Low Cost Polymer Optical Fibre based Transmission System for Feeding Integrated Broadband Wireless In-House LANs

Anthony Ng'oma, Ton Koonen, Idelfonso Tafur Monroy, Henrie van den Boom, Peter Smulders, Giok-Djan Khoe

COBRA Research Institute, Eindhoven University of Technology,
P.O. Box 513, NL 5600 MB Eindhoven, The Netherlands
(e-mail: a.ngoma@tue.nl)

A bi-directional transmission system using low cost Polymer Optical Fibre (POF) to feed the required large number of radio access points in next-generation integrated broadband wireless in-house LANs is proposed. Results from simulations and experiments show that, by tuning system parameters, a large variety of pure microwave carriers exceeding 60 GHz can be generated at the radio access points. Furthermore, the system supports data rates exceeding 100 Mbps using both linear and constant envelope modulation formats such as PSK and x-QAM. The consolidation of costly microwave signal processing equipment at the headend station leads to simpler remote radio access points resulting in system cost savings.

Introduction

Wireless Local Area Networks (WLANs) are being deployed increasingly in public and private buildings such as shopping malls, office blocks, and residential areas. However, the capacity of present WLAN standards (that is, 11 Mbps, and 24-54 Mbps for the IEEE802.11b and the IEEE802.11a, respectively) is insufficient to support the anticipated proliferation of integrated broadband wireless services (see Figure 1). Therefore, next generation WLANs must provide the needed greater capacity beyond 100 Mbps. However, high capacity WLANs require extensive wired networks for feeding the numerous radio access points necessitated by increased radio propagation losses at the high carrier frequencies (say 60 GHz) needed. The extensive feeder networks, coupled with the large number of radio access points seriously raise installation and maintenance costs of such systems.

An attractive approach in reducing installation and maintenance system costs is to use single mode optical fibre to transport and distribute the microwave signals, because it enables the consolidation of signal processing in one central place leading to significantly simpler remote radio access points [1]. However, single mode fibre is not suitable for use in office and residential environments due to the associated difficulty in handling and high installation costs. An attractive alternative is to use the large-core Polymer Optical Fibre (POF),

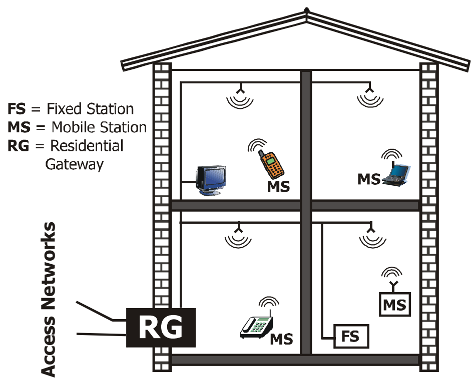


Figure 1: Broadband wireless LANs in residential environments

which is much easier to connect and handle than single-mode silica fibre, but has its bandwidth limited by modal dispersion.

In [2] and [3] we proposed the use of a novel optical frequency multiplication technique to overcome modal bandwidth limitations in POF and generate high frequency microwave signals on the downlink. In this paper we present a bi-directional POF-based system for realising next generation broadband WLANs in office and residential areas.

The POF-based Bi-directional Wireless LAN System

In the bi-directional WLAN system shown in Figure 2, the down-link signal is created in the headend by continuous sweeping of the wavelength of the electronically tunable laser. The frequency of the sweep signal f_{sw} is kept within the limits of the available modal bandwidth of the POF (2 GHz for 500m state-of-the-art GIPOF - [4]) used. The output of the tunable laser is intensity modulated with data to be transmitted, and then multiplexed onto the POF network as shown.

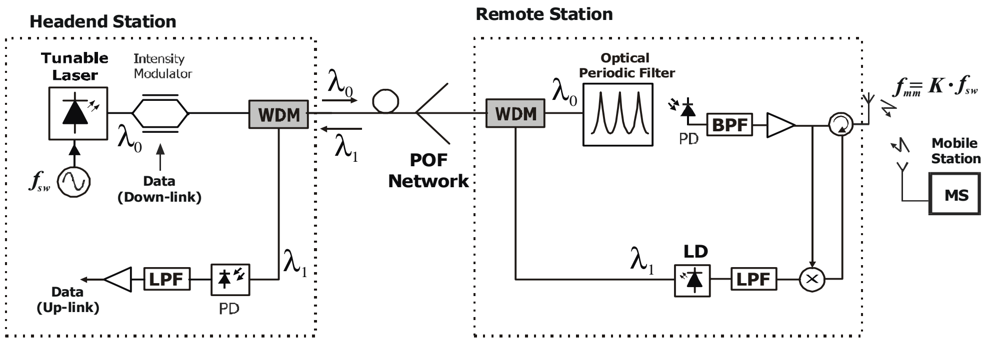


Figure 2: Bi-directional wireless system using POF Fibre

The interaction of the swept optical signal and the periodic filter at the remote station results in the frequency up-conversion $2 \cdot n \cdot \left(\frac{\Delta f_{opt}}{f_{FSR}} \right) \cdot f_{sw}$, where n, Δf_{opt}, and f_{FSR} are harmonic order, the peak-to-peak optical frequency deviation, and the periodic filter's free spectral range, respectively [3]. If a Fabry Perot is used as the periodic filter, then the periodic microwave signal at the photodiode output can be described by

$$i_0 \cdot m(t) \cos(2\pi f_{SC} t) \cdot \frac{1-R}{1+R} \cdot \left\{ 1 + 2 \sum_{n=1}^{\infty} R^n \cos(4\pi n N f_{sw}) \right\}$$

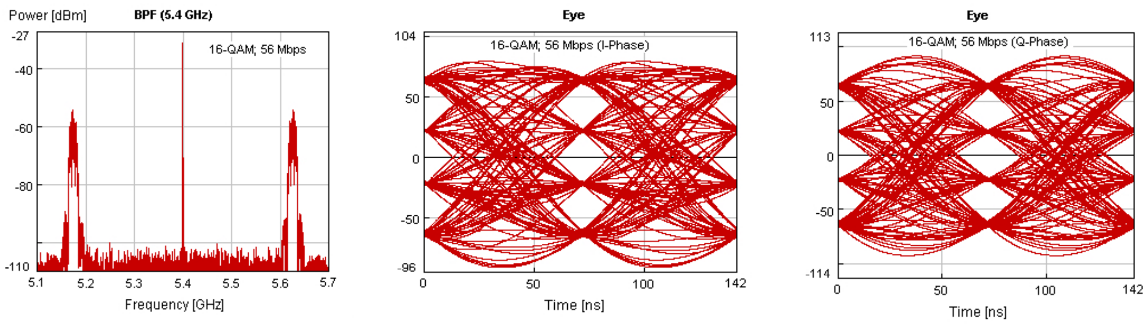
where $m(t)$, f_{SC}, and R are the modulating data signal, the subcarrier signal frequency if any, and the mirror reflectivity of the Fabry Perot interferometer, respectively.

The up-link can be realised by first down converting the signal received from the Mobile Station and then using the down-converted signal to modulate a light source operating at a separate wavelength from the down-link wavelength. In this way a single POF fibre can be used to carry both down- and up-link signals by using WDM, for instance. Using the microwave signals generated in the remote station (during silent downstream periods) for down-conversion eliminates the need for a separate microwave oscillator resulting in further simplification of the remote station.

Supported Data Modulation Formats

To determine the capability of the system in generating carriers with different data modulation formats, the system's downlink was simulated in Virtual Photonics Inc. (VPI) software. A 10 mW, 1310 nm CW laser and an optical Phase Modulator were used in place of the tunable laser because tuning speeds of commercially available tunable lasers are still limited. An integral of a triangular RF signal at $f_{sw} = 900\,\text{MHz}$ was used to drive the optical Phase Modulator through a peak-to-peak linear optical frequency deviation $\Delta f_{opt} = 28.8\,\text{GHz}$. No fibre was used in the simulations due to the non-availability of a multimode fibre model. The Fabry Perot interferometer set to a free spectral range $\Delta f_{FSR} = 9.6\,\text{GHz}$ was used as a periodic filter, which can be realised easily. This combination gives an up-conversion factor $K = 6n$, for the nth microwave harmonic. The observed RF spectrum at the output of the photodiode confirmed the presence of harmonic components at $5.4\,\text{GHz}$, $10.8\,\text{GHz}$, and so on and so forth.

To generate carriers with On-Off keyed (OOK) data modulation, baseband data is applied directly to the intensity modulator (Mach Zehnder Modulator – MZM). Up to 450 Mbps of NRZ data could be transported over the downlink. To generate Binary Phase Shift-Keyed (BPSK) carriers, data was first used to modulate a sub-carrier $f_{SC} = 225\,\text{MHz}$, which was in turn applied to the MZM. Up to 28 Mbps BPSK data rates could be transported. To transport x-QAM complex modulation formats, the same sub-carrier $f_{SC} = 225\,\text{MHz}$ was used. More than 56 Mbps data in both 16-QAM and 32-QAM were transmitted error free as shown in Figure 3. The up-link channel can support more than 1 Gbps bitrates [5].



(a) (b) (c)

Figure 3: Distributing 56 Mbps 16-QAM modulated carriers over the POF-based wireless LAN system: (a) RF spectrum at the BPF output centred around 5.4 GHz, (b) Eye pattern of recovered I-symbols, and (c) Eye pattern of recovered Q-symbols.

Measured Carrier Linewidth

The electrical linewidth of the carriers generated by the optical frequency multiplication technique has been found to be very small. In simulations, the 3dB electrical linewidth was found to be lower than 60 kHz and was limited by the frequency resolution provided by the simulation software and hardware. To determine precisely the 3dB linewidth of the generated carriers, an experiment was performed.

A 1310nm CW DFB laser operating at 10 mW had its output modulated by an optical Phase Modulator driven with a sine source at 2 GHz. The resulting signal was fed directly into a fibre-based Mach-Zehnder Interferometer. The output of the interferometer was detected and displayed on an RF spectrum analyser. Several harmonic components beyond 20GHz were observed. The -3 dB linewidth of the generated carriers was measured and found to be less than 20 Hz while at –20 dB the linewidth is less than 40 Hz as shown in Figure 4. This result implies that the laser's phase noise has no significant impact on the electrical linewidth of the carriers generated by the employed up-conversion technique. This is because the coherence time of the laser's phase noise is much longer than the time it takes to traverse adjacent slopes of the periodic filter's pass-band. As a result the generated FM-IM phase noise on the rising and falling edges of the filter's pass-band cancel each other out.

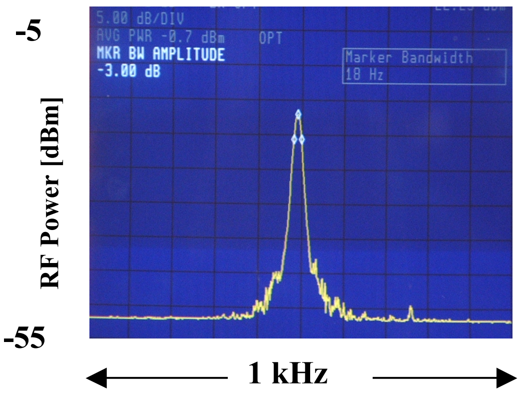


Figure 4: A 16 GHz carrier generated by optical frequency multiplication (3dB linewidth = 18 Hz)

Conclusions

A POF-based bi-directional wireless LAN system has been presented. The system employs optical frequency multiplication on the downlink to overcome modal bandwidth limitations in POF fibre. Experimental results show that high frequency carriers beyond POF's modal bandwidth can be generated and that their electrical carriers can have narrow linewidths (for instance 18 Hz at 16 GHz). This enables the WLAN system to carry signals with complex data modulation formats such as 16 and 32-QAM. The presented system is potentially well suited for cost-effective distribution of microwave signals via GIPOF networks, which are attractive for business and residential network environments, and can be integrated efficiently in a single network with wired applications such as Gigabit Ethernet LAN.

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