# DESIGN AND IMPLEMENTATION ISSUES OF A WIRELESS INFRARED ETHERNET LINK

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## ABSTRACT

The design and implementation of a wireless infrared Ethernet link is considered. It is shown that, using commercially available devices, it is technical and economically feasible to implement wireless infrared extensions of Ethernet networks, maintaining the degree of complexity in transceiver electronics at very low level. In particular, it is shown that Manchester coding can still be used in the infrared path without impairing system range and performance.
A laboratory prototype was developed and implemented using Manchester coding, achieving a bit error rate of $10^{-10}$ over a range typical of normal office environments. The utilization of low cost lenses, both for LED's radiation pattern correction and as optical power collecting elements was investigated and shown to provide significant performance improvements.

## INTRODUCTION

In the past few years, several wireless systems for in-house applications have become commercially available. Audio broadcast systems, wireless telephones, remote control units and cableless Local Area Networks are examples of such systems. The introduction of this concept, offering a wide range of new services, is being studied by several authors [1] [4], trying to collect information and developing a set of methodologies for the correct specification and utilization of these new systems. Among these systems, cableless Local Area Networks (cLANs) seem to have a great impact on the office automated environment, where easy terminal reconfiguration, mobility and the reduction on the number of cables are very important factors.

In the development of cableless LANs, two technologies have been used for the transmission of the information: radio frequency and optical infrared radiation. Both of these technologies have its advantages and drawbacks.
The use of radio frequency, including microwaves, requires the permission of the governmental institutions who regulate the use of the electromagnetic spectrum. In the cases where this is possible, the frequency band allocated for these services is, usually, very narrow. Moreover, the electromagnetic spectrum is already crowded and systems based on radio frequency have to deal with high levels of noise and interference. Nonetheless, radio frequency provides the best way to implement mobile systems, since no line-of-sight is necessary between emitters and receivers. Commercial systems have been developed using spread spectrum techniques to overpass noise and interference.

On the other hand, optical infrared radiation, as it is confined to the room where it is being used, does not requires permission for its use (at least in most countries), provides easy spectrum reallocation and is not affected by other similar systems working in the neighbourhood. The major problem in using optical infrared signals, is that it is not easy to achieve high data rates without line-of-sight transmission between emitter and receiver.
For this reason, systems developed until now do not exceed data rates higher than a few Mbits/sec. When higher speed is required, the use of optical infrared radiation is only feasible if more complex signal processing techniques are used including modulation and line coding and optical filtering.

This paper addresses a set of issues related to the design and implementation of a wireless infrared Ethernet link. These include:

-Power budgeting for a prescribed transmission performance.

-Modelling of the effects of lenses in the transmission path performance.

The working design scenario assumes an infrared link at 10 Mbps as the transmission system for a wireless Ethernet link.

It is shown that, under certain conditions, the utilization of low cost lenses, like Fresnel lenses, provide an easy and efficient way to reduce the required optical power.
An analytical model is developed to describe the use of lenses, both for LED's radiation pattern correction

Proceedings of The Third IEEE International Symposium on Personal, Indoor and Mobile Radio Communications
Boston, Massachusetts, USA, October 19-21, 1992

and as optical power collecting elements. Experimental results are presented which illustrate the improvements achieved using lenses and validate the theoretical model.

## REFERENCE MODEL AND DESIGN OPTIONS

The physical configuration of the system under study is presented in figure 1.

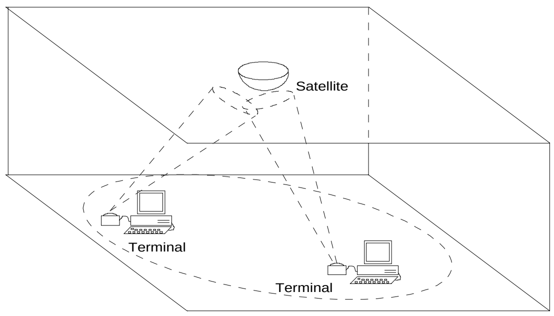



Figure 1. Typical configuration.

Each terminal is connected to the satellite via a bidireccional infrared link at 10 Mbps and the satellite acts like an active reflector, relaying all the signals emitted by the terminals. The aspects of network architecture and topology are addressed in a companion paper [2].
As the data rate is very high, a line-of-sight between each terminal equipment and the satellite should be provided. Otherwise, an enormous amount of optical power should be used to assure that enough power reaches the receiver through reflections from the walls, ceiling and floor, thus creating a diffuse system [3].

The system range, or maximum distance between any terminal and the satellite, depends on the emitted power and on the receiver sensitivity. In particular, the receiver sensitivity, defined as the minimum irradiance at the receiver site for a specified bit error rate, increases with the active area of the photodetector. However, the maximum area one can use, is limited by the parasitic capacitance of the photodetector. If this capacitance is too high, $f^2$ noise becomes the dominant impairment, and no more gain is obtained by increasing the active area of the detector [6].

Our transmission system, can be separated into an up-link, from the terminal to the satellite, and a down-link, from the satellite to the terminal.

### Down-link

The satellite emitter should exhibit a very wide radiation pattern, since its signals should reach every terminal placed within the room. On the other hand, if the terminal's receiver is allowed to be oriented toward the satellite, its field of view can be made narrower than the photodetector field of view[1], which is about 120°. This allows for the use of a lens, placed in front of the photodetector, which increases the collecting area and concentrates the collected power into the active area of the detector. Thus, the increase in the collecting area is attained without an increase in the parasitic capacitance, but at the expense of reducing the field of view of the receiver.

### Up-link

In the up-link, the situation is reversed. The satellite receiver should have a wide field of view, and then no lenses can be used. However, the radiation pattern of the terminal emitter can be as narrow as the field of view of its receiver, provided that it can be oriented the same way. Thus, most of the optical power, emitted from the terminal, is concentrated in the satellite area. This narrow radiation pattern can be achieved by the use of narrow beam LEDs (or LASERs) or, if necessary, by correcting the wide radiation pattern of a LED with the use of a lens.

This scenario determines new optical power requirements. Less optical power is demanded from the satellite, since the sensitivity of the terminal receiver is improved by the use of a lens. Also, the power emitted from the terminal can be lower, because a narrow radiation pattern produces an higher irradiance at the satellite.

## RECEIVER SENSITIVITY

Since the link to be implemented is part of an Ethernet LAN, Manchester line coding was found to be a simple and efficient solution. Clock recovery becomes easier and the spectrum of the encoded signal has a convenient shape, with small power components at the low frequencies. This allows for the use of high-pass filtering to avoid artificial light interference.

A commercial integrated transimpedance amplifier was used as the frontend. The receiver sensitivity was calculated using the receiver model from Personick, where noise due to ambient light is considered. Figure 2 shows the calculated sensitivity (in terms of irradiance) as a function of the photodetector active area (Ar). One can see that the penalty for using Manchester coding over NRZ is not significant (less

[1] Here, the photodetector field of view is defined as twice the angle (measured from the normal to the active area surface) at which the received power is 1/2 of the received power in the normal direction.

than 2dB for Ar<4cm$^2$). The calculations assume a parasitic capacitance of the photodetector of 120 pF/cm$^2$ and background light illumination of 250 µW/cm$^2$. Input pulses are rectangular and output pulses are 100% raised cosine.

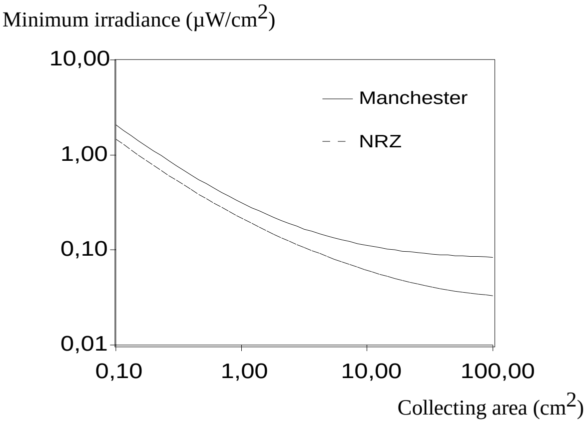



Figure 2. Receiver sensitivity versus photodetector active area, at 10 Mbps.

From figure 2, it can be seen that the required irradiance can be reduced by a factor of ten, or more, by increasing the collecting area of the detector from 0.1 to 10 cm$^2$. We can also notice the effect of the f$^2$ noise when, for large active areas, the detector capacitance becomes to high.

## USING LENSES

An alternative to the use of a large area photodetector, or array of detectors, is the use of a lens as an optical power collector. This situation is depicted in figure 3.

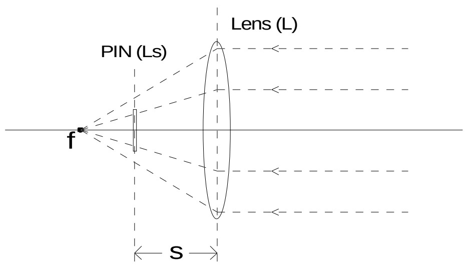
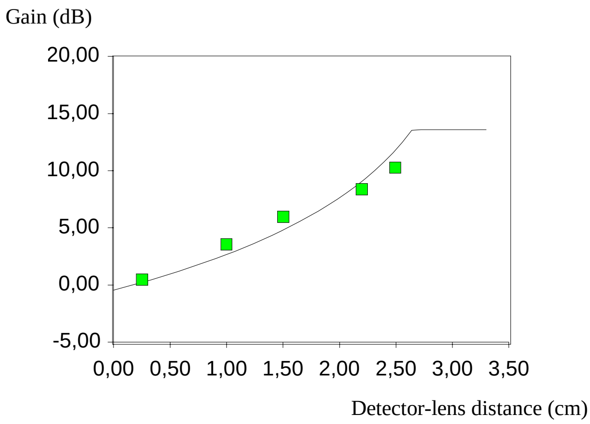



Figure 3. Using a lens to increase the collecting area of the receiver.

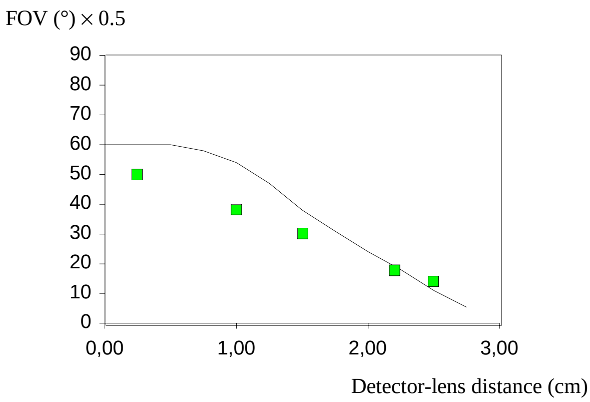
In figure 3, a positive lens is placed in front of a small area photodetector (say 0.1 cm$^2$). The optical power incident on the lens surface is concentrated into a very small area, at the focal plane of the lens. If the detector is placed at this focal plane, all the power incident on the lens surface reaches its active area. However, if the direction of incidence is not normal to the lens surface, some or even all the concentrated power may not reach the detector, that is, the field of view of the lens-detector arrangement is very narrow.

By placing the detector at a different position, between the lens and its focal plane, the field of view of the arrangement can be made wider, at the expense of reducing the fraction of the collected power that reaches the active area of the detector.

The gain in received power obtained by the use of a lens, along with the associated field of view, is plotted in figure 4 as a function of the detector position (s). It was used a Fresnel lens, with 5 cm diameter (L) and a focal distance (f) of 3.3 cm, and the photodetector has an active area of 1 cm$^2$.




a) received power gain




b) field of view.

Figure 4. Lens-detector performance.

Experimental results are also presented in figure 4. Note that, for the gain in received power, experimental results follows the theoretical calculations. However, the measured field of view is narrower than was expected, when the detector is placed near the lens. These differences are due to reflections on the lens surface for high angles of incidence and to lens aberrations. Since the most favorable situation happens when the detector is placed near the focal plane, where more gain is obtained, these effects are of little practical importance.

Now, the overall receiver performance, using a lens as the power collecting element, must be calculated. The new situation must take into account that the parasitic capacitance no longer increases with the collecting area and that the noise due to ambient light is lower than that obtained with the detector without a lens, for most of the situations[2]. The reduction in the ambient light noise is due to the narrower field of view of the receiver, even considering the increase in collecting area, and is confirmed by experimental measurements.

Figure 5 presents the new receiver sensitivity, when a lens is used as the optical power collector, as a function of the lens area. The detector ($1cm^2$, 120pF) is at the focal plane of the lens, and the background noise current is assumed to be 0.15mA (same value considered in figure 2 for $1cm^2$ of active area).

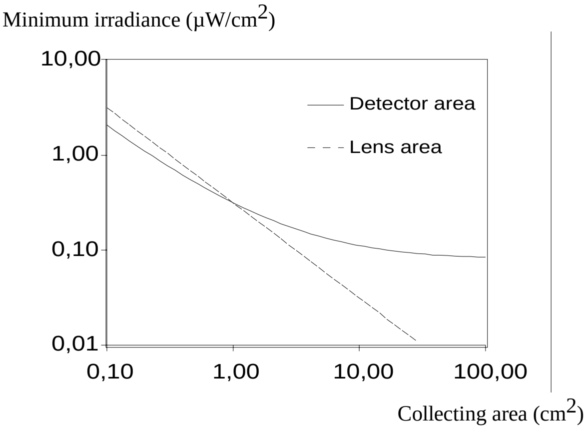


Figure 5. Receiver sensitivity, when a lens is used.

For the case of the lens considered in figure 4, the new receiver sensitivity is about 0.02 $\mu W/cm^2$ (FOV≈15°), against 0.3 $\mu W/cm^2$ (FOV≈100°) if no lens is used. The narrower field of view of this new receiver is certainly a disadvantage, but it can be made wider by the use of a conical surface connecting the detector to the lens [7].

In the up-link, a narrow beam optical source, oriented in the satellite direction, provides the best solution to achieve a large system range. Laser sources are the immediate choice. However, laser drivers and associated electronics are far more complex and expensive than that used with LEDs. Moreover, safety problems may occur if high radiance laser sources are used, unless a proper diffuser is used.

[2]This is not the case if there is a high power light source near the satellite.

The use of LEDs is the alternative, but commercial devices, capable of being driven at 20 Mbps, exhibit a very wide radiation pattern. The technique presented for the detector can also be used to reshape the LED radiation pattern. If a positive lens is placed in front of the LED, the resulting radiation pattern becomes narrower, increasing the maximum radiant intensity in the system axis. The optical arrangement is similar to that presented in figure 3 for the detector.
Figure 6 shows the irradiance produced by the LED (emitting 24 mW), at a plane 1m away, for different distances between the lens and the LED. As the lens is placed far away from the LED, the irradiance increases at the expense of a narrower radiation pattern. Small marks represent experimental measurements.

A small biconvex lens (diameter=2.5cm) was used in order to reduce the emitter size. In a practical system, an half-power beam width of 30° is assumed to allow an easy alignment of the source with the satellite.

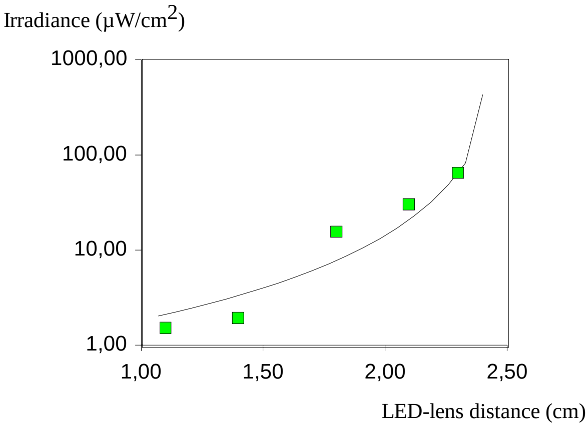


Figure 6. Irradiance produced by the LED-lens arrangement.

## OPTICAL POWER BUDGET

As stated previously, the correct utilization of lens, both associated with the detector and the optical source at the terminal, will allow for a reduction on the optical power requirements. Assuming a cell with an area of $50m^2$, the satellite placed at 3.5m from the floor, and both receivers with $1cm^2$ detectors, the optical power demanded from the satellite and terminal was found to be 410 mW and 270 mW, respectively. These values were calculated for the largest distance between terminal and satellite and considering Lambertian radiation patterns [7] for both optical sources.

If lenses are used at the terminal, a lower irradiance is required at the terminal and an high irradiance is produced at the satellite. The new situation reduces the optical power requirements of the satellite to less than 30 mW and that of the terminal to about 60 mW. This is accomplished with two LEDs at the terminal - plus the lens, and with a single LED at the satellite.

Bit error rate measurements were performed for several distances between emitter and receiver, and for different conditions of background illumination. The obtained results were extrapolated for the above power levels, and it was found that a bit error rate of $10^{-10}$ is expected for distances ranging from 4 to 6 meters.

## CONCLUSIONS

The work reported here, shows that by resorting to appropriate optical arrangements it is technically feasible to implement wireless links, using infrared radiation, as the transmission support for high-bandwidth wireless LANs like Ethernet. Optoelectronic devices (LEDs and PINs) are still one of the major limiting factors, both in terms of speed and system range. In order to overcame these limitations and reduce the effect of ambient light noise, more complex signal processing techniques are under study, which make use of the present results.

## ACKNOWLEDGEMENTS

The first author would like to thank JNICT - Junta Nacional de Investigação Científica e Tecnológica, for its financial support. This work was also partially funded by the European Commission via project ESPRIT.5631, "Wireless In-House Network Studies".

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