Combining Emitter and Receiver Diversity to Achieve Data Rates Above 100 Mbps on Diffuse Optical Channels

The use of combined emitter and receiver angular diversity to combat effectively the multipath dispersion of the indoor diffuse optical channel is studied. A system allowing transmission at baud rates above 100 Mbps with low inter-symbol interference and negligible power penalty is proposed.

Introduction: In recent years, there has been a growing interest on using high speed wireless local area networks (WLANs). The radio frequency spectrum is scarce and, in general, requires licensing. Infrared (IR) technology has a very large spectrum, free of use in most countries, and can be considered one of the supporting technologies for future broadband WLANs [1, 2]. However, multipath propagation of the optical signal originates inter-symbol interference (ISI) and imposes a growing penalty for baud rates above about 10 Mbps [2, 3]. The use of angular diversity on the receiver to minimise the multipath dispersion was already studied [4, 3]. A source with multiple narrow emitting beams conveniently oriented allows to reduce the channel propagation losses [5]. Combining a multi-beam transmitter with a sectored receiver, where at least one sector sees exactly one of those reflecting spots for most receiver positions, should also result in a substantial reduction in the delay spread of the collected signal. This letter proposes and studies a system using combined emitter and receiver angular diversity to combat the multipath dispersion of indoor IR diffuse communications, achieving data rates in excess of 100 Mbps.

System Configuration: The system configuration proposed in this work is based on a multi-beam transmitter and on a sectored receiver with multiple detectors. The emitter pattern was optimised to minimise the worst-case propagation losses after one reflection of the emitted signal. This process was done using a simulator of the indoor optical channel [3]. It considered only LEDs with half-power angle (hpa) of 1° and resulted on a configuration with: (i) 1 LED ($P_t = 80\ mW$ and $hpa = 1.0°$), vertically oriented and (ii) one matrix of 8 LEDs ($P_t = 115\, mW$ and $hpa = 1°$), inclined at 50° with the vertical and uniformly distributed over the azimuth. The sectored receiver has one segment of 12 sectors with azimutal aperture (fov_a) of 30° [3].

The multipath dispersion of the indoor optical channel will be estimated considering two parameters: the -3 dB channel bandwidth (BW) and the rms delay of the collected signal (σ_τ). The values of BW and σ_τ are evaluated from the channel impulse response, which is obtained through simulation. σ_τ is given by

$$\sigma_\tau = \sqrt{\frac{\sum_{i=0}^{N-1} (\tau_i - \overline{\tau})^2 p_i}{\sum_{i=0}^{N-1} p_i}} \tag{1}$$

where p_i is the power received with delay τ_i and $\overline{\tau}$ is the average delay of the collected signal, given by

$$\overline{\tau} = \frac{\sum_{i=0}^{N-1} \tau_i p_i}{\sum_{i=0}^{N-1} p_i} \tag{2}$$

We consider two distinct combining methods at the diversity receiver: (i) Best-Sector (BS) – The sector with the lowest σ_τ or the maximum BW is selected (estimation of the impulse response in all sectors is required, and a complex receiver structure may result) and (ii) Any-Sector (AS) – The sector is selected using a criterion independent of the channel impulse response (e.g. using the signal-to-noise ratio (SNR) as in [6]). To assess the performance of this method, we consider, at each receiver position, the average, taken over all sectors, of σ_τ or BW values.

Performance Evaluation: To evaluate the performance of the proposed system, we consider an empty room with $8 \times 8 \times 4\ m^3$ where all the room surfaces have an IR reflection coefficient of 0.7. The emitter is fixed at the room centre, 1 m above the floor, and emits 1 W. The receiver moves on a plane also 1 m above the floor. Two types of sources and receivers were considered: one source with a lambertian radiation pattern (*reference emitter*) and other with multiple emitting elements (*diversity emitter*), as defined previously; one receiver configuration with a single element detector (*reference receiver*) and other with multiple detectors (*sectored receiver*). The reference emitter and receiver are always aimed vertically.

The capabilities of combined emitter and receiver diversity in reducing the signal delay spread are evaluated by considering four system configurations: (i) ideal lambertian emitter and reference receiver, (ii) ideal lambertian emitter and sectored receiver, (iii) multi-beam transmitter and reference receiver and (iv) multi-beam transmitter and sectored receiver.

Results and Conclusions: The channel characteristics were evaluated for a representative set of approximately 80 receiver positions, uniformly distributed over the room space, while maintaining the emitter fixed at the room centre. Figures 1 and 2 present the statistics of BW and σ_τ, for the four system configurations under study. The figures show the average values and, for the system

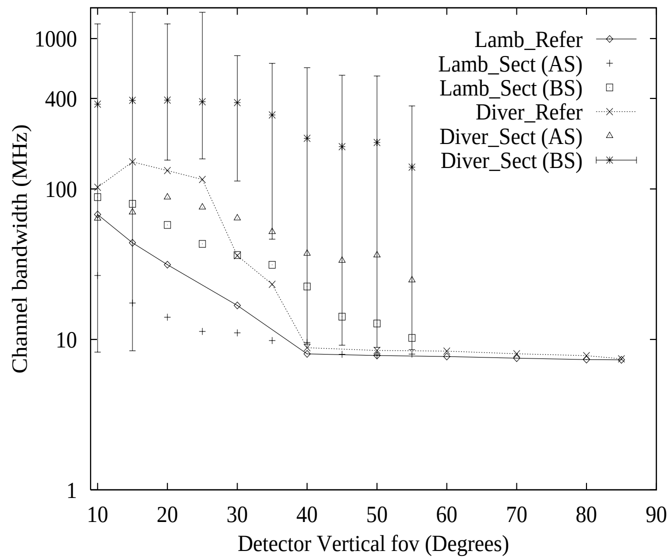

Figure 1: Diversity gain in terms of channel bandwidth.

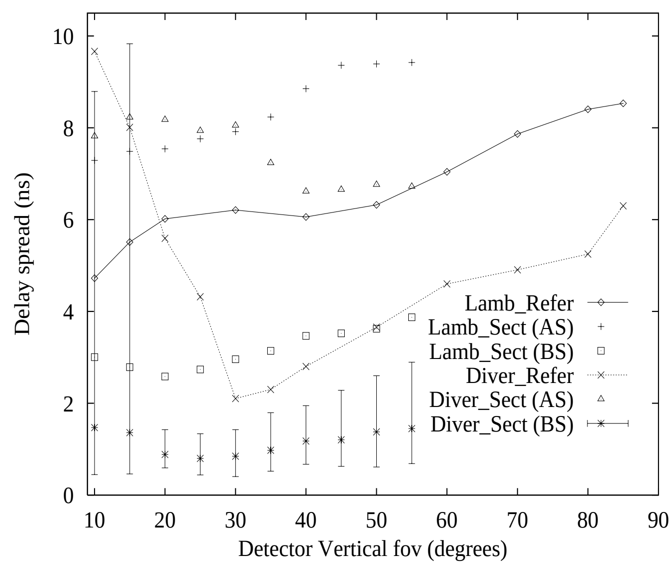

Figure 2: Diversity gains in terms of delay spread.

using combined emitter and receiver diversity with a BS selection (curve `Diver_Sect (BS)`), they also show the minimum and maximum values. The legends indicate: (i) emitter (Lamb – lambertian, Diver – with diversity), (ii) receiver (Refer – reference, Sect – sectored) and (iii) combinig method used (AS or BS). For each sector, the vertical aperture (fov_v) is given by the difference between the upper (θ_h) and the lower (θ_l) limits of the sector vertical aperture. The values of θ_h and θ_l are shown in Table 1 and were designed to assure that each sector sees only one emitting spot in the maximum possible number of receiver positions. Figure 1 shows that using combined emitter and

fov_v	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°
θ_l	45°	35°	35°	30°	23°	20°	20°	15°	15°	10°
θ_h	55°	50°	55°	55°	53°	55°	60°	60°	65°	65°

Table 1: Vertical limits of the sectors aperture.

receiver diversity with a BS selection originates a significant increase on the average values of BW to approximately 400 MHz, for $fov_v < 35°$. Moreover, configurations with $15° < fov_v < 35°$, result in minimum values of BW above one hundred MHz, which is important for worst-case designs. This is the system configuration we propose to combat effectively the multipath dispersion of the indoor diffuse channel. When $fov_v \leq 15°$, the minimum BW is smaller as there are receiver positions where none of the sectors see any of the reflection spots in the ceiling surface. Similarly, for $fov_v \geq 35°$, the minimum BW is reduced as there are positions where some sectors see more than one reflection spot, while others do not see any. In the reference system, the average values of BW is about 10 MHz. In systems with angular diversity only at the emitter or at the receiver, the average value of BW is, in general, smaller than 100 MHz, but the minimum values of BW remain about 10 MHz. The results of Figure 2 confirm these conclusions. Figure 3 shows the statistics of the collected power of the four system configurations under study. The results are normalised for an active area of 1 cm^2 and show that the proposed system configuration originates only a small reduction on the collected power, relatively to the reference system. For $15° < fov_v < 35°$, the average power penalty is smaller than 3 dB. In addition, we note that the minimum values of the collected power for the other three configurations (not shown in the figure) are, in general, smaller than the minimum values of the proposed system. In this configuration, when $fov_v \leq 15°$, there are receiver positions where no sector sees any reflection spot in the ceiling surface. This fact is confirmed by the low values of the minimum collected power.

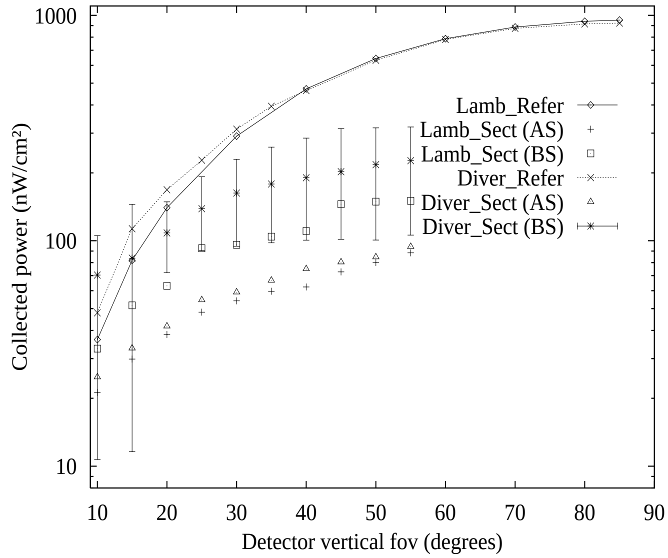

Figure 3: Diversity effects on the collected power.

The above results show that the use of combined emitter and receiver angular diversity allows to increase considerably the channel BW, allowing to transmit at baud rates above 100 $Mbps$ with negligible IES and small power penalty.

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