60GHz Radio-over-Fiber Techniques for 10Gb/s Broadband Wireless Transmission

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Abstract—In this paper, we discuss millimeter-wave radio-over-fiber (RoF) techniques for short to medium-range broadband wireless data transmission. We have constructed a 60GHz RoF link system with a compact wireless RoF transmitter consisting of a high-frequency photodiode and a mm-wave antenna only. Using OOK modulation this system achieved broadband short-range in-door and medium-range out-door transmission of 10Gb/s signals over wireless distances up to about 10m and 40m, respectively. We furthermore demonstrate the generation of a 10Gb/s 16-QAM modulated mm-wave carrier using photonic vector modulation (PVM) techniques resulting in a more spectrally efficient system. Based upon the experimental results we expect the maximum wireless distance the system could accommodate for 10Gb/s is in the range of several 100m (considering heavy rain fall) when using high gain antennas and adequate RF amplifier.

Index Terms—Radio over Fiber, Millimeter-Wave Communication, Gigabit Ethernet, Photonic Vector Modulation.

I. INTRODUCTION

A key technology trend in wireless communications is the increase in data rate needed to fulfill the expanding broadband requirements [1]. New techniques such as ultra wide band (UWB) and millimeter-wave wireless have already shown being capable of delivering Gigabit-Ethernet (1GbE), but with the ever increasing data rate of local area (LAN) and personal area networks (PAN), the introduction of 10Gb/s Ethernet (10GbE) wireless systems is expected. Such 10GbE wireless LAN will meet the demand for bridging broadband campus and corporate networks but they are also required at broadcast stations or conference sites having a strong demand for high data rates. Further applications are seen in storage area networks (SAN). In that regard, 60GHz wireless transmission is widely considered for short-range in-door communications with path lengths up to some 10m due to the high atmospheric gaseous losses at 60GHz. Especially for long-range fixed wireless access (FWA) applications also other mm-wave bands like the E-band (60 to 90GHz) or F-band (90 to 140GHz) are considered as those bands offer lower atmospheric gaseous losses.

In this paper, we discuss the potential of advanced mm-wave photonic components and RoF techniques for broadband 10Gb/s wireless transmission at 60GHz. At first, we present a 60GHz RoF link system using optical on-off-keying (OOK) modulation enabling broadband wireless transmission up to 12.5Gb/s at 60GHz. To our knowledge, this is the first demonstration of such a broadband wireless transmission over reasonable path lengths. Next, we present an advanced photonic vector modulation technique for 10Gb/s 16-QAM mm-wave carrier generation enabling a higher spectral efficiency. Based upon the experimental achievements and further theoretical calculations we predict maximum wireless path lengths up to the km-range for 10Gb/s transmission at 60GHz provided high gain antennas and adequate RF amplifiers are used. We furthermore compare our results with other mm-wave systems operating in the E- and F-band.

II. 10Gb/s PHOTONIC MM-WAVE SYSTEM USING OOK

For broadband wireless transmission at 60GHz we have constructed a radio-over-fiber link system consisting of an optical carrier generation unit and a subsequent broadband OOK data modulation unit as well as a compact wireless RoF transmitter and a wireless receiver. In the system, the 60GHz carrier is generated by optical means and is further optically modulated with broadband non return to zero on-off-keying (NRZ-OOK) data. After fiber-optic transmission to the wireless RoF transmitter via fiber (SMF), the optical mm-wave signal is o/e converted by a 70GHz photodetector and transmitted to the wireless receiver using 20dBi horn antennas.

For short-range in-door experiments the wireless signal was transmitted within a laboratory environment allowing a maximum wireless path length of about 11m. From bit error rate (BER) measurements (Fig. 1) we can demonstrate error-free broadband wireless transmission up to 12.5 Gb/s. No error floor was observed in the bit-error-rate (BER) measurements down to BERs of $10^{-11}$. For a BER of $10^{-9}$ (2B1-1, NRZ) and 2.5m wireless in-door transmission the measured receiver sensitivity for 10Gb/s is -47.6dBm. We also investigated the maximum wireless path length the system could accommodate at a given data rate to demonstrate the capacity of the constructed system link for short-range in-door communication. Here the RoF transmitter was also operated in passive mode, i.e. without biasing the photodiode and without any RF

Manuscript submitted February 15, 2008. This work was supported by the European Community under the Project IST FP6 IPHOBA C. Andreas Stöhr, Mario Weiβ, Sascha Fedderwitz, and Dieter Jäger are with Universität Duisburg-Essen, Duisburg, Germany (e-mail: andreas.stoehr@uni-due.de).

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amplification in the RoF transmitter and the transmitted RF power was fixed to -7.5dBm. Here, we achieved 10Gb/s broadband wireless transmission over distances up to about 10m. For medium-range out-door wireless line-of-sight (LoS) transmission we have employed an additional RF power amplifier in the wireless RoF transmitter and we have achieved 10Gb/s broadband transmission over wireless distances of up to 40m.

III. 10GB/S PHOTONIC MM-WAVE SYSTEM USING PVM

The use of more spectrally efficient modulation formats such as multi-level quadrature amplitude or phase modulation (MQAM or MPSK, respectively) is of high interest to alleviate the huge bandwidth requirements imposed by multi-Gb/s data rates. Recently, PVM architectures with low hardware requirements, both optical and electrical, showing the potential of this approach to generate up to 3.6 Gbit/s 16-QAM 40 GHz carriers have been reported.

The use of a novel technique for generating 16QAM mm-wave signals is reported in this paper. This architecture employs dual drive Mach-Zehnder modulators (DD-MZM) to generate two 4ASK baseband optical signals, which are externally modulated by a local oscillator (LO) at mm-wave frequency. An optical delay line (ODL) is used to obtain the quadrature condition required to generate the 16-QAM modulation. A -40 dBm 16 QAM 40GHz carrier has been generated using the proposed approach. The error vector magnitude (EVM) of the generated signals was estimated after electrical demodulation based on statistical parameters of the demodulated signals. Figure 2 shows the received I and Q eye diagrams, and the resulting constellation for an EVM of 21dB. This results show the validity of PVM to generate multi-level modulated mm-wave carriers.

IV. GENERAL CONSIDERATIONS

Based upon the experimental system results we further studied the potential of extending the wireless path length up to the km range (for 12.5Gb/s @ 60GHz) provided high gain antennas and RF amplifiers with suitable bandwidth are employed in the wireless RoF transmitters. The aim of this study was to investigate the potential of 60GHz RoF systems for medium-range wireless transmission and to compare it with other mm-wave systems operating in the E- and F-bands which are currently discussed for long-range wireless access. Although higher mm-wave frequencies in the E- and F-band offer lower gaseous attenuation, 60GHz might be favorable at least up to medium-range wireless distances. One major reason is that there is a strong interest in 60GHz in-door communications which is expected to significantly reduce component cost in a short term perspective. In addition, even when considering heavy rain fall, the maximum wireless distance for 60GHz transmission is expected to be in the km-range provided high-gain antenna are used. Fig. 3 shows that the maximum wireless distance to achieve a BER of $10^{-9}$ is approx. 2000m for 99%

![Fig. 1. BERs and 10Gb/s eye diagram after 2.5m wireless transmission.](image)

![Fig. 2. Downconverted 10Gb/s In-phase (a), and Quadrature (b) components, and resulting normalised constellation diagram (c).](image)

![Fig. 3. Maximum wireless path lengths for 50 dBi gain antennas under different weather conditions.](image)

V. CONCLUSION

In this paper, we have presented photonic millimeter-wave link systems using OOK and PVM schemes for short- to medium-range broadband wireless transmission up to 12.5Gb/s. To the best of our knowledge, this is the first time that both 12.5Gb/s wireless transmission over relevant wireless path lengths and 10Gb/s 16QAM mm-wave generation using PVM, have been achieved.

REFERENCES

Andreas Stöhr received the Dipl.-Ing. and Dr.-Ing. degree in Electrical Engineering from Gerhard-Mercator-University Duisburg (GMUD), Germany, in 1991 and 1997, respectively. Since 1995 he is a member of ZHO–Optoelektronik at Universität Duisburg-Essen, Germany. In 1998 and 1999 he joined the Communications Research Laboratory (CRL), Ministry of Posts and Telecommunications, Japan. His current research interests include the design and fabrication of III/V based microwave photonic devices and their application in microwave or millimeter-wave fiber-optic transmission systems as well as in optical sensors. He has published more than 100 papers in refereed journals and conferences.

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