Complete Mitigation of Brillouin Scattering Effects in Reflective Passive Optical Networks using Triple-Format OFDM Radio Signals

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Abstract: Brillouin scattering is identified as a severe limitation in narrow line-width, bi-directional reflective systems. A spectrum management mitigation technique for triple-format OFDM signals is demonstrated over 15 km passive optical network using reflective electro-absorption transceivers.

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1. Introduction

Bi-directional passive optical networks (PONs) are an accepted implementation for access applications. Here, we analyze narrow line width bi-directional transmission using a reflective electro-absorption transceiver (R-EAT). This well-known reflective architecture permits placement of laser sources only at the network operator premises and a low cost transceiver at users' homes [1]. The application scenario is shown in Fig. 1(a), where the R-EAT absorbs the downstream information (λ_{DS}=1300 nm) and reflects a narrow line-width upstream signal (λ_{US}=1550 nm) back from the users premises. We show this bi-directional process engenders severe stimulated Brillouin scattering (SBS) assisted four-wave mixing (FWM), especially when launch powers approaching +14 dBm are used to achieve the required range. The optical spectrum produced directly by the laser is shown in Fig. 1(b) as a dashed line. The bottom trace (as a solid line) is the reflected optical signal from the R-EAT without any RF modulation. Due to the SBS-FWM effect, part of the light is backscattered at a shifted optical frequency and double-sideband development is observed at around 10.9 GHz. This translates to severe base-band and band-pass electrical noise from 10.9 to 21.8 GHz. The noise-free spectral zone shown in Fig. 1(c) fits with the transmission of OFDM based signals suitable for triple-play (3-PLAY) services such as LTE at 2.6 GHz (telephone), WiMAX at 3.5 GHz (Internet data) and UWB from 3.1 to 10.6 GHz (high-definition television).

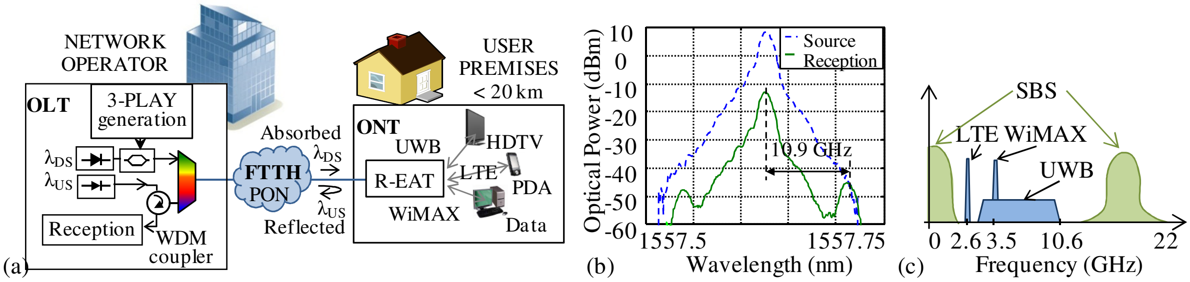

Fig. 1: (a) Application scenario of 3-PLAY distribution using reflective low-cost receiver at user premises. (b) Optical spectrum at Reception point after circulator (in (a)) showing SBS (resolution 0.01 nm) and (c) electrical spectrum proposed scheme

2. Bi-directional transmission in PON using a reflective electro-absorption transceiver

We implemented bi-directional transmission using a R-EAT absorbing the downstream information in one wavelength (λ_{DS}) and transmitting the narrow line-width upstream data over the reflected wavelength broadcast from the optical line terminator (OLT) to the user (λ_{US}). The experimental setup is shown in Fig. 2. The generated radio signals (RF_{in}) were: (i) advanced LTE using FDD at 2.6 GHz with 16QAM in 20 MHz bandwidth [2], (ii) fixed 802.16 WiMAX at 3.5 GHz using 16QAM in 24 MHz bandwidth [3], and (iii) WiMedia UWB at time frequency code TFC6 (3.96 GHz) with DCM (480 Mbit/s) in 528 MHz bandwidth [4]. The three signals were combined with a RF power combiner (Mini Circuits ZN4PD1-50) resulting in the spectrum and constellations shown in Fig. 2 (a)-(b).

The downstream path comprised a 1300 nm laser (DFB-1310-BF-31-CW-FC-537) with 14.5 dBm output power feeding a Mach-Zehnder electro-optical modulator (Covega LN-058) that modulated the triple-format signals at the quadrature bias point. The upstream optical signal was generated at the OLT using a 1550 nm laser with 14.5 dBm maximum power (Fitel FOL15DCWD-A81-19270-B). Both lasers were followed by a variable optical attenuator to

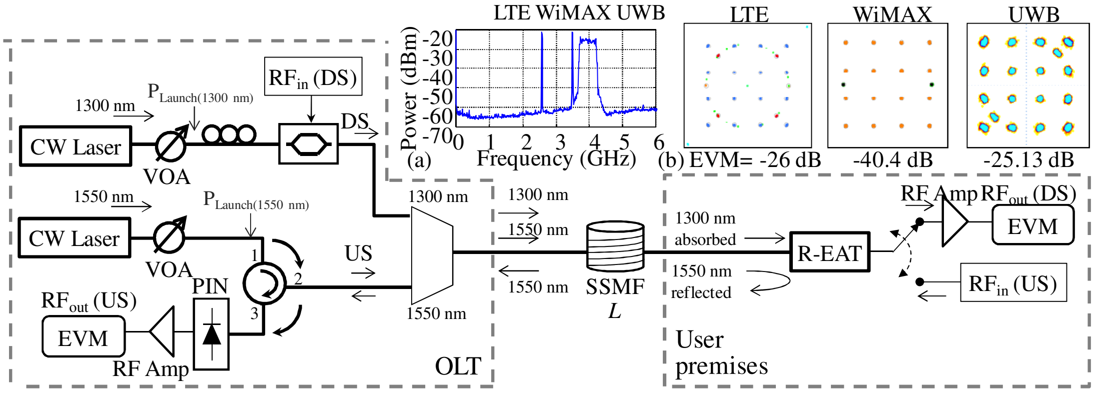

Fig. 2: Experimental setup. CW: Continuous wave, DS: Downstream, SSMF: Standard single mode fiber, US: Upstream, VOA: Variable optical attenuator. Inset (a) generated electrical spectrum RF$_{in}$ (RBW=1 MHz) and (b) corresponding constellations

adjust the optical launch power used by the operator. The resulting optical signals were combined and propagated through different spools of standard single mode fiber (SSMF).

At the user premises, the R-EAT (with -1.4 V bias) absorbed the signal at 1300 nm which was then amplified by 56 dB and analyzed. The LTE and WiMAX signals were demodulated with a signal analyzer (Agilent EXA N9010A) and UWB signal analyzed with a digital oscilloscope (Tektronix DPO 71254).

In the case of the upstream direction, the R EAT modulated the 1550 nm wavelength light by the composite electrical signal and returned it to the OLT through the same SSMF. At the OLT, the upstream signal was photodetected (PIN Discovery DSC-R402AC) after the optical circulator, amplified by 56 dB and analyzed. The error vector magnitude (EVM) of the three signals was observed as a function of the optical launch power in order to study the performance of the system. Afterwards, the quality of the signals was evaluated after propagation through different lengths of SSMF to quantify the maximum reach of the proposed architecture. This limit was obtained by comparing the measured EVM with the thresholds stated in current radio standards: -18 dB for 3GPP LTE using 16QAM [2], -24.43 dB for 802.16 WiMAX using 16QAM [3], and -17 dB for ECMA-368 UWB using DCM [4].

3. Absorbed path performance evaluation

We first evaluated the performance of the absorbed path at 1300 nm. Fig. 3(a) shows the obtained EVM for LTE, WiMAX and UWB measured with simultaneous presence of the three signals in back-to-back (B2B) configuration (*L*=0 km). It was observed that the EVM improved as the launch power was increased. The minimum launch power for the successful transmission of 3-PLAY was 5 dBm, limited by the performance of WiMAX. This high power level was necessary due to the high losses of the 1300 nm transmission path. Fig. 3(b) shows the EVM vs. length for the optimum launch power in each case (up to the 14.5 dBm available). It was noted that the WiMAX signal was below the specification after 25.3 km. Fig. 3(c) shows the received constellations achieved the standard limits at *L*=20.2 km and (d) the constellations at *L*=25.3 km where WiMAX did not meet the limit of -24.43 dB EVM, but this constellation suggests that, with error correction, the data could probably be recovered.

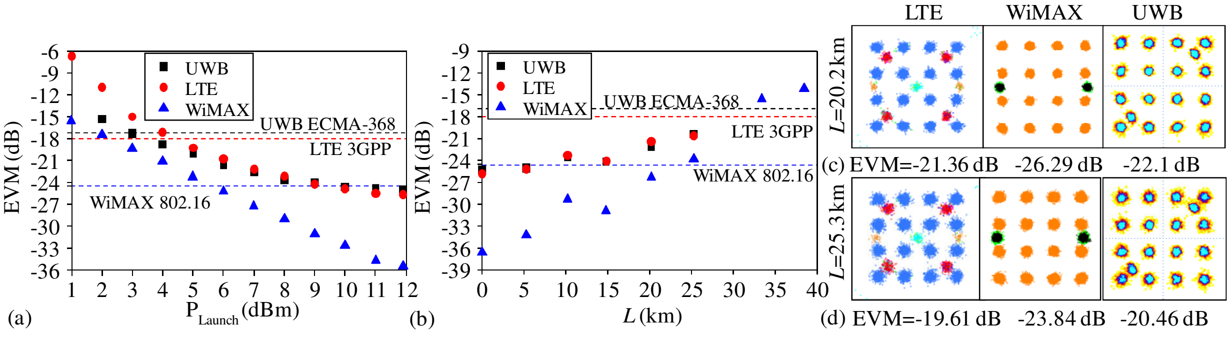

Fig. 3: (a) Measured EVM on LTE, WiMAX and UWB on the absorbed path (1300 nm) vs. optical launch power. (b) EVM vs. length *L*, and received constellations and EVM after: (c) *L*=20.2 km, (d) *L*=25.3 km

4. Reflected path performance evaluation

Considering the reflected path, Fig. 4(a) shows that the EVM of the signals had an optimum point at launch power of -1 dBm in back-to-back configuration. As the launch power was increased, the electrical amplifiers after the photodiode became saturated leading to distortion of the received signal. Fig. 4(b) shows the EVM vs. the fiber

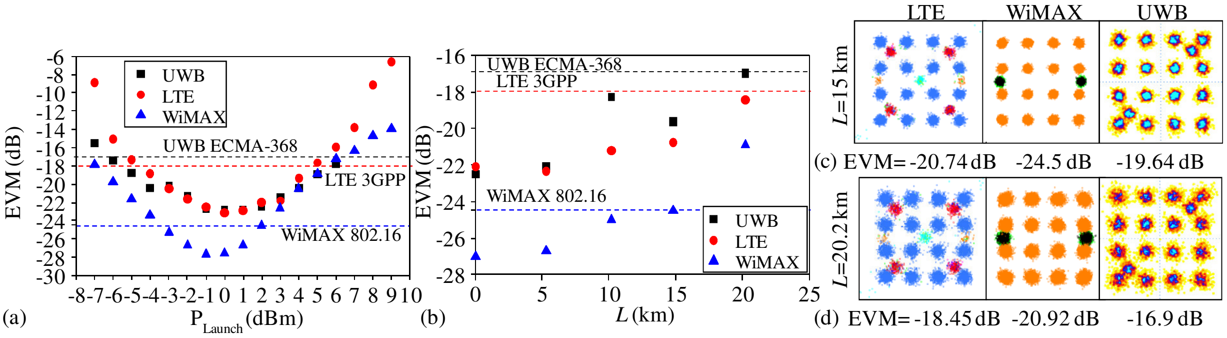

Fig. 4: Measured EVM on LTE, WiMAX and UWB on the reflected path (1550 nm) vs. optical launch power. (b) EVM vs. fibre length *L*, and constellations and EVM after (c) *L*=15 km, (d) *L*=20.2 km

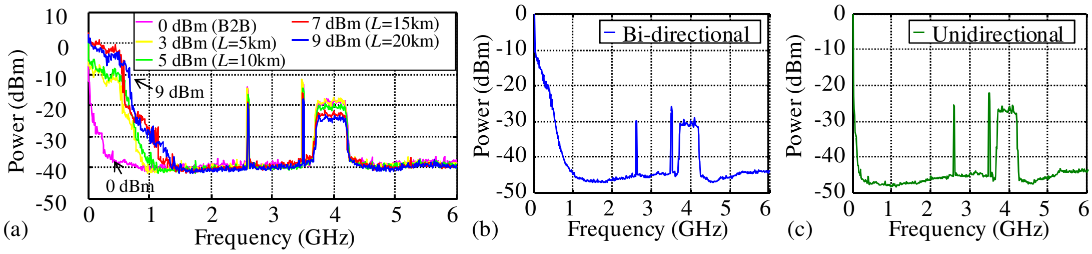

Fig. 5: Received electrical spectrum in the reflected path at 1550 nm (a) with different optimum launch powers for different lengths *L*, and after *L*=20.2 km in different locations: (b) circulator port 2 and (c) CW output (RBW=3 MHz in all cases)

length obtained for the optimum launch power in each case. It is clear that, at 1550 nm, the 1300 nm losses are avoided but in the proposed architecture the signal travels through twice the amount of SSMF. The reach where the all three signals comply with the standards is 15 km as shown in the constellations of Fig. 4(c). The constellations obtained for 20.2 km are shown in Fig. 4(d). Again in this case, WiMAX limits the performance, as LTE and UWB meet the standards threshold. However, at this range the WiMAX signal information could probably be recovered using error correction as there is minimal symbol collision in the constellation.

With respect to the received spectrum in the upstream path (Fig. 5) the expected low-frequency component due to SBS was observed and increased with launch power; thus limiting the maximum reach of the system. Further analysis indicated that the SBS-FWM effect was strongly enhanced by single-wave, bi-directional transmission due to optical mixing of the reflected optical wavelength from the R-EAT combined with the forward transmission path within the fiber. This was confirmed by relocating the fiber to implement/remove bi-directional transmission. Fig. 5(b)-(c) shows that the noise disappeared when there is no single-wavelength bi-directional transmission.

5. Conclusion

Brillouin scattering is identified as a key transmission impairment limiting the maximum reach in reflective architectures due to single-wavelength bi-directional propagation in the fiber. A spectrum management technique is proposed for bi-directional radio-over-fiber transmission of full-standard OFDM triple-format signals. The experimental results demonstrate successful communication of LTE, WiMAX and UWB after 15 km SSMF without optical amplification stages or error correction. Up to 20 km was achieved in the downstream path, but the upstream range was limited to 15 km by the SBS effect. This OFDM spectral management offers 3-PLAY services transmission at PON distances with only low-cost devices and no lasers at user's homes.

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6. References

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[2] 3GPP TS 36.101 V8.8.0 "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (Release 8)" (Dec. 2009)

[3] IEEE 802.16 Standard for local and metropolitan area networks "Part 16: Air Interface for Fixed Broadband Wireless Access Systems" (2009)

[4] ECMA-368 Standard: "High Rate Ultra Wideband PHY and MAC Standard", ECMA International Standard (2008)