CONVERGED OPTICAL NETWORKS FOR VIDEO AND DATA DISTRIBUTION IN HOSPITALITY ENVIRONMENTS

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Abstract: Current hospitality networks are already lagging behind in terms of broadband adoption and high-speed online offered services, and they might not be able to cope with the increasing bandwidth demands required to distribute high-definition video traffic. We propose the use of a converged optical network adapted to the specific needs of the hospitality environment, providing a low-cost and low-power solution based on a combination of silica and plastic optical fiber wiring, together with radio-over-fiber techniques for wireless access. We use detailed full-system simulations to analyze the validity of such infrastructure to provide a unified, pervasive and future-proof all-optical solution.

1 INTRODUCTION

The recent growth of demand for higher bandwidth in hospitality buildings (hotels, hospital, residences, etc.) comes from the exploding connectivity of devices and systems sharing data, the high-tech customization of guestroom technology (video streaming to TV and other devices, on-demand movies, high-speed Internet access, online gaming, voice-over-IP and videoconferencing, e-commerce and billing of the resort's services), and the increasingly pervasive mobile access to information (Cisco, 2009). Moreover, remote guest/staff control of room temperature and lighting (including energy management policies), electronic door locks, or other hotel services will only add to the number of connected and managed devices. Emerging technologies will strongly affect network performance and medium/long-term strategies to meet guest demands while still providing consistent quality of service and experience (Inge, 2009).

The deployment of mixed physical technologies on the network infrastructure (coaxial, Cat.5e/6, phone wire) results in large capital equipment installation and maintenance costs. Moreover, the common electrical cabling used poses limitations in diameter, weight, terminations and electromagnetical interference. One growing approach to simplify network design, installation and management costs is the use of converged networks, both wired and wireless, using a single cable for backbone and in-room wiring, to carry all communications for guestrooms as well as for staff systems. Here, the larger bandwidth of fiber over copper links becomes evident in high-density hospitality buildings, where user aggregation reduces installation and operation costs; moreover, recent developments on Plastic Optical Fiber (POF) (Nespola, 2010) and Radio-over-Fiber (RoF) transmission allow for low-cost and competitive converged all-optical architectures (Gomes, 2009).

In this paper, we study future requirements in hospitality environments to introduce high-definition video services through converged optical networks. In Section 2 we identify the design boundaries of such scenario through a statistical analysis of TV channel blocking and Section 3 proposes a future-proof fiber-based optical architecture that provides wired and wireless services, and the limitations on the span of such network are thoroughly described. Finally, Section 4 introduces full-system simulations of this architecture to analyze network response over intensive video traffic, depending on the floor distribution capacity. This allows the exploration of the concept of flexible optical resource allocation to cope with temporal limitations and cover specific hospitality services in a dynamic way.

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Table 1: Bandwidth requirements to support hospitality HD IPTV.

External WAN	**Maximum bitrate (Mb/s)**	**Average Throughput**		**HDTV channels (6 Mb/s/ch)**	**Full HDTV channels (12 Mb/s/ch)**
		(Mb/s)	**%**		
ADSL	8.2	8*	97.5%	1	0
ADSL2+	24.6	21.8*	88.6%	2	1
VDSL2	250	68*	27.2%	11	5
Gigabit Ethernet/GEPON	1000	941.5	94.1%	156	78
GPON	2500	2488	99.5%	414	207
10Gigabit GPON/ 10GEPON	10000	9415	94.1%	1569	784
In-building LAN					
Fast Ethernet	100	94.2	94.1%	16	7
Gigabit Ethernet	1000	941.5	94.1%	156	78
WiFi 802.11g	54	~10-22	18-40%	1-3	0-1
WiFi 802.11n (2.4/5 Ghz)	300/ 600	~65-260/ ~135-540	21-86%/ 22-90%	10-43/ 22-90	5-21/ 11-45

* Obtained from empirical measurements over 2500 m. (Kagklis, 2005). VDSL2 average is calculated theoretically for this same distance.

2 PREVIOUS WORKS

Previous works have attempted to measure the impact of technological investment in hotels (Sigala, 2004), reaching the conclusion that there is a significant productivity impact when the exploitation of the network and its integration with the infrastructure are strategically optimized, with architectures adapted to the business and its operations.

Similar converged optical architectures have been proposed recently but mostly for generic in-building scenarios. For example, (Xu, 2010) examines the transmission of uncompressed High-Definition TV (HDTV) under Ethernet passive optical networks (EPON) making use of the polarization diversity technique to improve reception sensitivity and increase the anti-interference capacity of the in-building wireless transmissions. (Walker, 2009) showcases a 600 Mb/s radio-over-fiber architecture able to integrate simultaneously Ultra-Wide-Band (UWB), wireless and WiMax signals over 1 km of silica fibre using reflective electro-absorption transceivers, and similarly, (Jia, 2009) proposes multi-band generation and transmission of all these wireless signals through photonic frequency tripling, demonstrating a testbed able to deliver uncompressed 1.485 Gb/s HDTV video signals over silica fiber and air links.

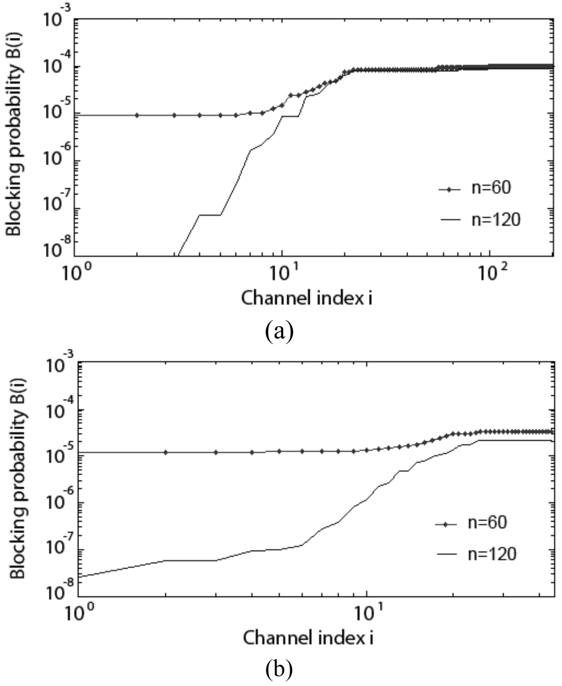
Regarding the use of plastic fiber for RoF transmission, it has been already demonstrated in (Guillory, 2009) on a home level, with a network delivering various signals (Ethernet, digital terrestrial or satellite TV, wireless) on graded-index POF, and very high bit rates - up to 16 Gb/s - have been achieved by using techniques such as orthogonal frequency-division multiplexing (Yu, 2008).

However, none of the architectures reviewed to date addresses the specifics of the hospitality networks, nor tries to provide a complete optical solution for the complex structured cabling systems commonly used in these commercial infrastructures.

3 FUTURE VIDEO BANDWIDTH REQUIREMENTS

In hospitality installations, IP television (IPTV) networks are quickly substituting traditional RF video systems due to its lower installation and maintenance costs, and the possibility to integrate other interactive hospitality services (Held, 2006). IPTV systems use a single type of data connection for television, data and telephony services, benefiting from the use of a single set of cabling. They commonly receive TV channels from either cable television or satellite connections, and they may also introduce receiver antennas to get free local broadcast channels. A key feature for the upgrading of hospitality TV systems to have IPTV capability is the use of a hybrid solution that can combine simulcast television content (analogue and digital distribution) with multicast and unicast IPTV channels.

However, high-definition IPTV distribution faces specific challenges in the hospitality scenario. The number of channels that must be available to guests tends to be higher than in residential deployments, as overcoming geographic boundaries is critical for travelers. Video-on-Demand (VoD) is highly promoted, as it offers relatively high margins and is a large part of the hospitality TV service revenues, but it puts an additional demand on temporal extra bandwidth requests. In Table 1, bandwidth demands for the distribution of high-definition IPTV channels are shown, not considering any additional type of traffic. Channel encoding is considered to be MPEG4/H.264 HiP (1280x720 or 1920x1080) at 24 frames per second. It is obvious that there is a clear limitation when using current hospitality deployments, consisting of different Digital Subscriber Lines (xDSL) to the building and Fast Ethernet or wireless in-door access, and will even become worse when extra video streams like security cameras or higher bitrate video services, like 3D TV (up to 24 Mb/s) are also included.



(a)

(b)

Figure 1: Channel blocking probability for (a) K = 200 HD-MPEG4 channels, and (b) K = 44 large bitrate (e.g. 3DTV) channels.

To analyze the designs boundaries of a common hospitality video distribution network, we will first focus on calculating the blocking probabilities for each TV channel under a xDSL-driven IPTV installation. Using the models proposed by (Lu, 2007), the blocking probability *B(i)* for channel *i* will be given by Equation 1, with B_{Proc} the blocking probability due to limited processing capability of a Digital Subscriber Line Access Multiplexer (DSLAM), and $B_{Link}(i)$ the blocking probability due to insufficient link capacity from a DSLAM to an edge router:

$$B(i) = B_{Proc} + (1 - B_{Proc}) \cdot B_{Link}(i) \tag{1}$$

$$B_{Proc} = \frac{\frac{(s-1)!}{(s-1-n)!n!} \cdot \rho_{DSLAM}^{n}}{\sum_{h=0}^{n} \frac{(s-1)!}{(s-1-h)!h!} \cdot \rho_{DSLAM}^{h}} \tag{2}$$

$$B_{Link}(i) = (1 - P(i)) \cdot B_{Engset}(i) \tag{3}$$

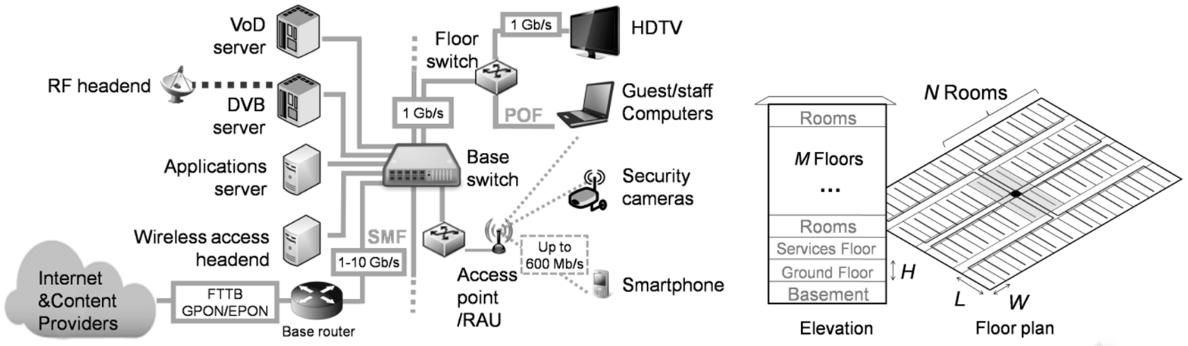
In these equations, *s* corresponds to the number of users per DSLAM, *n* is the channel replication capabilities of the DSLAM, and ρ_{DSLAM} is the ratio between guest arrivals and departures to the DSLAM, according to a Poisson distribution.

$$P(i) = 1 - \frac{1}{e^{\rho_i} - B_{Engset}(i) \cdot e^{\rho_i} + B_{Engset}(i)} \tag{4}$$

$$B_{Engset}(i) = \frac{\frac{1}{m!} \cdot \frac{d^m \left[\prod_{k=1}^{K} \frac{q_k + p_k z}{q_i + p_i z} \right]}{dz^m} \Big|_{z=0}}{\sum_{j=0}^{m} \frac{1}{j!} \frac{d^j \left[\prod_{k=1}^{K} \frac{q_k + p_k z}{q_i + p_i z} \right]}{dz^j} \Big|_{z=0}} \tag{5}$$

P(i) represents the probability of channel *i* to be ‘on’, as shown in Equation 4, with ρ_i as the ratio between guest arrivals and departures to channel *i*. $B_{Engset}(i)$ described in Equation (5) is the probability that the link from the DSLAM to the edge router is consumed by *m* channels other than the requested channel *i*. If we consider *C* as the link capacity coming into the building, and C_0 the channel bitrate (depending on the compression coding), we can calculate how many $m = C/C_0$ of the *K* offered channels can be transmitted simultaneously to *N* guests using *M* DSLAMs in peak usage hours, which normally correspond to a 41% guests connected between 16:00 and 22:00 (SKO, 2008). We will consider a single DSLAM for 180 guests. Channel switching rates are distributed with decreasing exponential popularity, according to a realistic distribution (SKO, 2008).

We will consider a non-blocking situation when $B(i) < 10^{-8}$ for all popular channels. Video bitrates depend on the encoding, 3 Mb/s for SDTV using MPEG2 or 1.6 Mb/s with MPEG4, and 12 Mb/s and 6 Mb/s accordingly for HDTV. In this case, the minimum non-blocking number of channel replications per DSLAM would be $n = 65$, although we will consider a more realistic value of $n = 120$. Table 2 shows the maximum available channels and



(a) (b)

Figure 2: (a) Converged optical network architecture, and (b) building elevation and floor plans.

Table 2: Maximum available channels and minimum incoming link capacity.

TV Channel bitrate (C_0)	K_{Max} for C=1000 Mb/s	C_{Min} for K=500 ch
1.6 Mb/s	674 ch	750 Mb/s
3 Mb/s	357 ch	1410 Mb/s
6 Mb/s	174 ch	2830 Mb/s
12 Mb/s	85 ch	5560 Mb/s

minimum incoming link capacity for different IPTV channel bitrates.

If we set the link capacity to $C = 1$ Gb/s, there is a clear limitation on the number of non-blocking HDTV channels that can be available. Considering a future offer in the order of 500 channels, the link capacity quickly scales up over the gigabit range due to fragmented channel viewing, limiting the use of traditional coax or twisted pair approaches. Figure 1 shows (a) the channel blocking probability for the same scenario in the case of 200 HDTV channels at 6 Mb/s bitrate, and (b) a future scenario with much larger bitrate channels (e.g. 3DTV) at 24 Mb/s bitrate. It can be clearly seen that only the two most popular channels are absolutely blocking free, and as channel popularity decreases (higher channel index), blocking can raise even four orders of magnitude. For a higher bitrate, blocking due to channel capacity can happen even for the most popular channels. When reducing *n* to 60 processing limitations quickly appear at the DSLAM for all channels alike.

If we now consider a Gigabit Passive Optical Network (GPON) link capacity of $C = 2.5$ Gb/s, when using HD-MPEG4 encoding we would be able to access 446 channels in a non-blocking way for this same scenario. In case of having wireless IPTV distribution, with links up to $C = 600$ Mb/s, we could transmit blocking-free only 103 channels. Of course, the number of channels will be reduced in a real implementation depending on bandwidth reservations for management and other extra services.

4 CONVERGED OPTICAL CABLING

The proposed optical architecture, shown in Figure 2a, consists of a router that connects to the external service/content providers through and optical access network, either Fiber-to-the-Building GPON or EPON connection. The building backbone from the basement router to the different floors is done through single mode fiber (SMF), and floor distribution is done through step-index plastic optical fiber (SI-POF), as shown in Figure 2a. Wireless access will be provided by a Distributed Antenna System (DAS), consisting of multiple Remote Antenna Units (RAUs) capable of transporting frequencies from 800 to 2500 MHz, including 2.5G/3G mobile and 802.11/16 wireless signals, through the SMF backbone.

To study the feasibility of such optical infrastructure, a transmission analysis is done first. Maximum floor link lengths will be mainly limited by the high transmission loss of SI-POF. The design boundaries then will be given by the transmission losses for a generic building geometry, as shown in Figure 2b. Here, *M* corresponds to the number of floors with rooms, *N* the number of rooms per corridor side, *C* the number of corridor sides, *H* the floor height, *L* the room length, *W* the room width, and L_0 the initial length from the floor switch to the first room (considered to be always 4 m). In each floor, a double SI-POF cable will be installed to

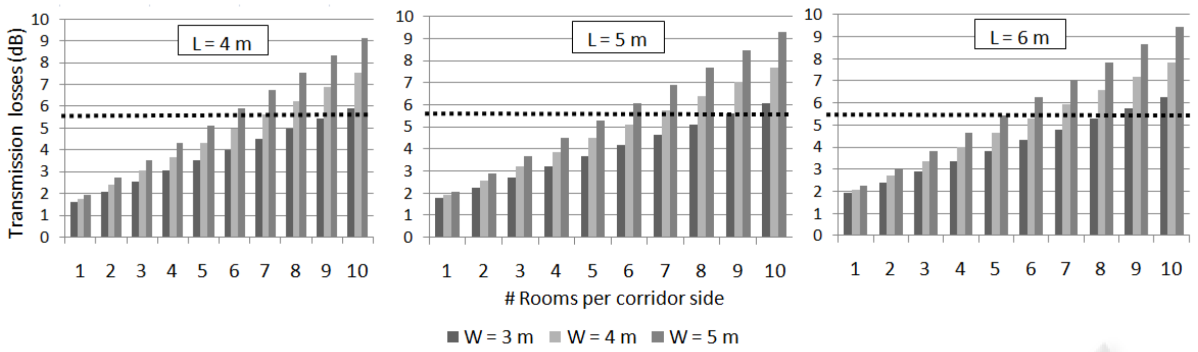


Figure 3: POF transmission losses depending on the room length, width and number of rooms per corridor.

each room to provide two wall plugs (for data access and an IPTV device). The basic floor distribution includes a central hallway with connections to security video-cameras and RAUs.

The transmission losses for SI-POF are considered to be L_T = 0.16 dB/m at 650 nm, and 0.09 dB/m at 510 nm. High-quality POF connectors (EM-RJ, SMI) introduce a loss L_C = 0.75 dB and tight bends (around 5 mm radius) can introduce losses of L_B = 1.5 dB per bend. Therefore, the maximum distance for any floor link will be given by Equation 6, the minimum transmission losses for the longest POF link calculated by Equation 7, and the power margin for each POF link given by Equation 8, with P_T and P_R the transmitter and receiver power respectively, in dBm:

$$D_{POF\_Max} = L_0 + N \cdot W + \left\lfloor \frac{C}{4} \right\rfloor \quad (6)$$

$$L_{Min} = D_{POF\_Max} \cdot L_T + L_C + L_B \quad (7)$$

$$PM = P_T - L_{Min} - P_R \quad (8)$$

Considering a link with a standard Light Emitting Diode (LED) with a transmitted power of P_T = -3 dBm and a PIN photoreceiver with a sensitivity of P_R = -19 dBm, two connectors (1.5 dB) and six tight bends (9 dB), the maximum transmission loss per link would be 5.5 dB.

Figure 3 shows the link transmission loss for different room configurations. Up to 30 m^2 room sizes, the POF links will be able to span up to 5 rooms in each corridor side without significant power loss. This would be enough to cover an average hotel with 20 rooms per floor (N = 5, C = 4). If using green LEDs, their lower attenuation would allow extending the reach to more than 10 rooms per corridor side. For the backbone RoF transmission, as the bandwidth of SI-POF is limited to only 500 MHz·Km, either SMF or GI-POF with bandwidth of 2500 MHz·Km, would be needed. Maximum link lengths in this case, considering full building span, would be $D_{RoF\_Max} = (M+3) \cdot H$, and considering the same power budget, for an average hotel floor height of 4 m, this would mean a maximum GI-POF link span of 12 floors. For longer heights, silica fiber links with lower losses would be mandatory for keeping the power budget.

5 HOSPITALITY DATA TRAFFIC

To study future network demands of hospitality environments under this converged optical architecture, we have simulated the whole infrastructure presented in Section 3 under OPNET™ Modeler.

An average 4-floor hospitality resort is considered, with 45 rooms per floor plus 45 staff computers making a total of 225 users while in full occupancy. This distribution mirrors a typical medium size hotel or a small hospital. The main building backbone is modeled to be 100 m SMF links running Gigabit Ethernet, and floor distribution is done through POF to wall plugs and through the RAUs for the wireless access. Average POF link lengths range from 6 to 50 m, and are considered to run Gigabit Ethernet, although Fast Ethernet links have been modeled as well for comparison.

Guest and staff users and devices have been profiled daily in time following future application usage distributions (ALPHA, 2008), and several services have been included in the analysis as shown in Table 3 and Figure 4. Application duration and their repetition rate are modeled through uniform and exponential distributions, and guest profiles are modeled under a low (0.5), medium (1) and high (2) usage factor over these values, with application and guest start times modeled through the OPNET Random Number Generators (PRNG), based on the operating system's `random()` implementation. We performed daytime simulations to see the dynamic evolution of traffic as users connect their devices into the network, and to obtain peak bandwidth demands, which will be dominated by the heavy video traffic. As daily TV usage begins early in the morning, we can see in Figure 5 the bandwidth demands per floor, quickly over passing the Fast Ethernet limit of 100 Mb/s. Making use of Gigabit Ethernet seems mandatory to avoid congestion if intensive video traffic (HDTV or high resolution videoconferencing) is considered. This is specially important in tele-healthcare applications. The similarity among floors in the bandwidth traces over the random statistical variability is due to the identical guest profiling used per floor to simplify design and simulation time and future work intends to add further detail to such guest distribution.

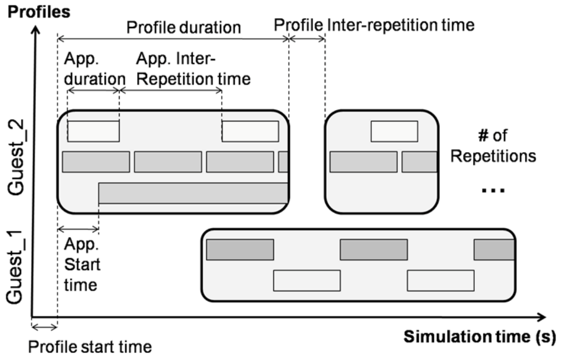


Figure 4: Guest profile definition.

Table 3: Application profile definition.

Application	BW (Mb/s)	Duration (s)	Repetition (s)
Web browsing*	1-100	Exp(600)	Exp(600)
Email	1	Exp(60)	Exp(600)
Database access	0.5	Uni(300)	Uni(300-600)
VoIP	0.096	Exp(600)	Exp(1800)
Videoconference	4	Exp(600)	Exp(7200)
File transfer	100	Exp(300)	Exp(1800)
IPTV	6-24	Exp(7200)	Exp(21600)

* Includes also video browsing, social networking and immersive online games and environments.

As a way to measure the responsiveness of the system, we we will use the channel switching time of the hospitality IPTV system. The channel switching time (or zapping delay) can be defined as the time difference between the user asking for a channel change by pressing a button on the remote control and the display of the first frame of the requested channel on the TV screen. In analog TV, channel change is around 100 ms since it only involves the receiver tuning to a new carrier frequency, demodulating the analog signal and displaying the picture on the screen. IPTV channel switching times can be higher due to delay factors (Uzunalioglu, 2009), like digital video decompression and buffering, IP network related issues (frame encapsulation, IGMP group joining, congestion, etc.) and content management (paid subscription channels, parental filtering, etc.). Fast switching IPTV systems are expected to have zapping delays of less than a second. To make our study more general, we will only consider the network components of the channel switching delay, as video codification and content management greatly depends on the specific IPTV implementation.

In Figure 6 we see the influence of full HDTV data streams (12 Mb/s per channel) over the channel switch requests (the zapping delay). We observe that, under a gigabit Ethernet network, this value still falls far from the margin of 125 ms limit for seamless zapping time, but over slower connections, delay quickly builds up and can degrade user experience and congest the remaining data network. For the same situation, but considering all users streaming high-definition WebTV video (6.3 Mb/s) instead of IPTV, or high-definition videoconferencing (4.3 Mb/s), there would be an average frame delivery delay of 2.74 ms under a Fast Ethernet network, or only 0.38 µs under a Gigabit Ethernet one.

We can conclude that the presented architecture remains valid for the services evaluated and still holds enough margins to cope with spikes due to seasonal trade show attendance or an increase in holiday travelling. Moreover, dynamic network load balancing on the optical domain can spread future demands over all available physical media, avoiding traffic surges, server bottlenecks, connectivity losses and downtimes. Considering specially the RoF distribution system, more wireless and mobile capacity can be allocated to an area (e.g. conference hall) during peak times and then re-allocated to other areas when off-peak (e.g. guestrooms in the evenings). This obviates the requirement for allocating permanent capacity, which would be a waste of resources in cases where traffic loads vary frequently and by large margins. Future explorations on the hospitality scenario will include the dynamic use of different optical wavelengths through reconfigurable Wavelength Division Multiplexing (WDM).

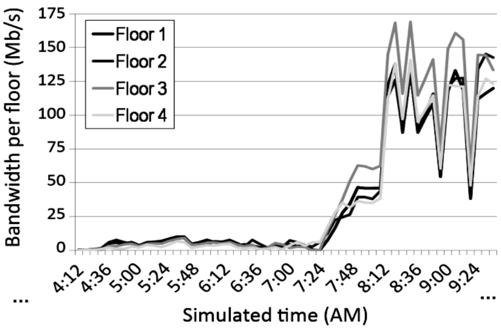
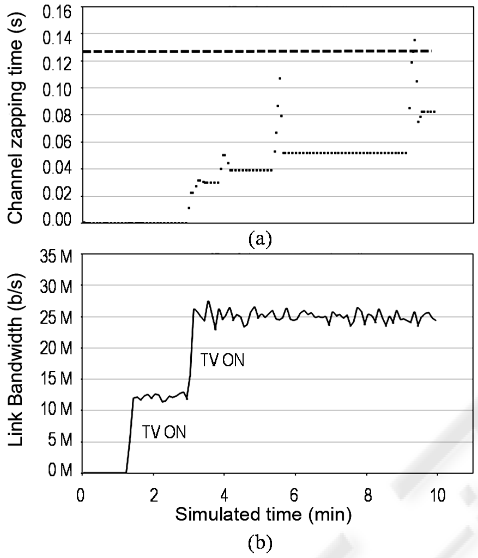


Figure 5: In-building data traffic at morning time.



(a)

(b)

Figure 6: (a) Channel zapping delay correlated to (b) bandwidth consumption in a Fast Ethernet POF link.

6 CONCLUSIONS

We have mapped the requirements for high-definition video distribution on hospitality environments, identifying bandwidth demands of more than 5 Gb/s. Thus, fiber emerges as the best cabling solution, and thus we propose a low-cost and future-proof converged optical network based on silica and plastic fiber. Such cabling infrastructure would be limited to 12 floors with 20 rooms each, and full network simulations have verified TV channel switching times of less than 125 ms.

ACKNOWLEDGEMENTS

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