On VLC as a 5G technology

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Synopsis

- We're really going to need more data capacity
- 5G is not fully baked, but will use smaller cells and locality
- VLC can play a role in 5G small cells
- Our work: dual-use and single use VLC integrated into hybrid RF-VLC system
- We've got numerous barriers
- Some work is still required…

There is ample motivation for more wireless capacity

Global mobile traffic will reach 290 exabytes (2019)

70% of mobile traffic occurs indoors!

More than 50% of traffic offloaded to alternative networks

Video will increase to 72% of **all** IP traffic by 2019

But only 9% CAGR in network speed!

55% CAGR in smartphone traffic

The IoT will contribute 26 billion devices by 2020

More devices and more demand per device

Demand factors are strong for more data

Cloud services

OneDrive

Dropbox

bitcasa
INFINITE STORAGE

Gaming

Video streaming

NETFLIX

amazon.com Prime

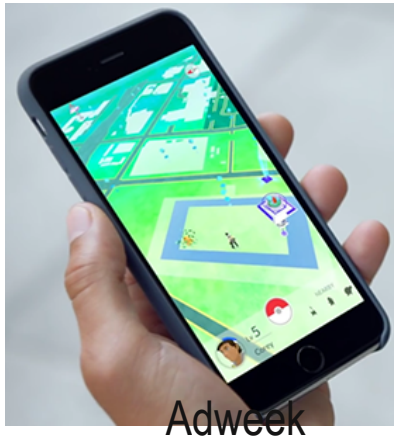
Voice recognition

Mapping

waze
OUTSMARTING TRAFFIC, TOGETHER

Augmented reality (AR)

Pokémon GO



Adweek

Devices increasingly powerful

Apple

iPhone 7 Plus: 1920x1080 at 401ppi
Galaxy S7 Edge: **2560x1440 resolution** at 534ppi

iPhone 7 Plus: Apple A10 Fusion chip, **quad-core** 2.23GHz, 3GB RAM
Galaxy S7 Edge: Samsung Exynos 8890 (**four 2.3GHz cores**, four 1.6GHz cores), 4GB RAM

iPhone 7 Plus: **Dual 12MP rear-facing**, 7MP front-facing
Galaxy S7 Edge: 12MP rear-facing with **4K video**, 5MP front-facing

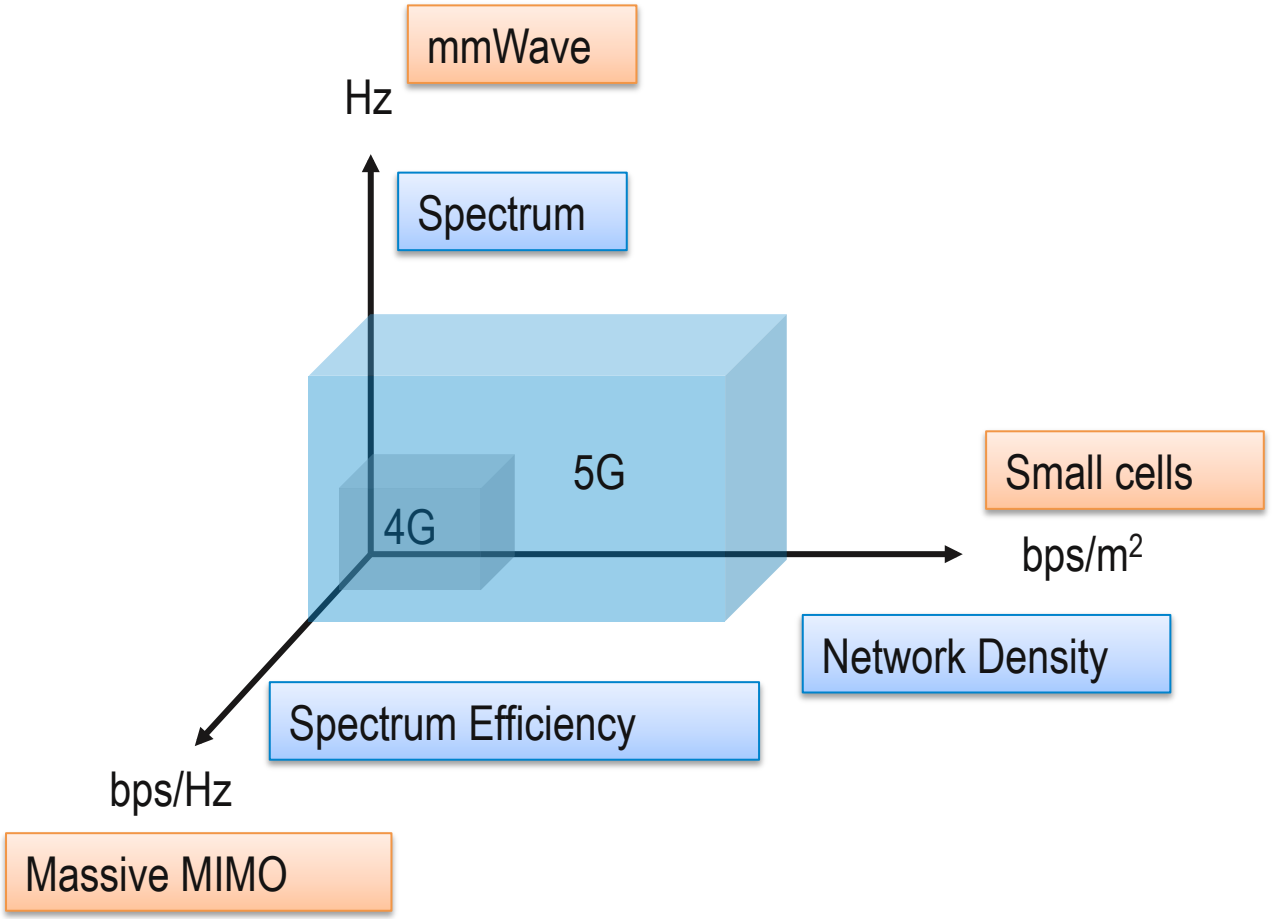
Saumsung

http://www.theinquirer.net/inquirer/review/2472079/iphone-7-plus-vs-galaxy-s7-edge-specs-comparison

What is 5G to us?

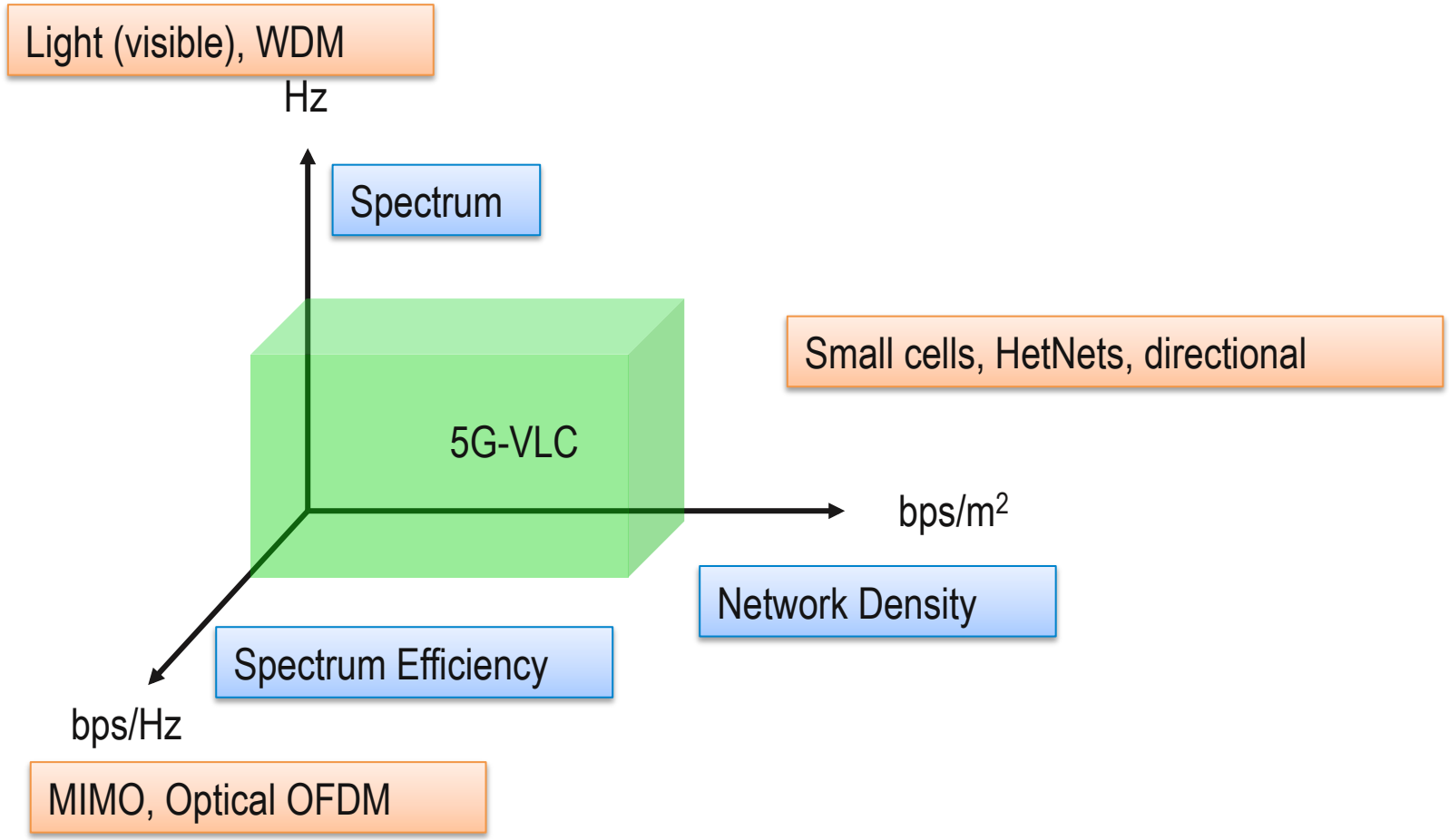
- **Localize**d, e.g., indoors, in living spaces
- **Smaller cells**
- Increased **average case performance** (in contrast to misleading peak rates)
- Increased data rates **per-user**, and increased **density of users**, at the same time

5G Vision: Getting to 1000x performance?

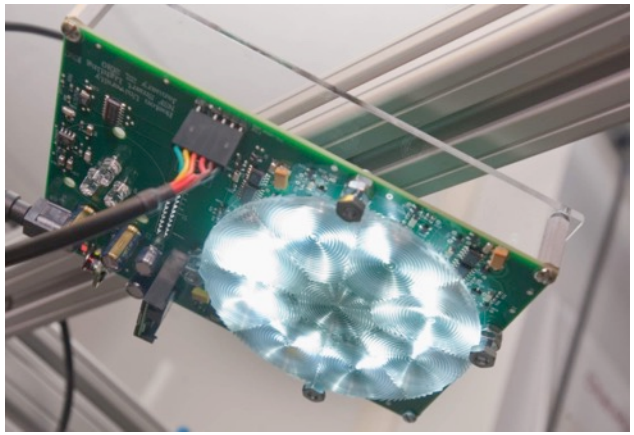


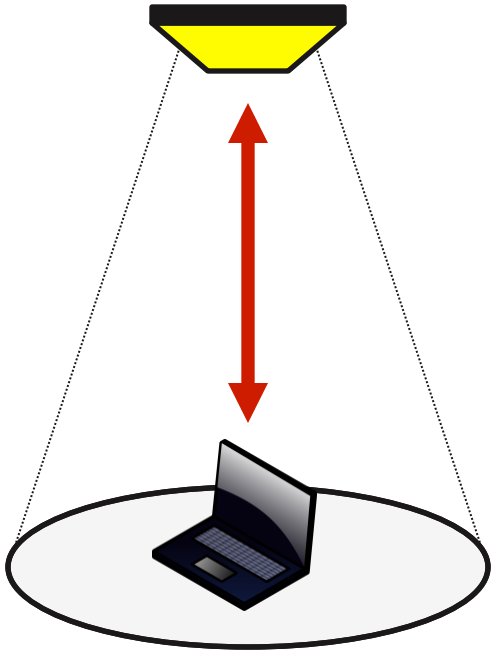
Adapted from J. Andrews 2014

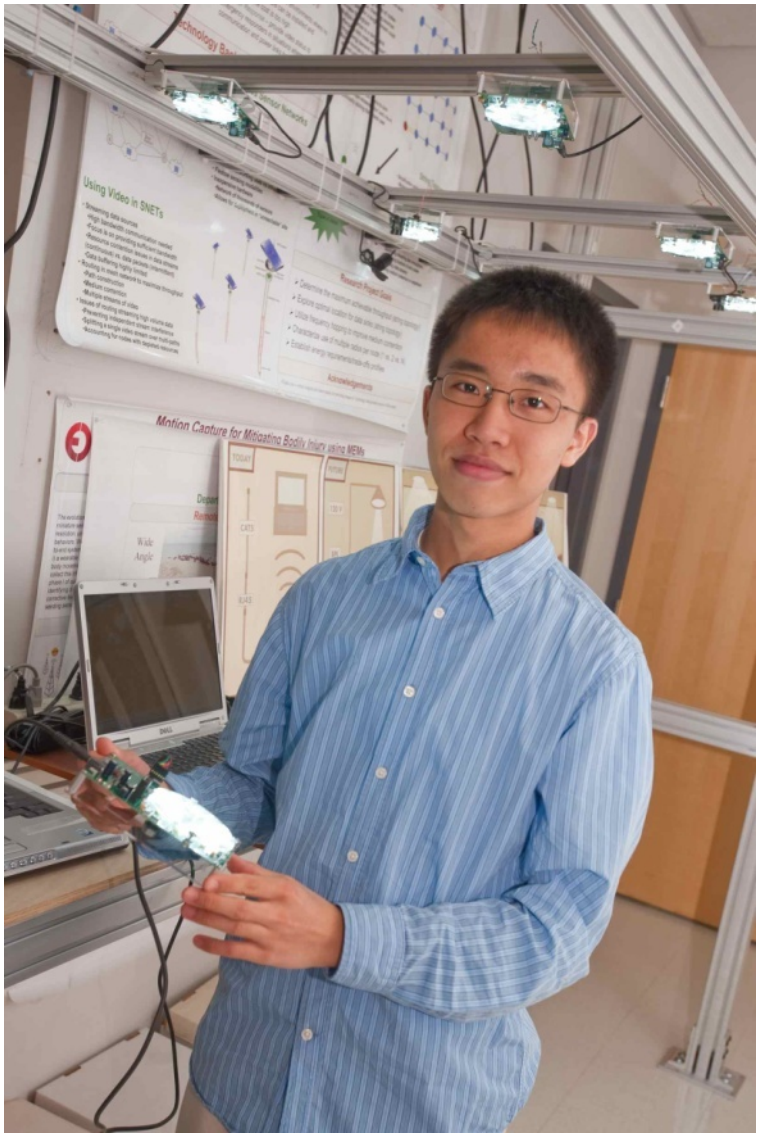
VLC and 5G: Brand New Spectrum!



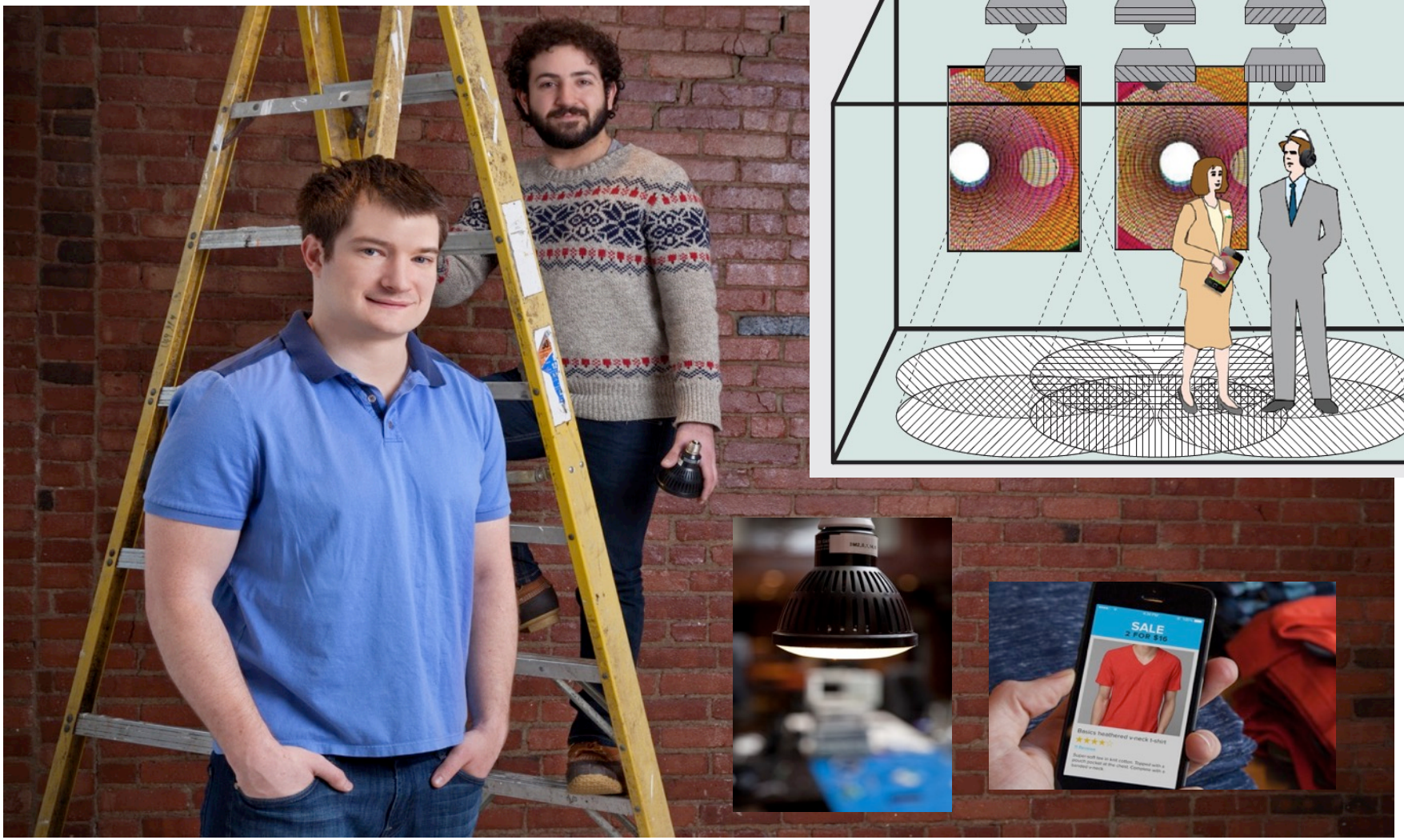
Basic luminaires as VLC access points (bidirectional)





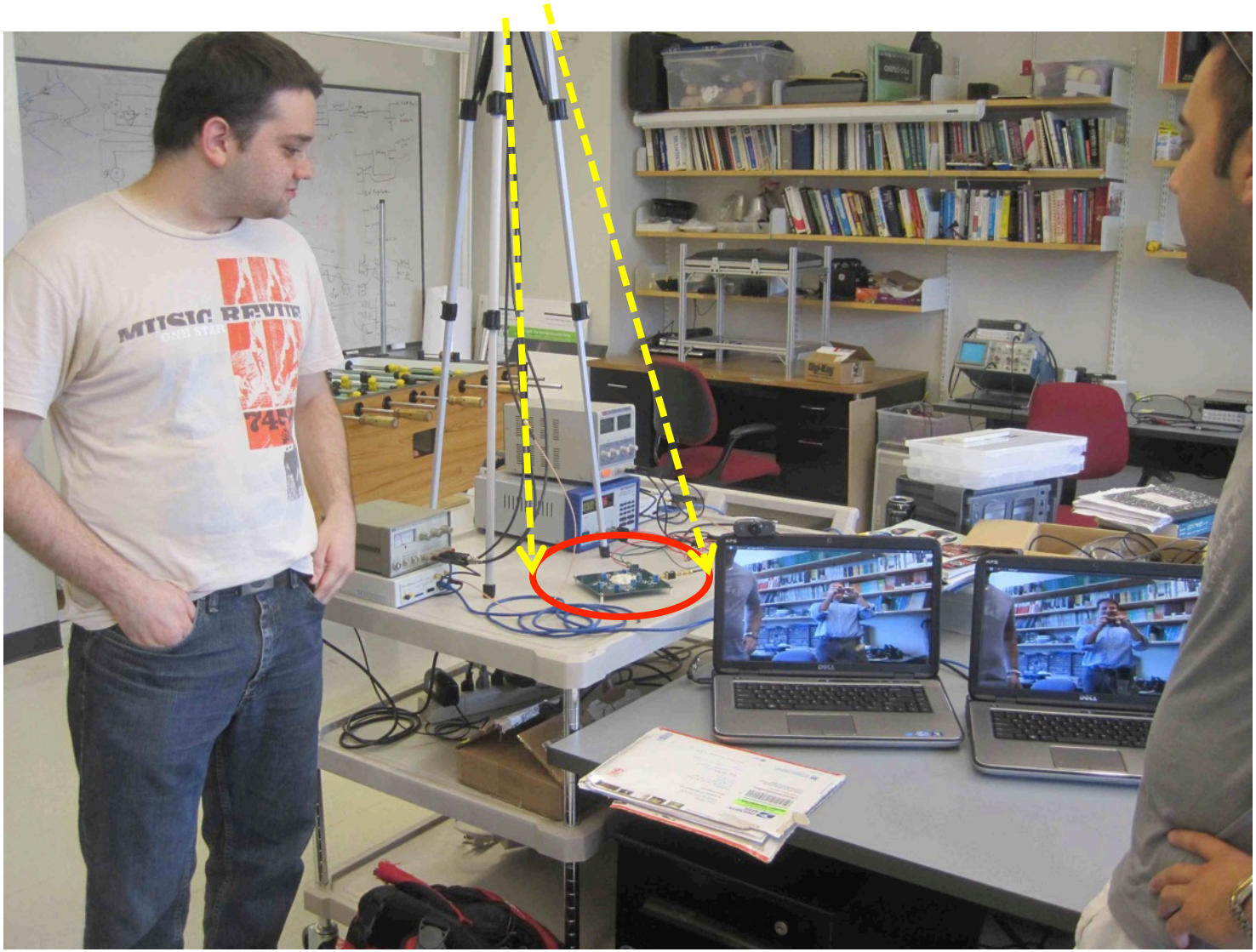


VLC is indoor positioning



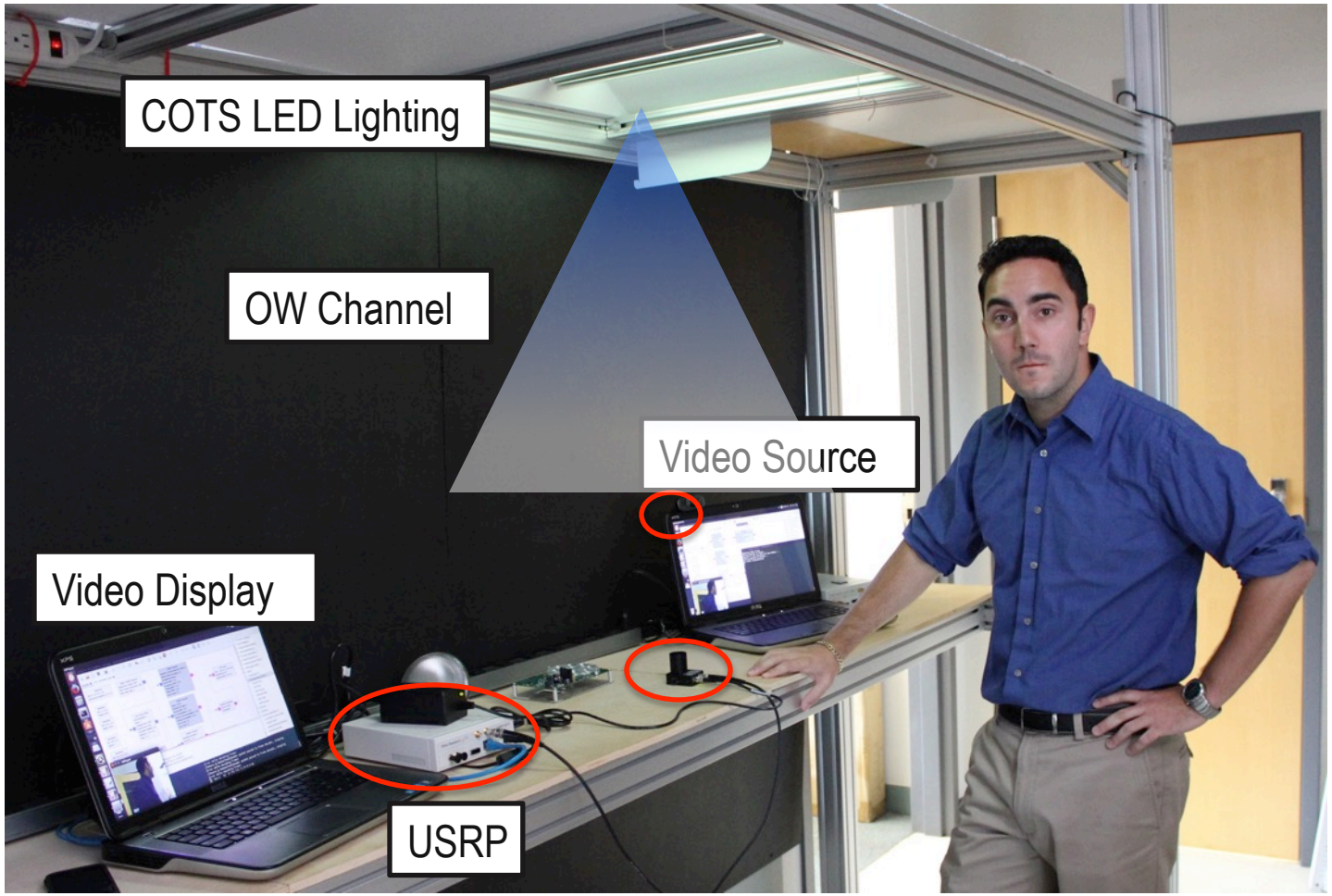
Bytelight, acquired by Acuity Brands; camera-based receiver

VLC supports high data rate downlinks



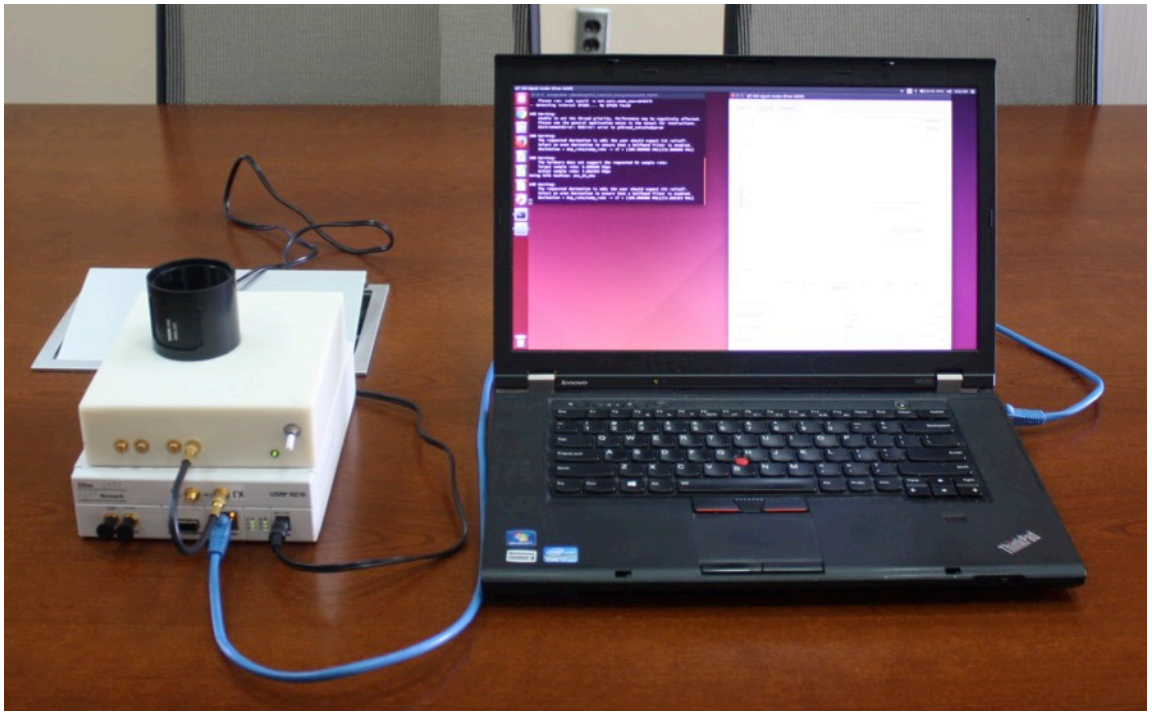
Video streaming with diversity receiver

VLC is dual use: uses lighting infrastructure



VLC integrated into smart conference room (2016)

Dual Use



VLC “dongle” – allows Internet browsing via VLC connection

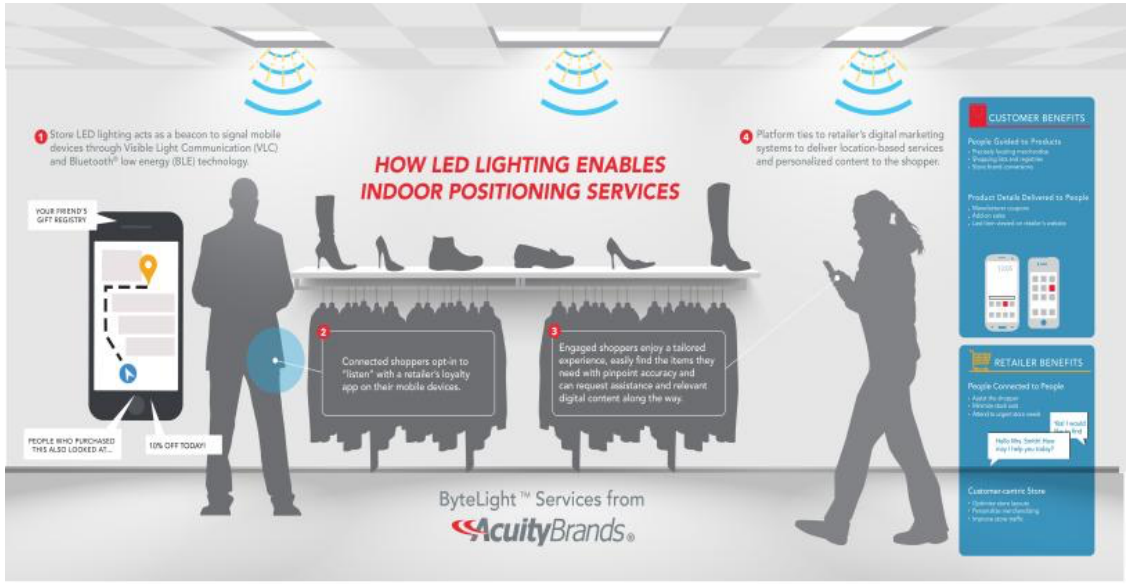
Primary use case is downlink only

Goal: create 1 Gb/s of new capacity per context

Primary use case is downlink only

But capacity can come from aggregation of channels

VLC is maturing



Positioning: Acuity Brands

Fraunhofer HHI

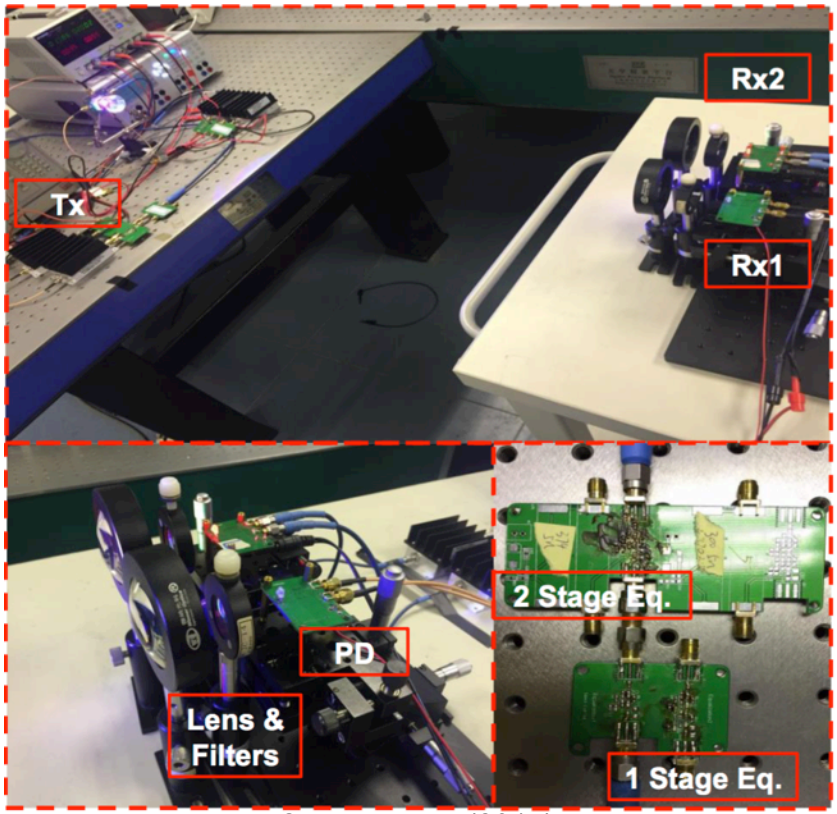
Torrey Pines Logic

Oledcomm

PureLiFi

Is VLC fast? Benchmarks

- 750 Mb/s single wavelength via equalization (non lighting LEDs, blue filtering) 2015
- 2 Gb/s single phosphorescent white LED
- 1.35 Gb/s with RGB LEDs
- 4 Gb/s and 8 Gb/s with various forms of equalization at source and receiver, RGBY, 1m
- 9.5 Gb/s with RGBY, lots of secret sauce, tuned, fixed, lenses

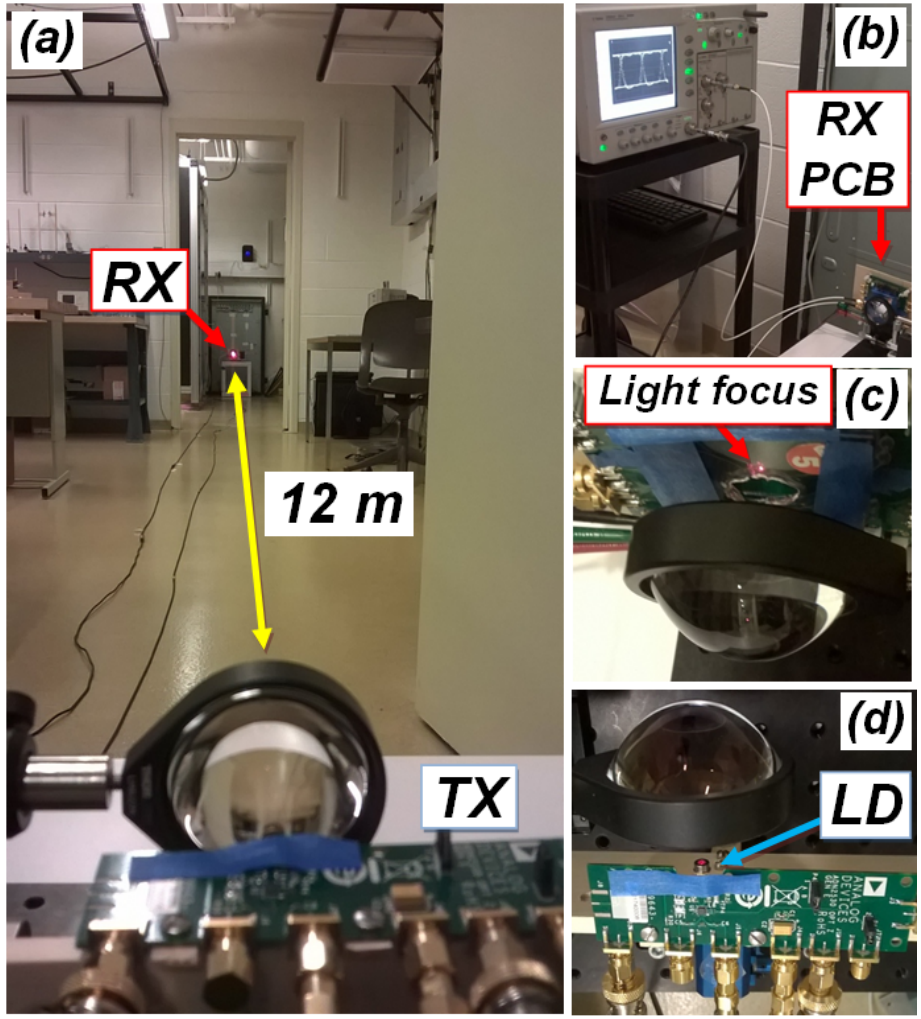


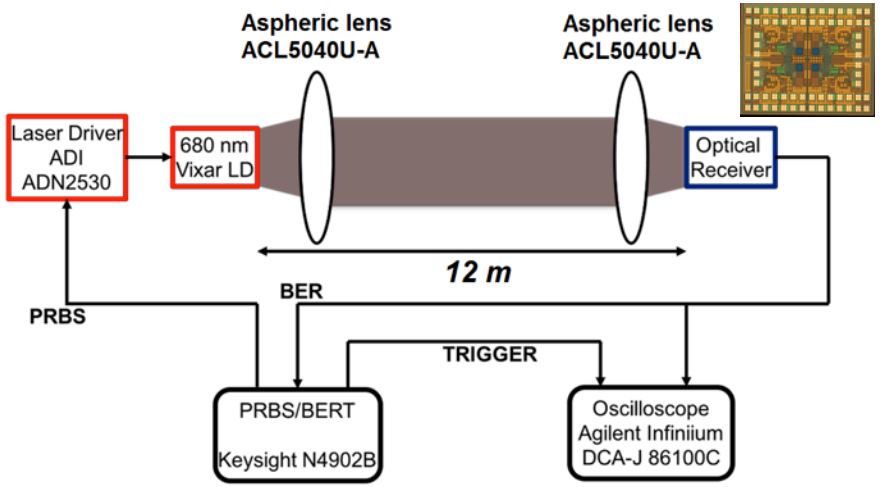
Nan Chi, Fudan U (2015)

VLC is now in the 10 Gb/s ballpark

Some issues remain to realize this as “lighting”

LESA is also in the race: 2X2 Receiver Array (Hella / Fahs)

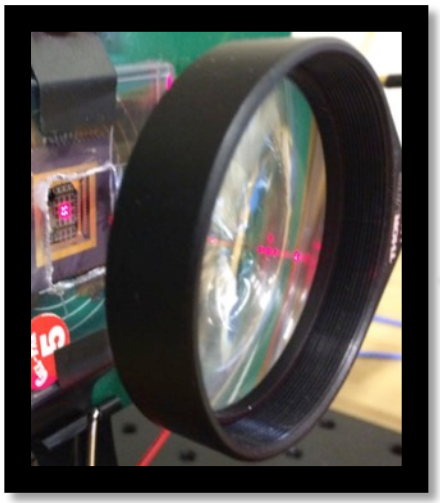


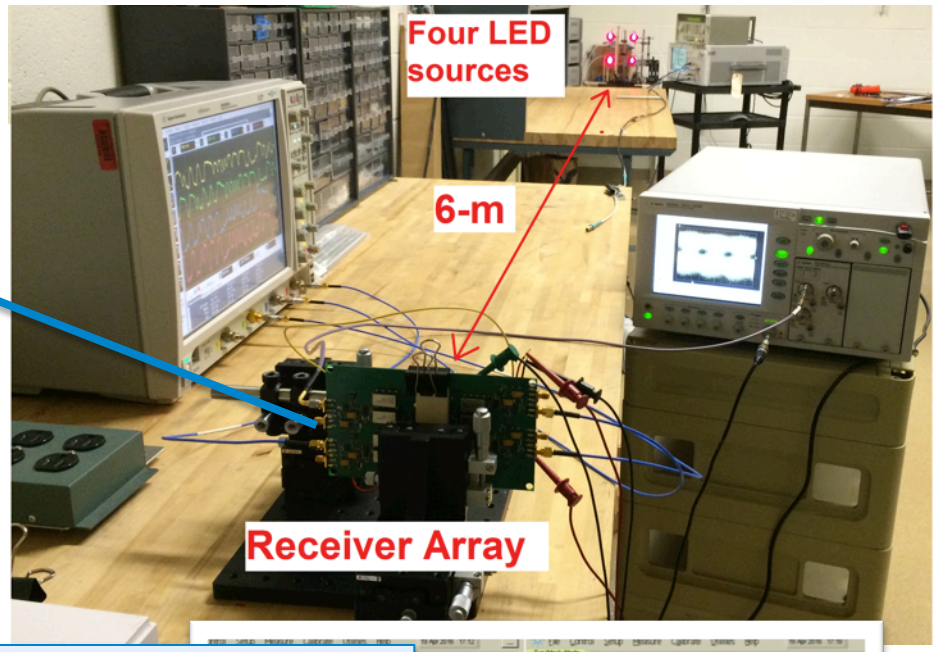


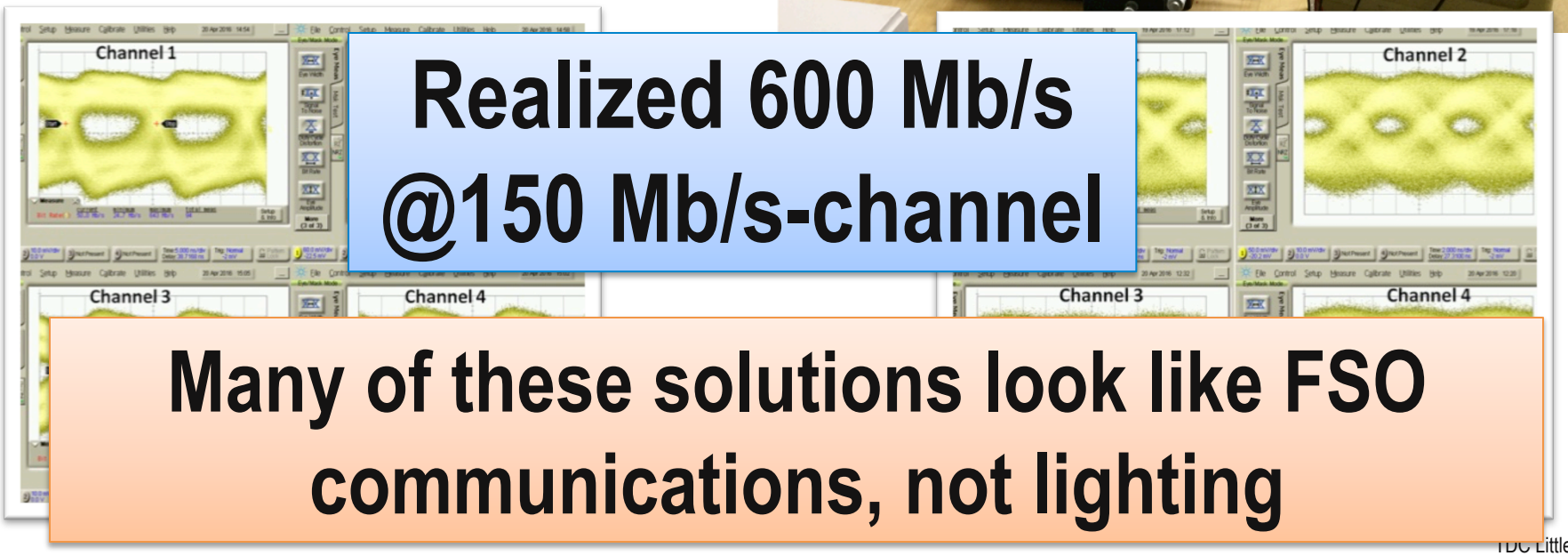
Realized a 12-m 2.5-Gb/s OOK VLC single link using a 680-nm red LD

With 4 LED sources:

Rx Front-side with 4 light points located on the photodiode array



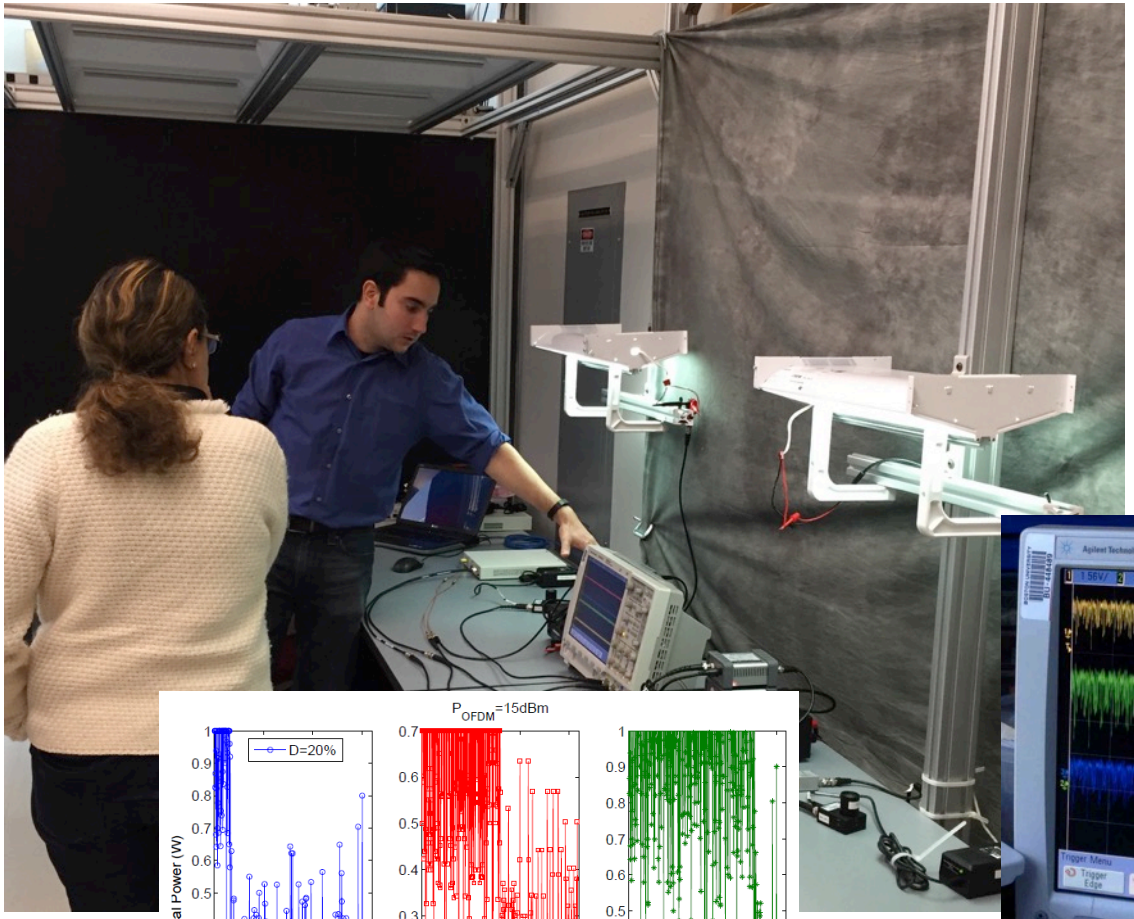




Realized 600 Mb/s @150 Mb/s-channel

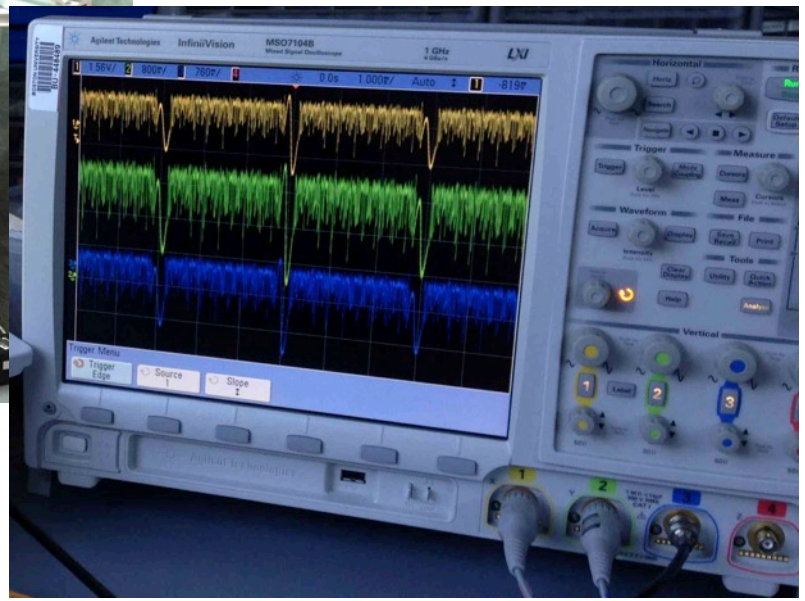
Many of these solutions look like FSO communications, not lighting

Diffuse lighting (LED) sources: modulation and dimming can coexist



PWM + OFDM

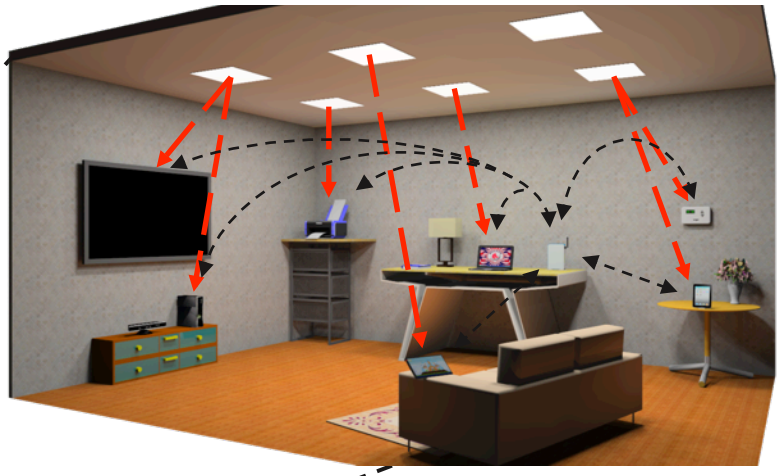
Limited by speed of lighting grade LEDs – typically 10's of MHz



Wireless is trending towards smaller and smaller cells

Macrocell coverage within a city

VLC Cells within an apartment



RF Small Cells within an apartment complex

The challenge is contention – here's a dense WiFi network

Partition into very small cells

Case: Dense network w/ WiFi offloading

Wiki, Jim Bahn

Aruba Networks

Aruba Networks

Levi's Stadium (2016)
27,316 unique wifi users
Peak: 18,901 simultaneous

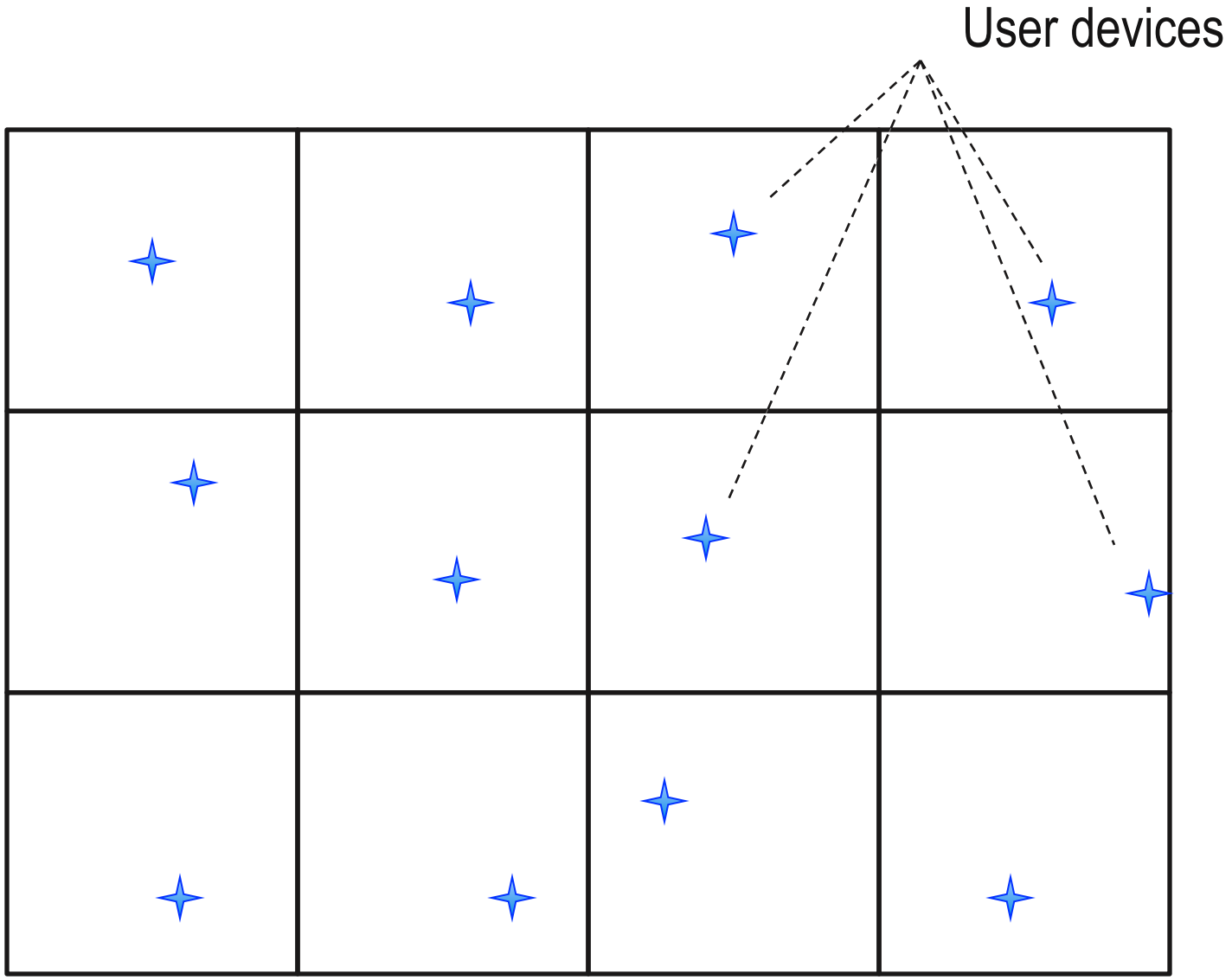
400 miles of cable
12,000 network ports
1,200 access points

Use attenuation to mitigate cell size!

"… offer 3.5 Gb/s of wifi bandwidth" → implies 2.9 Mb/s per AP (< highest average in Americas)

https://www.hpematter.com/issue-no-8-winter-2016/how-arubas-wi-fi-solutions-powered-levis-stadium-break-connectivity-records

Distribution of users in cells matters (locality)



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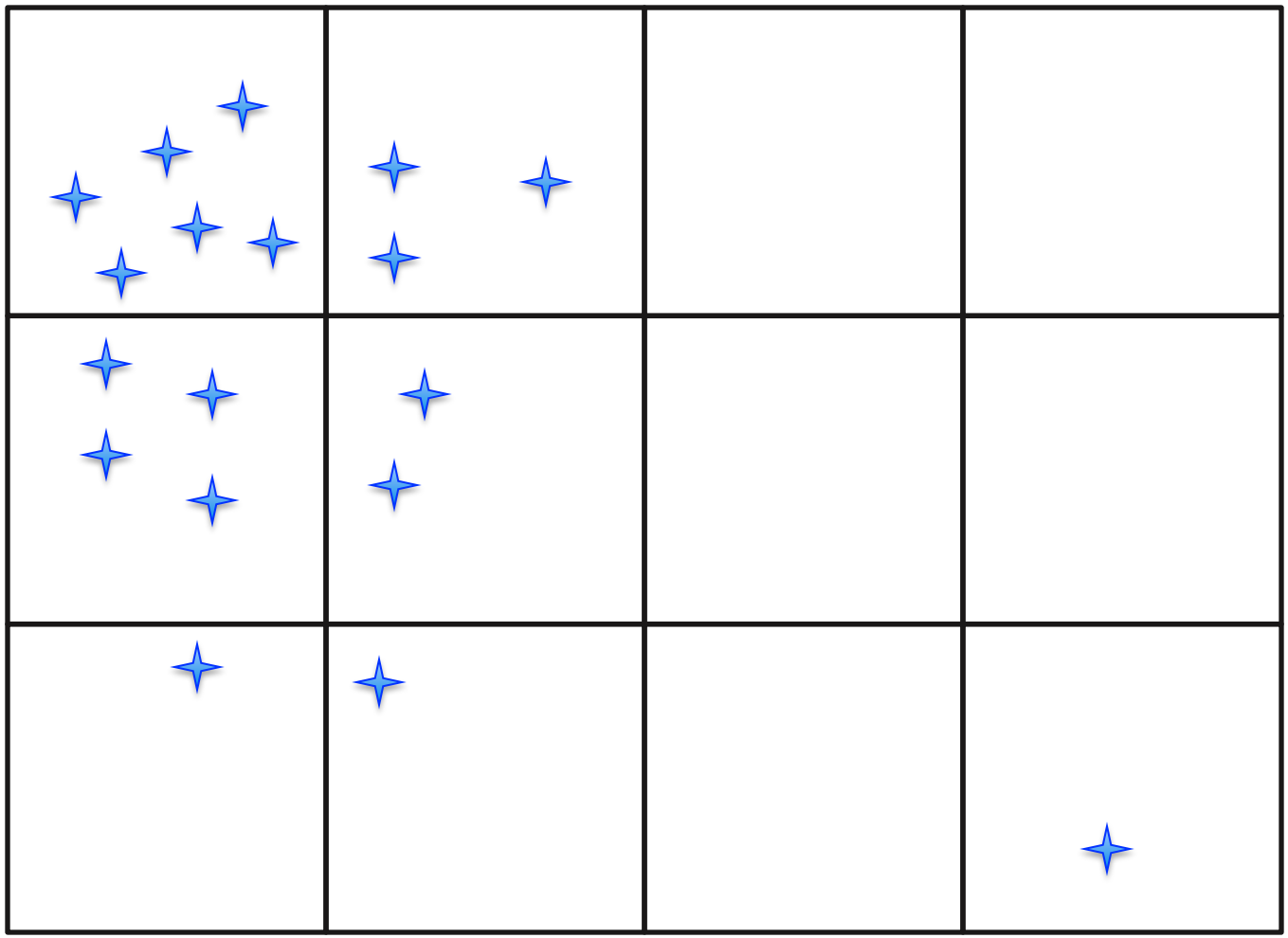

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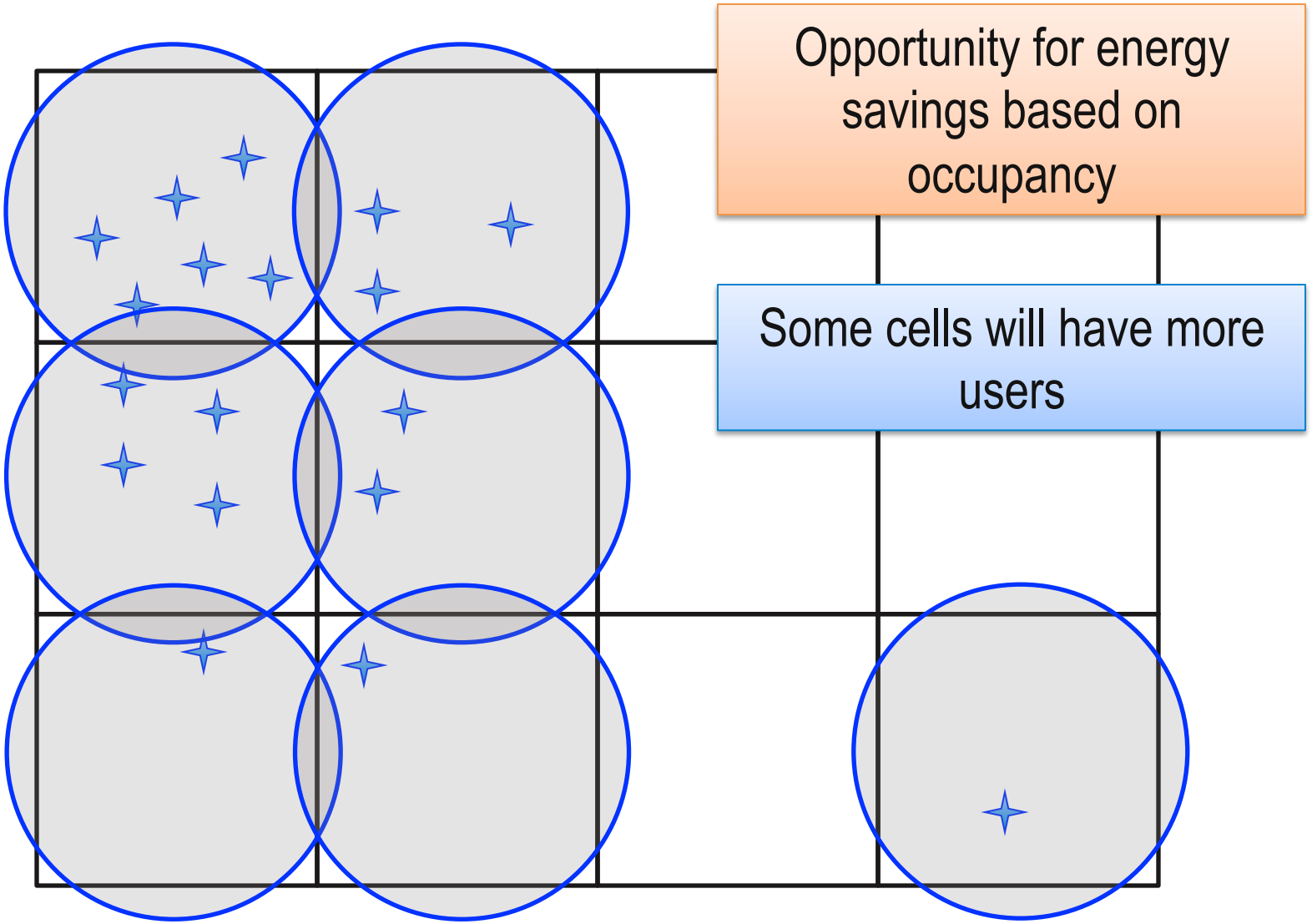
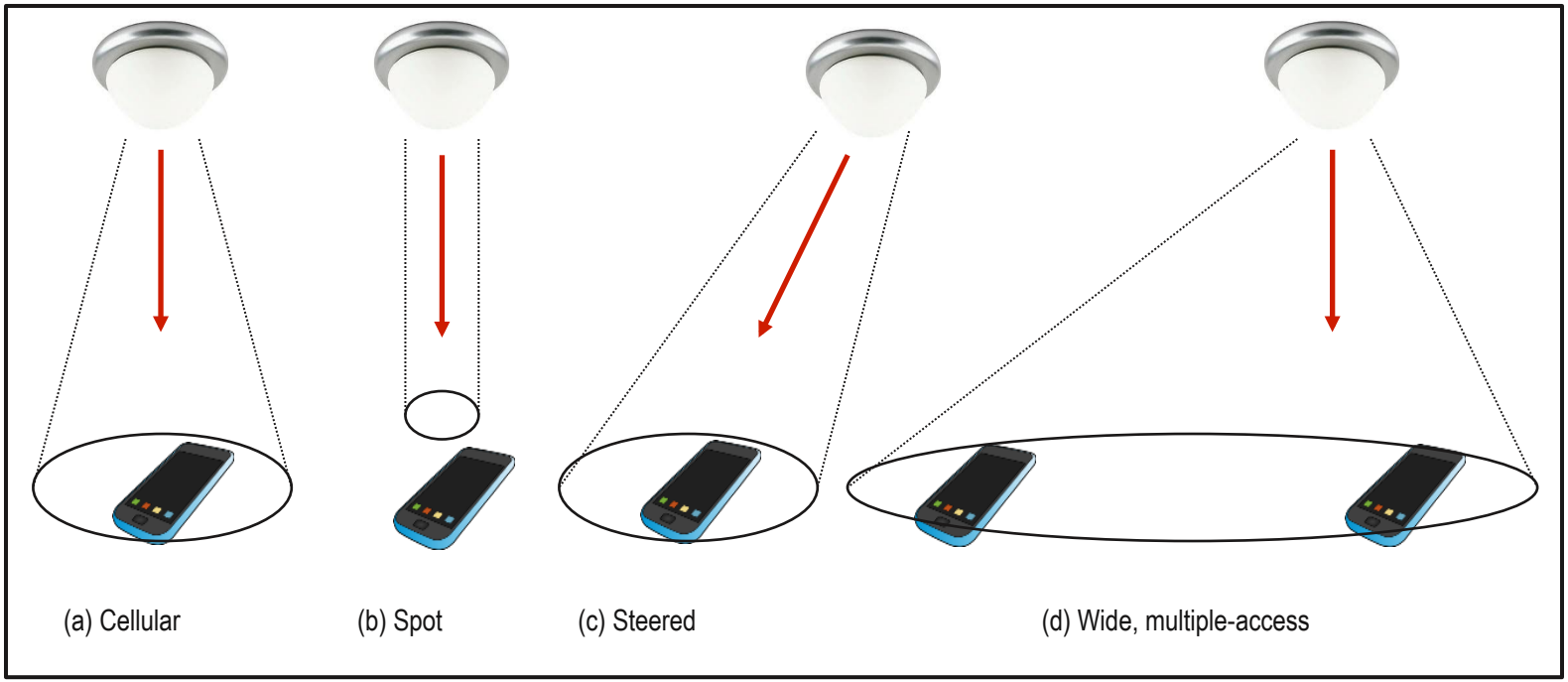
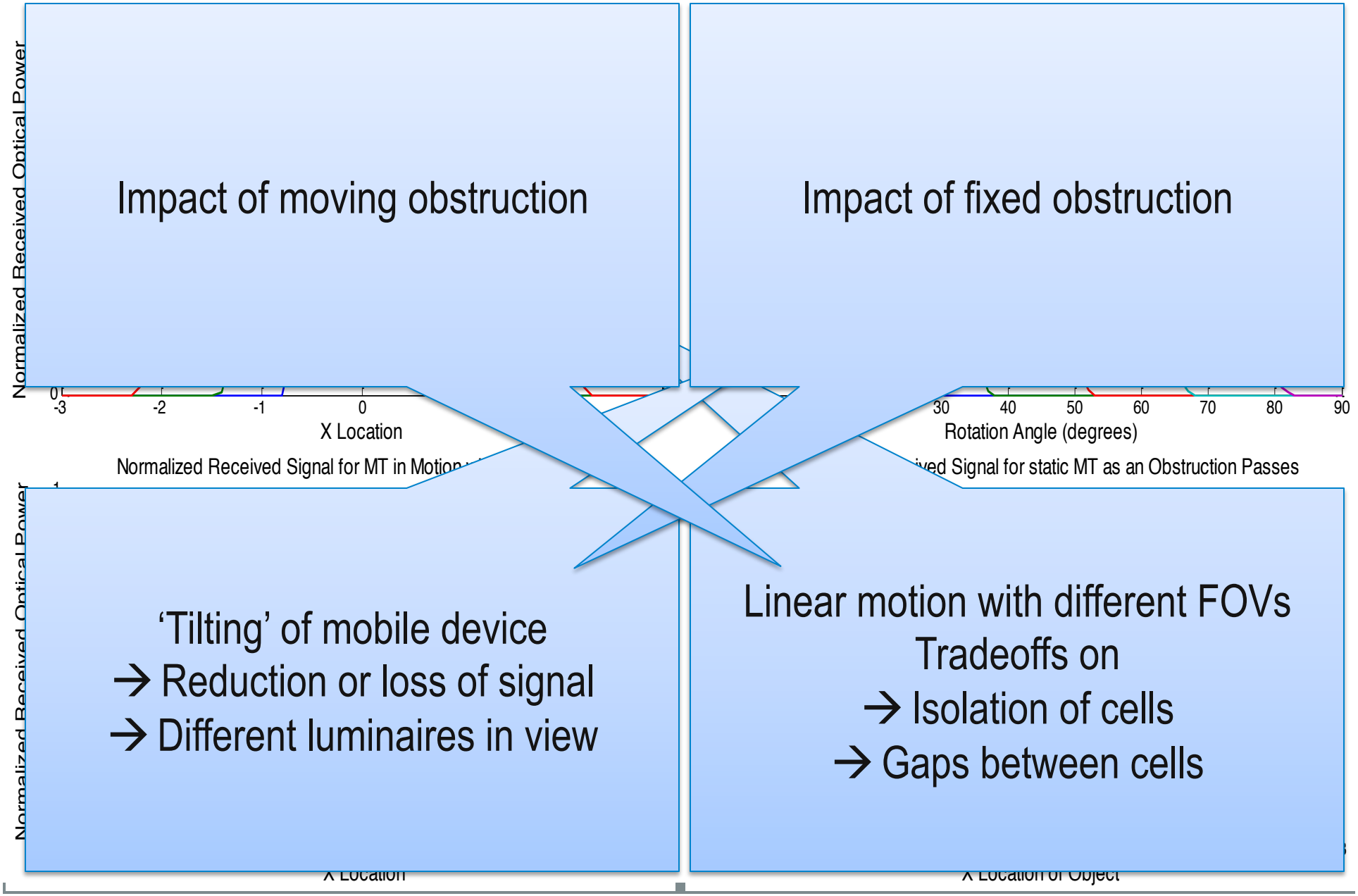


Making the VLC small cells more flexible



Device motion challenges “seamless”

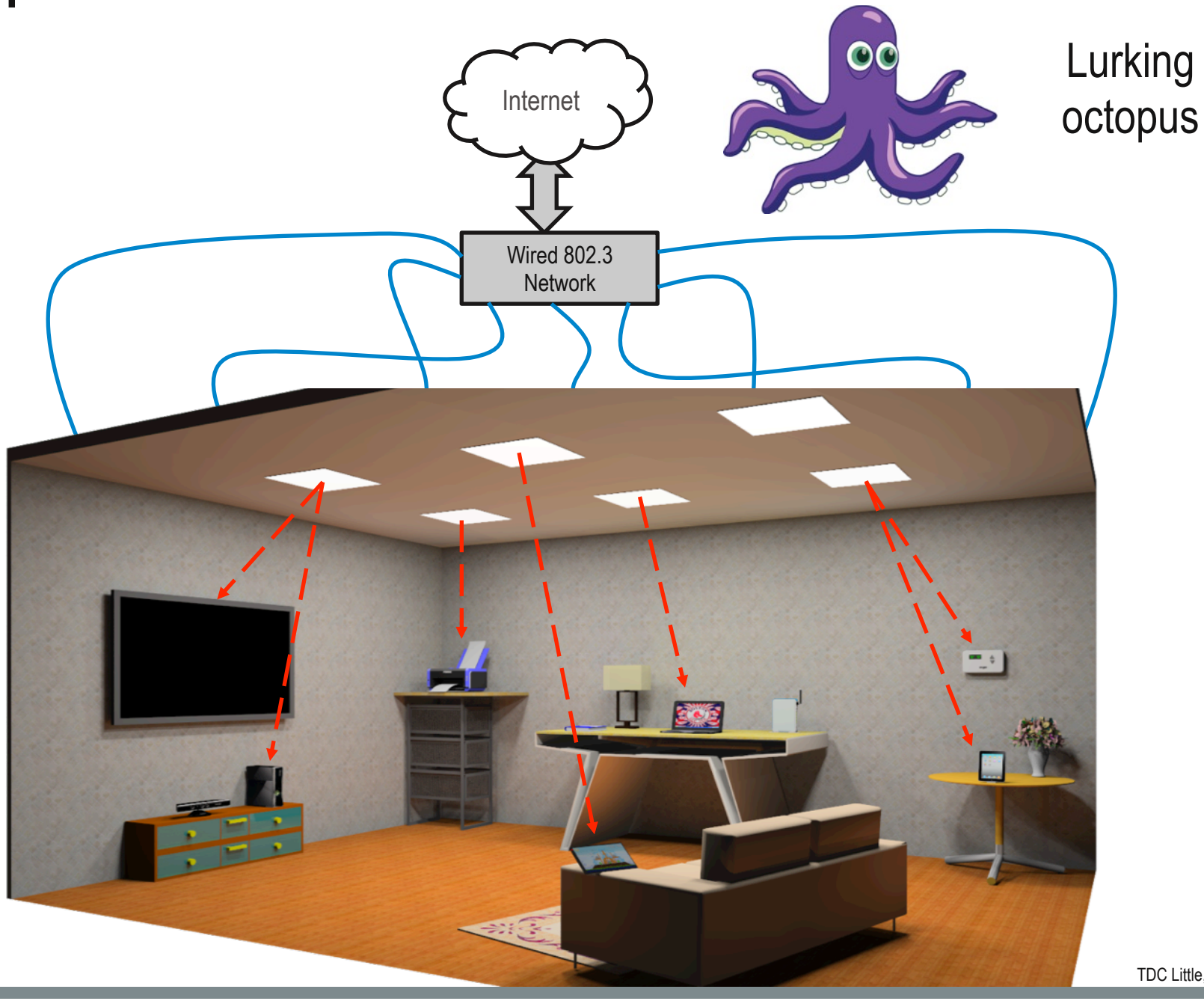


There are many system challenges for VLC in 5G

Challenges to VLC	Metric
Seamless connectivity	Free from gaps in service
Meet individual device data demand	Satisfy individual demand
Meet lighting needs under dual use	Meet luminance spec at tabletop
Free of dead zones	Coverage
Data ingress/egress from smart room	Cost of cabling
Occlusions	Coverage
Satisfy multiple users	Satisfy aggregate demand
Knowing where users/devices are located	Device position accuracy and tracking
Net energy use under Dual use	Efficacy of system in lighting function
Find the device and if it is being used, privacy	Tracking accuracy, ability to handover

Glare in uplink must be reconciled – probably with non-vis spectrum

Egress problem with VLC/5G

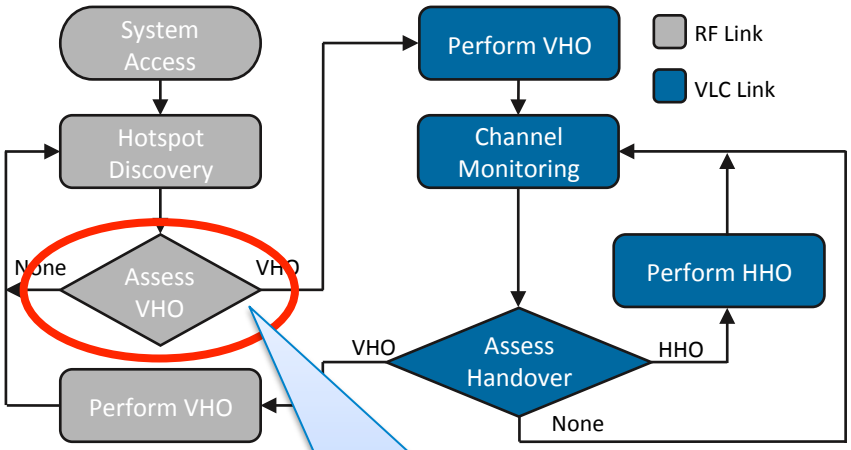


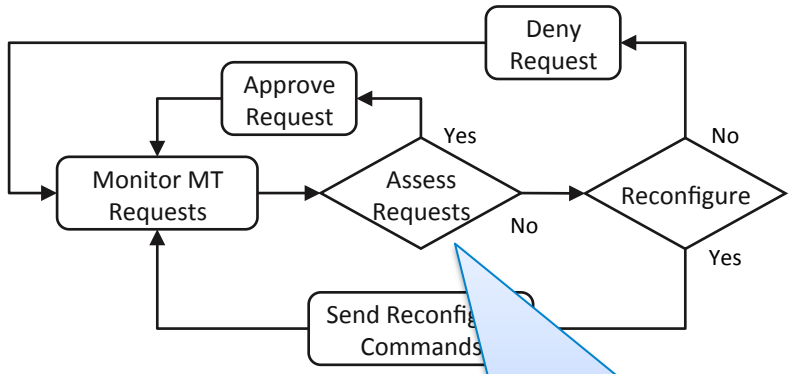
Combine VLC with RF uplink or offload (Heterogeneous Network)

Handover can be greedy or managed RF--VLC

User Centric

Network Centric



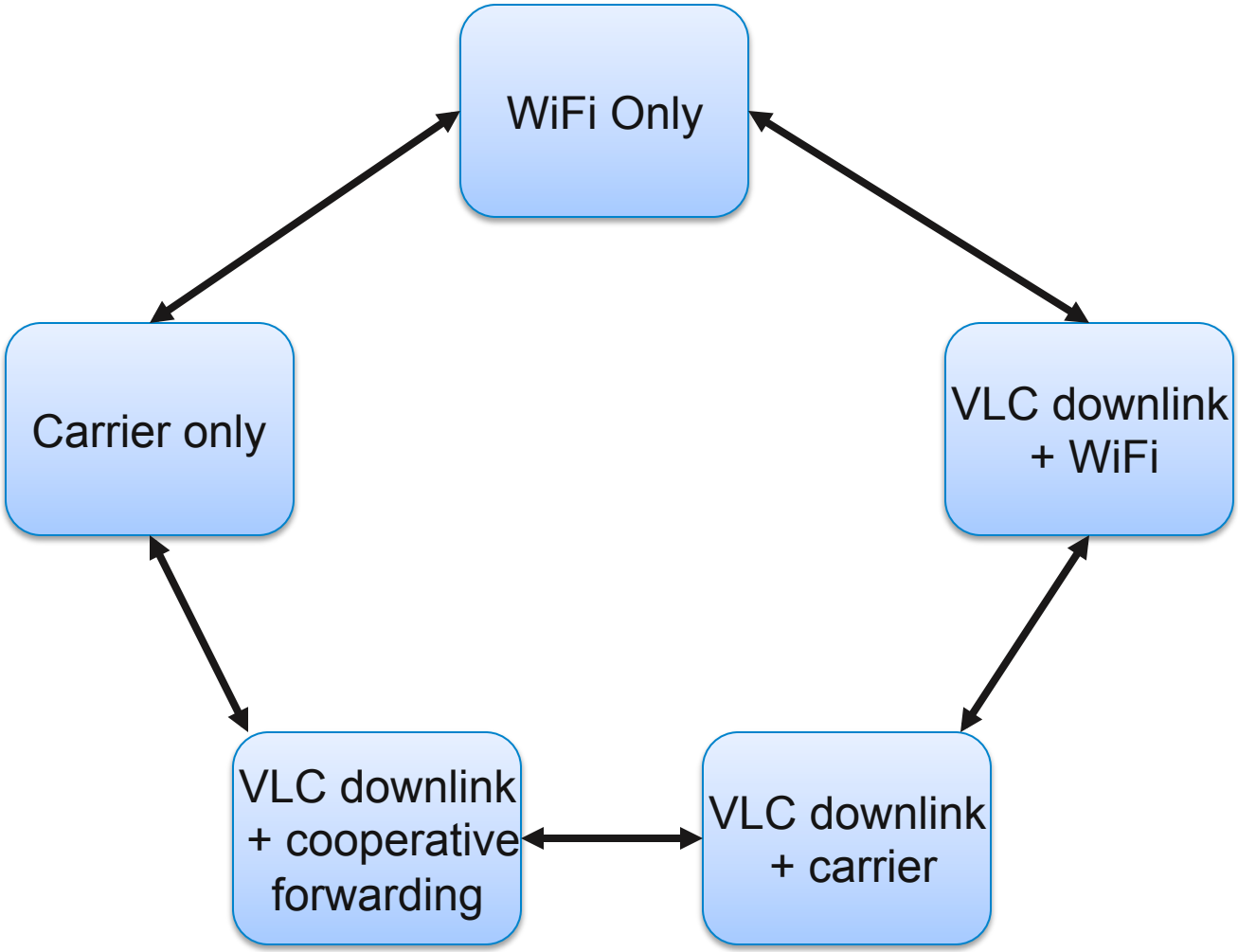


User assessment: SINR, mobility, channel state

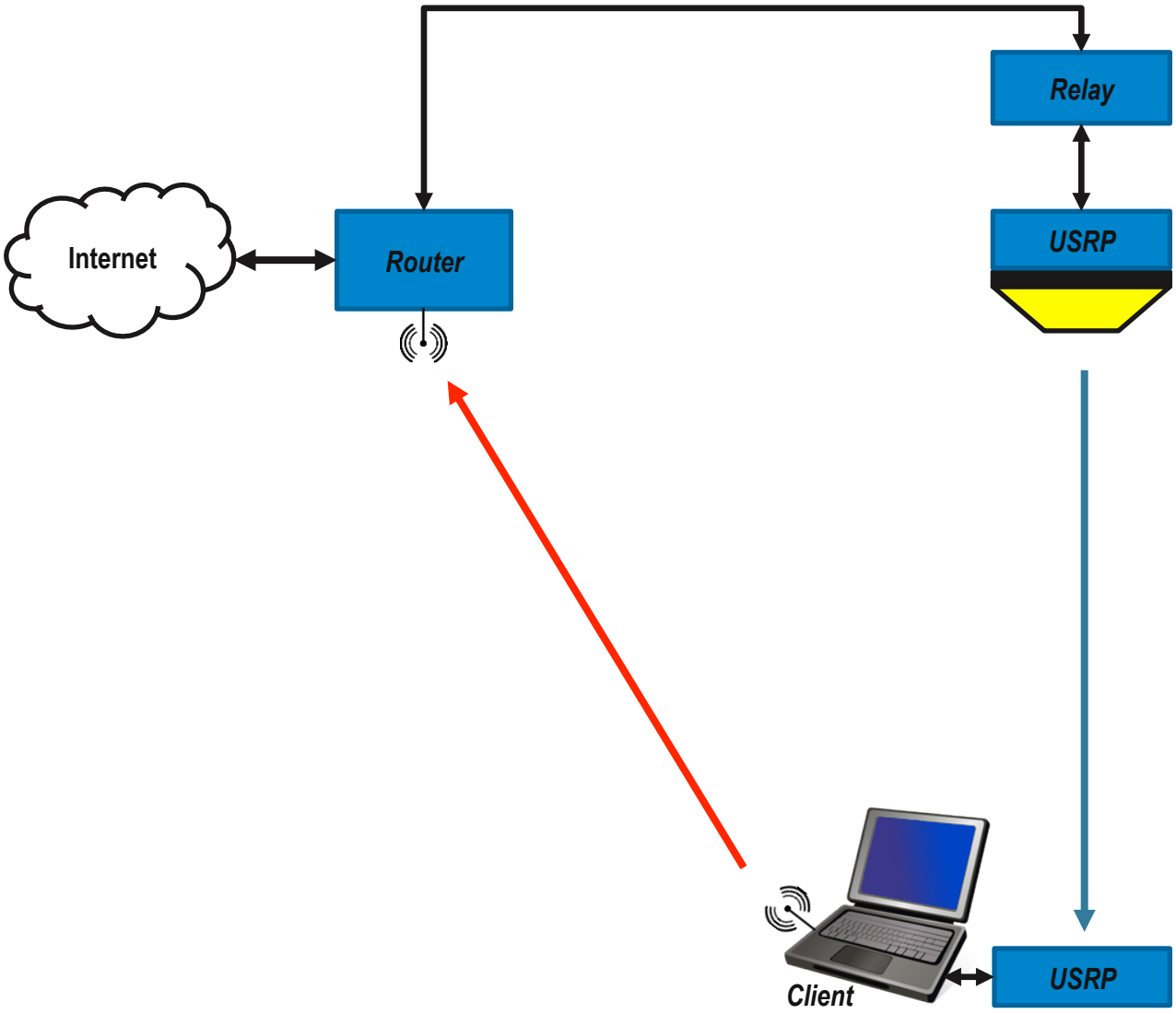
Network assessment: available resources, tracking all users

Predicting temporal effects (motion, channel conditions, activity) allows devices to make preemptive handovers

The system or user-device can adapt to best services



Single device RF-VLC integration

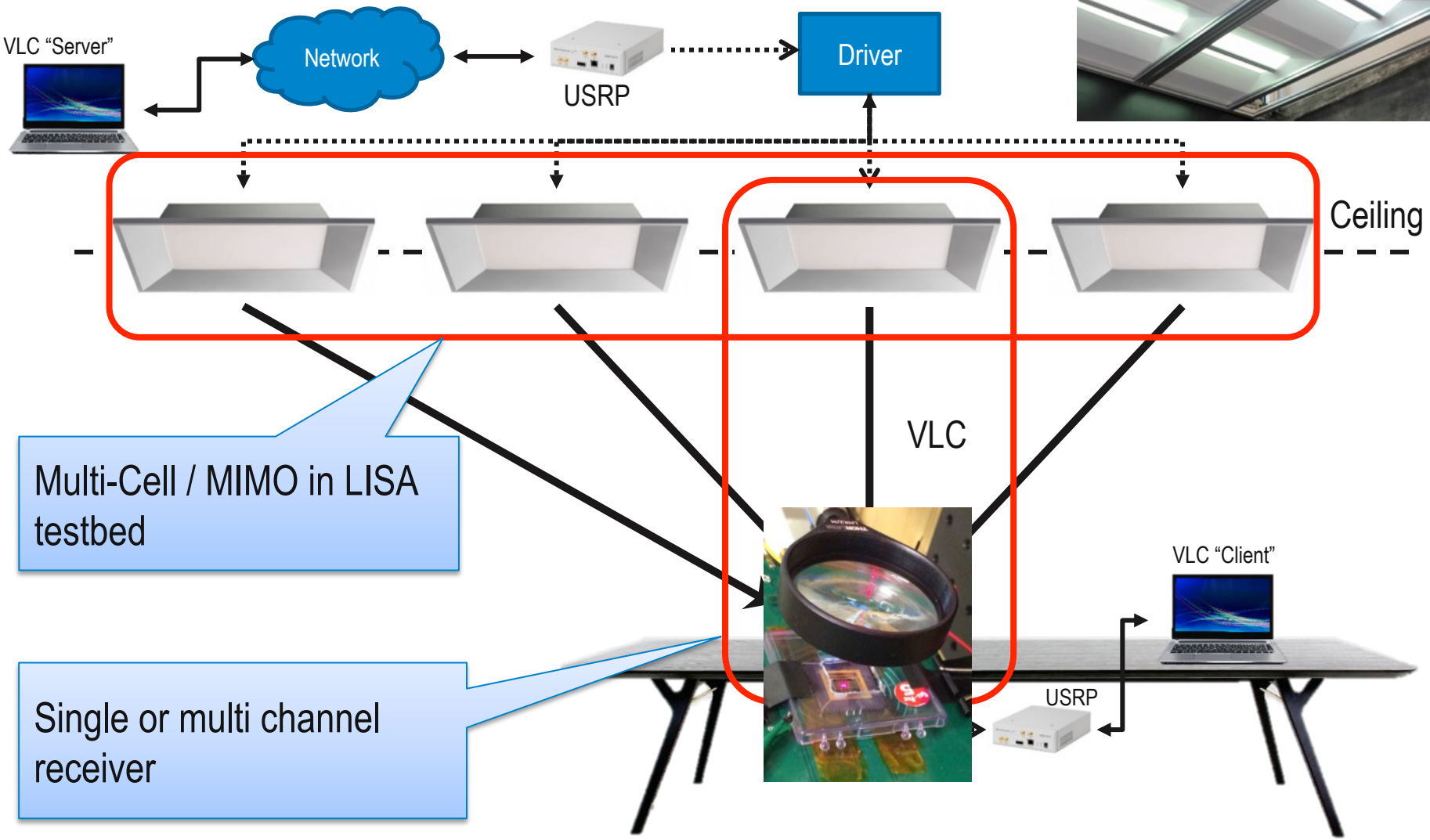


(c) BU MCL 10/3/2016

RF-VLC HetNet integration/Internet access demo

(c) BU MCL 10/3/2016

VLC Testbed: Integration and Expansion



Barriers to VLC in 5G

- Lighting and communication industry stovepipes
- Uplink, bidirectional
- Data egress to the APs (everyone's problem)
- New RF spectrum and massive MIMO are competitors, RF guys will continue to innovate
- Mixed rate devices (phones and non-phones) including IoT
- IoT — how to reconcile a high density of lower-rate, low-power devices in the context of 5G communications
- Impact of changing user devices and cloud services on the provisioning of 5G cells — how to model and predict needs as the devices change.

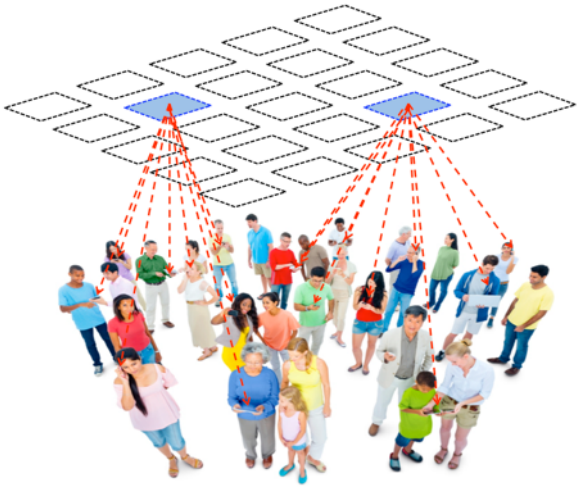
In summary,

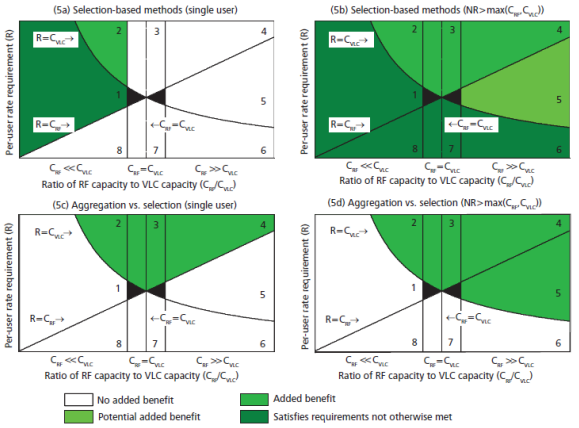
Device capability and user applications are driving 55% CAGR in mobile data

VLC is maturing, provides new spectrum, and is well suited for high user density

RF is not going away, but combined RF and VLC systems can provide best of both worlds

Currently investigating how to predict how to provision future 5G VLC/RF solutions





Acknowledgement

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https://lesa.rpi.edu

http://www.bu.edu/smartlighting/

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