Flexible Multi-Band OFDM Receiver Based on Optical Down-Conversion for Millimeter Waveband Wireless Base Stations

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Abstract *A novel and flexible photonics-based down-conversion scheme is proposed for wireless receivers in base stations. It allows simultaneous detection of multiple signals at carriers up to tens of GHz, enabling communications at millimeter waves. Experiments demonstrate the effective down-conversion of Wi-Fi signals at 2.4 and 39.8GHz with EVM<-43dB.*

Introduction

The growing demand for mobile broadband services is putting wireless networks under tremendous pressure. The capacity increase of new protocols as LTE (Long Term Evolution) and LTE-Advanced, and the reduction of network cell dimensions, will be inadequate to address all the future bandwidth requirements[1]. The wireless community is therefore considering to extend the exploited spectrum to the millimeter waveband (MMB, 3-300GHz) which is underutilized and offers enormous bandwidth[2]. Orthogonal frequency division multiplexing (OFDM) will probably be the preferred air-interface due to its resilience and flexibility, but its detection requires local oscillators with good phase stability to avoid inter-channel interference. In today's base stations, the wireless equipments cannot simultaneously manage wireless signals ranging from few MHz to several GHz. If a single transceiver with the capability of treating multiple frequency bands up to the MMB were available, it would strongly reduce the hardware requirements, and will enable the implementation of a flexible multi-protocol base station for future mobile networks. To the best of our knowledge, only one paper has explored the down-conversion of multiple signals[3], but applying a statistical approach that does not fit the mobile communication scenario.

In this paper we propose a novel flexible wireless receiver that exploits a mode locked laser (MLL) to simultaneously and precisely down-convert signals from several different bands ranging up to the MMB, without requiring frequency- or protocol-specific RF components. This way the huge data traffic managed by the base station can be received and processed at low frequency where detection is cheaper. We believe this receiver scheme allows the realization of future-proof mobile systems.

Concept

The proposed optical down-converter is based on the concept of optical sampling (see Fig. 1 for reference). If an optical pulse train (e.g., a MLL) with repetition rate f_{Rep} is modulated by an RF signal at f_{RF}, the spectrum of the modulating signal is replicated every f_{Rep} on the spectrum. When the modulated optical signal is revealed in a photodiode (PD), the heterodyne process will generate a copy of the RF signal down-converted within the range from DC to f_{Rep}. If the pulse train is modulated by the sum of several RF signals at different frequencies, all the RF signals will be down-converted to below f_{Rep} and, provided the pulse repetition rate is correctly chosen, they will not overlap with each other. Since the electrical spectrum of interest is limited to f_{Rep}, the required PD can have an E/O
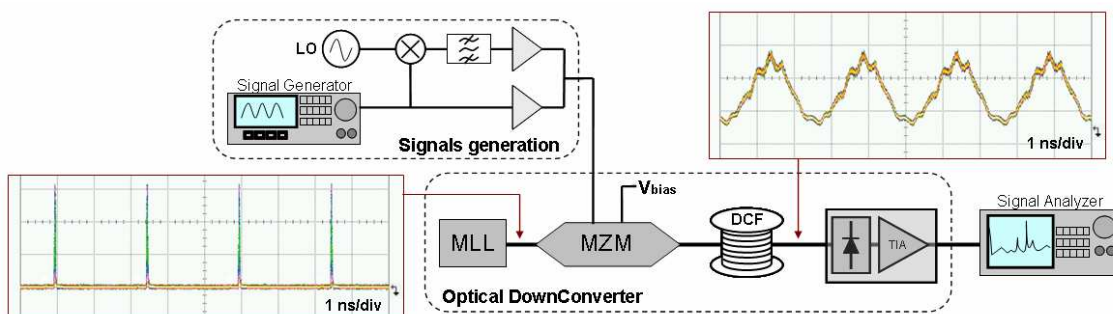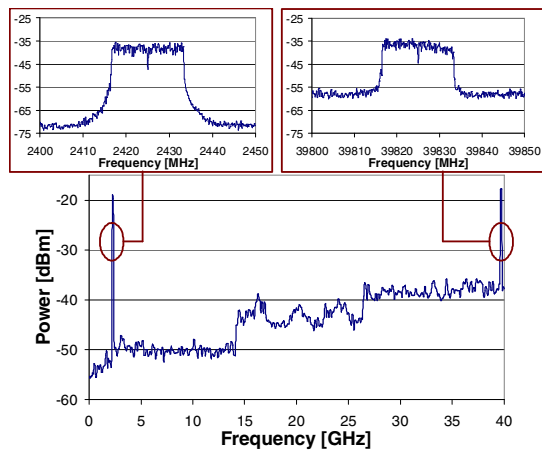

Fig. 1: Experimental setup. LO: Local Oscillator; MLL: Mode-Locked Laser; MZM: Mach-Zehnder Modulator; DCF: Dispersion Compensating Fiber; TIA: Trans-Impedance Amplifier. Insets: waveforms of the pulses before and after the DCF, as seen by the exploited photodiode (bandwidth 10GHz).

bandwidth just larger than f_{Rep}. On the other hand, the bandwidth of the pulsed laser must be larger than the maximum RF frequency to be down-converted. In order to match the bandwidth of the detected pulses to the analysis range, it is convenient to broaden the pulses (e.g., through chromatic dispersion) so that most of the power detected by the PD is below f_{Rep}.
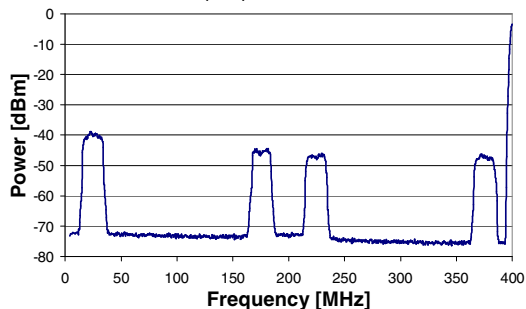
Experiment

The experimental setup is depicted in Fig. 1. A multi-band RF signal is first generated to test the proposed receiver. A vector signal generator (Agilent MXG-N5182) is exploited to generate 52 OFDM sub-carriers around 2.425GHz, carrying 54Mbps over a 64-QAM pattern, according to the 802.11g standard. To obtain two signal bands, the Wi-Fi signal is split and up-converted to 39.825GHz via an RF mixer driven by a local oscillator at 37.4GHz. A band-pass filter is used for rejecting the image frequency before summing the two signal bands together. A delay is also inserted for decorrelating the waveforms. The spectrum of the dual-band signal thus generated is reported in Fig. 2. The insets show the two Wi-Fi frames. The signal at 39.825GHz suffers non-uniform channel power due to the narrow bandwidth (40MHz at 39.812GHz) of the exploited RF filter.

In the optical down-converter, the generated multi-band signal modulates a pulsed laser in a Mach-Zehnder modulator (MZM) driven in its linear region. The laser is a passive MLL at 1554nm with a repetition frequency of 400MHz and a pulsewidth of 1.5ps. A spool of dispersion compensating fiber (DCF) with a total dispersion of 320ps/nm is inserted to broaden the pulses, so that they resemble a sinus wave at 400MHz (see inset in Fig. 1). The optical signal is then detected by a photodiode (PD), thus realizing the down-conversion of the two RF signals simultaneously. The electrical spectrum generated by the PD between DC and 400MHz is reported in Fig. 3. The signal at 2.425GHz is down-converted at 25MHz, and the signal at 39.825GHz is moved at 225MHz. The respective image-frequency signals at 375MHz and 175MHz are also generated. The first harmonic of the laser pulses is also visible at 400MHz. Finally the signal replicas at 25MHz and 225MHz are received by a vector signal analyzer (Agilent MXG).

Fig. 4a) reports the Error Vector Magnitude (EVM) measured on the down-converted 2.425GHz signal varying the RF power at the input of the MZM (squares), while maintaining the 39.825GHz channel at its optimum power (-4dBm). Increasing the RF input power, the EVM decreases due to the improving signal-to-noise ratio, until a minimum EVM of -43dB is reached at -2dBm. From this point on, after a short region of stable behaviour, the EVM starts increasing due to the saturation of the RF amplifiers used in the signal generation. The saturation cannot be ascribed to the transfer function of the MZM, since the total RF input power is low (<5dBm, while the MZM V_π is about 6V). The excellent quality of the down-converted signal is demonstrated by the inset in Fig. 4a) showing the demodulated 64-QAM constellation for the lowest EVM. The analysis has been repeated switching off the signal at 39.825GHz (diamonds), obtaining almost identical results and demonstrating that the simultaneous down-conversion of more than one channel does not affect the performance of the system. The results are compared with the direct demodulation of the 2.425GHz signal at the vector signal analyzer (triangles). The back-to-back curve reaches the minimum EVM of -44.7dB at -14dBm, and keeps constant to about 0dBM where the saturation of the RF amplifiers makes it increasing. The comparison between the back-to-back and the optically down-converted signals reveals that the proposed scheme shows only a small performance reduction, due to the out-of-band noise down-converted to the analysis range, and a decrease

Fig. 2: Electrical spectrum of the multi-band RF signal. Insets: OFDM spectra at 2.425GHz (right) and at 39.825GHz (left).

Fig. 3: Down-converted signals from DC to 400MHz.

of sensitivity related to the V_π of the used MZM.

The analysis has been repeated on the signal at 39.825GHz, as reported in Fig. 4b). The curve related to the down-converted signal at 39.825GHz taken with the 2.425GHz signal at its optimum power (-2dBm) (squares) shows the same behaviour as the previous case, except for the minimum EVM that here is -34.5dB due to the quality of the generated signal. Nevertheless the constellation reported in the inset for the best EVM is very clear. With respect to the curve obtained switching off the signal at 2.425GHz (diamonds), the measures show an EVM penalty of 0.5dB at low input power that disappears when the minimum EVM is reached. This degradation can be ascribed to a lack of isolation in the signal generation scheme, which allows the signal at 2.425GHz to counter-propagate in the 39.825GHz amplifier reducing its efficiency. Since the vector signal analyzer cannot directly demodulate the signal at 39.825GHz, here the optical down-conversion has been compared to an RF down-conversion from 39.825GHz to 2.425GHz (triangles). The back-to-back curve reaches the EVM floor at -13dBm, with a performance only 1.7dB better.

Comments and conclusions

The experimental results confirm that the proposed optical down-converter can simultaneously deal with multiple RF signals over a very wide frequency range, and without frequency-dependent performance degradations that are typical of RF down-conversions. This is due to the fact that common MLLs show a better

a)

b)

Fig. 4: EVM versus modulating signal power at a) 2.425GHz and b) 39.825GHz bands. Insets: Relative constellations at minimum EVM.

phase stability than high frequency oscillators, thus allowing a precise down-conversion of OFDM frames even at very high frequency, as demonstrated by our experiment. Integrated MLLs also shows a significant tunability in repetition rate which can help reconfiguring the optical down-converter. The small penalty measured in the EVM, due to the folded out-of-band noise, can be reduced by a fine design of the amplifiers bandwidths. The bandwidth limit of the proposed scheme is set by the electro-optical bandwidth of the modulator, which anyway can reach 110GHz[4]. A dual parallel MZM can also be used to realize a single-side band optical modulation, thus avoiding the image-frequency components in the down-converted frequency range, and eliminating the risk for dispersion effects[5]. Finally, an improve in the down-converter sensitivity can be achieved with modulators with reduced V_π.

In conclusion, we have proposed and demonstrated a novel optical down-converter scheme that exploits a MLL to simultaneously and precisely down-convert RF signals from several different bands, ranging up to the MMB. The scheme is suitable for the use in future wireless base stations managing large amount of data over several different protocols and carrier frequencies, since it can flexibly and precisely down-convert any RF signal without requiring frequency- or protocol-specific RF components. This feature also allows the reconfigurability of the base station to new transmission protocols without changing the hardware, thus reducing the capital expenditure. Finally, we believe this architecture can help the realization of future-proof flexible mobile systems.
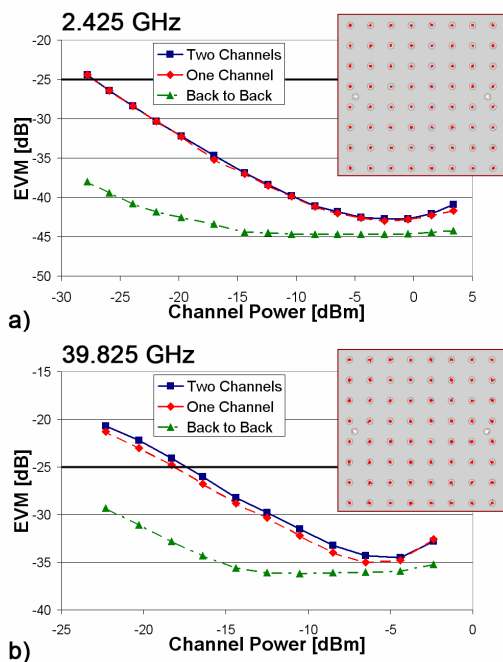
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