Indoor Free Space Optic: A new prototype, realization and evaluation

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ABSTRACT

The Free Space Optic (FSO) communication is a daily reality used by an increasing number of companies. For indoor environment, optical wireless communication becomes a good alternative with respect to radio proposals. For both technologies, the architecture is similar: emission/reception base station (Gateway or Bridge) are installed to cover zones, which are defined to ensure a quality of service. The customers may be connected to the Wireless Local Area Network (WLAN) with an adapter or module that emits and receives on this network.

But due to its specific characteristics, wireless optical technology could present important advantages such as: Transmitted data security, medical immunity, high data rate, etc... Nevertheless, the optical system may have a limit on the network management aspect and link budget. The scope of this paper is to present a proposal at crossroads between optical fibre telecom system and data processing.

In this document, we will present a prototype developed in Brittany during a regional collaborative project (Techim@ges). In order to answer to the management aspect and the link budget, this prototype uses an optical multiplexing technique in 1550 nm band: the Wavelength Division Multiple Access (WDMA). Moreover it also proposes a new class 1 high power emission solution. This full duplex system transmits these various wavelengths in free space, by using optical Multiplexer/Demultiplexer and optical modules. Each module has a defined and personal wavelength associated to the terminal identification (addresses MAC or IP). This approach permits a data rate at a minimum of a ten’s Mbit/s per customer and potentially hundred Mbps for a line of sight system.

The application field for the achieved and proposed prototype is potentially investigated from WLAN to WPAN.

Keys words: Optical Wireless, OW, Optical Wireless Communication, Hybrid Wireless Optic, WDM, Wireless optical network, WLAN, VLC, Visible Light Communication, IRC, Infrared Red Communication.

1. INTRODUCTION

Wireless optical communications are defined by the use of light in the visible (VLC – Visible Light Communication) or infrared (IRC – Infra Red Communication) area. This beam sent data, with a similar transmission supports; the free space. For more than one decade, many studies and experiments have allowed applications and products: From inter-satellite to military applications such as ORCA project [1]. We have also everyday uses much closer, from Point-to-Point optical outdoor communication systems or FSO (Free Space Optic) [2] and [3] to device remote controller.

In the regional collaboration framework named "Techimages", the France Telecom company and the laboratory FOTON in the engineering school ENSSAT have developed a prototype of an optical wireless communication prototype by using multi wavelength infrared transmission (WDM – Wavelength Dense Multiplexing). This item is not new, as it can be observed in [4] and [5], but the objectives are still clear and are to prevent the ISI (Interference Inter Symbol) and to increase the data rate. The new approach is the link creation between the wavelength and a MAC address. This prototype focuses particularity on the use of a designated wavelength from a WDM signal as a unique channel for an end-user or device. Basically, it acts as a multiple point-to-point bilateral communication system (mPP). Thus, it is possible to obtain many users or devices in simultaneous connections and each channel can offer a guaranteed data rate from a few Mbit/s to several tens of Mbit/s [6].

The other item is to propose a new class 1 high power emission solution, this element is also not really new,[7], [8] and [9] , but the values and the design are different.

In this document, after having presented the proposed network with wavelength and architecture design, we will describe the base and modules, which are the key elements of the optical link. Before concluding, we will also present the system simulations and results, this part will also include technical challenges and remarks.

2. NETWORK DESIGN

2.1 Wavelength

Three points are important to consider when choosing the wavelength: Eye safety, ambient light noise level and commercially available components. About the first point, if we reach the mass market, we need to have a product with class 1 safety in conformity with the standards in force: IEC 60825-1:2007 [10]. From this standard study, figure 1 shows the maximum radiant intensity versus wavelength and different source diameters D [11].

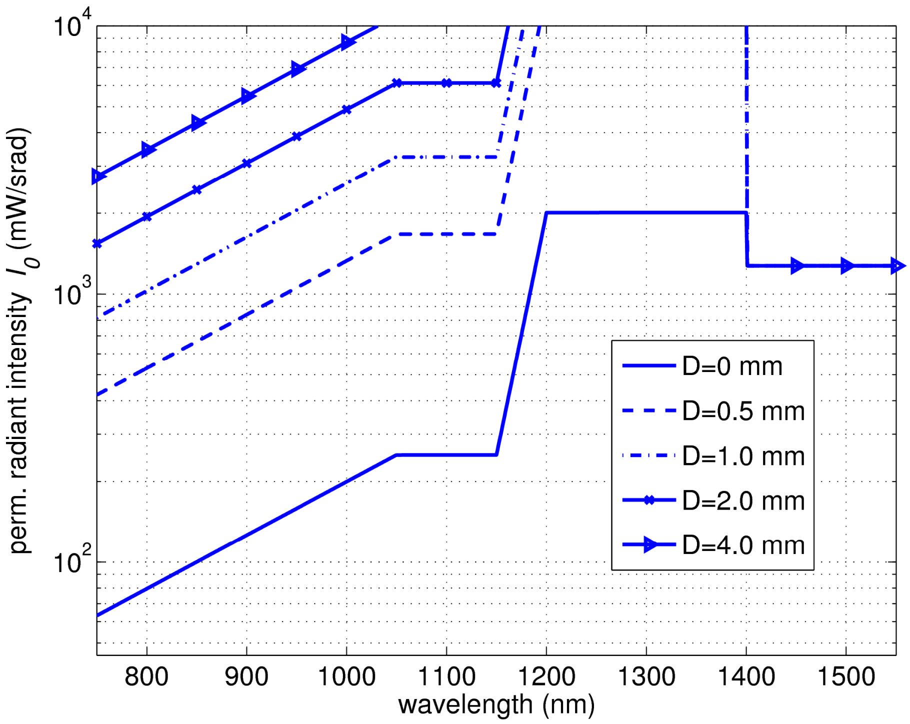


Figure 1: Permitted on-axis radiant intensity for extended sources.

This figure gives the “class 1” permitted radiant intensity (in mW/sr) for diverging laser sources. For wavelengths under 1400 nm, the radiation reaches the retina, so the permitted radiant intensity depends not only on the wavelength but also on the apparent source diameter D. Note that when D = 0 mm, the result is equivalent to point source. So, in the case of sources with a large source diameter, there is no specific reason to prefer a wavelength rather than another. It could be even more favorable in 850 or 1300 nm range.

The second point is the light noise level. This light noise level or photon noise is the result of photons coming from ambient sources of light. We can divide the photon noise into four major families of interferences. These four families are present in domestic or professional environments: incandescent lamps, fluorescent lamps, devices with LED and the sun. It is also possible to represent a hierarchical intensity. Figure 2 presents a non-cumulative power, at one meter of distance (except sun!), of the four major interferences optics families that can be present inside the buildings.

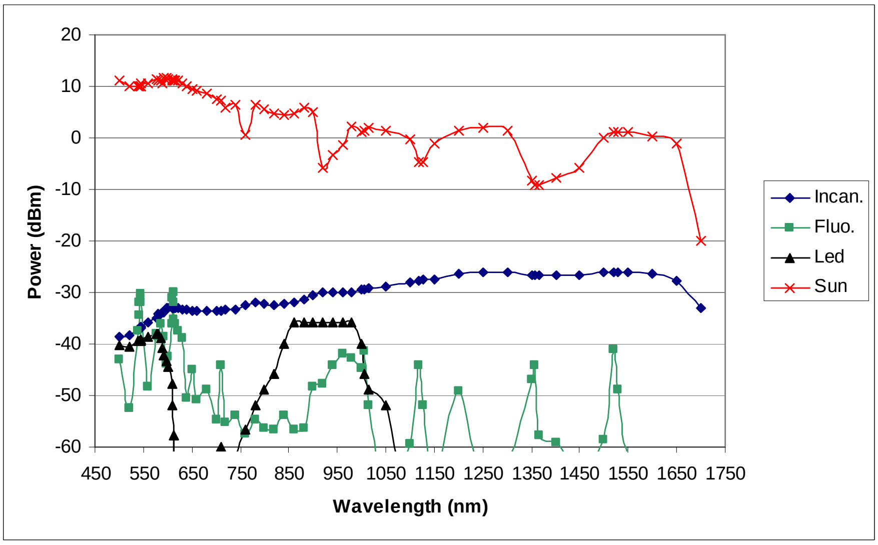


Figure 2: Four major families of optical noise

It appears that the sun, in line of sight configuration, is the most important source of noise. This disturber can be also consequent even in non line of sight configuration. Then, in the decreasing order of importance, comes the incandescent lamp. This type of lamp is going to disappear within a short term. Finally, they are the fluorescent lamps and LED. No value is indicated below -60 dBm, because currently, it is the minimum dark noise level (Id - dark current: 1 nA) of the majority of photodiodes. For instance, for the sun, the 1550 nm is more favorable compare to 850 nm: a positive value around 5 dB.

The last point is the availability of commercial components. We can find solution for the three main wavelength ranges, i.e. 850, 1300 and 1550 nm. But due to the use of 1550 nm window for core network and access network (FTTH – Fiber To The Home), we have found more easily specific module at that wavelength, especially for the optical amplifier.

For all these reasons, the choice was made on the 1550 nm.

2.2 Network architecture

This aspect is not specifically related to wireless infrared technology. When we have data communication shared for network management, there are difficulties related to multi user communication (collisions, runt frames, late collisions), associated to the use of "data" data rate and "network management" data rate on the same communication channel. So it could become difficult to suggest a network system offering a guaranteed data rate by user.

The solution presented is a new routing function. This routing function is carried out by the network displacement management at the physical level, i.e. at the optical level, by the assignment of wavelengths linked to the ID users. The realization of such a link, between the user or terminal identifier (MAC or IP addresses) and a physical characteristic (a wavelength) corresponds to its channel of communication, making it possible to offer a multiple point-to-point bilateral connection equivalent to a point to multi point network.

Thus, in a free space optic configuration, a coloured signal will be used for user 1, another colour for user 2, etc... This approach offers the potential to multiply the data rate or the bandwidth. Indeed, if we use, for example 4 channels (4 different wavelengths) with 10 Mbit/s data rate for each channel, we obtain 40 Mbit/s bandwidth; with a guaranteed data rate by user. The bandwidth potential is important because if we are based on the ITU-T-GRID, we can obtain 40 GHz or 0,8 nm channels space (Band C and L) and it is possible to use 20 to 40 channels. The bandwidth potential would therefore be up to 1 Gbit/s. The various free space optic wavelength combinations and recombinations are carried out using classic optical Multiplexer/Demultiplexer and specific wavelength optical modules; with each wavelength, at least one emission/reception user module is defined (connected to a PC).

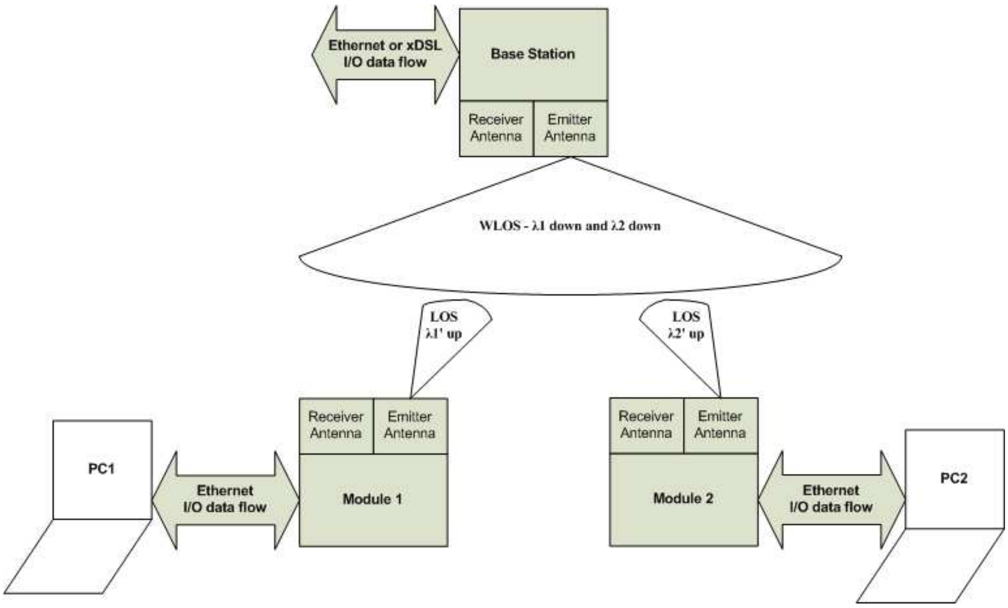


Figure 3: Prototype configuration

The figure 3 presents the prototype. It is defined by:

- The Base Station:
  - Connected to an Ethernet network or xDSL link
  - Emitter antenna with WLOS $\lambda 1$ downlink and $\lambda 2$ downlink
  - Receiver antenna with $\lambda 1'$ uplink module and $\lambda 2'$ uplink module
- Each Module x (x=1 or 2):
  - Connected to a PC (Personal Computer)
  - Emitter antenna with LOS $\lambda x'$ up

- Receiver antenna with λx downlink

3. BASE AND MODULES DESCRIPTION

3.1 Base

More precisely, the Base Station is defined in figure 4 as follows:

- A server with video demonstration and Ethernet 10/100/1000 Mbit/s with 10 Mbit/s restricted access (DELL Latitude D630),
- A Switch 12 ports Ethernet 10/100/1000 Mbit/s with 10 Mbit/s restricted access (Cisco Catalyst 2950),
- Two Media converter 10 Mbit/s (Garrett CS14),
- One 3 dB optical coupler,
- One Optical Amplifier with power up to 30 dBm (Keopsys KPS-OEM-C-WDM-HPFA),
- One emitter antenna,
- Two receiver antenna.

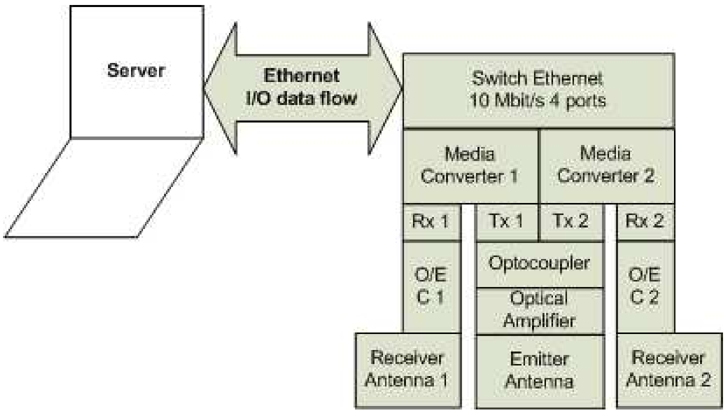


Figure 4: Base design

A server is connected to the switch Ethernet 10/100/1000 Mbps. Two ports from this switch are linked each to one Media Converter. The electrical link 10BASE-T Ethernet is regulated by the IEEE 802.3i. The main specification standard is:

- The rate is 10 Mbit/s.
- The pulse width is 100 ns ± 0.01%.
- The coding used is Manchester 0 volts for the high level and -2.05 volts for the low level.

Each Media Converter (1 and 2) convert the Ethernet electrical signal, Manchester type, in an output optical signal ($T\lambda1=1530$ and $T\lambda2=1550$ nm). The output modulation is OOK-NRZ On Off Key / No Return to Zero.
The Media Converter laser sources were replaced by DFB lasers (CWDM Foci LF-55 -1510/1530/1550/1570 nm) with electrical characteristics compatible. Also to be compatible on Ethernet receiver, the TIA (Trans Impedance Amplifier) HFBR-2316T was replaced by a TIA MAX 3657. So, the Media Converter Ethernet 10/100 Tbase-FL10 CS 14 was transformed to a Media Converter Ethernet 10/100 TBase-CWDM (1510/1530/1550/1570).

These two optical signals are coupled and sent to the optical amplifier. The optocoupler is a 50/50 optical coupler with four ports.
The optical input signal is amplified thanks to an EDFA Amplifier (Erbium Doped Fiber Amplifier). The output signals coming from Media Converter are then amplified up to 33 dBm with a noise factor of 6.5 dB. This power provides an output level of around 30 dBm for each wavelength at the output of the fibre, which transmits the signal from the amplifier to an emitter antenna.

In our conception, the emitter antenna is a point source associated to a holographic diffuser. This diffuser provides a powerful source that is then extended in order to respect the “standard class 1” eye-safety. This output level is below the “class 1” permitted radiant intensity for extended sources. For the downlink, the antenna full angle is 60° (HP =30 °). The “Base Station emitter” antenna transmits the multiplexed wavelengths optical signal.

Each receiver antenna is connected to it respective Rx media converter. The functions of receiver antenna are to concentrate, filter and convert the respective wavelengths ($\lambda 1'$ = 1510 and $\lambda 2'$=1570 nm) to Ethernet compatible signal. The optical CWDM filters (10 nm bandpass filters centered at λ =1510 nm, 1530 nm, 1550 nm and 1570 nm for zero incidence (0 °)) are made using multi layers processing. The detector is a photo detector PIN InGaAs with a large surface (D = 1mm) and a cutoff frequency of 12 MHz. Its responsivity is 0.90 A/W at 1550 nm.

This optical link Base Station – Module is a Wide Line Of Sight (WLOS) configuration.

3.2 Modules

On the other hand, each Module is defined as shown in figure 5 as follows:

- A Personal Computer to receive the video demonstration and Ethernet 10/100/1000 Mbit/s with 10 Mbit/s restricted access (DELL Latitude D610),
- One Media converter 10 Mbit/s (Garrett CS14),
- One Optical Amplifier (SOA - Semiconductor Optical Amplifier),
- One emitter antenna,
- One receiver antenna.

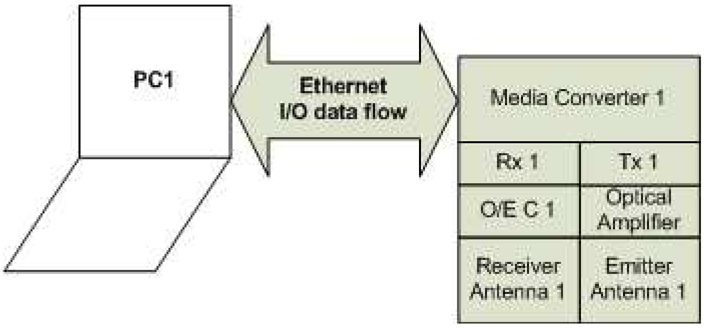


Figure 5: Module n°1 design

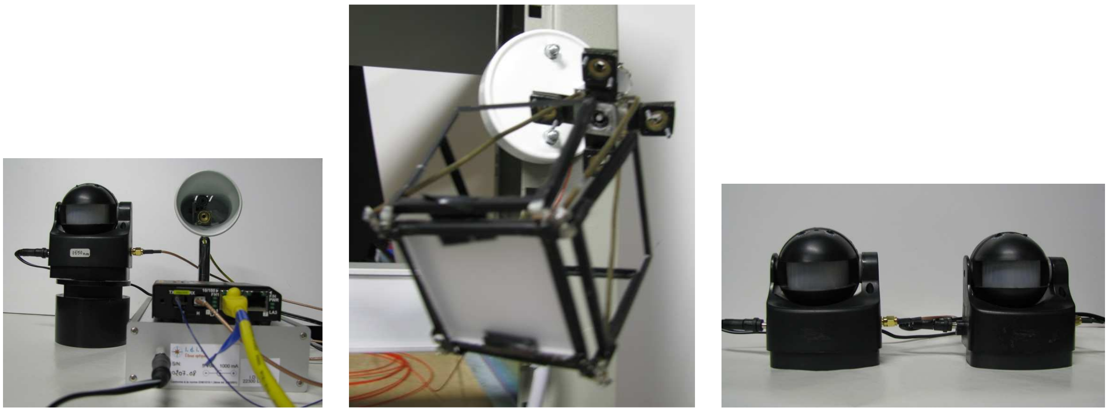
Each communication channel is attributed to one of modules. For instance, the PC1 is connected to the Module n°1 with its specific wavelength. We use the same modified Media Converter connected by an electrical connection Ethernet 10 Base-T. The Tx Media Converter is linked to a semiconductor optical amplifier (SOA) and provides a connection with a power level up to 18 dBm.

The uplink antenna have a small divergence angle, 5 degrees (HP=2,5°) and the system is made following the same conception as the Base Station: A point source with a holographic diffuser. This directive antenna has to be aligned manually towards the Base Station.

The receiver antenna is identical to the Base Station. Only CWDM filters values are modified and adapted to the receiver wavelength. The concentration optical system is a hemispherical lens with 10 mm diameter. The optical beam is collected by a detector similar to those of the Base Station.

This optical link Module – Base Station is a Line Of Sight (LOS) configuration.

Figure 6 shows some prototype elements pictures: a) Module, b) Base Station Emitter Antenna and c) Base Station Receiver Antennas.



a) b) c)

Figure 6: Prototype pictures

4. SYSTEM SIMULATION AND RESULTS

4.1 Budget link

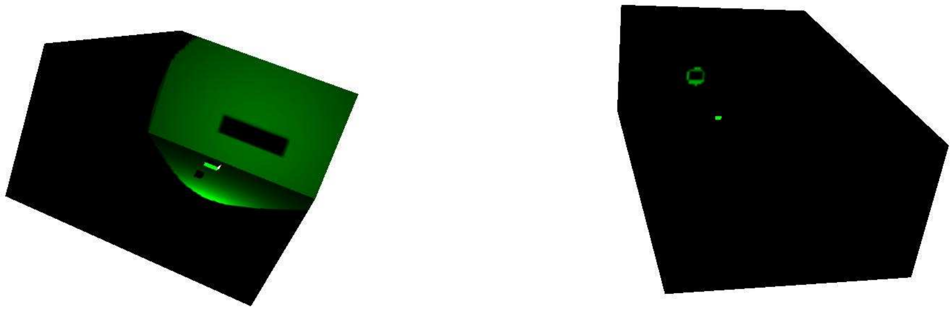
The overall budget link is presented in table 1. This simulation is achieved with generic models [12] and QOFI software [13].

Link	Upstream λ_i= 1510 nm	Upstream λ_i= 1570 nm	Downstream λ_i= 1530 nm	Downstream λ_i= 1550 nm
Data rate	10 Mbit/s	10 Mbit/s	10 Mbit/s	10 Mbit/s
Emitter Antenna Power Source type HP Diameter	 14.62 dBm Extended 2.5° 1.5 mm	 13.8 dBm Extended 2.5° 1.5 mm	 30 dBm Extended 30° 50 mm	 30 dBm Extended 30° 50 mm
Receiver Antenna Surface Equivalent FOV Sensibility (10 Mbit/s) Optical Gain	 1 mm^2 15° -30 dBm +1.5 dB	 1 mm^2 15° -30 dBm +1.5 dB	 1 mm^2 15° -30 dBm +1.5 dB	 1 mm^2 15° -30 dBm +1.5 dB
Link Configuration Modulation Canal Max attenuation	 LOS OOK/NRZ IM/DD -43 dB	 LOS OOK/NRZ IM/DD -42 dB	 WLOS OOK/NRZ IM/DD -59 dB	 WLOS OOK/NRZ IM/DD -59 dB
Distance	1.80 meter	1.80 meter	1.05 meter	1.05 meter

Table 1: Budget link

Note: For this budget link, the emitter antenna has a lower capacity than the one, which was expected (~14 dBm output power instead of 18 dBm). This is due to mounting process. The detectors have as well a lower sensitivity (-30 dBm instead of -37 dBm) than the one originally planned, because of component commercial availability. The optical gain of the receiver antenna is also lower (1.5 dB instead of the 3 dB originally planned). The result is a penalty on the link margin and shorter communication length (2 meters instead of 4 meters).

We can see here under the QOFI simulation cover, a) WLOS downlink and b) LOS uplink



a) b)

Figure 7: QOFI simulation

4.2 Experiment results and remarks

We managed the simultaneous video transmission demonstration via the WDM optical wireless prototype. But due to the optical losses linked to the mounting process and to the availability of components, the distances originally planned has been severely reduces. Other elements should be specified:

First, we met a huge difficulty in the supply of components in terms of availability and delay. Then, the choice of wavelength has led the search for a solution in the "world fibre" environment.

Currently, the components availability, which enables the issue of providing a power far exceeding the Watt and a modulation in the MHz range, to be reached, puts strong incentive to choose the 1550 nm wavelength range. The simplest solution is to use a low-power module (diode laser) associated to an optical amplifier. For cost and energy efficiency reasons, it would be preferable to add several diode lasers to ensure a significant divergence with high power.

Choosing a wavelength for each different channel is an elegant solution. However it requires the use of filters to select a reception channel. But there are two types of existing filters: absorption or dielectrics multilayered. The absorption filters are not quite selective because they have a large optical bandwidth (> 100 nm). The other solution is very sensitive to the angle of incidence and limits the FOV on the reception antenna. It requires coarse WDM with separated wavelength as lighting the filter with a non-incident angle is equivalent to permit the transmission of a different wavelength (10 nm shift of the central wavelength for 10 degrees angle).

Moreover, the Ethernet Media Converter selection does not offer the possibility of programming the MAC layer parameters.

7. CONCLUSION

The wireless infrared technological solution has the following main advantages:

- Operating spectrum: The frequencies of uses in these systems, offers a wide availability and an absence of regulation.
- Data security transmitted: The optic beam does not pass through walls, thus it offers a physical natural resistance against hacking.
- Important data rate: Due to the optical characteristic, we can obtain an important data rate.

- Medical immunity: Because of the powers used and international standards in force (IEC and FCC), these systems present interesting solutions.

We showed in this document that it was possible to increase the emitter optical power while staying within class 1 eye safe limits.

To move towards a realistic solution, we must improve the emitter power face to the divergence. We need also to increase the detection sensitivity. A reflection must be conducted in its direction by adding reflections on filtering, modulation, coding and multi-access techniques.

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