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Abstract: With this optical home network solution associating an NxN multimode architecture and CWDM technology, various applications and network topologies are supported by a unique multiformat infrastructure. Issues related to the use of MMF are discussed.

1. Introduction

The bit rate increase in the Home Network (HN) is an important challenge, but the most stringent issue probably lies in the great heterogeneity of the signals to be delivered to the various home devices: IP data for triple play services, RadioFrequency (RF) signals for broadcasted TV (terrestrial or satellite) or wireless applications (with Radio-over-Fiber between remote antennas), specific formats as HDMI signals (e.g. to link a High Definition (HD) disc player to a TV set). All these signals have to be transmitted separately, as they cannot be encapsulated in a unique format. Today, they are supported by different networks, but this situation will soon become unacceptable for the users, thus we need to converge towards only one multiformat infrastructure, conveying all these applications. Considering the large bandwidth which will be then required, optical fiber appears to be the only candidate for the transmission medium. A first option consists in multiplexing the signals in the electrical domain, and then modulating a laser with the resulting multiplex in an active star topology [1], but bandwidth limitations and spectrum overlapping risks will soon occur. Transmitting the different signals on dedicated wavelengths in an optical multiplex scheme appears as a very promising solution, as it provides a large flexibility for further evolutions in terms of bit rate increase and/or application architectures. Such flexibility is particularly important for an infrastructure that has to be future-proof since it will be installed in the walls of a house for decades. This concept has already been applied to singlemode fiber (SMF) [2], within the European project ICT ALPHA, for which Coarse Wavelength Division Multiplexing (CWDM) technology is mature. In this paper, we focus on silica graded index multimode fiber (MMF), as it is the most deployed fiber for in-building applications, with targeted installation costs lower than SMF.

2. A passive N x N architecture for a WDM HN

Today, most HN solutions are centered on a switch in an active star architecture, that is very simple and efficient for applications encapsulated over IP, but it is not appropriate for a WDM environment, as the switch constitutes a blocking point for optical wavelengths. The best alternative is then a passive optical plant centered on an NxN splitter, as depicted in figure 1. In each room, optical outlets are connected to an NxN splitter through a dual-fiber cable with one fiber per transmission direction. Signal injected at a splitter input (Tx) reaches then all splitter outputs (Rx). Different applications can be implemented on this infrastructure by using CWDM technology to separate incompatible formats (digital and analogue) or various topologies like a point to point (P2P), point to multipoint (P2Mpt) and multipoint to multipoint (Mpt2Mpt).

3. IP layer implementation schemes

The most basic application to be run in a HN is to ensure data exchanges between devices at IP level for triple play services (data, voice and TV over IP). These exchanges are based on P2P links in usual active star configurations, but this option is not fitted to a CWDM approach on an NxN passive optical plant as it results in a waste of the wavelength resource, each bidirectional P2P link requiring two wavelengths. This solution must be dedicated to a few links requiring a very high bit rate and an excellent Quality of Service (QoS) between two identified devices. Protocols and topologies designed for shared medium applications are then preferred.
    Two options have been considered:
- Point to multipoint (1xN) reuses Passive Optical Network (PON) access network concepts in the HN. The

gateway acts then as a HN Optical Line Termination (HN-OLT), premises being connected using HN Optical Network Terminations (HN-ONT). Two wavelengths are used to implement a PON on an NxN network, one for downstream, one for upstream. PON mechanisms guarantee a perfect QoS with coexisting real time and best effort traffic, as PON allows resource reservation. The main issue today is to reduce the cost of PON equipments by a major simplification thanks to relaxed specifications compared to the access network context.

- Multipoint to multipoint (NxN) derives from Local Access Networks (LAN). As an NxN passive architecture is an optical bus, simple Medium Access Control (MAC) like CSMA/CD can be reused. The advantage is the implementation simplicity: only one wavelength is required. The drawback is that such protocols have been designed for best effort traffic and QoS still has to be demonstrated for real time traffic in the specific HN context.
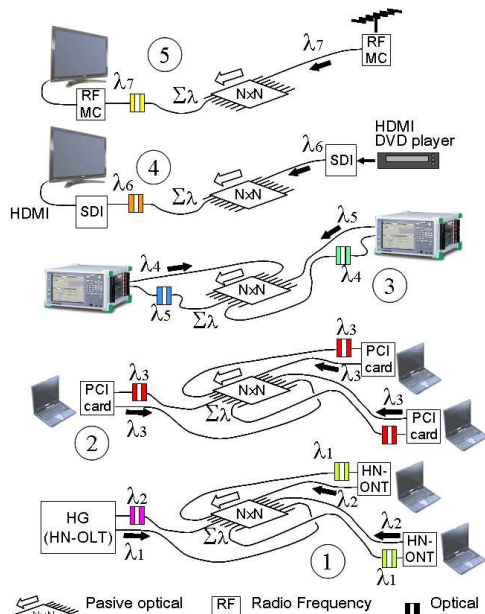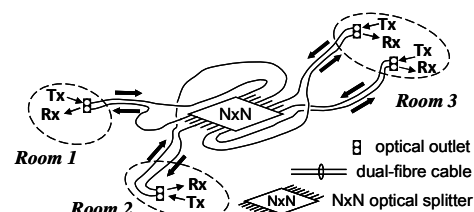

Fig. 1: NxN passive architecture

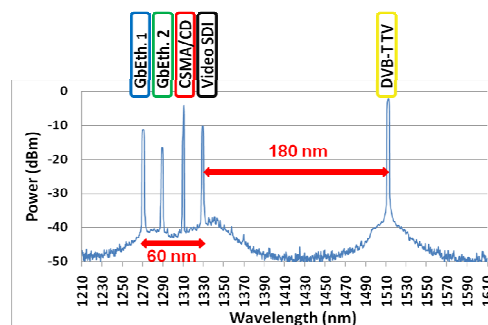**Fig. 2: Experimental network implementation**

Fig. 3: Implemented wavelength comb

4. Network realization on MMF

Five applications have been implemented on a graded index 50/125 µm MMF architecture centered on an 8x8 splitter (figure 2):

- PON application (1xN): Available PON equipment exists only for SMF technology, thus we used OEO (Optical-Electrical-Optical) transponders with especially designed Small Form-Factor Pluggable modules (SFP) for MMF and compatible with burst mode transmission. Downstream transmission was achieved with a VCSEL at $\lambda_1 = 850$ nm, while upstream transmission used a Fabry-Perot Laser Diode (FP-LD) at $\lambda_2 = 1300$ nm (fig. 2, ①).
- LAN application (NxN): Three personal computers (PC) were interconnected, using specific 100 Mbit/s optical Ethernet cards working at $\lambda_3 = 1310$ nm and implementing a CSMA/CD protocol (fig. 2, ②).
- P2P Gigabit Ethernet (GbE): A GbE bidirectional P2P link was achieved using two wavelengths $\lambda_4 = 1270$ nm and $\lambda_5 = 1290$ nm (fig. 2, ③) to demonstrate the possibility for high bit rate connections between two devices, for example for remote data storage.
- P2P HD video link: A SDI signal (Serial Digital Interface) at 1.4 Gbit/s has been conveyed between a Blu-Ray disc player and a TV set after being converted to an optical signal at $\lambda_6 = 1330$ nm (fig. 2, ④).
- P2Mpt broadcast TV: RF signal carrying Terrestrial Digital TV, coming from a roof antenna, modulated a laser at $\lambda_7 = 1510$ nm and was broadcasted through the NxN HN (fig. 2, ⑤).

For each application, Optical Add & Drop Multiplexers (OADM) designed for MMF were used to select the dedicated wavelengths. The four latter applications (LAN, P2P GbE, P2P SDI and broadcasted RF TV) have been run simultaneously, as shown by the observed optical spectrum in figure 3. The PON application has been tested but could not run at the same time, because of a mismatch in the upstream wavelength (1300 nm), not compatible with the CWDM grid, and for which no filter was available at this moment. Table 1 provides elements of the optical budget for the different applications, measured on the experimental setup. The margin has then been computed,

taking account of the insertion losses of connectors and OADMs inserted in each link. Fiber attenuation has not been included, being negligible for the short link lengths (a few tens meters) in the HN.

Tab. 1: Optical budgets of all the applications

Signal	λ (nm)	Optical budget (dB)	Insertion Losses (dB)			Margin (dB)
			Connectors	OADM	8x8 coupler	
PON	850	15	1.2	-	8.8 to 10.6	3.2 to 5
	1300	15	1.2	-	8.2 to 10.6	3.2 to 5.6
GbE	1270	30	2.4	1.4	1.5 to 18.9	7.3 to 24.7
	1290	30	2.4	1.4	2.9 to 20.4	5.8 to 23.3
CSMA/CD	1310	24	2.4	1.5	4.5 to 15.7	4.4 to 15.6
SDI	1330	21	2.4	1.4	5.9 to 13.3	3.9 to 11.3
DVB-T	1510	16	2.4	1.4	2.6 to 15.7	**-3.5** to 9.6

5. Issues related to multimode technology

The main difficulty we had to face was the lack of CWDM sources for MMF. Typically, VCSELs and FP-LDs (possibly LEDs) are used as sources for MMF at 850 nm and 1310 nm. Such sources were available only for the PON application in the especially designed SFP modules. So, for the other applications, we had to use DFB sources dedicated to SMF technology and thus to work under Restricted Mode Launch (RML) conditions. That strongly impacted the uniformity of the optical power at the outputs of the multimode splitter [3]. Insertion losses of the 8x8 splitter for all input/output combinations are reported in figure 4(a) for a multimode source, a VCSEL at 850 nm, and in figure 4(b) for a singlemode source, a DFB laser at 1270 nm. With the VCSEL, the measured insertion losses of the 8x8 splitter ranged from 8.8 to 10.6 dB. This good uniformity was confirmed with the second multimode source, a FP-LD at 1300 nm, with insertion losses within 8.2 and 10.6 dB. Conversely, with the DFB laser, insertion losses ranged from 3.2 to 18.7 dB. This high deviation shows the non-uniformity of the splitter when working under RML conditions, which may impact performances of some applications by strongly reducing the optical budget.
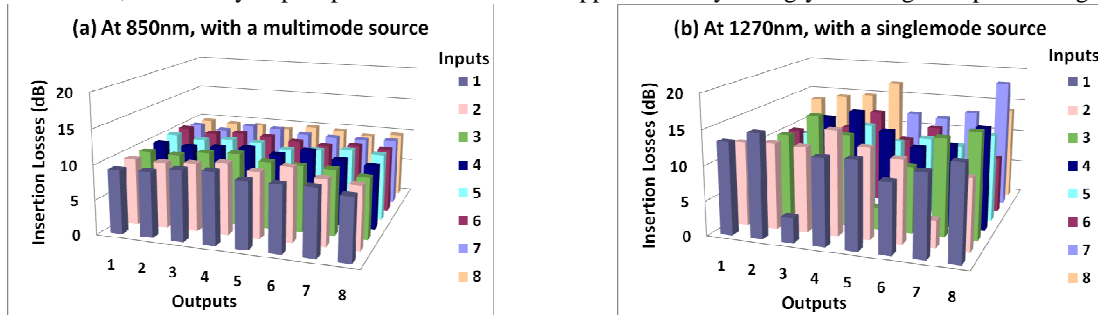

Fig. 4: Insertion losses of the 8 x 8 splitter

Thanks to the large optical budget available for most applications, the degradation of the splitter uniformity does not disturb the delivering of the service. Only the RF TV broadcasting may be strongly affected for some combinations of input/output ports of the splitter.

6. Conclusions

The possibility to convey different types of signals and to merge various services on a unique infrastructure is a major challenge for future home networks. We have demonstrated a solution associating passive NxN multimode fiber infrastructure and CWDM technology. MMF was preferred as it is a lower cost technology, in terms of systems and connectorization, compared to SMF. Main issues derive from the lack of appropriate CWDM components fitted to the transmission windows of the MMF. This problem should be solved in the future by extending the CWDM grid towards 850 nm and by an enhanced commercial offer for such CWDM components for MMF, particularly VCSELs and OADMs.

7. References

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