INVISIBLE: Enhanced Handover technique for Vehicular Visible Light Networks

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***Abstract*—Wide use of light emitting diode (LED) in cars and road sides unites is encouraging the exploitation of Visible Light Communication (VLC) paradigm in vehicular applications. However, real scenarios are characterized by poor Signal to Noise Ratio (SNR) conditions and, heavy interference among devices in the same area, that make effective handover operations critical for properly supporting mobility. A novel approach to perform handover in Vehicular Visible Light Networks (V-VLN), based on the evaluation of Interference to Noise Ratio (INR) and Interferer to Interference (IIR) Ratio, is proposed in this work, in place of the conventional approaches based on Signal to Noise Ratio (SNR) evaluation. Our approach has been numerically validated, taking into account Adaptive Modulation Scheme (AMS) and a VLC device moving at different speeds. Furthermore, a comparison with SNR-based approach has been provided. Simulation results show how INR-based handover mechanism outperforms SNR-based handover in terms of handover rate, the average delivered data per handover, and handover delay ratio.**

***Index Terms*—Adaptive modulation, Interference based handover, Vehicular visible light network**

I. Introduction

The growing number of mobile devices and their applications enforce a huge amount of data exchange, pushing radio frequency-based wireless technologies to their resources limit. New paradigms, such as visible light communication (VLC), are appeared to complement RF technologies in addressing the spectrum crunch. VLC exploits pre-existing infrastructures like Light Emitting Diodes (LEDs), in order to provide not only illumination, but also to transfer data. A plenty of indoor and outdoor VLC applications have emerged since the last decade, including LiFi, localization and underwater communications. Intrinsic security due to limited penetration depth and a huge bandwidth of totally free spectrum are the other key factors behind the growing interest in VLC [1] [2] [3] [4].

Vehicular Visible Light communication (V-VLC) represents one of the most attractive outdoor applications of this paradigm. The aim of V-VLC is to enhance safety and driving experience by exchanging information between a generic vehicle and its surrounding (e.g., Vehicle-to-Vehicle V2V, Vehicle-to-Infrastructure V2I) using car lamps, traffic lights, control cameras and so on. However, like the other outdoor VLC techniques, advances in V-VLC are slower comparing to indoor VLC, mainly due to environmental issues (e.g., sunlight noise, weather conditions, and higher mobility) [5]. In absence of ambient disturbances, VLC link quality depends on the distance between the transmitter and the receiver and their orientation in addition to the front-end configuration (*i.e.*, field of view FOV of the receiver, area of the photo diode PD and radiation pattern). If the relative movement between the transmitter and the receiver is in the order of the signal wavelength, the quality of the optical channel represented by the channel impulse response (CIR) does not change significantly, therefore it has a minor impact on the temporal characteristics of the channel [6]. In vehicular communication however, the transmitter-receiver motion is several orders of magnitude larger than the optical wavelength, which makes the V-VLC channel unstable [7]. Directional and line of sight (LOS) necessities of the VLC channel, further complicate the mobility management in V-VLC context [8]. A principal solution for mobility management is handover, where the Mobile Entity (ME) has to switch its communication session to another Access Point (AP) in the same network (horizontal handover) or to another technology (vertical handover). An effective handover is important as well to meet the quality of service (QoS) requisites (e.g., reliability, delay).

The handover procedure is generally carried out in three steps: decision, target-AP/technology selection and execution. In handover decision, the ME decides to switch from the current AP to another candidate according to quality of the link [9]. If there are multiple candidates, the ME has to select one of them, and finally handover execution takes place via exchanging control packets between the ME and the candidate AP.

By reference to the previous works in the context of V-VLC, handover is generally based on the link quality which is evaluated by signal to noise ratio (SNR), mainly considering in the analysis, the presence of Gaussian noise (i.e., shot noise and thermal noise) [10]. In the dynamic soft handover algorithm, the coordinated multipoint (CoMP) is implemented according to the rate of change in the maximum received power to adjust handover parameters such as handover margin and the time-to-trigger [11]. However, the evaluation of the system by observing only the SNR and ignoring any disturbances from other transmitters, does not provide an accurate performance evaluation [9].

Signal to interference and noise ratio (SINR) is also employed in handover decision, since it provides higher precision compared to SNR, especially when noise and interference power levels are on the same order of magnitude. In this case, the interference is modeled as a Gaussian random process too, considering the accumulation of many independent signals

Meysam Mayahi, Valeria Loscri and Antonio Costanzo are with Inria Lille - Nord Europe

where no individual signal dominates over the others [12].
Handover skipping could reduce the handover rate in hybrid LiFi-WiFi networks by implementing reference signal received power (RSRP) for vertical handover and SINR for horizontal handover [13].
Nevertheless, a dominant interferer is present in many real scenarios. In this case, a more accurate way to describe the interference distribution is by utilizing the interference to noise ratio (INR) [10].

In this work, we employ the INR as the main metric for handover procedures. We consider both Gaussian interference distribution, and dominant interferer distribution, but we select which of them is applied, on the basis of interferer to interference ratio (IIR). Moreover, target AP selection is made based on the QoS requirements of the application. In order to achieve further improvement on overall system performance, the adaptive modulation scheme (AMS), dynamically switching between On Off Keying (OOK) and Phase Shift Keying (PSK) Modulation with different order (4-8-16 PSK), has been implemented.

The main contributions of this work can be summarized as follows:

- We propose INVISIBLE, an Interference based haNdover mechanism for VISIBle Light nEtworks
- We integrate in the interference handover framework an adaptive modulation technique, to reduce the amount of horizontal handover

The structure of this paper is the following.
System model, analytical description of the problem and main operations, including details of the proposed algorithm, are provided in Section II. Details of the system implementation using the Network Simulator 3 (NS3) as well as the numerical results and comparison between conventional SNR-based technique and the proposed method are discussed in the Section III. In particular, the handover rate, the average delivered data per handover, and the handover delay ratio have been considered for different ME speeds (25kmph and 100kmph). Finally, we provide some discussions and conclude the paper in section IV.

II. System model

As illustrated in Fig. 1, we consider a V-VLC architecture, composed of street lights, acting as APs and randomly distributed along the direction of the road with a linear distribution density ρ_l, defined as the number of APs per kilometer. Each AP has a maximum transmission range d_{max}, which depends on the VLC front-end configuration and the optical channel, whose transfer function (h) is characterised by the Lambertian emission (h_{lam}) and the climate loss (h_{clm}) [14].

$$h = h_{lam} h_{clm} \tag{1}$$

The climate loss is statistically related to the variance of the amplitude and modeled by the ray tracing analysis [15]. Under

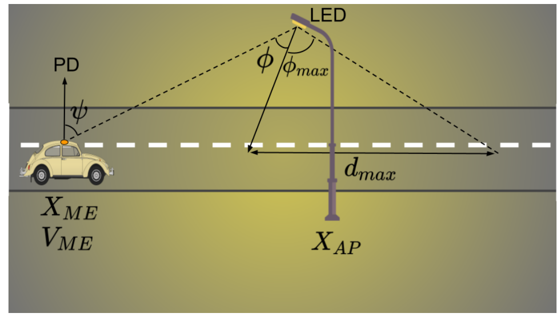

Fig. 1. Handover Scenario

LoS constraint, the channel model restricted to the Lambertian model [16]:

$$h_{Lam} = \frac{(m+1)A}{2\pi d^2} \cos^m(\phi) T_s(\psi) g(\psi) \cos(\psi) \tag{2}$$

Where m is the order of Lambertian emission, A is the area of the photo diode PD, d is the distance between the ME and the AP, ϕ and ψ are the angle of radiance and acceptance respectively. The optical filter gain is represented by T_s and g is photodetector concentrator gain. The main loss in the outdoor applications of VLC is due to daylight shot noise and thermal noise which are assumed to be Gaussian distributed with respective variances σ^2_{shot} and $\sigma^2_{thermal}$. Given independent noise sources, the central limit theorem is applied to find the variance of the aggregate noise current σ^2_n

$$\sigma^2_n = \sigma^2_{shot} + \sigma^2_{thermal} \tag{3}$$

The SNR provides an accurate optical link evaluation when the system is noise dominant.

$$SNR = \frac{(rP_{rx})^2}{\sigma^2_n} \tag{4}$$

In (4), r represents the PD responsivity and P_{rx} stands for the average received optical power. In interference dominant network, where the sensor is affected by the neighbouring transmitters, an accurate performance analysis requires evaluation of the interference and the noise jointly.
System interference is frequently modeled as Gaussian random process since it is assumed no individual signal dominates [12]. This assumption is not precise when the dominant interferer is present. In such scenarios the interference is properly modeled by the distribution of the dominant interferer [10]. In order to determine if a dominant interferer is present, one can define the interferer to interference ratio as

$$IIR = \max_i \left(\frac{P_{rx,i}}{\Sigma_{i \neq s} P_{rx,i}} \right) \tag{5}$$

where the useful signal s is not included within the interferers i. Lower IIR values fit well with the Gaussian distribution [10], while high values of IIR exclude this hypothesis. In fact, if IIR is greater than β, we consider that the interference distribution follows the dominant interferer. β is statistically defined the minimum IIR the system can detect. Once this aspect has been

TABLE I
MODULATION TABLE

α	Modulation scheme	Relative bitrate	d_{max}
$11.14[dB]$	OOK	$100[Kbit/s]$	$12.5[m]$
$11.3[dB]$	4PSK	$150[Kbit/s]$	$12.0[m]$
$18.4[dB]$	8PSK	$200[Kbit/s]$	$8.0[m]$
$20.6[dB]$	16PSK	$250[Kbit/s]$	$6.5[m]$

determined (interference dominated or not), one can relay on the appropriate metric in order to evaluate the quality of the link. In our system we calculate the total interference to noise ratio INR_t as :

$$INR_t = \sum_{i \neq s} INR_i \tag{6}$$

where the INR_i is the interference to noise ratio of the i^{th} interferer. Link performance evaluation depends on the QoS required by the application. One of the essential requirements is the reliability described as BER-SNR curve. Fixing the maximum error probability for vehicular safety applications equal to $10e-3$, the minimum required signal to noise ratio (α) is shown in table 1 [17]. If the system recognized as interference dominated (*i.e.* $INR_t \geq 10$), then it is possible to search for the dominant interferer using IIR. Dominant interferer could be represented as an Handover (HO) candidate if:

$$INR_i = \frac{(rP_{rx,i})^2}{\sigma_n^2} \geq \alpha \tag{7}$$

In order to increase the lifetime of the link, the vehicle should avoid unnecessary handovers [18]. Skipping unnecessary handover will reduce the handover rate. The handover is unnecessary if the sojourn time t_s is shorter than connection lifetime T_c which is the other important QoS requirement for lots of applications. Sojourn time is defined as the time estimated for the ME to be served by a given AP:

$$t_s = \frac{d_{max} + (X_{ME} - X_{AP})}{V_{ME}} \tag{8}$$

where X and V are the position and the velocity vectors respectively. Putting these conditions together, the dominant interferer will be candidate as AP if $INR_i \geq \alpha$ and $t_s \geq T_c$. This process will be successively reapplied if there are multiple dominant interferers.

The adaptive modulation scheme (AMS) is employed according to Algorithms 2 on top of handover mechanism (Algorithm 1) in order to obtain a proper trade off between the throughput and the communication robustness [14]. Switching between different modulations is based on the modulation parameters described in table 1.

III. RESULTS AND DISCUSSION

In this section we compare INVISIBLE handover mechanism with the SNR-based handover as a benchmark scheme described in algorithm 3. For the sake of fairness, we applied the AMS on top of both handover mechanisms using the NS3 simulation tool [19]. The main simulation parameters are shown in Table 2.

Algorithm 1 Interference-based handover

```
Require: s, α, β, T_c, t_i
  INR_t = Σ_{i≠s} INR_i
  while INR_t ≥ 10 do
    IIR = max_i ( P_{rx,i} / Σ_{i≠s} P_{rx,i} )
    if IIR ≥ β then
      INR_i = (rP_{rx,i})^2 / σ_n^2
      if INR_i ≥ α then
        t_s = (d_max + (X_ME − X_AP)) / V_ME
        if t_s ≥ T_c then
          T_c = t_s
          s = i
        end if
      end if
    end if
    INR_t = INR_t − INR_i
  end while
  return T_c, s
  if null then
    backoff t_i
  end if
```

Algorithm 2 Adaptive Modulation Scheme

```
Require: s, α
  while SNR ≥ α do
    adapt the modulation
    Transmit
    Receive
    SNR = (rP_rx)^2 / σ_n^2
  end while
  call handover
```

Algorithm 3 SNR based handover

```
Require: s, α, T_c, t_i
  SNR = max_{i≠s} ( (rP_{rx,i})^2 / σ_n^2 )
  if SNR ≥ α then
    t_s = (d_max + (X_ME − X_AP)) / V_ME
    if t_s ≥ T_c then
      T_c = t_s
      s = i
    end if
  end if
  return T_c, s
  if null then
    backoff t_i
  end if
```

TABLE II
MAIN PARAMETERS

Parameter	Term	Value[unit]
Responsivity	r	$0.2[A/W]$
Minimum Transmission time	T_c	$200[Milliseconds]$
Sampling Time	t_i	$100[Milliseconds]$
Minimum IIR	β	0.5
Half power semi-angle	ϕ_{max}	35°[degree]
Linear AP density	ρ_l	$20-200\ [Km^{-1}]$
INR-based HO frame size		$39[Bytes]$
SNR-based HO frame size		$28[Bytes]$
Number of LEDs		10
Input power		$1.0[W]$
Number of simulations		30
Duration of each simulation		$100[s]$
Rounds of each simulation		10

The HO rate of the proposed handover mechanism is illustrated in fig. 2 with two speeds and compared to the SNR-based handover algorithm. Considering the same AP density, the higher the speed, the shorter the average sojourn time and, so, the higher the handover rate:

$$HO_{rate} = \frac{1}{t_s} \times 60\ [1/min] \tag{9}$$

On the same speed when the AP density increases, the SNR based handover rate increases almost linearly. As the AP density increases the distance between the ME and the AP decreases and since the d_{max} is fixed, handover rate increases accordingly. On the other hand, the INR-based handover rate increases in sparse AP density and is almost constant in dense AP distribution. The INR-based handover algorithm, in fact, always selects the AP which provides the largest t_s. The largest sojourn time is when the distance between the ME and the AP is less than d_{max} and it is represented by farthest AP which stands at most d_{max} meter from the ME. In fig. 3 we

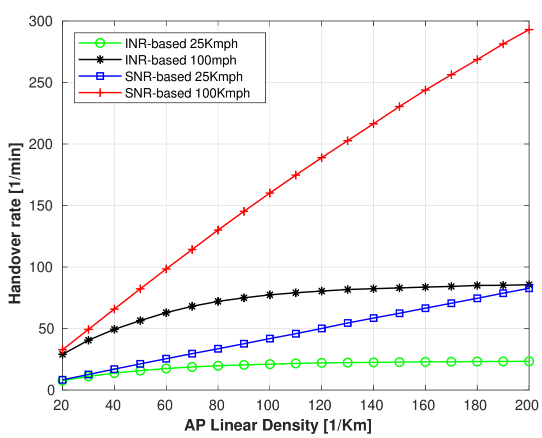

Fig. 2. Handover rate vs AP linear density with different speed of mobile entity.

assess the impact of the AP density on the average delivered data per handover, considering a slow speed of the vehicles, equal to 25Kmph and a rapid gait equal to 100 Kmph. The average delivered data per handover is the total amount of delivered data over the total number of handovers.

Since in the proposed mechanism, we transmit only when we are covered by the access point, as the speed increases, the sojourn time decreases, reducing the useful time to transmit and deliver data. In a given velocity, with sparse AP distribution (low AP density) the amount of delivered data per handover is higher not because we delivered more data (because we delivered almost the same amount of data when we are connected to a given AP) but because the total number of handover is less in both schemes.

As the AP density grows, both the amount of delivered data and the number of handover increase, but the number of handover grows faster than the amount of delivered data, therefore the overall ratio goes down.

From the other side, interference-based handover mechanism delivers almost the same amount of data by much lower number of handovers. In the other words, signal-based handover mechanism performs many unnecessary handover which degrades its performance comparing to interference-based mechanism.

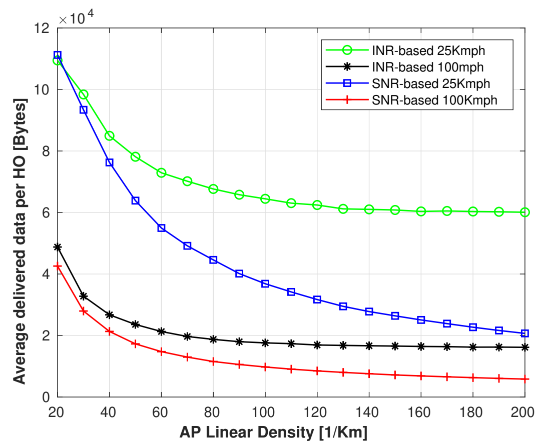

Fig. 3. Average delivered data per handover vs AP linear density with different speed of mobile nodes.

Handover delay is a vital parameter to assess the time efficiency of performing a handover [20]. The execution time of handover consists of handover request time and handover response time.

$$t_{HO} = t_{request} + t_{response} \tag{10}$$

where:

$$t_{request} = t_{response} = \frac{HO_{Frame\ Size}}{R_{b\ ME}} + \frac{HO_{Frame\ Size}}{R_{b\ AP}} \tag{11}$$

being $R_{b\ ME}$ and $R_{b\ AP}$ respectively the bit rate of the ME and the AP. We assumed the size of handover frame $HO_{FrameSize}$ is identical for the request and the response messages included in the MAC frame format given in the IEEE standard for short-range wireless optical communication using VLC 802.15.7 [21]. We normalize the general handover delay to the total handover number to measure the time percentage spent for executing the handover in a sojourn time.

$$HO_{Delay\ Ratio} = \frac{\overline{t_{HO}}}{\overline{t_s}} \times 100 \quad (12)$$

The evolution of the handover delay ratio comparing to the AP density, for 100Kmph and 25Kmph, is shown in Fig.4. For different speeds the average sojourn time $\overline{t_s}$ is different while the average handover delay $\overline{t_{HO}}$ is constant. The higher the speed the lower the sojourn time and as a consequence the higher the HO delay ratio. This ratio weakly increases in interference-based handover mechanism, however in the signal-based handover scheme this ratio shows a faster progress. For low AP density the performance of the signal-based HO is better because the HO frame size of SNR based is shorter than interference-based handover frame size while both schemes performing the same number of handover. When the AP density increases, the interference-based handover substantially outperforms the SNR-based handover, as it compensate the higher overhead by lower handover rate.

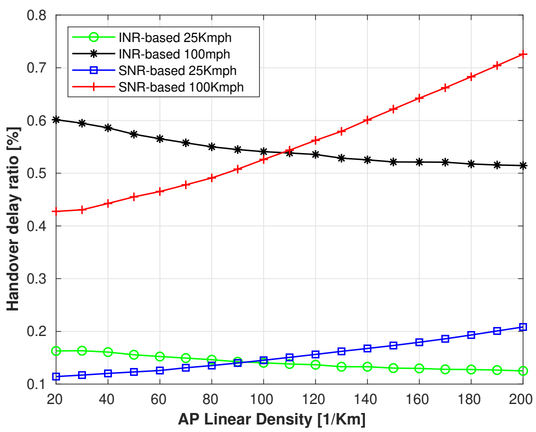

Fig. 4. Handover delay ratio

IV. Conclusion

An Enhanced Handover Technique for Vehicular Visible Light Communication Networks INVISIBLE, based on Interference to noise ratio and Interferer to Interference ratio, has been proposed and validated through simulations, using the software NS3. A comparison between our technique and the conventional technique based on SNR has been provided in terms of handover rate, average delivered data per handover and handover delay ratio.

Results show how proposed technique avoids useless handovers, and by consequence, considerably improves the average delivered data per handover and reducing the amount of overhead information in the network. At the same time, our technique shows a significantly reduced handover delay ratio, in comparison with SNR-based technique, in the dense scenarios. Since the latter aspect is frequent in vehicular network architectures with high number of users, this handover policy could be easily applied in most of real scenarios.

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