

# Interference Induced Asymmetry in IrDA 4PPM Infrared Wireless Links

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## Abstract

This paper examines the asymmetry effects of third user interference on IrDA FIR links at 4 Mbps employing 4PPM encoding. The analysis examines the variation in the interference-signal ratio (ISR) with the distance and orientation of an interfering device which affects the error probability of the PPM symbol.

## 1. Introduction

Infrared (IR) wireless links using the IrDA FIR (Fast Infrared) protocol at 4 Mbps employ 4PPM (Pulse Position Modulation) signal encoding at the physical layer [1]. PPM encoding is used at this data rate as it provides power efficiency with good noise immunity [2].

A performance analysis of L-PPM encoded links with variable symbol repetition, as used for the Advanced Infrared (AIr) physical layer, was given by Ozugur [3][4] where an interfering signal modelled as a raised-cosine pulse provided a constant interference-signal ratio (ISR). This was used with a separate signal-to-noise ratio (SNR) caused by background noise to provide conditional error probabilities for pulse and non-pulse PPM slots. These were combined to provide a packet error probability in terms of the link SNR and RR (Repetition Rate) value for a fixed ISR level.

Asymmetry in IR wireless links results when the error probability in both directions of the link is not equal. This can result from directional 'noise' due to light sources or from another transmitting IR wireless device. In addition to performance analyses and optimisation of the IrDA IrLAP data links protocol [5][6], an analysis of IR link asymmetry from third user interference has been provided by the authors previously [7][8]. The analysis examined the change in BER of an existing link with varying approach distance and orientation of the interfering user. However this assumed a basic NRZ modulation with binary-symmetric bit-error-probability. The analysis presented here uses a similar scenario but with links employing 4PPM

modulation in which the approach of the interferer affects the ISR seen by the existing link. This is therefore specifically applicable to IrDA FIR links at 4 Mbps.

## 2. PPM Performance Analysis

With 4PPM encoding, a PPM symbol consists of 4 sequential slots with a single signal pulse in one slot. If no or more than one pulse in a symbol is detected at the receiver, the symbol is rejected. Each symbol encodes a binary data pair of the original signal. The analysis by Ozugur uses an interfering signal taken to be a raised cosine shape pulse. This is chosen to model possible reflections and co-channel interference. The signal is given by:

$$s(t) = \left| \frac{s_{max} \sin(\pi t) \cos(\pi a t)}{\pi t (1 - 4a^2 t^2)} \right| \quad (1)$$

where the  $a$  is the raised-cosine factor (given as 0.75). The peak amplitude  $s_{max}$  produces an interference-signal-ratio (ISR). The ISR amplitude is split into  $M$  quantisation levels (chosen as 16) to produce an interference-signal-ratio quantisation level  $ISR_i$ .

$$ISR_i = \frac{ISR(2i-1)}{2M} \quad i=1, \dots, M \quad (2)$$

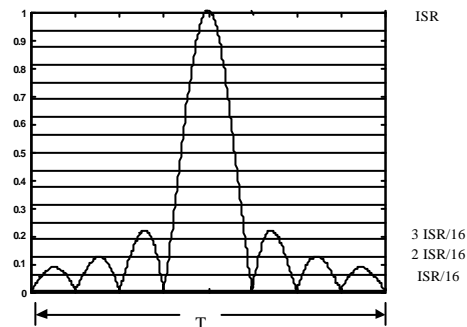


Figure 1. raised cosine interference signal pulse with ISR quantisation

The probability  $p_i$  is then defined as the proportion of the signal  $s(t)$  contained within the quantisation range  $ISR_i$  to  $ISR_{i+1}$ . This is determined numerically.

The signal-to-noise ratio at the receiver (from desired signal and background noise only) is defined as:

$$SNR = \frac{(P\sqrt{LT})^2}{\mathbf{s}^2} \quad (3)$$

where  $P$  is the received signal optical pulse power,  $L$  is the PPM slots per symbol (4 for 4 PPM),  $T$  is the slot period duration and  $\mathbf{s}$  is the noise variance.

The received power at slots containing a pulse and slots containing no pulse respectively are given by:

$$A_{i1} = P\sqrt{LT} \frac{1 + ISR_i}{1 + ISR_M} \quad (4)$$

$$A_{0i} = P\sqrt{LT} \frac{ISR_i}{1 + ISR_M} \quad (5)$$

The error probabilities for pulse slots and non-pulse slots respectively can therefore be given as:

$$p_{e1} = \sum_{i=1}^M p_i \left(1 - Q\left(\frac{Th - A_{i1}}{\mathbf{s}}\right)\right) \quad (6)$$

$$p_{e0} = \sum_{i=1}^M p_i Q\left(\frac{Th - A_{0i}}{\mathbf{s}}\right) \quad (7)$$

where  $Th$  is the normalised receiver threshold given by:

$$Th = 0.3P\sqrt{LT} (1 + ISR_M) \quad (8)$$

and  $Q(x)$  is the standard error function defined as:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-x^2/2} dx \quad (9)$$

The 4PPM symbol capture probability can then be given by:

$$p_{SC} = (1 - p_{e1})(1 - p_{e0})^3 \quad (10)$$

Since each 4PPM symbol represents 2 data bits, the packet error probability for a packet length of  $l$  bits can be given by:

$$p_e = 1 - p_{SC}^{l/2} \quad (11)$$

Figure 2. below shows the packet error probability against link SNR for packet length  $l = 1024$  bits.

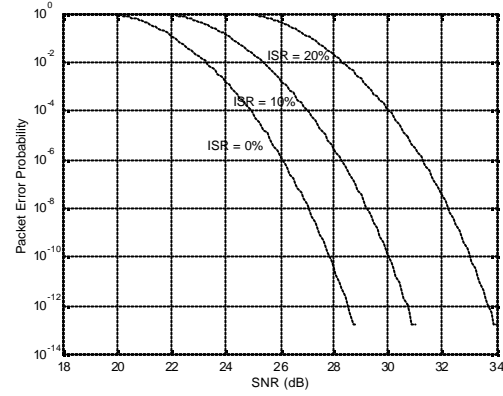


Figure 2. Packet Error Probability Vs SNR for packet length = 1024 bits.

### 3. Asymmetry analysis

The configuration of the link affected by third user interference is shown in figure 3. below.

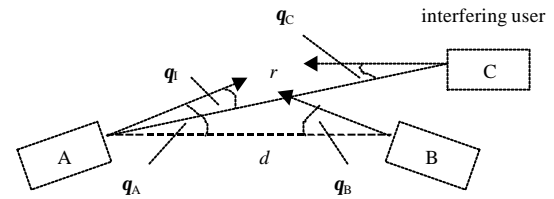


Figure 3. Geometry of link affected by third user interference

Users A and B are separated by a distance  $d$  and aligned at angles  $q_A$  and  $q_B$  to the line of sight axis (we assume plane geometry). Interfering user C is at a distance  $r$  from A aligned to the line of sight to A at angle  $q_C$  and to the transmission axis of A at interfering angle  $q_I$ .

The received optical power  $P_r$  at A from user B can be given by:

$$P_r(A,B) = \frac{P_t A(n+1) \cos^n(q_B) \cos^m(q_A)}{2pd^2} \quad (12)$$

where  $P_t$  is the transmitted power,  $A$  is the receiver area,  $n$  is the transmitter lobe index at B, and  $m$  is the receiver lobe index at A. This assumes modelling transmitters and receivers with the generalised Lambert's cosines law [8].

Similarly, the received power at A from interferer C can be given by:

$$P_r(A,C) = \frac{P_t A(n+1) \cos^n(q_C) \cos^m(q_I)}{2pr^2} \quad (13)$$

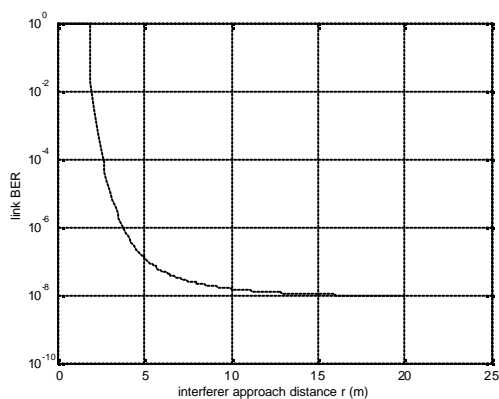
The IrDA physical layer specification requires a BER no worse than  $10^{-8}$  over a distance of at least 1 m. We can assume all the devices (A, B and C) have equal transmission and reception characteristics (i.e.  $P_t$ ,  $A$ ,  $n$  and  $m$ ). If we take distance  $d$  to be 1 m, link AB aligned such that  $q_A = q_B = 0$ , and C aligned to A such that  $q_C = 0$ , the interference-signal-ratio can be given by:

$$ISR = \frac{\cos^m(q_I)}{r^2} \quad (14)$$

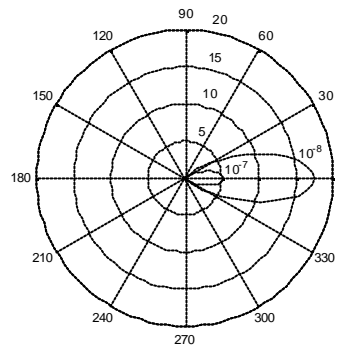
If we take the link BER over 1 m for the link without interference to be at most  $10^{-8}$ , thus satisfying the minimum IrDA physical layer requirement, the required packet error rate is approximately  $10^{-5}$  (using  $l=1024$  bits). From figure 2, it can be seen that an SNR of around 26 dB is required. This can be refined numerically to be 25.6 dB. This is then used to define the SNR value used in equations 3-11 to determine the packet error probability.

Figure 4. below shows the variation in link BER with the distance  $r$  of the interfering device. It can be seen that the BER 'floors' at  $10^{-8}$  which results from the given non-interference SNR.

Figure 5 shows a polar plot of interferer approach distance and alignment angle to provide link BER values of  $10^{-8}$  and  $10^{-7}$ . A receiver lobe index  $m$  of 20 is used to represent the minimum IrDA specification of  $\pm 15^\circ$  half power receiver angle.



**Figure 4. link BER Vs approach distance of interferer**

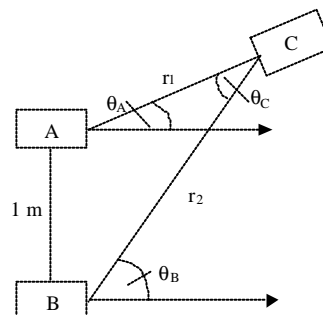


**Figure 5. Polar plot of interferer distance (m) and angle to provide link BER of  $10^{-8}$  and  $10^{-7}$**

It can be seen from figures 5 and 6 that although the BER begins to increase from  $10^{-8}$  at around 18 m, the increase only becomes significant below 5 m.

#### 4. Spatial Asymmetry Analysis

In this scenario users A and C are in an established link and interfered with by user B. A and B are now transmitting in parallel 1m apart. This is illustrated in figure 6. below.



**Figure 6. Spatial Asymmetry Scenario geometry**

The interference-signal-ratio (ISR) can here be given by:

$$ISR = \frac{\cos^n q_B \cos^m q_C r_1^2}{\cos^n q_A r_2^2} \quad (15)$$

Using trigonometry we can establish that:

$$r_2 = \sqrt{1 + r_1^2 - 2r_1 \cos(q_A + p/2)} \quad (16)$$

$$q_C = \sin^{-1} \left[ \frac{\sin(q_A + p/2)}{r_2} \right] \quad (17)$$

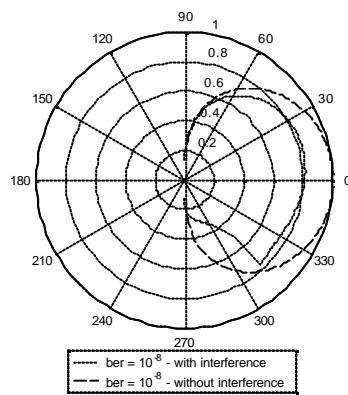
$$q_B = q_A + q_C \quad (18)$$

However in the scenario the SNR value of the link AB also changes with the angle and direction of the user C, as this affects the received power at A. The SNR can therefore be given by:

$$SNR = SNR_n \left[ \frac{\cos^m \theta_A}{r_1^2} \right]^2 \quad (19)$$

where  $SNR_n$  is the nominal SNR to achieve a BER of  $10^{-8}$  over 1 m, as determined previously.

The plot in figure 7 below shows the distance and angle of user C to A to provide a BER of  $10^{-8}$  both with and without interference from user B, using wide angle transceivers with  $n = m = 1$ .



**Figure 7. Spatial asymmetry of link AC distance and orientation of user C to A with fixed interferer B.**

The areas within the plotted curves produce a BER better than  $10^{-8}$ . It can be seen that with the presence of the third user interferer B, the C must move closer to B to maintain the link quality. The resultant spatial asymmetry when close to user B is evident. However, the asymmetry effects are only significant using wide angle transceivers.

## 5. Conclusions

In this paper we have analysed the link asymmetry effects from third user interference using links with 4PPM encoding. By taking a constant SNR to adhere to the minimum IrDA physical layer specification and determining the interference-signal-ratio (ISR) used in the PPM analysis model from an interfering device distance and geometry we have determined the minimum approach distance in order to maintain the link quality.

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