

Impact of Optical Modulators in LTE RoF System with Nonlinear Compensator for Enhanced Power Budget

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Abstract: Nonlinear propagation compensation for LTE-RoF system is experimentally demonstrated with proposed DMFD and EMFD methods. We discovered that the RoF dithering frequency requirement have to be much smaller with an average improvement of ~5.35 dB.

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1. Introduction and the Proposed System

The 3rd generation partnership program (3GPP) long term evolution (LTE) technology experiences limited cell radius of 1 km with a cell edge throughput of < 20 Mb/s [1]. We have established a cell edge throughput improvement and adjacent cell transmission with the relay node (RN) and radio-over-fibre (RoF) interface connecting to eNodeB (eNB) of LTE [2, 3]. The system design in [2, 3] has revealed that LTE-RoF system attains improved quality of service (QoS) in the optimum optical launch power (OLP) region ranged between ~-3 and ~2 dBm. At OLP of < -3dBm known as the linear region, the impairment depends on the positive frequency chirp (PFC) and the chromatic dispersion (CD) that degrades QoS, which can be compensated with an erbium doped fibre amplifier (EDFA). The nonlinear region initiates from OLP of > 2 dBm, the nonlinear impairments are self phase modulation (SPM) and stimulated Brillouin scattering (SBS), which severely deteriorates QoS of LTE-RoF system. Due to the high power requirement after photodetection (PD) in RN for signal distribution to user equipments (UEs), it is vital that LTE-RoF operates in the nonlinear region (high OLP) to enhance the power budget in RN.

The proposed LTE-RoF system is only SPM and SBS dependent [3], however since we are aiming on providing higher power budget, which corresponds to higher OLP, SBS becomes the dominant nonlinear factor. An index grating is formed when the propagating signal has a narrower linewidth than the SBS linewidth and subsequently energizes the back-reflecting Stokes wave [4]. An enhanced SBS threshold optical fibre was proposed as a solution in [5], but replacing the existing single mode fibre (SMF) infrastructure would not be cost effective [3]. Cross phase modulation based SBS compensation was proposed in [6], however this method cannot be adopted for the proposed single wavelength based LTE-RoF system [2, 3]. Therefore, for the first time, we are proposing the usage of direct modulation (DM) and external modulation (EM) based frequency dithering (FD) methods for SBS compensation in RoF system. Since FD operates based on the frequency chirping, the investigation on the effectiveness of FD with two different optical modulators is crucial as DM induces PFC and contrariwise for EM. FD method was first introduced for the baseband system [7] where FD frequency f_D has to be at least twice bigger than the signal frequency f_m , $\{f_D > 2f_m\}$. Conversely, since RoF operates with a pass-band frequency f_{RF} , we have discovered that

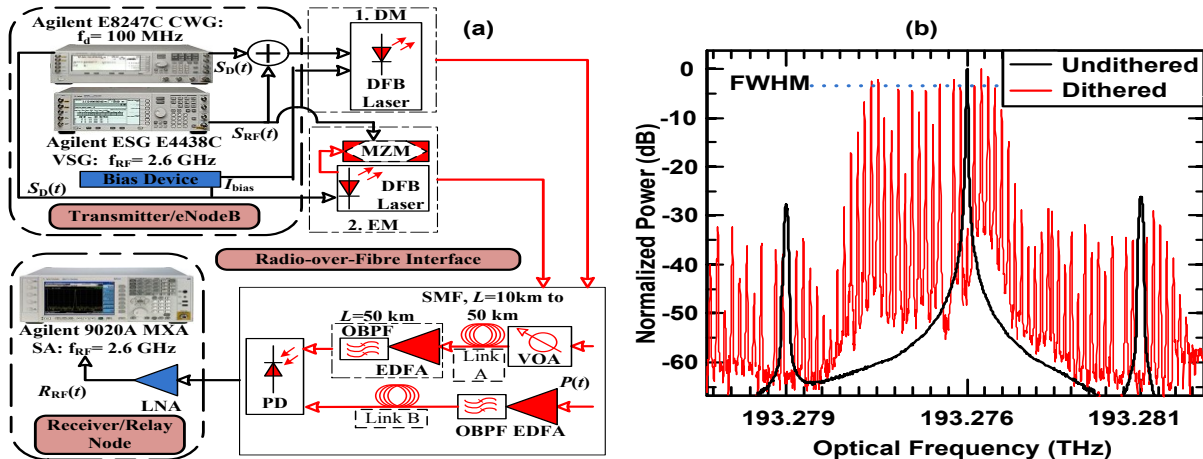


Fig. 1: (a) LTE-RoF experimental setup for SBS mitigation with DM and EM, and (b) Optical spectral of undithered and dithered signal. Abbreviations: CWG: continuous wave generator, VSG: vector signal generator, DM: direct modulation, DFB: distributed feedback laser, EM: external modulation, MZM: Mach-Zehnder modulator, VOA: variable optical attenuator, SMF: single mode fibre, EDFA: erbium doped fibre amplifier, OBPF: optical bandpass filter, PD: photodetector, LNA: low noise amplifier, and SA: signal analyzer

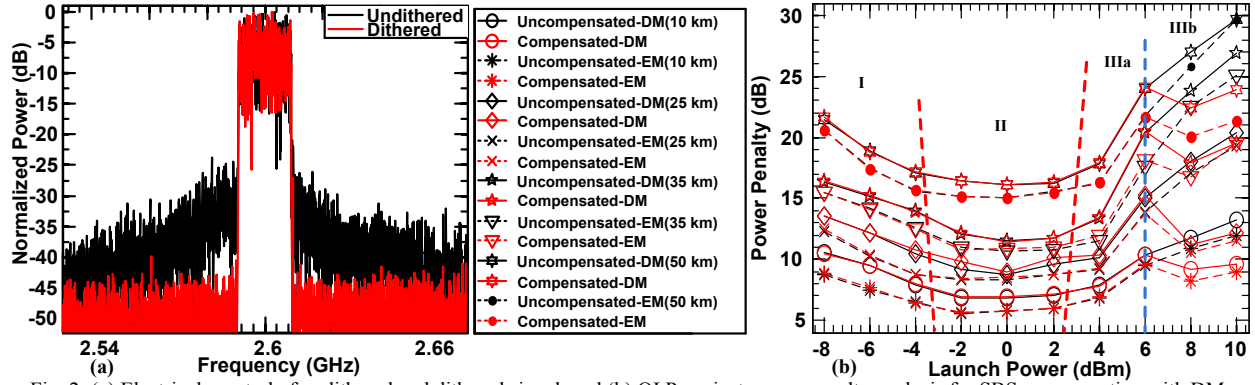


Fig. 2: (a) Electrical spectral of undithered and dithered signal, and (b) OLP against power penalty analysis for SBS compensation with DM and EM over 10 km to 50 km transmission spans.

the condition of $\{f_D < f_{RF}\}$ need to be maintained.

2. System Architecture

Fig. 1(a) illustrates the overall experimental setup for LTE-RoF system with DMFD and EMFD for SBS compensation. At the transmitter, LTE signal $S_{RF}(t)$ is composed of 64-quadrature amplitude modulation (QAM) with orthogonal frequency division multiplexing (OFDM) transmitted at f_{RF} of 2.6 GHz band via the vector signal generator (VSG) with a data rate of 100 Mbps. $S_{RF}(t)$ is then combined with the dithering signal $S_D(t)$ at f_D of 100 MHz only for DM. If $f_D > f_{RF}$, it will not induce the effect of FD because the laser is already modulated and chirped by $S_{RF}(t)$ and its 2nd order harmonic, therefore the condition of $\{f_D < f_{RF}\}$ has to be maintained. But, for the baseband system [7], the condition of $\{f_D > 2f_m\}$ is necessary as the baseband signal itself will be centered or close to the direct current. For the first case, the composite signal of $S_{RF}(t)$ and $S_D(t)$ is applied to the distributed feedback laser (DFB) laser for DM. However, the second case with a DFB source supplied to Mach-Zehnder modulator (MZM), which is the EM, $S_D(t)$ is inserted into DFB source while $S_{RF}(t)$ is supplied to MZM for EM. The FD phenomenon for the 2nd case cannot be performed via MZM because it does not induce PFC, which means the optical phase modulation required for the linewidth broadening needs to be done via the laser source irrespective of DM or EM. The output of DM and EM with FD can be observed in Fig. 1(b). DM and EM signals are passed through the link A, which consists of a variable optical attenuator (VOA) to investigate lower OLP $P(t)$, and SMFs of 10 to 50 km. EDFA and an optical bandpass filter (OBPF) within the link A is only utilized for a span of 50 km and above. In the link B, DM and EM signals are transmitted through EDFA and OBPF for higher $P(t)$. At the receiver, a PD with a responsivity of 0.42 followed by a low noise amplifier are used for the received signal $R_{RF}(t)$ for both links. The signal analyzer (SA) is then used to analyze and characterize the QoS of $R_{RF}(t)$.

3. Results and Discussions

DMFD and EMFD phenomena can be observed in Fig. 1(b), which was captured via an optical spectrum analyzer, BOSA 200 by Aragon Photonics. The undithered ($S_D(t)$ off) optical spectral at the output of DM and EM resulted in a linewidth of full width at half maximum (FWHM) of ~11.14 MHz, since SBS linewidth is typically around ~30 MHz [4], most propagating signals are back-reflected due to the formation of index grating. From Fig. 1(b), the dithered ($S_D(t)$ on) output of DM and EM shows an optical comb like signal formed by multiple peaks with an FWHM of ~37.47 MHz. Multiple peaks from DMFD and EMFD phenomena arises due to nonlinear mixing of the optical carrier $S_D(t)$ and $S_{RF}(t)$. The effect of the linewidth and the exploitation of FD, which achieved a linewidth of ~37.47 MHz can be observed in the electrical spectrum of SA, see Fig. 2(a). The undithered signal in Fig. 2(a) exhibits a high out-of-band emission (OBE) and an increased noise floor level owing to the narrow linewidth of ~11.14 MHz, which allows the formation of SBS index grating. However, with the increased linewidth via DMFD and EMFD, the dithered signal, Fig. 2(a), results in a flat noise floor and OBE free.

Fig. 2(b) depicts OLP against the power penalty for 64-QAM transmitted through 10, 25, 35 and 50 km spans; the power penalty is a comparative signal to noise ratio (SNR) metric, measured with respect to the back-to-back system. The measurement in Fig. 2(b) is concatenated into three propagation regions, namely I) linear region- PFC and CD induced distortion, II) intermixing region- reduced distortion achieved by the interaction between CD and PFC with SPM and SBS, and III) nonlinear region- which is split into IIIa (SPM) and IIIb (SBS). Regions I and II shows that DMFD and EMFD do not enhance the existing PFC affect because FD of DFB laser does not exhibit similar nature to a Fabry-Perot laser. DM experiences an average of ~3 dB additional penalty compared to EM for

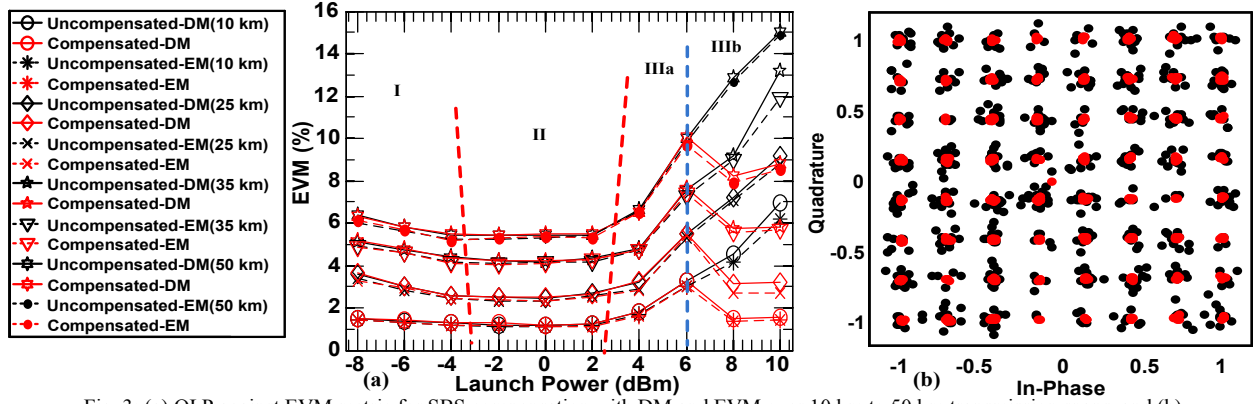


Fig. 3: (a) OLP against EVM metric for SBS compensation with DM and EM over 10 km to 50 km transmission spans, and (b) Uncompensated (black) and compensated (red) constellation diagram of 64-QAM

LTE-RoF system due to PFC, we have also theoretically presented in [2] for the impact of PFC with LTE-Advanced and RoF system resulting in an average of ~7 dB penalty.

The discussion on Fig. 2(b) is focused in the region IIIb due to the effectiveness of DMFD and EMFD. The transmission spans from 10 km to 50 km shows a periodical increase in system penalty, however, the system transmission limitation is 50 km and will be thoroughly explained with the aid of a error vector magnitude (EVM) later. At 50 km transmission, the observed DM and EM SNR improvements at 8 dBm OLP are ~4.59 dB and ~4.63 dB, respectively, while at OLP of 10 dBm resulted in improvements of ~5.79 dB and ~6.37 dB, respectively. The improvements at OLP of 10 dBm indicate that SBS induced distortion increases with the transmission span. Fig. 3(a) illustrates EVM of 64-QAM, which basically presents the explicit LTE-RoF QoS, where the aim is to achieve lower than 8% according to the 3GPP LTE requirement [8]. In terms of EVM, there are no changes observed in regions I and II, thereby agreeing to the response of the power penalty (Fig. 2(b)). Concentrating in the region IIIb, DM at 10 dBm of OLP and a 50 km span achieved EVM of ~14.96% and ~8.81%, which corresponds to uncompensated and compensated link, respectively, while EM at the same operating condition resulted in EVM of ~14.72% for an uncompensated link and ~8.51% for a compensated link. It is clear that compensated DM and EM links attained EVM slightly above the limit at a 50 km transmission span. The improvement associated with DMFD and EMFD in the received baseband system can be clearly observed from the 64-QAM constellation, see Fig. 3(b). Though EM system is superior to DM system by an average of ~3 dB power gain, EVM differences are comparatively small showing the effectiveness of DM system with reduced system complexity for LTE-RoF application.

4. Conclusions

In this paper, DMFD and EMFD methods were demonstrated to mitigate SBS for LTE-RoF system. We found that both systems do not deteriorate the PFC dependent regions from the intentional linewidth broadening. In addition, EM system exhibits ~3 dB of average power gain over DM system; however both systems achieved close proximity in the EVM measurement. Both proposed methods demonstrated a high efficiency, where operating at OLP of 10 dBm with a 50 km link span improved EVM from ~14.96% (DM) and 14.72% (EM) to ~8.81% and ~8.51%, respectively, which is close to the vicinity of 8% limit.

References

1. T. Wirth, V. Venkatkumar, T. Haustein, E. Schulz, and R. Halfmann, "LTE-Advanced Relaying for Outdoor Range Extension," in *Vehicle Technology Conference Fall (VTC 2009-Fall)*, IEEE 70th, 1-4 (2009).
2. T. Kanesan, W. P. Ng, Z. Ghassemlooy, and J. Perez, "Optimization of Optical Modulator for LTE RoF in Nonlinear Fiber Propagation," *Photonics Technology Letters*, IEEE **24**, 617-619 (2012).
3. W. P. Ng, T. Kanesan, Z. Ghassemlooy, and C. Lu, "Theoretical and Experimental Optimum System Design for LTE-RoF Over Varying Transmission Span and Identification of System Nonlinear Limit," *Photonics Journal*, IEEE **4**, 1560-1571 (2012).
4. A. Villafranca, J. Lázaro, ñ. Salinas, and I. Garcés, "Stimulated Brillouin scattering gain profile characterization by interaction between two narrow-linewidth optical sources," *Opt. Express* **13**, 7336-7341 (2005).
5. M. Sauer, A. Kobayakov, and A. B. Ruffin, "Radio-Over-Fiber Transmission With Mitigated Stimulated Brillouin Scattering," *Photonics Technology Letters*, IEEE **19**, 1487-1489 (2007).
6. J. D. Downie, and J. Hurley, "Experimental study of SBS mitigation and transmission improvement from cross-phase modulation in 10.7 Gb/s unrepeaters systems," *Opt. Express* **15**, 9527-9534 (2007).
7. A. Yariv, H. Blauvelt, D. Huff, and H. Zarem, "An experimental and theoretical study of the suppression of interferometric noise and distortion in AM optical links by phase dither," *Lightwave Technology, Journal of* **15**, 437-443 (1997).
8. 3GPP, "EVM for LTE Repeater (3GPP TSG-RAN4 Meeting #52, TS 36.143, Rel-8)," (2009).