RELAY-ASSISTED HANDOVER TECHNIQUE FOR VEHICULAR VLC NETWORKS

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Abstract – *In this paper, we propose a relay-assisted handover technique for vehicular visible light communication networks where streetlights are configured to serve as Access Points (APs). In the proposed system, the vehicle is served by a relay terminal in the form of a neighbor vehicle in addition to the serving AP if the measured bit error rate becomes higher than a threshold value. We evaluate the system performance using realistic site-specific channel models developed through non-sequential ray tracing features of OpticStudio for various deployment scenarios. The simulation results show that our technique provides a superior performance compared to conventional handover schemes.*

Keywords – Handover, ray tracing, relay, vehicular network, visible light communications

1. INTRODUCTION

Intelligent Transportation Systems (ITS) have emerged as an essential component of future smart cites [1]. ITS aim to improve road safety providing real-time information on traffic and road conditions. In addition, they provide high-speed Internet access and mobile commerce services for commuters [2]. Vehicular connectivity is required to enable data sharing between vehicles and the infrastructures along the road [3]. Current vehicular networks are mainly based on Radio Frequency (RF) technologies such as DSRC and C-V2X [4]. The widespread adoption of Light Emitting Diodes (LEDs) in exterior automotive lighting and roadside illumination infrastructure has prompted the investigation of Visible Light Communication (VLC) for vehicular networking. VLC is based on the principle of modulating light intensity and allows the dual use of LED-based Headlights (HLs), Taillights (TLs), streetlights and traffic lights for both illumination and communication purposes [5]. This facilitates the implementation of vehicular VLC with different forms such as Vehicle-to-Vehicle (V2V) and Infrastructure-to-Vehicle (I2V) communications [6].

An important design issue in vehicular VLC networks is handover required for efficient mobility management. While vertical and horizontal handover techniques were studied extensively in indoor VLC networks, see e.g., [7, 8, 9] and references therein, the literature is sparse in vehicular VLC networks with different mobility characteristics in comparison to indoor counterparts. In [10], Dang and Yoo considered a vehicular VLC network where a number of consecutive streetlights are grouped as a cell. They proposed a handover technique based on the estimated distance between the vehicle and each group of streetlights. In [11], N. Zhu et.al. proposed a soft handover algorithm based on received signal strengths for a vehicular VLC network scenario where individual streetlights serve as Access Points (APs) and investigated the performance for overlapping and non-overlapping coverage cases of APs. In [12], a handover skipping algorithm is proposed to reduce the handover rate by implementing the reference signal received power for the vertical handover while the Signal-to-Interference-plus-Noise Ratio (SINR) is used for the horizontal handover. Another handover approach based on the interference-to-noise ratio and the interfere-to-interference ratio is proposed in [13], utilizing the NS3 simulator. In [14], Demir et.al. proposed a velocity-aware dynamic handover scheme based on coordinated multipoint transmission. The proposed algorithm takes the rate of change in the received signal level as an input and accordingly updates handover parameters without explicit information of the vehicle velocity.

In this paper, we present a relay-assisted handover technique to improve the accuracy of handover decisions for vehicular VLC networks. Use of intermediate vehicles as relay nodes was already proposed in the literature to enable non-line-of-sight optical transmission between source and destination vehicles [15, 16]. However, to the best of our knowledge, relay-assisted handover in vehicular VLC systems has not been studied. In our proposed handover technique, the vehicle is mainly served by an AP in the form of a streetlight from which it gets the strongest signal. If the measured Bit Error Rate (BER) becomes higher than a threshold value, the vehicle is jointly served by a relay terminal and serving AP. We evaluate the performance of proposed relay-assisted handover technique using realistic site-specific channel models developed through non-sequential ray tracing and demonstrate significant performance gains over conventional hard handover especially in the case of blocking.

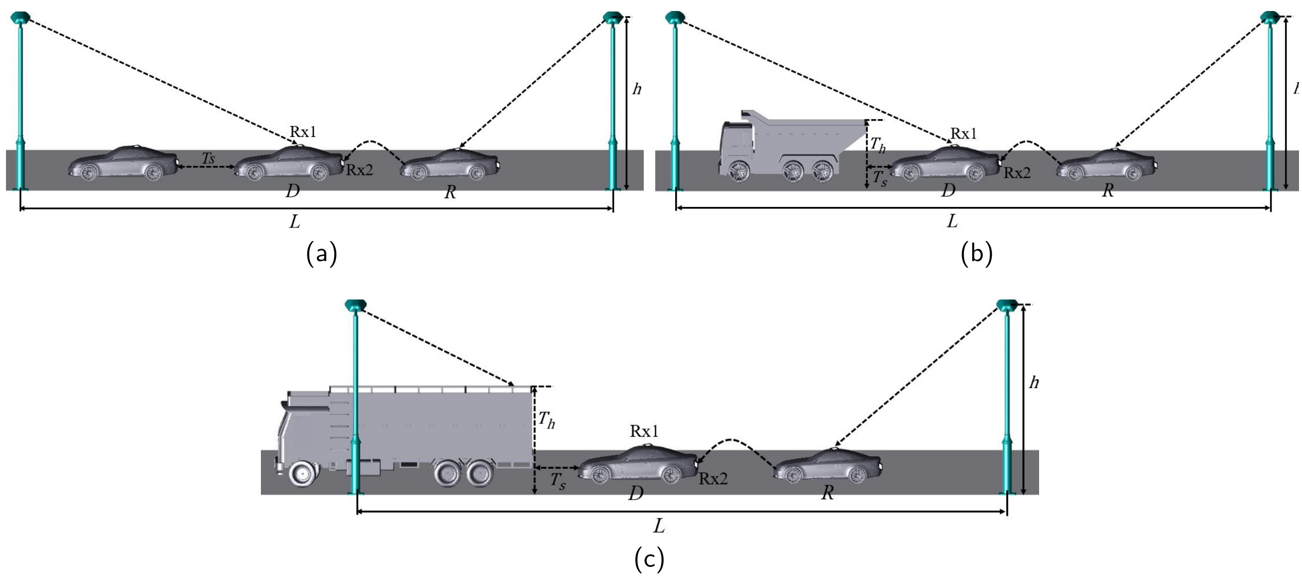

Fig. 1 – Vehicular VLC scenarios under consideration: (a) Scenario 1, (b) Scenario 2, and (c) Scenario 3.

The remainder of this paper is organized as follows. In Section 2, we describe the system model. In Section 3, we present the relay-assisted handover technique. In Section 4, we present simulation results and provide comparison with conventional handover techniques. Finally, we conclude in Section 5.

2. SYSTEM MODEL

As shown in Fig. 1, we consider a vehicular VLC network where LED-based streetlights serve as APs. Streetlight poles are placed at intervals of L distance. Each pole has a height of h, boom angle of θ, and boom length of B_l. APs are connected to a centralized controller (CU) which acts as a gateway to the Internet. We assume that a serving AP (S) can transmit data directly to the destination vehicle (D) and/or through a relaying vehicle (R). In order to receive the data from the serving APs, the vehicle is equipped with a Photodetector (PD) which is denoted by Rx1 and installed at its top as shown in Fig. 1. For relaying purposes, the two headlamps of the vehicle are used as wireless transmitters while another PD installed at the back of the vehicle (denoted by Rx2) is used as wireless receiver as indicated in Fig. 1.

The vehicle is mainly served by an AP from which it gets the strongest signal, but when the signal quality is not sufficient, relay-assisted (cooperative) transmission is activated. The orthogonal cooperation protocol [17] consists of two phases. In the broadcasting phase, the source terminal (streetlight) transmits the information to the relay vehicle and destination vehicle. In the relaying phase, the relay vehicle modulates the intensity of the LED light and retransmits the amplified version of the received signal to the destination vehicle. Finally, the destination vehicle performs Maximal Ratio Combining (MRC) on the signals received over two phases. If the relay-assisted transmission mode is not activated, there is only direct transmission, i.e., received signal from the streetlight.

The physical layer of the downlink builds upon Direct Current-biased Optical Orthogonal Frequency Division Multiplexing (DCO-OFDM) with square M–ary Quadrature Amplitude Modulation (QAM). Let $x_S(t)$ denote the properly DC-biased transmitted OFDM signal from the serving AP with an average electrical signal power of P_S. During the broadcasting phase, the received signal by the destination vehicle is given as

$$\begin{aligned} y_{SD}(t) = {} & R_{pd}\,\lambda\,\sqrt{P_S} H_{SD}(t) x_S(t) \\ & + R_{pd}\,\lambda\,\sqrt{P_S} \sum_{i \in I} H_{iD}(t) x_i(t) + n_D(t) \end{aligned} \tag{1}$$

where R_{pd} is the responsivity of the PD, λ represents the electrical to optical conversion ratio of the LED, and $H_{SD}(t)$ is the DC channel gain from the serving AP to the destination vehicle. Here, I denotes the set of interfering APs. $x_i(t)$ is the transmitted signal from the $i^{th} \in I$ AP and $H_{iD}(t)$ is the corresponding DC channel gain. $n_D(t)$ is the noise term with zero mean and variance of $\sigma_n^2 = N_0 B$. N_0 is the noise Power Spectral Density (PSD) and B is the modulation bandwidth. The signal received by the relay vehicle during the broadcasting phase is written as

$$\begin{aligned} y_{SR}(t) = {} & R_{pd}\,\lambda\,\sqrt{P_S} H_{SR}(t) x_S(t) \\ & + R_{pd}\,\lambda\,\sqrt{P_S} \sum_{i \in I} H_{iR}(t) x_i(t) + n_R(t) \end{aligned} \tag{2}$$

where $n_R(t)$ is the receiver noise with variance of σ_n^2. $H_{iR}(t)$ denotes the DC channel gain from the i^{th} AP to the relay terminal.

In the relaying phase, the relay vehicle amplifies the signal and transmits it to the destination vehicle. The

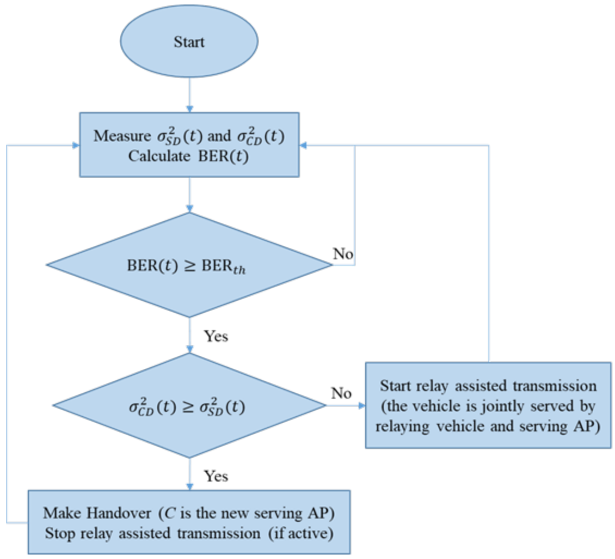

Fig. 2 – Flow chart of the proposed relay-assisted handover algorithm.

received signal at the destination vehicle is given as

$$y_{RD}(t) = R_{pd}\lambda G_R(t) H_{RD}(t) y_{SR}(t) + n_D(t) \qquad (3)$$

where $H_{RD}(t)$ denotes the DC channel gain from the relay terminal to the destination vehicle. $G_R(t)$ is the amplification factor given by $G_R(t) = \sqrt{P_R/(\sigma^2_{SR}(t) + \sum_{i\in I}\sigma^2_{iR}(t) + \sigma^2_n)}$ [18] where P_R is the average electrical signal power at the relay terminal. Here, $\sigma^2_{SR}(t) = \lambda^2 R^2_{pd} P_S H^2_{SR}(t)$ and $\sigma^2_{iR}(t) = \lambda^2 R^2_{pd} P_S H^2_{iD}(t)$ are respectively the variance of the received electrical powers at the relay vehicle from the serving AP and the i^{th} interfering AP. The receiver in the destination vehicle uses the MRC technique [19] to combine the received signals in (1) and (3).

3. RELAY-ASSISTED HANDOVER TECHNIQUE

Our proposed handover algorithm is based on the received signal levels and signal qualities indicated by the BER. First, we explain the calculation of the BER for a relay-assisted VLC system which is the critical input for the proposed handover technique. Then, we present the handover algorithm, as shown in Fig. 2.

An approximate upper bound of BER for an OFDM system with M-QAM is given by [20]

$$\text{BER}(t) \leq \frac{\sqrt{M}-1}{\sqrt{M}\log 2\sqrt{M}} \exp\left(-\frac{3\gamma(t)}{2(M-1)}\right) \qquad (4)$$

where $\gamma(t)$ is the SINR of the MRC output. It is the sum of individual SINRs obtained at broadcasting and relaying phases and is written as

$$\gamma(t) = \gamma_{SD}(t) + \gamma_{SRD}(t) \qquad (5)$$

Algorithm 1 Pseudo-code of relay-assisted handover algorithm

for each time slot **do**
  take measurements of $\sigma^2_{SD}(t)$ and $\sigma^2_{CD}(t)$;
  if BER$(t) \geq$ BER$_{th}$ **then**
    if $\sigma^2_{CD}(t) \geq \sigma^2_{SD}(t)$ **then**
      make handover
      stop relay-assisted transmission (if active);
    else
      start/continue relay-assisted transmission;

Based on (1), SINR for direct transmission is given by

$$\gamma_{SD}(t) = \frac{\sigma^2_{SD}(t)}{\sum_{i\in I}\sigma^2_{iD}(t) + \sigma^2_n} \qquad (6)$$

where $\sigma^2_{SD}(t) = \lambda^2 R^2_{pd} P_S H^2_{SD}(t)$ and $\sigma^2_{iD}(t) = \lambda^2 R^2_{pd} P_S H^2_{iD}(t)$ are respectively the variance of the received electrical powers at the destination vehicle from the serving AP and the i^{th} interfering AP. Similarly, based on (2) and (3), the SINR for relay-assisted transmission is calculated as

$$\gamma_{SRD}(t) = \frac{\lambda^2 R^2_{pd} G^2_R H^2_{RD}(t)\sigma^2_{SR}(t)}{\lambda^2 R^2_{pd} G^2_R H^2_{RD}(t)\left(\sum_{i\in I}\sigma^2_{iR}(t) + \sigma^2_n\right) + \sigma^2_n} \qquad (7)$$

The CU periodically collects received information from APs and decides which AP should serve the vehicle. We assume a perfect uplink feedback channel between the vehicle and APs. The pseudo-code of the proposed handover algorithm is provided in Algorithm 1. In our technique, the vehicle reports quantized versions of the received signal power levels, i.e., $\sigma^2_{SD}(t)$ and $\sigma^2_{iD}(t)$, and BER measurements, i.e., BER(t), to the transmitter AP via the uplink. If the value of $\sigma^2_{SD}(t)$ indicates that there is a sufficiently strong AP signal satisfying the required BER threshold, the vehicle is served by that specific AP. Handover to a candidate AP is triggered if the measured BER falls above a threshold value BER$(t) \geq$ BER$_{th}$, and the received signal level from the candidate AP ($\sigma^2_{CD}(t)$) exceeds that of the current serving AP, i.e., $\sigma^2_{CD}(t) \geq \sigma^2_{SD}(t)$.

When directly received signals from APs are not sufficient enough for signal quality and there is no candidate AP that meets the handover criteria, relay-transmission is activated. This activation takes place when the measured BER falls above the threshold value BER$(t) \geq$ BER$_{th}$. It continues until a handover is triggered to a candidate AP satisfying the handover requirements. It should be further noted that a handover algorithm based only on the received signal levels forces the vehicle to be connected to the AP with strong signal level even if the interference is high resulting in an unacceptable signal quality.

Table 1 – Simulation parameters

Transmitter	Streetlamp	Vestel Ephesus M4S 68
	Headlamp	Philips Luxeon Rebel
	Conversion ratio (λ)	0.5
Receiver	Area (Rx1, Rx2)	150 mm^2, 100 mm^2
	Half field-of-view (FoV)	90°
	Responsivity (R_{pd})	1 A/W
Poles	Material	Galvanized steel metal
	Spacing (L)	20 m
	Height (h)	7 m
	Boom Length (B_l)	1 m
	Boom Angle (θ)	10°
Noise	Noise density (N_0)	1×10^{-21} A^2/Hz
	Bandwidth (B)	5 MHz
	BER threshold (BER$_{th}$)	10^{-3} [21]
	Modulation order (M)	16

Therefore, our algorithm incorporates the signal quality together with the relative signal levels for better accuracy.

4. SIMULATION RESULTS

In our simulations, we consider a single-lane road with streetlights on one side. Channel Impulse Responses (CIRs) are obtained between each streetlamp and destination vehicle, and between destination and relay vehicles at each 1 m over the traveling distance between two poles. Our channel modeling builds upon the advanced ray tracing features of OpticStudio [5, 22]. This approach lets us obtain the CIRs of vehicular VLC scenarios with complex geometries and realistic light sources. First, the 3D CAD models for vehicles, roads, and infrastructure poles are imported into the simulation platform along with their optical characteristics (i.e., coating ma- terial, reflectance, etc.). Then, light sources (i.e., radiation pattern, emitted power, etc.) and the PD (i.e., field-of-view angle, sensitive area, etc.) are integrated into the platform. Specifically, Vestel Ephesus M4S-68 and Philips Luxeon Rebel white LED are deployed for streetlight and vehicle HLs whose radiation patterns can be found in [5]. Other simulation parameters are listed in Table 1. Once the simulation scenario is constructed, non-sequential ray tracing is run to obtain the CIRs. Further details on channel modeling methodology can be found in our previous papers [5, 22].

We consider different I2V scenarios described below.

- **Scenario 1:** As shown in Fig. 1a, we consider the ideal case in this scenario where there is no blockage for the signals transmitted from the streetlights to the destination vehicle.

- **Scenario 2:** In this scenario, we assume possible shadowing/blockage. As shown in Fig. 1b, we consider a truck with a height of T_h = 2.7 m which moves at the front of the destination vehicle. We assume two values of separation distance between the destination car and the blocking truck, i.e., T_s = 5 m (Scenario 2.1) and T_s = 2 m (Scenario 2.2).

- **Scenario 3:** Here, we assume another scenario where the likelihood of blockage increases with respect to Scenario 2. As shown in Fig. 1c, we consider a loaded truck with a height of T_h = 4.6 m. Similar to the previous case, we assume two values of separation distance between the destination car and the blocking truck, i.e., T_s = 5 m (Scenario 3.1) and T_s = 2 m (Scenario 3.2).

In Fig. 3, we present the performance of the proposed handover technique and compare it with benchmark schemes. We assume that the vehicles travel in the right lane with the speed of 10 m/s (36 km/hr) and the distance between destination and relay vehicles is 10 m. As benchmarks, we consider a conventional hard handover algorithm [23] and Coordinated Multipoint (CoMP) handover algorithm [8]. In a hard handover scheme, handover occurs when the received power from a candidate AP is greater than the received power of the current serving AP by a margin of HOM. HOM stands for handover margin and represents the predefined hysteresis value which is used to avoid unnecessary handovers. In the CoMP handover algorithm, the user can be jointly served by two coordinating APs in transition regions between them. The handover margin is set as $HOM = 1$ dB [23] for a hard handover scheme and $HOM = 3$ dB [8] values in the CoMP handover algorithm.

It is observed from Fig. 3a (Scenario 1) that hard handover and CoMP handover algorithms have severe fluctuations in SINR. The lowest SINR values experienced in hard handover and CoMP handover schemes are -3.13 dB and 1.60 dB, respectively. The lowest value experienced in the proposed handover scheme is 18.46 dB. This is much higher than the values obtained in other schemes demonstrating its superiority. In Fig. 3b (Scenario 2.1), it is observed that the performance results remain the same as in Scenario 1 (i.e., non-blocking case). This result shows that the presence of the truck did not result in any blockage. In Fig. 3c (Scenario 2.2), since the distance be- tween the truck and the destination vehicle is shortened (i.e., T_s = 2 m) in comparison to that in Scenario 2.1 (i.e., T_s = 5 m), the effect of the blockage is now observed in the performance of hard handover and CoMP handover algorithms. Specifically, the lowest SINR values in hard handover and CoMP handover schemes are obtained as -5.03 dB and -2.18 dB, respectively. In contrast, the proposed handover technique has a more robust performance and the lowest SINR value is obtained as 18.46 dB. In Fig. 3d (Scenario 3.1), the height of the loaded truck is now T_h = 4.6 m assuming T_s = 5 m. Therefore, the effect of blocking for hard handover and CoMP handover techniques becomes more obvious. In Fig 3e (Scenario 3.2), the distance between the truck and the destination vehicle becomes even shorter (T_s = 2 m). This results in significant performance degradation in a hard handover and CoMP handover where the lowest SINR value drops to -15.8 dB while the lowest SINR value in the proposed handover scheme is 12.93 dB.

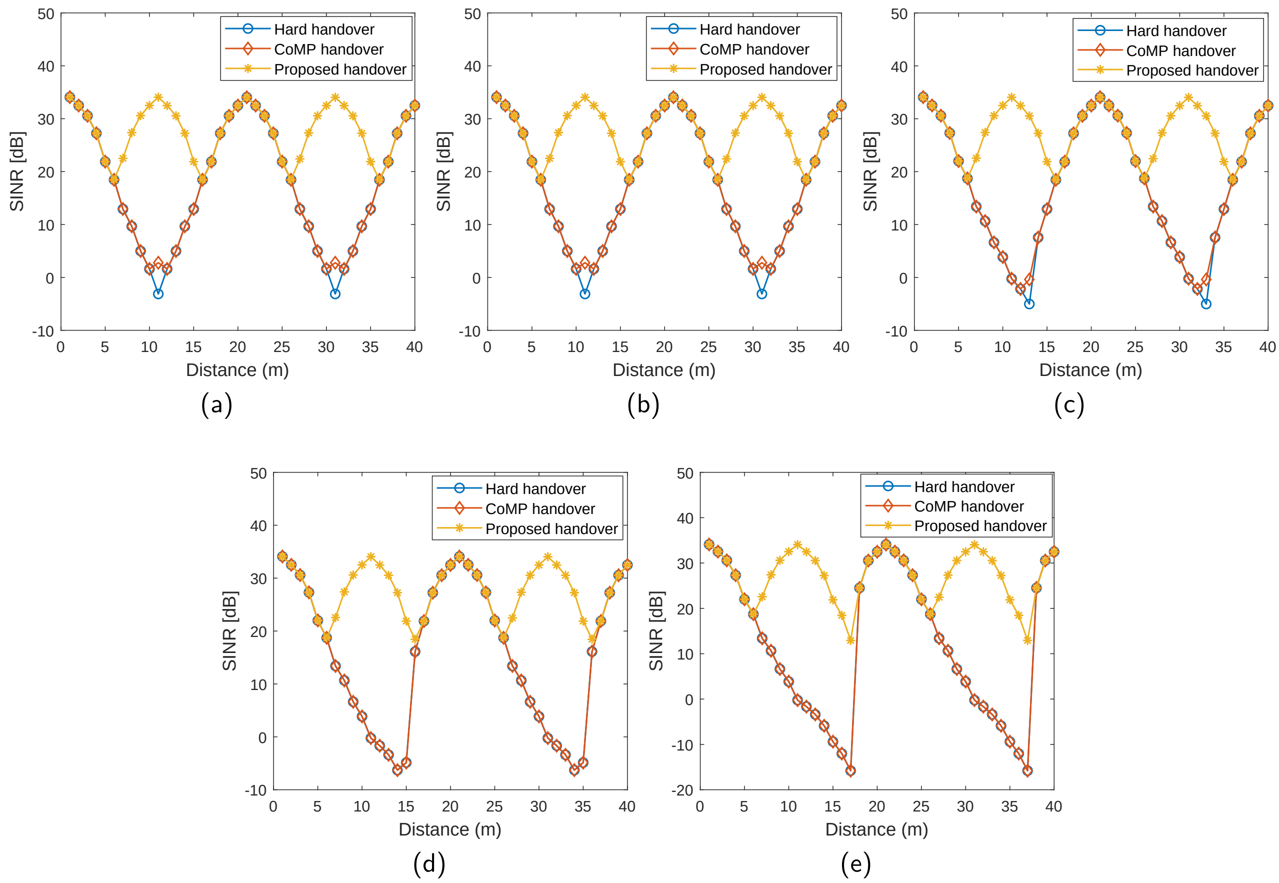

Fig. 3 – Comparison of proposed handover algorithm with hard handover and COMP handover techniques a) Scenario 1 b) Scenario 2.1 c) Scenario 2.2 d) Scenario 3.1 e) Scenario 3.2.

The results in Fig. 3 demonstrate that unlike benchmark schemes, the proposed algorithm is able to provide a stable and robust performance in the presence of a blockage.

Table 2 compares the proposed handover technique with the existing ones in terms of the minimum SINR values for all vehicular scenarios under consideration. It can be observed that the proposed handover technique with the relay-assisted handover algorithm provides a higher value of the minimum SINR at all scenarios compared with the existing ones (i.e., hard handover and CoMP handover). For example, consider Scenario 1 where the ideal case without any blockage is considered. The minimum SINR values for a hard handover, CoMP handover, and the proposed relay-assisted handover are recorded as -3.13 dB, 1.60 dB, and 18.46 dB, respectively, which indicates an improvement of more than 20 dB. Such improvement further increases when there is a blockage in the system. For example, consider Scenario 3.2, which represents the worst-case scenario, an improvement of more than 27 dB is recorded.

To further get insight into working principles of the proposed handover scheme, we present a connectivity graph to show when relay-assisted transmission is activated. A circle marker shows the locations where a vehicle is

Table 2 – Minimum SINR for handover techniques

	Hard Handover	CoMP Handover	Proposed Handover
Scenario 1	-3.13 dB	1.60 dB	18.46 dB
Scenario 2.1	-3.13 dB	1.60 dB	18.46 dB
Scenario 2.2	-5.03 dB	-2.18 dB	18.46 dB
Scenario 3.1	-6.29 dB	-6.29 dB	18.46 dB
Scenario 3.2	-15.8 dB	-15.8 dB	12.93 dB

served by only direct transmission without any involvement of relay, whereas a triangle marker shows the locations where relay-assisted transmission is active. In Fig. 4a (Scenarios 1, 2.1, 2.2 and 3.1), it is observed that relay transmission starts when the vehicle is 7 m away from a serving AP and continues for 10 m. Then handover to the neighbor AP is triggered and the vehicle is served by only direct transmission for the next 10 meters. In Fig. 4b (Scenario 3.2), it is observed that relay transmission starts when the vehicle is 7 m away from a serving AP (pole) and continues for 11 m. Then handover to the neighbor AP is triggered and the vehicle is served by only direct transmission for the next 9 m.

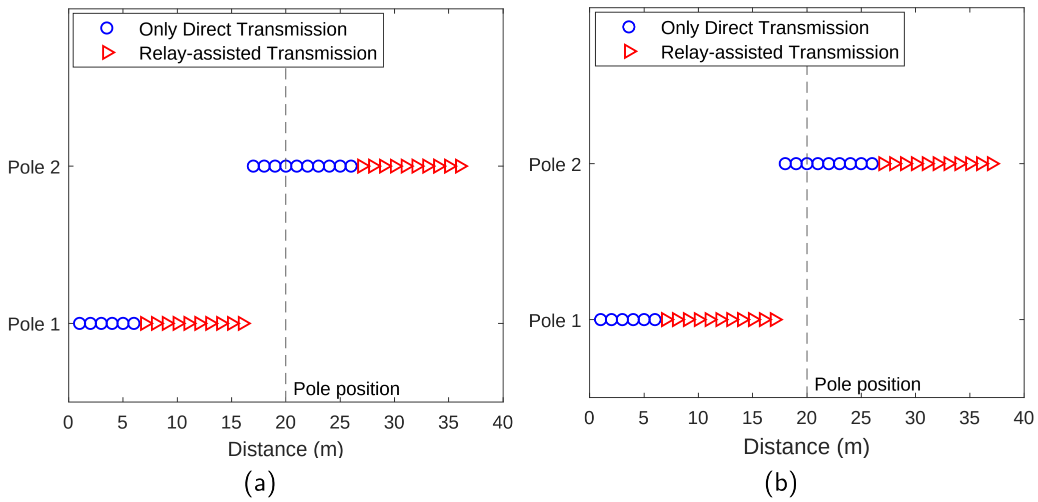

Fig. 4 – Serving AP (street pole) versus distance for proposed handover system a) Scenario 1, Scenario 2.1, Scenario 2.2, Scenario 3.1 b) Scenario 3.2.

5. CONCLUSION

In this paper, we have proposed a relay-assisted handover technique for vehicular VLC networks where APs are in the form of streetlights. The vehicle is mainly served by an AP from which it gets the strongest signal. relay-assisted transmission is activated if the measured BER falls above the threshold value. Through extensive simulations, we have investigated the performance of a proposed relay-assisted handover technique using site-specific channel models developed through non-sequential ray tracing. We have considered several scenarios with and without blockage. Simulation results have demonstrated that our technique provides a robust and stable performance even in the presence of a blockage and has a superior performance in comparison to conventional hard handover and CoMP handover schemes.

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