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Cooperative Optical Wireless Transmission for improving performance in indoor scenarios for Visible Light Communications

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Abstract — *In this paper, a novel cooperative transmission and reception scheme in Visible Light Communications (VLC) is proposed and evaluated. This new scheme provides improvements and reliability in large indoor scenarios, such as corridors, laboratories, shops or conference rooms, where the coverage needs to be obtained by using different access points when VLC is used. The main idea behind the proposal is a simple cooperative transmission scheme where the receiver terminal will obtain the signal from different access points at the same time. This proposal outperforms traditional VLC schemes, especially in Non-Line-of-Sight reception where around 3 dB of gain with respect to the traditional schemes can be obtained for unoptimized parameters and larger than 3 dB could be easily achieved. The cooperation is studied in terms of the percentage of light coming from the main access point and a parameter called sidelobes' amplitude level. The performance is evaluated according to the location into the atto-cell*[1].

Index Terms — VLC, CoMP, Cooperative transmission and reception, Pulse Position Division Multiplexing.

I. INTRODUCTION

Nowadays, there exists a huge demand for high data rate services in wireless communications which will be satisfied with difficulty in the near future because of the spectrum limitations. Hence, the trend is the cooperation among different technologies working in different frequency bands, such as common Radio Frequency (RF) services and Optical Wireless Communications (OWC), which has demonstrated that provides high speed wireless transmission in indoor environments [1]. Although there are already studies and proposals in this field of interest [2], the coexistence between RF and OWC is still an open research area [3], [4], but it is not the focus of this paper. Moreover, although consumer optical communications are mostly guided [5], the number of wireless applications for it is growing in recent years [6], [7], mainly for the following advantages that make OWC an appropriate candidate to complement RF communications:

- Environments: Since the signals in OWC do not interfere with RF systems, this technology can be installed in scenarios where RF services are not allowed such as hospitals and airplanes. Larger bandwidths can be used (hundreds of megahertz) [8] allowing very high data rates.
- Security: One of the main concerns of RF waves is the control of its propagation. In indoor scenarios any RF system could jam other systems located at other rooms. However, optical waves do not go through walls and systems will be independent in each room.
- Cost: The components in OWC are low-cost and off-the-shelf [9]. Thus, from the consumer electronics' point of view, this technology is very attractive [10].

Visible Light Communications (VLC) can provide illumination and data transmission at once, so it is oriented to indoor environments [11], [12]. Current research goes toward a model composed by optical atto-cells [13], in such a way that a user is always served by the best access point (AP) and a seamless communication is guaranteed. However, if the same frequency resources are used in neighbor cells, co-channel interference appears leading to a decrease of the signal to interference noise ratio (SINR). To overcome this problem a huge amount of solutions have been proposed, such as a static resource partitioning approach [14], the employment of soft frequency reuse (SFR) [15] or the adaptation of RF techniques as joint transmission (JT) in optical atto-cell networks [16]. Some of them use Direct-current-biased optical orthogonal frequency division multiplexing (DCO-OFDM) [17], which is a promising technique to achieve high speed transmission in VLC, but it also implies drawbacks. For example, the nonlinear current to optical power transfer function of the light-emitting diode (LED), together with the high peak to average power ratio (PAPR) of multiple carrier frequencies modulation schemes, make its implementation more difficult [18].

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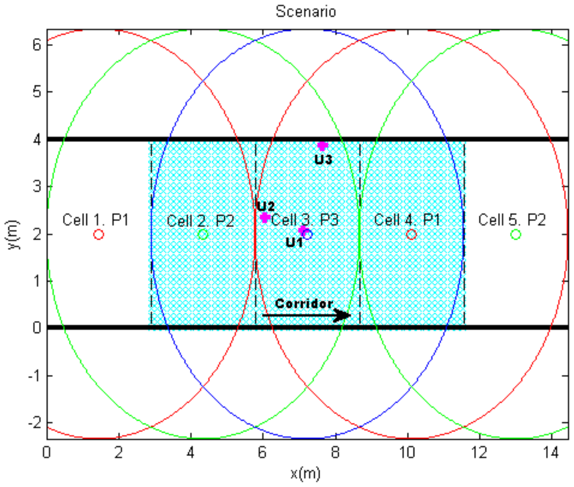

Fig. 1. Overhead View of a Corridor Scenario with 5 access points.

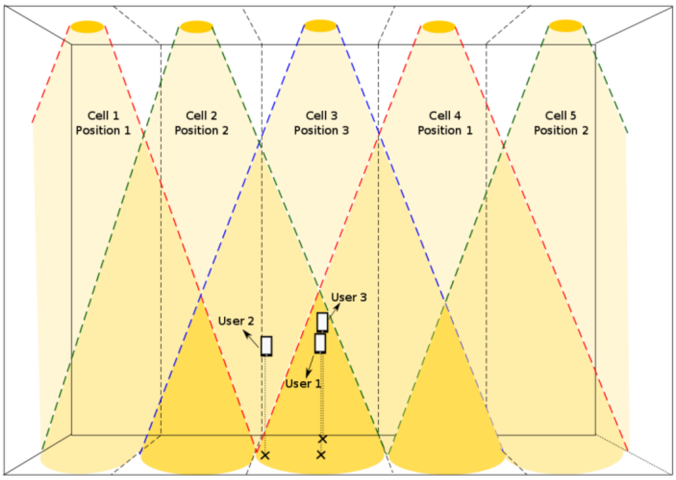

Fig. 2. Perspective of a Corridor Scenario with 5 access points.

These problems and the difficulty that implies the use of different wavelengths to avoid the inter-cell interference make one think about doing it in another way. A simple cooperative multipoint transmission and reception scheme is then proposed.

VLC involves issues such as interference between lighting sources (here considered in shot noise), flickering effect [19] or shadowing. Among the aforementioned aspects, one of the most relevant and common is the shadowing. There are in the literature few though complex solutions to deal with it such as adaptive link scheduling [20], [21], or position diversity obtained by the independent transmission from different access points of I and Q signals [22]. In this paper, a much simpler solution for this problem is developed. A cooperative multipoint transmission and reception scheme is proposed and evaluated for VLC, where different VLC access points cooperate transmitting their own data and also extra cooperative signals that help the receivers of neighbor cells. The proposal provides Signal to Noise Ratio (SNR) improvements, especially when there is Non-Line-of-Sight (NLOS) between the access point and the receiver, a common situation in corridor scenarios when there are many people or in laboratories and shops with furniture. An adaptive scheme is also proposed that uses Coordinated MultiPoint transmission and reception (CoMP) in NLOS points and simple Pulse Position Division Multiplexing (PPDM) in Line-of-Sight (LOS) cases. As it will be seen in section IV, the scheme proposed for CoMP OWC is able to provide more than 3 dB of gain in the SNR with respect to the traditional schemes, what impacts in a decrease of error probability.

TABLE I
SYSTEM PARAMETERS

Parameter	Variable	Value	Unit Symbol
Transmit Power	P_t	72	Watt
Number of LEDs	-	3600	-
Data Rate	R_b	100	Mbps
Background current	I_{bg}	5100	µA
Absolute temperature	T_k	298	K
Open-loop voltage gain	G	10	-
FET transconductance	g_m	30	mS
FET channel noise factor	Γ	1.5	-
Fixed capacitance	η	112	pF/cm^2
Semi-angle at half illuminance of the LED	$\Phi_{1/2}$	70	deg.
Field of View (FOV) at a receiver	Ψ_c	60	deg.
Detector physical area of the Photodiode (PD)	A	1.0	cm^2
Optical filter gain	$G_f(\Psi)$	1.0	-
Refractive index of the lens a PD	n	1.5	-
Detector's responsivity	γ	0.54	A/W
Probability of obstruction	P_{obs}	0-100	%
Percentage of light	θ	0-100	%
Sidelobes' amplitude level with respect to the main lobe	ρ	0-240	%

The structure of the paper is as follows. After the introduction, section II describes the scenario and channel model used. Section III presents the proposed cooperative VLC scheme to improve the signal reception while power transmission is reduced and obstacles are avoided. This scheme is evaluated in section IV where the main aspects and results are discussed. Finally, in section V some conclusions are drawn.

II. SCENARIO AND MODEL

In VLC a common scenario provides the coverage by means of several optical overlapped access points, such as in the corridor scenario shown in Fig. 1 and Fig. 2, which will be used for illustrating the results. The scheme can be applied to other environments and it can be straightforwardly adapted. In that corridor in Fig. 1 and Fig. 2, five cells are shown. As it can be seen, there are areas where signal can be received from three neighboring cells. The cells in the neighborhood are

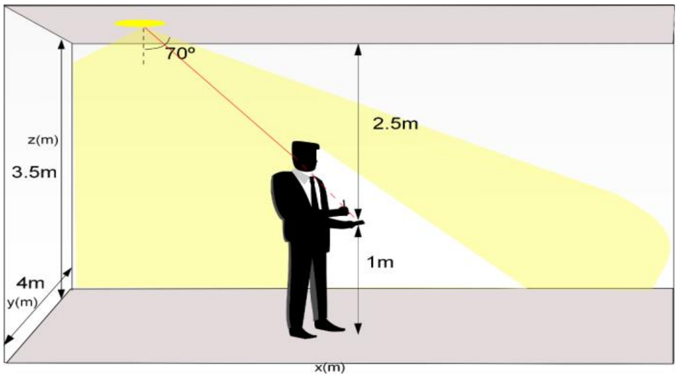

Fig. 3. NLOS due to people.

defined as the closest cells surrounding each one whose coverage areas overlap within the interest cell. Also, Fig. 1 highlights three users whose positions with respect to the base station are really different, with the aim of studying their performance later on. These corridor scenarios are some of the important places where extra hotspots in different technologies will be needed to increase capacity, *e.g.*, in Long Term Evolution (LTE) and LTE Advanced scenarios [23]. Indeed, this is what happens at university corridors during the spare time between classes, time for students to access to their social networks from their smartphones. In such locations, cooperation between RF and OWC will be very interesting.

A. NLOS in OWC

Obstacles are frequent in these scenarios if one thinks of people at the corridor, conference or large room with their receivers at middle height (at hands) and the serving access point being behind the person as it can be seen in Fig. 3. This is even harder in crowded corridors as the university corridors described above. Obstacles are also important in a laboratory, where all the furniture can intercept LOS while the receivers are on top of the tables. In these very common scenarios is where the proposal outperforms the traditional OWC systems.

B. Optical Channel Model

The optical channel model used can be described as [24]

$$H = \begin{cases} \dfrac{(m+1)A}{2\pi D_d^2}\cos^m(\varphi)G_f(\psi)g(\psi)\cos(\psi), \\ \quad 0 \le \psi \le \Psi_c \\ 0, \\ \quad \psi > \Psi_c \end{cases} \tag{1}$$

where D_d is the distance between the transmitter and the receiver, φ is the angle of irradiance, ψ is the angle of incidence and the optical concentrator $g(\psi)$ is given by

$$g(\psi) = \begin{cases} \dfrac{n^2}{\sin^2\Psi_c}, & 0 \le \psi \le \Psi_c \\ 0, & \psi \ge \Psi_c \end{cases} \tag{2}$$

being the order of Lambertian emission $m = 0.646$, obtained by $m = -\dfrac{\ln 2}{\ln(\cos\varphi_{1/2})}$. The values and the meaning of all the parameters are shown in TABLE I.

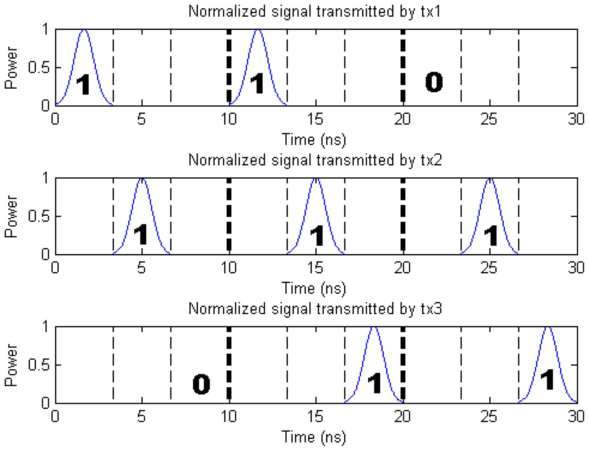

Fig. 4. On-Off Keying PPDM without cooperation.

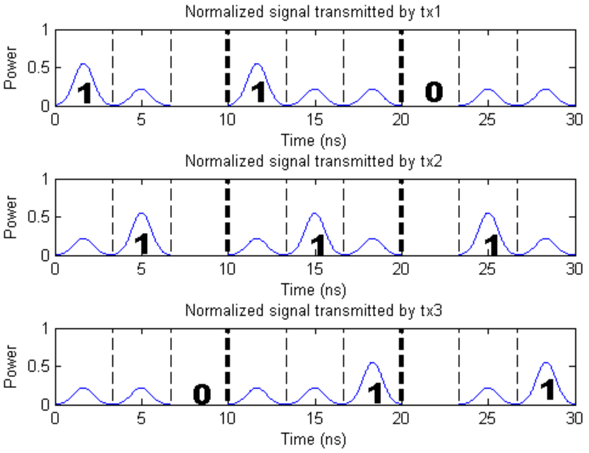

Fig. 5. On-Off Keying PPDM with cooperation.

The received optical power is thus computed as follows

$$P_r = H \cdot P_t, \tag{3}$$

being P_t the optical transmitted power. Finally, the SNR is approximated by

$$SNR = \frac{\gamma^2 P^2_{rSignal}}{\sigma^2_{shot} + \sigma^2_{thermal} + \gamma^2 P^2_{rISI}}, \tag{4}$$

where σ^2_{shot}, $\sigma^2_{thermal}$ and P_{rISI} are the shot noise variance, thermal noise variance and received power by the intersymbol interference (ISI), respectively, and defined as

$$\sigma^2_{shot} = 2q\gamma(P_{rSignal} + P_{rISI})R_b + 2qI_{bg}I_2R_b \tag{5}$$

$$\sigma^2_{thermal} = \frac{8\pi kT_k}{G}\eta A I_2 R^2_b + \frac{16\pi^2 kT_k\Gamma}{g_m}\eta^2 A^2 I_3 R^3_b \tag{6}$$

$$P_{rISI} = \int_T^{\infty}\left(\sum_{i=1}^{LEDs} h_i(t) \otimes X(t)\right)dt \tag{7}$$

being q the electronic charge, k the Boltzmann's constant and the noise bandwidth factors $I_2 = 0.562$ and $I_3 = 0.0868$. It must be highlighted that effects of dispersion in a practical

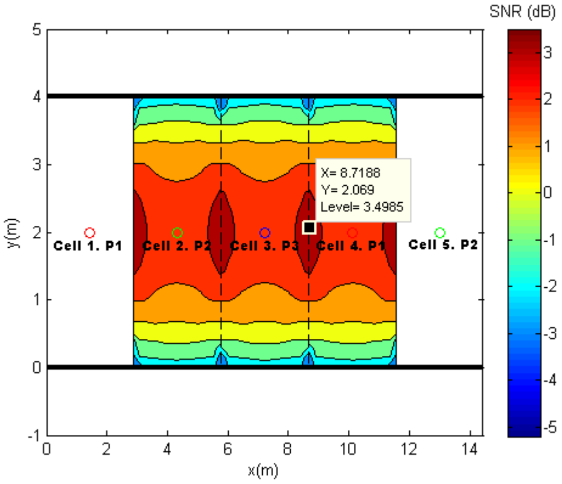

Fig. 6. SNR with CoMP in a scenario where all the users are obstructed.

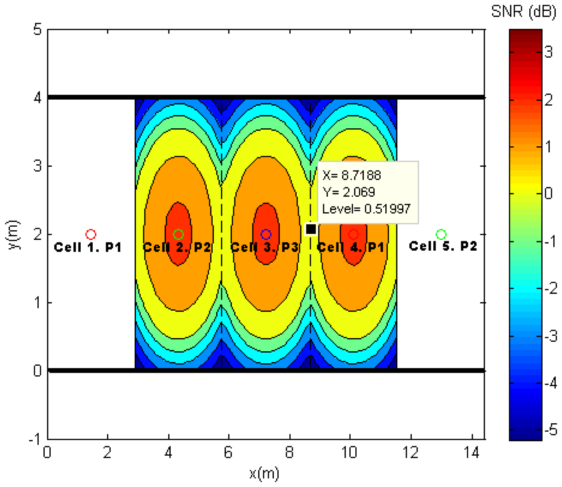

Fig. 7. SNR without CoMP in a scenario where all the users are obstructed.

sense are taken into account as an intersymbol interference [25].

The P_{rISI} is secondly considered in this study as the focus is to overcome the shadowing effect. Since it is time-consuming and hard to study the ISI effect in every position in the scenario, it is taken the ISI input referred noise variance corresponding to the used data rate [24].

III. PROPOSED COOPERATIVE VISIBLE LIGHT TRANSMISSION SCHEME

Two of the main challenges in VLC are the obstacles and the limit on maximum transmitted power due to safety reasons. In order to deal with both of them, a cooperative transmission scheme is proposed and developed. The proposed scheme is valid for indoor scenarios although it can also be easily extended to outdoor deployments.

The usage of On-Off Keying (OOK) modulation in VLC access points is a simple way to transmit data to the receivers. In these scenarios described above where the coverage needs to be provided by several transmitters, each atto-cell uses a different wavelength for avoiding inter-cell interference [1]. However, this scheme increases complexity at the receiver that needs to be able to detect different wavelengths by using an array of photodetectors with different wavelength sensitivities or filters. Besides, the handover process needs more signal processing.

Otherwise, the proposal uses a single wavelength, which can be optimized for the specific environmental light conditions. In order to avoid inter-cell interference, a Pulse Position Division Multiplexing is carried out at the access points, *i.e.*, each cell in the neighborhood transmits its pulses in a different position within the interval (see Fig. 4 and Fig. 5). In this way, several advantages are obtained. Firstly, receivers are simpler because only one wavelength has to be detected. Secondly, since the receiver is tuned to the wavelength, it is able to detect signals from the other cells in the neighborhood, and thus, a cooperative transmission and reception can be performed in the following way: at each cell, the access point knows the data to be transmitted by itself and also by the others cells in the neighborhood by using the backhaul feedback link. Thereby, it could help the other cells in the neighborhood by transmitting during the appropriate interval their data albeit with less energy, as it can be seen in Fig. 5. In this way, the detected power at the receiver side will come from the serving access point and the cooperative neighboring cells. Note that cooperative pulses use lower power for fair comparison and for reducing interference.

This scheme allows obtaining several advantages: first of all, since the detected power at the receiver is higher, the transmitted energy by the serving access point can be decreased maintaining the same performance and thus increasing the safety margin. In the second place, since the light comes from different paths, spatial diversity is obtained, what also provides a reduction in probability of obstruction (avoiding it in most of the cases) for this scenario. Besides, diversity provides further performance improvements and thus, the transmit power can be even decreased maintaining the target Bit Error Rate (BER).

For the sake of clarity, in the scenario depicted in Fig. 1 and Fig. 2, an example of such transmission scheme is shown in Fig. 5 with serving access point cell 3 (using position P3 within the frame) and two neighboring cells, 2 and 4 (using positions P2 and P1, respectively). In this example, cell 3 transmits {0, 1, 1} and the other two neighboring cells 2 and 4 transmit {1, 1, 1} and {1, 1, 0}, respectively. As it can be seen in Fig. 4, if there is not cooperation, each cell transmits its data in the proper interval. On the other hand, in the proposal the neighboring cells cooperate in the transmission of the data and thus helping the receiver following the PPDM scheme. See Fig. 5, where the cooperative sidelobes can be appreciated.

The received optical power by user 1 which is in cell 3 (Fig. 1) in the CoMP scheme is as follows

$$P_{r_{user1}} = P_{t_2}\cdot H_2 + P_{t_3}\cdot H_3 + P_{t_4}\cdot H_4, \quad (8)$$

where P_{t_2} is the transmitted signal coming from cell 2 and

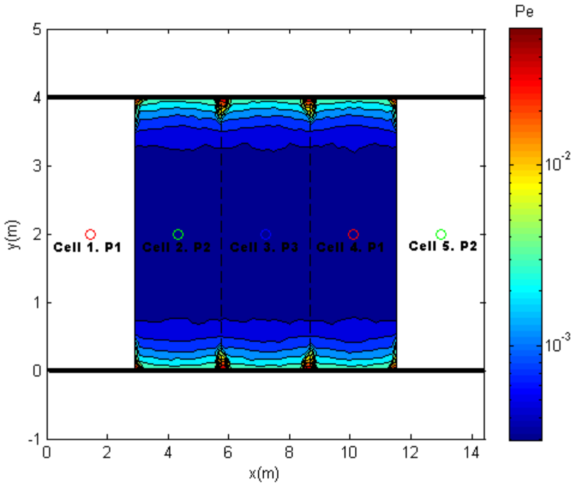

Fig. 8. BER with CoMP in a scenario where all the users are obstructed.

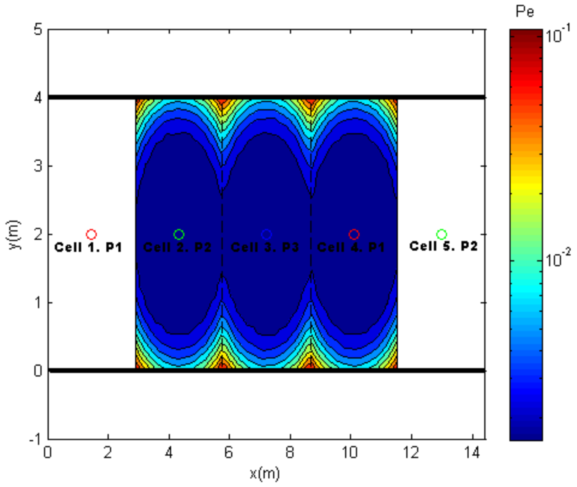

Fig. 9. BER without CoMP in a scenario where all the users are obstructed.

H_2 the corresponding channel coefficient. The same for P_{t_3}, H_3, P_{t_4} and H_4. It should be noted that when user 1 experiences obstruction with respect to its access point (cell 3), H_3 approaches to 0, but, since the signal is also received from cell 2 and 4 in the scheme, the receiver could still decode the data.

A. Receiver Scheme

At the receiver side, it is assumed to have some information about the transmitter and the channel state information (CSI). First, the receiver knows the transmit power P_t and the sidelobes' amplitude level with respect to the main lobe ρ used by transmitters. Second, it must know which its serving cell is, and finally the symbol period *T*. This information can be easily obtained through a feedback channel.

The decision at the receiver is performed via threshold. In order to get such threshold, the following procedure has been followed at the receiver. The pulses transmitted from the access points have been modeled according to a normal distribution, being the pulse generator function

$$g_p(t) = N(0, \sigma_s), \tag{9}$$

where σ_s is the pulse standard deviation, keeping in mind that dimming is determined by the pulse width [26] and being a function of

$$T_S = \frac{T}{3} \tag{10}$$

due to the fact that in the PPDM scheme each symbol period is divided in three intervals for each cooperative access point. Nevertheless it can be extrapolated to other scenarios where there are more than 2 neighbor atto-cells (*N*) and consequently

$$T_S = \frac{T}{N+1}. \tag{11}$$

Then, it is necessary to define an auxiliary vector with a reference normalized distribution in the amplitude of the lobes, which is useful for the CoMP case

$$A = \begin{bmatrix} 1 & \rho & \rho \end{bmatrix} \tag{12}$$

where the main cell would be the first one.

In this paper, the transmitted signals in both no-CoMP and CoMP schemes are normalized in envelope. CoMP reference signal will be designed in such a way that the envelope energy is the same as the no-CoMP system. Thus, an auxiliary reference signal for the no-CoMP case is defined as

$$s_{aux}^{no-CoMP}(t) = A_1 \cdot g_p(t). \tag{13}$$

The reference signal normalized in the envelope is

$$s_{ref}^{no-CoMP}(t) = s_{aux}^{no-CoMP}(t) \sqrt{\frac{P_t}{\frac{1}{T}\int_0^T s_{aux}^{no-CoMP}(t)^2\,dt}}. \tag{14}$$

Now, the total energy of this no-CoMP reference signal is computed in order to normalize the CoMP reference signal, and having a fair comparison

$$S_{env} = \int_0^T s_{ref}^{no-CoMP}(t)dt. \tag{15}$$

The procedure for the CoMP reference signal is similar to the previous one and could be summarized with the following equations

$$s_{aux}^{CoMP}(t) = \sum_{k=1}^{3} A_k g_p(t-(k-1)T_s), \tag{16}$$

where k indicates the time interval of each period. The reference signal normalized in the envelope is

$$s_{ref}^{CoMP}(t) = \frac{s_{aux}^{CoMP}(t)}{\int_0^T s_{aux}^{CoMP}(t)dt} S_{env}. \tag{17}$$

Finally, to establish the threshold, the maximum values of both $s_{ref}^{no-CoMP}$ and s_{ref}^{CoMP} are taken as the reference values of the transmitted signal

$$\mathrm{Ref}_{no-CoMP} = \max\left(s_{ref}^{no-CoMP}(t)\right), \tag{18}$$

$$\mathrm{Ref}_{CoMP} = \max\left(s_{ref}^{CoMP}(t)\right). \tag{19}$$

To conclude the receiver scheme, the decider must be introduced. Once the threshold is established, the received

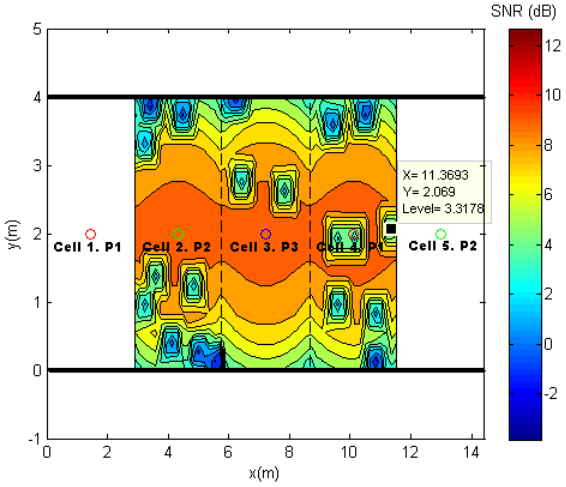

Fig. 10. SNR with CoMP in a scenario where some users are obstructed.

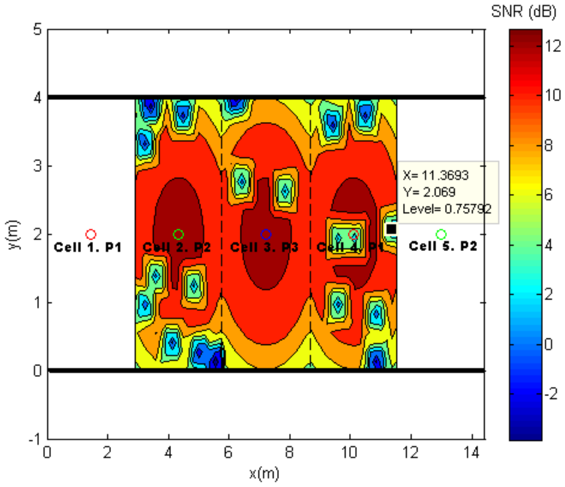

Fig. 11. SNR without CoMP in a scenario where some users are obstructed.

signal is sampled in the optimal time instants. They are, for a given user belonging to a specific cell, the center of the interval of the corresponding symbol period. If the sample overcomes the threshold the decider considers that a 1 has been received. Otherwise, a 0 would have been received. This decider is explained as

$$H_1 = 1 \tag{20}$$

$$H_0 = 0 \tag{21}$$

$$H_1 \overset{Th}{\lessgtr} H_0. \tag{22}$$

The hypothesis H_1 indicates that a 1 was received and the hypothesis H_0 indicates that a 0 was received.

IV. RESULTS AND DISCUSSION

Once the scheme has been described, some simulations have been carried out in order to show the improvements in the SNR at the receiver side when there are obstacles. The data rate R_b was fixed to be 100 Mbps and the transmit power P_t = 72 W, as it is shown in TABLE 1 [24]. The access points are placed at the ceiling (3.5 m high) and all the receivers are at 1 m on average. It should be noted that for a fair comparison, the transmitted energy from the two schemes is such that the power of the transmitted signal is the same in both CoMP and the traditional schemes.

In this scenario and scheme, there are several parameters that can be defined, analyzed and optimized, namely:

- Probability of obstruction (P_{obs}): the probability that a user is obstructed with respect to its main cell.
- Percentage of light (θ): how much light arrives to the receiver when the user is obstructed.
- Sidelobes' amplitude level (ρ): how much power, in percentage and compared to the main lobe, is given to the sidelobes in the CoMP scheme.

If nothing is specified, it is assumed a θ = 30% of light arrived from their main cell in case of obstruction and a ρ = 40% of secondary lobes' amplitude in the CoMP scheme, which is defined relative to the main lobe.

A. *Scenario I: All the users obstructed*

In the first scenario, all the users are obstructed, typical case of a crowded corridor during break time between classes. In fact, it is likely that communication will be massively established during this period of time since it is when people have spare time.

The results are plotted from Fig. 6 to Fig. 9. They are depicted supposing that 30% of light is arriving to the receiver and thus there is not a complete obstruction (where the gain with respect to the traditional scheme would be even higher). Fig. 6 and Fig. 7 show a clear improvement in the SNR for all the user's positions. It can also be observed that the area of strong signal reception (higher SNR) in CoMP are the cell edges where the cooperation between cells is more emphasized, and it is one of the areas where currently research community is more interested to improve. A maximum gain of 3.32 dB (around 3 dB in the highlighted point), and a minimum gain of 0.41 dB are obtained for the specific simulation parameters. It is also important to mention that the SNR values at the cell's corners are lower due to the fact that only one cooperation between two cells exists (see Fig. 1 or Fig. 2 to check the limits of cooperation).

In Fig. 8 and Fig. 9 the study of the same scenario in terms of error probability is shown, where it can be checked a gain everywhere when there exists obstruction. It can also be observed that the area of strong signal reception (less error probability) is much larger in the case of CoMP. In the worst points (red zones), the CoMP scheme at least reduces in a half the probability of error with respect to the traditional one, whereas in cell edges (very critical zones) the CoMP scheme is able to reduce it more than one order of magnitude. In general for this scenario, CoMP achieves much lower probability of error than traditional schemes.

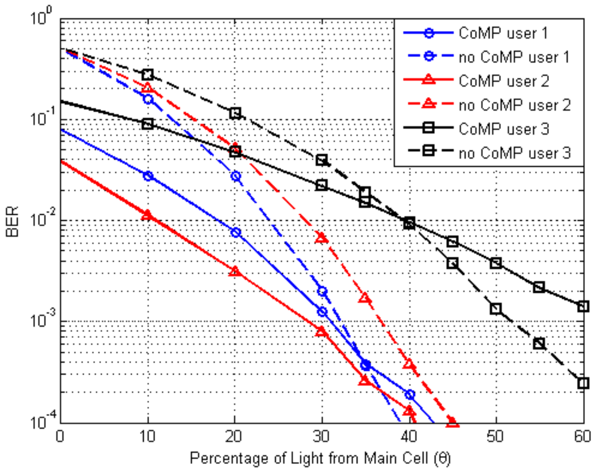

Fig. 12. BER with CoMP and no-CoMP for different users depending on the light arrived from their main cell (secondary lobes' amplitude ρ=40%).

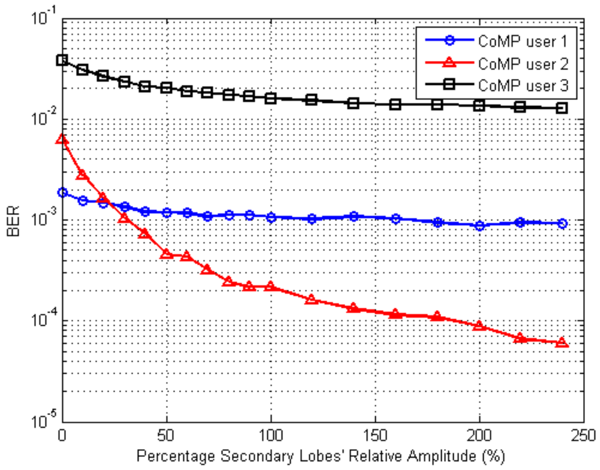

Fig. 13. BER with CoMP depending on the secondary lobes' amplitude. Different users and all of them obstructed (light arrived from the main cell θ=30%).

B. Scenario II: Some users obstructed

The second one is a scenario where only certain users are obstructed. This scenario is much more conservative and assumes that only a small number of users do not have LOS (for the specific results in this paper, only the 1% of users are obstructed). This scenario is an optimist typical conference room, supermarket or laboratory.

The results are plotted in Fig. 10 and Fig. 11, where some obstructions occur (supposing that a 30% of the light is arriving from their main cells when there is an obstruction). In this case, the CoMP solution provides a better performance for the obstructed users, gaining 2.55dB in the SNR at the most. The gain depends on system's parameters such as power or FOV and on scenario's characteristics like distance between cells or heights. However, the CoMP solution obtains 3dB at most less than the no-CoMP when there is not any obstruction. The reason is that when there are no obstacles, the distance from the serving access point is shorter and thus the optimum solution is to transmit all the power from it. For these cases, an adaptive solution is proposed. In this adaptive solution, CoMP is used when the SNR is lower than the worst case in the no-CoMP scenario without any obstruction (about 5dB in this scenario), what would mean that there is an obstacle for that user. On the other hand, the traditional OOK PPDM is applied for the cases where the SNR is higher than the established threshold. This adaptive proposal only requires a small feedback load and it can be easily implemented even in fast channels where the obstacles are present only in a small fraction of the time.

In order to make an exhaustive study of the proposed CoMP system, the Fig. 12 and Fig. 13 are also included, where the grade of obstruction and the level of the secondary cooperative lobes (sidelobes) are studied, respectively.

Revisiting Fig. 1 and Fig. 2, the three users that have been studied intensively can be observed. User 1 is just under its access point, whereas user 2 and user 3 are further away. User 2 is on the cell edge, where it is expected to experiment a great contribution from neighbor cells. On the contrary, user 3 not only is far away from its access point, but also is far away from the neighbor cells, so it is one of the worst positions in terms of performance.

Fig. 12 shows the importance of CoMP in different positions (see user 1, user 2 and user 3's positions in Fig. 1) depending on the amount of light from the main cell arriving to the receiver. Regardless the position, until a certain amount of light the CoMP system provides better performance than the traditional one. Later on, when this threshold is achieved, what means that the grade of obstruction is not so severe, the no-CoMP option starts to overcome the CoMP system. The highest threshold corresponds to user 2 because it is placed on the cell edge, where the CoMP option provides better performance as it can be checked in Fig. 6. On the other hand, since user 1 is close to its access point, the traditional scheme soon achieves the CoMP performance (from 35% of light). Regarding user 3, though it is far away from its main access point, the contributions from the neighbor cells are not so important and a threshold of 40% is achieved.

In Fig. 13 the impact of the secondary lobes' amplitude is studied for the three different users when θ = 30%. The gradient of the curves represents how important is the CoMP for such users, because the parameter ρ belongs to the CoMP alternative. Since user 2 experiments larger changes, the contribution from the neighbor cells is bigger than in the other two cases. The closer to the edge of its atto-cell a user is, the more contributions from neighbor atto-cells it receives.

It can also be observed in Fig. 13 that performance saturates in terms of BER from approximately 180% of secondary lobes' relative amplitude, which means that secondary lobes' amplitude is 80% bigger than the main lobe (always keeping the power constraint). This saturation value will depend on how much light arrives when there is an obstruction (θ). In this paper, a common value of ρ = 40% has been used in order to guarantee a good performance in a wide range of scenarios.

It should be noted here that cell 1 and cell 5 (see Fig. 1 and Fig. 2) are not studied for the sake of clarity in results, although they are transmitting.

V. CONCLUSIONS

In this paper, a CoMP yet simple scheme for VLC in large indoor scenarios is proposed and evaluated. Gains larger than 3dB in the SNR are easily obtained in crowded scenarios. Moreover, since the proposal only uses a single wavelength, it can be implemented with cheap and already developed receivers. An adaptive solution to overcome the LOS cases is also proposed, establishing a sidelobes' amplitude level ρ = 180% in CoMP case. This solution only needs a very reduced feedback load.

Since this work proposes a single wavelength solution by using OOK and most of the literature is based on multicarrier solutions applied to atto-cells, a limited comparison with them can be presented. This is a closer-to-reality proposal, in exchange for less data rate which depends on the number of slots and this, at the same time, on the neighbor atto-cells. This paper can be straightforwardly extended to other large indoor scenarios and sets the foundations for future more advanced CoMP schemes in VLC.

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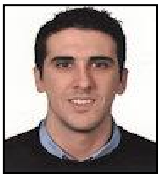
BIOGRAPHIES



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