Ultra-wideband radio-over-fiber techniques and networks

Benoît Charbonnier[1], Frédéric Lecoche[1], Mario Weiß[2], Andreas Stöhr[2], F. van Dijk[3], A. Enard[3], F. Blache[3], M. Goix[3], F. Mallecot[3], D.G. Moodie[4], A. Borghesani[4], C.W.Ford[4]

[1]France Télécom Research and Development, Lannion, France [2]Universität Duisburg-Essen, Optoelektronik, Duisburg, Germany
[3]Alcatel-Thales III-V Lab, a joint lab of Bell Labs and Thales Research & Technology, Palaiseau, France
[4]CIP Technologies, Ipswich Suffolk, UK
benoit.charbonnier@orange-ftgroup.com

Abstract: This paper summarizes the motivations and results obtained regarding the optical distribution of a 60GHz radio signal throughout buildings to provide users with Ultra-Broad-Band Wireless Home Area Network with datarates >1Gbps and continuous coverage.

OCIS Codes: (060.0060) Fiber optics and optical communications, (060.5625) Radio frequency photonics

1. Introduction and motivations

Ultra-Wide Band (UWB) over fiber has attracted a lot of interest, leading to numerous publications and technical demonstrations of the feasibility of remoting UWB over optical fiber at high data rate, high carrier frequencies and over large distances [1-6]. In the communications arena, remoting UWB over fiber allows an UWB device to communicate with another one beyond the very limited reach of the UWB radio signal (less than 20 m). Indeed, UWB has been mainly designed to allow high data rate transmissions over short distances primarily in indoor environments where delay spread is potentially large. Such transmissions used for Wireless Personal Area Networks (WPAN) allow communications between devices in the users reach e.g. computers, personal organizers, camcorders, TV sets, DVD players, printers etc… and have been designed in group such as, for instance, ECMA-368 [7], ECMA-387 [8], IEEE802.15.3c [9] as well as industry consortia such as WirelessHD [10]. This is driven by ideas of in-home communication lifestyle that have been promoted by various groups such as DLNA [11] or HGI [12] which have performed many studies focusing on the requirement in the years to come regarding en-user services. These studies conclude that a data rate of 1 Gbps must be supported in home networks by 2010-2020 (also confirmed in [13]). To accompany this trend, Telecom operators are investing large amounts of money in the deployment of access solutions that are able to provide an ever increasing bandwidth (currently up to symmetric rates of around 100 Mbps via Fibre to the Home FTTH, increasing to 1 Gbps and more in the coming years [14]). However, and this is the key idea of this paper, it is impossible to market an access bandwidth greater than what the home network can handle. Finally, an implementation factor has to be taken into account: end-users are determined to continue using a wireless end-connectivity to preserve the flexibility and ease of use provided today by WiFi. UWB radios certainly can achieve the high data rate goal set-out in this study, especially the ones operating in mm-wave RF bands and in particular the 60 GHz band where no coexistence problems with WLAN and other radio mobile systems exist. But, such systems create typically small high speed radio cells (WPANs) limited to a single room. Associating several WPAN cells together will indeed create the required Ultra Broad-Band Wireless Home Area Network (UBB-WHAN). To link the different radio access points together, some kind of backbone network must be deployed (Figure 1). Such backbone must be able to transport large amounts of data (several Gbps) over only short distances (typically 50 m with a maximum of around 100 m [15]). The cable must comply over a long period of time (10s of years) to a datarate evolution (several Gbps?) that is difficult to forecast today and as a result, it seems preferable to deploy Silica single mode optical fiber (SMF) as the UBB-WHAN backbone. In this paper we report recent results demonstrating the potential of radio-over-fiber in the Home Network context to successfully transport and distribute a bidirectional 60 GHz radio interface.

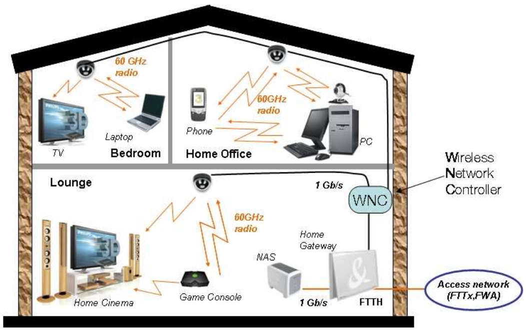

Figure 1: 60GHz UBB-WHAN architecture proposal

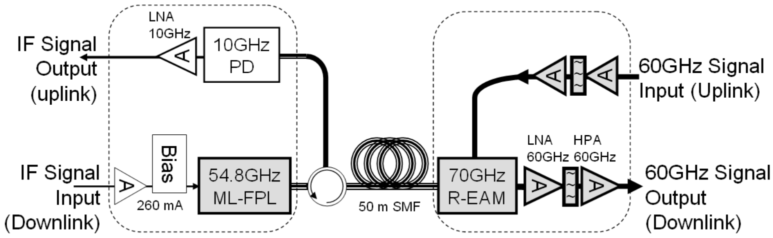

Figure 2: 60GHz bi-directional UBB-WHAN building block. Wireless Network Controller interface (left), remote access point (right)

2. 60GHz Radio-over-Fiber for UBB-WHAN

The building block for the architecture proposed and experimented is represented on Figure 2. We suppose that a radio transceiver is used in the central radio network management element generating and receiving an intermediate frequency (around 5 GHz) radio signal carrying several gigabits per second. The downlink radio signal (from the central element to the user), to be used and distributed in the different rooms of the house, must be converted to an optical signal as well as converted to the 60 GHz frequency window. This is achieved by means of the direct modulation of a 55 GHz self pulsating Fabry Perot Quantum Dot Laser (FPL). This modulation process creates intermixing products between the oscillation frequency of the laser and the intermediate frequency of the radio signal thus transposing it to 60 GHz (55 GHz + 5 GHz). At the remote radio head, a Reflective Electro-Absorption Modulator (REAM) is used as a photo-detector to transfer the signal back into the electrical domain and a series of filters (to remove the lower frequency side band and the 55 GHz carrier) plus amplifiers are used to prepare the signal for transmission into the air. On the uplink path (from the user to the central element), the 60 GHz radio signal is first amplified to modulate the REAM. The pulsed light from the FPL is again re-modulated thus creating intermixing products and transferring the incoming radio signal to around 5 GHz (corresponding to 60 GHz minus 55 GHz). In the central element, a conventional 10 GHz bandwidth photo-detector, transfers the down-converted signal back to the electrical domain for demodulation by the IF radio transceiver. In this set-up the radio signal protocol relies on Time Domain Division (TDD), that is, the frequencies used in the uplink and downlink directions are the same and only one transmission direction is allowed at a time, so that, when the uplink signal modulates the FPL in the REAM, the FPL is un-modulated. This allows the bias of the REAM to be changed in order to optimise its performance when operating as a photo-detector (downlink) or modulator (uplink).

3. Experimental demonstration

Among the different modulations recommended by the IEEE802.15.3c group, we chose to use OFDM as it has more stringent requirements in terms of linearity [16]. The OFDM signal under test is created on a PC using Matlab® with a FFT block size of 512 with 336 data sub carriers. Each sub carrier is modulated in QPSK. The baseband is sampled at 2.59 GHz. A total raw data rate of 3.03 Gbps is achieved for a bandwidth of 1.87 GHz. The signal is generated by a 10 GS/s dual output Arbitrary Waveform Generator (AWG) and both outputs (representing both I and Q components) are sent to a RF mixer to generate the radio signal on a 4.5 GHz carrier. After amplification, the RF power is +12 dBm. For the reference measurement, this signal is sent into a commercial mixer fed with a +16 dBm 54.5 GHz local oscillator to transfer it to a carrier frequency of 59 GHz. After filtering (to remove the lower modulation sideband) a power of +13 dBm is obtained. To measure the performance, the signal is first attenuated to the optimal power level (around -22 dBm) then down-converted using an electrical mixer fed with a 54.5 GHz Local Oscillator (LO) and finally, it is captured over 10 µs using a 40 GS/s Real-time oscilloscope (RTO). OFDM demodulation and Error Vector Magnitude (EVM) [17] evaluation are then performed off-line

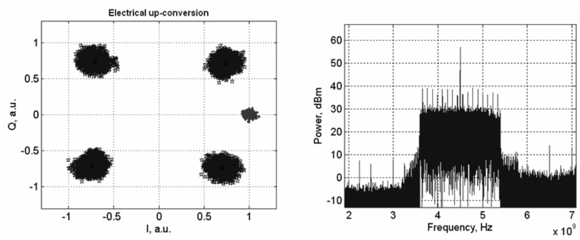

Figure 3: 60GHz all electronic reference performance results. Constellation (left) and spectrum (right).

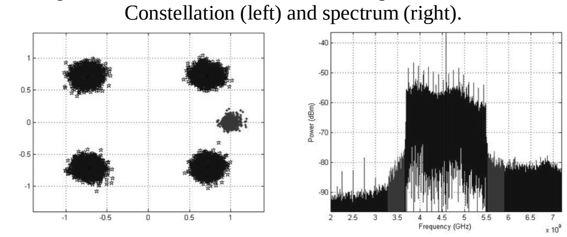

Figure 4: 60GHz downlink performance results. Constellation (left) and spectrum (right).

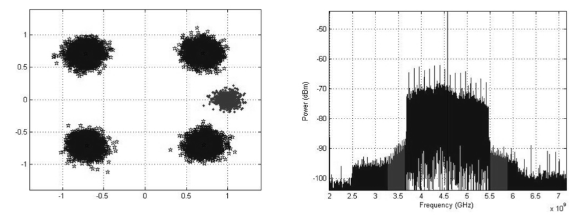

Figure 5: 60GHz uplink performance results. Constellation (left) and spectrum (right).

using Matlab®. The spectrum of the received OFDM signal and the associated constellation diagram obtained after demodulation are shown on Figure 3. The mean EVM is 9 % for a signal-to-noise ratio (SNR) of 25.2 dB. From the EVM, the Bit Error Rate is evaluated to be (theoretically) better than 10^{-21}.

To test the downlink transmission, the IF signal (4.5 GHz) is used to modulate the bias current of the FPL (average bias current set to 260 mA). The optical output power of the FPL is +6.5 dBm. The signal passes through an optical circulator before a 50 m Standard Single Mode Fiber (SMF) transmission. This fiber simulates the distribution of the radio signal within the home. At the end of the fiber, a 70 GHz REAM (Bias reverse voltage set to -4.1 V) converts the 60 GHz signal into an electric signal, subsequently, two Low Noise Amplifiers (LNA, G=18 dBm from 55 to 65 GHz) and a band pass filter (58 to 64 GHz) were used to simulate the TX head. Performance analysis is made as described earlier. The computed EVM is 11.06% for a SNR of 23.5 dB (Figure 4). From the EVM, BER can be estimated around 10^{-19}.

To test the uplink set-up, The IF radio signal (4.5 GHz) is electrically up-converted to 59.8 GHz by a commercial mixer fed by a LO at 54.8 GHz. At this point, the RF power is adapted with a variable attenuator to pass through the two LNAs and the pass band filter. The signal modulates the REAM (-2.8 V bias voltage) with an input power of +11.6 dBm. The power of the laser at the input of REAM is +5.9 dBm. The reflected IF signal is then photo-detected, captured by the RTO and analyzed. The computed EVM is 12.79% and the SNR is 20.37 dB (Figure 5). From the calculated EVM, the BER can be estimated around 10^{-14}.

4. Conclusion

The technical challenges created by the increasing wish to exchange/share multimedia content between friends and family is only partly answered by telecom operators deploying high bandwidth access networks. This effort has also to be extended to enabling Ultra-Broad Band Home Networks with wireless interfaces, allowing users to connect at high data rates (>1Gbps) with the same ease of use as what WiFi currently provides. 60 GHz UWB radio over fiber in this context can achieve the required function and performance. We demonstrate in this paper the frequency conversion and distribution (bidirectional) of a multi-gigabit wireless radio interface (3 Gbps) over 50 m of SMF using a Mode Locked Fabry Perot Laser and a Reflective Electro-Absorption Modulator.

5. Acknowledgements

The authors acknowledge the European Commission for its financial support to this work in the frame of the project IST FP6 035317 IPHOBAC (www.ist-iphobac.org).

6. References

[1] T. Kuri, K. Kitayama, A. Stöhr, and Y. Ogawa, “Fiber-optic millimeter-wave downlink system using 60 GHz-band external modulation,” Lightwave Technology, Journal of, vol. 17, no. 5, pp. 799–806, 1999.

[2] T. Taniguchi, N. Sakurai, K. Kumozaki, and T. Imai, “Loop-back optical heterodyne technique for 1.0-Gb/s data transmission over 60-GHz radio-on-fiber uplink,” IEEE J. Lightwave Technology, vol. 25, no. 6, pp. 1484–1494, 2007.

[3] A. Stöhr, C. Miesner, and D. Jäger, “All-optical radio-independent millimeter-wave radio-on-fiber system with lean antenna base stations,” in Microwave Photonics, 2002. International Topical Meeting on Microwave Photonics, pp. 213–216, 2002.

[4] C. Lim, A. Nirmalathas, and D. Novak, “Techniques for multichannel data transmission using a multisection laser in millimeter-wave fiber-radio systems,” IEEE Trans. Microwave Theory Tech., vol. 47, no. 7, pp. 1351–1357, 1999.

[5] A. Hirata, T. Kosugi, H. Takahashi, R. Yamaguchi, F: Nakajima, T. Furuta, H. Ito, H. Sugahara, Y. Sato, T. Nagatsuma, “120-GHz-band millimeter-wave photonic wireless link for 10-Gb/s data transmission,” IEEE Trans. Microw. Theory Tech., vol. 54, no. 5, pp. 1937-1944, 2006.

[6] Po-Tsung Shih, Chun-Ting Lin, Han-Sheng Huang, Wen-Jr Jiang, Jyehong Chen, Anthony Ng’oma, Michael Sauer, Sien Chi, "13.75-Gb/s OFDM Signal Generation for 60-GHz RoF System within 7-GHz License-Free Band via Frequency Sextupling", ECOC2009, paper 4.5.4, Vienna, Austria, 20-24 September 2009.

[7] Standard ECMA-368, "High Rate Ultra Wideband PHY and MAC Standard", 3rd edition (December 2008), http://www.ecma-international.org/publications/files/ECMA-ST/ECMA-368.pdf

[8] Standard ECMA-387 (1 nd Ed.), "High Rate 60 GHz PHY, MAC and HDMI PAL", December 2008 http://www.ecma-international.org/publications/files/ECMA-ST/ECMA-387.pdf

[9] “Ieee 802.15 wpan millimeter wave alternative phy task group 3c (tg3c).” http://www.ieee802.org/15/pub/TG3c.html.

[10] WirelessHD Specification Version 1.0 Overview October 9, 2007 http://www.wirelesshd.org/

[11] Digital Living Network Alliance http://www.dlna.org/home

[12] Home Gateway Initiative http://www.homegatewayinitiative.org/

[13] B. Charbonnier, H. Wessing, B. Lannoo, M.Popov, "Future Home Network Requirements", European Workshop on photonic solutions for wireless, access and in-house networks, Duisburg, Germany, May 18-20 2009.

[14] GPON 2.4 G http://www.itu.int/newsarchive/press_releases/2003/04.html

[15] K. Oguchi, T. Okodo, K. Tojo and K. Okada, "Physical network configuration of next generation home network", OFC2006, Paper JThB95, March, p. 5.

[16] A. Bourdoux, J. Nsenga, W.V. Thillo, P. Wambacq, L. Van der Perre, "Gigabits/s radios @ 60 GHz: to OFDM or not to OFDM?", Spread Spectrum Techniques and Applications, 2008. ISSSTA '08, 25-28 Aug. 2008 Page(s):560 - 565

[17] V.J.Urick et al, " Wide-Band QAM-Over-Fibre Using Phase Modulation and Interferometric Demodulation", IEEE PTL Vol. 16, N° 10, 2004