A Relay-Assisted Vehicular Visible Light Communications Network

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***Abstract*— In this paper, we experimentally investigate a relay-assisted vehicular visible light communications (VLC) link using a vehicle taillight. The results demonstrate that, the decode-and-forward relay scheme is a suitable candidate for vehicular VLC connectivity as part of the intelligent transport systems.**

Keywords—relay-assisted, vehicular networks, visible light communications

I. Introduction

Visible light communications (VLC) has been proposed for vehicular communications as a complementary technology in intelligent transport systems (ITS) [1]. Presently, the radio frequency (RF) wireless communications technology is the established option in ITS, which is known as the dedicated short-range communications (DSRC), which supports several applications such as emergency braking warning and intersection collision warnings [2]. However, some doubts still exist on the capability of DSRC in meeting the low latency and high-reliability requirements in ITS considering both the network outages and security issues [3]. Interestingly, VLC provides improved scalability than RF in scenarios with a high vehicle density, whereby RF suffers from long packet delays due to the channel congestion [4].

Relay-assisted VLC links have been proposed to extend the communications span in vehicular VLC (VVLC) systems [5]. In [6], an indoor relay-assisted VLC was experimentally investigated for a last meter access network with a multiband carrier-less amplitude and phase modulation (*m*-CAP). The results showed data rate improvement by 25% and 60% for amplify and forward (AF) and decode and forward (DF) relay schemes, respectively compared with the direct link (no relays). In [7], the viability of employing multiple taillights (TLs) and multiple photo-detectors (PDs)-based receivers (Rxs) was studied using orthogonal frequency division multiplexing (OFDM)-based transmission scheme for direct transmission (DT) and multi-hop transmission (MHT) by means of simulation, but based on a VVLC optical channel model obtained through experiments. Consequently, it was shown that, for the link with spatial multiplexing MHT offered reduced average signal power of -59 dBm for a single hope (for a 16 m link span) compared with -27 dBm for DT (for a 12 m link span). However, to the best of authors knowledge, only few works have been reported on relay-assisted VVLC links especially based on experimental measurements [7]. Consequently in this work, we investigate AF and DF schemes using vehicle's TLs and PDs as the VLC transmitters (Txs) and the Rxs, respectively and show that, the DF scheme is a suitable candidate for VVLC interconnection in ITS.

II. Experimental Setup and Results

The schematic block diagram of the proposed AF and DF relay-assisted VLC system is shown in Figs. 1(a) and (b) respectively. At the Tx, a non return-to-zero on-off keying (NRZ-OOK) signal is applied to an arbitrary waveform generator (AWG) (Teledyne T3AWG3252), the output of which is used for intensity modulation of the Tx1. via the light emitting diode (LED) driver. Following transmission over the free space and optical to electrical and electrical to optical conversion at the AF relay node the signal is detected at the Rx2 the output of which is captured using a real-time digital signal oscilloscope (DSO) (LeCroy WaveRunner Z640i) for offline processing in MATLAB. Note, we have used Truck-DACA08712AM, Thorlabs APD430A2/M (silicon-based avalanche PD with a low noise transimpedance amplifier) and Thorlabs PDA10A2 as the Txs, Rx1 and Rx2, respectively. Biconvex lenses with a focal length of 35 mm are used at the Rxs to improve the signal to noise ratio (SNR). As for the DF scheme, see Fig. 1(b), the received signal at the relay node is firstly decoded and then retransmitted to Rx2.

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Two data rates R_b of 250 kb/s and 500kb/s are used, and the results obtained show that, the DF relay provides improved bit error rate (BER) performance compared with the AF relay scheme over the same transmission distance. Figure 2 shows the eye diagrams following processing and detection of the captured signals at Rx2, for two different link spans L_s of 12 and 16 m for the AF and DF

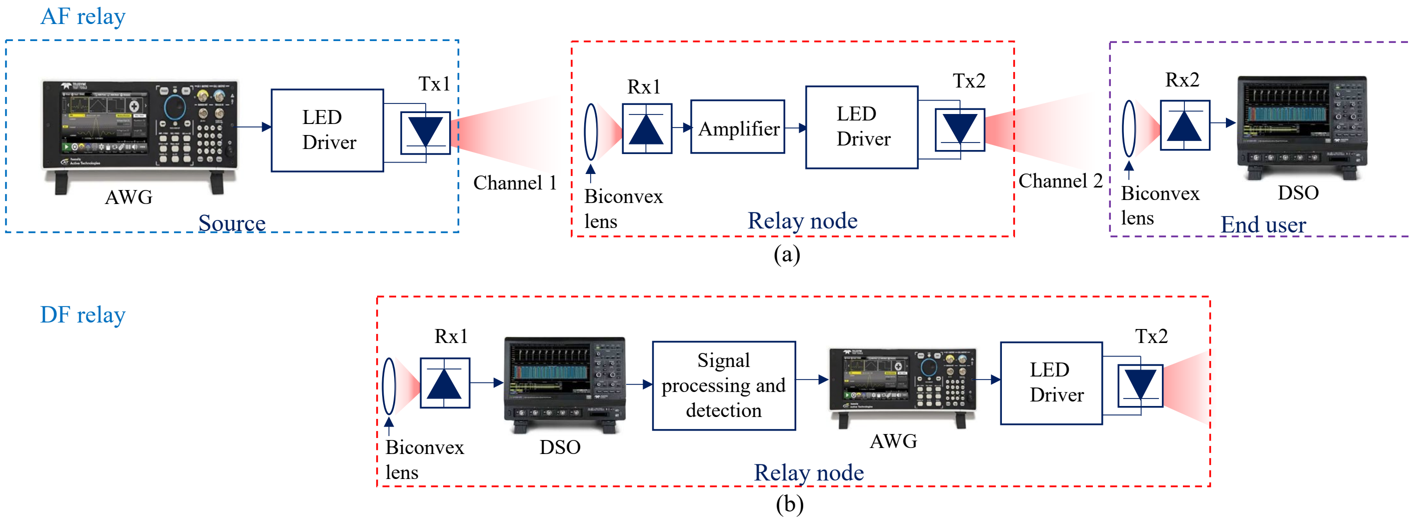

Fig. 1: Experimental setup for the VVLC relay-assisted link with: (a) AF and (b) DF relay schemes (just relay node shown)

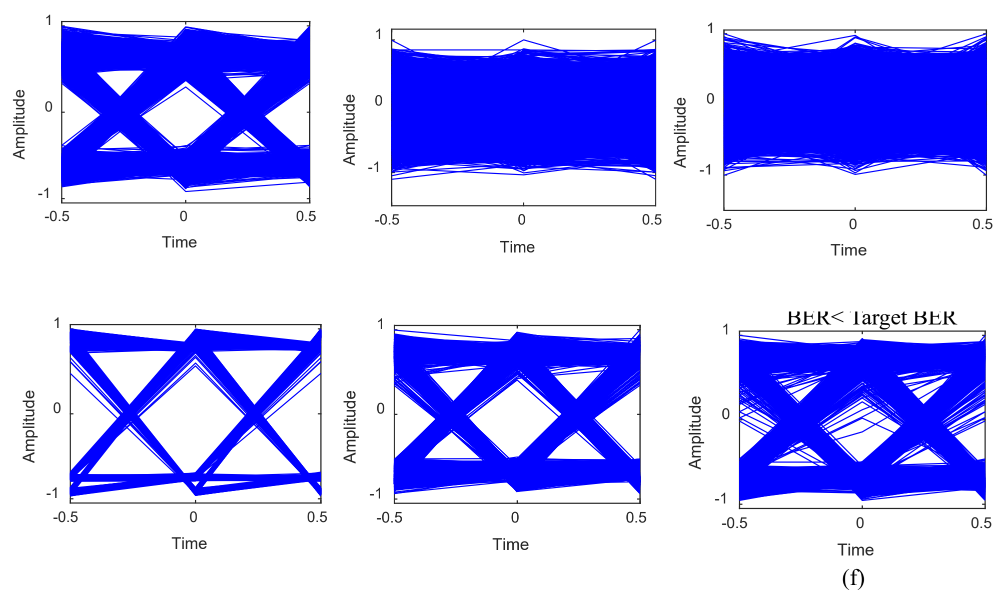

Fig. 2: Measured eye diagrams for R_b of 250 kb/s for: (a) AF and (b) DF with L_s of 12 m, and (c) AF and (d) DF with L_s of 16 m; and R_b of 500 kb/s for: (e) AF and (f) DF with L_s of 16 m

relay links. Note that, the transmission distances between the Tx1 and the Rx1 and Tx2 to the Rx2 are 8 and 8-16 m, respectively. For the link with the AF relay (Fig. 2(c)) with L_s = 16 m and R_b of 250 kb/s the eye diagram is completely closed with a BER of 1.31×10^{-2} while for the DF link (Fig. 2(d)) with the same L_s and R_b the BER is below the target forward error correction (FEC) limit of 10^{-4}. This is because, the link with the AF relay suffers from noise accumulation over the transmission span and the received signal at the relay node is simply amplified with no regeneration or reshaping in contrast to the DF relay. For the DF relay scheme, see Figs. 2(b), (d) and (f), the eye diagrams are all open with the BER values below the target FEC limit. For the AF relay scheme, the SNR decreases significantly with the link span (i.e., as L_s of 12 m in Fig. 2(a) to 16 m in Fig. 2(c)). Moreover, for both relay schemes, the eye opening decreases with the increasing R_b.

III. Conclusions

We experimentally investigated AF and DF relay schemes for the VVLC system. The results obtained demonstrates that, the DF relaying scheme can provide longer transmission range and higher data rates compared with the AF scheme.

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