Performance Analysis of Multi-format WDM-RoF Links Based on Low Cost Laser and SOA

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Abstract. In this paper, we experimentally study the effects of using low cost optical amplifiers and lasers in multi-format multi-wavelength radio over fiber signals. We analyze the propagation of UMTS, WLAN and WiMAX radio signals in a single channel scenario and study the impact of amplifying the referred radio signals together with amplitude modulated ones, which can be ethernet, in WDM scenario.

Keywords: RoF, UMTS, WLAN, WiMAX, SOA.

1 Introduction

Radio waves are nowadays the most popular way to communicate, since they are used in the very front end of every user, as they provide an extremely important facility: mobility. On the other hand, the demand and increase of penetration of data and voice, has pushed the operators into several developments and strategies to enable full time, space and, whenever possible, bandwidth coverage to the users. This attitude leads the operators and their suppliers to find all types of technical solutions that can make the three aforementioned guidelines possible. Some of the challenges are for example to manage bandwidth in highly dense sporadic places, (commercial centers, shows, sport games) or to allow coverage in places where wave propagation is not easy. In some of these cases fiber information distribution can be a solution [1].

Passive Optical Networks (PON) are concurrently being deployed everywhere, in order to allow the operators to arrive with better quality and in a transparent way to the customers' home. Radio distribution over PONs can be seen as a promising technique to overcome many of the radio frequency (RF) spectrum limitations. The signal distribution is also improved with the RF signals being transmitted in their raw form to antennas eliminating some signal processing. Thus, the transmission equipment will be more simplified and by using micro-cells the required power level will be reduced eliminating the need for expensive power amplifiers and frequency multiplexers [2]. However, this can only be a reality if it is proven to be possible to implement in a cost effective way. In Fig. 1 it is presented a possible scenario where one or more services will share the same trunk fiber and can or not share one of the

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arms of the PON, depending on the needs of the location/costumer. The losses of the PON splitting ration need to be compensated by a booster amplifier located at the central office. The presence of several signals can limit their propagation and detection, and this is the topic of this work.

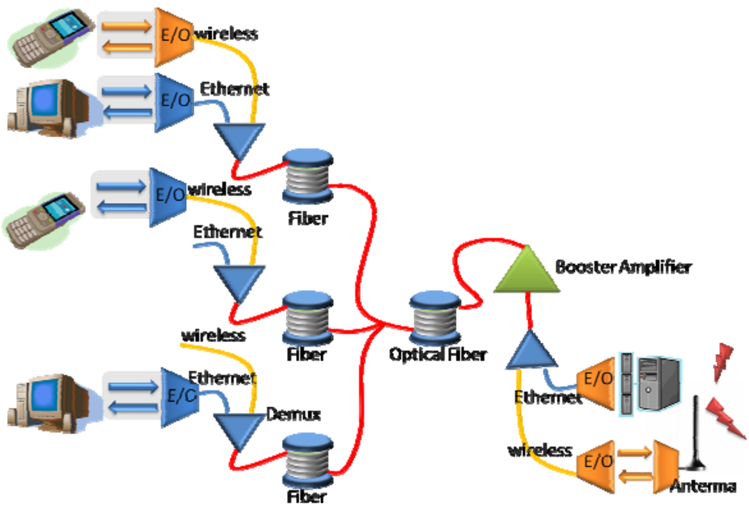

Fig. 1. Block diagram of a possible scenario

In this work we analyze different aspects of such approach. We use low cost optical sources (coarse WDM DFB uncooled lasers, directly modulated) and amplifiers (Semiconductor Optical Amplifiers – SOA) and observe the impact of propagating multi-format multi-wavelength signals through the optical link. We considered three different types of signals of distinct technologies: UMTS, WLAN and WiMAX.

2 UMTS, WLAN and WiMAX Signals

UMTS is a third generation mobile service that uses Code Division Multiple Access (CDMA) in order to guarantee multiple connections. The signal bandwidth available is 3.84 MHz so an increase on the number of accesses will decrease the bandwidth assigned to each user. In a UMTS communication there are two distinct frequency bands: the Uplink band to establish the transmission between the User equipment and the Base Station, and a Downlink band to make the communications in the reverse direction.

A wireless LAN, WLAN, is based on the principle of transmitting simultaneously many narrow-band orthogonal frequencies, provided by Orthogonal Frequency-Division Multiplexing (OFDM). This gives users the mobility to move around within a broad coverage area and still be connected to the network. The 802.11g standard for WLAN offers wireless transmission over relatively short distances at 54 Mbps.

The WiMAX technology uses the same physical layer (OFDM) as WLAN but is a longer range system that allows a growth in the coverage cell area. The communication is established between a Base station and a Subscriber station, and it uses 2 channels: uplink and downlink. WiMAX uses a mechanism based on setting up connections between the Base Station and the user device, guaranteeing a certain quality of service (QoS) for each flow. The 802.16 standard for WiMAX is applied across a wide swath of the RF spectrum that allows if to function on any frequency below 66 GHz, but for higher frequencies the base station range decreases to a few hundred meters in an urban environment.

Some characteristics of these signals are presented on Table 1.

Table 1. Radio signals characteristics

	UMTS - 3G	WLAN	WiMAX
Standard		802.11g	802.16
Physical layer mode	WCDMA-3GPP	OFDM	OFDM
Modulation	QPSK	64 QAM	QPSK ¾
Bit rate (Mbps)	3,84	54	15
Limit for EVM (%)	12	5,62	1,41

The performance metric for signal transmissions is EVM (Error Vector Magnitude) that measures the degradation of the obtained constellation during transmission. In Fig. 2 is expressed the error vector as the difference between the theoretical waveform and a modified version of the measured waveform.

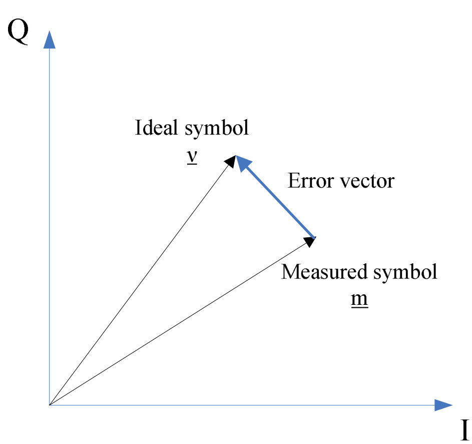

Fig. 2. Error Vector Magnitude (EVM)

3 Semiconductor Optical Amplifier

The SOA gain dynamic is determined by the carrier recombination lifetime (few hundred picoseconds). This means that the amplifier gain will react relatively quickly to changes in the input signal power, producing variations both in power and phase. These variations can cause signal distortion, which will surely be more evident in multichannel systems, where the dynamic gain leads to inter-channel crosstalk. This is in contrast to doped fiber amplifiers, which have recombination lifetimes of the order of milliseconds leading to negligible signal distortion.

SOAs also exhibit nonlinear behavior. These nonlinearities can cause problems such as frequency chirping and generation of inter-modulation products. The main cause for these nonlinearities is the carrier density change. The effects we are interested in within this study are: cross gain modulation (XGM), self gain modulation (SGM), cross phase modulation (XPM) and self-phase modulation (SPM).

When injecting a single channel in the SOA, changes on its optical power may lead to phase shifts creating SPM. If more than one signal is injected into an SOA, there will be cross-phase modulation (XPM) between the signals. XPM can be used to create wavelength converters and other functional devices.

The material gain spectrum of an SOA is homogenously broadened. This means that carrier density changes in the amplifier will affect all of the input signals creating SGM when having only one channel. In the other hand it is possible that a strong signal at one wavelength to affect the gain of a weak signal at another wavelength. This non-linear mechanism is called XGM.

4 Experimental Setup and Results

In Fig. 3 and Fig. 4 are illustrated the setups used. The Radio Frequency (RF) signals are provided through a Rohde & Schwartz vector signal generator that is used to directly modulate a laser, emitting at 1.55 μm. In the WDM scenario the RF signal is on one channel and the AM modulated one (an amplitude modulated ECL laser) 2 nm higher. The optical signal is then pre-amplified in both cases using a SOA with an internal pump laser (1 nm below the RF channel) to control saturation, and transmitted over a standard single mode fiber. At the output the RF signal channel is filtered, detected and applied to a vector signal analyzer to assess performance.

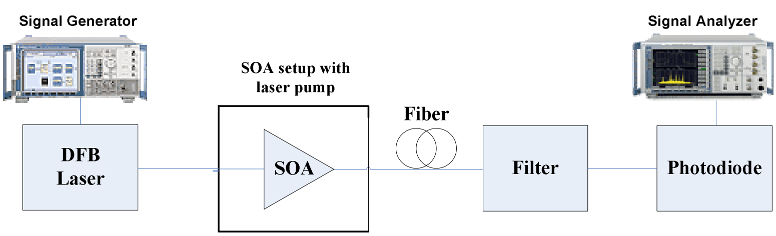

Fig. 3. Single Channel setup

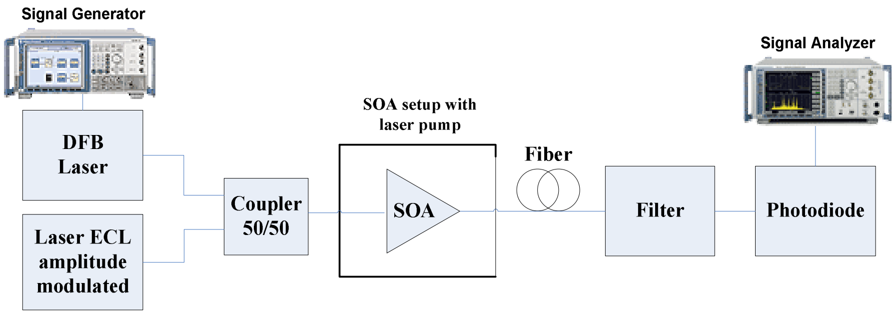

Fig. 4. WDM setup

To study the effects of SOA saturation on the transmission of the RF signals it is important to know the amplifiers gain response. In Fig. 5 are illustrated the curves of the SOA gain response when using different polarizations of the laser pump to saturate it.

For the different biasing currents it is observed the SOA saturation behavior evidenced by its gain decrease and stabilization for the higher currents. Without the pump laser, the gain falls 3 dB when the input signal reaches -11dBm. For the other biasing currents the gain is mainly constant with the increase of the input signal power, showing that the amplifier is already in saturation.

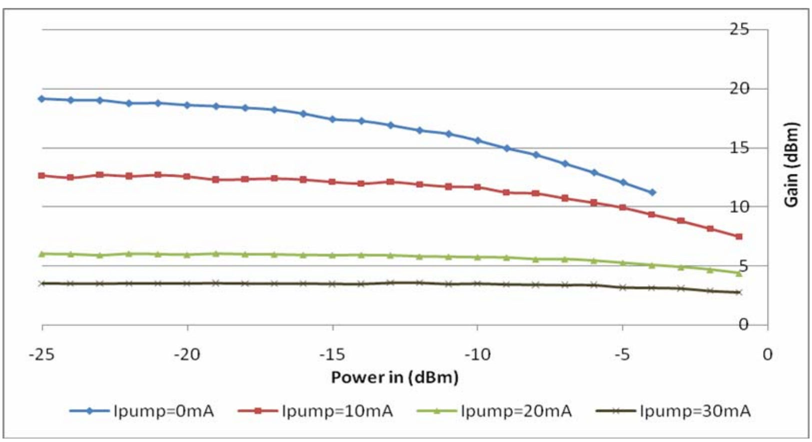

Fig. 5. Gain saturation curves of the SOA

When transmitting UMTS signals (setup of Fig. 3 with L=40 km) the results on Fig. 6 are obtained. The best results for the unsaturated operation (pump laser off) due to higher gain. Biasing the pump laser with 10 mA leads to higher degradation when compared to the other pump biasing currents. This fact can be explained by the observation of the SOA saturation curves, presented in Fig. 5, that show a more linear behavior for higher input powers at the SOA, in the case of 20 and 30 mA. Thus, the gain saturation can be more relevant when pump is biased with 10 mA. When

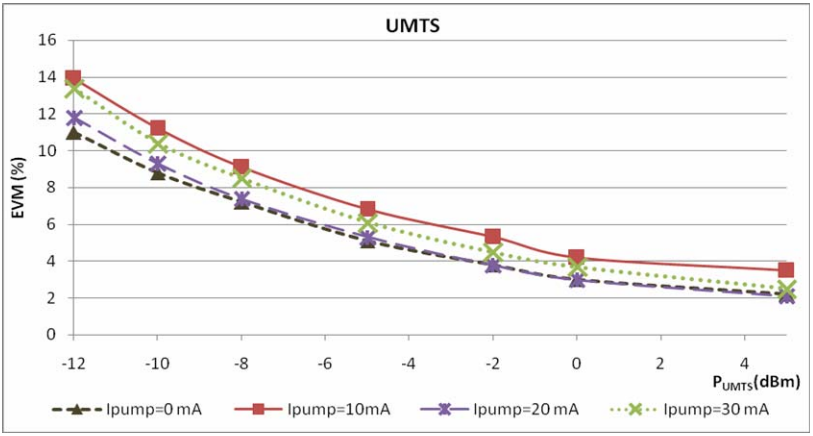

Fig. 6. EVM versus input RF power for SOA with different polarization currents.ves of the SOA

comparing the results for 20 and 30mA, they are similar, but with higher EVM values for 30 mA, due to higher saturation, therefore lower gain.

The results verified for the UMTS are similar to the ones of WiMAX and WLAN therefore not presented here.

Fig. 7 shows the behavior of the signals for two powers of the pump laser and show that indeed the results follow the previously discussed ones, when smaller the saturation the better behavior of the system.

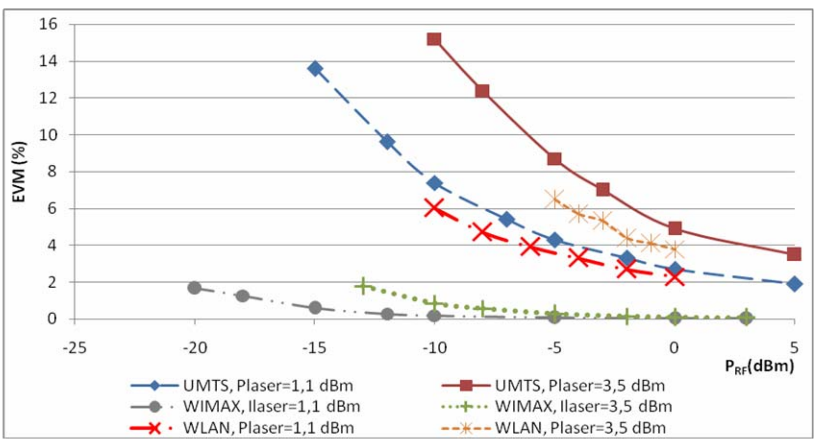

Fig. 7. Single channel setup for a direct link and different polarizations of the DFB laser

To achieve the perception if the distortion effects of the SOA affect propagation transmission over 40 km and 60 km was performed and the results are summarized in Fig. 8.

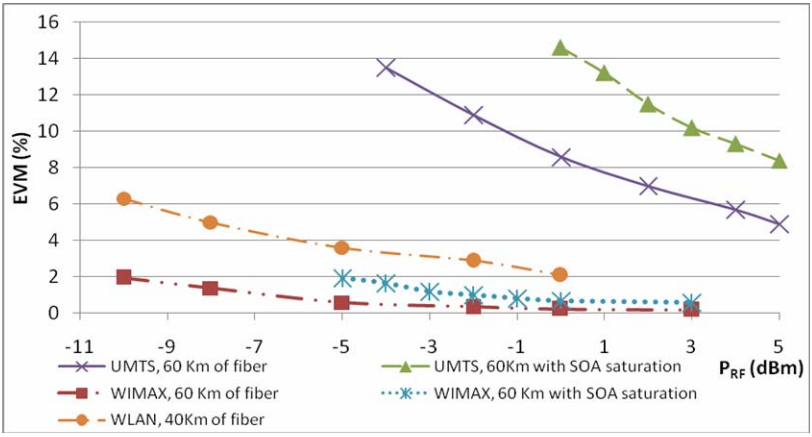

Fig. 8. EVM versus input RF power considering: unsaturated SOA; saturated SOA with a pump laser current of 30mA

From Fig. 8 it can be noticed that with the SOA in saturation the results become worst due to its internal dynamics (SPM and SGM respectively, Self Phase and Self Gain Modulation). Nevertheless for WLAN signals the results get considerably worst and the transmission is only possible for 40 km with unsaturated SOA. This is due to the format used which is based in quite close constellation, where any distortion can induce errors. Constellations can be observed for 40 km of fiber with the SOA in linear operation, in Fig. 9.

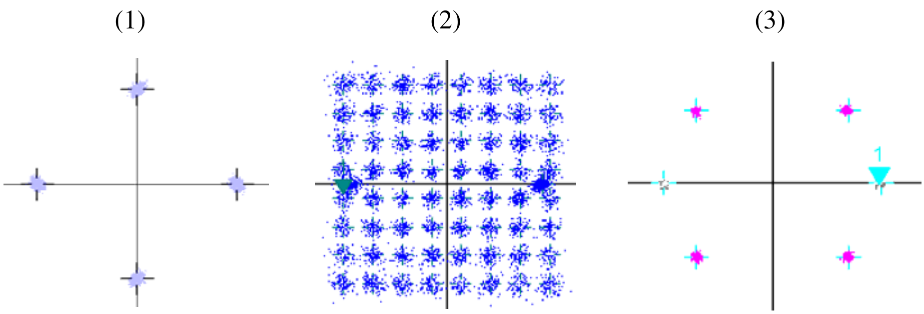

Fig. 9. Constellation of the RF received signals for the single channel setup for 40 km of fiber: (1) UMTS; (2) WLAN; (3) WiMAX

In the described WDM scenario (Fig. 4), when transmitting an Amplitude Modulated (AM) signal together with the referred RF signals, besides SPM and SGM, it will be also present Cross Phase and Cross Gain Modulation (XPM and XGM), caused by phase and gain changes induced by the AM modulated signal. FWM (Four Wave Mixing) effect is mitigated due to the uneven channel separation used. The results are illustrated in Fig. 10 and all EVM values were obtained for a SOA laser

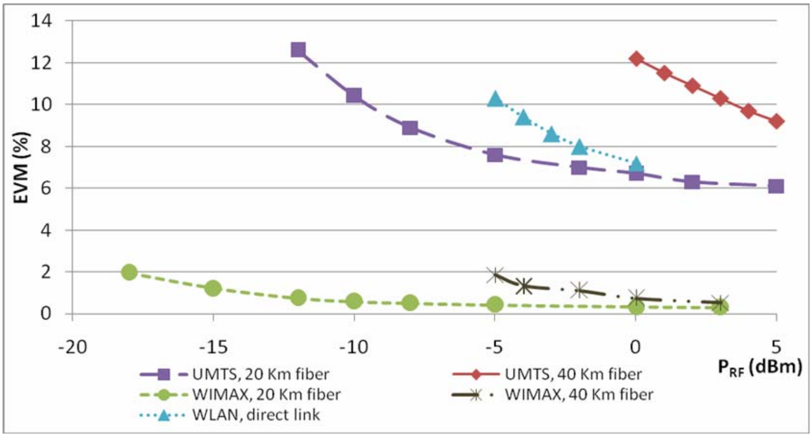

Fig. 10. EVM versus RF signal power for the WDM setup

pump current of 20 mA. The transmission of WLAN signals in this scenario was not possible within the standard values even in a back to back, however for UMTS and WiMAX signals has reached 40 km, however for higher RF powers than in the UMTS case.

In both setups, it can be concluded that the WLAN signals are the ones that require higher RF powers, and the WiMAX case, despite having the smaller EVM limit value, grants transmission with lower levels. The effects of crosstalk can be confirmed observing the constellations of UMTS signals (Fig. 11) obtained for the two setups, single channel and WDM. In the WDM setup, when varying the laser pump current of the SOA, for a fixed power of -5 dBm on the AM laser, we observe the degradation on the results obtained by XGM (Fig. 11 (2) for a pump current of 20 mA and (3) for a pump current of 30 mA).

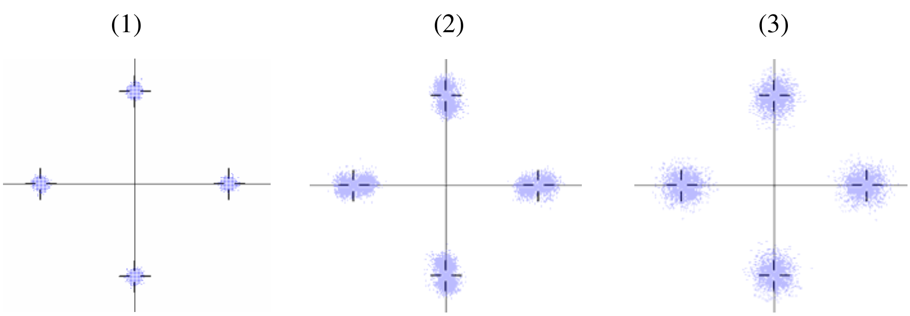

Fig. 11. Constellations of the received UMTS signal: (1) single channel; (2) and (3) WDM with the SOA less (20mA) and more (30mA) saturated by the internal pump

On the next experiment, varying the attenuation of the AM laser output, the modulation index and mean power of this channel will decrease and will result on an improved received RF signal, due to less significant inter-channel crosstalk and lower saturation. This can be observed in Fig. 12, where it is presented the EVM evolution versus AM power considering the SOA's pump laser polarized with 30 mA.

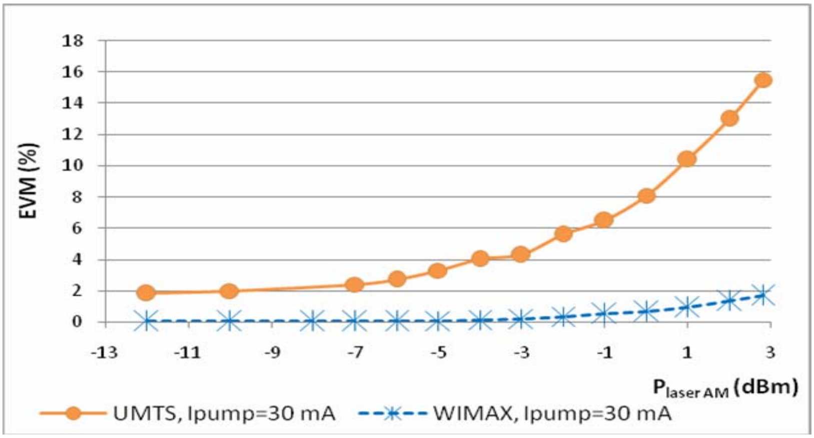

Fig. 12. Varying the power of the AM laser for the WDM setup

With the purpose of measuring the modulation index of the AM channel it was obtained the extinction ratio of the signal by attenuating the laser power and directly connecting it to the PIN followed by an oscilloscope. Considering the PIN photodiode responsivity it was determined the modulation index at the SOA input for a same pump laser biasing. The EVM versus modulation index of the AM laser is presented in Fig. 13.

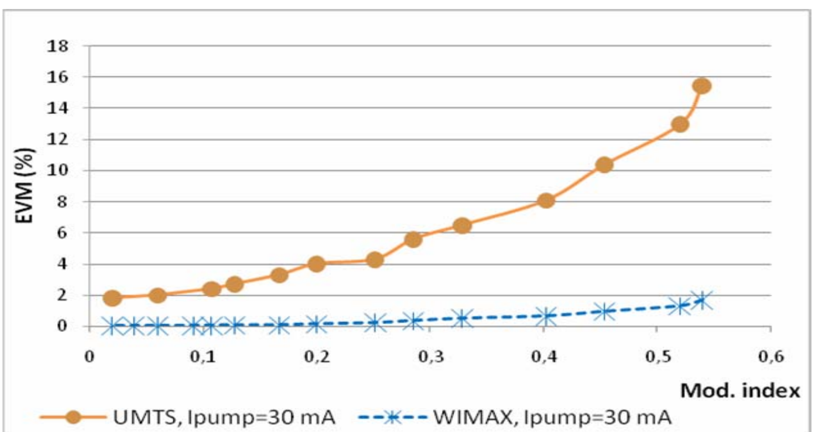

Fig. 13. Varying the modulation index of the AM laser for the WDM setup

Like it was expected the decrease on the modulation index of the AM channel obtained by attenuating the output power of the laser and maintaining the same power on the pump laser to saturate the SOA, showed a system performance increase. This behavior is justified by less interchannel crosstalk effects, thus the results will be less affected by the SOA non-linearities like XPM and XGM.

In Fig. 14 (1) for 3 dBm of the AM laser corresponding to a modulation index of 0.54, are observed besides the amplitude fluctuations, phase changes in the constellation due to the strong saturation and gain dynamics. In (2) and (3) for a modulation index of 0.4 and 0.2 respectively, the crosstalk effects are reduced and the symbols are more concentrated improving the EVM results.

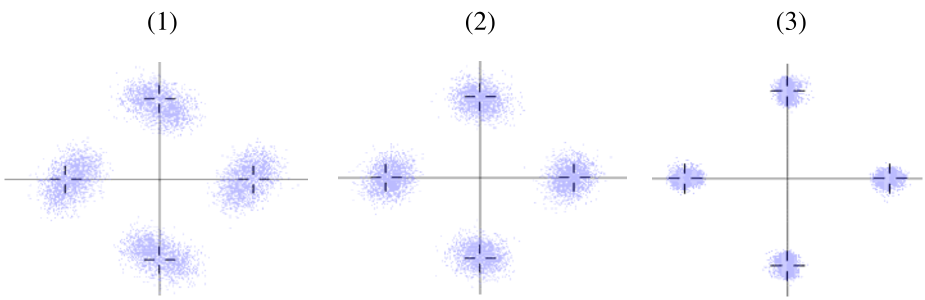

Fig. 14. Constellations of the received UMTS signal: (1)- Mod. index=0.54, (2)- Mod. index=0.4 and (3)- Mod. index=0.2

Table 2 summarizes the obtained results. Two EVM values for each situation were taken: one for the higher power of the RF signal - best transmission conditions, another for the worst condition where transmission was still possible within the standards.

Table 2. Transmission metric EVM values for all setups tested

RF signal	Single Channel						WDM					
	Direct link		40 km		60 km		Direct link		20 km		40 km	
	PRF (dBm)	EVM (%)	PRF (dBm)	EVM (%)	PRF (dBm)	EVM (%)	PRF (dBm)	EVM (%)	PRF (dBm)	EVM (%)	PRF (dBm)	EVM (%)
UMTS	-18	9,6	-12	11	-2	10,9	-15	10	-10	10,4	1	11,5
	5	1,9	5	2,7	5	4,9	5	4,7	5	6,1	5	9,2
WLAN	-10	4,7	-8	5	0	10,5	0	9,4	0	11,4	Not possible	
	0	2,3	0	3,2								
WiMAX	-24	1,26	-15	1,05	-8	1,38	-20	0,93	-15	1,2	-4	1,32
	3	0,026	3	0,063	3	0,19	3	0,15	3	0,29	3	0,52

Analyzing the performance of the RF signals tested in the different setups, the WiMAX was the signal less affected by the nonlinearities providing the transmission within the standard EVM values with the lower RF level. UMTS signals also allowed the transmission over considerable distances but more affected by the nonlinear effects referred producing phase shifts on the received constellations, thus limiting the transmission within the standard. The signal that shown more limited was the WLAN. This fact is related to the modulation used (64-QAM) that, due to the very close constellation used leads to smaller robustness penalizing the EVM and consequently the transmission conditions, not even allowing the transmission with another AM signal.

5 Conclusions

The feasibility of a RoF network, for transporting UMTS, WLAN and WiMAX signals, was experimentally demonstrated. Results demonstrate that the use of a cost effective solution for the optical link, recurring to directly modulated lasers and SOAs, can still provide EVM lower than the standard limits for 60 km on the UMTS and WiMAX cases, and 40 km for the WLAN. It is also shown that a WDM system with SOA, considering a UMTS or WiMAX modulated signal and an AM signal, allows the transmission for 20 km and 40 km. By decreasing the modulation index of the AM laser the results will not be so penalized by the crosstalk effects.

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