Millimeter-Wave Wireless LAN Based on Simultaneous Upconversion Technique of Optical WDM Channels

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ABSTRACT

The technique of simultaneous electro-optical upconversion is applied to seven operational DWDM channels for generating individual 60 GHz signals in each optical channel. In data transmission experiments including air link, two signal modulation schemes have been applied: OFDM at 50 MBit/s and BPSK at 156 MBit/s. An optical channel spacing of 100 GHz was used and low uncoded bit error rates were obtained in all experiments.

I. INTRODUCTION

The continuously growing demand for high data rate mobile communication leads to the development of wireless LAN's at millimeter-wave transmission frequencies. Due to the high air link loss at mm-wave range, numerous picocells are created within the communication system. For feeding the high number of remote access stations (transponders) from a central base station, optical mm-wave transmission is widely considered in order to avoid any signal processing and oscillators at the transponders. Hence, a major system design goal is the design of efficient optical feeding architectures which reduce the overall system complexity. In [1], we proposed and demonstrated a system where a subharmonic master oscillator, simultaneously imposed on a WDM optical backbone, was used at any of the remote transponders for electrical upconversion. In this paper, we use this single external modulator for simultaneous electro-optical upconversion [2] of individual IF signals in seven operational WDM channels to 60 GHz range. Applying this technique, the effort for mm-wave signal generation is reduced significantly. Data transmission experiments applying modulation schemes such as OFDM (50 MBit/s) and BPSK (156 MBit/s) and realistic air link scenarios demonstrate the feasibility of the technique. Low bit error rates were obtained in all experiments.

II. SYSTEM CONCEPT

Based on a dense wavelength-division multiplex system, the technique of simultaneous electro-optical upconversion requires just one single high-speed external modulator for generating individual mm-wave signals in each optical channel. Apart from this single modulator, all other optical components within the feeding system are standard telecom products. The system setup is depicted in Fig. 1. Four blocks are incorporated - central base station, optical backbone, transponder (remote radio access station) and the portable/mobile user segment. By using dense WDM as a means of feeding a larger number of transponders, the system is easily extendable and optical amplification can be accomplished on the common backbone section. An optical channel is assigned to each picocell by its wavelength and the optical mm-wave signal is dropped off the fiber bus at the transponder's site by using a fiber Bragg grating based add-drop-multiplexer (ADM). A feature of flexibility in our system concept is the generation of an oscillator signal for downconversion of the received signal at the transponder if a certain picocell is in uplink mode. In this case, the corresponding laser diode is just emitting an CW optical carrier and the modulator is imposing the oscillator tone onto this channel while upconverting IF signals at other channels. By biasing the external Mach-Zehnder modulator (MZM) at V_π and driving the device with a master tone at f_{MLO}, optical double-sideband modulation with suppressed carrier is achieved for all wavelengths at the same time. At any of the photodiodes the $\pm f_{\mathrm{MLO}}$ spaced sidebands and the laser drive signals f_{IFx} are heterodyned, resulting in mixing products of type $\pm u{\cdot}f_{\mathrm{MLO}} \pm v{\cdot}f_{\mathrm{Ifx}}$. By assigning f_{IFx} to the associated wavelength λ_{x}, different millimetric frequencies can be obtained at the picocells and, furthermore, they are not restricted to synchronous operation.

III. EXPERIMENTS AND RESULTS

The concept developed has been proved with the built demonstrator by numerous experiments in down- and uplink transmission mode [3]. Here, transmission experiments in downlink are presented, with a total number of seven operational optical WDM channels. Different modulation schemes have been employed - binary phase shift keying (BPSK) and a multicarrier scheme utilizing 512 individually modulated frequency subcarriers (OFDM). The latter technique is particularly well-suited, since influence of multipath effects within the air channel can be reduced, thus greatly improving measurement repeatability. Further, the high susceptibility of OFDM to linear and non-linear distortions makes it an ideal choice for linearity testing purposes of the complete system, eventually phase noise requirements are rather stringent.

During downlink, seven central base station laser diodes ($\lambda_1 \ldots \lambda_7$) have been directly modulated *(i)* with an OFDM signal stream at 50 MBit/s, centered at $f_{\mathrm{IF1}} = 2.268$ GHz or, *(ii)* alternatively, with a BPSK modulated signal of 156 MBit/s at $f_{\mathrm{IF2}} = 2.222$ GHz. Output number eight of the IF splitter cascade has been used to monitor the laser diodes' drive signal. Prior to optical combining, delay lines had been introduced in order to decorrelate the bit patterns. Table 1 summarizes the parameters of the WDM channel assignment. On the common backbone the Mach-Zehnder modulator being biased at V_π and driven by $f_{\mathrm{MLO}} = 28.800$ GHz ($P_{\mathrm{mod}} = +17$ dBm) simultaneously upconverted all seven IF input signals. Fig. 2 depicts the optical spectrum measured directly at the output of the central base station (point B in block diagram). The pairs of first order sidebands separated by $2{\cdot}f_{\mathrm{MLO}}$ can be distinguished clearly, as well as the suppressed carriers. However, the resolution of the optical spectrum analyzer does not permit observation of the IF sidebands. After transmission over l_1=12.8 km standard SMF and optical amplification, one optical channel is selected and dropped at the transponder site by means of an apodized Bragg grating filter ($B_{-1\mathrm{dB}} = 67$ GHz). The optical spectrum prior to photodetection ($\eta_{\mathrm{PD}} \approx 0.1$ A/W, point A in block diagram), with λ_3 selected, is shown in Fig. 3. More than 25 dB adjacent channel rejection has been achieved. In a real system, adjacent optical channels would be modulated with different IF bands (Section II). In the demonstrated case though, an identical f_{IF} was utilized for all WDM channels, which potentially causes more severe crosstalk problems.

In the transponder, the combination product with $u = 2$ and $v = 1$ ($f_{\mathrm{RF1}} = 59.868$ or $f_{\mathrm{RF2}} = 59.822$ GHz) is filtered, amplified by a V-band high gain cascade ($G_1 > 50$ dB) and subsequently transmitted ($P_{\mathrm{out}} \leq 5$ dBm) omni-directionally by means of a monopole antenna ($G_{\mathrm{tx}} = 4$ dBi) over specially shaped groundplane [4]. The mobile station equipped with a horn antenna ($G_{\mathrm{rx}} = 20$ dBi) at $d = 5$ m comprised of a double conversion heterodyne structure with vector demodulation/modulation to and from baseband. An automatic frequency control was implemented for OFDM transmission, compensating for the mobile station's first oscillator drift and keeping accuracy within $\delta f = \pm 500$ Hz. The measured downlink bit error performances of five selected (seven operational) WDM channels for BPSK modulation with 156 MBit/s and OFDM at 50 MBit/s are shown in Figs. 4 and 5, respectively. At a *BER* of 10^{-8} for BPSK and 10^{-7} for OFDM, the variation of required signal-to-noise ratio has been found $\Delta SNR = \pm 0.7$ dB and ± 0.8 dB, respectively, which is considered a reasonably low value.

IV. CONCLUSIONS

An efficient and flexible radio-optical feeding system for a wireless LAN at 60 GHz has been proposed by means of simultaneous electro-optical upconversion. Utilizing seven optical WDM channels separated by $\Delta\lambda = 0.8$ nm, downlink data transmission experiments with 50 MBit/s 512-carrier QPSK-OFDM and BPSK at 156 MBit/s have been carried out successfully, reflected by uncoded bit error performances of $2 \cdot 10^{-8}$ and $6 \cdot 10^{-10}$ for the given modulations, respectively. Further, the variation in error performance between the measured WDM channels remained well within ±1 dB. Care was taken to employ a realistic link scenario with omnidirectional picocell coverage and appropriate range, thus verifying the feasibility of the system designed.

V. ACKNOWLEDGEMENT

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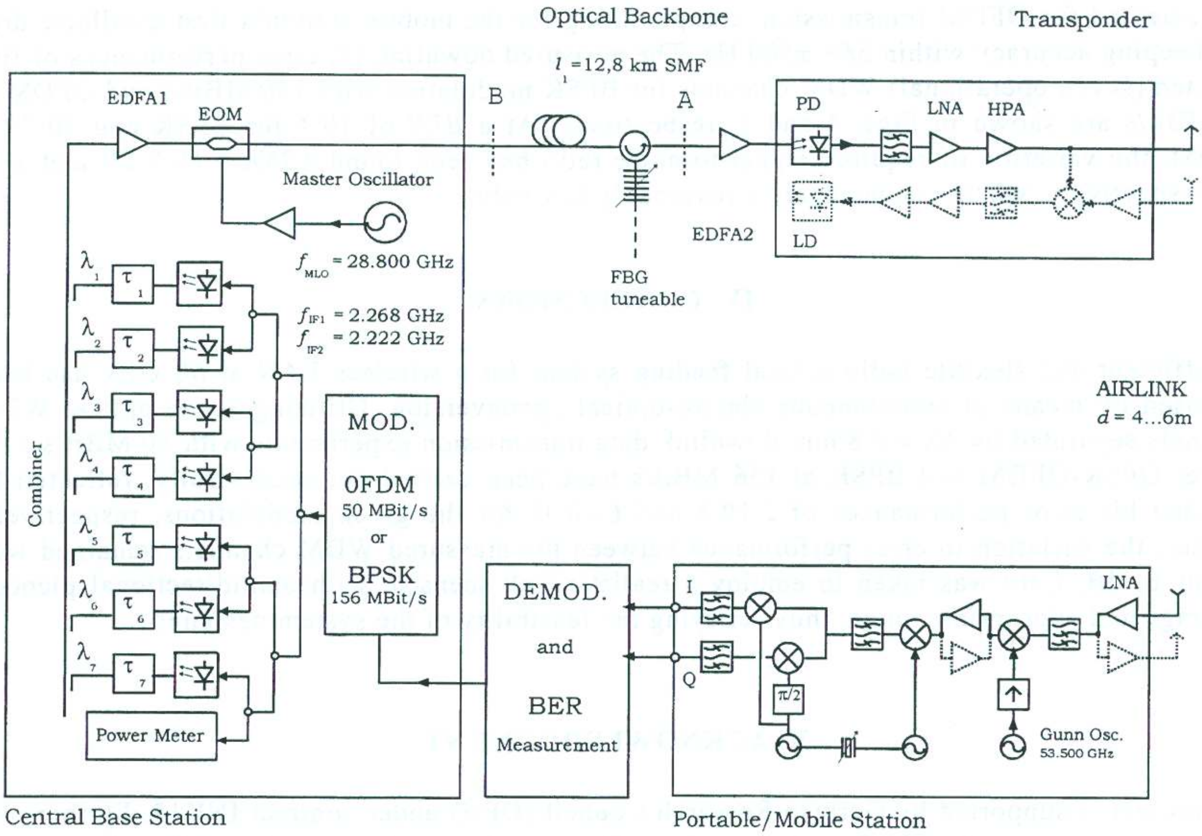

Fig. 1: Experimental Setup

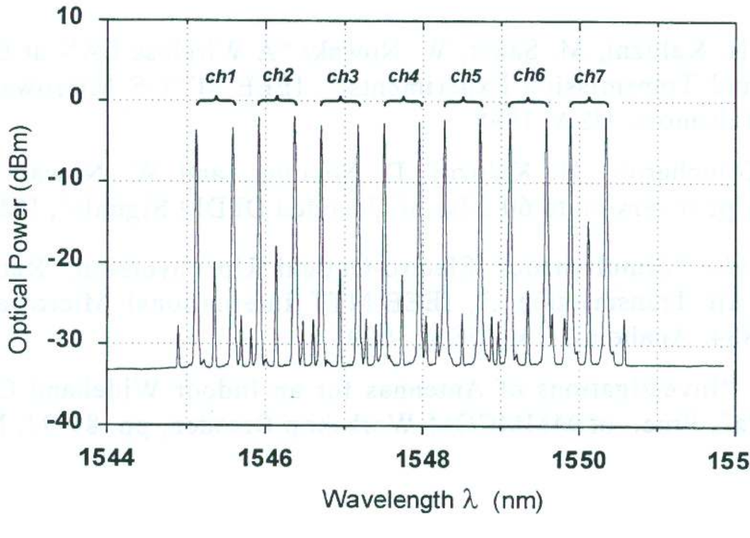

Fig. 2: Optical spectrum at Central Base Station output (ref. point B in experimental set-up). Seven WDM channels are fed into optical backbone.

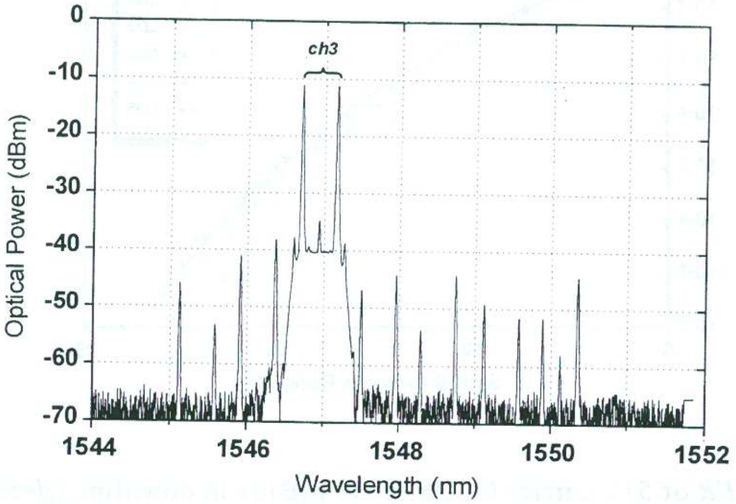

Fig. 3: Optical spectrum prior to photodetection (ref. point A in experimental setup). WDM channel at λ_3 selected by Bragg grating filter.

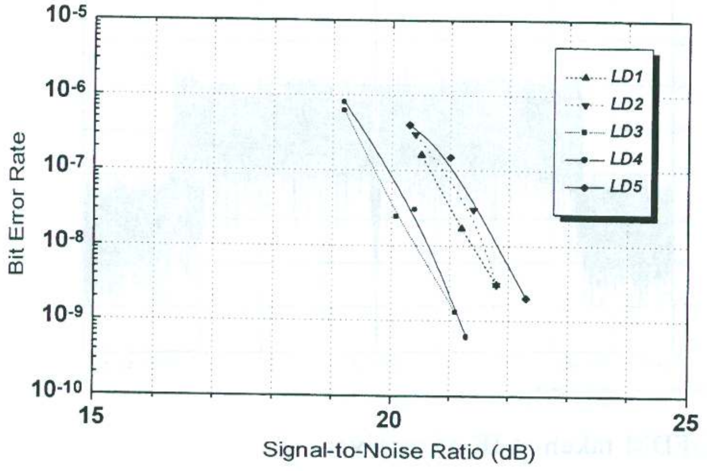

Fig. 4: Measured *BER* of BPSK at 156 MBit/s in downlink (*d*=5m) for given WDM channels 1 through 5. Seven optical channels in operation.

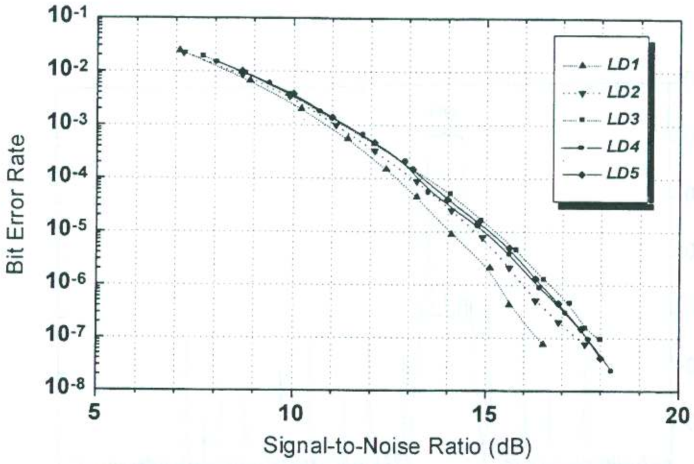

Fig. 5: Measured *BER* of 512-carrier OFDM at 50 MBit/s in downlink (*d*=5m) for given WDM channels 1 through 5. Seven optical channels in operation.

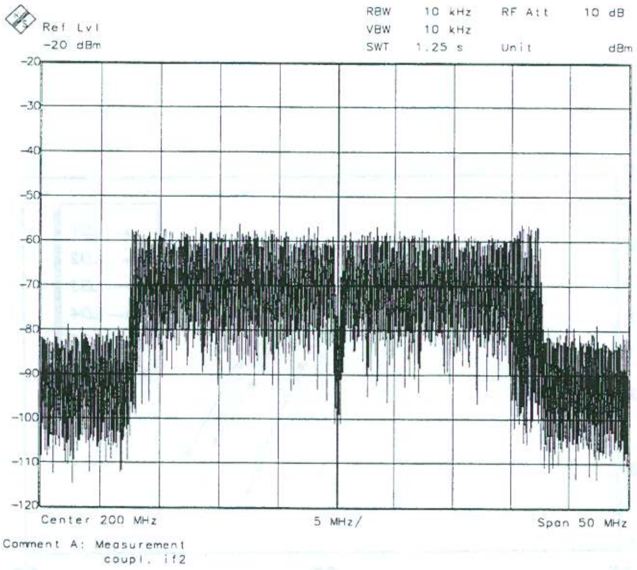

Fig. 6: Spectrum of OFDM taken at IF of receiver.

WDM Channel/ Laser Diode Nr.	Wavelength λ (nm)	Delay Line (μs)
1	1545.32	0
2	1546.12	0.50
3	1546.92	0.25
4	1547.72	1.10
5	1548.52	1.00
6	1549.32	1.25
7	1550.12	1.35

Table 1: WDM channel assignment.