Inter-cell Interference Coordination for Multi-color Visible Light Communication Networks

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Outline

- Background
- System model
- Dynamic Scheduler
- Simulation results
- Conclusion

Background

- **Visible light communication (VLC)**
  - **Large transmission bandwidth**
  - **Security**
  - **Color resources (by RGB LED)**
- **Problem of dense deployment**
  - **Inter-cell interference**
  - **Degraded performance of cell-edge users**
- **Inter-cell interference coordination (ICIC)**
  - **Fractional frequency reuse (FFR)**
  - **Soft frequency reuse (SFR)**

Background

- **ICIC research in VLC**
  - Single color, downlink OFDMA
  - Frequency and power allocation
  - Static
- **Dynamic Scheduler**
  - Multi colors for multiple access
  - Considering lighting constraint
  - Satisfying user's SINR QoS requirement
  - Improving the cell-edge user's performance
  - Small penalty of overall throughput

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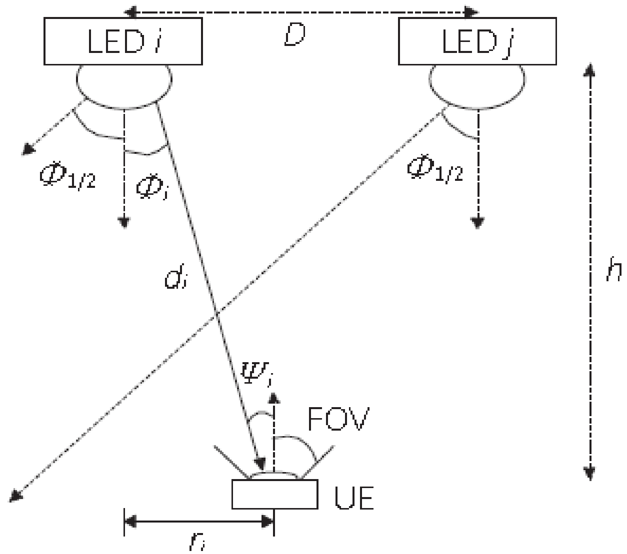
System model

■ The signal model



Symbol	Representation
i	Transmitter
u	User equipment
k	Color index
D	Inter-LED distance
$\phi_{1/2}$	Half-power semi-angle
ϕ_i	Emergence angle
ψ_c	Field of view (FOV)
ψ_i	Incidence angle
h	vertical separation
$d_{i,u}$	Distance i and u
A_{pd}	PD area
$m = -1/log(cos\phi_{1/2})$	Lambert index
n	Refractive index
Receiver's FOV	$60°$

■ Optical channel gain

$$G_{k,u}^{(i)} = \frac{(m+1)A_{pd}}{2\pi d_{i,u}^2} cos^m(\phi_i) T_{k,k} g_c(\psi_i) cos(\psi_i),$$

➢ Optical filter gain matrix:

$$T = \begin{bmatrix} 0.99 & 0.09 & 0 \\ 0.01 & 0.91 & 0 \\ 0 & 0.01 & 0.99 \end{bmatrix}$$

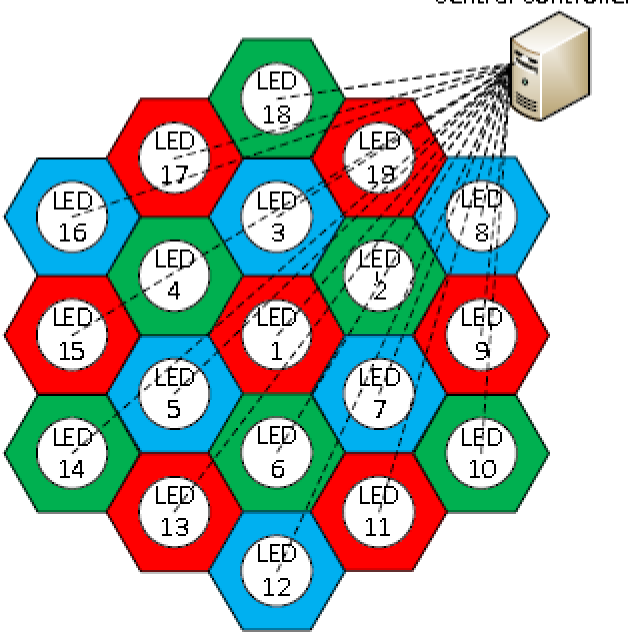
➢ Optical concentrator gain:

$$g_c(\psi_i) = \begin{cases} \frac{n^2}{sin^2\psi_c}, & 0 \le \psi_i \le \psi_c; \\ 0, & \psi_i > \psi_c; \end{cases}$$

System model

Two-ring network layout

- Cell-center and cell-edge zones
- Cell-center and cell-edge user equipment (UE)
- RGB colors each cell



SFR

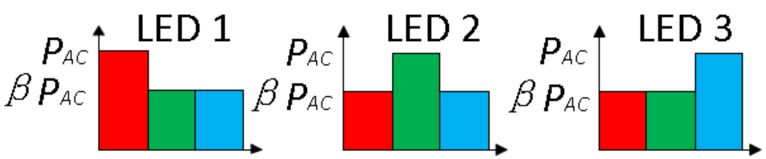
- One color for cell-edge zone
- Other two colors for cell-center zone
- Different colors among adjacent cell-edge zones
- Constant AC power ratio β $(0 < \beta < 1)$

FFR

- power ratio $\beta = 0$
- One color shared by cell-edge and cell-center UEs

No ICIC

- power ratio $\beta = 1$
- Colors shared by cell-edge and cell-center UEs



System model

■ Received SINR

$$\gamma_{u,k}^{(i)} = \frac{(G_{k,u}^{(i)} P_k^{(i)})^2}{I_{sum} + \sigma^2},$$

➢ Noise variance:

$$\sigma^2 = 2qI_{bg}B_k + \frac{4K_bTB_k}{R_f}$$

Symbol	Representation
$P_k^{(i)}$	AC power of color k in cell i
I_{sum}	Total received interference
I'_{sum}	Dominant interference
I_0^{cross}	Cross-color interference from current cell
I_1^{co}	Co-color interference from neighboring cell
I_{bg}	Background current
T	Absolute temperature
R_f	Feedback resistance
K_b	Boltzmanns constant

■ SINR estimate

$$\gamma_{u,k}^{(i)'} = \frac{(G_{k,u}^{(i)} P_k^{(i)})^2}{I'_{sum} + \sigma^2} = \frac{(G_{k,u}^{(i)} P_k^{(i)})^2}{I_0^{cross} + I_1^{co} + \sigma^2}.$$

■ Achievable Rate

$$R_{u,k}^{(i)'} = B_k \log_2(1 + \gamma_{u,k}^{(i)'})$$

System model

System design criteria

- Illumination constraint:
  fixed CIE color space point

- Power constraints:
  small power variation and linear regime

$$\begin{cases} \boldsymbol{C}\boldsymbol{q} = (x_T, y_T, z_T)^T, \\ \bar{\boldsymbol{P}} = \kappa \boldsymbol{q}, \end{cases}$$

$$\kappa = min\{\frac{P_1^{max}}{q_1}, \frac{P_2^{max}}{q_2}, \frac{P_3^{max}}{q_3}\},$$

$$P_k^{(i)} \leq \tilde{P}_k \triangleq \sqrt{\alpha_k \eta^2 \bar{P}_k^2}, k = 1, 2, 3,$$

- QoS requirement: SINR threshold

$$\gamma_{u,k}^{(i)} \geq \Gamma$$

Symbol	Representation
(x_T, y_T, z_T)	Target CIE color space point
$\boldsymbol{C}$	Linear transform from DC power to CIE space
$\boldsymbol{q}$, κ	Temporary variables
$\bar{\boldsymbol{P}} \triangleq [\bar{P}_1, \bar{P}_2, \bar{P}_3]^T$	DC power of the three colors
$[P_k^{min}, P_k^{max}]$	Linear regime of color k
α_k	peak to average power ratio
η	Modulation depth
Γ	SINR thereshold
$\tilde{P}_k$	AC power of color k

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Dynamic scheduler

- **Relax power ratio in SFR**

$$(\tilde{P} : \beta\tilde{P} : \beta\tilde{P}) \rightarrow (\beta_1^{(i)}\tilde{P}_1 : \beta_2^{(i)}\tilde{P}_2 : \beta_3^{(i)}\tilde{P}_3)$$

- **Distributed LED-level algorithm**

Round Robin Scheduling

For each cell: serve users in first-in-first-out manner

↓

Power Ratio Adjusting

For each color: set β to satisfy $\gamma' = \Gamma$

↓

Restriction Table Preparing

For each color:
If $\beta > 1$, set $\beta = 1$, and restrict neighboring cells iteratively until SINR requirement is satisfied

Dynamic scheduler

■ Centralized algorithm

- Receive restriction and rate tables from each cell

$$\{\mathcal{T}_1^{(i)}, \mathcal{T}_2^{(i)}, \mathcal{T}_3^{(i)}\}, \{R^{(i)'}_{\zeta_1^{(i)},1}, R^{(i)'}_{\zeta_2^{(i)},2}, R^{(i)'}_{\zeta_3^{(i)},3}\}$$

- Form rate matrix and restriction list

$$R_{i,k} = \begin{cases} R^{(i)'}_{\zeta_k^{(i)},k}, & \text{cell } i \text{ asks or be asked for color } k \text{ restriction;} \\ 0, & \text{otherwise;} \end{cases}$$

$$\mathcal{J}_k = \{J_{n_1}, \cdots, J_{n_i}, \cdots, J_{n_k}\}$$

- 0-1 integer programming problem

$$\max_{Z_{J_i,k}\in\{0,1\}} \sum_{i=n_1}^{n_k} R_{J_i,k} Z_{J_i,k},$$

$$s.t.\ Z_{J_i,k} + Z_{i',k} \leq 1, \forall i' \in \mathcal{T}_k^{(J_i)}, \forall J_i \in \mathcal{J}_k,$$

- Color and power allocation

$$Z_{i,k} = 0 : P_k^{(i)} = 0$$

$$Z_{i,k} = 1$$

$$P_k^{(i)} = \begin{cases} \beta_k^{(i)} \tilde{P}_k, & \beta_k^{(i)} \leq 1; \\ \tilde{P}_k, & \text{otherwise;} \end{cases}$$

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Simulation results

■ Simulation settings

- Sufficiently many round robin scheduling
- User moves toward a random direction at the speed of 1Km/h
- Feedback signal intensity to the serving cell
- Performance benchmarks: SFR, FFR, No ICIC

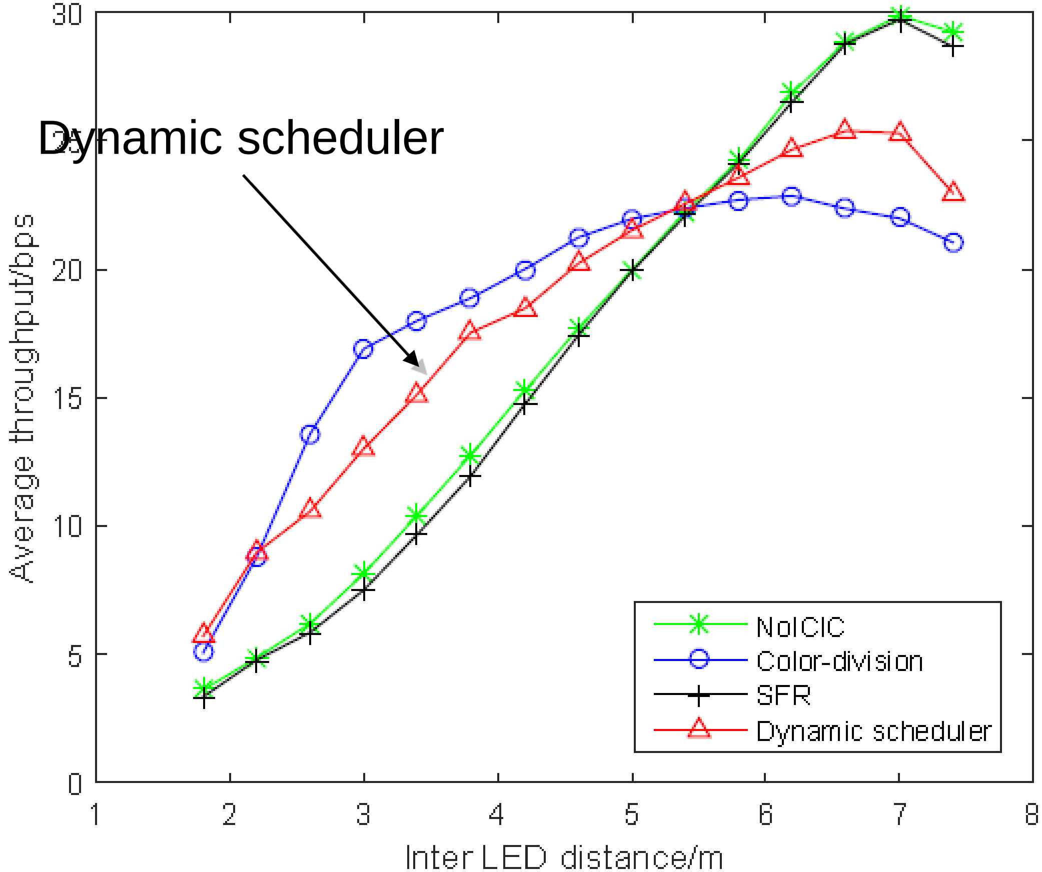
SYSTEM PARAMETERS

Parameter	Value
Half-power semi-angle $\phi_{1/2}$	60°
Maximum power per color p_k^{max}	$5W$
Working color point in CIE	$(0.344,\ 0.353,\ 0.303)$
Modulation Bandwidth B_k	$1Hz$
Vertical separation h	$2.15m$
PD area A_{pd}	$1cm^2$
PD responsibility R_{pd}	$0.28A/W$
Refractive index n	1.5
Receiver's FOV	60°
Color number K	3
Power ratio β in SFR	$1/2$
Area ratio A_{rt}	$1/3$
Modulation factor α_k	$5/9$
SINR threshold Γ	$10dB$
Background current I_{bg}	$5100\mu A$
Absolute temperature T	$295K$
Resistance R_f	$6K\Omega$

Simulation results

■ Overall throughput comparison

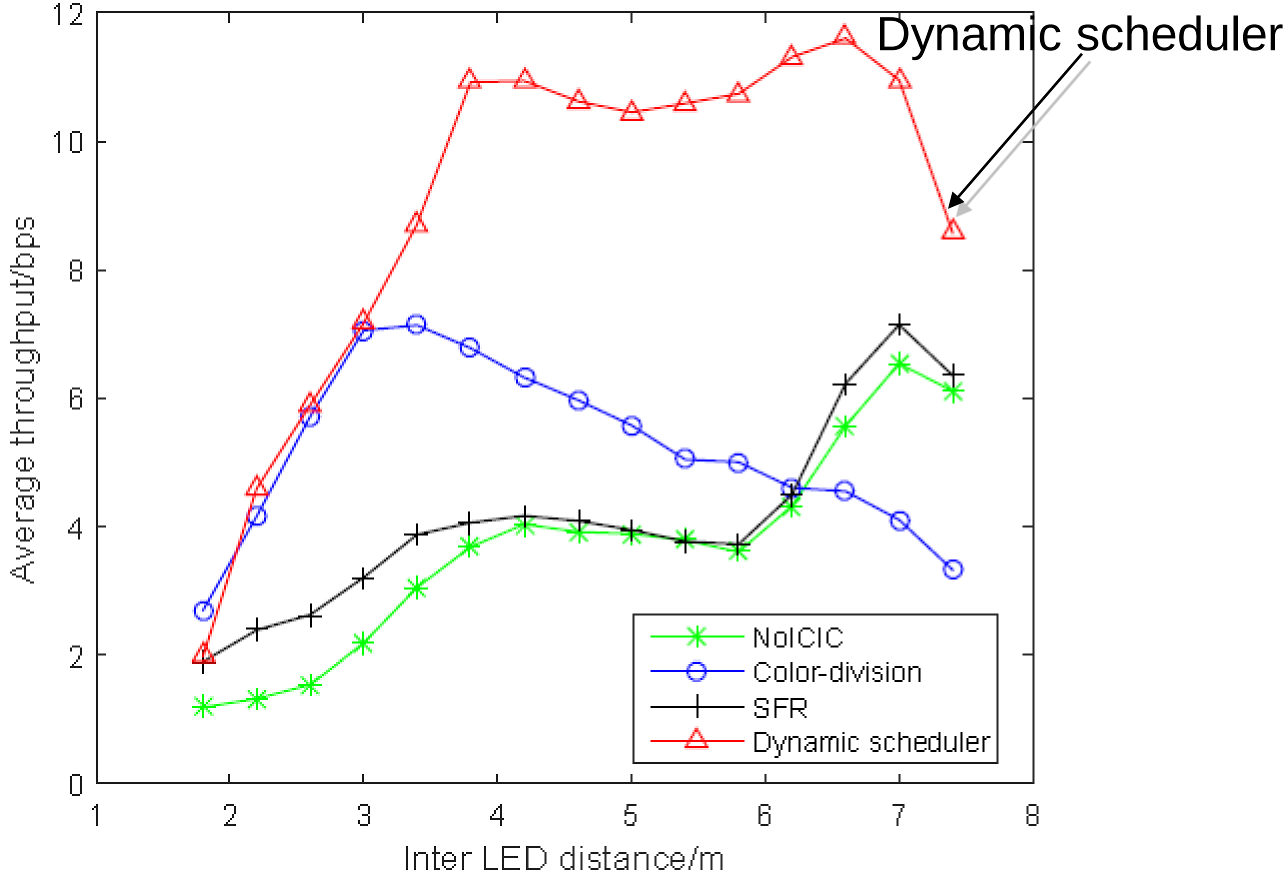
- Overall throughput of the dynamic scheduler is between those of SFR, FFR and No ICIC.
- penalty brought by the cell-edge throughput improvement is small.



Simulation results

■ Cell-edge throughput comparison

- ➢ Cell-edge throughput of dynamic scheduler is the largest.
- ➢ QoS requirement (represented by SINR) is satisfied in dynamic scheduler.



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Conclusion

- A SFR-based dynamic scheduler is proposed for ICIC in the multi-color VLC network
- Interfering colors are limited dynamically to coordinate inter-cell interference
- Cell-edge throughput is improved at a small penalty of overall throughput
- QoS requirement of SINR is satisfied during the dynamic scheduling

Thank you!

Q&A