The last mile problem solution using free space optical transmission broadband

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Abstract

High costs generated when deploying Optic Fiber Networks at the transport level, together with other factors that avoid PONs arriving to the home and/or office, have impulsed the design and implementation of partially optical networks (FITL), including an alternative that uses infrared light. This work explores the basis of the new infrared access networks, it gives some design highlights and shows an example of a simple application on tele-education.

Key words. *Communications, Free Space Optical Transmission (FSO), Optical Networks, Channel. Propagation*

Resumen

Los altos costos generados al instalar redes de fibra óptica en el nivel de transporte, junto con otros factores que evitan que las redes ópticas pasivas (PON) lleguen al hogar y a las oficinas, han impulsado el diseño y la puesta en práctica de las redes parcialmente ópticas (FITL), incluyendo una alternativa que utiliza la luz infrarroja. Este trabajo explora la base de las nuevas redes de acceso infrarrojas, da algunas sugerencias para el diseño y muestra un ejemplo de una aplicación en tele-educación.

Palabras Clave. *Bucle de abonado, enlaces ópticos de espacio libre, FSO, fibra óptica, PON, redes ópticas pasivas, solución de último kilómetro.*

I. INTRODUCTION

The new competitive telecommunications services provider Companies, must fight for obtain Broadband access networks installation and operation businesses. Installation and operation costs asociated to deployment of links and transmission and switching equipment in optical access networks, could be justified when subscribers density promisses enough money back to cover both investments and planned profits. In that case when economic estimatives or optical fiber carrier company policies does not allow the arriving of fiber to the end user's installations, it is necessary the deployment of access networks called «secondaries» that matches a highly enough «Quality of Service vs. Financial Costs» relation in such a way that company gets the programmed profitability and gives the expected service. This, when we talking about broadband access services (for example: Internet) for home and business users with not very high data flows [1]. Otherwise, there are local area networks (LANs) that requires small cost links and easily deployment. It also exists some needs, even not satisfied in an optimal manner, when designing access networks for low mobility users (walking mobility or low velocity), which require low cost in conection and multi-service. A wireless tecnology taht includes low power consumption, low cost, high reliability, adequate capacity for such an user's services needs and highly easy deployment, would convert in an up-to-date solution on environments where users density and increasing are irregular, as from the point of view of subscriber quantity as geografical areas and the random location where they are. A good collection of networking equipment and information devices based on infrared light transmission, are being offered by several vendors, including PC peripherals, handhelds and all that types of Information Appliances (IA) that obtains their rigth utilization accessing with high velocities on Internet.

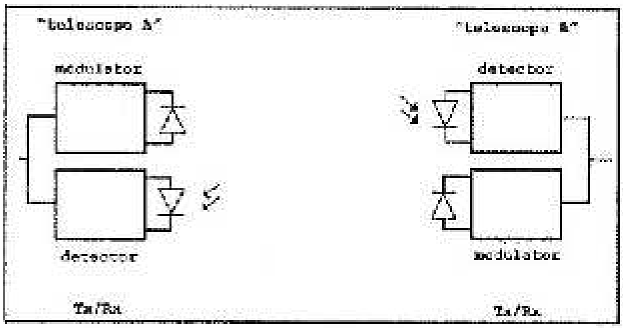
All this, by the deployment of access networks using complementary optical technologies: Optic Fiber Transmission (OF) and Free Space Optical Transmission (FSO) [2].

II. INFRARED TRANSMISSION SYSTEMS

Information transmission systems based on sending and receiving optical signals, wired or wireless, work over infrared (IR) electromagnetic spectrum range. Transmission systems based on optic fibers, propagate infrared light along low atenuattion and high linearity areas of such transmission media, which are in the wavelength regions of 1310 nm, 1550 nm and 850 nm.

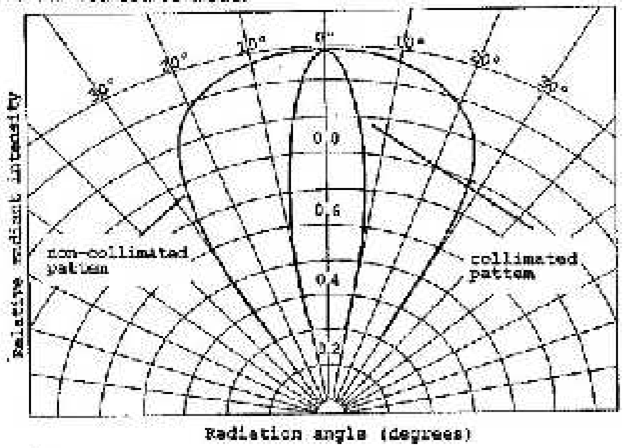
Different to that optical systems by fiber, optical transmission systems through the free space does not use a guided medium to propagate the signal. In such a systems the designers does not care about uses infrared energy in the wavelengths aforementioned, but their design aims over the physical level concentrates on getting the more propagated distance without fading infrared light power below that observable by the detection system [3].

Fig 1. Simplified squeme of a bidirectional infrared transmission system.



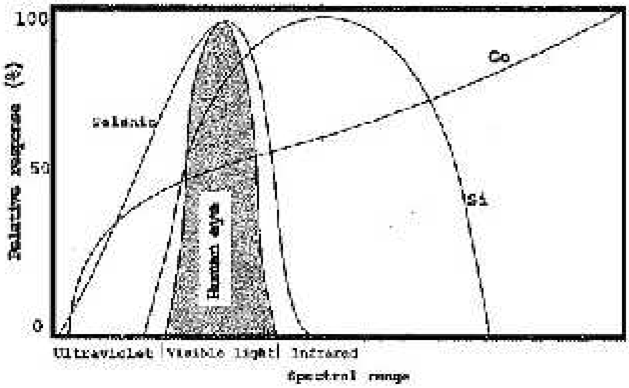
An infrared transmission system is composed by a transmission device, a reception device and a propagation medium with characteristics for optimal optic transmission. The transision media is the vaccum (in this case the air) and presents a sumatory of an electromagnetic propagation resistance factors on infrared wavelengths. Such a sumatory is the result of free space losses (that can be calculated by using the Friss expression), lobe fading, intensity losses caused by high temperatures (by the generation of vapors that makes refractions), atmospheric depressions (rain and fog) and, as a primordial factor, the need for a line of sight between transmitter and receiver to establish the link.

Fig 2. Typical radiation patterns, collimated and not collimated, for an infrared source diode.



The emitter system for infrared transmission (Fig.1) is composed by a modulation block and a radiation source on that spectrum region. Such a radiation source is generally constituted by an infrared emission diode (IRD) or infrared laser diode (ILD) manufactured on Galium Arsenium and whose crystal case can reach highly collimated radiations, or well lobe widths of up to 30 (Fig.2), depending on if it uses, or not, physical optic for its output structure (mirrors and convergent lens). Detection systems, or receivers, are composed by photodiodes or phototransistors, made of Silice or Germanium, the Germanium being the better one absorber of intensity over a wide infrared spectrum range (Fig.3).

Fig 3. Spectral sensibility of Ge, Si and Selenium regarding human vision.



The measurement of electromagnetic wave intensity is taken in mW/cm^2, therefore sensibility of the detection elements on the receiving system depends upon the intensity that carries the wave and sensibility of such a photosemiconductors. In addition to the detection element, the receiving system also has amplification blocks and demodulation systems using modulating wave detection. Transmission systems configured in such a way, modulate the infrared carrier by amplitud or intensity, either by direct modulation or pseudo-modulation (indirect phase or frecuency modulation of a sub-carrier before modulating the infrared carrier wave), being the amplitud shift keying (ASK or OOK) the most used scheme.

A. Performance of IR Transmission Systems

The performance of infrared transmission systems, regarding emitters and receivers, depends mainly upon the modulation efficiency and signal to noise ratio (SNR) obtained at the receiver's input. Both conditions are determinant factors for the bit error rate (BER). It must be remembered that modulation efficiency of an ASK (or OOK) system could be calculated in the same way as for Amplitude Modulation (AM), obviously having into account the high frecuency of the optical carrier.

B. Link Losses

Infrared links show serious difficulties for propagation as counterpart for that happening with microwave links, radiofrecuency and, of course, wired links, which presents proved easy propagation characteristics. Due to small wavelength used in FSO, in both ranges 1310 nm and 1550 nm, the optimal atmospheric conditions to get a right performance of infrared networks are hard to obtain. High temperatures cause humidities due to the vapors produced by liquids in roofs, streets and mainly everything containing water directly affected by the sun light, wich makes a progressive difraction of the infrared beam and finally getting-off the line of sight pattern required between transmitter end receiver «telescopes». Rain, and especially fog, because the small of its water particles, compared in widht with link wavelengths, is the worst case of atmospheric state for the performance of an access network or infrared LAN.

Finally, due to the light beam colinearity, its necessary line of sight between both «telescopes», transmitter and receiver, in order to prevent the energy absorption and/or reflection on obstacles like buildings, trees, among others. However, actual standards about infrared tranmission, specifyes the minimal power requirements so the beam can go at least across two typical window glasses, with wich it obtains one of the best access network installation setting: from inside the comsumer premises through the windows glasses and arriving to a Point of Presence (PoP) owned by the infrared access networks carrier (now called EtherLECs or ATMLECs, because the protocols used for link acces control throughout the «secondary» access network). Overall, as a conclusion for this section, whatever particle whose width is comparable with the infrared modulated light wavelength, converts automatically on a dispersion element, with parcial or total attenuation, avoiding that the wave arrives below the minimal SNR required at the receiver input on any of the two ways, downstream or upstream.

III. NETWORK PROTOCOLS FOR INFRARED ACCESS

Having high velocity access networks is an idea that implies thinking about two levels non hierarchical SDH/SONET networks providing the multi-technology access networks with high payload bandwidths throughout all of its add/drop multiplexers (ADM access nodes). The protocol paradigm of medium access over passive broadcast networks, or even in active multiplexed networks, is the Asynchronous Transfer Mode (ATM). It can calculate distances in terms of clock pulses, in order to obtain a transmission convergence and make the broadcasting, sending and receiving of ATM cells. These cells are inserted on the SDH/SONET cells payload. So, with the establishment of ATM virtual circuits, and at the same time using synchronous digital hierarchy virtual containers, the subscriber's access into the transport network can be done by interconecting them with data networks: Internet, or other private and public networks [4].

Passive Optical Networks (PON) have the architecture that uses ATM as its data link and medium access control protocol, although actually exist two well known and proven protocols, Ethernet and Gigabit Ethernet, are intended for bringing efficient protocols and interfaces set to communicate subscribers and ISPs [5].

All Information Appliances that are being developed in the new wave of Home Networking uses Internet access through gateways connected to access networks. These environments will be very important business targets, taking into account the infrared transmission as an efficient alternative, costs-effective and easily deployable along Internet broadband access networks. There are two main wireless technologies to use in home networking products: Infrared (IR) y Radiofrecuency (RF). Until now, most of the developers and vendors has seen infrared networks like a corporate medium-low scale LANs technology or as a technology that makes possible interconecting several appliances (information aplications or devices) into a house, room, SOHO (Small Office/Home Office) or whatever business with medium data flow level[6]. However, the scope is that in the near future besides having LAN infrared networks inside a house, it also can obtain broadband access through networks based on IR topologies like those proposed on the next section.

In addition to the use Ethernet and ATM, and even directly SDH/SONET frames, as the interfaces and protocols for data link and medium access control, in the world it exists *de* facto protocols proposed by Infrared Data Association (IrDA), among other propietary ones, and adopted by all information appliances and access networks developers, designers and manufacturers using this technology, including aplication software made by the big monsters: Microsoft™ y Linux™ [7].

Fig. 4. IrDA Protocols Set.

IrTRAN	IrObex	IrLAN	IrCOM	IrMC	Aplicacation
LM-IAS	Transport Protocol Tiny-TinTP				Transport
Link Management Ir-IrLMP					MAC
Link Access Protocol -IrLAP					LLC
Serial Asynchronous (9.6-115.2 Kbps)	Serial Synchonous (1.152 Mbps)	Sync 4PPM (4 Mbps)			Physical

When an access network is implemented using equipment based on the protocols set of IrDA (Fig.4), ATM and SDH/SONET protocols, and hence TCP/IP protocols (the most used over ATM), would perform its functions over the Network Layer (having into account the TCP/IP network model). On the other hand, using only the standardized IrDA Physical Interfaces and Protocols, ATM or Ethernet standards adopts the roles of data link, transission convergence (in the ATM case) and network layer (TCP/IP, ATM and/or Ethernet) (Fig.5).

IV. FSO ACCESS NETWORKS TOPOLOGIES

Fiber Into The Loop (FITL) constitutes the paradigmatic revolution at the moment. The longer penetration the optical fiber have in the local loop side, the longer data and services capacities could be offered by the optical carrier (network operator) and the other competitive carrier companies (CLECs).

Fig. 5. Aplication of irDA protocols in an access networks environment, for example in order to get Intenet access.

TCP	UDP		Transport
TCP/IP			Network
ATM Transmision Convergence			MAC
ATM			LLC
Serial Asynchronous (9.6-115.2 Kbps)	Serial Synchonous (1.152 Mbps)	Sync 4PPM (4 Mbps)	Physical

Access networks containing some part (or parts) of it running over optic fiber links are clasified in Fiber To The Home (FTTH), Fiber To The Building (FTTB), Fiber To The Curb (FTTC) or Fiber To The Cabinet or pedestal (FTTCa) (see Fig.6) [8]. On the classification above the most indicated environments where combining optic fiber with short range high performance transmission technologies are: FTTC and FTTCa. Infrared light links are more reliable and faster when the range (distance) that it must cover is smaller. Therefore, designing access networks for distributing bandwidth among certain areas, each of which covers some hundreds of meters in diameter, is a new opportunity that can be used by competitives and new companies to deploy access networks driving the optical fiber deployed up to the Curb or Cabinet (pedestal), that can be offered by high velocity transport networks carriers (Fig.7). A Passive Optical Network (PON) topology has an OLT (Optical Line Termination), an ODN (Optical Distribution Network) and, in order to make the interface with multitude of complementary access technologies, considered as «secondary» access networks (of course, including FSO), an ONU (Optical Network Unit). These are the PON components and elements, which represents the most designed and deployed access network configuration throughout the globe (Fig.8) [8].

Fig. 6. FITL Topologies enabling FSO.

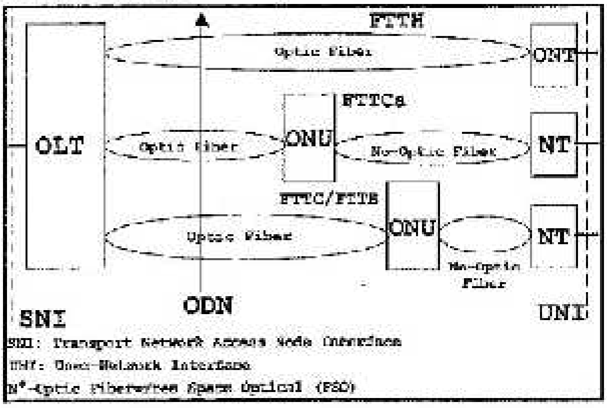
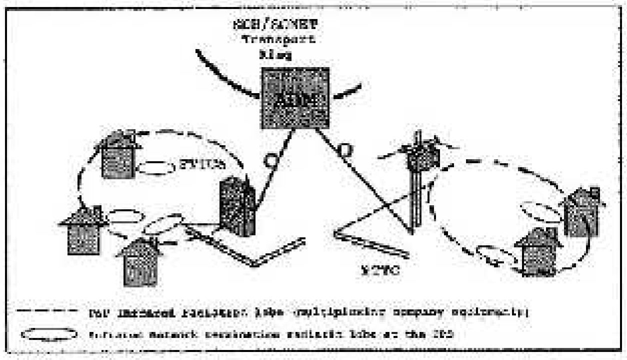
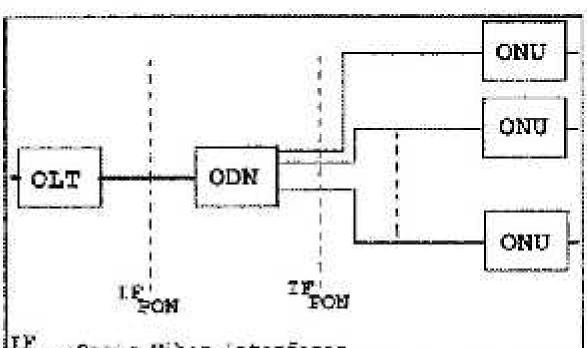


Fig. 7. FTTC and FFTCa topology environments using Free Space Optical (FSO).



Choosing network element capcities is the key for introducing FSO, including ILEC's or CLEC's ONUs and carrier's ADMs that comunicate with infrared user terminals on one side, and with those ONUs on the other side. It must be considered the protocol set used for Mux/Demux infrared access equipment, since PONs has standardized processing velocities working over ATM and, has actually developed, over the Ethernet and Gigabit Ethernet protocols. ONU has four main parts: Interface with ODN part, ATM cells assembling and multiplexion part, adaption functions part and, with standardized Q3 interfaces, OAM control and management part.

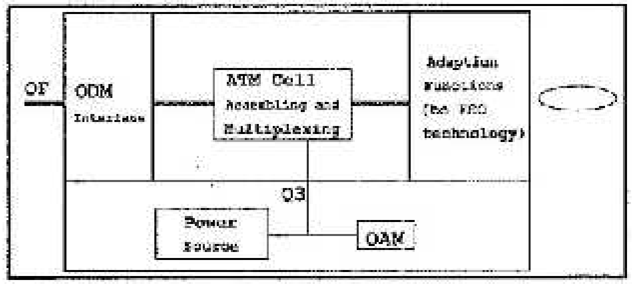
Fig. 8. PON Components.



V. FSO NETWORK ARCHITECTURES

At this point, the most important part to have into account is the interface between ONUs and the concentration and multiplexig equipment in the secondary FSO. The key thing is to understand an ONU function (Fig.9).

Fig. 9. Internal simplified scheme of an ONU.



For the FSON/PON data interface and physical part, is necessary for ONU's respective adaption functions designing send-receiving and infrared access Mux/Demux for broadcasting multiple users and, in some special cases, for adapting data flows driven through point-to-point infrared links. The integration of ONUs, Mux/Demux and ATM (or Ethernet) assembling cells systems, is done in one functinal package or modular equipment, in the same way that it was done with DSLAMs (Digital Subscriber Lines Multiplexer) and ATM switches. In the infrared scheme, such integrated equipments include all logical elements necessary to operate and interface with ATM/ Ethernet PON systems, realizing subscribers multiplexion to IR links and doing the assemble and management of unit cells on the protocol used for data link and network access in geneal. An integrated system as the one described above, would exhibit an access network topology for both FTTC and FTTCa, having into account that in-pole installations as a particular case of FTTC is the most indicated choice for making a secure line of sight infrared broadband links.

VI. ACCESS NETWORKS MODEL DESIGN APPLIED TO FREE SPACE OPTICAL

It is necessary to make a definition regarding the levels at which telecommunication networks can be studied, just like for detemining on which of those levels to realize the reasoning. All of this with modern broadband access networks on the scope and specially in the case of Free Space Optical. Here it is offered a choice that consist on a four abstraction levels organization. The four levels that compose the telecommunications network design model have been proposed regarding to precedent models and looking for the most complete model possible, that save the designing work from most imprecisions, interpretations and descriptions less complete used in books and articles (magazines) from several particular or corparate authors. Management, Functional, Architectural and Physical levels, are only the first step to reach such problem's solution, observed in the most of the literature readed and examinated for writing this section; it is good as a point of reference in the multidimensional space of telecommunication networks design, as well. It will only be taken into account the functional level from the four levels mentioned above, hence in the example exhibited on the next section it will be suposed several aspects that prevent the need for designing at the management level and, much less, at the architectural and physical level, where the manufacturers does their work.

A. Functional Level

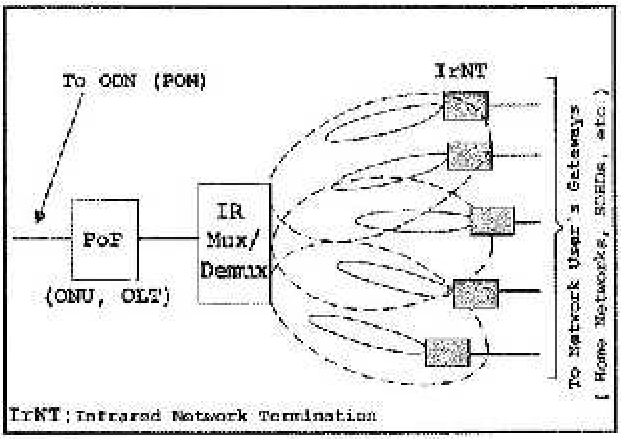
At this level engineers and scientists are thinking about information transmission capacities that the network must to match. Thinking about that as an organization of sub-systems and taking those, at the same time, as functions correlating input and output capacities. At this point it have to think about geographical extensions to be covered by the network, transmission magnitudes for the services required by subscribers, dividing the network into levels and sections (actually in two levels: Transport level and Access level) and its organization using blocks or parts (subsystems) that perform the access, switching and transport global functions. The Telecommunications Management Network (TMN) must be taken into account designing at this abstraction level, since it requires its own capacity, functional blocks and interfaces to intercommunicate with manageable network elements [9].

B. Functional Design Level Applied to Secondary FSO Networks.

In the section above were defined the activities that will be done on the next example. A secondary FSO network, offering broadband access to Internet requires basically of a PoP (Point of Presence), an infrared subscribers links multiplexer equipment and Infrared Network Terminations (INT) (Fig.10), which are directly connected to the consumer premises equipment. Using an infrared-through-the-window (IrTW) scheme, the link between PoP (composed by an ONU and an infrared multiplexer) and consumer premises equipment consists of an infrared electromagnetic energy beam flying acroos the home or office windows glasses.

About the TMN, it will only be taken into account that PoP equipment, that includes carrier's ONUs and infrared subscriber's access multiplexing equipment owned by the CLEC (EtherLEC, ATMLEC or whatever broadband access company), it must have into its functions a system block whose interface is Q3, necessary for control and management (OAM) of the capacity resources agreed with the consumer by means of SLA (Service Level Agreement). In the analysis of geographical extension to be covered it is necessary to consider that reachable distances for infrared links show much variation with the different manufacturers, however there is a «virtual agreement» about those access links: For the scenario of «secondary» FSO access networks, those must be between several hundred meters and maximum 500 meters.

Fig. 10. Simplified scheme of a «secondary» topology basen on FSO.



Finally, and before we are going to play with some little numbers, it must be taken into account that capacities of PoP equipment owned by PON propietary carrier companies (ILECs, EtherLECs or CLECs), can be used to estimate the users quantity that it can serve and the quality of service (QoS) provided (maximum tranmsission velocity for each user).

VII. ACCESSING INTERNET IN TELE-EDUCATION ENVIRONMENT USING FSO

This example will provide an idea of the service potential, and hence for business, that would be carried by an eventual Free Space Optics deployment. The scenario, that includes actual state of local data carriers, topography of the area to get cover and services demanded by potential costumers is covered next.

A. Geographical Location

Providing Internet access and connection with other propietary and public data networks is required, for a number of seven buildings located into a University campus whose superficial extension is close to 3750 m². Buildings have distances of 350 m up to 450 m away from each other and present irregular heights. Each building network equipment (switches, hubs and routers) room have well located windows and easy access to exterior walls and the roof.

B. Data Carrier (Operator) Actual State

Broadband networks carrier has a group of SDH rings transport networks and also has two PoPs closely to University campus. Each of such a PoPs is composed by two ONUs (these, in turn, have up to 32 optical connections, one for each potential user) whose capacity is standardized: 622.08 Mbps (downlink) and 155.52 Mbps (uplink) between the OLT and the ONU. The passive optical network at which these ONUs are attached works using ATM as the Data Link Layer and, if necessary, it can also work as the Network Layer.

C. Services Demanded by Potential Costumers

Those basically are related to Internet. It's wanted to have access to Internet from each building at such a velocity that allows 40 computers in the same building LAN to connect with a minimum velocity of 150 Kbps. Moreover, there is a videoconference room in each building. Regarding to MPEG standards, real-time video having videoconference quality, this is, with a 800X600 @ 30 frames/second resolution, requires at least 3.5 Mbps in both link channel directions, taking into account that such a video format (MPEG) uses compression schemes.

With the information above about the scene to be covered by the deployment of FSO, it is required to know equipment quantity, types and capacities necessary to install such an access network.

As it was mentioned before this example is only done from the point of view of the reference design model functional level. It can start by calculating the required capacity of each link for the every 40 LAN computer's basic Internet access. It is necessary to establish unique infrared access, or a group formed by several links, that provides a 6 Mbps of transmission velocity (150 Kbps*40 computers). Since there are 7 buildings each with a LAN, it is required a total of 42 Mbps to provide basic Internet access for all LANs. The required capacity for each video conferencing building room is 3.5 Mbps, therefore it need 24.5 Mbps for all the buildings together. In total, both Internet access and videoconferencing access need 30.5 Mbps for all buildings together. However, videoconferencing are used almost always in the two ways, downstream and upstream, sending video and receiving video at the same time, hence it would be necessary to double the links capacity toward the video rooms. Then, the necessity of transmission velocity would increase up to 7 Mbps of payload, 49 Mbps in total for all the 7 videoconference rooms.

Taking as a point of reference the IrDA (Infrared Data Association) standards and protocols for physical and data link layers, in the 4 Mbps synchronous transmission modality, it would be necessary 23 synchronous like infrared links, for covering the University total demand of 91 Mbps. From the 23 links, two are for covering the basic Internet access demand on each building LAN. It would left 9 free links. But FSO architecture has the filosophy of providing an easly established line of sight between user's equipment and infrared multiplexing equipment; therefore, in order to provide 7 Mbps to each of the videoconferencing rooms it is necessary to use two 4 Mbps IrDA interfaces composed by two IrDA links. Then, it would need a total of 14 synchronous IrDA and, finally, the global total would be 28 infrared IrDA like links.

It knows that each optic fiber carrier's PoP has two Optical Network Units (ONU) with the mentioned standards capacities and functioning over ATM. To ensure the interface velocity with the 28 infrared links it is required a minimum capacity of 28*4 Mbps = 112 Mbps. This velocity would be covered by any of the four ONUs, supposing they are not being used or do not have much load, since the PON that connects it to the transport network acces node, work on the standard downstream 622 Mbps link maximum velocity, in other words, from the SDH access node, through the PoPs (ONUs) y distributing among all the optical network terminations, in this case infrared network terminations. This means that with only one ONU working, for example, at the symetric velocity of 155/155 Mbps, with a same PON's capacity, and having into account that the infrared multiplexing equipment must have a transmission and processing velocity prior to 112 Mbps, it is provided the required capacities for the proposed scenario services demands. With the characteristics cited above and having into accout that the mean distance among buildings is about 350 m and 450 m, it would only need a good location for transmitters and receivers (better said transceivers) so they have the required line of sight between user's windows and carrier's PoPs.

VIII. CONCLUSIONS

FSO access networks are a complete flexible solution. However, actually there is few and imprecise information about capacities, technologies and architectures where Free Space Optics (or Free Space Optical) are applied. There is certain vacuum about information related to neccesary networks elements for FSO designs, besides its characteristics. However, with not much information about FSO and using the standards of IrDA and ITU (about Optic Fiber PONs) and regarding basic knowledge about infrared technologies, designs and close estimations can be done in order to make initial decisions on business environments. Paths proposed to follow for investigating and studing are: FITL architectures with FSO, Infrared Access Multiplexing Systems, Design of Infrared Transmission Systems, developing of schemes and guides for designing FSO networks, R+D on Broadband Infrared Emission and Reception Devices and Mathematical Modelling of such devices and FSO Systems.

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