

The application of Spreading Sequences to Indoor Wireless Infrared Transmission

Tim O'Farrell
School of Electronic and Electrical Engineering
University of Leeds
Leeds LS2 9JT,
email :- t.ofarrell@ee.leeds.ac.uk

Abstract

Multipath dispersion and fluorescent light interference are major sources of impairment in indoor wireless infrared (IR) channels. This paper studies the use of spreading sequences to ameliorate their affect on system performance without the need for complex signal processing. The properties of spreading sequences are exploited in order to suppress ISI caused by multipath and narrow band interference caused by fluorescent lighting. Two spreading sequence techniques are presented called Sequence Inverse Keying (SIK) and M -ary Bi-orthogonal Keying (MBOK). Their BER performance is presented for different system parameters. The results show that spreading sequences can substantially reduce the performance degradation caused by these impairments.

1. Introduction

This paper studies the application of spreading sequences to high data rate, indoor wireless IR communication. The phenomenal success of spreading sequences in modern radio communications, noticeably IEEE802.11b, cellular CDMA and UWB, strongly motivates its use in an IR wireless context. The key advantages of indoor IR wireless communications are virtually unlimited bandwidth, compatible worldwide and inherent security due to the confinement of IR signals within rooms. However, like radio channels, a transmitted signal in the IR channel can undergo multiple reflections before reaching the receiver. The resulting inter-symbol interference (ISI) is a primary impediment to high speed IR wireless transmission. Most attempts to resolve impairments caused by multipath propagation have focused on the use of equalisation, angular and imaging diversity [1]. Research has shown that the luminous flux produced by fluorescent lighting is not constant in time, but shows large fluctuations and fast variations in time [2]. The interference due to the time variations in the power of the light is potentially detrimental to IR systems [3]. Electrical high pass filtering is typically used to remove the interference produced by fluorescent lamps since the electrical spectrum of the interference is concentrated in the low frequency region. However, the removal of the low frequency components causes baseline wander in simple base-band systems.

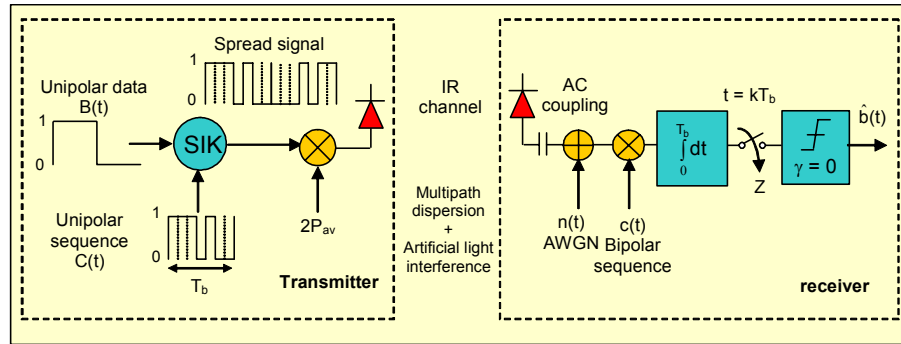
Although these impairments differ in the IR channel compared to the radio case, fundamentally they behave the same. Thus spreading sequence techniques, which have been successfully used in radio systems to combat the same impairments, can be beneficially applied to indoor wireless IR systems. Spreading sequences offer a transmission waveform that can resolve and suppress multipaths in an IR channel without having to resort to relatively complex solutions such as equalisation, coded modulation or elaborate optical front-ends. In radio systems, DSSS uses bipolar spreading sequences which cannot be used as such in the all-positive (unipolar) IR medium. This limitation was first removed in [4] by introducing the notion of unipolar-bipolar sequencing that allows the same spreading codes of radio systems to be used in optical systems. Originally, the technique was proposed for optical fibre Code Division Multiple Access LANs to 1) remove the degradation caused by jumps in the DC level when multiple users randomly access the shared channel; and 2) offer larger code sets and smaller multiple access interference than unipolar codes, such as optical orthogonal codes or prime codes, of the same spreading factor. Unipolar-bipolar sequencing, which involves transmission of a unipolar spreading sequence and correlation with a bipolar version of the same spreading sequence, preserves the correlation properties of bipolar-bipolar sequencing, albeit with the introduction of a fixed dc offset unless balanced spreading sequences are used. In an IR channel, this means that unipolar-bipolar sequencing can resolve and suppress ISI caused by multipath propagation

and attenuate narrow band interference in a manner similar to that in a spread spectrum radio system. The full potential of unipolar-bipolar sequencing is exploited best in a multi-user system when more than one user accesses the IR channel simultaneously. In practice, most wireless IR systems limit channel access to a single user at a time and as such the photodetector can be ac-coupled to the preamplifier, thus obviating the need for balanced spreading sequences.

2. Spreading Sequences for Wireless IR

This section describes the operation of SIK and MBOK and explains how multipath dispersion and fluorescent light interference are attenuated.

Sequence Inverse Keying: A schematic of the transmitter and receiver of an SIK system is shown in Figure 1 [5]. At the transmitter, the unipolar data, $B(t)$ is used to sequence inverse key an unipolar spreading sequence, $C(t)$ such that the transmitted signal comprises of $C(t)$ or its complement. The duration of N chips in one period of the spreading sequence is equal to the bit duration. The unipolar spread signal is scaled by $2P_{av}$ where P_{av} is the mean signal optical power. Alternatively, SIK modulation of $B(t)$ on $C(t)$ can be represented as the multiplication of the bipolar version of the data, $b(t)$ and the bipolar version of the spreading sequence $c(t)$ with a dc offset term added, i.e. $B(t) \otimes C(t) = [b(t)c(t) + q(t)]/2$ where \otimes denotes SIK and $q(t)$ is a constant unit amplitude signal.



During

Figure 1: Modelling of an IR wireless SIK system

transmission through the channel, the spread signal undergoes multipath dispersion and is corrupted by fluorescent light interference. At the receiver, the detected photocurrent is high-pass filtered to remove the dc component. An equivalent simplified schematic diagram for an ac-coupled SIK system is illustrated in Figure 1(b). The spreading sequence has a large number of chip transitions within a bit duration. The high transition rate of these chips significantly reduces the baseline wander effect due to ac-coupling. Despreading of the ac-coupled photocurrent is realised by multiplying directly with $c(t)$. The despread signal is integrated over one data bit duration T_b , sampled at T_b intervals to produce correlator output signal Z as given in Eqn. (1) where β_l is the relative power of the l -th resolved multipath, $C_c(l)$ is the aperiodic autocorrelation function (ACF) of the spreading sequence, l is the discrete time shift, P_m is the average power of the fluorescent light interference and $i_L(t)$ is the zero-mean interference waveform, and n_o is the Gaussian noise component. Z is then fed to a threshold detector with the threshold level set to zero.

$$Z = RP_{av}\beta_0 b_0 + \frac{RP_{av}}{N} \sum_{l=1}^{L-1} \beta_l [b_{-1}C_c(l-N) + b_0C_c(l)] + \frac{RP_m}{N} i_L(T_b) + n_o \quad (1)$$

Without interference and Gaussian noise, a positive Z means +1 was transmitted and a negative Z means -1 was transmitted. The presence of interferences increases the probability of error when $\hat{b}(t)$ is detected. The delayed multipath signals, i.e. the second term of Eqn. (1) which are not synchronised with the receiver reference sequence is modulated by the previous data bit b_{-1} and the present data bit b_0 over the integration interval. Since the data sequence is random, the delayed multipath signals may

change sign during the integration interval. In order to reduce the effect of multipath dispersion as much as possible, spreading sequences such as an m-sequence with odd ACF having the least sidelobe magnitudes should be used.

For systems with a high chip rate, $i_L(t)$ fluctuates slowly with respect to the spreading sequence over the integration period and may be considered constant over the integration period. This constant value $i_L(T_b)$ in the third term of Eqn. (1) is a random variable that depends on the sampled value of the interference waveform. When the bandwidth of the integrator is equal to the data Nyquist bandwidth, the interference power at the integrator output is attenuated by the spreading factor compared to a non-spread system. In contrast, for OOK the interference adds directly to the OOK symbol causing substantial distortion w.r.t. the fixed detection threshold giving a large number of bit errors.

***M*-ary Bi-orthogonal Keying:** Though SIK is tolerant of interference, a key reservation concerning the use of this system is the spreading factor which limits the system bandwidth efficiency. A method for improving bandwidth and power efficiency is *M*-ary modulation. An *M*-ary Bi-Orthogonal Keying scheme [5] using orthogonal spreading sequences improves the power and bandwidth efficiency while retaining the beneficial properties of sequence spreading. In MBOK, $\log_2 M$ data bits per spreading sequence are transmitted, which lowers the chipping rate and consequently reduces the effect of multipath dispersion at the expense of system complexity.

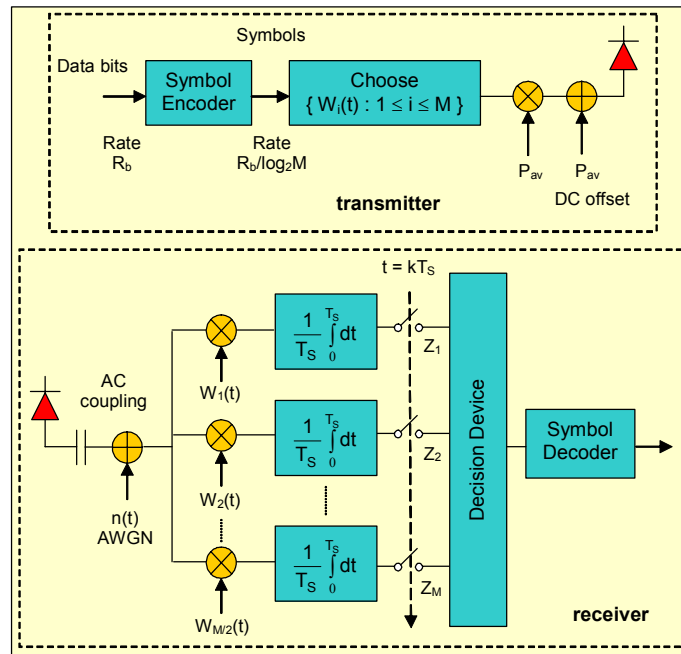


Figure 2: Schematic of an MBOK wireless IR system.

A schematic diagram of an ac-coupled MBOK system is shown in Figure 2. At the transmitter, blocks of $k = \log_2 M$ binary data bits of rate $1/T_b$ are mapped onto symbols of rate $1/T_s = 1/(T_b \log_2 M)$. An orthogonal code consisting of $M/2$ orthogonal sequences of length N , $\mathbf{W}_{M/2,N}$ and the complements of $\mathbf{W}_{M/2,N}$ are used to represent the M equiprobable symbols. One easy way to obtain a set of orthogonal codes in which the $M/2$ orthogonal sequences are selected for MBOK is from the rows of an Hadamard matrix [15]. The receiver for an MBOK system requires only $M/2$ correlators. This is because in the absence of Gaussian noise and interference, the μ -th correlator output, Z_{μ} , expressed in Eqn. (2), produces $+RP_{av}\beta_0$ at the sampling time for a $+W_{\mu}(t)$ sequence transmitted, or $-RP_{av}\beta_0$ for its complement, and zero for all the other sequences. Thus only the positive $M/2$ code sequences $\mathbf{W}_{M/2,N}$ need to be generated at the receiver. The decision device then selects the correlator output with the largest magnitude (in this case the μ -th symbol) and acquires the sign (positive or negative) information of this variable.

$$Z_\mu = RP_{av}\beta_0 + \frac{RP_{av}}{N} \sum_{l=1}^{L-1} \beta_l [C_{w_\gamma, w_\mu}(l-N) + C_{w_\mu}(l)] + \frac{RP_m i_L(T_S)}{N} \sum_{n=0}^{N-1} w_{\mu, n} + n_o \quad (2)$$

In the presence of multipath dispersion, the multipath signal delayed by τ_l with respect to the receiver reference sequence carrier the γ -th symbol during the time interval $[\tau_l - T_S, \tau_l]$ and the μ -th symbol during the time interval $[\tau_l, \tau_l + T_S]$ during the integration period of T_S . Since the data blocks that are grouped into symbols are random, there is an $1/M$ chance that γ and μ are equal. Hence, the performance of MBOK depends on the aperiodic ACF and CCF of the sequences in the set. The approximation of $i_L(t)$ by $i_L(T_S)$ and the use of soft-decision decoding means that the effect of fluorescent light interference depends on the chip balance of each sequence in the set.

5. Simulation Results

The BER versus E_b/N_o performances of SIK and MBOK under the influence of multipath dispersion and electronic ballast driven fluorescent light interference are presented in this section. The results were obtained by the method of computer simulation. A multipath impulse response with up to 3 reflections was used based on the simulation model in [6] and parameterisation in [5]. The relative power in the LOS path is normalised to unity. The average power of the fluorescent light interference is 10 times the average signal power. The results for OOK are included as a benchmark. SIK and OOK have the same BER theoretical performance in AWGN.

Figure 3 shows the performance of SIK at 10, 20 and 40 Mb/s and OOK at 20 and 40 Mb/s. M-sequences of lengths 7 (SIK7) and 15 (SIK15) are tested. For SIK7, the power penalties range from 6 to 8 dB while for SIK15, the penalties are about 4 dB. The performance of unequalised OOK in the same multipath channel is also plotted for comparison. The penalties for OOK are large, i.e. 17dB at 20 Mb/s and increases to 23 dB at 40 Mb/s. These results demonstrate the resilience of spreading sequences against multipath dispersion and fluorescent light interference.

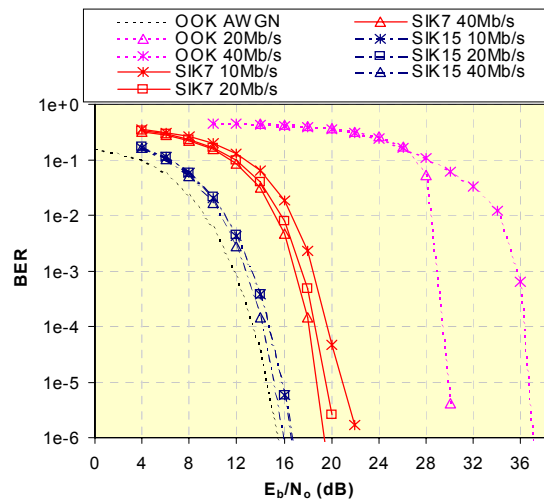


Figure 3: BER vs E_b/N_o performance of SIK7 and SIK15 at 10, 20 and 40 Mb/s and OOK at 20 and 40 Mb/s

The combined impact of multipath dispersion and artificial light interference on 8BOK (i.e. $M = 8$) at 10Mb/s is shown in Figure 4. Two types of orthogonal spreading codes are investigated. The first type of orthogonal code uses sequences taken from the even-numbered rows of an (8×8) Hadamard matrix and their complements (denoted WC). The second type is obtained by masking WC with a long PN sequence (denoted MC). The power penalties relative to OOK in AWGN are 0 dB for WC and 15.5 dB for MC. Clearly, the WC code offers the best performance as all the sequences in the code are balanced. Masking WC by a long PN sequence disrupts the balanced property leading to large interference contributions at the correlator outputs.

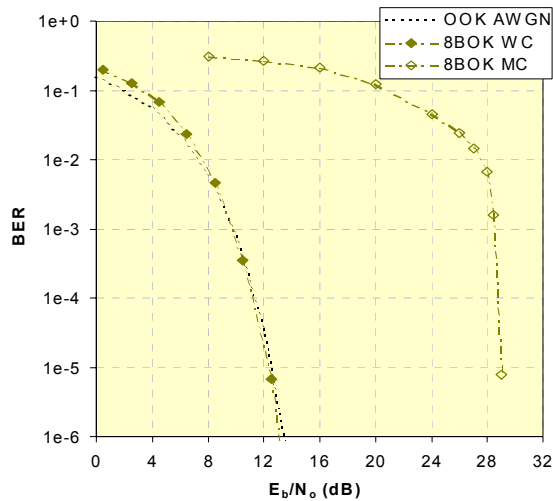


Figure 4: The BER vs E_b/N_o performance of 8BOK

6. Conclusions

Though the precise details of the SIK and MBOK schemes differ from their radio counter parts due to the unipolar nature of the IR (optical) channel, like the radio case both schemes benefit from the spreading sequence properties and processing gain advantage. Typically, spreading sequences with small aperiodic auto- and cross-correlation sidelobes should be used in order to minimise ISI resulting from multipath propagation. In order to minimise narrow band interference effects balanced spreading sequences should be used. MBOK offers the additional advantages of enhanced power and bandwidth efficiency. In this paper, the fundamental premise that major signal impairments in the IR medium can be overcome by the design of an appropriate transmit waveform is asserted by using spreading sequences. This approach can play a key role in achieving low complexity, high speed transmission for indoor wireless IR communication.

7. References

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