

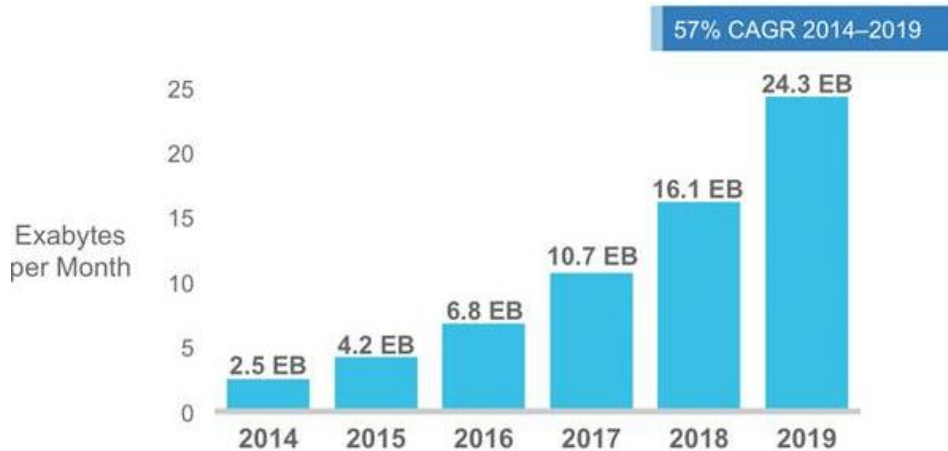


**THE ELISHA YEGAL BAR-NESS
CENTER FOR WIRELESS COMMUNICATIONS
AND SIGNAL PROCESSING RESEARCH**

Visible-light Enhanced 5G System

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March 24,2015

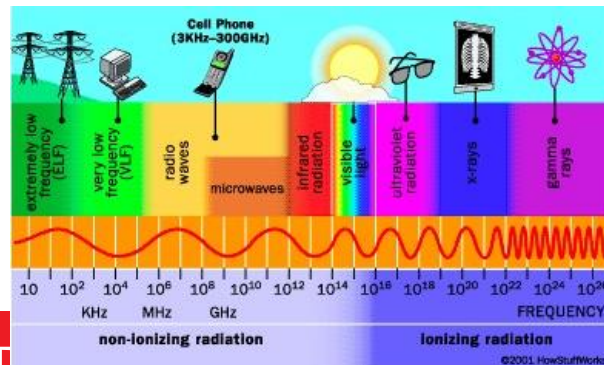
Spectrum Crunch



<http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html>

In 2015 70% of the video data is being requested from indoor locations

According to the Cisco Visual Networking Index, about 53% of the outdoor wireless data traffic is expected to be offloaded to WiFi in 2018



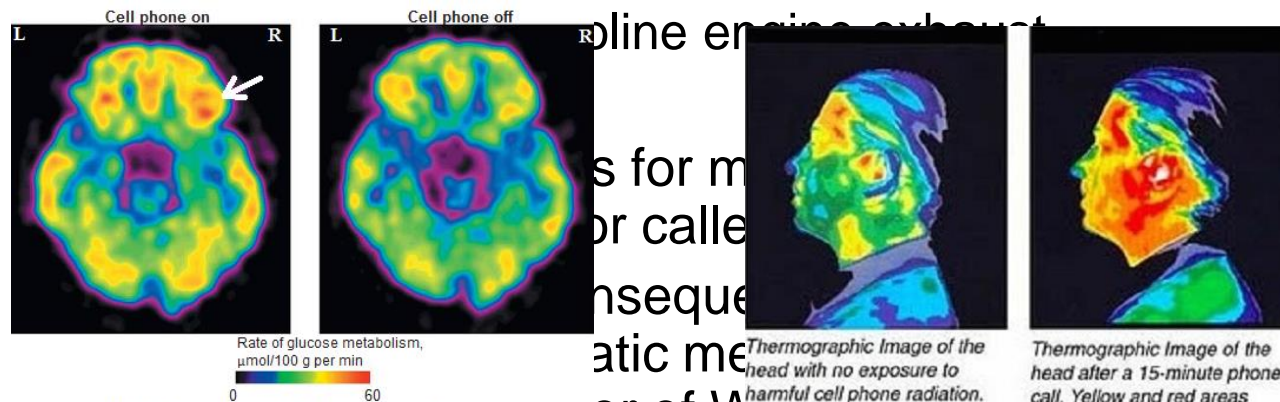
Energy Hungry Wireless Access

- In the US, IT energy consumption more than that for automotive industry.
- Wireless mobile infrastructure consumes half of this amount.
- With the expected increase in wireless traffic, the energy consumption will increase significantly.



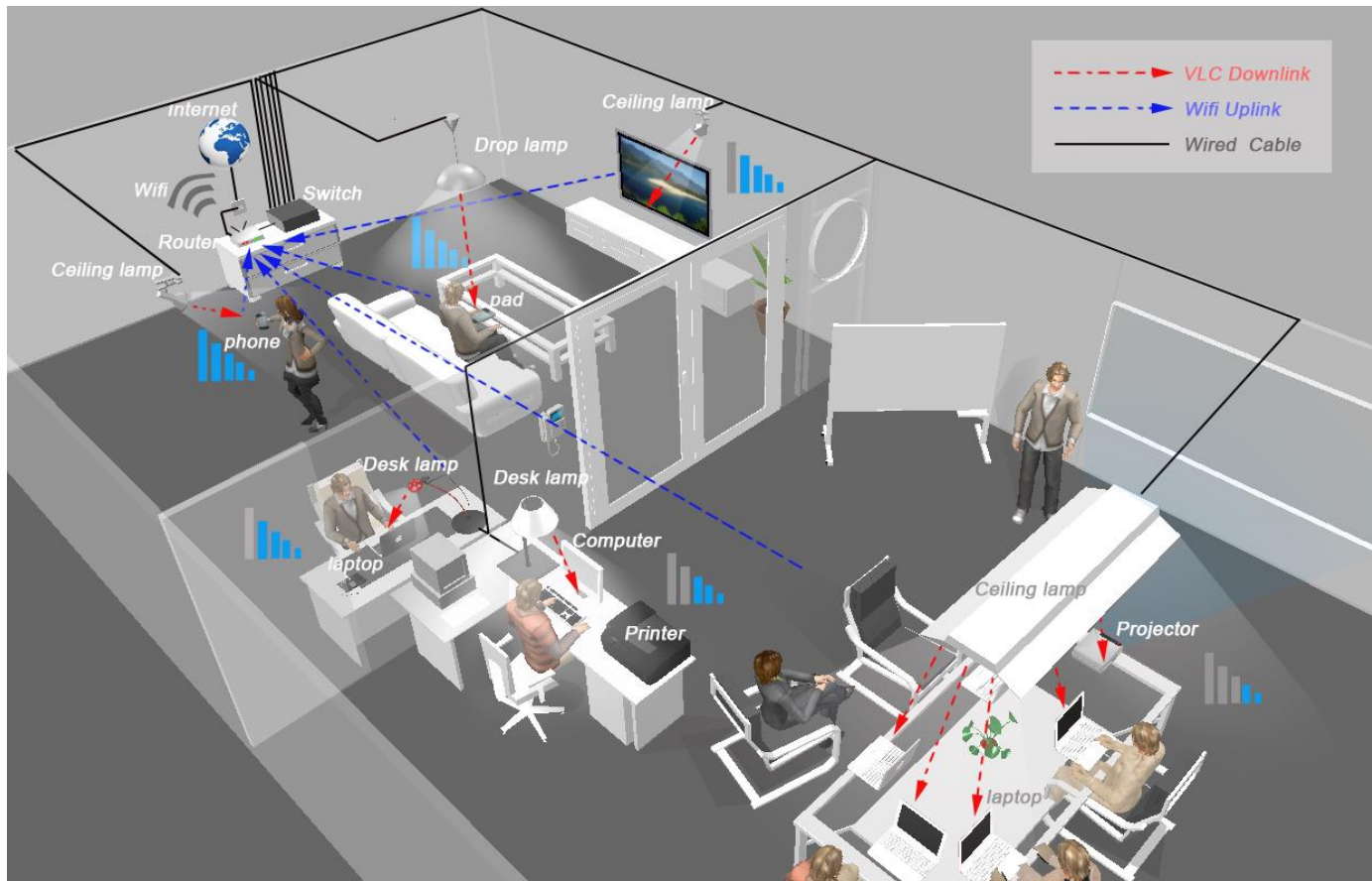
Cellular Phones cause Cancer

- WHO classifies cell phones as a possible Carcinogen
- Cell phones same cancer risk categories as (Feb-2015)



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- Cell phone companies started to recommend people to have their cell phones at a given distance from the body.
- <http://www.phonescausebraincancer.com>

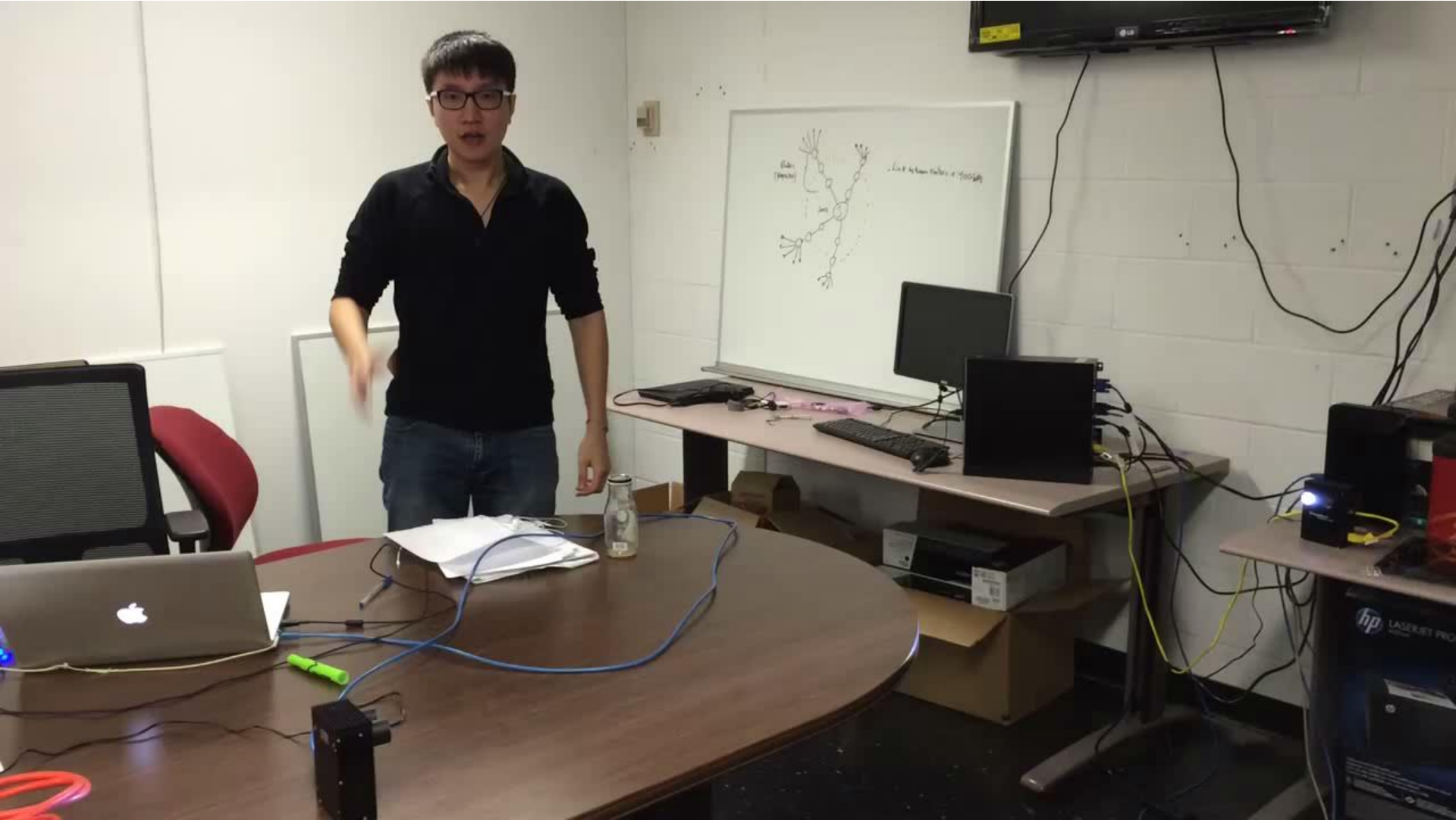
A Unified Solution



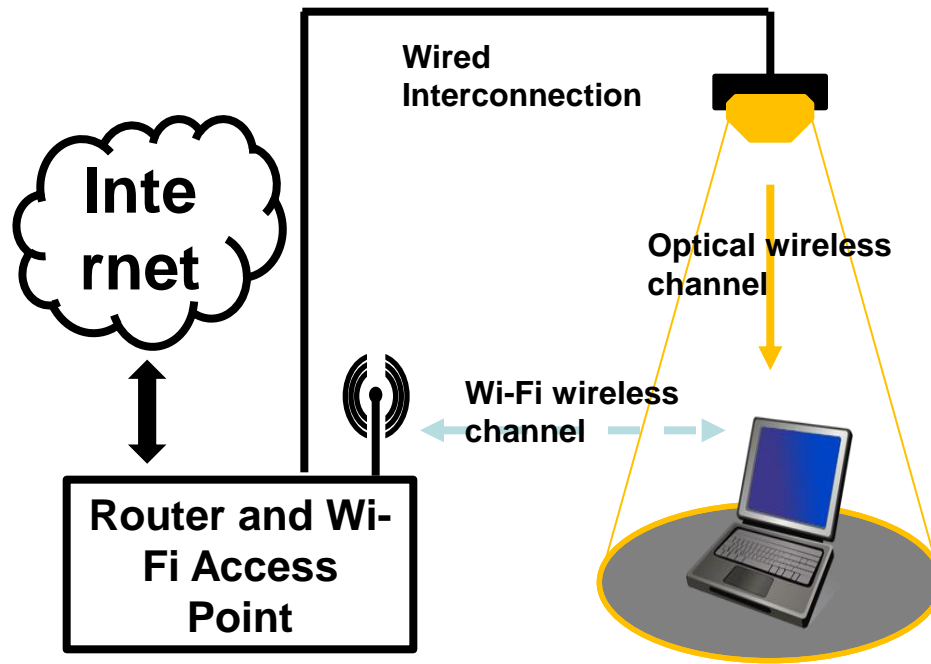
VLC Frontends

- Developed in cooperation with Fraunhofer HHI and Boston University.
- Three colors RGB
- Lenses at the receiver
- Use OFDM for modulation
- Offer a modulation bandwidth through careful impedance matching between the LED and the high-power analog driver.

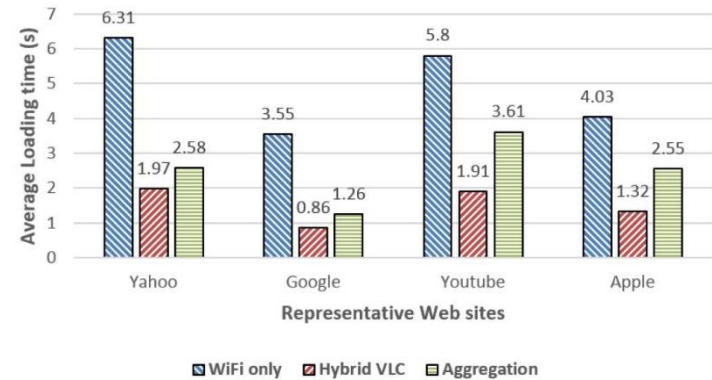
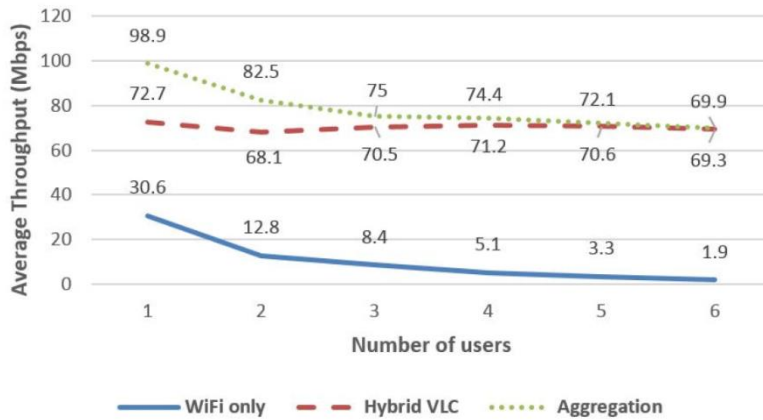




Hybrid System & Bonding



Hybrid System & Bonding



Joint lighting and power control (System Model)

- Hybrid System consisting of K RF and VLC hotspots.
- RF hotspots are characterized by:
 - P_{on} : Power consumption needed to turn it on
 - P_t : Power consumption required for transmission

System Model

- VLC hotspots are characterized by:
 - P_o: Optical power required to maintain certain level of illumination
 - P_t: Power consumption required for transmission
 - Depends on Efficiency η
 - Based on empirical results, efficiency decreases when data rate increases

$$\eta(R) = \frac{1}{aR+b}$$

Problem Formulation

$$X_k = \begin{cases} 1 & \text{if the } k\text{-th hotspot is on} \\ 0 & \text{otherwise.} \end{cases}$$

$$Y_{ki} = \begin{cases} 1 & \text{if the } i\text{-th user is connected to the } k\text{-th hotspot} \\ 0 & \text{otherwise.} \end{cases}$$

$$\min \sum_{k=1}^K P_k^{on} X_k + \sum_{k=1}^K \sum_{i=1}^I P_{ki} Y_{ki}$$

s.t

$$Y_{ki} \leq X_k, \quad \forall i, k \quad (1)$$

$$\sum_{k=1}^K Y_{ki} \geq 1 \quad \forall i \quad (2)$$

Problem Complexity

- Our Problem is NP-complete
- Reduction from the Set Cover problem

Online Algorithm

- Add a virtual source connected to all hotspots.
- Notations:

n' : Number of users seen so far

S : Virtual Source

c_e : Cost of edge $e \in E$

c_{tot} : Total cost incurred by the algorithm

α : Guess of the optimal fractional solution

w_e : Actual weight of each edge

w'_e : Virtual weight of each edge

Online Algorithm

1

Algorithm 1 Online Hybrid RF-VLC System

$$n' = 0$$

$$\alpha = \min c_e$$

$$w_e = w'_e = \frac{1}{m^2}$$

$$c_{tot} = 0$$

Upon the arrival of a new user u

$$n' \leftarrow n' + 1$$

$\forall e$, choose $\lceil 2 \ln(n' + 1) \rceil$ independently random variables $\Gamma(e, j)$, $1 \leq j \leq \lceil 2 \ln(n' + 1) \rceil$ uniformly distributed in the interval $[0,1]$. Set $\gamma_e = \min_j \Gamma(e, j)$

START:

$\forall e$ such that $c_e \leq \frac{\alpha}{m}$, set $w_e = w'_e = 1$

$\forall e$ such that $\frac{\alpha}{m} \leq c_e \leq \alpha$, set $c'_e = \frac{c_e}{\alpha/m}$

if the maximum flow between S and u is at least 1 **then**
do nothing

else

while the flow is less than 1 **do**

 Compute the minimum weight cut \mathcal{C} between S and u

$\forall e \in \mathcal{C}$, $w'_e \leftarrow w'_e(1 + \frac{1}{c'_e})$

if $w'_e \geq \gamma_e$ **then**
 $w_e = 1$

$$w_e = \max\{w_e, w'_e\}$$

$$c_{tot} = \sum_e w_e c_e$$

if $c_{tot} > \alpha \mathcal{O}(\log(m))$ **then**

$$\alpha \leftarrow 2\alpha$$

Go to **START**

Performance Analysis

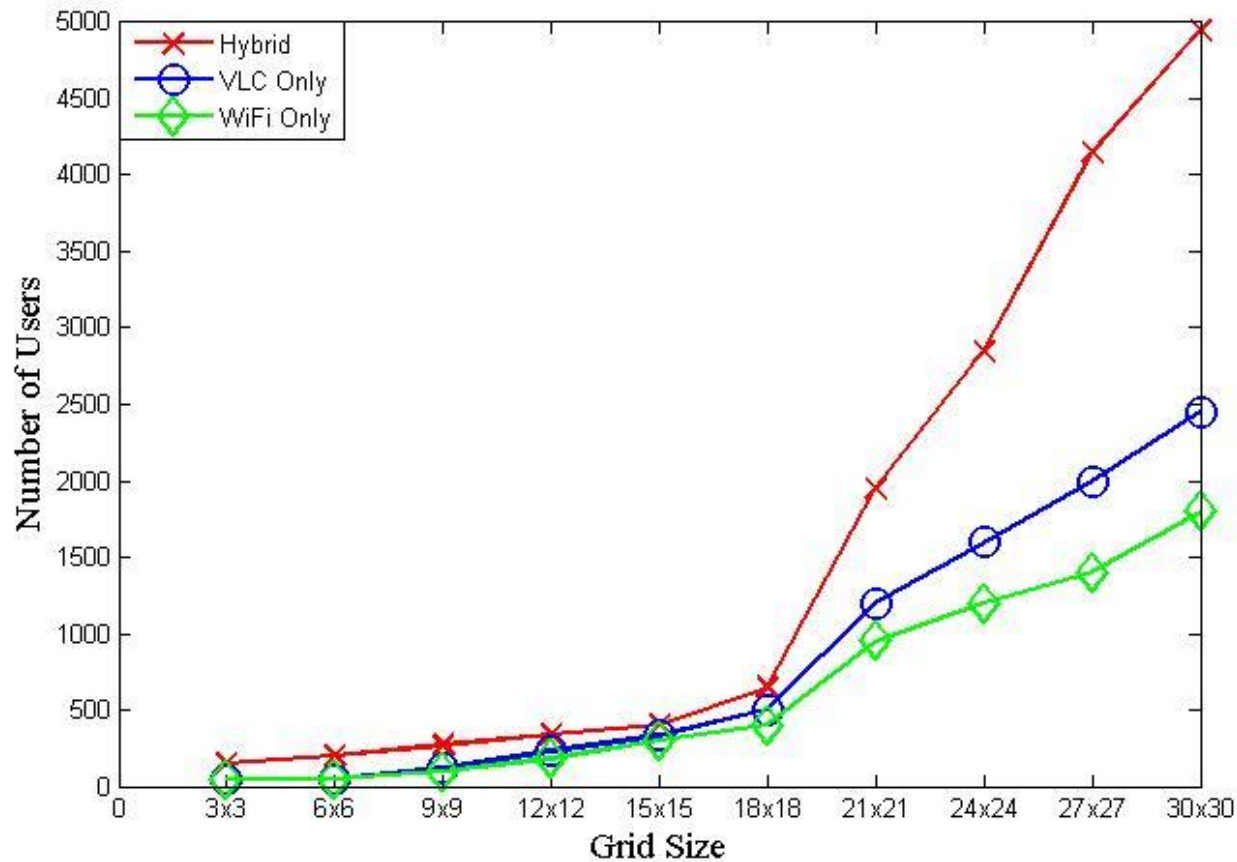
- *Theorem:* The online algorithm produces an integral solution that is $\mathcal{O}(\log(m) \log(n))$ competitive, and is feasible with probability $1 - \frac{1}{n^2}$, where m is the number of hotspots, and n is the number of users.
- *Theorem:* The best competitive ratio (for the fractional case) achieved by any online algorithm is $\Omega(\log(m))$

Simulation Results

- Two Settings:
 - One big room, no windows
 - Multiple small rooms
- Schemes simulated:
 - Hybrid System
 - VLC only
 - RF only

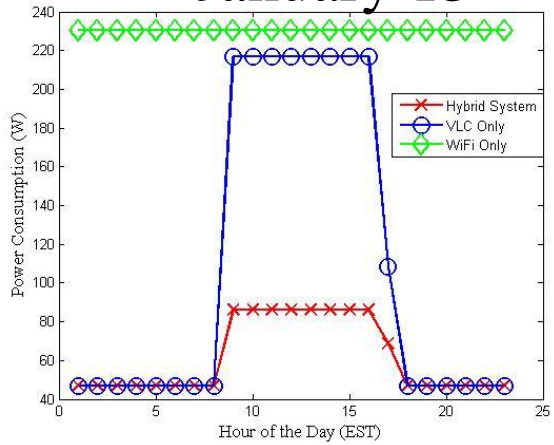
Simulation Results

- One big room, no windows

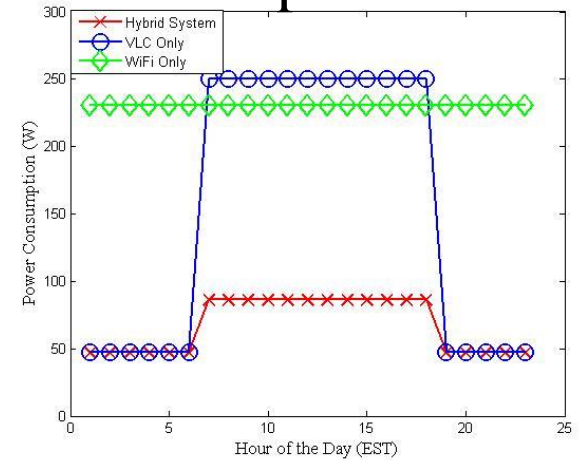


Simulation Results

January 13

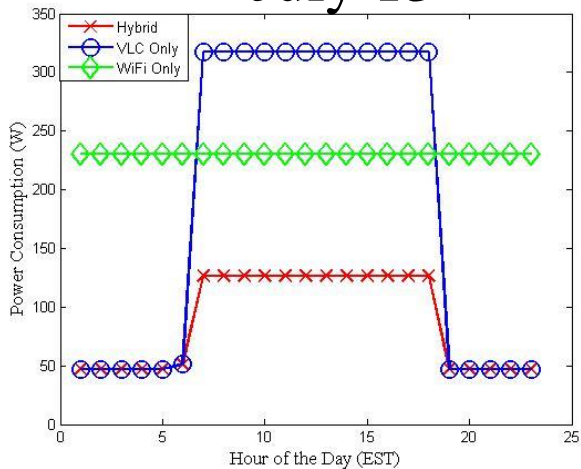


April 13

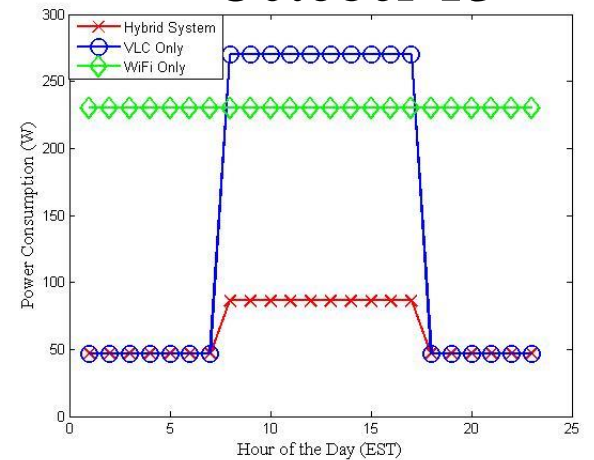


Multiple Small Rooms

July 13



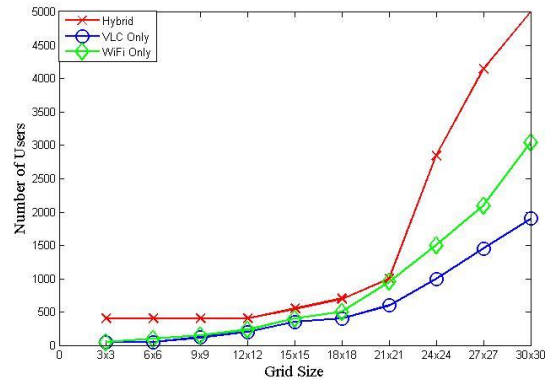
October 13



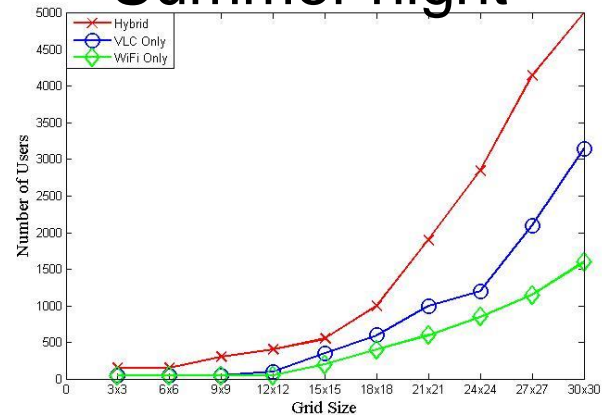
Simulation Results

- Multiple Small Rooms

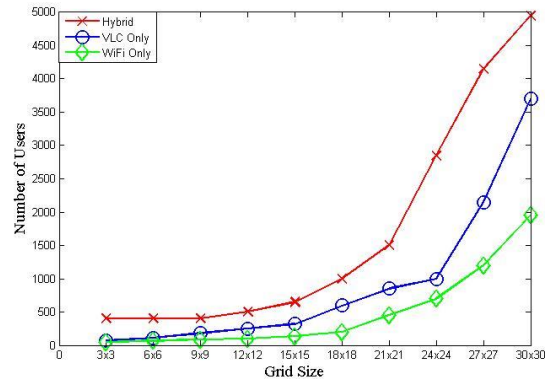
Summer noon



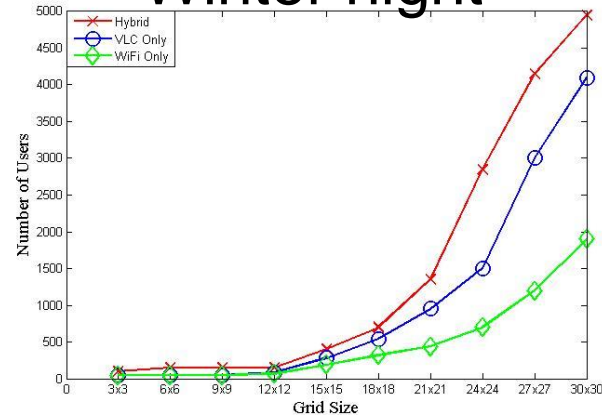
Summer night



Winter noon



Winter night



Partners



Fraunhofer

Heinrich Hertz Institute

Thanks

Questions and
feedback?



NJIT



The Science and Technology University of New Jersey