Asymmetry of Free Space Optical Links.

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ABSTRACT

The concept of asymmetry in free space optical links is discussed. Simple equations describing the minimum carrier sense distance, the minimum and maximum distance of reliable link, and maximum interference distance are derived. Examples from the recently drafted IRDA specification for IR Links are given. A solution is presented to the parity variation problem by controlling the field of view of such transceivers.

Keywords: Optical Communications, Data Communications, Free Space Optical Links, Asymmetric Communications.

1. INTRODUCTION

Symmetry in relation to an optical link, occurs when for two communicating nodes, A and B, the transmissions from node A are received by node B and vice versa. This allows a receiver user to detect when a caller user is first attempting to link up, and also ensures that the receiver's reply is being heard by the caller user.

Symmetry in free space optical links is a desired characteristic for bi-directional links and networks. It is assumed that there are no physical obstacles preventing the transmissions from reaching some users, hence there are no hidden nodes. A positive consequence of symmetry arises in the scenario when in an already established link between two users, a third party is prevented from interfering the existing link. Due to symmetry, the third user would recognise the existence of the link and would not attempt to transmit and disturb the link underway. The discussion is particularly relevant to low cost and fixed threshold receivers, which are under study within the Infrared Data Association, IRDA, [1]. For a single bi-directional link, Physical Layer component tolerances result in transceivers not being identical, hence of differing transmission intensity and receiver thresholds. This means that a bi-directional link would sustain itself up to a specified maximum distance. At longer distances one communication link breaks down first, causing asymmetry. At even longer distances both link directions are eventually ineffective. Unlike fibre optic links, personal portable and palmtop computer users of low cost and simple IR links are more likely to experience such asymmetry problems since this distance is angularly dependent and device dependent. If an IR link is established between nodes A and B, and a neighbouring user C of lower receiver sensitivity and higher transmitter power than A or B (asymmetric) is attempting to connect to one of the communicating users, C is unaware of the interference it has caused. This is often called the 'Deaf Man shouting ' problem. The opposite situation, when the node C receiver is sensitive to detect transmissions from node A, but its transmitter is weaker to be detected by A. This is normally not a serious problem since by observing the link protocol, C at least does not disturb the link between A and B.

Similarly, two independent bi-directional links side by side can interfere each other due to this asymmetry and there is a minimum distance for the link pairs below which interference does not allow for reliable communication.
This distance can be up to a few metres, or in 3D corresponding to the volume of a typical room. Under those circumstances, the undesired result is that only one bidirectional link is allowed to operate at one time.

2. PARITY OF FREE SPACE IR LINKS.

Parity is defined as the product of a transmitter output Intensity, T_A, (mW/Sr), and receiver threshold R_A, (mW/cm^2). This should be constant in order to achieve link symmetry. If we consider two linked transceivers A and B pointed at each other, then the maximum distance that A can 'hear' B is:

$$d_{AB} = \sqrt{T_B / R_A} .$$

The maximum distance B can detect A is:

$$d_{BA} = \sqrt{T_A / R_B} .$$

For symmetry, it is desired that $d_{AB} = d_{BA}$, as discussed above, without necessarily $T_A = T_B$. We therefore must have:

$$T_A \times R_A = T_B \times R_B . \qquad ....(1)$$

Hence in order to achieve symmetry among the various IR links we must maintain the parity $T_A \times R_A$, constant among the various transceivers.

3. PARITY OF IRDA LINKS:

The first IR wireless link standard adopted by the Infrared Data Association, makes use of RZ encoding at data rate of 115.2 kbit/s. It is expected widespread future use of such links in palmtop, notebook PCs and other similar products hence the analysis described here is based on the IRDA standard.
For the purpose of symmetry, the IRDA physical layer can be simplified to the following specifications:

Maximum allowed transmitted intensity from device: 500mW/Sr.
Minimum allowed transmitted intensity from device: 40mW/Sr.
Minimum receiver threshold for 1m distance operation: 0.3 mW/cm^2
Maximum receiver threshold for 1m distance operation: 4 mW/cm^2 .

From the above, Maximum Parity = 500x4 = **2000** $nW/(Sr*cm^2)$
Minimum Parity = 40x0.3 = **12** $nW/(Sr*cm^2)$ **.**

Parity variation is often defined as $b = \frac{MaximumParity}{MinimumParity} = \frac{T_{\max} \times R_{\max}}{T_{\min} \times R_{\min}}$ ....(2)

From equation 2, we obtain that the parity variation for the IRDA standard links is $b = 167$.

This undesirably wide parity variation results from component and circuit tolerances, and it is difficult to reduce without incurring a significant cost increase, which is a worse 'evil' among manufacturers. It is therefore clear that the parity is not maintained for IRDA links, and it is likely that two linking IRDA devices would have inherent asymmetry.
However it is a desired longer term goal to be able to guarantee a smaller variation in parity, in order to ensure better symmetry.

4. CARRIER SENSE DISTANCE

Let us consider the scenario described earlier, of a bi-directional link between node A and B, with a third node, C, as shown in Figure 1.

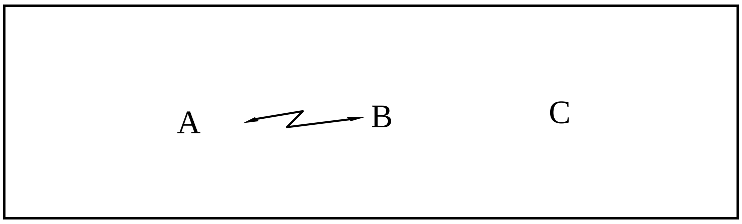

Figure 1: Node C senses bi-directional link AB

The carrier sense distance of node C from transmissions of A is the distance AC at which node C starts detecting activity from node A. This occurs as C approaches A.
If A and B are IRDA links, the IRDA protocol has a turnaround time between A and B every 500 ms. This ensures that both A and B have a chance to transmit and also to confirm each other's presence.
Assuming A is transmitting half the time, A transmits at 115200 bits/s.
Over this period, it transmits 115200 x 0.25 = 28800 bits, only half of which are zeros, [P(1)=P(0)], i.e. 14400 zeros.

At the carrier sense distance we assume at least one of the 14400 bits is detected by C, and when that occurs, C backs off realising that there is activity between A and B.

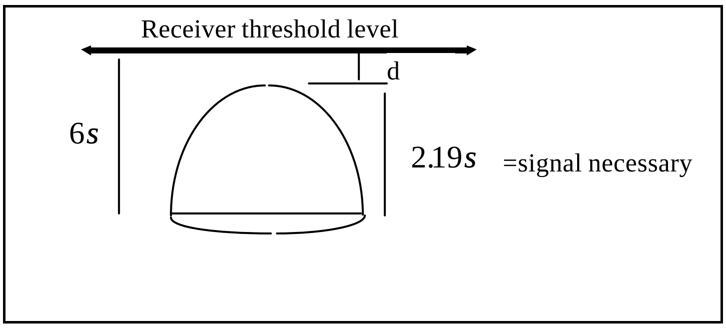

Figure 2: Receiver threshold and signal strength at carrier sense distance

Hence if P_c is the probability of one correct bit detected out of 14400, we have $P_c = 1/14400 = 69.4 \times 10^{-4}$, alternatively,

$$69.4\times10^{-4} = Erfc(\frac{d}{s}) \qquad \text{.......................(3)}$$

From tables we obtain $d = 3.81s$

This is illustrated in Figure 2, where the relative position of the threshold and signal eye pattern is sketched.

In order to derive the carrier sense distance, d_{cs}, the IRDA specification is used as follows: For $40mW/Sr$ transmitter intensity and $4mW/cm^2$ receiver threshold, we obtain a distance of 1m at error rates of 10^{-9}. This is the minimum IRDA link specification.

Hence we can deduce, that the minimum carrier sense distance is :

$$d_{cs} = \sqrt{\frac{12s}{2.19s}}, \quad \text{or } d_{cs} = 2.34\,m. \qquad \text{.........................(4)}$$

5. MINIMUM DISTANCE FOR A RELIABLE LINK

Let us assume that node B transmits to A, with the minimum allowed transmitter intensity $T_{\min}$, and node A has a receiver threshold, $R_{\max}$. A and B are at maximum range, but still guaranteeing fixed error rate, in our case 10^{-9}, as shown in Figure 3.

Figure 3: Minimum distance for reliable link.

The minimum distance for reliable link, y, is given by:

$$y = k\sqrt{\frac{T_{\min}}{R_{\max}}}. \qquad \text{......................... (5)}$$

This distance for IRDA is 1m, for $T_{\min} = 40mW/Sr \text{ and } R_{\max} = 4mW/cm^2$

in the above formula, k, is in general a constant.

6. MINIMUM CARRIER SENSE DISTANCE

In general, the minimum carrier sense distance is related to the minimum distance for reliable link as follows:

$$d_{cs} = 2.34y \qquad \text{..(6)}$$

where ‘y’, is the minimum reliable link distance.

7. MAXIMUM DISTANCE FOR RELIABLE LINK

The maximum distance for reliable link is given by:

$$y_1 = k_1\sqrt{\frac{T_{\max}}{R_{\min}}} = k_1\sqrt{\frac{bT_{\min}}{R_{\max}}} \text{ , } \quad \text{............................(7)}$$

where b is the parity ratio, discussed above.

Therefore, $y_1 = y\sqrt{b}$.

8. MAXIMUM INTERFERENCE DISTANCE

This distance is related to the carrier sense distance. The maximum carrier sense distance is the maximum interference distance.

Hence $d\max_{cs} = 2.3 \times y_1$

alternatively, $d\max_{cs} = 2.3 \times y \times \sqrt{b}$ . ...(8)

This is the distance that a 'loud' transmitter is able to corrupt the link of a sensitive receiver.

Therefore, as a result of asymmetry, there would be a maximum and minimum optical link distance, as well as a maximum and minimum carrier sense distance.

9. ADJACENT LINK INTERFERENCE

In this work so far, the analysis has been restricted to near line of sight situations, where the communicating nodes A and B are aligned, together with the interfering node C.
The angular dependence has not been included, for simplicity.
There is however a scenario which is of great interest to users, illustrated in Figure 4, that of two independent adjacent wireless optical links. Users A,B,C, and D could be sitting around a table for example, exchanging data files using wireless IR links.

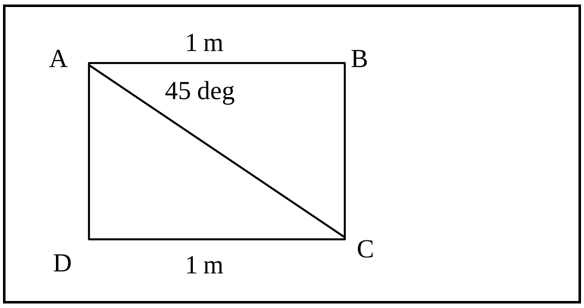

Figure 4: Potentially interfering concurrent links AB and DC.

Since the IRDA standard links are specified with 1m range, it is assumed here that the distances AD and BC are 1m.
The question addressed here is how close the two links are allowed to be, before adjacent link interference occurs. For example, if node C has a low sensitivity receiver and a high end specification transmitter, (Deaf Man Shouting), is potentially interfering with node A diagonally, due to radiation spillover. The minimum distances AD and AC are therefore of interest.
Without loss of generality, the transmitting sources, LEDs, and receiving photodiodes, are assumed to have Gaussian radiation pattern of the form:

$$I(q) = I_0 \times \exp\left(\frac{q * 0.832}{q_h}\right)^2 \text{ ....(9)}$$

where q_h is the angle in degrees at the radiation pattern falls to 0.5, and q is the angle in degrees. The minimum distance AC is given by the maximum distance of interference between node A and C. This distance is given by:

$$d_{AC} = 2.34 \times d_0 \times \sqrt{b} \qquad \text{......................................(10)}$$

where $d_0 = \sqrt{I_1(45) \times I_2(45)}$.

where $I_1(45)$ is the angular dependence of the transmitting LED radiation pattern at 45 degrees, and $I_2(45)$ the angular dependence of the receiver at 45 degrees, (diagonally).

Therefore $$d_0 = \sqrt{\exp(-(\frac{0.832 * 45}{q_{h1}})^2) \times \exp(-(\frac{0.832 * 45}{q_{h2}})^2)} \quad \text{...............(11)}$$

with q_{h1} *and* q_{h2} are the half angles of the LEDs and photodetectors.

The distance AD, the minimum distance which no interference occurs is given by:

$$d_{AD} = \frac{d_{AC}}{\sqrt{2}} . \quad \text{...(12)}$$

10. RESULTS

In order to determine the minimum distance AD, the links are allowed equation 12 is calculated for different values of parity variation.

Figure 5 displays the minimum allowed distance between parallel links in metres, as a function of the transmitter intensity half angle, in degrees. Figure 5 is calculated for a parity variation of only 4. This is unrealistic in practice, due to the fact that component tolerances are far greater. In this, and subsequent figures, the receiver half angle is assumed to be 30 degrees. This is chosen to be as wide as possible within the IRDA specification, so as to reduce the need for precise alignment between transceivers. Figure 5 shows that as we reduce the transmitter half angle, the distance AD, is allowed to be smaller. That means in practice, that we can operate the two parallel bidirectional links closer together without interference.

If we take as a minimum neighbouring distance yardstick, say 0.5m, then it is clear that with a transmitter half angle of 25 degrees this is achievable.

Figure 6 is a similar plot with the same parameters except the parity variation is set equal to 12. A similar trend is observed. The minimum required transmitter half angle is now approximately 21 degrees.

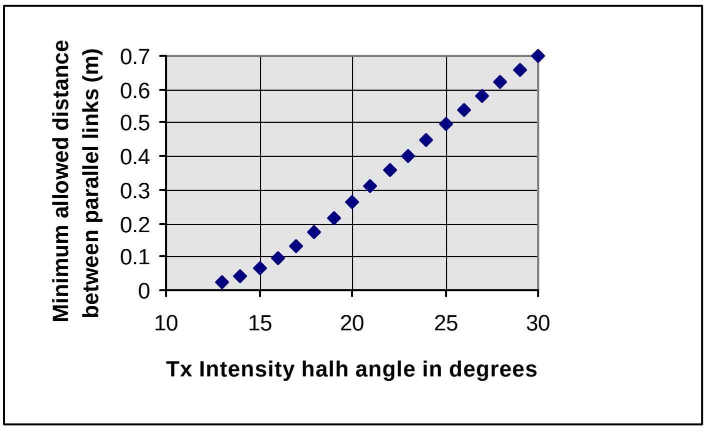

Figure 5: Minimum allowed distance between parallel links (m), Parity variation = 4, Receiver half angle 30 deg.

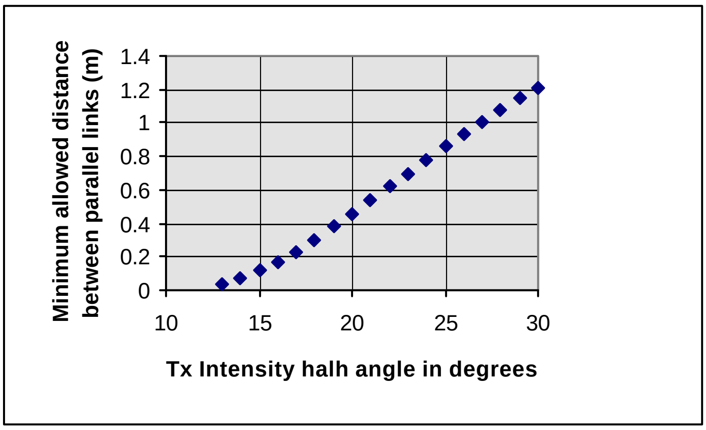

Figure 6: Minimum allowed distance between parallel links (m), Parity variation =12, Receiver half angle 30 deg.

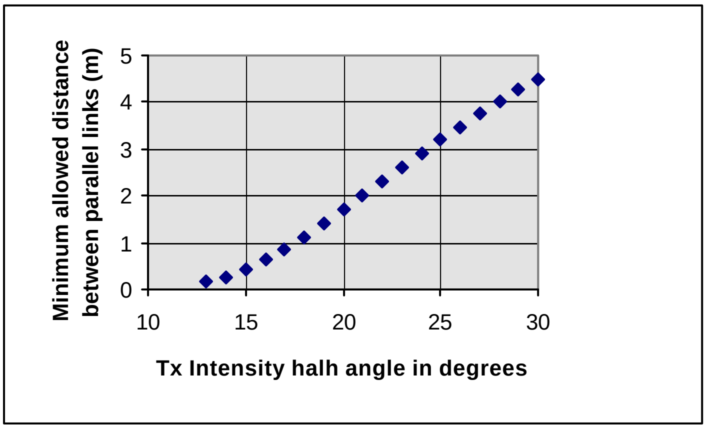

Figure 7: Minimum allowed distance between parallel links (m), Parity variation =157, Receiver half angle 30 deg.

Finally Figure 7 shows another plot with the maximum parity variation expected in IRDA of 167. This is the worst case variation and it can be seen that a transmitter half angle of 15 degrees would suffice for a minimum distance between the links of 0.5 metres, without interference. However, if the transmitter angle is totally unrestricted, say 30 degrees, the second link should not be closer than 4.5 m from the first, otherwise they interfere.

10. CONCLUSIONS

The issue of asymmetry in free space optical links was discussed in relation to the latest IRDA standard. To achieve symmetry, the parity variation must be very small, and currently this is not a viable option. A solution is presented, where the receiver angle may be large so as alignment between devices is not critical, but by restricting only the transmitter angle. If the transmitter half angle is reduced to 15 degrees, then even for the worst parity variation of 157 we can still operate two independent parallel links side by side at 0.5m away.

7. REFERENCES:

1. IRDA: For information contact IRDA administrator, PO Box 495, Brookdale, California 95007-0495, USA