing necessity of operating several wireless devices within proximity of one another, which causes interference between them, has raised the need to further investigation and evaluation of the SIR receiver under the presence of IEEE 802.11b networks [3]. In general, interference between devices happens when there is an intersection between frequencies and time of the transmitted signals [1]. This causes the signals to collide, resulting in the corruption of the transmitted data. If this occurs, it results in dropping the received data, or requesting a retransmission of the data [4]. Several analysis techniques of IEEE 802.11 interference on Wireless Local Area Network (WLAN) and GFSK systems have been implemented by researchers to measure the effect of inference on the quality of the received data. Shellhammar [5], Golmie [6], and Zyren [7], [8], dedicated their performance evaluation to obtain the likelihood of the data impacting one another by quantifying the packet error rate for the network. In the mentioned references, the likelihood of packet error rate was measured based on the probability of collided packets to time and frequency [8]. Furthermore, a tentative evaluation was performed and explored by Howitt et al. [9], and Fumolari [10], for multiple-nodes of Bluetooth and WLAN systems. In [11], Zurbes et al. designed a flexible configuration while assessing the effect of interference on multiple Bluetooth devices placed in a particular location. They concluded, out of 100 parallel network sessions, the impact of interference on their systems is about 5%. In [12], Soltanian and Van Dyck measured the impact of interference on the LDI and Viterbi receivers of a Bluetooth system under the presence of IEEE802.11b interferer.

This paper is an extension of our previous work which handled the SMC receiver design. However, our previous work only considered additive white Gaussian noise (AWGN) channel, and it did not consider any nearby interference to the GFSK system [1]. In addition, the focus of this research is to study a more realistic and practical system environments, in which the GFSK system will be affected by one or more interfering noises coming from nearby environments. The performance impact of the SIR receiver for a Bluetooth network while IEEE 802.11 interferer block is present will be discussed and assessed. The assessment will be performed to measure the BER and FER. The evaluation will prove the robustness of the SIR technique as a GFSK receiver even if IEEE802.11 interferer block is present in the system.

The sections of this article are arranged as follows. Protocol overview is presented in section 2. Followed by a brief introduction of GFSK signal structure presented in section 3. Section 4 will discuss the interference model. Section 5 will discuss the impact of the results. Finally, the paper is concluded in section 6.

2. PROTOCOL OVERVIEW

A. Bluetooth

Worldwide, Bluetooth has become very desirable and efficient technology intending to replace wired connections between devices that are in a small proximity to each other. The technology uses GFSK modulation scheme [13] operating at 2.40 GHz ISM unlicensed band. The technology uses a 1 mW antenna interface with 0 dB gain while operating. This technology uses the 2.4 GHz unlicensed band. The band is split into 79 sub-channels that are 1 MHz apart. The radio signal is hopped using frequency hopping spread spectrum (FHSS) technique. With the aid of time division multiplexer (TDM), each transmitted packet is hopped on different frequency [14]. Packets with odd numbers slots are then conveyed on a different frequency using a maximum hopping rate of 1600 hops/s [15].

Table 1. Synchronous connection-oriented packet structure [19].

Access Code (72 bits)	Header (54 bits)	Payload (240 bits)

A Bluetooth network consists of a master device that is connected to up to seven slave devices referred to as a piconet [3]. Each low power piconet operates at a maximum of 1 Mbps, and has a range of approximately 10 m. There are two categories of connections between two devices: 1) Synchronous Connection-Oriented (SCO) 2) Asynchronous Connection-Less (ACL) link.In this paper, SCO has been used as a connection scheme. The connection between two devices (a master and a slave) in SCO connection is defined to be a symmetric connection. The master transmits SCO packet in a Tx time intervals defined as Tsco slots. The slave receives the packet and responds with another packet on the following Tx opportunity [2]. The structure of a voice packet is described in Table 1 [4].The header has 1/3 repetition code and a dmin equal to 14, is then added to the access code [19]. Out of 13 detected errors, 6 of them may be corrected. However, if a fault seen in the access or in the header code causes the packet to be dropped. Table 2 illustrates the handling procedures when the error is seen in the packet [2].

B. IEEE 802.11b

The physical (PHY) and medium access control (MAC) layer protocols are defined in the IEEE 802.11 standard [3]. FHSS, direct sequence spread spectrum (DSSS), and infrared (IR) is described in detail in the IEEE 802.11 specifications, and in [15]. For FHSS and DSSS devices, a maximum of 1 W of transmit power is required and the sensitivity is set to -80 dBm. The gain of the antenna is limited to 6 dBi. For FHSS, every signal is randomly hopped across the modulating frequency [16]. Both TX and Rx signals are harmonized to shadow the same frequency scheme. As stated, 79 slots are being designated ranged between 2.4000 to 2.4835 GHz, 1 MHz apart. The multilevel GFSK signal uses a 1 and a 2 Mbits/s basic access rate [4].

To avoid signal collision, the PHY and MAC layers aid each one another. Clear channel assessment (CCA) algorithm is used by the PHY layer to decide if the channel is clear for transmission [16]. Furthermore, carrier-sense is used to determine if the channel is available, and it is used by the MAC layer to predict of any future traffic, [18], and [19]. Communication between devices is established when a node transmit a short request-to-send (RTS) frame. The Rx node transmits a CTS message with the proper address. If the CTS message was not acknowledged, then it is determined that the message was collided, and the procedure is repeated all over again [18], [19].

Table 2. Error handling procedures [19].

Error Location	Error Correction	Action Taken
Access code	dmin = 14	Packet dropped
Packet Header	1/3 repetition	Packet dropped
HV1 payload	1/3 repetition	Packet accepted
HV2 payload	2/3 block code	Packet accepted
HV3 payload	No FEC	Packet accepted
DM1, DM3, DM5	2/3 block code	Packet dropped
DH1, DH3, DH5	No FEC	Packet accepted

3. SYSTEM DEFINITION

The GFSK transmitted signal is expressed as [1], [13]

$$s(t,\boldsymbol{\alpha},h) = \sqrt{\frac{2E_s}{T}}\cos\{2\pi f_0 t + \varphi(t,\boldsymbol{\alpha},h) + \varphi_0\}, \qquad (1)$$

where E_s is signal energy, f_0 is the carrier frequency, T is modulation interval, φ_0 is phase constant shift, and $\varphi(t,\boldsymbol{\alpha},h)$ is a phase constant of transmitted signal and is defined as [10]

$$\varphi(t,\boldsymbol{\alpha},h) = 2\pi \sum_{k=n-L+1}^{n} q(t - kT\alpha_k) + \pi h \sum_{k=-\infty}^{n-L} \alpha_k, \qquad (2)$$

where$T \le t \le (n+1)T)$ transmitted bits, is the modulation index, $\alpha = \cdots, \alpha_{-2}, \alpha_{-1}, \alpha_0, \alpha_1, \alpha_2, \ldots$ is an infinite sequence of identically distributed data symbols, belong to the alphabet

$\alpha_k \in \{\pm 1\}$1}αk∈{±1} is the frequency pulse length g(t) (e.g. $L = 22$ for Bluetooth).$q(t) = \int_{-\infty}^{t} g(\tau)d\tau$ is normalized phase pulse that is determined by integrating g (t) [1]

$$g(t) = \frac{1}{2T}\left(Q\left(c.B\left(t-\frac{T}{2}\right)\right) - Q\left(c.B\left(t+\frac{T}{2}\right)\right)\right),$$

With $c = 2\pi/\sqrt{\log(2)}2)$, BT is a time-bandwidth product, and $Q(\cdot)$ is the Gaussian Q-function.

4. INTERFERENCE MODEL

The system architecture including the IEEE802.11 interferer block is shown in Fig. 1. The interfered signal can be represented by [4] [12]

$$y(t,\boldsymbol{b}) = A\cos\big(2\pi(f_0 + f_d)t + \varphi_1(t,\boldsymbol{b},h)\big), \qquad (3)$$

where A is the magnitude of the Rx, b is an independent arbitrary input, and ϕ interferer dependent phase shift. f measure the difference between the Bluetooth frequency and the interferer frequency. The 802.11b system uses 22 MHz bandwidth. In this analysis, fd=1MHz the power of BT Tx signal was set to 1 mW. The power of the interferer signal was set to 100 mW. The signal-to-noise ratio (SNR) of the system was set to 30 dB, at the same time, changing the Carrier-to-interference ratio (CIR) from −20 dB to 10 dB [19], [21]. The assessment considered two main cases: The first case assesses the system when 50% interference transmission. The second case assesses the system when 100% interference transmission [19], [20].

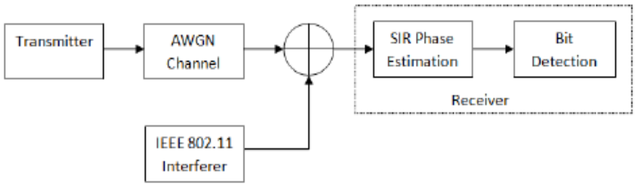

Figure 1. System block diagram of SMC receiver in presence of IEEE802.11 Interferer [1].

5. INTERFERENCE EVALUATION RESULTS

A. Physical Layer Performance

In this analysis, the physical layer impact assessment was carried on the SIR receiver while setting the IEEE 802.11 interferer signal transmission to 100%. The SNR was set to 30 dB. In practical environment, the interference could be generated due to a nearby Bluetooth setup, or caused by nearby WLAN systems. AWGN channel was used to assist in simulating the transmission medium. The performance assessment of the SIR receiver was compared to the LDI receiver [17], and to the Viterbi receiver [14]. Figure 2 shows the results of this comparison. The figure shows the SIR receiver outperformed the LDI receiver by approximately 17 dB and nearly 12 dB enhancements over the Viterbi receiver. The results also demonstrate that the SIR receiver approaches BER of 10−3 at CIR −19 dB.

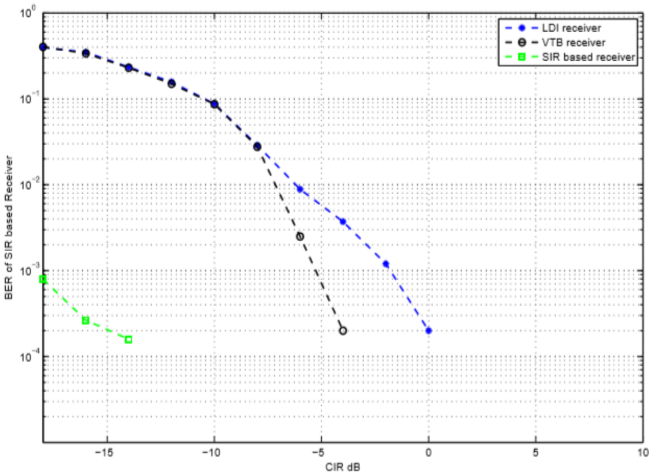

Figure 2. Physical layer assessment for SIR, LDI, and VTB receivers (SNR = 30 dB, 100% IEEE 802.11 interference).

Figure 3 shows the performance assessment of the SIR receiver while varying IEEE 802.11 interference levels. The line curve with square symbol (blue) signifies the performance of the SIR receiver while setting IEEE 802.11 to transmit at a 100% interference rate. This occurs when nearby BT networks or WLAN networks are constantly transmitting for the full duration of the assessed network. This will increase the likelihood of packets collision. The curve with diamond symbol (black) in figure 3 signifies the evaluation of the SIR receiver when the system is being affected by 50% of the IEEE 802.11b interference signal. This occurs when the distance between the assessed system and the interfering system is farther apart, or the interfering system is transmitting half of the duration. Figure 3 illustrates that as the transmission of the interferer signal strengthens in duration, the robustness of the SIR receiver decrease but remains at acceptable SNR values. Table III shows a summary of the results at the physical layer.

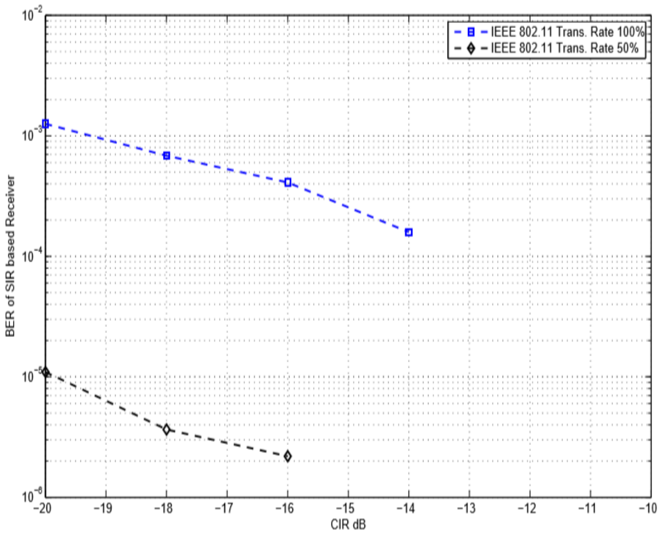

Figure 3. Physical layer assessment of the SIR receiver (50% vs. 100% of IEEE802.11 interference transmission rate SNR = 30 dB).

B. System Layer Performance

Even though the outcome of the performance assessment of the physical layer yielded excellent results, further investigation of the SIR receiver was still required at the system level layer to conclude its robustness for reasons listed in [19]. The system layer is assessed to evaluate the impact of the interfering signal on the frequency hopping, error detection, and Bluetooth traffic pattern. The analysis will consider the likelihood of a transmitting Bluetooth packet falls below the interference bandwidth. Furthermore, the BER is evaluated because it depends on the frequency off set between the Rx signals and the interferer signals.

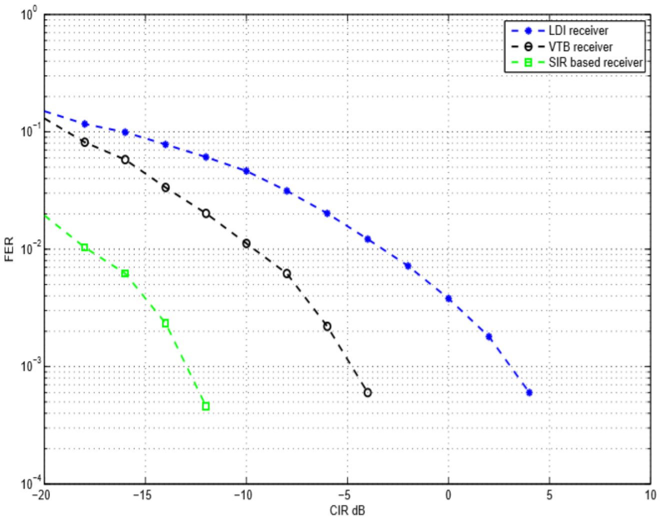

Figure 4. System layer assessment of the SIR receiver in an IEEE802.11 interference with SNR = 30 dB.

The assessment considered HV1 voice packets being transmitting back and forth in a two-way communication system between a BT master and slave while and interferer block (IEEE 802.11) is transmitting. The rate of the transmission was set to 64 Kb/sec. The structure of the packet is as described in Table-I. The access code word of HV1 packets have a large Hamming distance between them, and the header and payload are protected by 1/3 rate repetition codes. Each packet is constructed from 366 bits. If an uncorrected error is seen in the access or header code, then the packet is dropped. Figure 4 signifies the likelihood of the frame error rate (FER) with respect to the CIR for the SIR receiver in comparison to the performance of the LDI, and Viterbi receivers.

From figure 4, it is seen that the LDI receiver requires a CIR value of 3 dB to be able to have a low and acceptable frame error rate, while a CIR of −5 dB is required for the Viterbi receiver. On the other hand, the SIR receiver acquires a low FER at CIR of −12 dB which a huge improvement compared to both receivers. Table III shows a summary of the results at the system layer in a tabular format.

Table 3. GFSK physical and system levels layers results in the presence of IEEE 802.11 interference.

	IEEE 802.11 Rate	LDI Receiver	Viterbi Receiver	SIR Receiver
PHY (BER 10^-3)	100%	CIR -2 dB	CIR -7 dB	CIR -19 dB
System Layer (FER)	100%	CIR 3 dB	CIR -5 dB	CIR -12 dB

6. CONCLUSION

This research has been focused on studying the robustness of the SIR receiver that was published in [1]. The assessment was performed to decide if the SIR receiver has the capability of managing nearby interferences while non-coherently and correctly demodulate the received GFSK signal. Evaluating the SIR receiver in the presence of IEEE 802.11 networks add to the usage practicality of the receiver since most real-life environment setup will be affected by interfering networks that are located within proximity of each other. The assessment was completed at the physical and system level layers using MATLAB/Simulink as the simulation tool. The assessment considered two scenarios at the physical layer. The first scenario was to assess the performance of the receiver at a 50% interference rate. The second scenario was to assess the performance at a 100% interference rate.

At the physical layer and while affecting the GFSK environment by 100% interference rate generated by an IEEE 802.11 interferer block, the SIR receiver was able to achieve a BER of 10^-3 at CIR -19 dB for the studied SNR case. However, the LDI receiver and Viterbi receiver achieved a BER of 10^-3 at CIR -3 dB, CIR -7 dB, respectively. These results prove that the SIR receiver has an approximately 16-17 dB improvement over the LDI receiver, and nearly 12 dB improvement over the Viterbi receiver. The BER of 10^−3 is the acceptable BER specified in the Bluetooth standards [19]. Also, the assessment revealed that when the SIR receiver is provoked by a 50% interferer signal, the SIR receiver exposed additional robustness improvement.

At the system level, the SIR receiver provided a considerable performance achievement in comparison to the LDI and Viterbi receivers when assessed in terms of FER. The LDI receiver required a CIR value of 3 dB to be able to have a low and acceptable frame error rate, while Viterbi receiver required a CIR of −5 dB to achieve an acceptable frame error rate. On the other hand, the SIR receiver acquires a low frame error rate at CIR of −12 dB which a huge improvement compared to both receivers. The SIR receiver showed about 14-15dB improvements over the LDI receiver and an approximately 7 dB improvement when compared to the Viterbi receiver in terms to frame error rate. Finally, this assessment analysis concludes that the SIR receiver is robust, high power efficient, and low complex receiver that is very capable of demodulating a GFSK signal, even though the signal is being affected by full duration interference noise coming by nearby. The assessment proved that the SIR receiver achieved considerable performance perfection over the LDI and Viterbi receivers.

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