Nonlinear limit of alternative method to 2 x 2 MIMO for LTE RoF system

Kanesan, T. , Rajbhandari, S. , Giacoumidis, E. and Aldaya, I.

Original citation & hyperlink:
Kanesan, T. , Rajbhandari, S. , Giacoumidis, E. and Aldaya, I. (2014) Nonlinear limit of alternative method to 2 x 2 MIMO for LTE RoF system. Electronics Letters, volume 50 (4): 300-301
http://dx.doi.org/10.1049/el.2013.2972

ISSN 0013-5194
DOI 10.1049/el.2013.2972

Nonlinear limit of alternative method to 2 × 2 MIMO for LTE RoF system

T. Kanesan, S. Rajbhandari, E. Giacoumidis and I. Aldaya

Owing to the limited cell size of eNodeB (eNB), the relay node has emerged as an attractive solution for the long-term evolution (LTE) system. The nonlinear limit of the alternative method to multiple-input and multiple-output (MIMO) based on frequency division multiplexing (FDM) for orthogonal FDM (OFDM) is analysed over varying transmission spans. In this reported work, it is shown that the degradation pattern over the linear, intermixing and nonlinear propagation regions is consistent for the 2 and the 2.6 GHz bands. The proposed bands experienced a linear increase in the error vector magnitude (EVM) for both the linear and the nonlinear regions proportional to the increasing transmission spans. In addition, an optical launch power between −2 and 2 dBm achieved a significantly lower EVM than the LTE limit of 8% for the 10–60 km spans.

Introduction: The long-term evolution (LTE) technology was established as a solution to meet the exponentially increasing bandwidth demand from the end users of mobile broadband [1]. However, it is in the nature of any technologies to experience bottlenecks. In the case of the LTE, it is the reduction in the cell size due to the high operating carrier frequency (2.6 GHz) in urban locations with a non-line-of-sight transmission condition [1]. To avoid additional deployment of a complex eNodeB (eNB) [2], Kanesan *et al.* [3] proposed the use of relay nodes (RNs) for an eNB cell extension, with radio-over-fibre (RoF) operating as the interface. The system architecture introduced in [3] enabled the RoF to accommodate the LTE technology for both the single-input and the single-output and the multiple-input and the multiple-output (MIMO) configurations.

The requirement of a specific RoF architecture for the MIMO is due to the group of signals in the MIMO being upconverted to the same carrier frequency. Thus, combining the MIMO signals to modulate a single laser or an external modulator annihilates the required spatial diversity, which makes it impossible to recover the individual antenna signals at the receiver. Some of the straightforward solutions to the aforementioned problem are: (i) individual optoelectronic devices for each MIMO signal on the basis of the wavelength division multiplexing [4] and (ii) optical polarisation multiplexing with a coherent detection for the MIMO modulation [5]. Both the given options will significantly add to the capital expenditure and the operating expenditure of the LTE network. Since the deployment of the RoF itself will introduce an additional implementation expenditure, cost control is a very important factor. Hence, simplicity needs to be strictly retained. In [3], analogue frequency division multiplexing (FDM) for the orthogonal FDM (OFDM) was established as an alternative method in the LTE for the MIMO transmission using the RoF. The proposed scheme only uses direct detection (DD), with a requirement of additional frequency bands and matched bandpass filters. The study conducted in [3] was limited to the linear propagation region (optical launch power (OLP) < 0 dBm) and a single transmission span of 60 km.

In this Letter, we explore the impact of a higher OLP in sustaining an adequate link budget to accommodate multiple RNs from a single eNB. In addition, an investigation on varying the transmission spans is conducted to identify the ultimate nonlinear limit of the proposed system to provide a guideline for the network operators.

Experimental system demonstration: The proposed system is designed using off-the-shelf devices and components as shown in Fig. 1. In the transmitter (eNB), a 64-quadrature amplitude modulation (QAM) OFDM scheme is generated in both the signal generators, with a fast Fourier transform size of 2048 each and a subcarrier spacing of 15 kHz. A cyclic prefix length of 1/4 is appended to the 64-QAM OFDM signals prior to upconversion to $f_1 = 2$ GHz and $f_2 = 2.6$ GHz, and passively combined to generate a FDM for the OFDM. The combined signals are directly applied to a wideband matched distributed feedback (DFB) laser to perform a direct modulation. Thereafter, the optical signal is coupled into an optical attenuator (OA), an erbium-doped fibre amplifier and an optical bandpass filter for a linear, an intermixing and a nonlinear propagation over 10–60 km of the standard singlemode fibres (SMFs), finally detected by means of the DD. The electrical signal in the RN is amplified by a low-noise amplifier to compensate for the attenuation of the SMF, subsequently split and fed to two different signal analysers that correspond to the individual FDM frequencies for qualitative analyses.

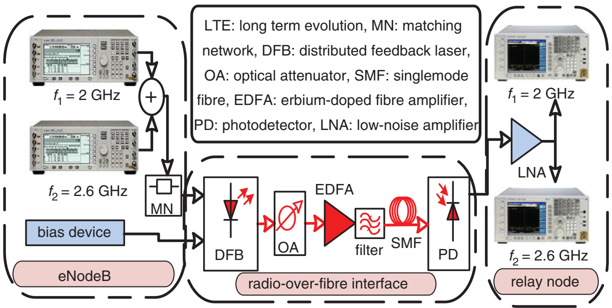

Fig. 1 *Experimental setup for identification of nonlinear limit*

Results and discussion: The qualitative analyses of the proposed system were performed in terms of a power penalty, which is a comparative measurement of the back-to-back electrical signal-to-noise ratio (SNR), and the error vector magnitude (EVM). Fig. 2 depicts the power penalty against the OLP of the 64-QAM FDM for the OFDM system, where the theoretical evaluation performed via MATLAB™ is also included to verify the experimental results. Fig. 2 shows the result of the longest span of 60 km only, i.e. the worst nonlinear condition for the experimental setup. The results for the other transmission spans are summarised in Fig. 4. Based on the power penalty profile shown in Fig. 2, the optical propagation can be categorised into three regions: (I) linear-frequency chirp (FC) and chromatic dispersion (CD) dependent region, (II) intermixing-distortion suppressed region from the interaction between the FC and the CD with a nonlinearity, and finally (III) nonlinear-distortion arising from the self-phase modulation and the stimulated Brillouin scattering. The regions shown in Fig. 3 reflect the same characteristics as discussed earlier.

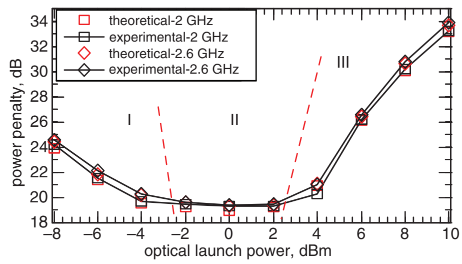

Fig. 2 *Power penalty for 64-QAM LTE over 60 km of RoF link*

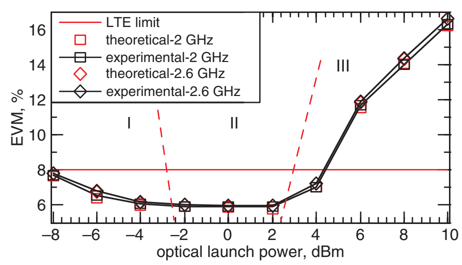

Fig. 3 *EVM for 64-QAM LTE over 60 km of RoF link*

For the range of the OLP ≤3 dBm corresponding to region I (Fig. 2), the SNR deteriorates with a decreasing OLP, hence the increase in the power penalty, and effectively indicates a linear behaviour. At −8 dBm, the 2 and the 2.6 GHz signals resulted in an average power penalty of ∼24.5 dB with the theoretical value agreeing with the outcome. However, the 2 GHz signal exhibits a slightly lower power penalty (∼0.8 dB) to the 2.6 GHz signal due to the higher magnitude response of the DFB at 2 GHz. In region III, the power penalty increases albeit the increasing OLP is a result of the nonlinear response. At 10 dBm, the average power penalty observed is ∼33.6 dB with a good agreement with the theory. This analysis reveals the importance of a nonlinear analysis and the criticality of defining a nonlinear limit, simply because there is an additional ∼9.1 dB penalty in comparison to the linear region. Ideally, region II provides the lowest distortion between −2 and 2 dBm with an average power penalty of ∼20 dB. This region is attractive for a practical implementation owing to the intermixing effect between the linearity and the nonlinearity of the SMF and concurrently yields an optimum operating condition.

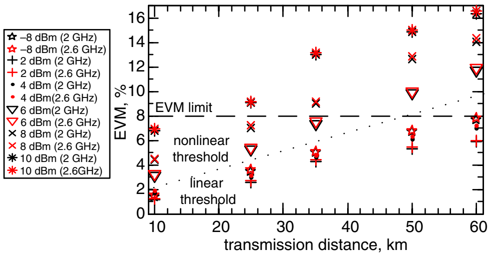

Fig. 4 *EVM response relative to transmission distance for varying OLP*

Fig. 3 provides the EVM measurement across all the three regions. The goal here is to achieve an EVM < 8% as designated for an LTE network [6]. It is clear at a 60 km transmission, the OLP between −8 and 4.3 dBm achieves an EVM < 8% for both 2 and 2.6 GHz. Moreover, the optimum OLPs in region II resulted in an average EVM of ∼6%. This offers an OLP margin of up to 4.3 dBm for the network operators at the 60 km transmission.

Most urban areas are predominantly smaller in radius. Hence, an experimental prediction for the nonlinear limit of the varying transmission spans (10, 25, 35, 50 and 60 km, respectively), relative to the EVM at different OLPs is also performed and summarised in Fig. 4. The investigation in Fig. 4 exhibits that the linear and the nonlinear distortions increase linearly with the transmission distance for both the bands. In terms of the linear region, the OLPs between −8 and 2 dBm are not shown as the resulting variation in the EVM is insignificant. It is clear that the nonlinearity of the SMF actively distorts the system's performance above the OLP of 6 dBm, which becomes the nonlinear threshold. Despite the fact that the system severely deteriorates at >6 dBm for all the transmission spans, the 10 km span demonstrates that the EVM for the entire OLP is below the 8% limit. It is clear that the proposed system should avoid operation above the nonlinear threshold (OLP = 6 dBm) for a link span >35 km.

Conclusion: An optimum OLP region (−2 to 2 dBm) has been presented and discussed for the proposed system, which provides a reduced distortion region without any optical equalisation for both the bands. In addition, the nonlinear limit of the FDM for the OFDM LTE RoF system was defined as 6 dBm, and evidently provided an OLP margin of −8 to 4.3 dBm in the worst-case transmission condition to achieve an EVM < 8%. However, the network operators were provided with an enhanced margin by analysing varying transmission spans in accordance to the smaller urban areas. The investigation illustrates that the OLP margin could augment in the range of −8 to 10 dBm for a 10 km span, and gradually experience a compression in the OLP margin for the increasing transmission spans.

9 September 2013

doi: 10.1049/el.2013.2972

One or more of the Figures in this Letter are available in colour online.

T. Kanesan (*Telekom Research and Development, Cyberjaya, Selangor, Malaysia*)

E-mail: Thavamaran.Kanesan@ieee.org

S. Rajbhandari (*Department of Engineering Science, University of Oxford, Parks Road, Oxford, OX1 3PJ, United Kingdom*)

E. Giacoumidis (*Aston Institute of Photonic Technologies, Aston University, Birmingham, B4 7ET, United Kingdom*)

I. Aldaya (*Department of Electrical and Computational Engineering, Tecnologico de Montorrey, Garza Sada, Monterrey 92984, Mexico*)

T. Kanesan: Also with the Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, United Kingdom

References

1 Wirth, T., Venkatkumar, V., Haustein, T., Schulz, E., and Halfmann, R.: 'LTE-advanced relaying for outdoor range extension'. Proc. IEEE 70th Vehicular Technology Conf. Fall, VTC 2009-Fall, Anchorage, AK, USA, September 2009, pp. 1–4

2 Peters, S.W., Panah, A.Y., Truong, K.T., and Heath, J.R.W.: 'Relay architectures for 3GPP LTE-advanced', *EURASIP J. Wirel. Commun. Netw.*, 2009, **2009**, pp. 1–14

3 Kanesan, T., Ng, W.P., Ghassemlooy, Z., and Lu, C.: 'Theoretical and experimental design of an alternative system to 2 × 2 MIMO for LTE over 60 km directly modulated RoF link'. Proc. IEEE Global Telecommunications Conf., (GLOBECOM), Anaheim, CA, USA, December 2012, pp. 1–4

4 Chin-Pang, L., and Seeds, A.J.: 'Transmission of wireless MIMO-type signals over a single optical fiber without WDM', *IEEE Trans. Microw. Theory Tech.*, 2010, **58**, (11), pp. 3094–3102

5 Jansen, S.L., Morita, I., and Tanaka, H.: '16 × 52.5-Gb/s, 50-GHz spaced, POLMUX-CO-OFDM transmission over 4160 km of SSMF enabled by MIMO processing'. 33rd European Conf. Exhibition of Optical Communication – Post Deadline Papers, (ECOC 2008), Brussels, Belgium, September 2008, pp. 1–2

6 3GPP: 'LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); FDD repeater radio transmission and reception', (3GPP TS 36.106), **10.0.0**, (Rel-10), 2011