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Optical Routing of Millimeter-Wave Signals with a New Optical Frequency Multiplication Scheme

Hyun-Do Jung*, Chigo Okonkwo, Eduward Tangdiongga, and Ton Koonen

COBRA Research Institute, Eindhoven University of Technology, 5600MB, the Netherlands

* *Corresponding author*: Phone: +31 40 247 5627, Fax: +31 40 245 5197, E-Mail: jhd94@ieee.org

Abstract – We demonstrate a new OFM configuration using XGM in SOA for simultaneous all-optical generation and routing of mm-wave signals for in-building networks. After routing, EVM of 4.5% is achieved for 20MS/s, 64-QAM data at 39.6GHz.

1. Introduction –The millimeter-wave (mm-wave) frequency band (26~70GHz) has raised much interest in broadband wireless access applications as it offers a large bandwidth, avoids the spectral congestion occurring in the lower microwave bands, and reduces interference by creating picocells, but the difficulties in millimeter-wave generation, transmission, and processing limit its wide usage. However, with the development of fiber-optic technologies, Radio-over-Fiber (RoF) techniques can offer valuable solutions for these problems [1],[2]. Moreover, the combination of mm-wave technology with Radio-over-Fiber (mm-RoF) has emerged as a key technology for in-building networks. By means of mm-RoF systems, picocells in a building can be extended to several rooms instead of having a single large wireless network, which covers the whole building and causes interference problems. Recent proposals have suggested that radio signals are broadcasted through the optical fiber link and the channel selection is done at each destination. With broadcast-and-select configurations, however, there are concerns regarding high power consumption and security. In this paper, we demonstrate a new optical frequency multiplication (OFM) configuration [3] for in-building networks shown in Fig. 1. Key functionalities of the proposed architecture are simultaneous all-optical mm-wave generation and selective routing of the mm-wave signals to individual rooms based on encoded header information [4]. This centralized optical routing can dynamically adjust the optical connectivity and RF frequency allocation. Hence the radio-cells can be dynamically adjusted in size and capacity, which improve the traffic handling capacities and network operational efficiency. As a proof of concept, we successfully demonstrated optical up-conversion of 3.6GHz radio signal carrying 20MSymbols/s 64-QAM data to 39.6GHz mm-wave frequency, and selective optical routing of mm-wave signals to the destination. At the destination, the detected signal showed error vector magnitude (EVM) of 4.5% at 39.6GHz.

2. Operational principle of the proposed system – Figure 1 illustrates the in-building network scenario. An optical transparent gateway routes wired radio data signals from the central station (CS) to each room based on address information [4]. The proposed all-optical routing system for mm-wave signals consists of a tunable source, a phase modulator, a 3-dB coupler, an SOA, a Mach-Zehnder Interferometer (MZI), and an optical router based on an arrayed waveguide grating (AWG). The continuous wave (CW) optical signal (λ_{CW}) from the tunable source, which are selected based on the address information extracted from the downstream optical signal,

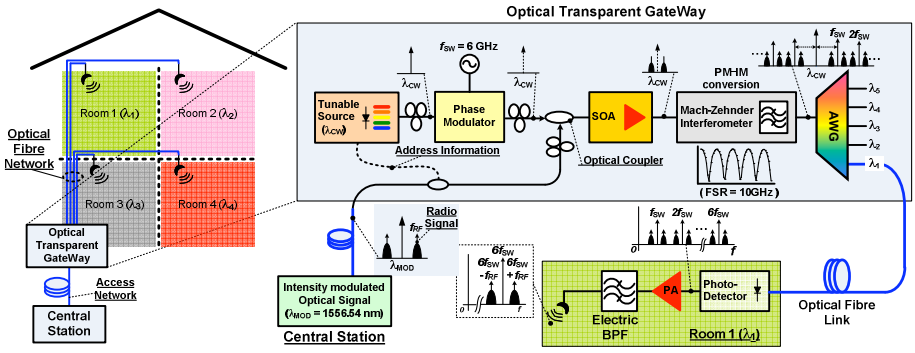

Fig. 1 Concept and experimental setup (Radio signal from the central station: 20Msymbols/s, 64-QAM at 3.6GHz RF carrier)

are phase-modulated (PM) by the RF sweep signal (f_{SW}) to generate optical harmonics (the OFM technique [3]). These PM optical signal (λ_{CW}) is injected into the SOA together with the intensity-modulated (IM) optical signal (λ_{MOD}) carrying the radio signal from the CS. By cross-gain modulation (XGM) in the SOA, the radio signal is duplicated onto the PM optical signal (λ_{CW}). In the MZI, PM-IM conversion allows the mm-wave carriers at the multiples of the RF sweep frequency (f_{SW}) to appear at the optical wavelength (λ_{CW}) as illustrated in Fig. 1. Then, the converted optical signal (λ_{CW}) are routed by means of the AWG to the destination (room), where it is detected and the mm-wave radio signal is selected by a bandpass filter (BPF).

3. Experimental results and discussion –To generate mm-wave carrier signal, the CW optical signal (λ_{CW}) from the tunable source was phase-modulated with a 6GHz RF sweep signal (f_{SW}). The CW wavelength (λ_{CW}) was selected by header processing based on the address information extracted from the modulated optical signal (λ_{MOD}) [4]. Figure 2 (a) shows the RF spectra of the multiple harmonics generated by the OFM technique. The proper adjustment of both the phase modulation index (β) and the center-wavelength (λ_{CW}) of the tunable source allows the amplitude of each harmonic signal to be tuned. In the experiment, the 6th order harmonic (36GHz) was optimized at 6.8 (β), 1550.735 nm (λ_{CW}). This PM optical signal was inserted into the SOA with the IM optical signal carrying the radio data signal (f_{RF} = 3.6GHz) shown in Fig. 2 (b). Then, the radio signal was duplicated (wavelength-converted) on the PM optical signal and optically up-converted along with the harmonics of f_{SW} to $f_{UP} = n \cdot f_{SW} \pm f_{RF}$ (where n is the order of harmonics) by XGM of the SOA; Fig. 2 (c) depicts the radio signal up-converted to f_{UP} = 39.6GHz (6th harmonic of f_{SW}). As shown in the figure, the SNR of the mm-wave signal is reduced by around 16dB and there is an EVM penalty of 2.5%, compared to the input RF signal. In addition, a nonlinear skirt slope appears at the edge of the signal band. This degradation comes from the ASE noise of the SOA, the wavelength-conversion penalty, and the nonlinearity of the SOA gain profile. Nevertheless, the performance of the routed signal at the destination meets the EVM requirements for the wireless standards.

4. Conclusions –In this paper, we proposed a new configuration for all-optical generation and routing of mm-wave signals using the OFM technique for in-building networks. By using XGM in an SOA, we can optically up-convert radio signals at low frequency to mm-wave frequency region and convert radio signals to different wavelength signal at the same time. In the experiment, we successfully demonstrated optical up-conversion from a 3.6GHz radio signal carrying 20MS/s 64-QAM data to a 39.6GHz mm-wave frequency and optical routing of the mm-wave signal to different destination. At the receiver side, the routed signal showed the EVM performance of 4.5% for 20MS/s 64-QAM data at 39.6GHz.

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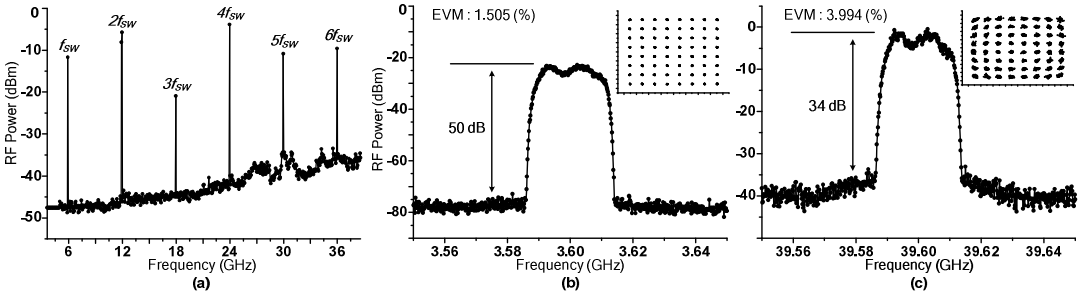

Fig. 1 RF Spectra of (a) multiple harmonics generated with RF sweep frequency (f_{SW} = 6GHz), (b) input 64-QAM signal (20MS/s) at 3.6GHz, (c) received 64-QAM signal (20MS/s) at 39.6GHz. (Inset : Constellation diagram)