ASYMMETRIC THROUGHPUT IN OPTICAL WIRELESS LINKS

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Abstract

In this work we study optical wireless asymmetric communication. Specifically the work is focused on IrDA wireless links and third party interference to an already established optical link. We derive bit error rates at the physical layer, and furthermore, we calculate the average throughput of IrDA link access protocol (IrLAP) under the influence of third party interference. Results of the BER and IrLAP throughput degradation are presented.

Introduction

Wired communication links are mostly designed to be symmetric. By symmetry here we mean that bi-directional communications over the same link are of the same quality. Quality here is measured by low bit error rate (BER) and in this work we also determine the link access protocol throughput as the ultimate measure. In wired communications symmetric communication is possible because noise in a wired medium is much more controlled than in wireless media. In wireless communications and specifically in optical wireless links, bi-directional link asymmetry can be observed due to a number of reasons, [1], [3].

The ambient noise, which directly influences the performance of IR links, is not always the same for both linked users. For example, a user working on a PC/laptop and exchanging bi-directional information with another user may have a table lamp switched on in close proximity the receiving circuits, with result to cause excess noise in his own receiver compared to the other communicating user. Since it is possible and likely that users are under the influence of different quantity and sometimes type of ambient noise, it should not be expected that the links be symmetric.

Another scenario which is likely to cause asymmetric bi-directional communication is when two users are linked and communicating under the same ambient noise conditions but a third user unaware of the already established link, is attempting to transmit. 'Third user' or 'interferer user' transmission in the proximity may detriment one of the existing link directions. This effect is accentuated by the fact that due to manufacturing tolerances on mass produced devices by the same or different manufacturer, no two transceivers are identical. It is possible therefore to have an interferer device with higher transmitted power and lower sensitivity receiver than the other two devices. This implies that the interferer may be unaware of the presence of the active link, and as a result continues to transmit, degrading one of the established link directions. This causes asymmetric throughput. The effect is often called the 'deaf-man-shouting' problem.

In this paper we describe an analysis of the degradation of the bit error rate (BER) of the affected link direction, as a function of the interferer parameters such as transmit power receiver threshold, and spatial position. We present results of the BER as a function of the 2D position of the interfering device. Characteristics of asymmetries of this type are presented. We also present results of the IrDA link access protocol (IrLAP) throughput degradation due to the asymmetry of link BER. The results presented are for a specific IR link protocol, the IrDA IrLAP protocol, using a calculation of average packet end-to-end transmission times, and incorporating re-transmissions due to link errors, [2],[4]. We show that the affected link throughput in the case of 'deaf man shouting' interferer can be serious. Understanding the various types of asymmetries is important towards the design of robust future optical wireless links.

Basic system, two IR device model

The IR users A and B are linked and exchange data. Figure 1 illustrates the model. User 1 has transmitter Tx1 and receiver Rx1 and user 2 has Tx2 and Rx2. When A is transmitting to B, the link distance ‘d’ is related to the other system parameters, for NRZ data, by:

$$d = \sqrt{\frac{(m+1).\,P_T A \cos^m q_A . \cos^n q_B}{4p\,\sqrt{2e(P_B + P_R)\, r\,.\,B.\,SNR}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where m and n are the Tx1 and Rx2 radiation pattern lobe index. We assume here a normalised radiation pattern following shape as $Cos^m q_A$ and $\mathrm{Cos}^n \theta_B$ respectively.

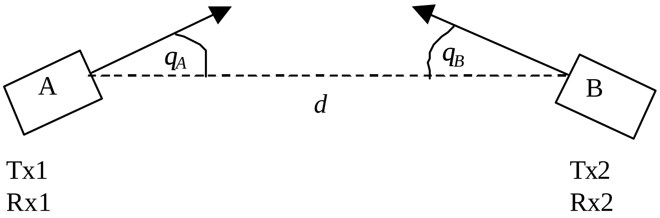

Figure 1: Two user IR link model Tx1 and Rx2 are at distance d apart, subtended by angles q_A, and q_B to d.

P_T, P_B and P_R are the transmitted, received and ambient optical power, B is the receiver bandwidth, SNR is the signal to noise ratio, A is the detector area, r is the detector responsivity, (in A/W), and ‘e’ is the electronic charge. Equation 1, clearly describes the relation between the IR link distance and SNR which in turn is related to link Bit Error Rate, (BER), for fixed ambient light noise and the other parameters. The established link between users A and B is symmetric about the connecting line AB. Assuming the transmitting and receiving devices of A and B are the same, or the transceivers have the same parity, then the throughput is the same in both directions AB and BA, resulting in symmetric bi-directional throughput, provided the ambient light noise is not asymmetric.

Modelling third user interference

In this work, we assume that the ambient background noise (lamps, lighting of various types, cause ambient noise in all devices present. We consider, in the same way as that shown in Figure 1, two users A and B connected and exchanging data. For the sake of clarity we assume users A and B are identical and perfectly aligned. That implies that the angles q_A, and q_B are zero. This assumption implies that a maximum link distance between A and B is possible. The link A and B is symmetrical. Extending the model, we assume here the presence of a third user C, located further from user B, and invisible to user B, as illustrated in Figure 2. The receiver of user A however, will be affected by transmissions from C. The effect of transmissions from user C therefore is expected to cause degradation of link BA, due to interference from C to A. We assume C is located anywhere on the plane of AB, pointing towards A. We further assume for simplicity that $q_C = 0$. This means that C is aligned and pointing towards A. This maybe a situation when C attempts to connect to A being unaware however of the existing link between BA. The link AB is however unaffected by C. Asymmetry in link throughput between AB and BA would therefore occur due to transmissions from C towards A.

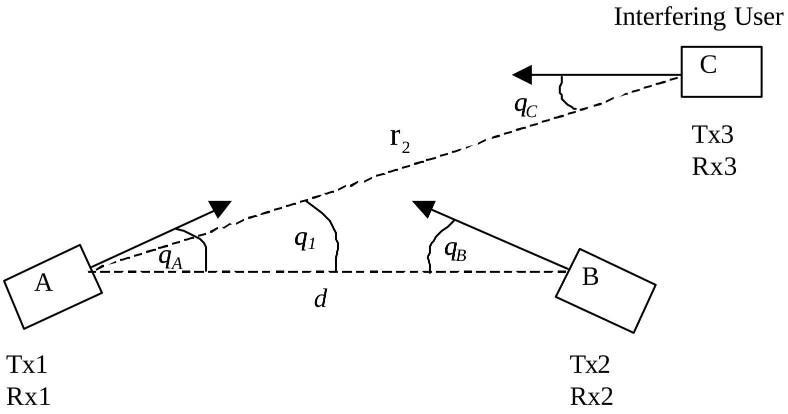

Figure 2: Interference by user C: User A is linked to B. User C interferes with user A.

Bit Error Rate of IrDA links

We assume that the transmissions from C degrade the eye diagram of the link BA as shown in Figure 3. The magnitude of the interference from C is shown by a vector in the opposite direction to the signal.

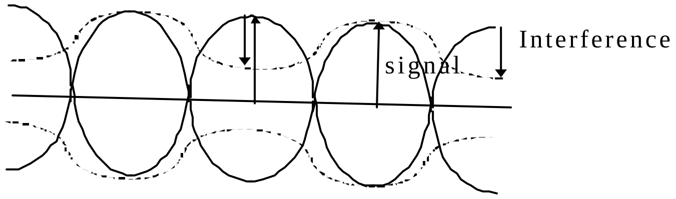

Figure 3: Eye diagram at receiver of user A. The interference from user C causes eye closure.

For user A, the probability of error P_e for the received data from user B, under the influence of interference from C is given by $P_e = Q(\sqrt{SNR})$. It follows that:

$$P_e = Q\left[\frac{\text{signal - interferen ce}}{s}\right] \quad \text{...(2)}$$

as illustrated in Figure 3, with Q being the complementary error function, and s is the rms noise amplitude at the receiver. Using the geometry of Figure 3, we can determine the signal and interference strengths in equation (2).

$$\text{signal} = \frac{P_B.R.A(m+1)[\cos^n q_A \cos^m q_B]}{2p \qquad d^2} \quad \text{.........................(3)}$$

and $$\text{interferen ce} = \frac{P_C.R.A(m+1)[\cos^n(q_A - q_1)\cos^m q_C]}{2p \qquad r_2^2} \quad \text{.........................(4)}$$

and P_C is the transmitted power from the interfering user C, P_B is the user B transmit power, R is the receiver responsivity in A/W, m, and n are the transmitter and receiver lobe cosine values.

When $\frac{\text{signal - interference}}{\sigma} = 6$, this results in a BER = 10^{-9}.

Equation (2) for an IrDA link specified at d=1m, with error rate at this distance $P_e = 10^{-9}$ without interference. It takes the following form with interference from user C, (Figure 2):

$$P_e = Q[\frac{6T_B\cos^n\theta_A\cos^m\theta_B}{R_A d^2} - \frac{6T_BT_C\cos^m\theta_C\cos^n(\theta_A-\theta_1)}{r_2^2 R_A^2}] \ldots\ldots\ldots\ldots..(5)$$

Where R_A is user A receiver threshold in W/m^2, T_B,T_C are the transmit intensity of user B and interferer user C respectively in W/Sr.

Results

In order to demonstrate the effect of the interfering user C on the link BA error rate quality, we use the above principles on IrDA optical links. We combine the derived probability of errors using the model described here, with a model of the IrLAP (link layer protocol) to produce normalised throughput results. We have modeled here both the physical and link layer of IrDA. As outlined earlier, user C degrades the quality of link BA. As C approaches A, the degradation worsens, until C senses that A is actively linked with B. This happens at a distance called 'carrier sense' (CS). Carrier sense distance is the minimum distance from A necessary for C to sense transmissions from A. If CS is long enough, it stops C early from degrading significantly BA. However, we show here that if user C transmits with intensity more than 80 mW/Sr which is within the lower of the specified transmit intensity limits of the IrDA standard, it is possible for C to destroy the quality of link BA before it senses the presence of activity. The carrier sense distance [3] for a typical IrDA link is taken here to be 2.3 meters.

The results of Figure 4 were derived with the assumptions that Users A and B are aligned and the interfering user C is on the same line as AB and also aligned and aimed at user A. This translates to $\theta_A = \theta_B = \theta_C = \theta_1 = 0$. We can observe that as the interfering user's transmitted power increases the throughput of BA link deteriorates. This is understood from the fact that the interference level increases and the bit error rate of link BA increases. The results of Figure 4 have been derived for the IrLAP protocol of IrDA, [4]. User A is transmitting to user B with 40 mW/Sr intensity. When the intensity of the transmission from C has reached 80mW/Sr, the throughput is less than 0.2 before CS can detect activity by user A. As the power increases even more, then the link throughput will be zero. This indicates that carrier sense is not sufficient in protecting an existing link. IrDA versions 1.x do not have a carrier sense provision. We can determine from Figure 4 that a user C identical to user A and B, (40 mW/Sr), if it approaches user A to less than 2 m, will noticeably reduce its throughput unless carrier sense is active. At 1.5 m distance it would deteriorate the throughput to zero. Manufacturing component tolerances and the standard transmitter band limits are wide enough to allow an interfering user to deteriorate or even destroy the quality and throughput of an IR link.

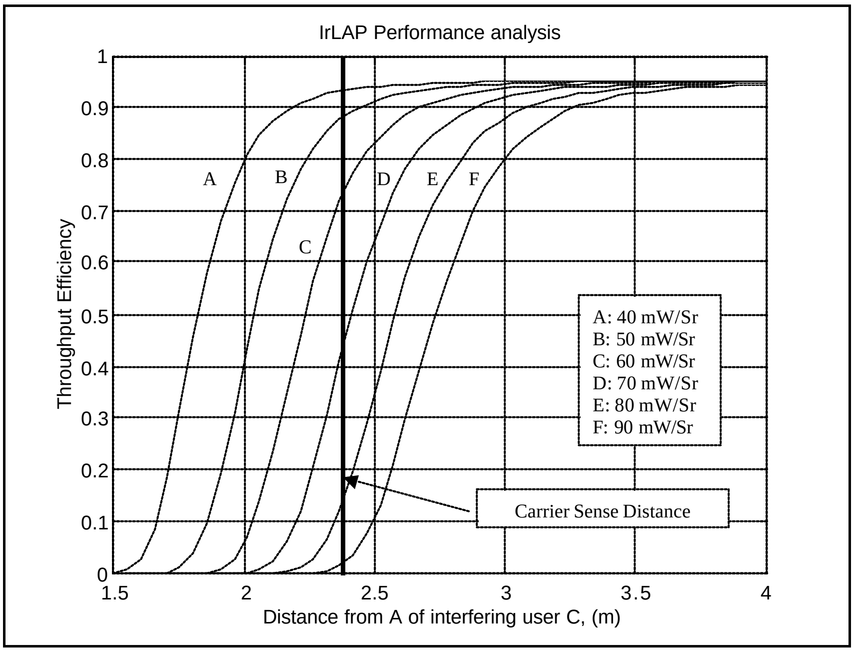

Figure 4: IrLAP throughput of link BA when an interfering user C is along the axis AB.

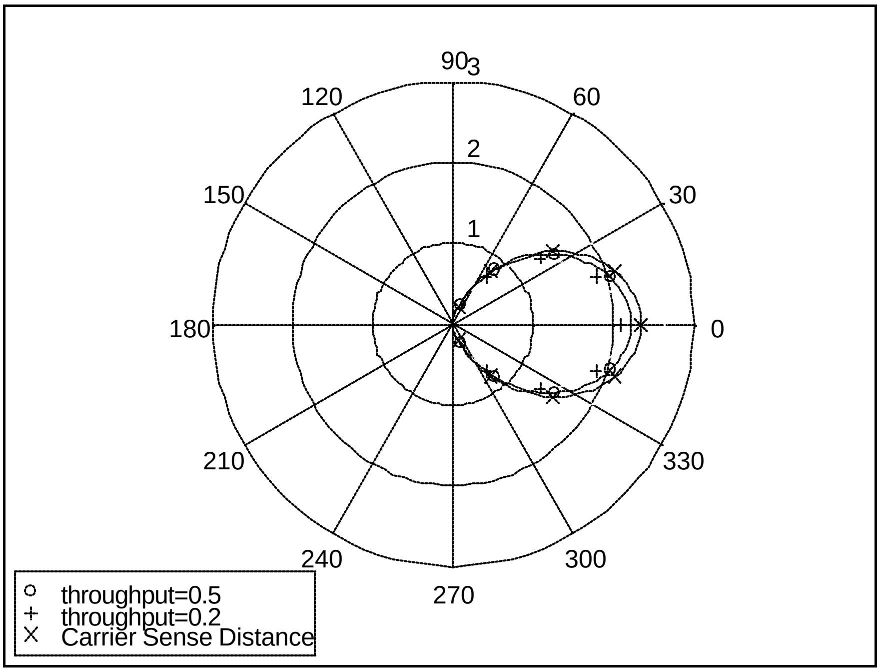

Figure 5: Darkened area represents the location of interferer C relative to user A. user A is located at the center of the polar plot. The darkened area represents the BA link throughput of better than 0.9. The inner contours represent throughput=0.5, and 0.2. The carrier sense distance is the contour at 2.3 m along the zero degree axis. T_C = 60 mW/Sr and T_B = 40mW/Sr.

In deriving the results of Figure 5 and 6, user C was allowed to move freely on a 2D plane containing A and B. If there is a carrier sense operation active, as shown in Figure 5, (first contour inside from the outer) it is sufficient to prevent throughput loss, since it is active just as the throughput of BA is about to drop. Finally, when the interfering user, C, transmit intensity is increased to 70 mW/Sr, still well within the IrDA limits, Figure 6 shows that the throughput of link BA is zero at a distance approximately 2 m along *q* = 0, without carrier sense. The chosen carrier sense distance of 2.3 m is not adequate to protect the link BA when the intensity of C is increased to 90mW/Sr.

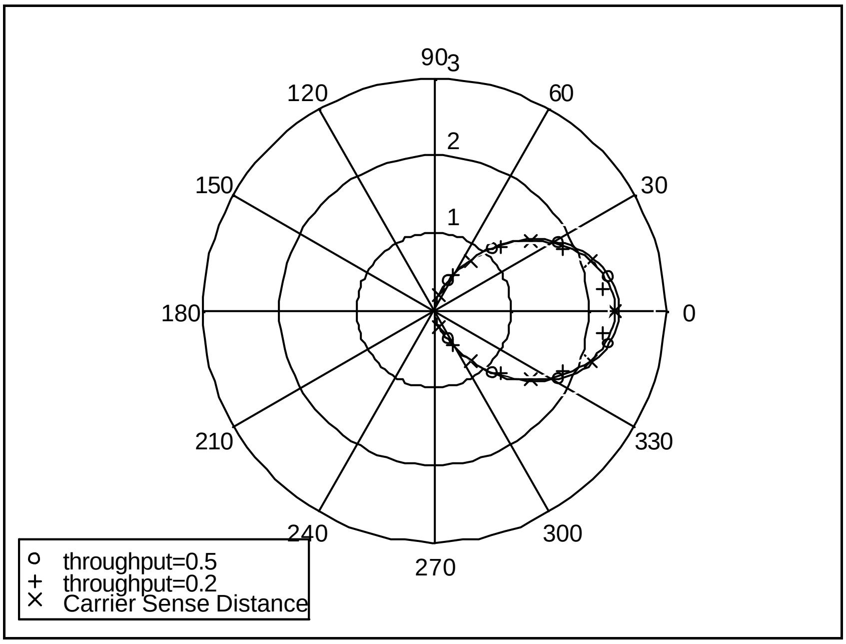

Figure 6: T_C = 90mW /Sr, T_B = 40mW/Sr: Carrier sense distance at 2.3 m along *q* = 0 , is not adequate to prevent the throughput of link BA to be zero.

Conclusion

A model has been developed to describe the effect of third user interference on an active IR link. The model allows the position of the third user interferer to vary in 2D space. The results of the analysis for an IrDA link, indicate that it is possible for the interferer to shadow the existing link. The throughput can be degraded to zero, provided the intensity of the third user transmitter is as low as 80 mW/Sr, which is within the lower limit of an IrDA transmitter. This demonstrates the importance of carrier sense as a means of deterring third users transmitting within the range of an existing IrDA link. There is no provision in the IrDA 1.x standard for this kind of interference. However, for the AIR standard this is being recognized and carrier sense is part of the operation of the link.

References

[1]: Asymmetry of Free Space Optical Links: Anthony Boucouvalas, SPIE Proceedings on All Optical Communication Systems: Architecture, Control and Network Issues: 25-26 Oct. 1995 Philadelphia, USA.

[2]: IRDA: For information contact IrDA administrator, PO Box 495, Brookdale, California 95007-0495, USA

[3]: Interference Induced IR Link Spatial Asymmetries, A.C. Boucouvalas, Jennifer Jerrams-Smith, and David Heathcote
Third Communication Networks Symposium, Manchester Metropolitan University, 8-9th July 1996.

[4] IrLAP protocol performance analysis of IrDA wireless communications.
A.C. Boucouvalas, P.Barker,
IEE, Electronics letters, Vol.34,no.25, pp.2380-2381,1998.

Acknowledgements: We would like to thank British Telecom Laboratories UK, for their financial support in carrying out this work.