Infrared communication channel optimisation for quasi−diffuse multi−spot wireless indoor networking

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Abstract: In this report we develop an indoor infrared (IR) channel model and use it to study optimum configurations for quasi−diffuse multi−spot IR wireless communications. By means of these simulation tools we show how we can reduce multi−path effects and co−channel interference in order to improve detection for high−speed data rates.

Introduction

Recently there has been growing interest in InfraRed (IR) optical wireless communications [1]. IR wireless forms a practical basis for many applications and provides solutions for environments where wired links or Radio Frequency (RF) wireless may not give the best implementation. For wide applicability, a wireless link should be compact, consume little power, and be easy to align, yet robust against background noise and interference from the other users. As a transmission medium for indoor wireless communications, infrared has several advantages over radio, such as an enormous unregulated bandwidth for high bit rates and absence of interference between links operating in rooms separated by walls. Furthermore infrared components are usually inexpensive, small and consume little power.

This paper addresses one of the most promising candidates for high−speed in−house IR wireless communications, called Multi−Spot Diffusing Configuration (MSDC) [2]. MSDC is actually a quasi−diffuse configuration using multi−beam transmitters emitting nearly collimated beams and an array of detectors with each one having a narrow Field−Of−View (FOV). In some cases, the detector array is formed into an imaging receiver [3]. The goal of this paper is to evaluate the impulse response of an indoor free−space optical IR channel with a variety of MSDC configurations for the array of sources and detectors and their angular directivities. We present the results from these simulations and discuss how to optimize the infrared channel for higher data rates.

Multi−Spot Quasi−Diffuse IR channel model

The geometry of the IR channel considered in this report is shown schematically in Figure 1 in the form of a room. In this figure, we define a pair of transmitters (T) and detectors (D) and assume that their IR beams couple primarily via the ceiling, since this is the best reflecting surface available in most common rooms. In this report, we model the beams and the FOV of the transmitters and detectors using a generalized Lambertian pattern [4]. This pattern is defined by $[(n+1)\cos^n(\alpha)]/2\pi$, where α is the angle from the directivity vector of the transmitter/detector and n is an integer for setting the narrowness of the beam/FOV. The patterns of IR light incident on the ceiling and their detected portions are calculated using this expression and assuming a uniform reflectivity function for the ceiling surface. Note that changing these assumptions to more realistic beam/FOV forms and reflectivity functions are not expected to change the main qualitative conclusions of this report for the data−rate optimizations.

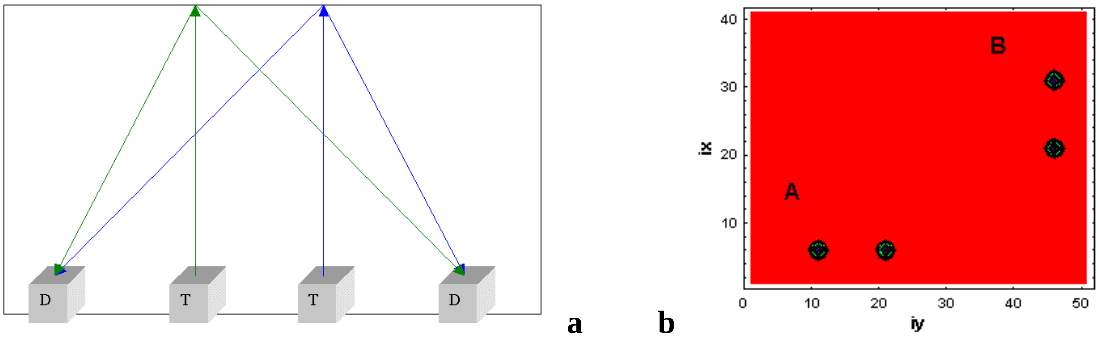

Fig. 1: *(a) gives the cross−section diagram of a room for the IR channel model. The transmitters (T) and detectors (D) interact via reflections from the ceiling only. Figure (b) on the right indicates the positions of two specific sets (A,B) transmitter/detector pairs on the floor of a 4x5 meter room (axes in dm) with a 2m high ceiling. These give our simulation geometry.*

For the rest of this report, we assume that we have an IR channel defined between a pair of transmitter/receivers (TxRx) indicated as A and B in Figure 1b. This figure shows the positions of these transmitters and detectors on the floor of a 4x5 meter room with 2m height. All of the communications and channel responses are defined between the TxRx pairs of the sets A and B. Figure 2 shows the patterns of IR illumination on the ceiling detected by set B, both elements acting as a combined receiver, when the elements in set A are acting as a combined transmitter, for two different directivity configurations. More specifically, the directivity patterns of the transmitters and receivers are chosen first arbitrarily for Figure 2a and then optimized for the pattern in Figure 2b. The light output powers of the sources in this report are taken to be unity for all cases.

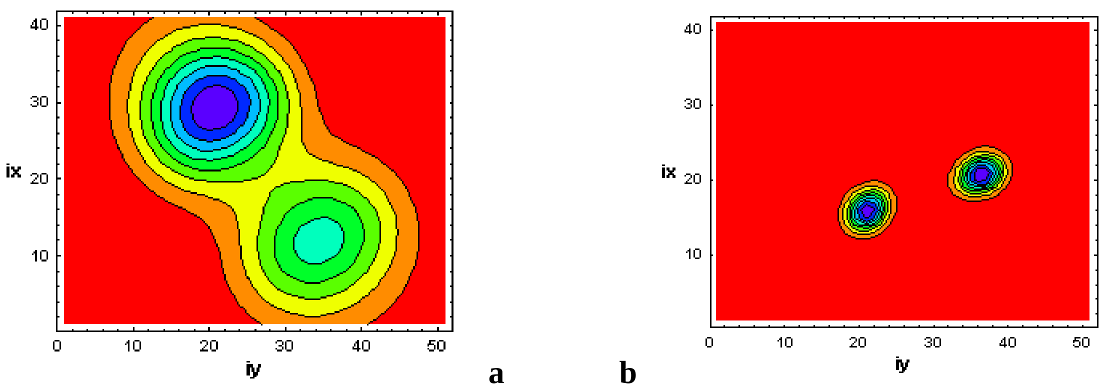

Fig. 2. *(a) and (b) above indicate the detected IR light patterns by set B when set A is transmitting in the two cases corresponding to an arbitrary and optimized, respectively, beam/FOV angles and widths discussed in the next section. The parameter n, defining the width of the beams, are chosen to be between 5−20 for case (a) and between 100−200 for case (b).*

IR channel impulse response optimization

The pattern in Figure 2a is only the intensity of the detected IR illumination. Each point in this pattern has time delays associated with the travel of that light from its source to the detector. The impulse response of the channel is obtained by binning the intensities of light traveling between each source and detector into time slots. The impulse response of the IR channel example in Figure 2a is shown in Figure 3a below. It is seen that this impulse response shows multi−path behavior due to the arbitrary selection of the source/detector directivity angles for the example in Figure 2a. Taking the Fourier transform of this impulse response in Figure 3a gives us the frequency response and channel bandwidth as shown in Figure 3b. The + in Figure 3b indicates point for the 3dB bandwidth which is only about 10 MHz for this case.

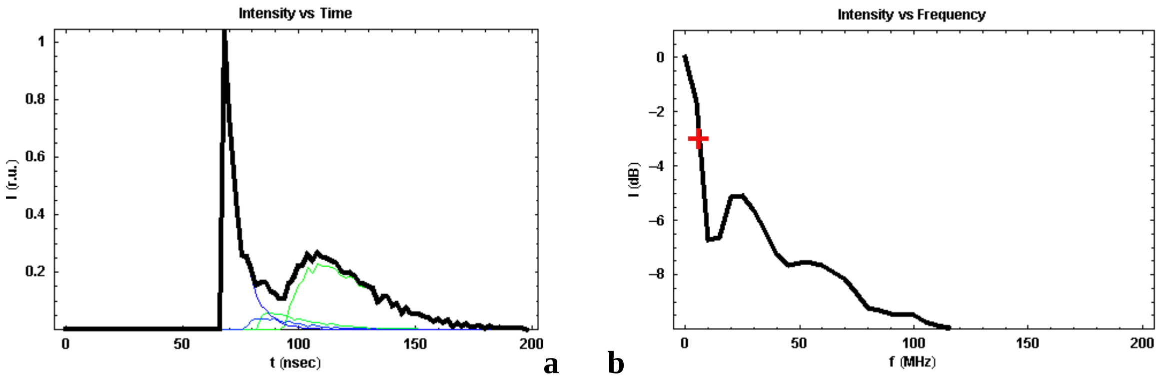

Fig. 3: *Figure 3a shows the impulse response of the channel corresponding to the illumination pattern example in Figure 2a corresponding to an arbitrary arrangement of source/detector directivity angles. Thin lines in (a) give impulse responses between individual source/detector pairs before summing. Figure 3b shows the frequency response for the impulse response in 3a. The + in 3b indicates the 3dB point of the channel response. Intensity is in relative units.*

By narrowing the beam/FOV patterns of the previous example and also by changing the directivity angles, as shown in Figure 2b, we can optimize the impulse response of the IR channel. The results of this optimization are shown in Figure 4 below. The impulse response of the optimized IR channel example is shown in Figure 4a. It is seen that this impulse response shows a single narrow peak due to a special selection of the source/detector directivity angles and widths. The frequency response and channel bandwidth is shown in Figure 4b. The 3dB bandwidth for this case is about 80 MHz

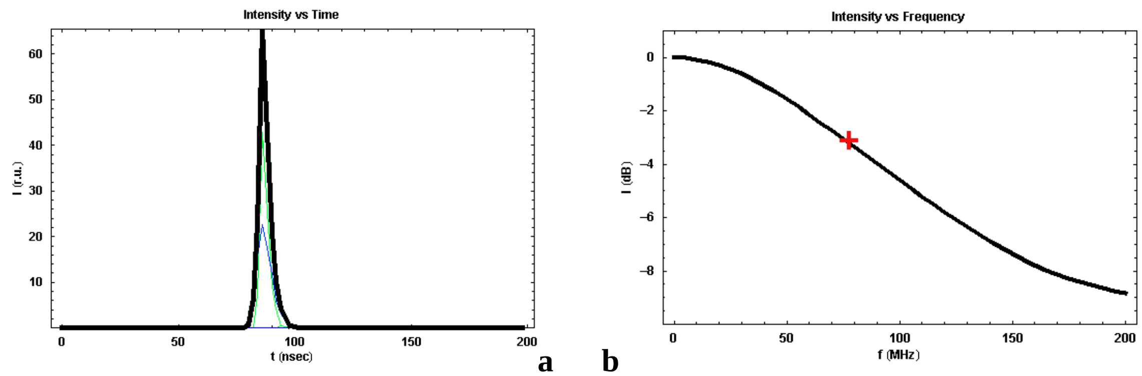

Fig. 4: *Figure 4a shows the impulse response of the channel after optimization of source/detector directivity angles and widths. Figure 4b shows the frequency response and indicates the 3dB point of the channel bandwidth.*

IR channel data rates

In order to get a good estimate of data−rates achievable with our IR channel, we must know more about the noise contributions. However, detailed analysis of different types of noise in the IR channel and corresponding IR powers needed for a given bit−error−rate is beyond the coverage of this report. Therefore, in Figure 3 and 4, we assume a white noise level that is low with respect to the amplitude of the channel frequency response in both cases. Then we can compare the data rates for channels in Figure 3 and 4 by considering primarily their 3dB points. As indicated in these figures, we have the 3dB bandwidth for the arbitrarily configured case (Figure 3) at about 10 MHz and in the optimized configuration (Figure 4) at about 80 MHz .Therefore, we conclude that the infrared communication bandwidth in our specific examples can be improved by a factor 8. Furthermore, if we make the assumption that for the arbitrary case in Figure 4 one would have to normally operate with signal−to−noise ratios (SNR) in the range of 10−30 dB, then we can expect to gain another factor of about 2 from the higher peak signal powers in Figure 4 as compared to the Figure 3. Since with proper modulation and SNR ratio, the efficiency of spectral utilization can reach several bits/sec/Hz, we then can expect that an optimized quasi−diffuse multi−spot IR communications channel can reach data rates of about several 100 Mbps. However, we must emphasize again that such comparisons and the data rates in realistic situations would depend on the actual SNR and the type of modulation. These issues will be investigated in more detail in another report. We also plan to investigate the dependence of performance gains at higher numbers of source/detector pairs.

Discussion and conclusions

In this paper have considered multi−spot diffusing configuration (MSDC) for IR communications and we studied the impulse and frequency responses of the indoor IR channel. We demonstrated that we can optimize the directionality and the field−of−view of the sources and detectors in order to get a better impulse response and a larger bandwidth. In this way we showed that we can improve the data−rate considerably. Specifically, we have shown by simulations that we can achieve improvements in data rates by about an order of magnitude after optimizing sources/detectors array configurations.

References

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