Wireless Networks Project Defense

Zero-Forcing Beamforming for Visible Light Communication Systems

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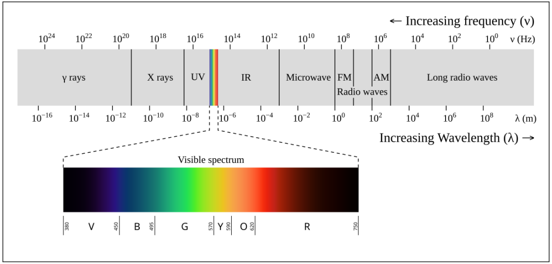
Overview

Spectrum crunch problem

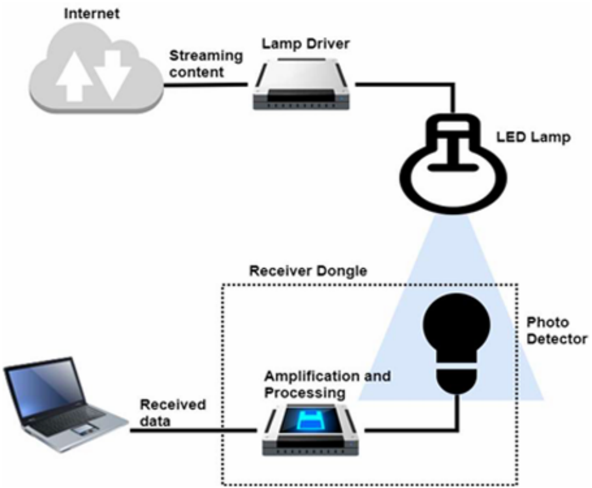
- With the growth of IoT, traditional RF technologies (Wi-Fi, 4G or 5G) are experiencing more and more congestion (**Spectrum crunch**).
- Visible light spectrum is bigger, less congested and higher frequencies $\Longrightarrow$ higher speeds (data rates $\approx$ 220 gigabits per second).



Visible light spectrum used by Visible Light Communication(VLC) technologies (400 THz to 800 THz) is approximately 1000 times larger than the radio frequency spectrum (3 kHz to 300 GHz).

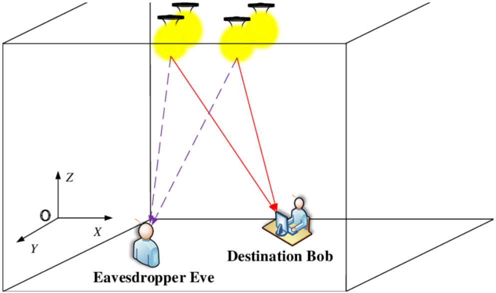
VLC systems

- Visible light cannot go through walls $\implies$ indoor networks
- Because LED switching speed is high $\implies$ lamp can also be used for illumination.



VLC security problems

- Visible light $\Longrightarrow$ transmissions are open and broadcasted.
- Photoreceptor devices in the environment can receive confidential messages!

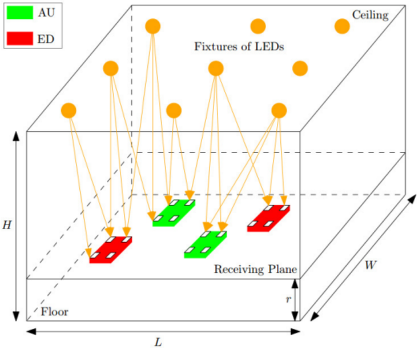


Two types of eavesdropping devices

- **Active ED:** device in direct communication with the access points.
- **Passive ED:** camera, smartphone or other photoreceptor not in the network.

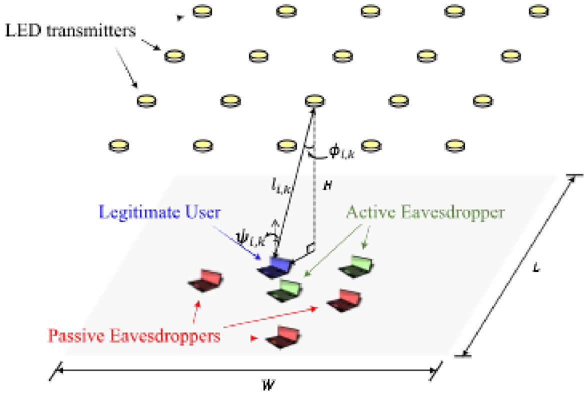
Modelisation: Wiretap VLC system

- **IM** (intensity modulation) and DD (direct detection demodulation) $\Longrightarrow$ we are intereseted on the intensity of light that is provided by the AP and that is received by the detector in each device.
- N APs located at its ceiling, 1 AU, P AEDs $\{AE_1, AE_2, ..., AE_P\}$ and Q randomly distributed PEDs $\{PE_1, PE_2, ..., PE_Q\}$.
- We use the index $k \in \{AU, AE_p, PE_q\}$ to refer to a generic device.



Zero-forcing beamforming

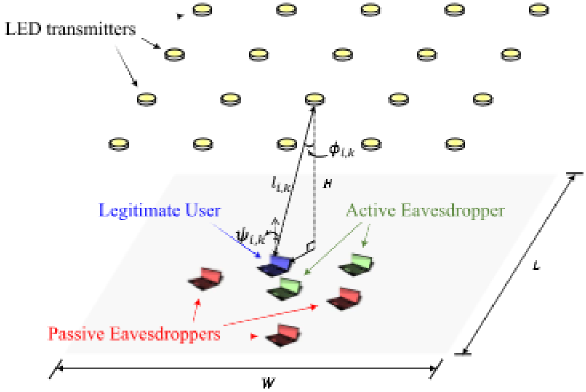
- **Idea**: use interference of waves from APs to maximize signal at AU and minimize it at EDs.
- Our goal is to determine the beamforming vector $w = [w_1, w_2, ..., w_N]^T \in \mathbb{R}^N$ where w_i is a weight for the signal from the i-th AP.



Received signal $y_k(t)$ at device k

- To model the Line of Sight (LoS) gain on the path from i-th AP to device k, we use channel gain $h_{i,k} \in \mathbb{R}$.

$$y_k(t) = \alpha I_D C(h_k \cdot w)s(t) + n_k(t) \tag{1}$$



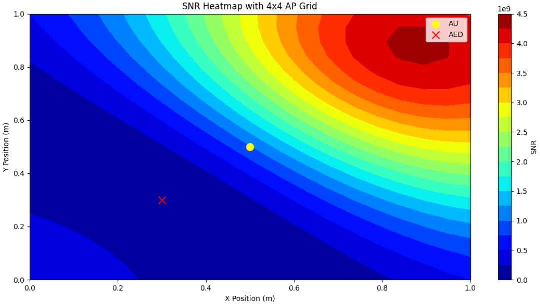
Solving problem for one AED

The beamforming vector w must:

1. Maximize the received signal at the AU.
2. Ensure that the signal received at the AED is zero.

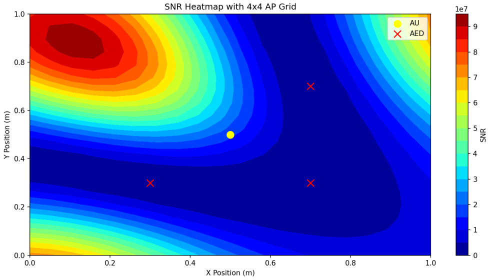
$$h_{AED} \cdot w = 0 \implies w \in h_{AED}^{\perp} \tag{2}$$

To maximize SNR at AU, we project h_{AU} in $h_{AED}^{\perp}$.

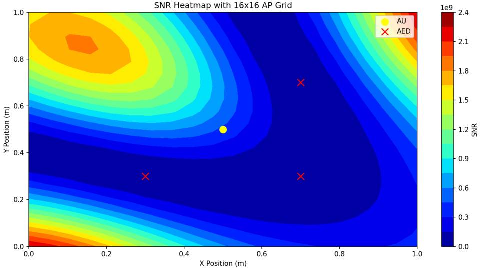


Solving problem for $P > 1$ AEDs

$$Y_{AED}(t) = \alpha I_D C(H_{AED} w) s(t) + N_{AED}(t) \quad \text{with } H_{AED} = \begin{bmatrix} h_{AED_1}^T \\ h_{AED_2}^T \\ \vdots \\ h_{AED_P}^T \end{bmatrix} \tag{3}$$



(a) $N = 4$



(b) $N = 16$

Solving problem for $P > 1$ AEDs and PEDs

The beamforming vector w must:

1. Maximize the received signal at the AU.
2. Ensure that the signal received at the AED is zero.
3. **Ensure that the peak SNR is achieved at the AU**

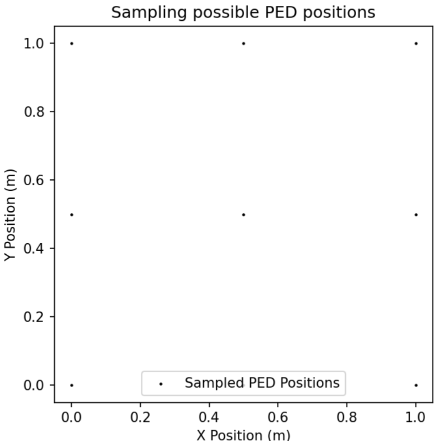
$$\min_{w} \quad \max_{(x,y)\in\Omega} \mathrm{SNR}(x, y, w) \tag{4}$$

$$\text{s.t.} \quad H_{AED} w = 0, \tag{5}$$

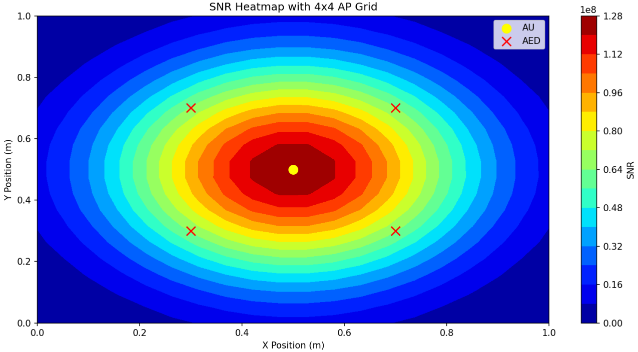
$$h_{AU} \cdot w = 1 \qquad \text{to ensure SNR is maximal at the AU} \tag{6}$$

Numerical approximation

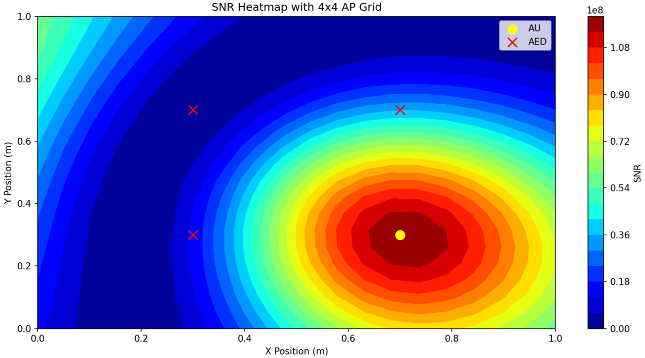
- Scipy offers different optimizers to solve multiple constraints optimization problems
  - `SLSQP` (Sequential Least Squares)
  - `trust-constr` (Trust Region Constrained Algorithm)
- Computation time rises fast with number of APs and PEDs.



Simulation results with AEDs and PEDs



Simulation results with AEDs and PEDs



Thank you for your attention!