In-house networks using multimode polymer optical fiber for broadband wireless services

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In-House Networks Using Multimode Polymer Optical Fiber for Broadband Wireless Services

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Abstract. A novel system concept is presented to transport microwave signals over an in-house multimode graded-index polymer optical fiber network, in order to feed the radio access points in high-capacity wireless LANs. By employing optical frequency multiplying, the network's intrinsically limited bandwidth is overcome. The feasibility of this concept to carry data at several hundreds of Mbit/s speed for various microwave signal formats at carrier frequencies in the tens of GHz range is shown. The concept enables cost-effective system implementation, and easy upgrading by offering data signal transparency. It can readily be integrated with other system technologies such as wired Gigabit Ethernet in a single multi-service in-house polymer optical fiber network.

Keywords: in-house networks, polymer optical fiber, optical frequency multiplying, broadband wireless services

1 Introduction

Silica single-mode optical fiber has already established an undisputable position in core telecommunication networks and in metropolitan area networks, reaching Tbit/s throughputs. As a next step, it is intruding the capillaries of the network, the access lines. When moving towards the end user, however, and penetrating his residential area, the costs of installing and maintaining the fiber network become ever more important. Clear advantages are offered by deploying polymer optical fiber (POF): its large core diameter considerably eases coupling and splicing, and its ductility and flexibility simplifies installation in often less accessible customer locations.

However, although considerable improvements have been made recently, the attenuation of POF is still orders of magnitude higher than that of silica single-mode fiber. As it guides a huge number of modes, the dispersion of POF is also much larger. State-of-the-art perfluorinated graded-index POF (GIPOF) has losses below 20 dB/km at 1300 nm (and < 30 dB/km at 800 nm), and bandwidth length products of around 1 GHz·km. Therefore, POF systems still have limited bandwidth and reach. For short links such as in in-house networks, however, high transport capacities have been achieved. Single-wavelength systems have reached 11 Gbit/s over 100 m of GIPOF [1], and recently, a single-wavelength GIPOF system carrying a Gigabit Ethernet signal (1.25 Gbit/s) over almost 1 km GIPOF has been experimentally demonstrated [2]. Wavelength multiplexing and novel approaches such as mode group diversity multiplexing offer further opportunities to extend the capacity of GIPOF networks for digital data transport [3].

Wireless LANs are taking a rapidly evolving market share of in-house broadband communications, in particular in business and academic environments. In order to provide high bit rates to the users, high carrier frequencies and small radio cells are required. Current wireless LAN products operate in the ISM band (2.4 GHz), and offer transport capacities of 11 Mbit/s per carrier frequency, following the IEEE 802.11b standard. IEEE 802.11a systems can carry up to 54 Mbit/s per carrier in the 5.2 GHz band [4]. Systems offering more than 100 Mbit/s will require carrier frequencies beyond 10 GHz; 60 GHz systems are under investigation [5].

When the data rates and the carrier frequencies increase, the radio cells that can be served become smaller. Thus the number of antennas needed to cover for instance an office building grows, requiring a more extensive wired network to feed the antennas of the radio access points (RAPs). Furthermore, it becomes advantageous to carry the microwave signals directly over this network; this enables to consolidate the signal processing functions (for e.g., handover and macro-diversity) at the headend station and thus considerably simplifies the antenna sites.

GIPOF is a very attractive medium to be used in the feeder network, but its limited bandwidth prohibits carrying directly the microwave signals. To overcome this barrier, in this paper a novel approach relying on optical frequency multiplying is proposed, where fast tunable laser sources are used at the headend in combination with a periodic filter at the antenna site. Thus, by providing transparency for the microwave signals in combination with installation easiness, GIPOF is a very attractive medium for in-house cabling between wireless LAN access points and its headend station.

2 System Concept

The proposed novel system concept is shown in Fig. 1.

At the transmitting end, the wavelength λ_0 of the light emitted by a fast tunable laser diode is swept periodically at a high frequency rate f_{sw} over a limited wavelength range, while keeping the light power constant. Alternatively, the laser diode may operate at a fixed wavelength, and the wavelength is periodically swept by means of an external phase modulator driven by a signal with frequency f_{sw} (see Fig. 8). The data signal is intensity-modulated on this optical-frequency-swept signal by means of a low-chirp external modulator (such as a symmetrically driven Mach Zehnder Interferometer).

Via a power-split network, the signal is distributed among various RAPs. In a RAP, an optical periodic bandpass filter (e.g., a Fabry-Perot etalon) is used in front of an optical receiver. The transmission peaks of this filter are spaced by its free spectral range (FSR). When the wavelength λ_0 is swept over N peaks, the intensity of the signal impinging on the photodiode fluctuates with a frequency $2N \cdot f_{sw}$. This signal is detected, and after amplification and bandpass filtering (to reduce harmonics and noise) it is fed to the antenna. The intensity-modulated data signal, being the envelope of the optical frequency swept signal, is also detected by the photodiode, but not up-converted in frequency. Thus the antenna at the RAP emits a radio wave at the microwave frequency $f_{mm} = 2N \cdot f_{sw}$, carrying transparently the data signal impressed at the headend station. Thus high-frequency microwave signals can be obtained by remotely generating optical signals at modest optical sweep frequencies.

An upper limit to the optical sweep frequency is put by the dispersion of the GIPOF link. For instance, with a GIPOF having a 1 GHz·km bandwidth-times-length product, sweep frequencies up to 2 GHz for in-house

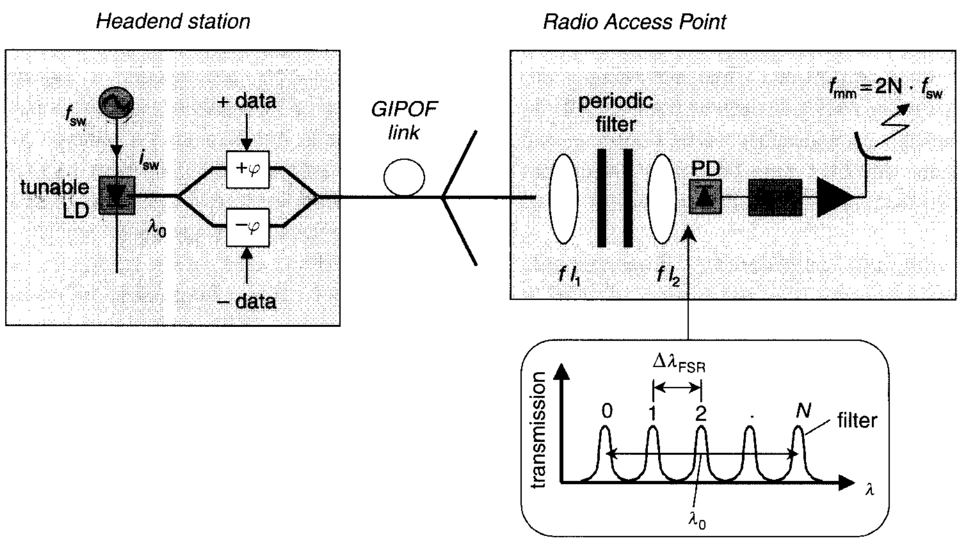

Fig. 1. Transporting microwave signals in a graded-index polymer optical fiber network.

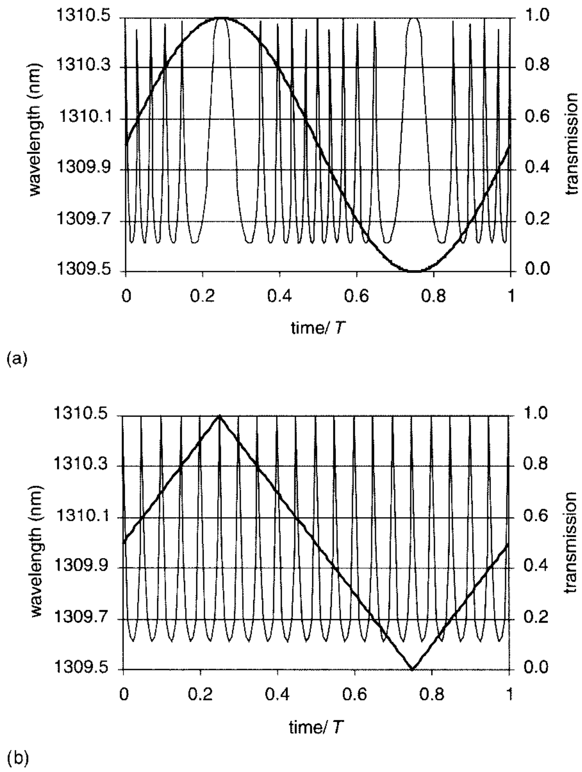

Fig. 2. Generated microwave signals for sinusoidally and triangularly sweeping of the laser wavelength (with sweep frequency $f_{sw} = 1/T$), using a Fabry Perot optical filter at the receiver, for (a) sinusoidal wavelength sweep (b) triangular wavelength sweep.

fiber lengths up to 500 m are obtainable. A similar limit is put to the data transport speed. The microwave carrier frequency which can be realised may surpass the GIPOF link bandwidth by as much as an order of magnitude, by appropriately designing the ratio of the optical frequency sweep range and the spacing of the transmission peaks of the periodic optical bandpass filter.

The shape of the generated microwave signal depends on the shape of the laser wavelength sweep and on the periodic filter characteristic. When using for instance a Fabry-Perot etalon as the periodic filter and a sinusoidal sweep of the laser wavelength, the microwave signal shows strong frequency modulation and therefore many spectral components; see Fig. 2(a). A much better defined microwave signal is obtained for a triangular sweep of the laser wavelength, provided the wavelength sweep range equals an integer number of the filter's FSR. The generated microwave signal then shows a nice regular pattern as given in Fig. 2(b). This periodic microwave signal can be expanded in a Fourier series according to

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

where $F = 4R/(1-R)^2$ and R is the power reflection coefficient of the Fabry Perot plates. The relative powers of the various spectral components are shown in Fig. 3. The power of the fundamental component $2N \cdot f_{sw}$ is maximized when $R = \sqrt{2} - 1 \approx 41\%$, for which the higher-order harmonics are down by more than 7.6 dB. A better suppression of these harmonics while not reducing significantly the power of the fundamental component is obtained for a lower plate reflectivity; e.g., for $R = 20\%$, the fundamental component's power is only 2.2 dB lower, whereas the other harmonics are down by more than 14 dB. Such a lower reflectivity is also advantageous for low-cost design. The harmonics are further reduced by the electrical bandpass filter and the band-limited amplifier following the photodiode. At higher reflectivity R, the power of the n-th-order harmonic increases, and reaches its maximum for $R = (\sqrt{1+n^2} - 1)/n$. By appropriately choosing the central frequency of the electrical bandpass filter, one may also select one of these higher harmonics to become the system's microwave carrier frequency. Again, the intensity-

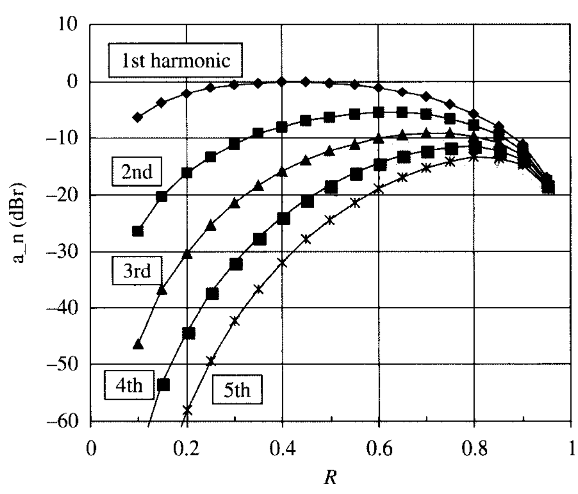

Fig. 3. Relative powers of the harmonic components of the generated microwave signal in case of a triangular source wavelength sweep and a Fabry Perot optical filter with plate reflectivity R.

modulated data signal is not being affected, and is transparently transferred to the microwave carrier.

When the triangular wavelength sweep range does not match an integer number of the filter's FSR, the microwave signal shows a periodicity equal to the sweep interval, which yields relatively weak spectral lines close to the fundamental component and its harmonics. With a sinusoidal wavelength sweep, these spectral sidelines have considerably higher power, and many of them will pass the electrical bandpass filter, yielding a clearly less pure microwave carrier than the one achieved with the well-aligned triangular wavelength sweep.

3 System Simulations

3.1 Transporting a CW Microwave Signal

Preliminary system simulations with the Virtual Photonics Inc. software package have shown the feasibility of the concept. The laser wavelength λ_0 is around 1.3 μm (i.e., in the low-loss window of perfluorinated GIPOF), and the full width at half maximum (FWHM) linewidth is 1 MHz while the laser diode provides 10 mW fiber-coupled power. The laser wavelength is swept over $\Delta f_{opt} = 28.8$ GHz (corresponding to 0.17 nm) at a sweep rate of $f_{sw} = 900$ MHz, by means of an external phase modulator driven over 4π. This sweep rate should not cause fiber dispersion problems for GIPOF link lengths up to 500 m. At the receiver, a Fabry-Perot filter with an FSR of 9.6 GHz (corresponding to a plate spacing of 15.6 mm) and a plate reflectivity of 20% is deployed. Thus a frequency multiplication factor $2N = 2 \cdot \lfloor \Delta f_{opt}/FSR_{FP} \rfloor = 6$ is obtained, which yields a microwave signal with a fundamental frequency of 5.4 GHz. The spectrum of this signal at the photodiode output is shown in Fig. 4. The fundamental frequency component at 5.4 GHz is 14 dB stronger than the second-order harmonic at 10.8 GHz, which agrees with the theoretical curves of Fig. 3; also the power levels of the higher-order harmonics are in agreement with these curves. The spurious spectral lines spaced at 900 MHz are due to Δf_{opt} not being an exact integer multiple of the FSR of the Fabry Perot filter, due to numerical rounding errors. The signal is significantly cleaned up by a Gaussian bandpass filter after the photodiode and centered at 5.4 GHz having a -3 dB bandwidth of 1 GHz; the spectrum of the signal at the filter output is given in Fig. 5. With a laser linewidth of 1 MHz, the spectral width of the CW 5.4 GHz microwave signal is found to be less than 1 kHz.

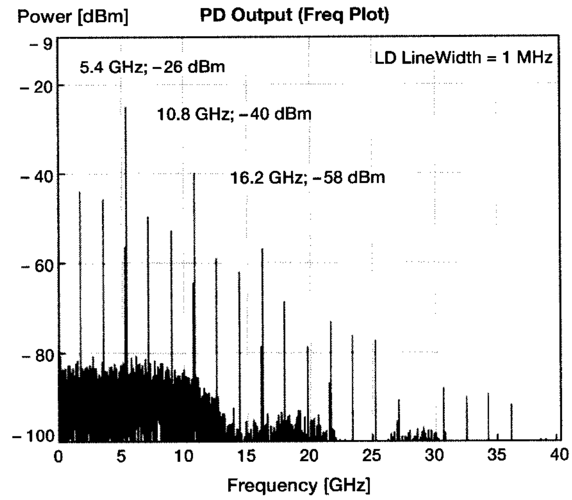

Fig. 4. Spectrum of CW signal at output of photodiode.

3.2 Transporting an ASK Modulated Microwave Signal

Secondly, the system has been simulated with a 225 Mbit/s on/off data pattern; the other system parameters are the same as in the CW case simulated before. A clear 5.4 GHz amplitude shift keying (ASK) modulated microwave signal is generated at the bandpass filter output, as shown in Fig. 6.

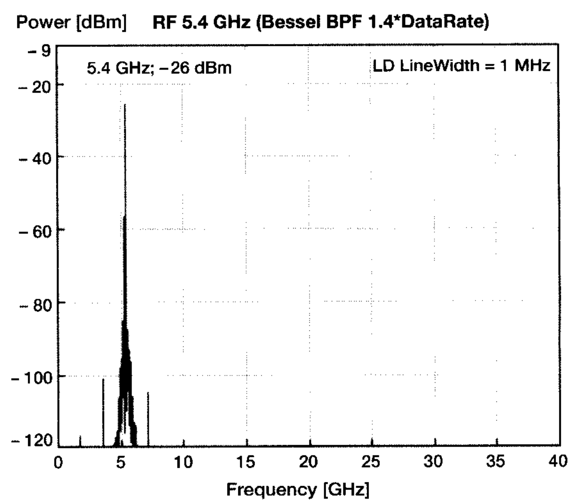

Fig. 5. Spectrum of CW signal at output of bandpass filter centered at 5.4 GHz.

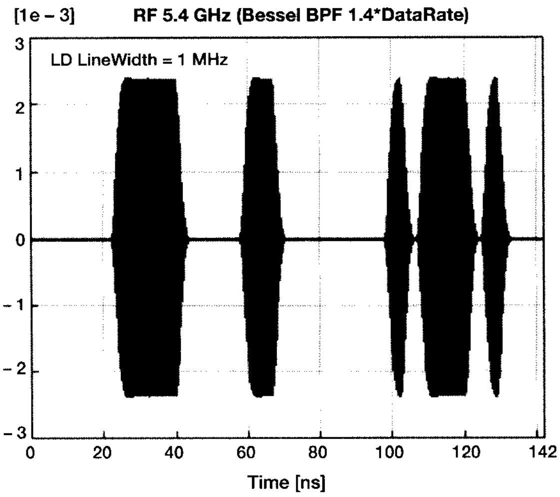

Fig. 6. Microwave signal with 225 Mbit/s ASK data modulation at output of bandpass filter centered at 5.4 GHz.

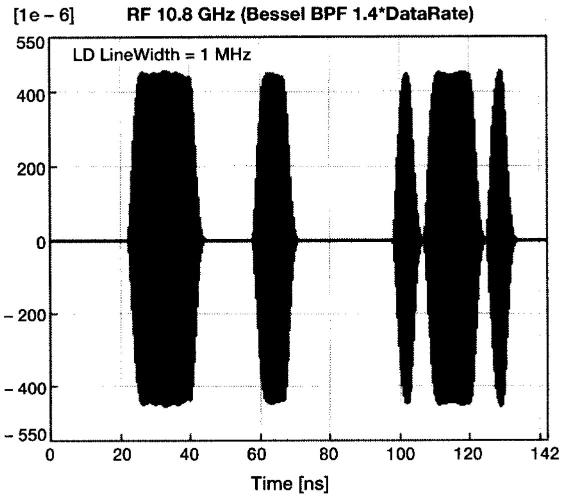

Fig. 7. Microwave signal with 225 Mbit/s ASK data modulation at output of bandpass filter centered at 10.8 GHz.

By only changing the center frequency of the bandpass filter in order to pass the second harmonic of the photodiode output signal, it is also feasible to generate an ASK modulated microwave signal at 10.8 GHz. As displayed in Fig. 7, its power is about 14 dB lower than that of the 5.4 GHz ASK modulated signal, which agrees with the theoretical curves of Fig. 3.

3.3 Transporting a BPSK Modulated Microwave Signal

Wireless LANs mostly use signal formats based on amplitude as well as phase modulation. In OFDM systems as adopted a.o. in specification IEEE 802.11a for transport of up to 54 Mbit/s in the 5.2 GHz region [4], the data may be modulated in BPSK, QPSK, 16-QAM or even 64-QAM format on as much as 52 multiplexed orthogonal subcarriers. As a first assessment of the feasibility for carrying phase-modulated signals, the system has been simulated for a binary phase shift keying (BPSK) signal format. The setup of the system is shown in Fig. 8. A 28.125 Mbit/s data signal is BPSK modulated on a subcarrier of 225 MHz, which drives the Mach Zehnder Interferometer intensity modulator at the headend station. The other parameters are equal to those of the ASK system simulated before. The waveform of the sweep signal

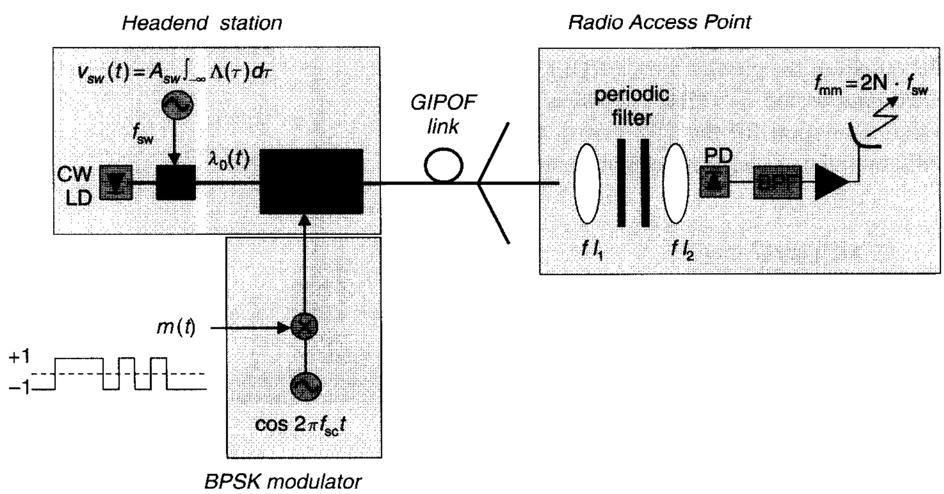

Fig. 8. Transporting BPSK-modulated microwave signals in a GIPOF network.

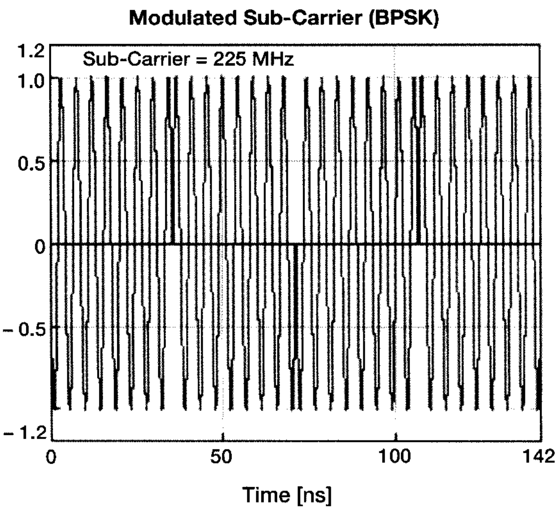

Fig. 9. Data signal at 28.125 Mbit/s BPSK-modulated on a 225 MHz subcarrier.

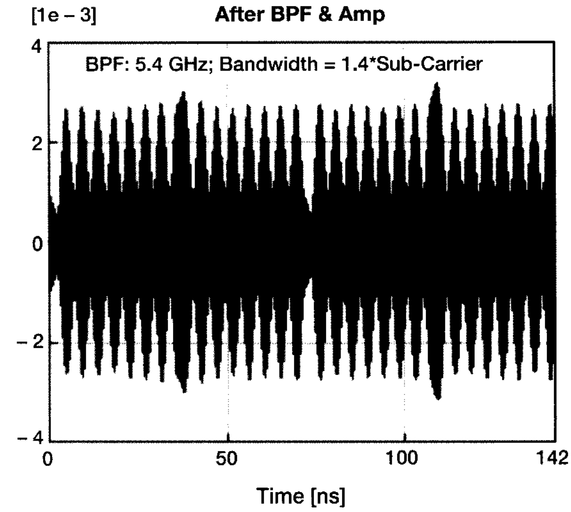

Fig. 10. BPSK modulated data signal on 225 MHz subcarrier, riding on the 5.4 GHz microwave signal.

driving the phase modulator is the integral of a triangular waveform, thus yielding the desired triangular wavelength sweep.

At the headend station, the input data signal assumed is a 28.125 Mbit/s bipolar alternating one/zero pattern. Fig. 9 displays the signal after BPSK modulation on a 225 MHz subcarrier, showing the data-induced phase reversals. This signal is subsequently intensity-modulated on the wavelength-swept light signal, by means of the Mach Zehnder Interferometer intensity modulator. Using the same sweep rate of $f_{sw} = 900$ MHz, sweep optical frequency range of $\Delta f_{opt} = 28.8$ GHz, and Fabry Perot periodic filter with FSR $= 9.6$ GHz, again a microwave signal with fundamental frequency of 5.4 GHz is generated at the output of the photodiode, carrying the BPSK modulated data on the 225 MHz subcarrier. In analogy with the expression for the CW microwave signal, the BPSK modulated microwave signal can be described as

$$\begin{aligned} i(t) &= \frac{i_0 \cdot m(t)\cos(2\pi f_{sc} t)}{1 + F \cdot \sin^2(2\pi N f_{sw} t)} \\ &= i_0 \cdot m(t)\cos(2\pi f_{sc} t) \cdot \frac{1-R}{1+R} \\ &\quad \cdot \left\{ 1 + 2\sum_{n=1}^{\infty} R^n \cos(4\pi n N f_{sw} t) \right\}, \end{aligned}$$

where f_{sc} denotes the subcarrier frequency, and $m(t)$ the bipolar input data signal (see Fig. 8).

Fig. 10 shows the signal at the output of the bandpass filter (with sufficiently large bandwidth to pass on the BPSK modulated subcarrier) after the photodiode. On the envelope of this signal, the BPSK modulation is clearly visible. The signal's frequency spectrum, centered around 5.4 GHz and including the two sidebands due to the BPSK modulated subcarrier, is shown in Fig. 11. This modulated microwave signal is radiated by the antenna to the mobile user terminals, where it will be downconverted with a local 5.4 GHz oscillator, and subsequently BPSK-demodulated by

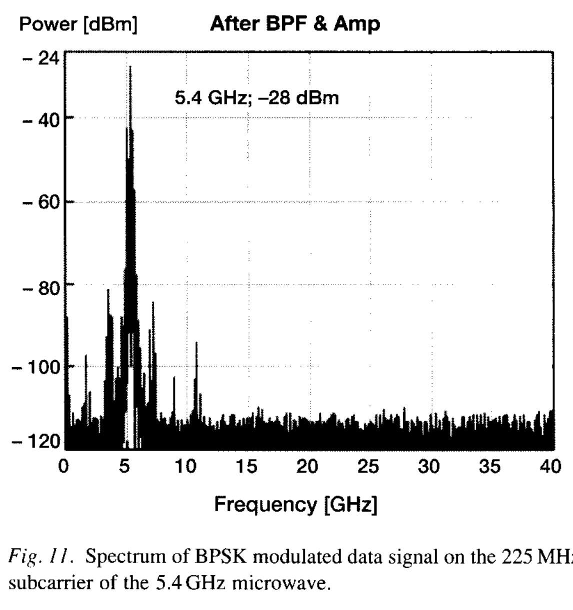

Fig. 11. Spectrum of BPSK modulated data signal on the 225 MHz subcarrier of the 5.4 GHz microwave.

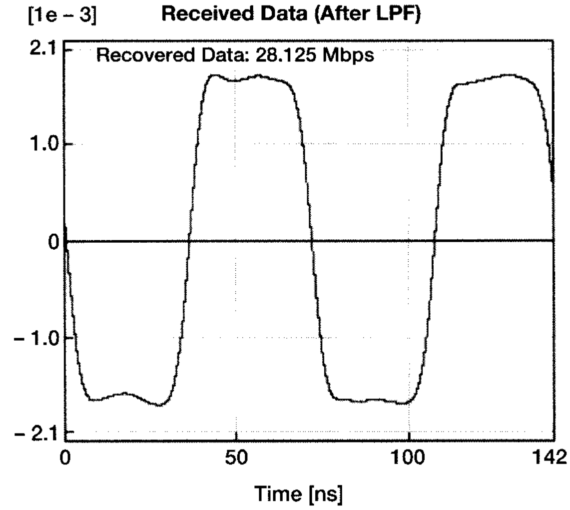

Fig. 12. Recovered data signal after BPSK demodulation at wireless user terminal.

means of synchronous detection (mixing with synchronized 225 MHz oscillator signal, and low-pass filtering). The resulting demodulated signal is shown in Fig. 12; obviously, the data pattern sent from the headend can be recovered with a high degree of confidence.

The system can be extended to support a wide variety of modulation formats such as QPSK and x-level QAM, by replacing the BPSK modulator in Fig. 8 by a quadrature modulator, as shown in Fig. 13. Simulations have been made of the system performance for a 56 Mbit/s 16-QAM signal modulated on a 225 MHz subcarrier. The spectrum of the microwave signal at the output of the bandpass filter is shown in Fig. 14. The eye patterns of the demodulated in-phase

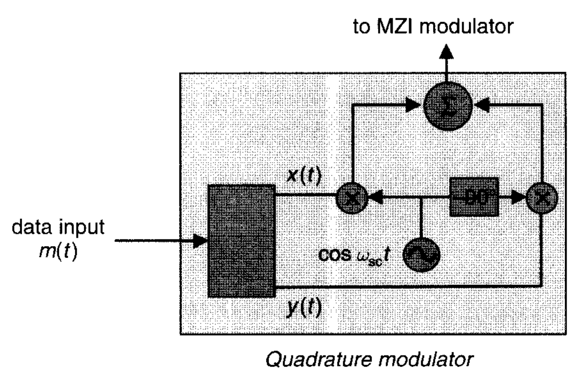

Fig. 13. Quadrature modulation of data signal $m(t)$ on a subcarrier, enabling a wide variety of modulation formats (QPSK, x-level QAM, ...).

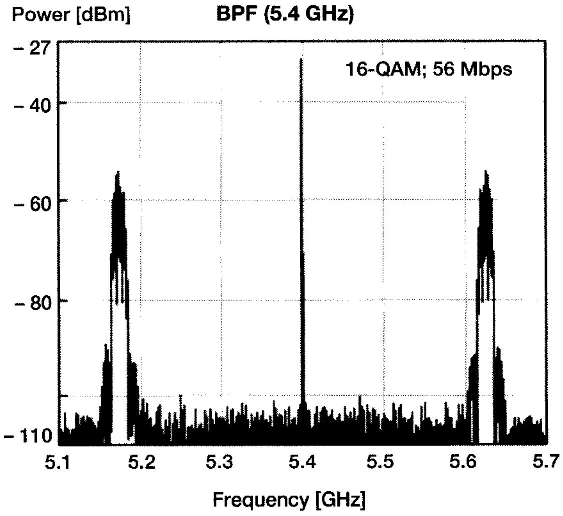

Fig. 14. Spectrum of 16-QAM signal transporting 56 Mbit/s data at carrier frequency 5.4 GHz.

and quadrature signals at the wireless mobile terminal, obtained after downconversion and synchronous demodulation, are depicted in Figs 15 and 16, respectively. Both eye patterns are clearly open, indicating a system performance can be achieved with low bit error rate.

4 Extension to a Bidirectional System

In order to support interactive communications, as needed in wireless LANs, the proposed concept can be

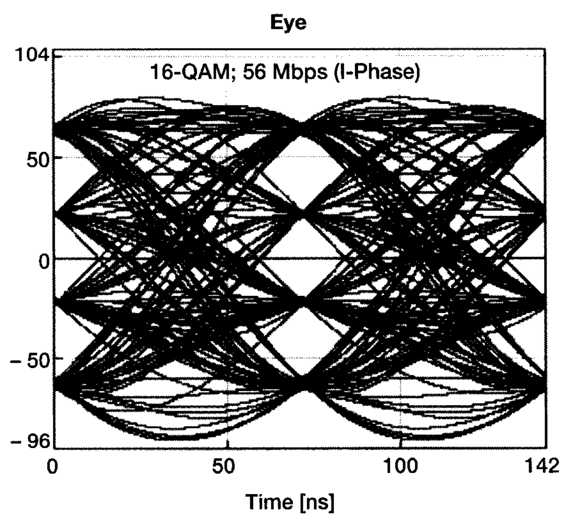

Fig. 15. Eye pattern of demodulated 16-QAM in-phase symbols.

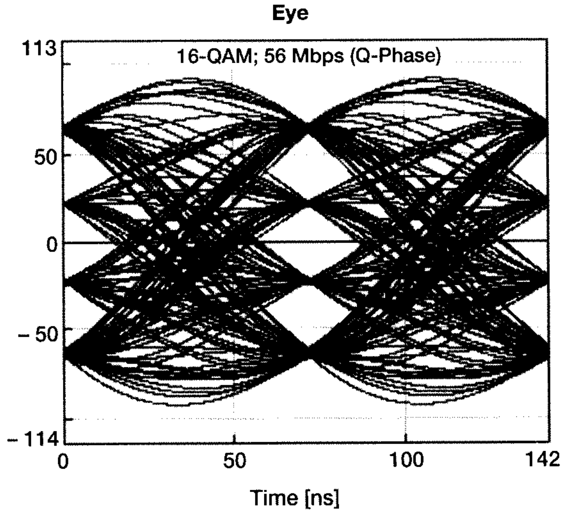

Fig. 16. Eye pattern of demodulated 16-QAM quadrature-phase symbols.

extended to a bidirectional system as shown in Fig. 17. Two wavelengths are used, λ_0 for downstream and λ_1 for upstream traffic, which are combined with wavelength division multiplexing (WDM) devices. Thus, due to the wavelength selectivity provided by these WDM devices, near-end crosstalk is adequately suppressed. When no data is going downstream, the unmodulated microwave signal generated in the RAP is used for downconverting in a mixer the upstream signal from the mobile terminal. Thus data can be transported bidirectionally in time-division half-duplex mode. Following a medium-access control protocol, the upstream data is intensity-modulated in baseband on a laser diode in the RAP, and detected at the headend station. The upstream data speed is limited by the bandwidth of the GIPOF link, which may be as high as 2 GHz for 500 m reach.

5 Flexible and Transparent Multi-Service In-House POF Network

Presently, different in-house network infrastructures are deployed to carry a variety of services: coaxial cable for CATV/FM radio broadcast and data signals, twisted copper pair cable for voice telephony and data, power line for control of home appliances, and also wireless LANs for data. This set of in-house networks is well-suited for the present service offerings and business goals. However, on the longer term a trend is emerging in which service delivery (e.g., of voice or data) is not necessarily restricted to a particular one of the available in-house networks. Also it is expected that the functionalities are linked across these networks, and to the variety of outdoor access network infrastructures (coaxial cable, twisted copper pair, satellite, fiber), via a residential gateway. Convergence of the in-house networks into a single versatile infrastructure would then considerably ease the maintenance of the network, the upgrading, and the introduction of new services. Therefore, an in-house network not only needs to provide higher data transport capacities, but it should

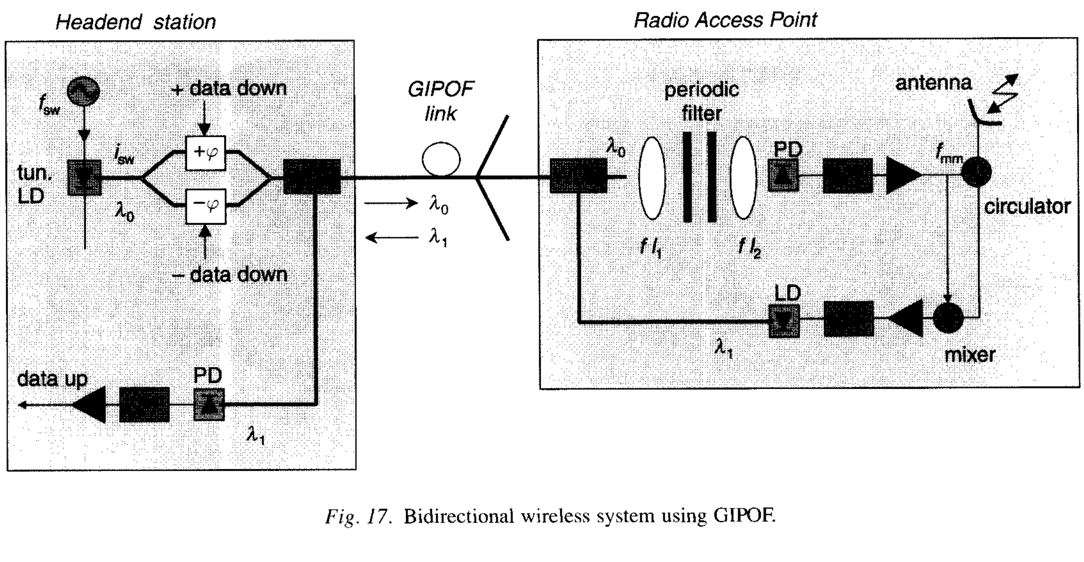

Fig. 17. Bidirectional wireless system using GIPOF.

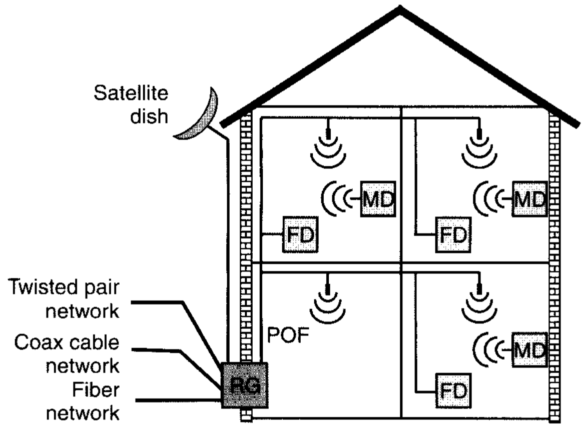

Fig. 18. Transparent in-house POF network (RG = residential gateway; FD = fixed device; MD = mobile device).

also become more flexible and transparent. It should enable the user to become less location-bound, and thus increase his/her mobility. Also it should support IP-based traffic, which is becoming the major carrier of services.

Optical fiber is excellently suited for providing high bandwidth and service format transparency, and in particular POF is very attractive for in-house networks due to its additional advantage of easy handling and installation. As depicted in Fig. 18, a POF network infrastructure can provide a universal transparent broadband in-house network, providing both fixed and mobile devices with a wealth of broadband services. The radio-over-POF system concept for feeding the mobile devices can be readily integrated with other system architectures such as a fixed-wired Gigabit Ethernet LAN, e.g., by hosting the different systems on different wavelengths in the POF network. For example, a Gigabit Ethernet system with a reach of up to 1 km over GIPOF at a wavelength of 840 nm has been demonstrated [2], and can be overlaid with the radio-over-POF system at 1300 nm as presented in this paper.

6 Conclusions

A novel system concept for carrying microwave signals over an in-house POF network has been reported, surpassing its intrinsically limited bandwidth. This optical frequency multiplying method deploys wavelength sweeping of an optical source in the headend station across the characteristics of a periodic optical bandpass filter at the access point. It benefits from the installation easiness of polymer optical fiber, and it allows consolidation of mobility functions at the headend station and simplification of the radio access points.

The feasibility of the concept for various microwave signal formats has been shown, e.g., for a 56 Mbit/s 16-QAM microwave signal at a carrier frequency of 5.4 GHz. Microwave carrier frequencies significantly beyond the bandwidth of the polymer optical fiber network can be realized, with high spectral purity. Carrier frequencies of e.g., 60 GHz are within reach in POF networks spanning up to 500 m (bandwidth up to 2 GHz), by sweeping the laser wavelength at a rate of 1 GHz over a 1.2 nm range, and using at the radio access point an optical periodic filter with 5 GHz FSR followed by a 60 GHz photodiode. Data transfer speeds are limited by the fiber's bandwidth, and may go up to several hundreds of Mbit/s. The concept also supports bi-directional half-duplex communication.

The system concept may enable cost-effective installation of high-capacity wireless LANs, and easy upgrading by offering data signal transparency. It can readily be integrated with other system technologies, such as Gigabit Ethernet, in a single flexible and transparent multi-service in-house POF network.

Acknowledgment

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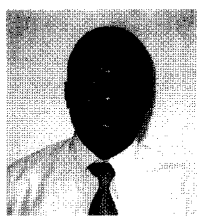
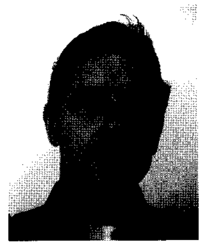
Ton Koonen received his M.Sc. degree (cum laude) in Electrical Engineering from Eindhoven University of Technology in 1979. He served from 1979 to 2000 as member of technical staff and as technical manager at Bell Laboratories, Lucent Technologies in The Netherlands, where he led a group working on applied research in fiber-optic broadband access networks. From 1991 to 2000 he also was a part-time professor in Photonic Networks at the University of Twente in The Netherlands. Since 2001, he has been a full professor in Broadband Communication Networks at the COBRA Institute, in the Department of Electrical Engineering at Eindhoven University of Technology, The Netherlands. He has initiated and managed various projects in this field in the European ACTS and IST programs, and is currently managing the IST project STOLAS on optical packet routed networks. He is also managing the BraBant BreedBand (B4) alliance, a pre-competitive research co-operation on broadband network techniques and applications between the university and various industrial partners. He has (co-)authored over 70 papers and some book chapters on optical fiber communication. In 1999, he received the Bell Labs Fellow award ''for outstanding contributions to high-speed transmission systems and for advancing optical technologies to support the convergence of access networks''. He is also a Senior Member of IEEE.



Anthony Ng'oma received his B.Eng. degree (with Merit) in Electronic Engineering and Telecommunications in 1995, and an M.Eng. degree in 1997, both from the University of Zambia. In April 2002, he received the MTD post-masters degree in Information and Communication Technology from Eindhoven University of Technology in The Netherlands.

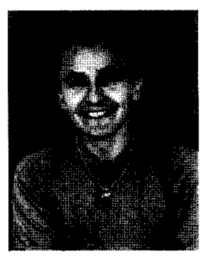
In 1995 he worked as a Computer Networks Engineer at CompuTech (Z) Ltd. He also worked as a staff member at the University of Zambia between 1997 and 1999. He joined the Electro-Optical Communication group at Eindhoven University of Technology in December 1999. He is presently undertaking Ph.D. research in the field of broadband fiber-wireless access technologies.



Peter Smulders received the M.Sc. degree in Electrical Engineering graduated from Eindhoven University of Technology in 1985. In 1985 he joined the Propagation and Electromagnetic Compatibility Department of the Research Neher Laboratories of The Netherlands PTT (currently KPN Research). During that time he was doing research in the field of compromising emanation from civil data processing equipment.

In 1988 he moved to the Eindhoven University of Technology as a staff member of the Telecommunications Division. Next to his lecturing duties he performed a Ph.D. research in the field of broadband wireless LANs. His current work addresses the feasibility of a low-cost, low power, small-sized wireless LAN technology operating in the 60 GHz band. With this low-cost technology it should be possible to serve an unprecedented maximum user data rate of 400 Mbit/s as well as an unprecedented aggregate network capacity of up to 10 Gbit/s. He is senior member of IEEE and his field of interest that covers 60 GHz channel properties, 60 GHz RF/IF technology including antennas, modulation and coding and MAC and higher layers is reflected in numerous IEEE publications. His future research activities will include low-cost antenna- and front-end technology and tailor-made baseband processing algorithms.

Henrie van den Boom received the M.Sc. degree in Electrical Engineering from Eindhoven University of Technology in 1984. Since then he has been an Assistant Professor at the Electro-Optical Communications group of the Department of Electrical Engineering of the same university. He lectures in basic telecommunication theory and optoelectronic communication systems and networks. He has been involved in research on coherent optical communication systems, optical cross-connected networks and broadband communications in Hybrid fiber Coax networks. Currently he is working on Polymer Optical fiber systems and networks.



Idelfonso Tafur Monroy graduated from the Bonch-Bruevitch Institute of Communications, St. Petersburg, Russia, in 1992, where he received the M.Sc. degree in Multichannel Telecommunications. In 1993 he enrolled as a graduate student in the Department of Signals, Sensors and Systems at the Royal Institute of Technology, Stockholm, Sweden, where he received in 1996 the Technology Licenciate degree in Telecommunication Theory. In 1999 he received the Ph.D. degree in Electrical Engineering from the Eindhoven University of Technology, The Netherlands. Currently he is a researcher in the area optical networking and communication systems at the Eindhoven University of Technology. He is a coauthor of the book entitled *Crosstalk in WDM Communication Networks*, Kluwer 2002. He is currently involved in the European Commission IST project Switching Technologies for Optically Labeled Signals (STOLAS).

Giok-Djan Khoe received his M.Sc. degree in Electrical Engineering, cum laude, from the Eindhoven University of Technology in 1971. Subsequently he joined the Dutch Foundation for Fundamental Research on Matter (FOM) Laboratory on Plasma Physics, Rijnhuizen. In 1973 he joined the Philips Research Laboratories to start research in the area of optical fiber communication systems. In 1983, he was appointed as part-time professor at Eindhoven University of Technology. He became a full professor at the same University in 1994 and is currently chairman of the Department of Telecommunication Technology and Electromagnetics (TTE).

Most of his work has been devoted to single-mode fiber systems and components. Currently his research programs are centered on ultrafast all-optical signal processing, high capacity transport systems and systems in the environment of the users. He holds more than 40 United States Patents and has authored and co-authored more than 100 papers, invited papers and chapters in books.

His professional activities include many conferences, where he has served in technical committees, management committees and advisory committees as a member or chairman. Recently, he was general co-chair of the ECOC 2001. He has been involved in journal activities, as associate editor, as a member of the advisory board or as reviewer. Today, he is associate editor of JQE. In Europe, he is closely involved in Research Programs of the European Community and in Dutch national research programs, as participant, evaluator, auditor and program committee member.

He is one of the founders of the Dutch COBRA University Research Institute and one of the three recipients of the prestigious "Top Research Institute Photonics" grant that is awarded to COBRA in 1998 by The Netherlands Ministry of Education, Culture and Science. In 2001, he brought 4 groups together to start a new international alliance called the European Institute on Telecommunication Technologies (eiTT).

He has served in the LEOS organization as European Representative in the BoG, VP Finance and Administration, BoG Elected Member and member of the Executive Committee of the IEEE Benelux Section. He was founder of the LEOS Benelux Chapter. He has been an IEEE Fellow since 1991 and received the MOC/GRIN award in 1997. Currently in 2002 he has been appointed the President Elect of LEOS.