Flexible Emitter Radiation Pattern for IR Indoor Wireless Local Area Networks

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Abstract

This document presents a flexible emitter radiation pattern (ERP) for infrared (IR) indoor wireless local area networks (WLAN). IR systems based on the specified ERP will present similar performance in quite dissimilar indoor environments. The specification is based on a long process of optimisation complying with the requirements of minimising I) the propagation losses and II) the number of hidden stations. Moreover, the optimisation process took into account the constrains imposed by safety standards. Both, open plant and walled rooms with quite dissimilar propagation characteristics were considered. The algorithm used to optimise the ERP is presented and discussed. A mask specifying the bounds that must be respected for conformance testing is proposed. Using our ERP, we present simulation results for the achieved range in both open plant and walled rooms. The results show that the specified ERP allows proper operation in dissimilar environments with smooth degradation with the propagation conditions. The specified ERP has been included in the first version of the standard for the IR PHY of the IEEE 802.11 working group.

This work is being carried out as part of the ESPRIT.6892 - POWER (Portable Workstation for Education in Europe) project commissioned by the European Community.

1 Introduction

In the last few years, there has been an enourmous increase in the use of infrared (IR) technology for wireless indoor applications. There are several companies designing IR Wireless Local Area Networks (WLAN) with very different characteristics, including the emitter radiation pattern (ERP). Those systems need to work properly in very different indoor environments. Moreover, it may be necessary to operate systems from different manufacturers together in the same room. In addition, excess tolerance in the specification of the ERP can lead to hidden stations.

In an attempt to aliviate these facts, the IEEE decided, a few years ago, to setup a working group, the IEEE 802.11, to develop a standard for indoor wireless LANs. IR is a cheap technology which has associated a bandwidth virtually unlimited and does not requires licensing. Therefore, it is one of the technologies being considered by the IEEE 802.11. As specified in the IR physical (PHY) layer section of the draft standard [1], a dual rate approach of 1 or 2 Mbit/s using pulse position modulation (PPM) and a diffuse propagation mode are considered for IR systems.

As in most of the diffuse IR WLAN systems, the ERP presented in this paper makes use of light emitting diodes (LED) as the emitting source. As shown in [2], vertical orientation of all LEDs is by far not the best solution in view of the minimisation of the propagation losses. Also, from the user point of view, no aiming of the transceivers should be required for proper operation. We believe that the specification of the ERP should be based on an array of LEDs where the characteristics and orientation of each element should be optimised. As referred in [3, 4], excessive tolerance in the specification of the

ERP can lead to hidden stations. Therefore, a tight specification of the ERP is also required. Safety aspects may impose some constraints [5, 6] on the configuration of the array and on the parameters of its LED elements and have to be taken into account. All the studies performed in this document made use of a simulation package which implements a model for the indoor optical channel [7].

The ERP specified in this paper has been included in the first version of the standard for the IR PHY of the IEEE 802.11 working group. The paper follows with brief comments about safety aspects that affect IR wireless indoor systems. In section III, a detailed explanation of the methodology followed in obtaining the ERP is given and a mask specifying the bounds of the ERP is proposed. Conformance testing for the ERP specification is addressed in section IV. Simulation results for the achieved range in both open plants and walled rooms are presented in section V. Section VI, presents the main conclusions of this work.

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2 Safety Issues

The limits imposed by safety regulations must be considered on the design of IR communication systems. Those limits are based on the maximum IR power density and/or radiant energy for which human exposure falls bellow the maximum permissible exposure levels [5]. In IR systems, these levels are imposed by eye safety limits. Specifically, eye safety limits will set the maximum emitted power and minimum beam divergence of the ERP. Safety is considered inicially to select safe LEDs for the ERP optimisation process. After the ERP has been optimised, safety rules have also to be verifyed.

A study of safety aspects of the ERP specified in this document have been realized [8]. The study considered several standards for the safe use of laser systems [9, 10, 11] and was based on the recent IEC 825 -Safety of Laser Products [5]. The results showed that the ERP specified for the baseband IR PHY draft standard is in conformance with the IEC safety standard rules.

3 Emitter Radiation Pattern

The definition of an optimised ERP is a difficult task because of the many different environments an IR system is being designed for. Environments differ in terms of configuration of static and mobile reflectors (walls, ceiling, furniture, persons, etc.) and of their reflecting properties. Nevertheless, we may consider that typical environments fall into 2 categories: open plants and walled rooms. It is essential to provide a specification that degrades smoothly with the environment conditions. By smooth degradation, we mean that propagation losses have to increase monotonously with distance in all environments, avoiding coverage discontinuities within the overall system range. Figure 1 illustrates this concept. With all LEDs pointed into the same direction, figure 1a, the irradiance smoothly degrades with the range. However, there is an unnecessarily high level of irradiance near the emitter leading to shorter ranges. The optimisation of the ERP consists in spreading the irradiance in excess near the emitter to obtain higher ranges.

This can be done through the optimised array approach illustrated in figure 1b. In this curve, there is a constant irradiance level, Imin, up to a cut-off range, Rmin, after which the irradiance smoothly degrades with the range. The potential drawback of using a constant irradiance level is that, if we are operating near limiting conditions, any further degradation in the propagation conditions may lead to a sudden coverage loss over the whole cell. For this reason, we will specify the Rmin and Imin parameters in such a way that a total coverage loss can only happen in environments where it is not useful to use an IR diffuse system anymore. So, the cut-off range, Rmin, corresponds to the minimum range for all environments where the IR system is supposed to operate and the minimum constant irradiance level, Imin, is derived from worst-case propagation conditions. We have assumed $Rmin = 4$ meter and that Imin corresponds to an open plant with a ceiling reflection coefficient of $r = 0.4$.

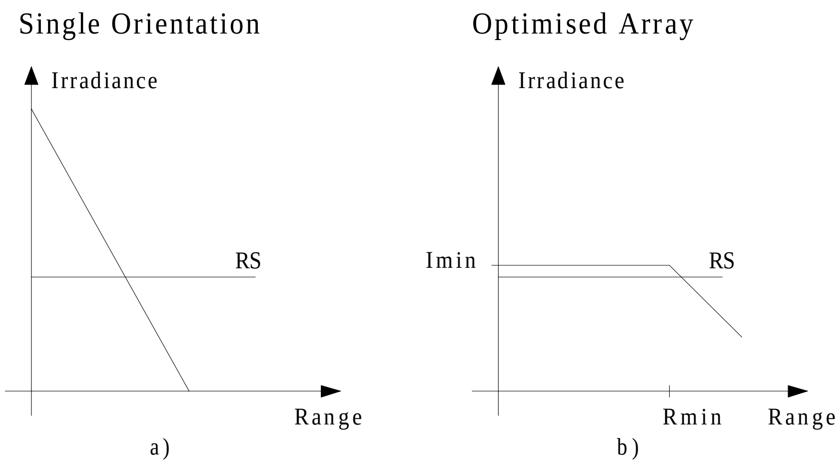

Figure 1: Ideal optimisation of the emitter radiation pattern.

Optimisation of the ERP should also consider the existing LEDs to make sure that possible implementations are practical and cost effective. Finally, the ERP specification has to include some tolerances to take into account the different characteristics of the LEDs and the variability associated with the manufacturing processes as well as tolerances in the array configuration (position and orientation of the LEDs).

3.1 Optimisation Initial Constraints Summary

There is an inicial set of constraints which have to be considered during optimisation of the ERP. The ERP specification:

- must be in conformance with the safety standards.
- must allow proper operation in both open plants and walled rooms.
- must provide for a minimum range and result in a smooth range degradation with the propagation conditions.
- should have a tight specification to avoid the hidden station problem.
- should result on a minimisation of the worst-case propagation losses.
- should take into account the constraints related to manufacturing the LEDs.
- should consider the tolerances of the LEDs and of the array configuration.

3.2 Optimisation Algorithm

Figure 2 presents the optimisation algorithm. The initial constraints defined above have to be taken into account during the whole process of optimisation. The algorithm starts by considering open plants (OP) because, since they rely on a single reflecting surface, these environments are potentially worse than walled rooms (WR). We define a worst-case environment for OPs by specifying the reflection coefficient of the ceiling and the distance from the transceiver plane to the ceiling. For this environment we optimise the ERP for the highest achievable range and set it to be the target range. We proceed by disturbing the ERP parameters: half power beam width (HPBW), total emitted power and orientation of each LED. The tolerances on the ERP parameters were defined taking into account reasonable manufacturing tolerances for the array and for its individual components. The disturbance process has in view to guarantee that the tolerances on the ERP parameters lead to range variations which do not exceed a predefined margin (ΔRANGE). If this is not achieved on a first trial the algorithm will reduce the target range and optimise again the ERP. After reaching the stop condition, we define the worst-case environment for WRs by specifying the room dimensions and the reflection coefficients of all surfaces. All room dimensions are initially set equal to the target range obtained for OPs. For this environment we determine the Minimum Collected Power (MCP) and test it against the Receiver Sensitivity (RS). We will change the room dimensions in case the MCP is lower or much higher than the RS. If the MCP is lower we decrease the room dimensions. If it is much higher the room dimensions are increased. We then start a disturbance process similar to the one performed for OPs. If the MCP is lower than the RS, for any of the disturbances, we reduce the room dimensions until the MCP goes higher than the RS. Then, we compare the range of WR with that of OP. If the WR range is lower than the OP range this means that we have failed our initial ERP optimisation. Therefore, we will optimise the ERP in OPs for the WR range and start again the disturbance process in OPs. The optimisation process stops when the WR range is higher than the OP range. The optimisation process described above converges rapidly for any set of initial parameters. Experimental results of a 1 Mbps indoor IR transceiver that followed this algorithm to optimise the ERP were presented by Tavares [12]. We would like to note that this process includes a significant human interaction and common sense!

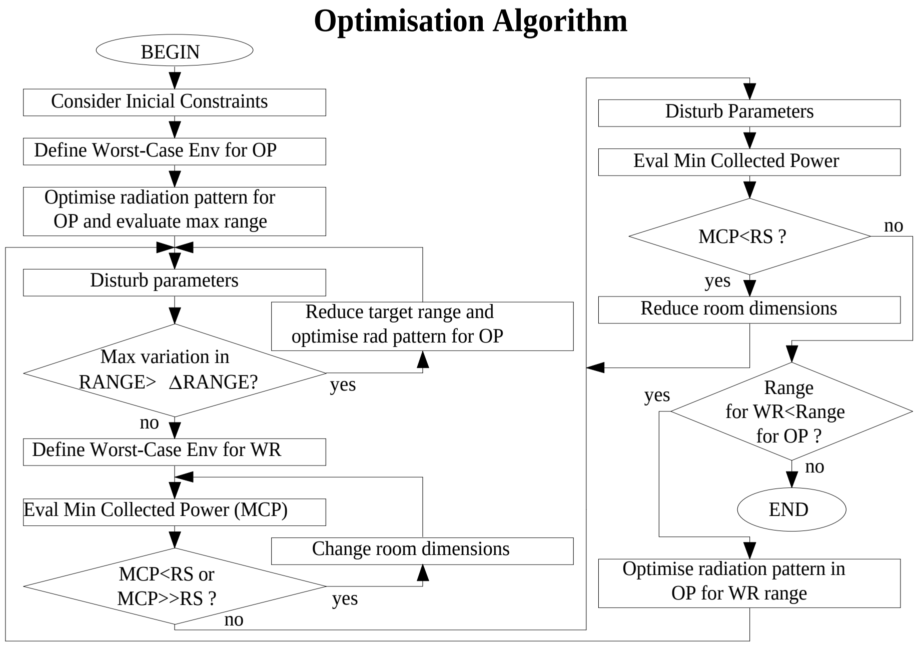

Figure 2: Optimisation algorithm.

3.3 ERP Mask Definition

The ERP mask is represented in figure 3. It was derived by: i) determining the optimised ERP from the algorithm described above and ii) disturbing the ERP parameters assuming the tolerances considered during the optimisation process. The curves represent the irradiance, normalised to the average emitted power, as a function of the angle between the normal to the emitter and the axis from the emitter centre to the receiver, assuming that the centre of the emitter array and the receiver are placed 1 meter apart. The receiver is assumed to be always aimed at the emitter centre. We searched for a 2D mask of the ERP because it is easier to understand and test. Nevertheless practical ERP implementations may not present azimuth symmetry. Therefore, the 2D mask represents an average over a limited azimuth range.

The azimuth conformance testing points will be specified in the following section. As mentioned above, the different ERP curves shown in figure 3 result from disturbing the different ERP parameters. The disturbances considered are 10% for the elevation angles of the LEDs in the array and about 25% and 50% for the HPBW of the narrower and larger LEDs, respectively.

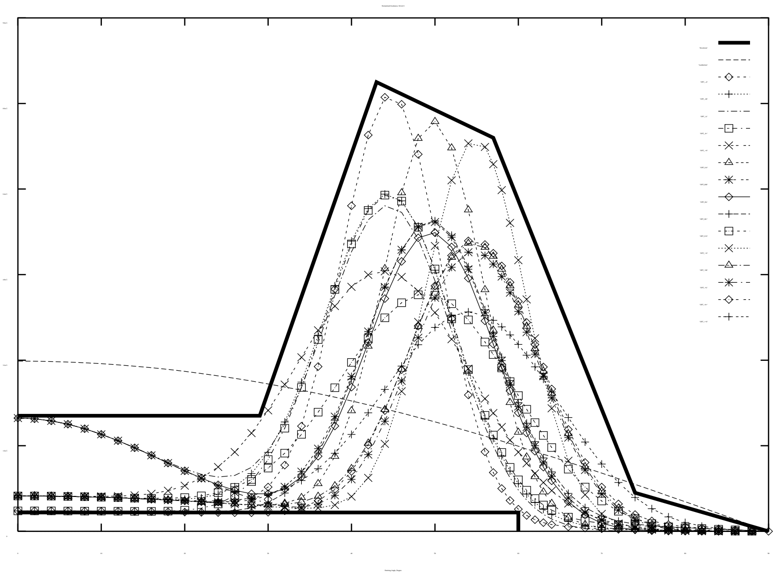

Figure 3: Emitter radiation pattern mask.

Table 1 presents the analytic specification of the mask shown in figure 3.

Angle	Normalized Irradiance (W/cm^2)
$\alpha \leq 60°$	$> 3.5e^{-6}$
$\alpha \leq 22°$	$\leq 2.2e^{-5}$
$29° < \alpha \leq 43°$	$\leq -1.06e^{-4} + 4.4e^{-6}\alpha$
$43° < \alpha \leq 57°$	$\leq 1.15e^{-4} - 7.1e^{-7}\alpha$
$57° < \alpha \leq 74°$	$\leq 2.98e^{-4} - 3.9e^{-6}\alpha$
$74° < \alpha \leq 90°$	$\leq 4.05e^{-5} - 4.5e^{-7}\alpha$

Table 1: Analytic specification of the ERP mask.

It is worth to mention that the ERP mask is normalised to the average emitter power and therefore is valid for any method of modulation and not only for the IR baseband dual-rate (1 or 2 Mbit/s) PPM of the IEEE 802.11 draft standard. However, safety issues may have to be reevaluated

4 Conformance Testing Guidelines

This section defines the measurement set-up and the conformance test methodology for the proposed ERP mask. The procedures are as follows:

1. Set-up the emitter in a test fixture that allows elevation and azimuth rotation.
2. Attach the receiver 1 meter apart.
3. Point the emitter face to face with receiver.

4. Measure the received power for elevation angles from 0°, to 90°, in steps of 10°; For each elevation angle measure the received power for azimuth angles of 0°, 4°, 11°, 20° and 31°.

5. Repeat the measurements for arbitrarily selected values of initial emitter azimuth angles.

Conformance is achieved if for all 10 elevations the average of the received power over the 5 azimuths falls within the specified mask for any arbitrarily selected initial azimuth. Most probable ERP implementations will present azimuth periodicity. Therefore, the azimuth points were selected to specifically avoid any periodic pattern.

5 Results

In this section, we present simulation results for the achieved range in both open plants and walled rooms. According to Gfeller [13], the IR reflection coefficients (r) of typical surfaces vary from 0.4 to 0.9. These values have also been confirmed by measurements done in our laboratories. We will also consider these range of r values in our simulations.

5.1 Open Plant

A large open plant with 20 by 20 meter and 4 meter height was considered. Only the first ceiling reflection was considered. Emitter and receiver are placed 1 meter above the floor level and vertically oriented to the ceiling. Figure 4 shows the range results for the ERPs presented in figure 3, including the Lambertian ERP. These assume a reflection coefficient of $r = 0.5$. Other values of r will affect the curves by a scale factor. This scale factor is represented in figure 4 by the horizontal solid segments which then represent the equivalent receiver sensitivities.

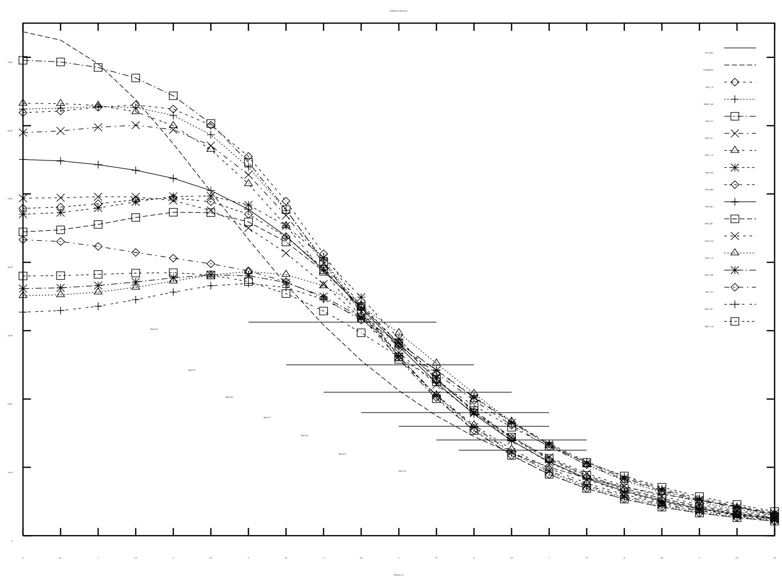

Figure 4: Range for open plant.

The results show that optimisation of the ERP results in higher ranges than with a vertically oriented Lambertian emitter. Under worst-case conditions (r=0.4), the range achieved by the optimised ERP is above 4.5 meter. The range increases significantly with the reflection coefficient. The results also show, that the range does not change significantly with the tolerances of the ERP. Moreover, the results satisfy the initial performance target for the open plant environment.

5.2 Walled Room

The evaluation of the collected power in walled rooms considered 5 orders of reflection. The room dimensions vary from 4.0 by 4.0 meter to 9.1 by 9.1 meter. For each value of room dimensions, we considered 3 different situations in terms of reflection coefficients:

Case I – Assumes worst-case conditions. Ceiling and 3 of the walls with r=0.4, floor and remaining wall with r=0.3 (labelled as "min_****" in figure 5).

Case II – Assumes typical conditions. Ceiling with r=0.8, 3 of the walls with r=0.7 and floor and remaining wall with r=0.4 (labelled as "typ_****" in figure 5).

Case III – Assumes all room surfaces with the same r=0.7 (labelled as "ideal_****" in figure 5).

The walled room results are shown in figure 5. The curves plot worst-case propagation losses versus room dimensions. For each case, in addition to the optimised ERP array we also present the results for a vertically oriented Lambertian emitter. The worst-case propagation losses resulting from the ERP tolerances are also presented as error bars around the curve for the optimised ERP array.

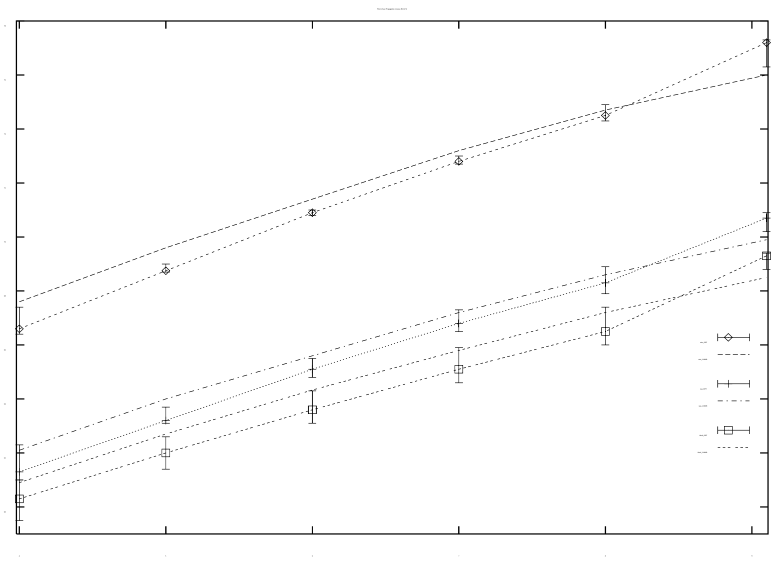

Figure 5: Worst-case propagation losses in walled rooms.

As it was expected, the losses increase with the room dimensions. In all cases, the optimised ERP results in losses smaller than those obtained with the Lambertian emitter, except for rooms with dimensions above 8 by 8 m. We note that the gains of the optimised ERP relatively to the Lambertian emitter are not significant. This has two main reasons: i) the optimisation was not targeted for a single well defined environment; instead it considered dissimilar environments which the IR transceivers will certainly be required to operate in and ii) due to limitations imposed by safety issues LEDs with HPBW lower than aproximately 10° could not be used. According to the results, the dual-rate PPM system using the proposed ERP mask operates properly in a room with dimensions larger than 7 by 7 m assuming typical propagation conditions (Case II). Under worst-case conditions (Case I) the system would operate in a room with dimensions of 4 by 4 m. In a Case III room the proposed ERP mask would allow system operation in rooms larger than 8 by 8 m.

6 Conclusions

We have presented a flexible Emitter Radiation Pattern (ERP) for infrared (IR) wireless local area networks. The specification of this ERP was done considering a dissimilar, yet typical, set of propagation environments. The algorithm followed to optimise the ERP has been presented. Initial constraints were defined that included safety aspects, worst-case propagation conditions, manufacturing tolerances and minimum range requirements. A mask bounding the optimised ERP has been proposed. A measurement set-up and a set of conformance testing guidelines were defined. Finally, results in terms of achieved range were presented showing that the optimised ERP allows for suitable operation over dissimilar environments with smooth degradation with the propagation conditions.

The specified mask for the ERP is part of the baseband IR PHY of the IEEE 802.11 draft standard.

7 Acknowledgments

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