Gigabit/s Wireless over Fibre Systems for Future Access Networks

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Abstract: We aim to assess the feasibility of wireless over fibre systems that can operate at millimetre-wave frequencies for delivering gigabit/s wireless data to portable or fixed customer units. We have demonstrated the error-free transmission of 1 Gbit/s D-BPSK signals over 2.2 km of single-mode fibre and over 2 metres of RF cable in the 40 GHz band.

1. Introduction

In order to support the ever-growing demand for broadband connectivity, the next generation of wireless communication networks envisage operation at millimetre-wave frequencies (>30GHz) where larger allocable bandwidth is available for gigabit/s transmissions.[1] Frequencies in the 40 GHz region have already been allocated for Multipoint Video Distribution Services (MVDS) and in the 60 GHz band for Mobile Broadband Systems (MBS). Gigabit Ethernet point-to-point links operating in the 60, 70, 80 GHz bands are being commercially deployed (BridgeWave, LOEA, TeraBeam, GigaBeam).

Wireless-over-fibre is a key technology for providing a future-proof solution to deliver high data rates while extending the coverage of wireless networks. The transparency of analogue optical links to the modulation formats of various wireless signals allows for the simultaneous distribution of multiple services. The high bandwidth and low attenuation of optical fibres can be used to deliver multi-gigabit/s services over long distances. Furthermore, signals conveyed through optical fibres are not prone to radio frequency interference and benefit from enhanced security. As opposed to purely wireless solutions, radio over fibre systems do not require extra spectrum for backhaul.

Wireless-over-fibre systems have become a commercial reality at microwave frequencies. Directly modulated laser sources with direct photo-detection have already been successfully used for transporting GSM and/or 802.11 WLAN signals for commercial applications in public spaces such as airports, shopping malls, tunnels, stadiums (Andrew, Fiber-Span, ZinWave).

This work specifically targets the feasibility of millimetre-wave over fibre systems for delivering 1 Gbit/s wireless data to mobile, portable or fixed customer units in an indoor or urban environment. This provides an approach to Gbit/s access in deployments where mobility is a requirement or the cost of Fiber To The Home (FTTH) is not justified.

2. Millimetre-wave Wireless Sub-system

2.1 Wireless coverage

In order to estimate the coverage at millimetre-wave frequencies under direct Line of Sight (LOS) conditions, the free-space propagation model is used. The maximum propagation distance (d) for meeting the SNR requirements for different modulation schemes at a fixed data rate of 1 Gbit/s is obtained from the following formula : $d = 10^{\alpha/20}$, where

$$\alpha = P_{Tx} - 30 + G_{Tx} + G_{Rx} - 20 \times Log\left(\frac{4\pi . f}{c}\right) - 10 \times Log\left(k_B W T\right) - SNR - NF - Fm - A \qquad \textit{Eq. 1}$$

Parameters: Transmitter Power (P_{Tx}= 26 dBm), Transmitter/Receiver Antenna Gain (G_{Tx}= G_{Rx}= 14 dBi), carrier frequency (f= 35 GHz), speed of light in vacuum (c), Boltzmann's constant (k_B), Temperature (T= 295 K), Receiver Bandwidth (W), Receiver Noise Figure (NF = 5 dB), Fade margin (20 dB), Additional loss (A = 0 dB)

Modulation Scheme	Required SNR (dB) [2]	Bandwidth Efficiency (Mbits/s/MHz) [3]	Bandwidth (MHz) (for 1Gbits/s)	Range or cell radius d (m)
64-QAM	22	4.8	208.33	**52**
16-QAM	16	3.2	312.50	**85**
QPSK	9	1.6	625.00	**135**
BPSK	6	0.8	1250.00	**134**

Table 1. Maximum propagation distances at 35 GHz for different modulation schemes for 1 Gbit/s data rate

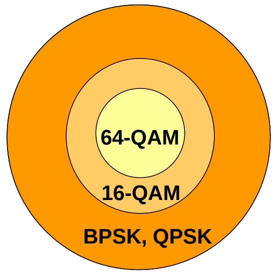

Figure 1. Wireless coverage cell radii and modulation schemes

As illustrated in *Figure 1,* wireless coverage reduces with the use of more complex modulation schemes. Results from *Table 1* suggest the feasibility of gigabit/s wireless access networks at 35 GHz with a maximum cell radius of ~134 meters using simple BPSK modulation scheme. These ranges were calculated from *Eq. 1* using maximum allowed Effective Isotropic Radiated Power (EIRP) in compliance with RF safety standards [4]. A fade margin of 20 dB was used to account for multi-path effects in an urban environment with no additional loss. However, for a more refined analysis, additional losses due to atmospheric gases (H_2O, O_2), rain, foliage or any obstruction, scattering and diffraction under Non Line of Sight (NLOS) condition should be taken into account.

However, this reduction in propagation distances has the advantage of allowing for well-defined coverage cells, an excellent frequency reusability factor for efficient spectrum utilisation, and reduced interference amongst adjacent channels. As a result, the greatly increased number of base stations required to serve a given geographical area requires the base stations to be simple, with a low cost interface to the fixed network.

2.2 Wireless Protocols and propagation delays

When transmitting wireless signals (UMTS, GMS, IEEE 802.11, IEEE 802.16) over fibre, wireless protocols will generally impose a limitation on the maximum fibre span that can be deployed between the Central Office (CO) and Base Stations (BS). Additional propagation delay introduced by the fibre link needs to be taken into account since it may actually outrun the timing boundaries specified in such protocols. For instance, it is estimated that IEEE 802.11 limits the optical path to less than 800 m [5], while IEEE 802.16 can induce a maximum of 9% capacity reduction with a 4500-m optical link [6].

2. System description

Figure 2 illustrates suitable system architectures for gigabit/s wireless over fibre systems, based on cost and technological considerations. Wireless signals are transmitted over an optical carrier from a CO to various remote nodes (RN) and/or to BSs. For indoor applications, the star topology is preferred, whereas a star-tree or star-bus topology is preferable to extend the range for outdoor applications, as compared with a ring architecture. A number of advantages have been reported for the Star / Star-Tree over the Ring topologies, including a wider coverage area [7] for a given number of CO, a larger capacity [8] and higher quality of service.

Therefore, we propose to implement a star/star-tree optical network for distributing wireless signals at Intermediate Frequency (IF) over bi-directional single-mode fibre links. In addition to overcoming chromatic dispersion limitations, the transportation of signals at IF enables low-cost directly modulated Distributed FeedBack (DFB) lasers, as well as modest bandwidth photo-detectors to be used. However, a low phase noise reference millimetre-wave local oscillator (LO) is required at each BS for frequency up/down conversion. This LO signal can be optically distributed from the CO to each BS to provide exact frequency synchronisation amongst all base stations, where electrical up/down-conversion is carried out at the interface with the wireless sub-system. The use of uncooled directly modulated lasers with Coarse Wavelength Division Multiplexing (CWDM) components in combination with the remote delivery of the LO signal allows substantial reduction in overall systems complexity and cost, as will be necessary for the widespread adoption of millimetre-wave wireless access systems.

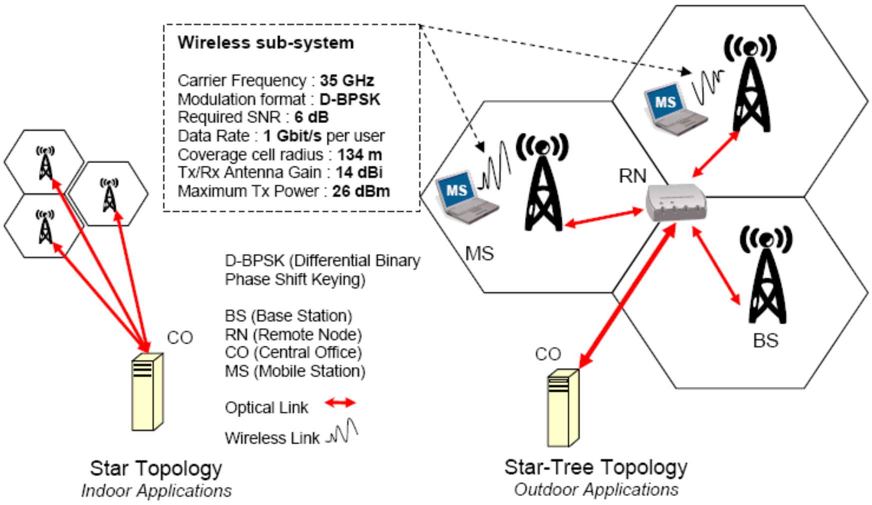

Figure 2. Star/Star-Tree wireless over fibre system architectures for indoor/outdoor applications

4. Experimental work and preliminary results

A full-duplex D-BPSK (Differential Binary Phase Shift Keying) demonstrator for gigabit/s transmission in the 40 GHz band is currently being implemented as shown in *Figure 3*. The D-BPSK modulator consists of a high-speed differential encoder followed by a mixer. At the receiver side, a conventional D-BPSK demodulator was implemented with a 50:50 splitter, a double balanced mixer and a one-bit delay line.

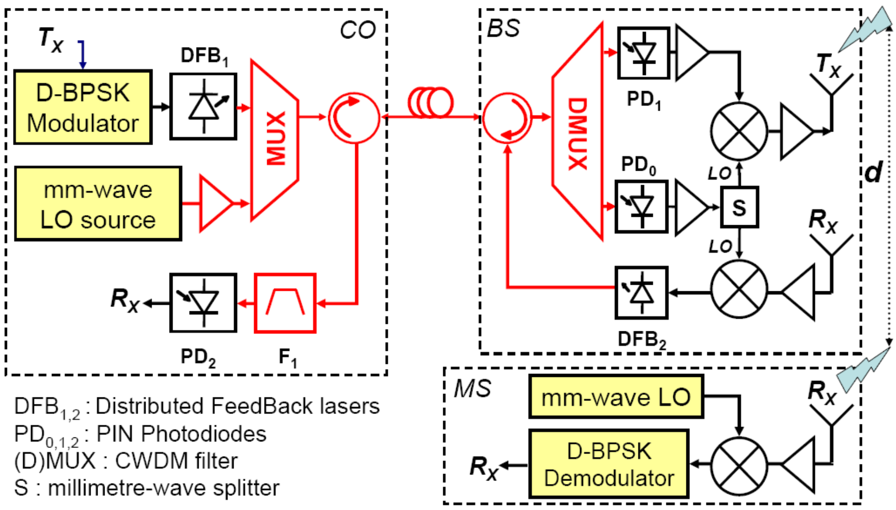

Figure 3. Full-duplex Gbit/s D-BPSK wireless-over-fibre experimental demonstrator.

Preliminary results on the downlink include error-free transmission of 1 Gbit/s D-BPSK signals on a 5 GHz carrier, over 2.2 km of single-mode fibre at 1570 nm, followed by frequency up/down conversion for wireless transmission in the 40 GHz band. Due to licence-related issues and on practical grounds, the 35 GHz up-converted signal was transmitted from the BS to the MS through a 2-m RF cable before being down-converted to IF (5 GHz) and demodulated by the D-BPSK demodulator. For frequency up and down conversion at the BS and at the MS (respectively), two separate 40 GHz electrical sources were used. As illustrated in *Figure 4*, the demodulated eye-diagram shows good opening in accordance with the measured BER ($<10^{-7}$ – measurement limited).

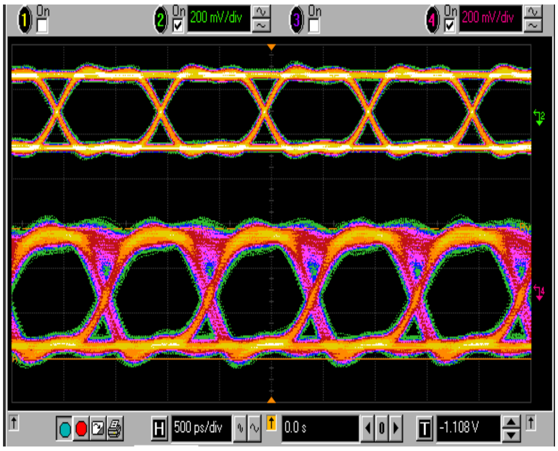

Figure 4. Tx input (up) and Rx demodulated (down) eye-diagrams at 1 Gbit/s on the downlink.

In future experimental work, a 40 GHz LO will be generated by a heterodyne technique and optically distributed from the CO to the BS as illustrated in *Figure 3*, in order to provide exact synchronization between all base stations.

5. Conclusions

Successful transmission of 1 Gbit/s D-BPSK signals over 2.2 km of single fibre, with up/down conversion for wireless transmission in the 40 GHz band has been demonstrated with a BER < 10^{-7}. Simple calculations on wireless propagation at 35 GHz predict that gigabit/s radio-over-fibre networks may be deployed with a wireless coverage cell of up to ~135 m in radius, in an urban environment. Merging optical and wireless networks seems to be a suitable solution for solving the last-mile bottleneck and meet the high demand of wireless high speed connectivity.

6. Acknowledgments

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7. References

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