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Wireless Access Method and Physical Layer Specification

Title: Radiation Pattern Specification for the Baseband IR PHY

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Summary

This document proposes a specification for the Emitter Radiation Pattern (ERP) of the baseband IR PHY proposal presented previously [1, 2, 3, 4]. The proposed ERP is also valid for other IR PHYs. A specification of the ERP is required in the future IEEE 802.11 standard to comply with the requirement of minimising i) the propagation losses and ii) the number of hidden stations. The proposed specification is based on a long process of optimisation. Both open plants and walled rooms with quite dissimilar propagation conditions 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 plants and walled rooms. The results show that the specified ERP allows proper operation in dissimilar environments with a smooth degradation with the propagation conditions.

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

I - Introduction

As specified in the baseband IR PHY proposal [1, 2, 3, 4] the system under consideration uses a diffuse propagation mode. Therefore, no aiming of the transceivers should be required for proper operation.

As shown in [5], vertical orientation of all LEDs is by far not the best solution in view of the minimisation of the propagation losses. We believe that the specification of the Emitter Radiation Pattern (ERP) should be based on an array of LEDs where the characteristics and orientation of each element should be optimised. As referred in [2, 6], 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 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 [5].

This contribution 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 study.

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II - Safety Issues

The specification of the ERP has to take into account the constrains imposed by safety standards. A study about safety issues of the dual-rate PPM system proposed in the draft standard [4] is being submitted as a companion document [8]. The study is based on the recent IEC 825 -Safety of Laser Products [7] and shows that the specified emitter radiation pattern is safe.

III - 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.

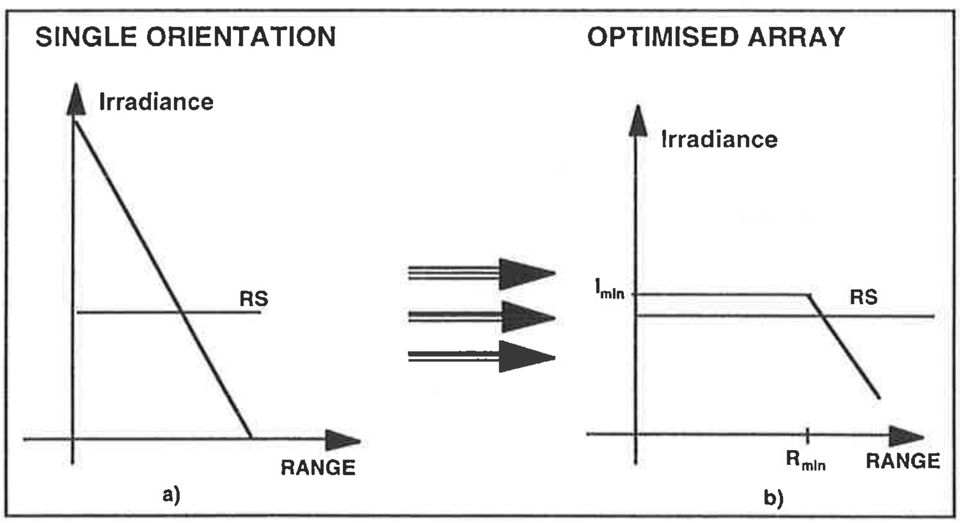

Fig. 1- Ideal optimisation of the emitter radiation pattern.

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, I_{min}, up to a cut-off range, R_{min}, 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 R_{min} and I_{min} parameters in such a way that a total coverage loss can only happen in environments where it is not useful to use an IR system anymore. So, the cut-off range, R_{min}, will correspond to the minimum range for all environments where the IR systems is supposed to operate and the minimum constant irradiance level, I_{min}, is will be derived from worst-case propagation conditions. We have assumed R_{min}=4 meter and that I_{min} corresponds to an open plant with a ceiling reflection coefficient of ρ=0.4.

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).

Optimisation Initial Constraints Summary

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

Optimisation Algorithm

Figure 2 represents 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 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. We would like to note that this process includes a significant human interaction and common sense!

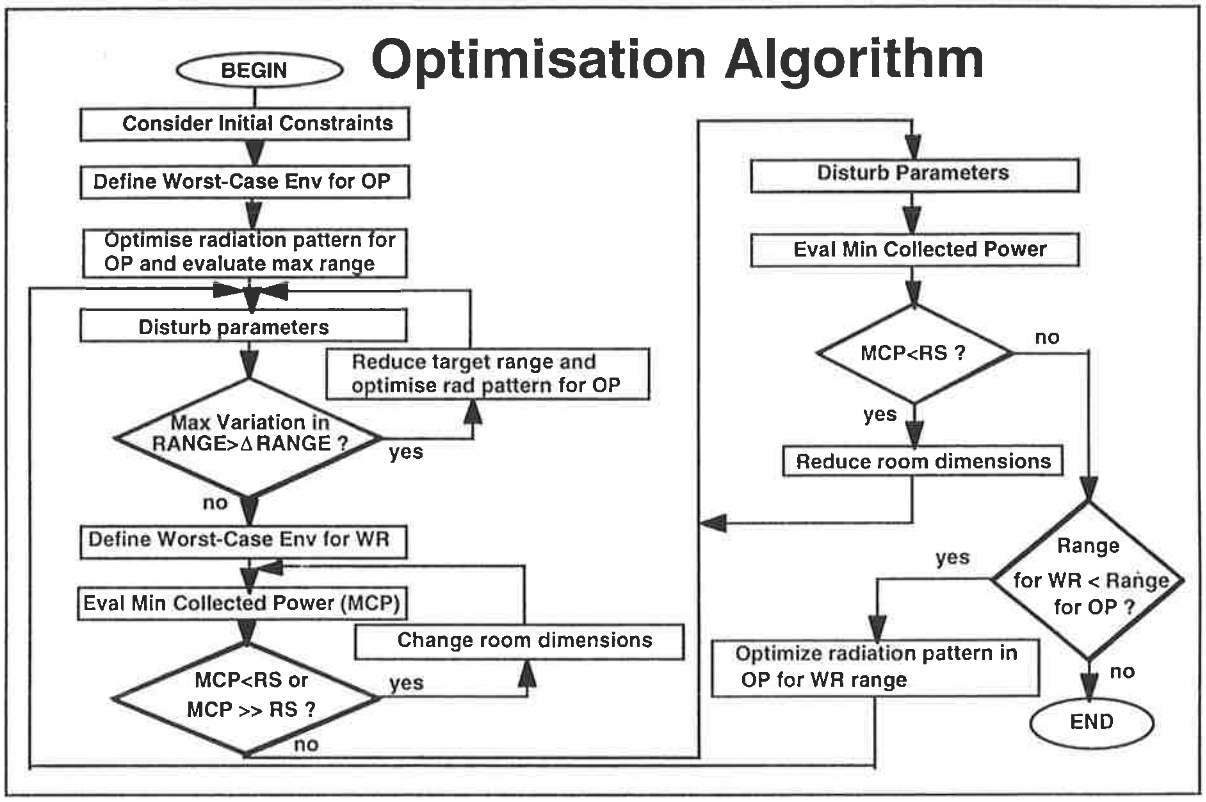

Fig. 2 - Optimisation algorithm.

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.

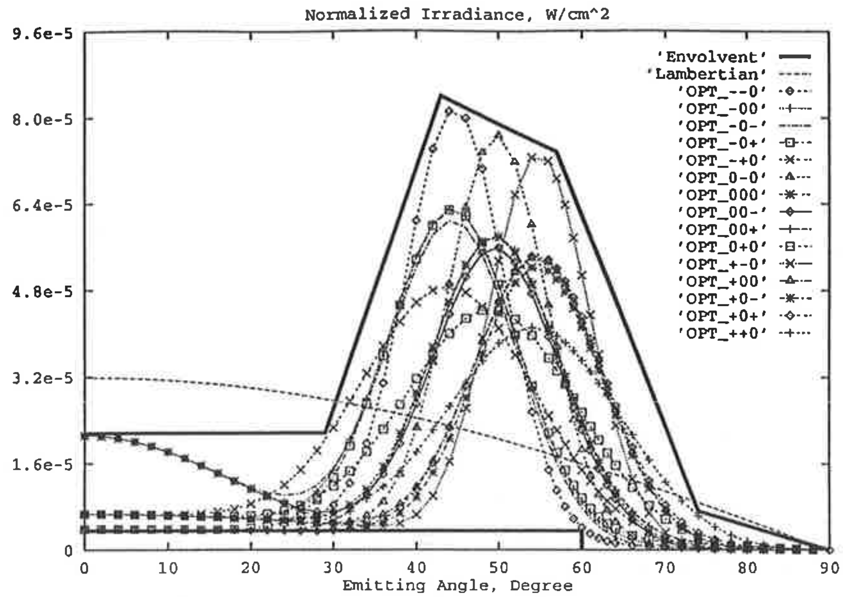

Fig. 3 - Emitter Radiation Pattern Mask

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

ANGLE (degree)	Normalized Irradiance (W/cm^2)
• α<= 60	> 3.5e-6
• α<=22	<= 2.2e-5
• 29<α<=43	<= -1.06e-4+(0.44e-5)*α
• 43<α<=57	<= 1.15e-4-(7.1e-7)*α
• 57<α<=74	<= 2.98e-4-(3.9e-6)*α
• 74<α<=90	<= 4.05e-5-(4.5e-7)*α

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 baseband dual-rate PPM draft standard.

IV - 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.

V - Results

In this section, we present simulation results for the achieved range in both open plants and walled rooms.

According to Gfeller [9], the IR reflection coefficients, ρ, 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 ρ values in our simulations.

A) - 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 ρ=0.5. Other ρ values 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.

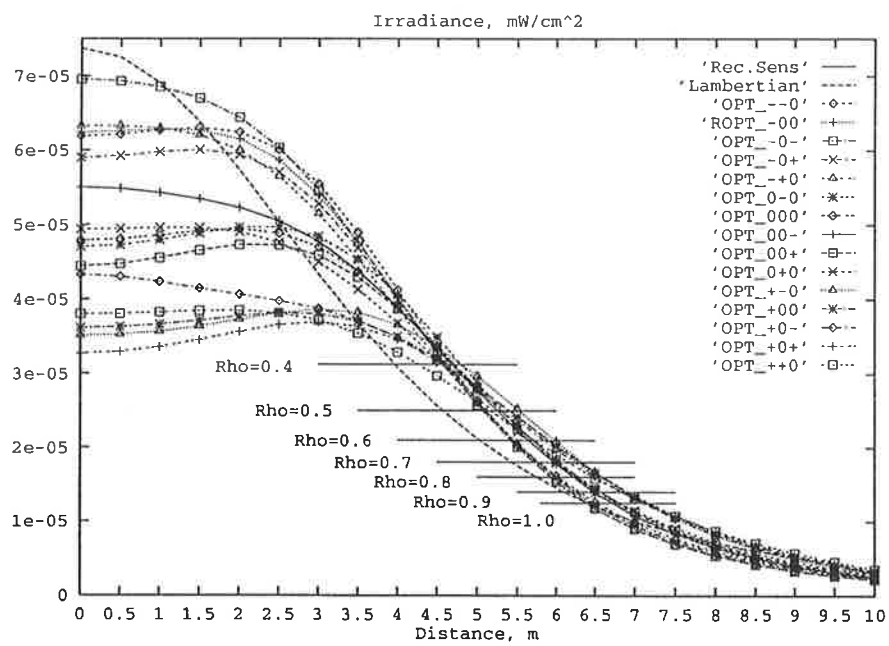

Fig. 4 - Range for Open Plant.

The results show that optimisation of the ERP results in higher ranges than with a vertically oriented Lambertian emitter. Under worst-case conditions (ρ=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.

B) - Walled Room

The evaluation of the collected power considered 5 orders of reflection. The room dimensions of walled rooms vary from 4.0 by 4.0 m to 9.1 by 9.1 m (30 by 30 foot).

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 ρ=0.4, floor and remaining wall with ρ=0.3 (labelled as "min_****" in figure 5).
- Case II assumes typical conditions. Ceiling with ρ=0.8, 3 of the walls with ρ=0.7 and floor and remaining wall with ρ=0.4 (labelled as "typ_****" in figure 5).
- Case III assumes all room surfaces with the same ρ=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.

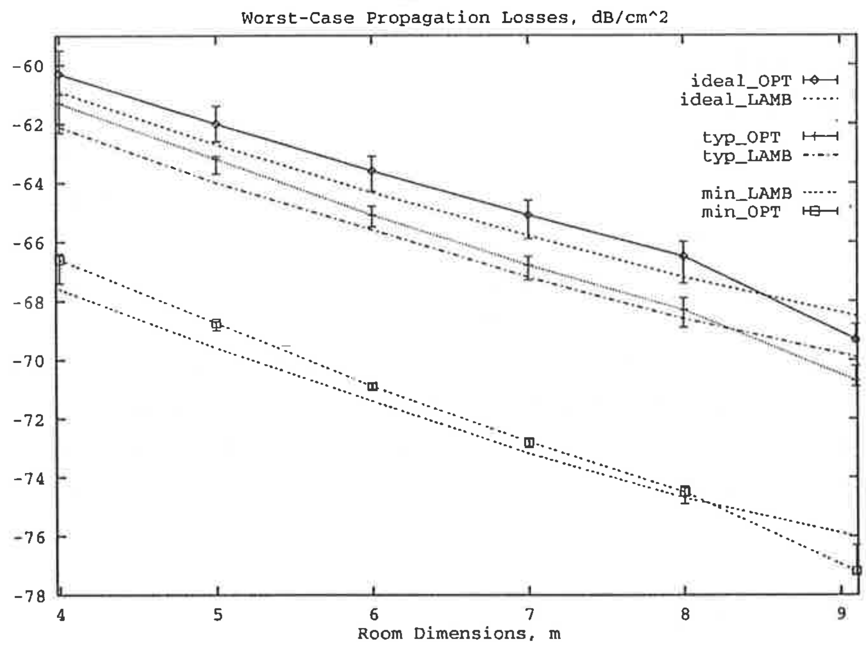

Fig. 5 - Worst-case propagation losses in walled rooms.

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 aprox. 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.

VI - Conclusions

We have defined an algorithm for the optimisation of the Emitter Radiation Pattern (ERP) considering a dissimilar, yet typical, set of propagation environments. Initial constraints were defined that included safety aspects, worst-case propagation conditions, manufacturing tolerances and minimum range requirements. A mask for the ERP was proposed to become part of the baseband IR PHY draft standard. 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 all meaningful environments. The proposed ERP is not applicable exclusively to the baseband IR PHY but can also be used in other IR PHYs.

Acknowledgements

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