Directional and Spatial Asymmetry in IrDA 4PPM Infrared Wireless Links with Third User Interference

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Abstract

This paper examines the spatial and directional asymmetry effects on the BER of an IrDA 4PPM infrared wireless link due to interference from a similar third user IR device. Using the variation of interference-signal-ratio (ISR) from the third user interferer to an established link with a fixed SNR we provide the error probability of the PPM symbol. We present an analysis of the variation of BER of an established link due to the varying position of an interferer. The analysis is extended to examine the BER of a movable link node in relation to a fixed interferer.

1. Introduction

The quality of Infrared (IR) Wireless links can be degraded by both background ambient light noise and third-user interference [1]. IR links using the IrDA protocol are particularly susceptible to interference from a third IR wireless user as there is no inherent mechanism (e.g. carrier sensing) in the protocol to prevent it [2]. Interference can occur for example with two separate IR links in close proximity. This type of scenario can lead to spatial asymmetry of a link in which the link BER varies with distance and orientation of a receiver relative to the interferer. This is in addition to possible directional asymmetry of the link where the BER in each direction is unequal.

In addition to performance analyses of the IrDA IrLAP protocol [3, 4] the authors have also examined asymmetry in IrDA links [5, 6], assuming a basic NRZ OOK modulation with a binary-symmetric error probability.

IrDA FIR (Fast Infrared) links at 4 Mbits/s use 4PPM encoding to provide power efficiency with good noise immunity. An analysis of L-PPM encoded links with variable symbol repetition and third user interference was given by Ozugur [7, 8]. An interfering signal modelled as a raised-cosine pulse provided a constant interference-signal-ratio (ISR) which was used with an SNR from background ambient light to provide error probabilities for pulse and non-pulse slots. These were then used to provide a packet error probability in terms of the link SNR and ISR values. The analysis presented here examines directional and spatial asymmetry in IrDA links at 4 Mbits/s using 4PPM encoding using a fixed background SNR and varying ISR from link distance and orientation in relation to the third user interferer. Polar plots are produced to show the loci of an interferer in order to achieve the minimum link quality. This is then extended to examine the loci of a movable node in an established link in relation to a fixed interferer.

2. PPM Performance Analysis

A 4PPM 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 examined L-PPM with variable symbol repetition as used for IR wireless LANs. The analysis 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:

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

where the a is the raised-cosine factor (given as 0.75). The peak amplitude s_{max} produces an interference-signal-ratio (ISR). The phase of the interfering signal with respect to the intended signal is taken to be random. Thus, the sample amplitude can be any value between 0 and s_{max} within the PPM symbol period.

To model this, the ISR amplitude is split into M quantisation levels (chosen as 16) to produce an interference-signal-ratio quantisation level ISR_i. This is shown in figure 1.

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

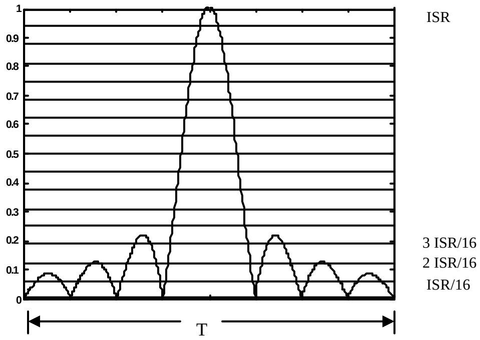

Figure 1. raised cosine interference signal pulse with ISR quantisation

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:

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

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 *s* is the noise variance.

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

$$A_{1i} = P\sqrt{LT}\,\frac{1+ISR_i}{1+ISR_M} \qquad (4)$$

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

The error probabilities for pulse slots and non-pulse slots respectively are given as:

$$p_{e1} = \sum_{i=1}^{M} p_i(1 - Q(\frac{Th - A_{1i}}{s})) \qquad (6)$$

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

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

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

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

$$Q(x) = \frac{1}{\sqrt{2p}}\int_{x}^{\infty} e^{-x^2/2}dx \qquad (9)$$

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

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

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

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

Figure 2. below shows the packet error probability against link SNR for packet length *l* = 1024 bits with ISR values of 0%, 10% and 20%.

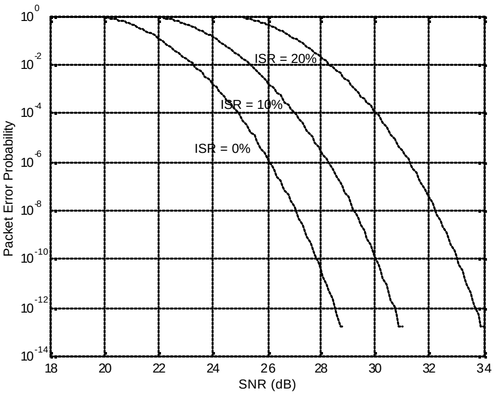

Figure 2. Packet error probability Vs SNR for packet length = 1024 bits

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 for the IrDA 4 Mbits/s 4PPM link, an SNR of around 25.5 dB is required. This can be refined numerically to be 25.54 dB. This is then used to define the SNR value used in equations 3-11 to determine the packet error probability. Figure 3. shows BER Vs ISR for SNR 25.54 dB.

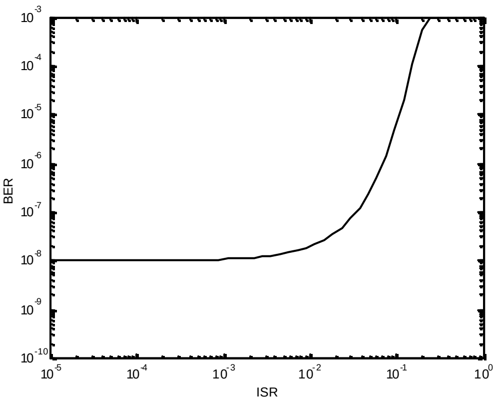

Figure 3. Packet Error probability Vs ISR for SNR = 25.54 dB

3. Directional Asymmetry Model

Directional asymmetry in a link is where the BER of the link is not directionally equal. Therefore for a link between devices A and B, the condition for directional asymmetry is:

$$\text{BER(A, B)} \neq \text{BER(B, A)} \qquad (12)$$

Considering third user interference with a uniform ambient light level giving a constant SNR, the condition for asymmetry is in terms of the interference-signal-ration (*ISR*):

$$ISR(\text{A}) \neq ISR(\text{B}) = 0 \qquad (13)$$

The configuration of the link affected by third user interference is shown in figure 4 below.

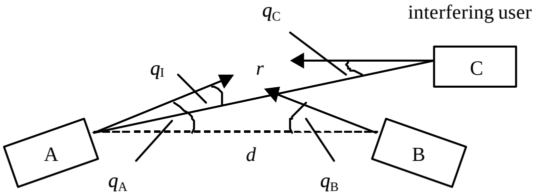

Figure 4. Geometry of link affected by third user interference

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:

$$P_r(\text{A,B}) = \frac{P_t A(n+1)\cos^n(q_B)\cos^m(q_A)}{2pd^2} \qquad (14)$$

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 [9]. Similarly, the received power at A from interferer C can be given by:

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

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 ISR at user A can be given by:

$$ISR(\text{A}) = \frac{\cos^m(q_I)}{r^2} \qquad (15)$$

Device B is unaffected by interferer C and thus has an ISR of zero.

$$ISR(\text{B}) = 0 \qquad (16)$$

Figure 5. below shows the variation in link BER with the distance r of the interfering device for an SNR value 25.54 dB. It can be seen that the increase from 10^{-8} only becomes significant below 5 m. The dotted line shows the unaffected BER of link AB at 10^{-8}. This demonstrates the directional asymmetry in the link.

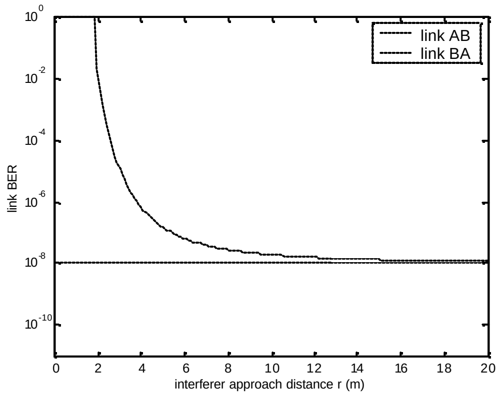

Figure 5. link AB and BA BER vs approach distance of interferer C towards A

Figure 6. shows a polar plot of interferer approach distance (m) and alignment angle to provide link BER values of 10^{-7}, 10^{-6} and 10^{-5}. A receiver lobe index m of 20 is used to represent the minimum IrDA specification of ± 15° half power receiver angle. Figure 7 shows the same analysis for wide angle transceivers with $m = 1$. It can be seen that for the narrow angle transceivers, the interferer approach distance can be very small at a wide approach angle.

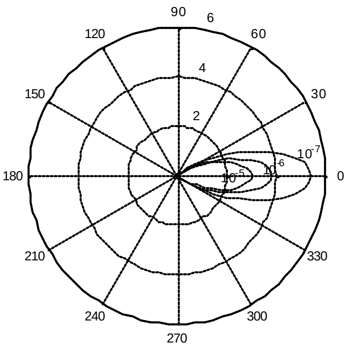

Figure 6. Interferer position for link BER of 10^{-7}, 10^{-6} and 10^{-5} for narrow angle transceivers

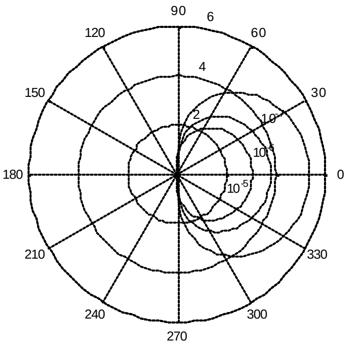

Figure 7. Interferer position for link BER of 10^{-7}, 10^{-6} and 10^{-5} for wide angle transceivers

4. Spatial Asymmetry Model

In this scenario, user A and interferer B are fixed and transmitting in parallel separated by a distance d. User C is movable and in an established LOS link with user A at a distance r_1 and alignment angle q_A. User C is interfered by user B at a distance r_2 and aligned to B at angle q_C while B is aligned to C at q_C.

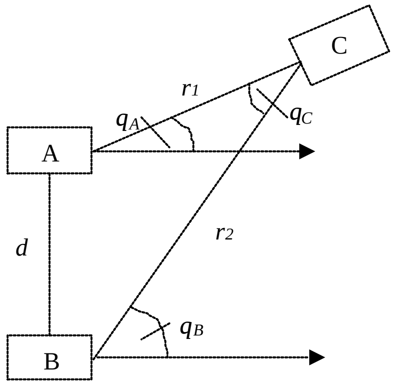

Figure 8. Spatial Asymmetry Model Geometry for link AC with fixed interferer B

The received optical power at C from A is given by:

$$P_r(C,A) = \frac{P_A A_C (n+1)\cos^n q_A}{2pr_1^{\,2}} \tag{15}$$

where P_A is the transmitter power at A, n is the transmitter radiation mode index, and A_C is the receiver area. Similarly the received power at C from interferer B is given by:

$$P_r(C,B) = \frac{P_B A_C (n+1)\cos^n q_B \cos^m q_C}{2pr_2^{\,2}} \tag{16}$$

where m is the mode index of the receiver.

If we assume that all devices have equal transmitter and receiver characteristics (i.e. transmitter power, receiver area, mode indices), the interference-signal-ratio (ISR) can be given by:

$$ISR = \frac{\cos^n q_B \cos^m q_C r_1^{\,2}}{\cos^n q_A r_2^{\,2}} \tag{17}$$

We establish from this using trigonometry that:

$$r_2 = \sqrt{d^2 + r_1^{\,2} - 2r_1 d\cos(q_A + p/2)} \tag{18}$$

$$q_C = \sin^{-1}\left[\frac{\sin(q_A + p/2)}{r_2}\right] \tag{19}$$

$$q_B = q_A + q_C \tag{20}$$

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:

$$SNR = SNRn\left[\frac{\cos^{m} q_{A}}{r_{1}^{2}}\right]^{2} \qquad (21)$$

where *SNRn* is the nominal SNR (i.e. 25.54 dB) to achieve a BER of 10^{-8} over 1 m, as determined previously.

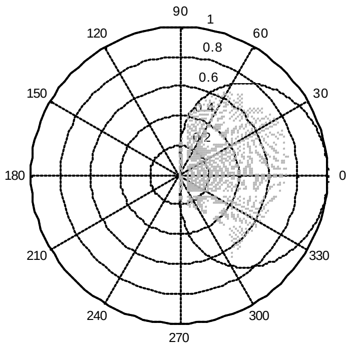

Figure 9. Asymmetry pattern for wide angle transceivers with d = 0.8 m

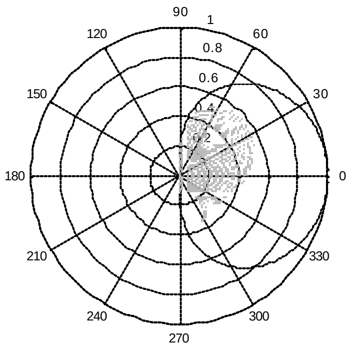

Figure 10. Asymmetry pattern for wide angle transceivers with d = 0.4 m

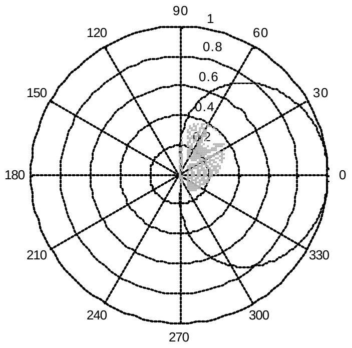

Figure 11. Asymmetry pattern for wide angle transceivers with d = 0.2 m

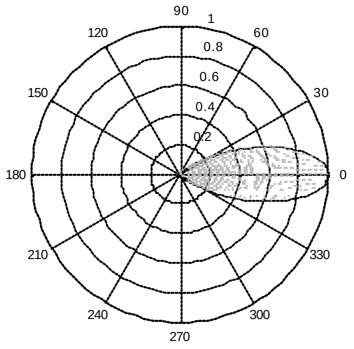

Figure 12. Asymmetry pattern for narrow angle transceivers with d = 0.8 m

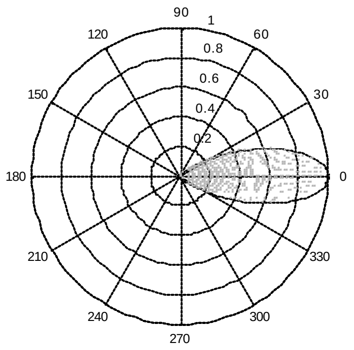

Figure 13. Asymmetry pattern for narrow angle transceivers with d = 0.4 m

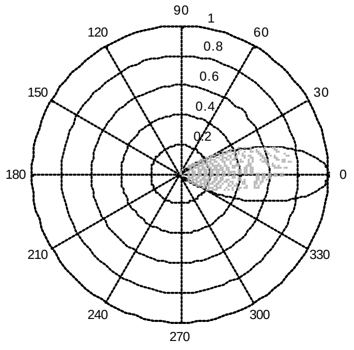

Figure 14. Asymmetry for narrow angle transceivers with d = 0.2 m

Figures 9 – 14 show the asymmetry patterns for both wide and narrow angle transceivers with closing interferer separation distance d. The shaded area in each plot in the spatial range (q_A (deg), r_1 (m)) to achieve a BER better than or equal to 10^{-8} in the presence of the interfering user at distance d. The solid line represents the spatial range limit with no interferer present.

It can be seen that the spatial asymmetry effect is much more significant for wide angle transceivers. For the narrow angle transceivers, the effect only becomes noticeable at an interferer distance $d < 0.5$ m.

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 demonstrated both directional asymmetry from an approaching interferer to a fixed established link and spatial asymmetry from a movable link node in relation to a fixed interferer. It can be seen that by using narrow angle transceivers, the effect of a third user interferer can be reduced.

References

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