# A combined optical-wireless broadband Internet access: transmission challenges

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***Abstract* — The demand for high bit rate Internet access with portable computers is rapidly growing and needs an easily configurable, fast local area network. In a combined system optical transmission can provide high bit rate and radio connection to the personal computers ensures the flexibility and comfort in establishing network connection. In this paper the transmission challenges of both the wireless and optical sections are investigated based partly on the results obtained in the FRANS project of the European Union.**

## I. Introduction

According to the recent trend people take their portable computers to different places they have to work at. To provide network connection in such a quickly changing environment the radio connection is the most effective way.

In the presently used systems a fiber optic link is applied to transmit the information in the baseband to a node where the data are converted and routed to the terminals via coaxial cables or wireless connections. This way the nodes perform several functions what is cumbersome because usually they are unattended outdoor installations. That problem is overcome by the present new approach transmitting the wireless modulation format over the fiber optic link as well. Therefore the function of the nodes is significantly simplified. Some approaches have already been developed utilizing the radio over fiber concept. However, most of them have not considered the problems of the wireless section, which also has an effect on the transparent optical link.

In this paper the transmission challenges of both the wireless and the optical sections are investigated and their results are presented. Some of these problems have already been studied in the framework of the European project called FRANS (Fiber Radio ATM Networks and Services) what the authors have been participating in. A part of their results [1] is discussed here beside their more recent new contributions.

The topics to be presented are: amplitude and phase non-linearities, noise sources, spurious free dynamic range and their effect on the bit error rate. The main components contributing to the degradation of the transmitted signal are the modulated laser of the fiber optic link and the power amplifier of the wireless section.

## II. System concept

The limited bandwidth of the wireless path requires efficient utilization of the band. It means that frequency saving modulation formats with variable link bandwidth to the computers based on the actual needs, large fading margins in the signal to noise ratio and careful frequency allocation protocol have to be applied for avoiding interference problems.

One possible system architecture can be seen in Fig.1. A fiber ring is used for transmitting the broadband modulated radio frequency (RF) signals to the radio nodes, and for transmitting data signals in the baseband at the same time. A complex control station is responsible for data switching, carrier frequency and bandwidth selection for the radio channels. In the selection process avoiding interference between radio channels and providing necessary bandwidth are the main goals. A control channel is allocated for establishing the radio connections to the radio users. The radio band is divided to a wider down-link and a narrower up-link part, since the data traffic of the Internet is typically not symmetrical. The multi-state QAM like 16 QAM or 64 QAM scheme is chosen for modulation, because these are the most efficient methods in utilizing the bandwidth. At the same time these modulation schemes are most sensitive for distortion and noise.

The optical ring consists of point to point short distance and hence, low loss connections between radio nodes. These nodes are very simple and cheep as they consist of only a photoreceiver, a direct modulated laser source and some simple circuits like branching filter. Because of the

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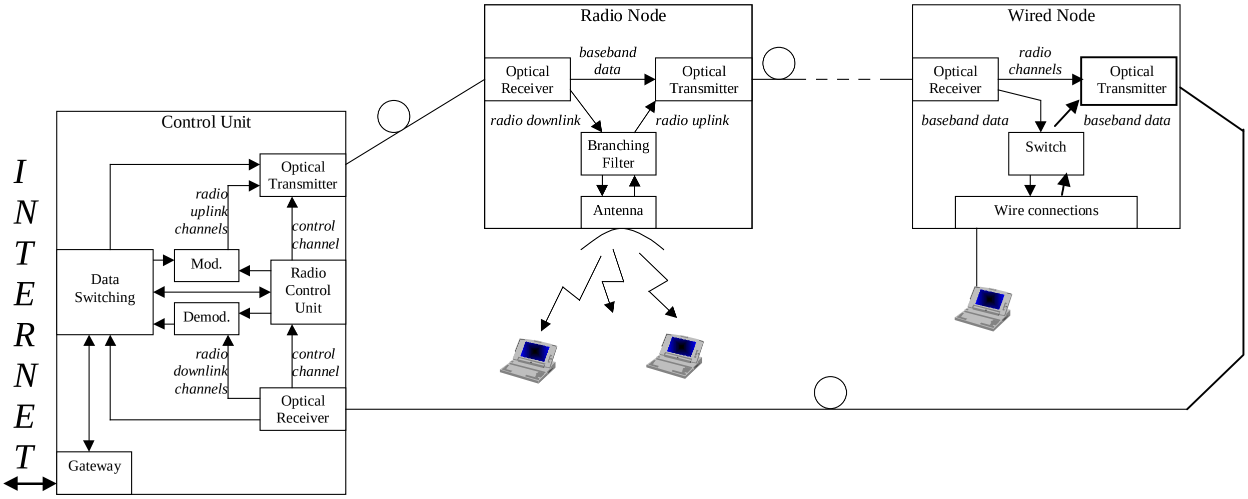


Fig. 1. A combined radio-fiber network

low optical loss, the system noise will be determined mainly by the laser relative intensity noise (RIN). The laser is the key device also in linearity, as it is modulated in the base band and in the RF range at the same time which means that all the RF carriers are mixed with the baseband signal. Therefore the direct modulated laser source has to be mainly investigated.

The system shown in Fig. 1 is only one, thought to be the cheapest, candidate for a combined optical-radio system. Its drawback is the complicated control unit and that users can not make direct connection to each other leaving the control unit out. Other system architectures can be imagined with more sophisticated optical part consisting of optical add-drop multiplexers, optical amplifiers, electroabsorption modulators [2] etc., and simpler control unit. The effect of noise and distortion of the optical part has to be always investigated.

## II. Distortions

In QAM modulation a symbol is represented in the constellation by its amplitude and phase, therefore the signal transmission is sensitive to amplitude and phase distortions. Both in the optical and wireless transmissions linear and nonlinear distortions are encountered.

The nonlinear amplitude distortion is caused by the AM compression and nonlinear phase distortion is the result of the AM-to-PM conversion. These characteristics have a dynamic behavior as they are dependent on the modulation frequency or bit rate. To overcome the linear distortion proper passband characteristics should be designed. However more attention has to be paid to the nonlinear properties because the distortions caused by them cannot be easily compensated. The main sources of nonlinearity are the modulated laser and the power amplifiers of the wireless transmitters. These components will be discussed in detail.

To define the limit of the linear regime a new test method is introduced: it is called spectrum method. It applies two input signals: one of them is much smaller than the other one. The large signal (with amplitude $V_0$) is used to drive the circuit into the nonlinear regime and the small signal (with amplitude $V_s$) is used to get information about the nonlinearity. Due to the nonlinear transfer the input signals will be distorted during the transmission and 3 signals will appear at the output: a large signal (with amplitude $V_c$) and two small signals (with amplitudes $V_u$ and $V_l$). The index u refers to the upper sideband and the index l refers to the lower sideband.

The AM compression (cp) is the ratio of the input and output amplitude modulation depths (m):

$$cp = \frac{m_{AM}^{(in)}}{m_{AM}^{(out)}} = \frac{V_s}{V_u - V_l} \cdot \frac{V_c}{V_0} \qquad (1)$$

The AM-to-PM conversion is also obtained from the measured data as follows:

$$cv = \frac{180}{3{,}14}\left(\frac{V_u}{V_c} + \frac{V_l}{V_c}\right) - 6{,}88\left[{}^{\circ}\!/_{dB}\right] \qquad (2)$$

As can be seen only 3 spectral lines have to be measured. The dependence of the AM compression and AM-to-PM conversion on the modulation frequency is obtained easily by varying the frequency separation of the side-band signal from the carrier. This dynamic behavior is very important when higher bit rates are used.

It is observed that both the AM compression and the AM-to-PM conversion are less dependent on the modulation frequency or bit rate when the bandwidth of the circuit is broader. The AM compression and AM-to-

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PM conversion are measured on the modulated lasers of the optical nodes and will be presented.

Utilizing the measured parameters computer simulations are carried out to establish relations between the nonlinear characteristics and the bit error rate. In the simulations a new approach, the orthogonal frequency division multiplex (OFDM) is also considered for the wireless section of the system because of its immunity against intersymbol interference caused by propagation delays.

## III. Optical System

In the optical nodes a bias current modulated Fabry-Perot type laser is used because this way the optical transmitter is cost effective. This laser type is intensively investigated for RF applications [3]. To achieve a low bit error rate (BER) when radio frequency channels are transmitted, two main properties are dominant: the spurious free dynamic range (SFDR) and the limit of the linear regime.

The dynamic range is determined by the noise floor (laser RIN) and the third order intercept point (IP3). With proper optical matching of the laser diode the dynamic range has been enhanced to 102 dB/Hz$^{3/2}$ which is a rather good value considering requirements [4].

The measurement results are shown in Fig. 2.

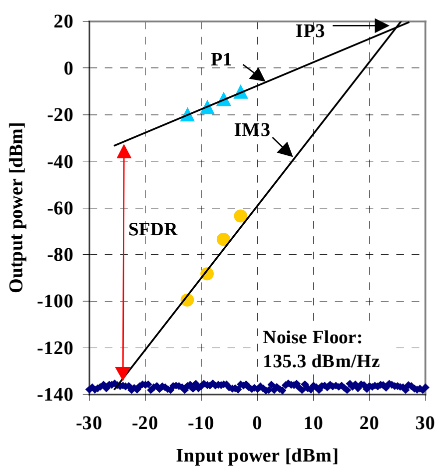


Fig. 2. SFDR measurement of a 1300nm FP laser diode

When the laser simultaneously transmits data in the baseband and on radio channels at RF as in the system of Fig. 1, the second order nonlinearity also gets an important role. The baseband signal is mixed with the RF carriers causing distortions. This is shown in Fig. 3, where the laser was modulated with two RF carriers at 2 GHz (Fig. 3 upper) and than a 500 KHz baseband signal was added (Fig. 3 lower).

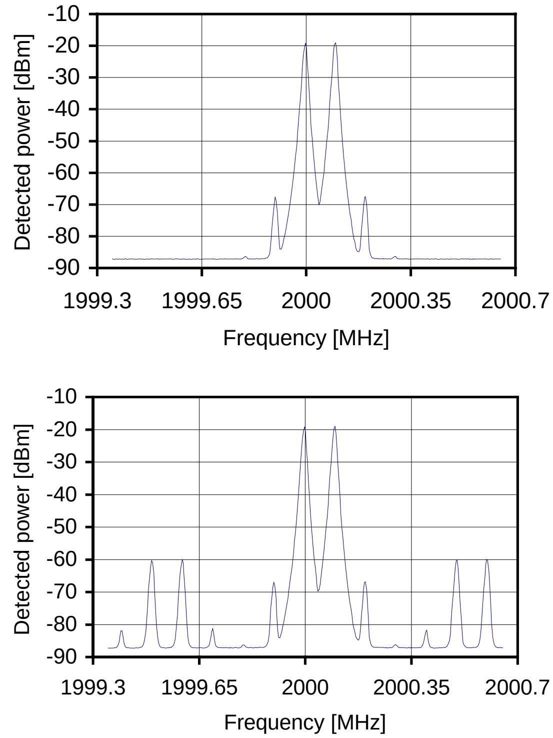


Fig. 3. Measurement of laser nonlinearity

In Fig 3. the laser was biased to 0.8 mW optical power in fiber, the modulation depth $m_{BB}$=2.7% was for the base band and $m_{RF}$=11.4% was for the RF signal. Increasing the laser power to 1.2 mW, and hence decreasing the modulation depths, the 3$^{rd}$ order product improved 15 dB, the second order 9 dB. This yields that very low modulation depth has to be used to avoid distortions to degrade BER seriously. This can be avoided by up-converting the baseband signal into the RF also.

## IV. Wireless System

The radio carriers are modulated by IQ modulators providing 16 or 64 QAM. This modulation requires low phase noise of local oscillators. Fig. 4 shows calculated curves how the BER depends on the signal to noise ratio (S/N) at different phase jitters. In the calculation 16 QAM and normal distribution amplitude noise and phase jitter were supposed. The figure shows also the cases, when nonlinear effects are added (+nonlin). The main nonlinear effects are the AM compression and AM-to-PM conversion in the laser and in the power amplifier of the wireless transmitters. In Fig. 4 1dB compression and 1 degree/dB AM-to-PM conversion were supposed for the most external constellation points. For comparison Fig. 5 shows 64 QAM taking only noise into account.

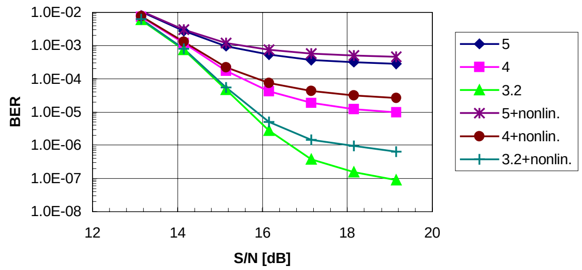


Fig. 4. BER vs. S/N at different phase jitters, 16 QAM

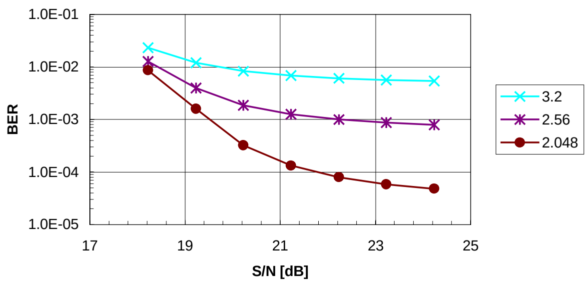


Fig. 5. BER vs. S/N at different phase jitters, 64 QAM

In the FRANS project a millimeter wave reference signal was generated and distributed as a reference in a mobile communication system. The signal generation based on a subharmonically locked PLL and the third harmonic of the VCO, built on hybrid integrated technology, was used as output. The PLL was locked to a signal at 1.055 GHz which was optically transmitted. The phase jitter at 25.32GHz and the BER in data transmission were measured. The results are shown in Fig. 6 and Fig. 7 indicating the applicability of this technology.

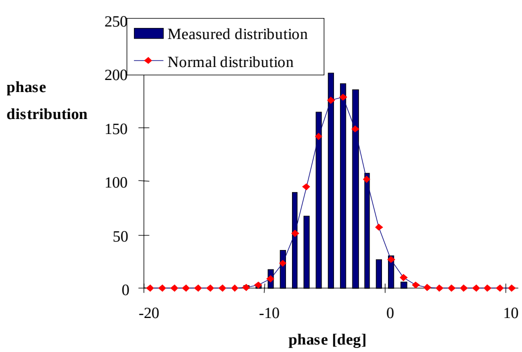


Fig. 5. Measured phase jitter distribution at 25.32GHz

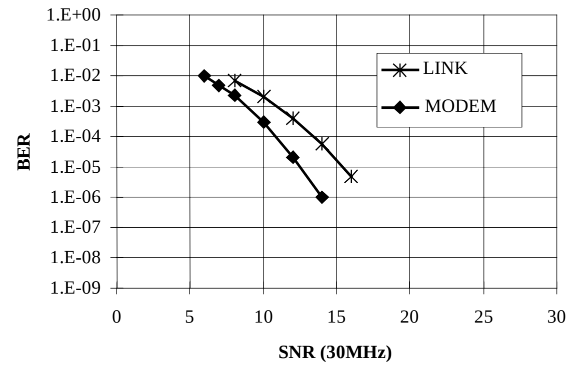


Fig. 7. BER vs. S/N measured on a combined fiber-radio link operating at 25.32GHz

## V. Conclusion

A novel approach has been presented for broadband Internet access utilizing an optical-wireless combined system. The transmission challenges of the wireless and the optical parts have been studied: mainly how the non-linearity, noise, and modulation methods affect the bit error rate. By a proper design these effects can be minimized.


## Acknowledgement

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