27 Gbit/s Photonic Wireless 60 GHz Transmission System using 16-QAM OFDM

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Abstract — In this paper, we present a simple architecture for a super-broadband 60 GHz photonic wireless system. Using a cascaded optical RF and data modulation approach, advanced photonic components and a high-spectral efficient QAM-OFDM modulation format, we realized a compact 60 GHz photonic wireless system having a spectral efficiency as large as 3.86 bit/s/Hz. By making use of the 7 GHz spectral bandwidth in the 60 GHz band which was opened up for unlicensed broadband wireless services worldwide, we achieved record data throughputs. For example, by using a 16-QAM OFDM subcarrier modulation, we experimentally demonstrate photonic wireless transmission of 27.04 Gbit/s with a mean EVM of 17.63%. Wireless experiments were carried out in a lab environment with a maximum transmit power of -1 dBm and 23 dBi gain antennas for a wireless span of 2.5 m. This can be extended to some 100 m span when using high-gain antennas and higher transmit power levels.

I. INTRODUCTION

The boom in mobile internet and data services leaves no doubt that today’s wireless networks will very soon face a capacity crunch. Worldwide mobile data and internet traffic is doubling about every 18 month and operators encourage subscribers to mitigate from previous generation mobile standard such as GSM with a bandwidth of a few hundred kilobit per second to HSPA and LTE in the future offering a peak bandwidth of up to 150 Mbit/s [1]. As a result, future wireless backhauling in mobile networks and in access networks must be capable of providing throughputs well in the gigabit per second range.

Traditionally, all-electronic wireless backhauling systems where operated in the microwave domain but because of the congestion in the microwave bands and because of regulatory constraints, their capacity is limited to about a maximum of 100-400 Mbit/s. A solution for multi-gigabit wireless systems is seen shifting the carrier frequency to the mm-wave frequency bands where sufficient bandwidth was made available for broadband wireless services by regulatory agencies worldwide.

The 7 GHz spectrum in the 60 GHz band (57-64 GHz) which is regulated worldwide for unlicensed wireless services is a promising candidate for future multi-gigabit wireless systems. However, realising such a broadband wireless communication system presents many technical challenges owing to the high carrier frequencies, the wide bandwidths used and the higher loss due to oxygen absorption.

In comparison to all-electronic wireless systems, photonic solutions generally have the edge whenever high aggregate bit rates and/or long transmission distances are involved and consequently most broadband wireless demonstrations to date employed photonic approaches [2-10]. We have previously reported on a photonic broadband 12.5 Gbit/s wireless system operating at 60 GHz using ASK modulation [11-12]. However, in that case the spectral efficiency was below 0.5 bit/s/Hz meaning that within the regulated bandwidth from 57 GHz to 64 GHz it was only possible to transmit a maximum throughput of about 3.5 Gbit/s.

In this paper, we report on a compact and high spectral-efficient super-broadband photonic wireless system operating within the 7 GHz spectral bandwidth in the 60 GHz band. For the first time, we successfully demonstrate photonic wireless transmission of record data throughputs up to 27.04 Gbit/s using a 16-QAM OFDM modulation format resulting in a spectral efficiency as high as 3.86 bit/s/Hz.

II. EXPERIMENTAL SETUP

Fig. 1 shows the configuration of the 60 GHz photonic wireless testbed. In general, the system consists of an optical mm-wave carrier generator unit with a subsequent broadband data modulation, a photonic wireless transmitter and a coherent wireless receiver.

A. Photonic millimeter-wave generation

For optical mm-wave carrier generation, light from a DFB laser source at a wavelength of 1548.9 nm is modulated using a single-drive 35 GHz bandwidth Mach-Zehnder modulator (MZM-1), which is biased to the minimum transmission point.
A. Photonic 60GHz Carrier Generator

B. Data Modulator

C. Photonic 60GHz Transmitter

D. Wireless 60GHz Receiver

Fig. 1. Schematic of the compact 60 GHz photonic wireless link consisting of an optical mm-wave carrier generator based upon external modulation, a subsequent broadband OFDM data modulation, a photonic wireless transmitter and a wireless coherent receiver. The configuration for wireless and back-to-back experiments is further indicated in the figure.

(MTP) for generating an optical double-sideband signal with suppressed carrier (DSB-SC). A polarization controller is used to minimize the polarization dependent losses. The modulator is driven by a sinusoidal source with a frequency of $f_{LO1} = 34.7$ GHz thus creating a double-sideband RF carrier with a frequency of 69.4 GHz. With an applied power of +13 dBm, the optical carrier suppression is measured to be approximately 19 dB. To compensate for the modulation losses while operating at MTP, an EDFA was implemented followed by an optical band-pass filter to remove ASE noise. The signal power of the data-modulated optical mm-wave carrier is approximately +14 dBm at this stage.

B. Signal generation and data modulation

Photonic data modulation is performed by external modulation as well. The DC-bias is set to the quadrature point to achieve a quasi-linear modulation of the optical signal in conjunction with a sufficiently low power of the modulating data signal. A polarization controller is used before the modulator to minimize the polarization dependent loss.

The applied OFDM signal under test is created on a computer using Matlab® with an FFT block size of 2048 data subcarriers, 34 pilots and 5 null subcarriers. Total signal bandwidth is set to 7 GHz, while applying QAM-modulation for each data subcarrier. Signal generation is performed by a Tektronix AWG7102 10 GS/s dual-output arbitrary waveform generator (AWG), where the I- and the Q-component of the OFDM signal are combined and applied to a mixer. A sinusoidal microwave source is applied to the LO input of the mixer to up-convert the signal to an IF carrier frequency of 8.5 GHz. The LO power level is +24 dBm. The upconverted OFDM signal is amplified by a 18 dB gain power-amplifier (PA-1) to a level of approx. 3.5 dBm and applied to the RF electrode of MZM-2.

C. Wireless Radio-over-Fiber transmitter

After fiber-optic transmission to the wireless ROF transmitter, the optical mm-wave signal is o/e converted by a 70 GHz photodetector. The converted mm-wave signal is amplified by LNA-1 with a gain of G=20 dB and a noise figure of NF = 6dB and LNA-2 (G=18 dB, NF = 6) to a transmit power of approx. -1 dBm and coupled to a 23 dBi gain horn antenna. Considering carrier and intermediate frequency, the OFDM signal is centered at $f_{RF} - f_{IF} = 60.9$ GHz, giving a consumed bandwidth of 57.4 – 64.4 GHz. This does not quite exactly meet the worldwide regulatory specifications of 57 - 64 GHz [13],[14]. This is due to the insufficient bandwidth of LNA-2.

D. Wireless 60 GHz receiver

The wireless receiver consists of an identical 23 dBi horn antenna. After amplification by a low-noise amplifier LNA-3 with a gain of G = 18.6 dB and a noise figure of NF = 4.5 dB, the signal is coupled to a low-loss custom design balanced mixer for down-conversion. The LO frequency $f_{LO2}$ is 53.2 GHz which down-converts the mm-wave signal to an intermediate frequency centered around 7.7 GHz. This signal is further amplified by LNA-4 (G = 22 dB, NF = 4 dB) to a power level of approximately +5 dBm and coupled to a Agilent DSO91304A 13 GHz bandwidth real time oscilloscope (RTO) with a sampling speed of 40 GS/s to capture the IF signal. Finally, OFDM demodulation and EVM evaluation are performed offline using Matlab®.

III. PERFORMANCE EVALUATION

For evaluating the system performance, we have performed experiments in a laboratory environment with a fiber-optic transmission span of 10 m and a wireless path length of 2.5 m. The data subcarriers of the 7 GHz bandwidth OFDM signal are modulated with either 8- or 16-QAM OFDM signals corresponding to transmitted data rates of 20.28 and 27.04 Gbit/s, respectively. For the measurements, transmitter and receiver are placed at a height of approximately 90 cm above the floor level.

The received spectrum and constellation diagram for 20.28 Gbit/s photonic-wireless transmission using 8-QAM subcarrier modulation are shown in Fig. 2. The measured mean EVM is 18.8 % for a SNR of 18.9 dB. From the EVM, a BER of $2.2 \times 10^{-4}$ can be computed which is below the forward error correction (FEC) limit of $2.2 \times 10^{-3}$ [15].
We further demonstrated 16-QAM modulated OFDM transmission, which corresponds to a data rate of 27.04 GHz at a bandwidth of 7 GHz. The received spectrum and the constellation diagram are shown in Fig. 3. The measured mean EVM is here 17.6 % for a SNR of 21.5 dB. From the EVM, a BER of $4.2 \times 10^{-3}$ can be computed, which is slightly above the FEC limit [15].

IV. CONCLUSION

In this paper, we have presented a compact broadband photonic wireless 60 GHz transmission system based on a cascaded RF and data modulation approach. By using an 8-QAM and 16-QAM OFDM modulation format we achieved record spectral efficiencies up to 3.86 bit/s/Hz. Experiments have been carried out with 10 m fiber-optic and 2.5 m wireless transmission. For 8-QAM OFDM modulation a data rate of 20.28 Gbit/s with a measured mean EVM of 18.8 % and a SNR of 18.9 dB resulting in a BER of $2.2 \times 10^{-7}$ has been achieved. For 16-QAM OFDM modulation a record throughput of 27.04 Gbit/s was successfully achieved. In that case, the measured mean EVM and SNR were 17.6 % and 21.5 dB, respectively resulting in a BER of $4.2 \times 10^{-3}$ which is slightly above the FEC limit. Efforts to reduce the carrier power in the signal spectrum are under way to allow more RF power to be used for data modulation and hence bring the BER back under the FEC limit. Also, the wireless span of 2.5 m was limited by the laboratory environment. The transmit power and antenna gain used in the experiments were -1 dBm and 23 dB, respectively. By increasing the transmit power and antenna gain, we expect being able to extend the wireless span up to a few 100 m given the measured wireless receiver sensitivity.

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