How Smart Lighting Fills a Gap in Wireless Communications

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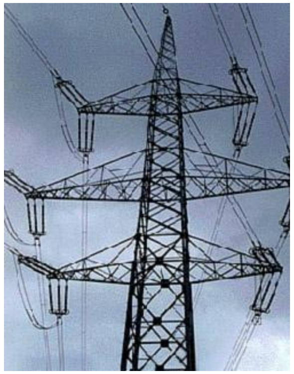
BOSTON UNIVERSITY

Overview

- Why Smart Lighting?
- Smart Light == Controllable light
- Smart light in communications
- Use cases that drive core research
- Survey of center projects and efforts to date

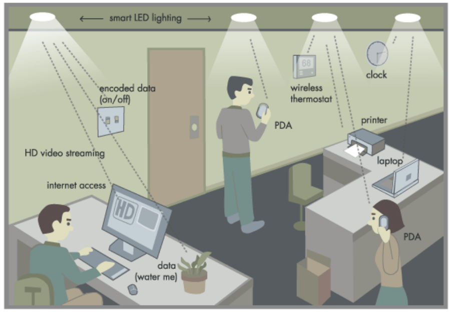
Why is Solid Sate Lighting Important?
Emergence of New Lighting Technologies



Energy Perspective*

- 19% of electricity worldwide is used for lighting, and electricity is 16% of total energy produced -- 30 billion light bulbs are in use worldwide
- White LED's at 200 lm/W (projected 2025), could save 1 billion barrels of oil per year (250 nuclear power plants)

- ## Information Perspective
  - New lighting technologies may integrate information and illumination, leading to **dual-use** and adaptive infrastructure
    - Free space optical networks (VLC)
    - Optical sensing and imaging systems.



Economic Implications*

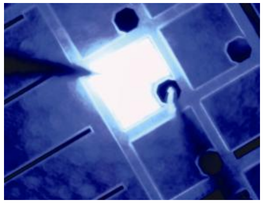
- Worldwide LED market (2007): $8.5 billion, growth 8%
- Current markets: mobile devices, displays, autos
- Growing markets: general lighting, 8-10% (2010)

*Data from P. Mottier, *LEDs for Lighting Applications",* John Wiley, 2009.

Key Concept is Controllable Light

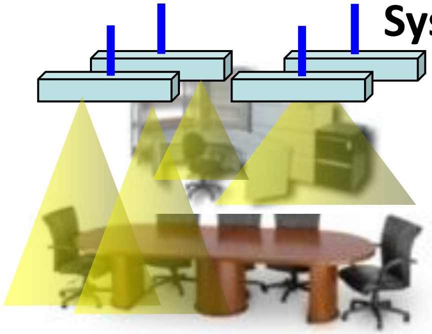
Conventional Lighting:

Limited Controllability
Limited Efficiency



Solid-State Lighting:

Controllability
Efficiency

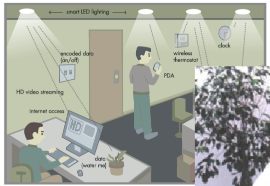


Smart Lighting Systems:

Adaptibility
Awareness

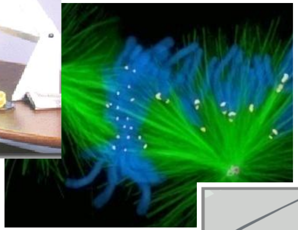
APPLICATIONS AND IMPACTS

HOME and OFFICE
[Adaptive Lighting]

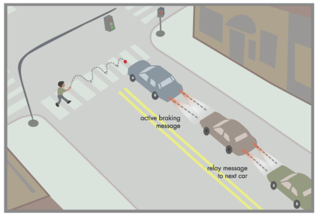


HEALTH
[Personal Lighting]

SENSING and IMAGING *[Information]*



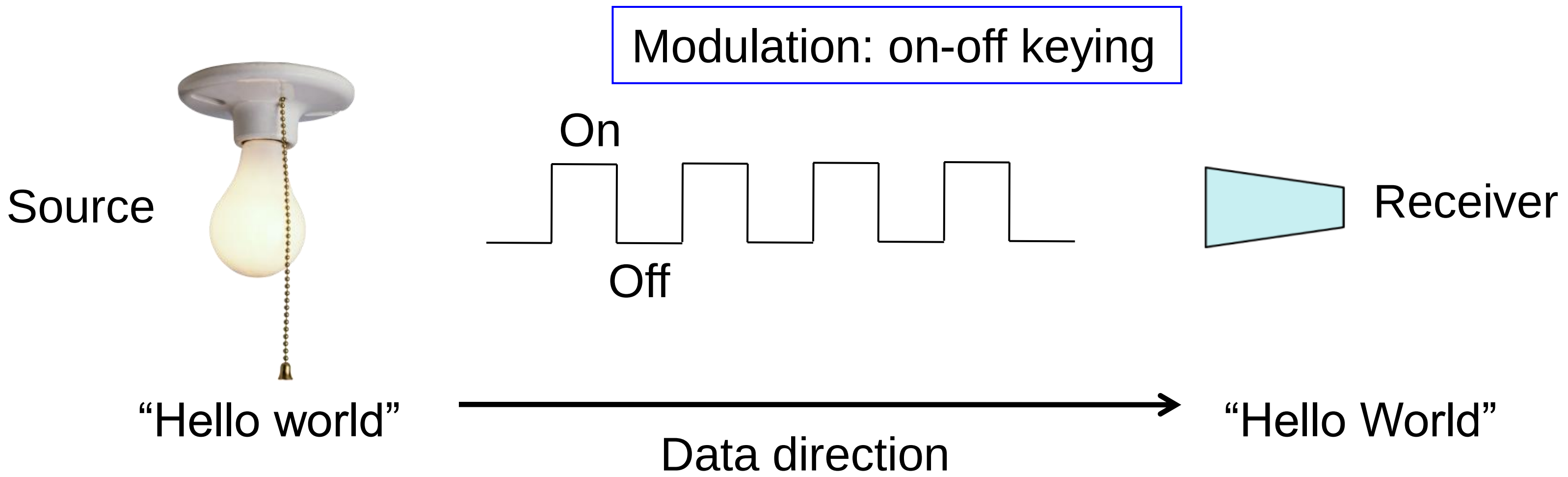
COMMUNICATIONS
[Dual-Use]



ENERGY EFFICIENCY
[Infrastructure]

Intensity, color, dispersion, polarization, modulation, quality

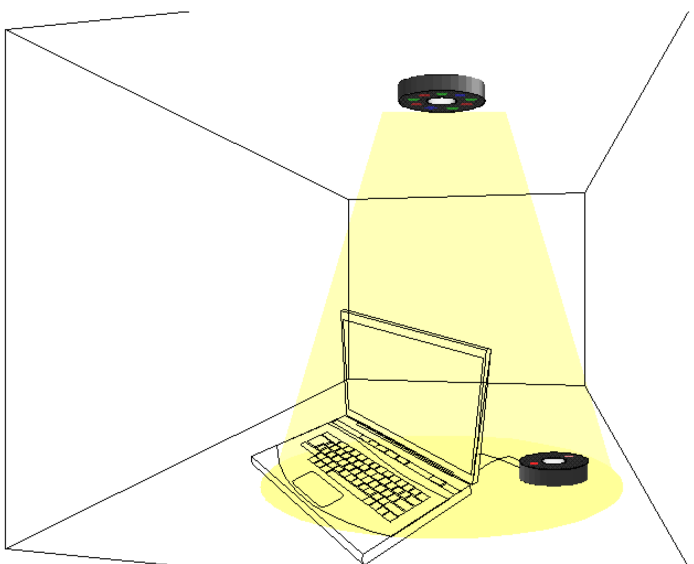
Smart Lighting for Communications



LEDs can be controlled, and modulated
Unlike conventional lighting

Important: want to communicate AND illuminate

“Visible Light” Communications == VLC



Do We Need VLC?

- There is little demand for VLC today
- VLC is a technology looking for a problem

Answer:

- VLC has unique attributes suitable for specific applications
  - Security, require absence of RF, directionality, indoor localization
- VLC has potential as an **opportunistic medium**
  - Energy neutral
  - Could be in every light bulb

Challenge: can we provide a useful communications substrate

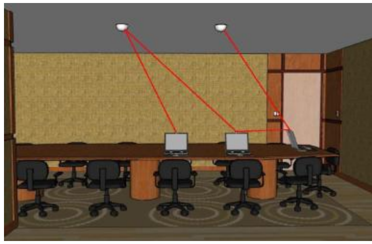
- That does not add significantly to cost of lighting?
- That is energy efficient?
- That supports a broad enough range of applications (low and high data rates)?

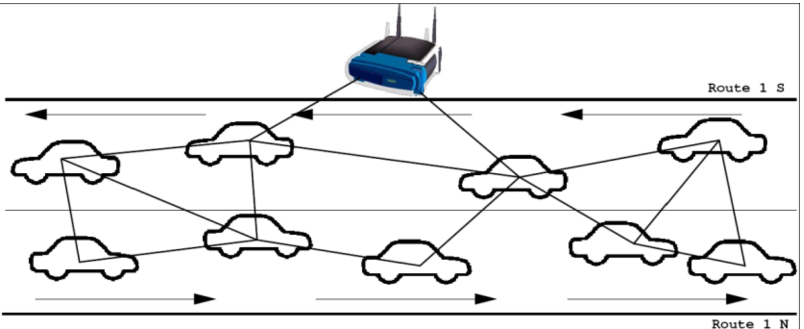
Strong focus on “Dual-Use” model: lighting and communication

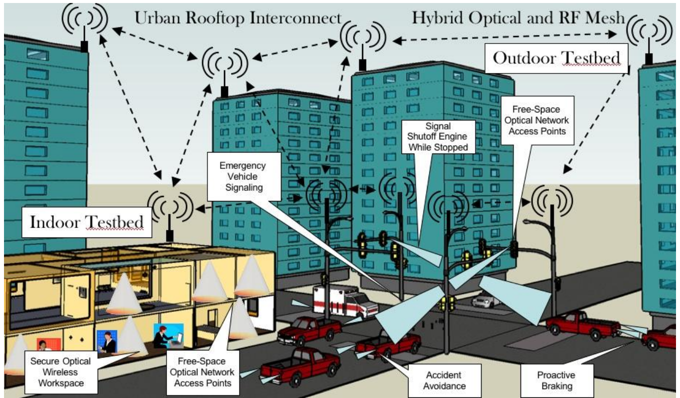
VLC: Where it Matters

From Airbus (www.airbus.com)

- **Deliver HD video to individual seats**
  - Airbus holds > 500 people; HD requires 13 Mb/s; short range personal lighting/communication for channel isolation; copper is heavy. High bandwidth density (>10 Mb/m^3)
- **Localized communication between vehicles**
  - Emerging safety-oriented technology: active braking, traffic monitoring; warning message propagation.
  - Directional transmission, PRF < 1%, < 100ms latency
- **Indoor localization**
  - Finding roaming patients and doctors in a hospital; RF techniques can be problematic; lights can be uniquely modulated with ID; tagging bats; security in downlink channel. Data trickle.
- **Providing opportunistic mobile access**
  - Hotspots wherever there is illumination. Ubiquity.
  - Moving vehicles. Internet access
  - Mesh networks







But What about RF?

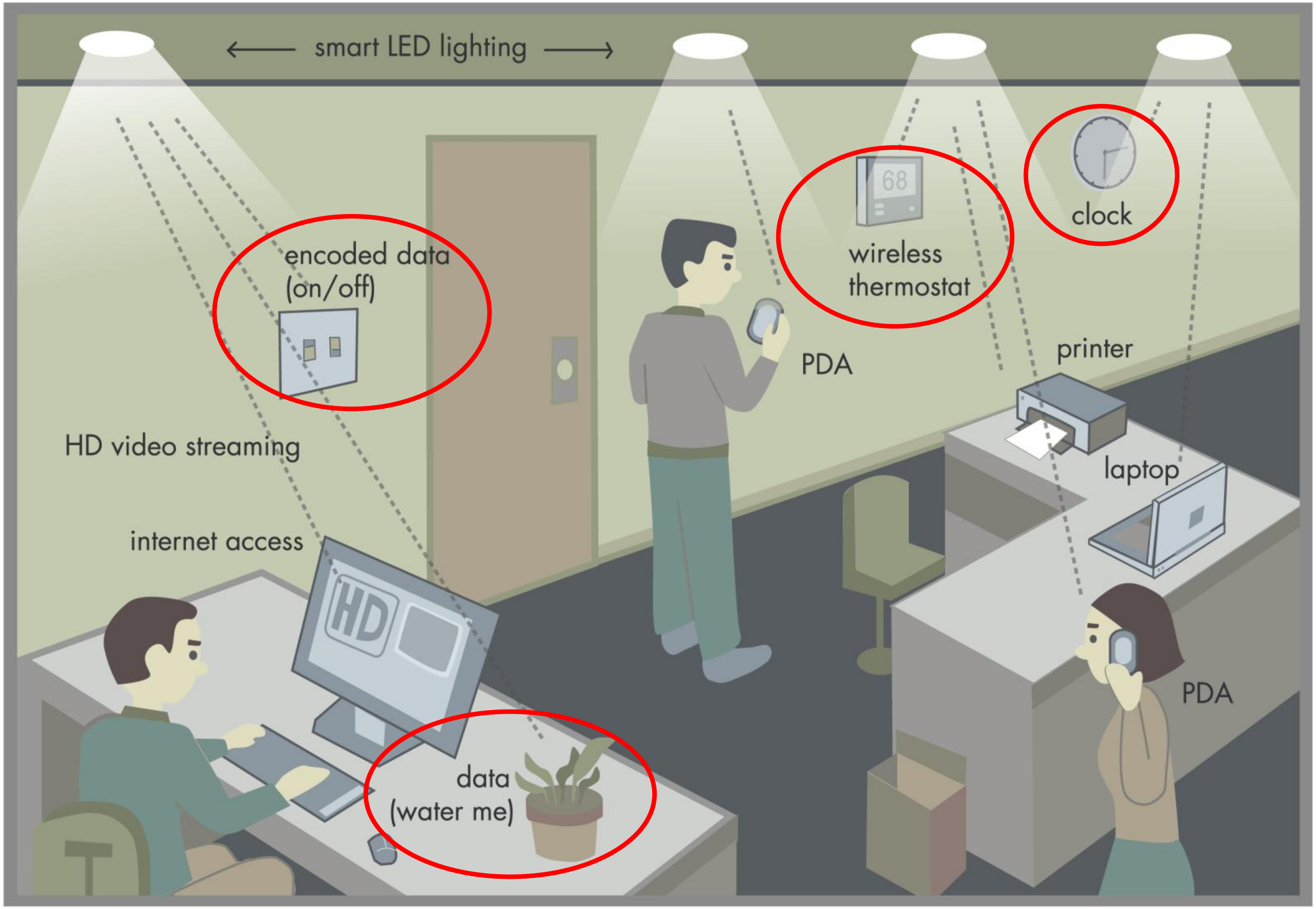
Attribute	RF@2.4GHz	LED Optical	Advantage
Security/Privacy	Penetrates walls	Does not penetrate walls, prevents snooping	LED optical
Available Bandwidth Capacity	Signals sent at same frequency can interfere with one another	Light can be directed – smart light sources can be tuned to adapt to	LED optical
Cost Spect			ptical
Inter			
Multi	times" and/or are out of phase		ptical
Path Redundancy	Achieved with multiple access points	Achieved with multiple LEDs	LED optical
Transmission Speed	100 megabits per second deployed	Comparable, but with reuse of volume for higher aggregate speed.	LED optical
Estimated Comparative Cost	<$20	<$2 (Based on IrDA)	LED optical

Visible light communications can have significant benefits over RF

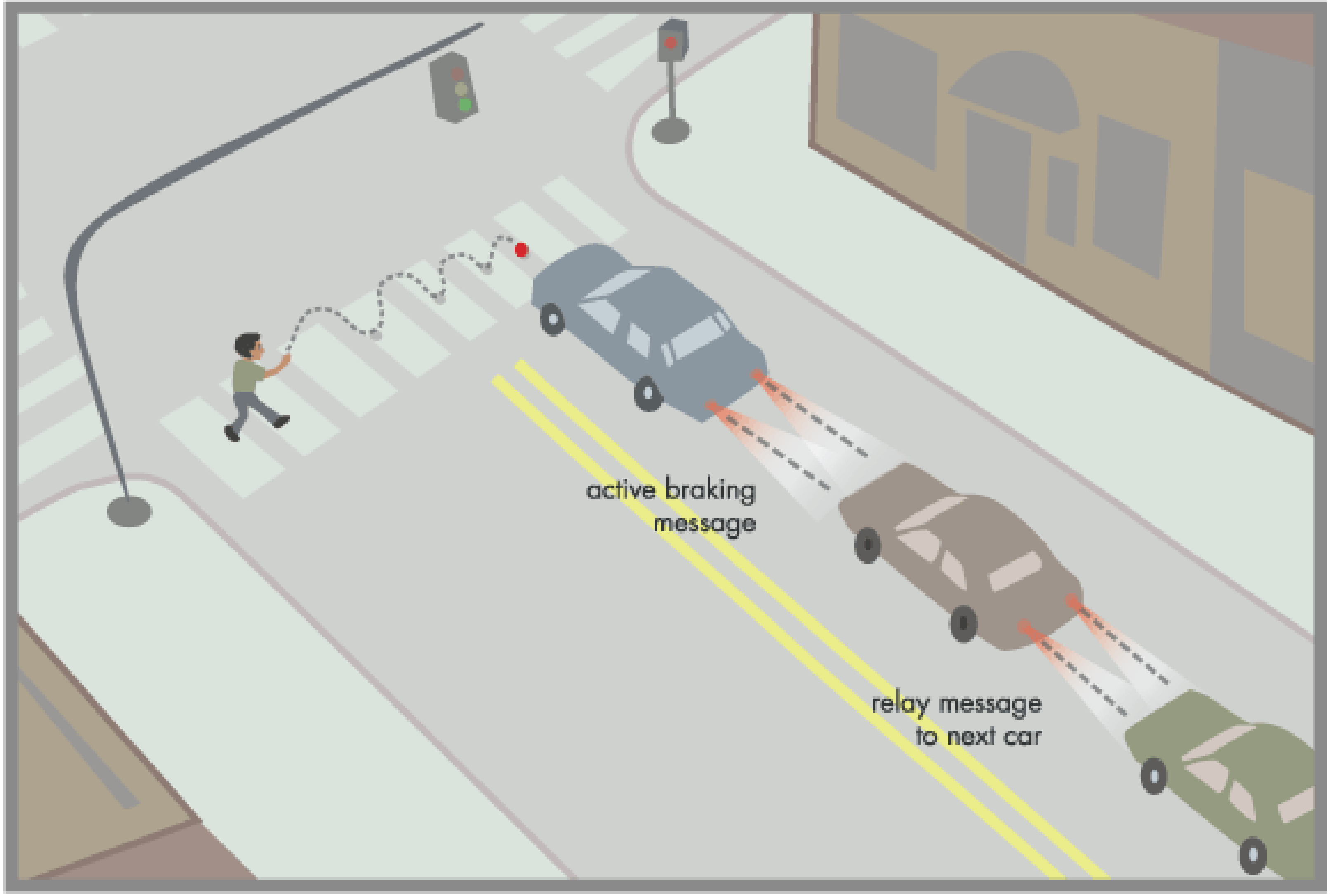
Representative Use Cases

- Safety in transportation
  - V2V directional communications for safety, convenience, and fuel efficiency
- Reducing total cost of ownership in smart spaces: industrial automation, sensor nets, and control
  - By wire replacement and low cost, low rate optical communications substrate
- High bandwidth density video streaming
  - For entertainment, convenience, education, device interconnect
- Ubiquitous opportunistic data networks by optical means: head to head against incumbent RF but with lower cost

Reducing TCO in Smart Spaces



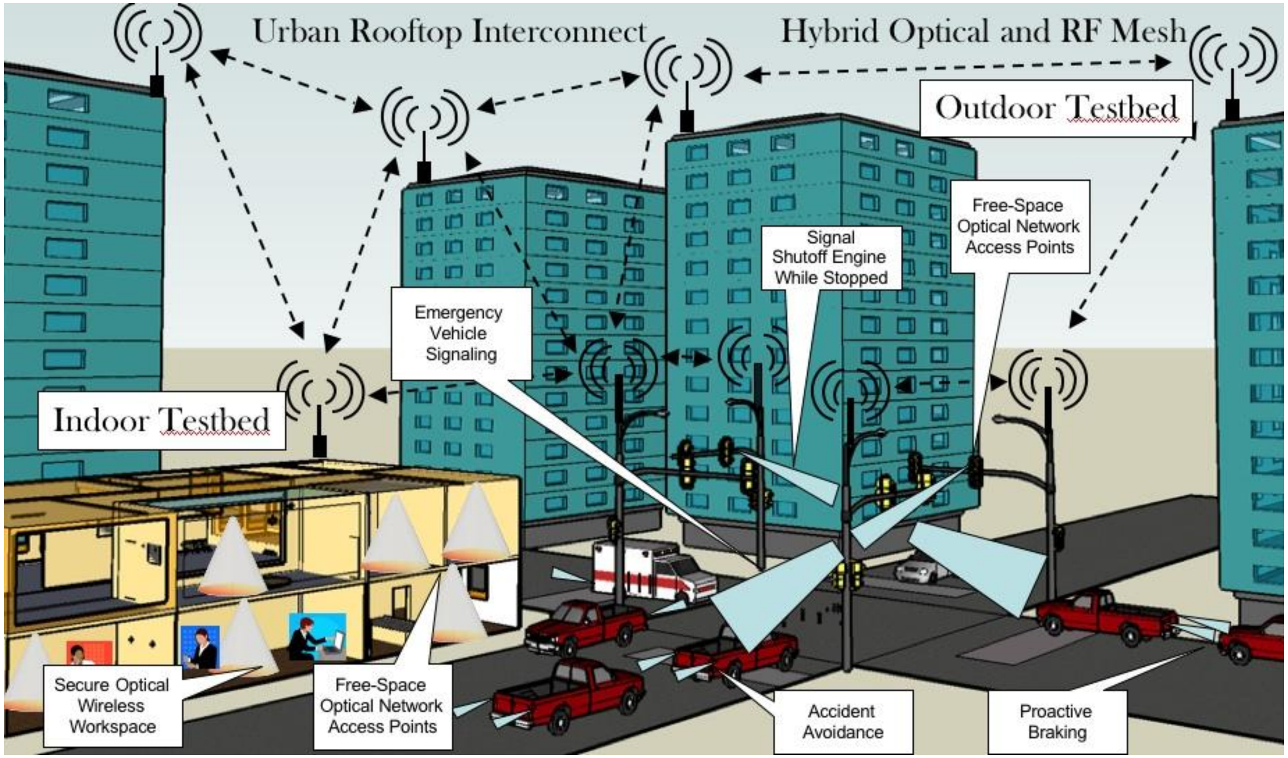
Safety in Transportation



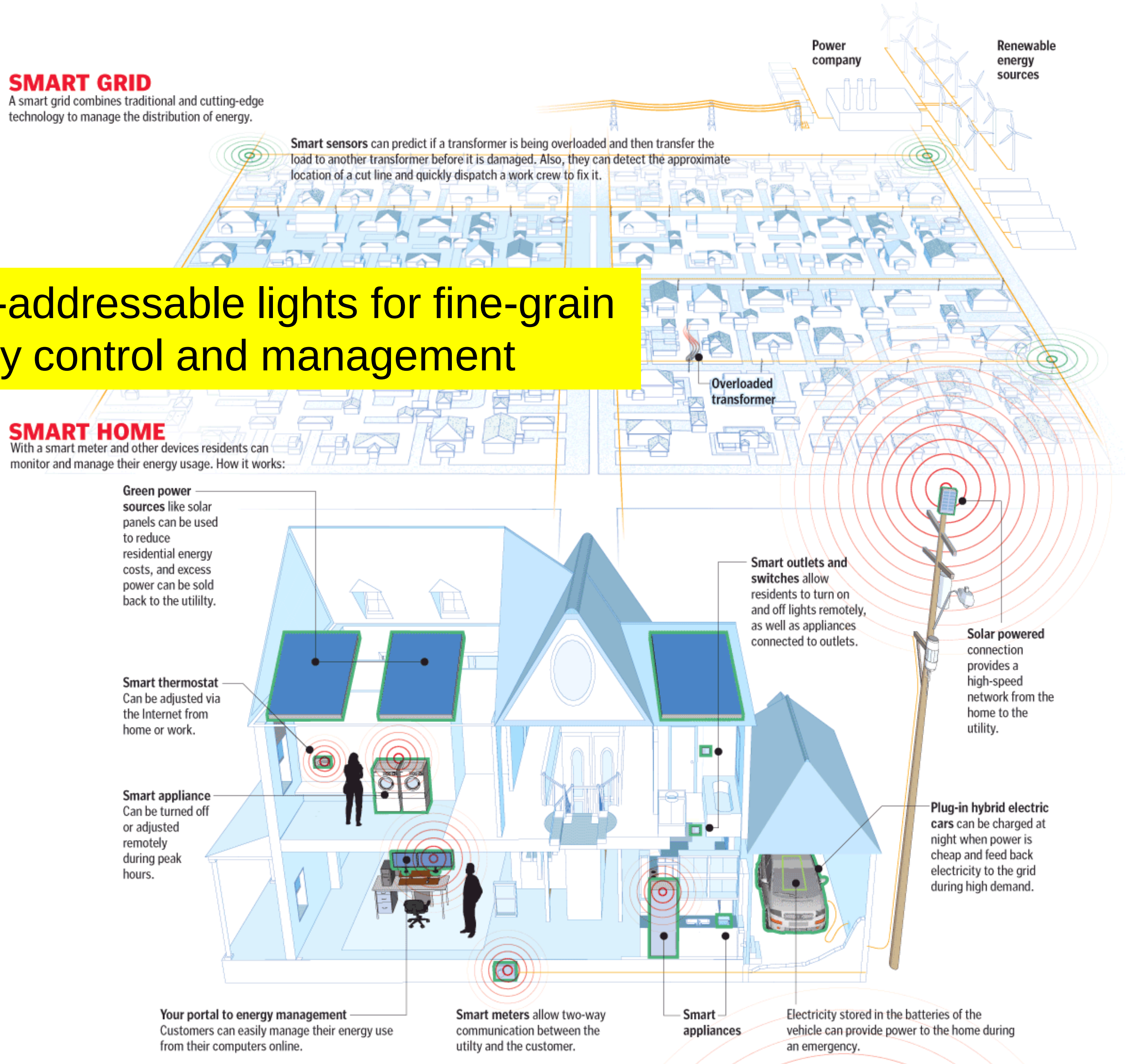
High Bandwidth Density Video Streaming

From Airbus

Providing ubiquitous network access where there is human-created light



Smart Grids



Individually-addressable lights for fine-grain energy control and management

Boston Globe, Feb 1, 2010

No.	Description	Enviro	Direction	Data Flow	Data Rate b/s	Distance	Intensity	Channel	Beam	Pointing	Topology	Control
1	Mobile to mobile	In/Out	bi		~100 M	1m to 10m	Single LED	LOS		Manual	pt-to-pt	Dist
2	Information Broadcast	In/Out	uni	Asym	10M—1G	3m to 10m	Strong	Primarily LOS		Manual/ Auto	pt-to-pt	Dist
3	RF Prohibited	In/Out					DL strong UL weak				pt-multipt	
4	Point to Multipoint	In										
5	Mobile to Fixed	In	bi	Sym	10M--100M	1m		LOS		Manual	pt-to-pt	Dist
6	Mobile to Infrastructure	In	bi/uni	Asym	UL: 10M DL: 10M– 100M	3m to 10m		LOS		Manual	pt-to-pt	Dist
7	Fixed to Infrastructure		bi/uni		10M	3m		LOS		Automatic	WLAN	Dist
8	Vehicle to Infrastructure	Out	bi	Asym	100k	100m?	Strong	LOS	Wide	Automatic	WPAN	Centr
9	Vehicle to Vehicle	Out	bi	Sym	100k	100m?	Strong	LOS	Wide	Automatic	WPAN	Dist
10	Mobile Display	In	bi	Asym	100M		weak	LOS			pt-to-pt	
11	Sign ITS	Out	bi	Asym	10M		Sign: strong Mobile: weak	LOS	Sign: wide Mobile: narrow	Manual	pt-to-pt	Dist
12	Illumination	In	bi	Asym	10M	10m	Lighting: Strong Mobile: weak	LOS/ NLOS	Light: Wide Moible: narrow			Centr
13	Navigation	In/Out	bi/uni		Uni: 10k Bi: DL: 10k—10M UL: 10M --100M						pt-to-pt	
14	Short Range High Speed	In	bi	Sym	10M	3m	Weak	LOS	Wide	Manual	pt-to-pt	Dist
15	Long Range Low Speed	Out	bi	Sym	1M	100m	Strong	LOS	Wide	Automatic	WPAN	?
16	Aircraft Intra-Cabin Communications	In	bi	Sym		100m	Strong	LOS	Wide		pt-to-pt	Centr
17	Underwater Communications	Out										
18	Image Sensor with LED Tags	In/Out	uni									
19	CE Device Control	In	bi/uni		10k	5m		LOS		Manual	pt-to-pt	Centr
20	E-content vending	In	bi	Asym	UL: 10k DL: 1G	0.5m				Manual	pt-to-pt	Centr
21	E-commerce	In	bi	Sym	10k	1m				Manual	pt-to-pt	Centr

Summary of 802.15 WPAN TG 7 Use Cases

What Are We Doing Today?

- Dual use paradigm – illuminate with LEDs and support communications
- **Project 1: "High Bandwidth Density"**
  - Bandwidth density is a unique characteristic of LOS sources that differentiates FSO from RF
  - Target bandwidth density (areal) of > 1Mb/s/m2 at 3m (ceiling to desktop)
- **Project 2: "Mobility"**
  - Existing work with optical devices including the LOS characteristic breaks the multiple access paradigm
  - Target mobility metric of 1m/s (walking) and handoff latency < 1s

Tying it together: Comms FIs

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Rensselaer Polytechnic Institute

Mona Hella

Tufts UNIVERSITY

Valencia Joyner

Rensselaer Polytechnic Institute

Partha Dutta

Rensselaer Polytechnic Institute

Rena Huang

BOSTON UNIVERSITY

Tarik Borogovac

BOSTON UNIVERSITY

Jeff Carruthers

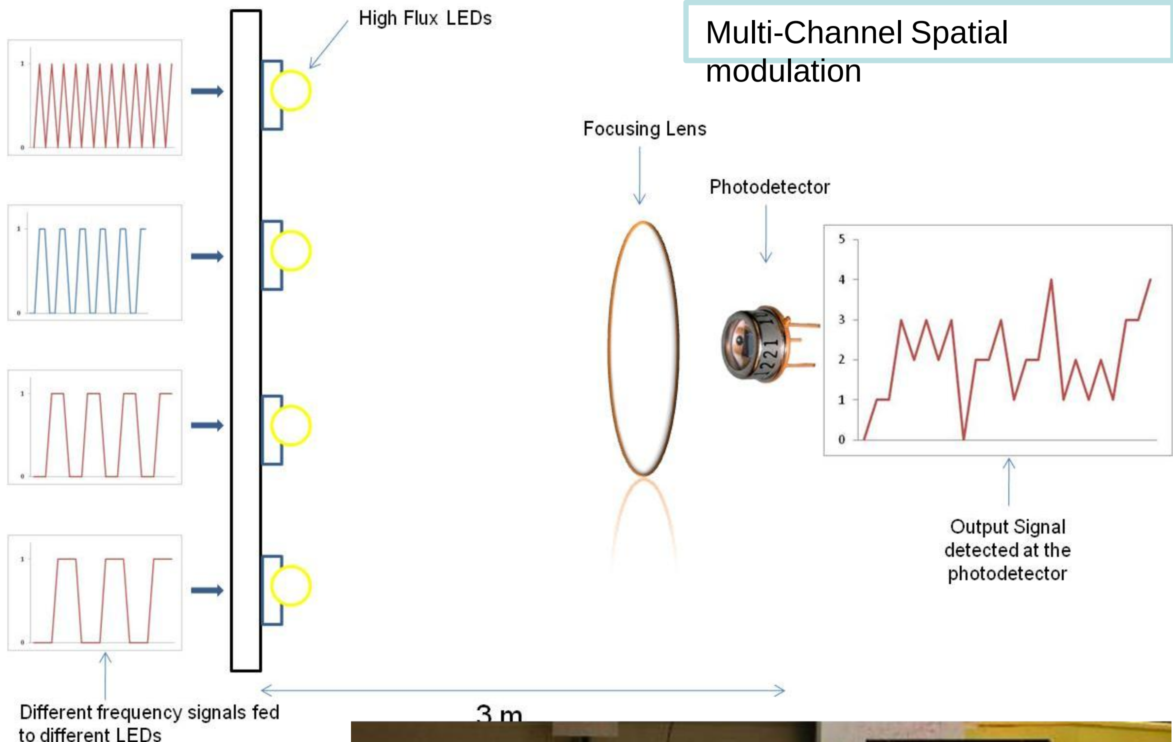
Rensselaer Polytechnic Institute

Leila Parsa

Partha Dutta: Modeling of free-space optics; focus on VLC network with scalable scalable **distance-bandwidth** and **bandwidth-density** products

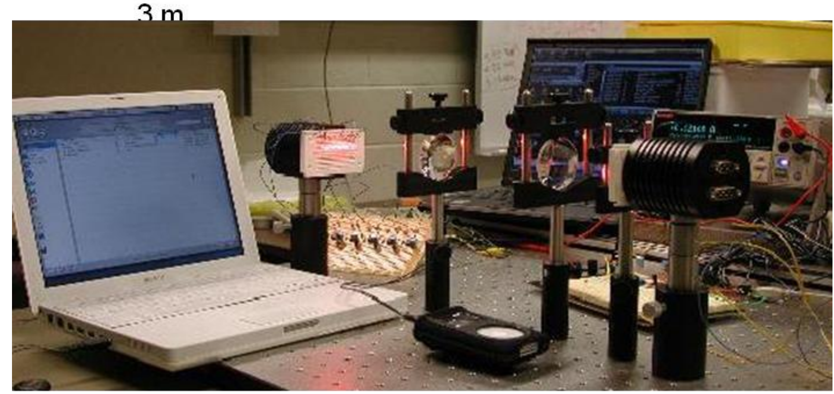
- Use of Multi-Channel Spatial modulation to increase the aggregate bandwidth of the Communication Channel.
- Non-LOS Communication using optics, and wide viewing angle LEDs
- Increase in range using Multi-Hop Systems.
- Investigation of new optical filtering techniques to tackle noise from white light sources.

Multi-Channel Spatial modulation



<u>5-Channel Optical Sound Mixer</u>

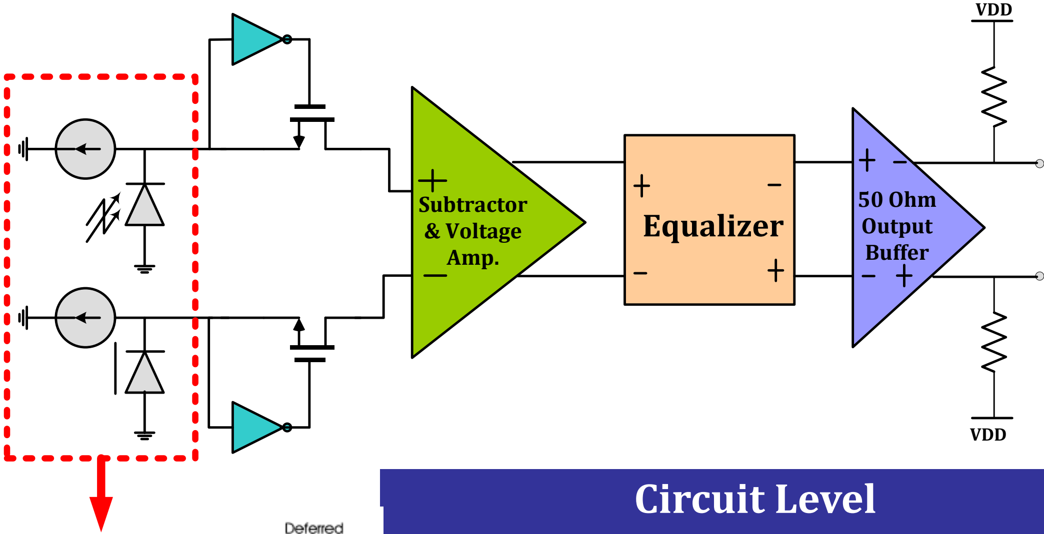
Graduate Student : Sruthi Muralidharan

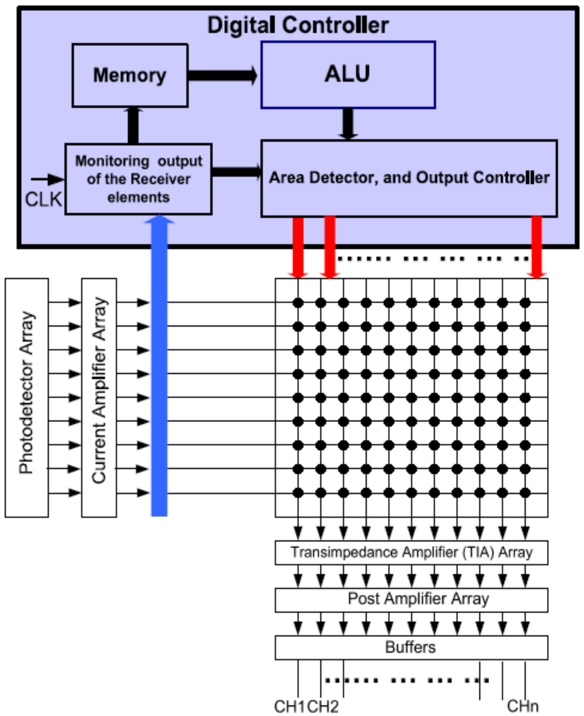


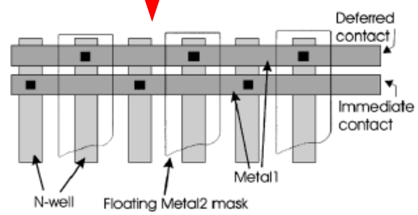
Implementation of a 5 Channel Optical Sound Mixer

Mona Hella: Multi-Channel FSO Receiver

Line of sight tracking in high data rate non-diffuse approaches → planar and 3D (spherical antenna) array of optical transceivers







Integrated Spatially modulated light detectors

Circuit Level

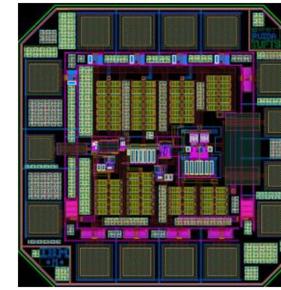
- Variable signal fading due to adverse weather conditions → wide dynamic range amplifiers
- Background noise specially in Visible Light Communication (VLC)
- Integration of high speed photo-detectors in main stream silicon technologies.
- Cross talk in adjacent PDs arrays in optical receivers
- Power consumption requirements→ limitation on array size.

Dual Scenario

Imaging Receiver → LOS tracking for mobile nodes

Multi-channel receiver → high data rate for static nodes/Multi-logic channels

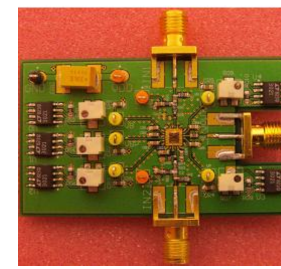
Dr. Valencia M. Joyner, Assistant Prof., Tufts University
Ali Mirvakili, Graduate Research Assistant

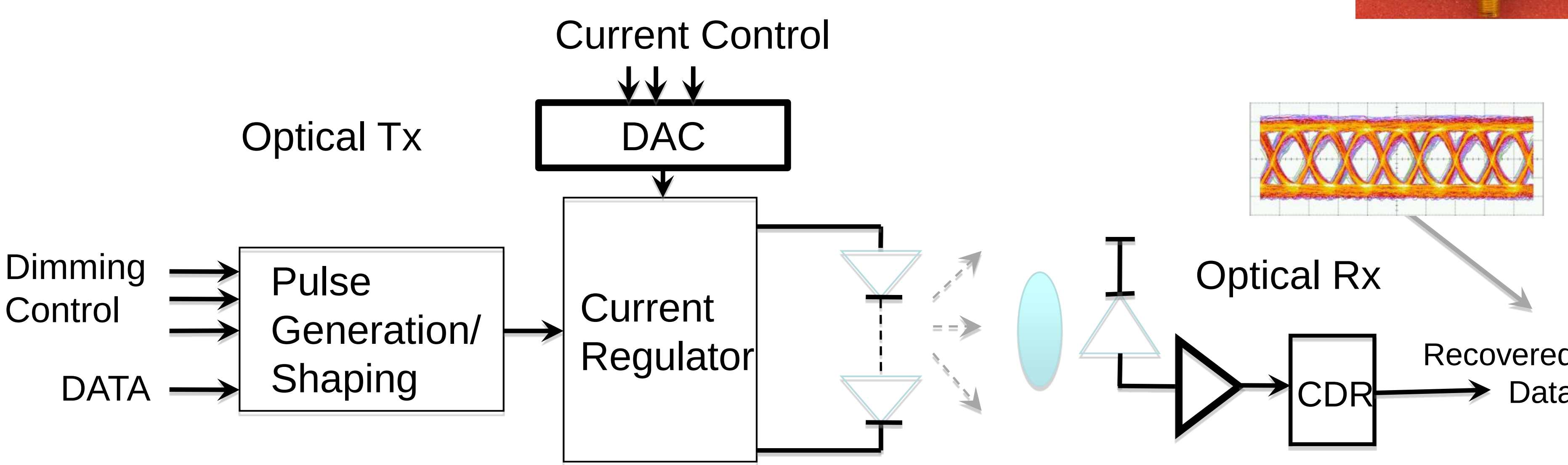


Research focus: Silicon-based Optoelectronic VLSI systems; Low-power, mixed-mode (RF, optical, analog, digital) IC design

Research Objectives:

- Single-wavelength LED transmitter board providing PWM dimming and 40 Mb/s data NRZ transmission (May)
- Optical transmitter/receiver demonstration operating at 40Mb/s (July)
- Simulation-based study of advanced signal processing circuitry to overcome inherent bandwidth limitations of LEDs





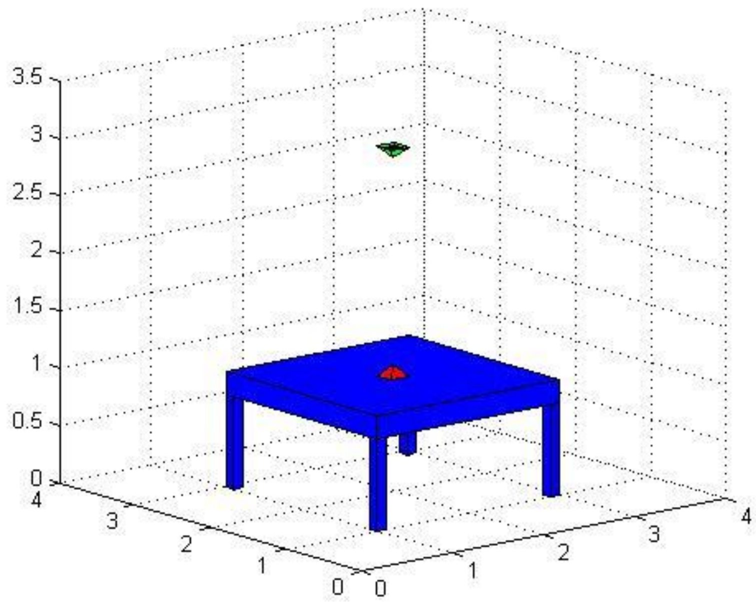
Rena Huang: RF/FSO synergies

- Dual-Mode RF and FSO communications
- Shared substrate/miniaturized packaging
- 2 x 2 split patch antenna at 30-40 GHz for RF
- Integration of bare-die LEDs
- Low power consumption

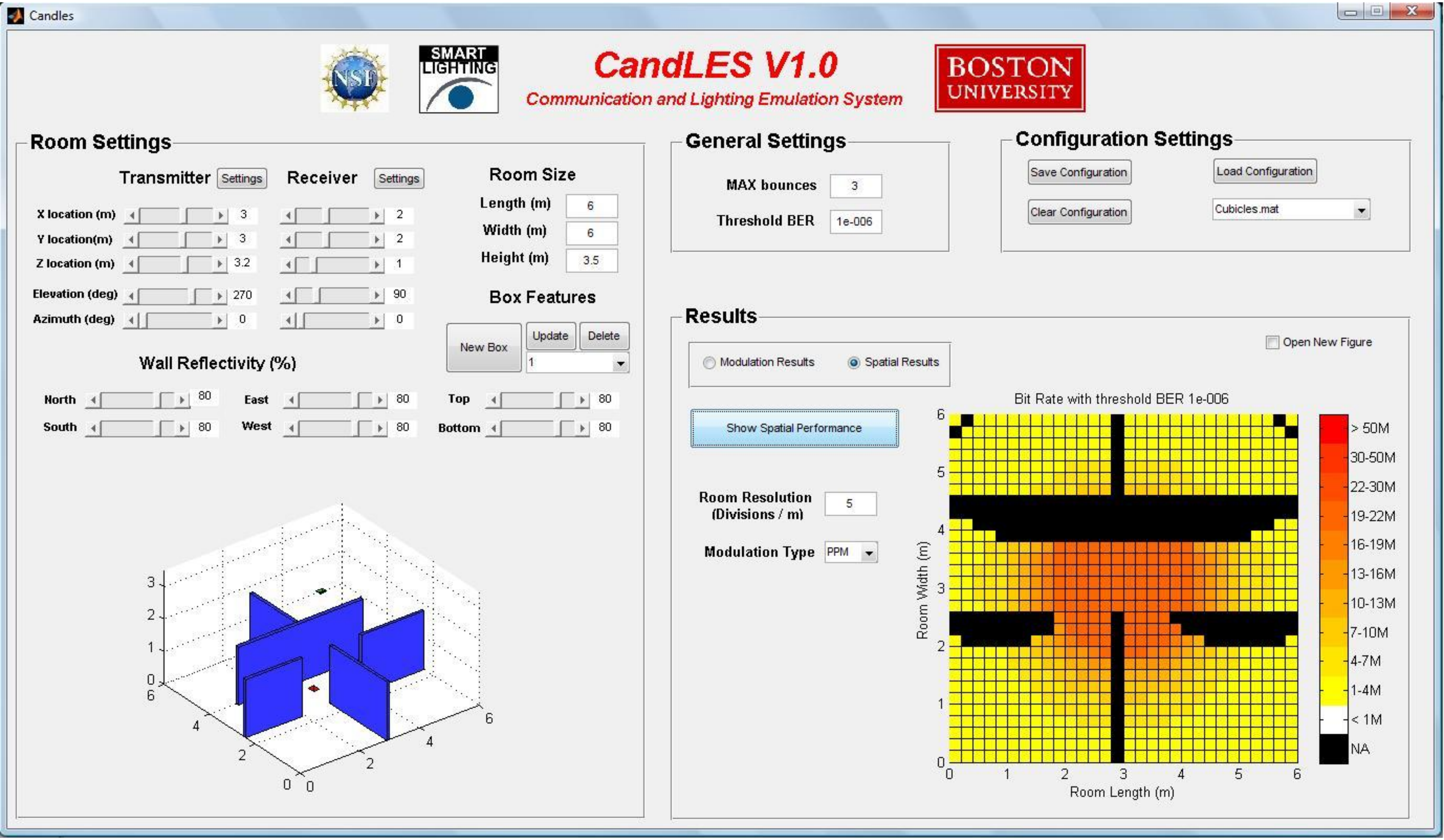
Harness best of both worlds

Tarik Borogovac: Bit Rate vs Location [Rahaim]

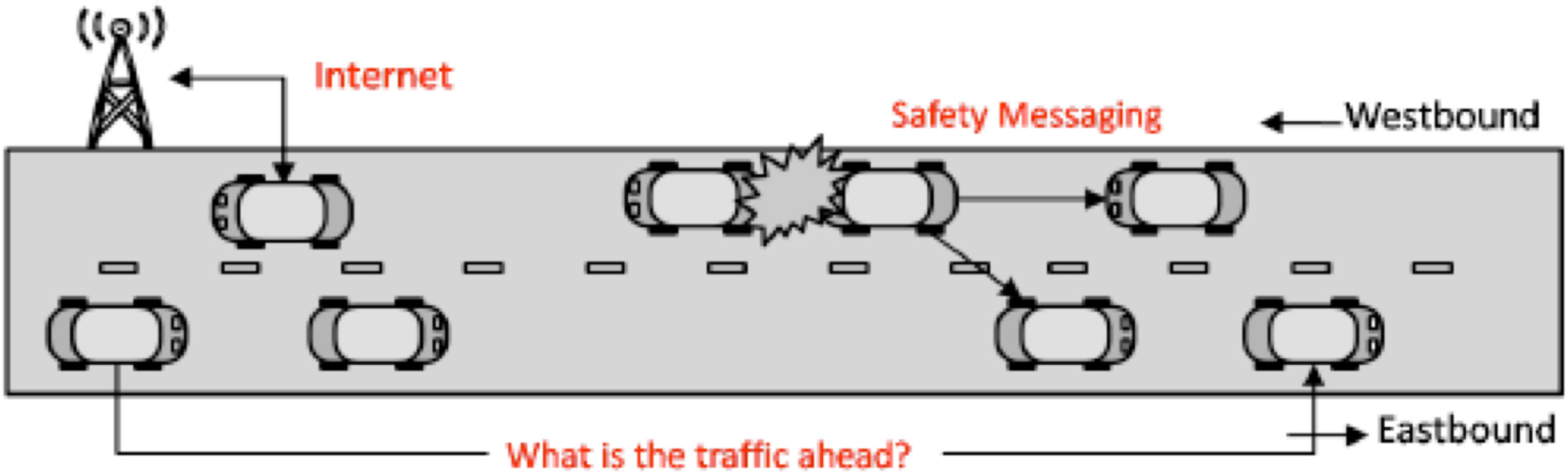
- Given a threshold BER, characterize available bit rates across a plane for a Smart Room
- Design/analysis tool using Matlab



Communication and Lighting Emulation System [Rahaim]

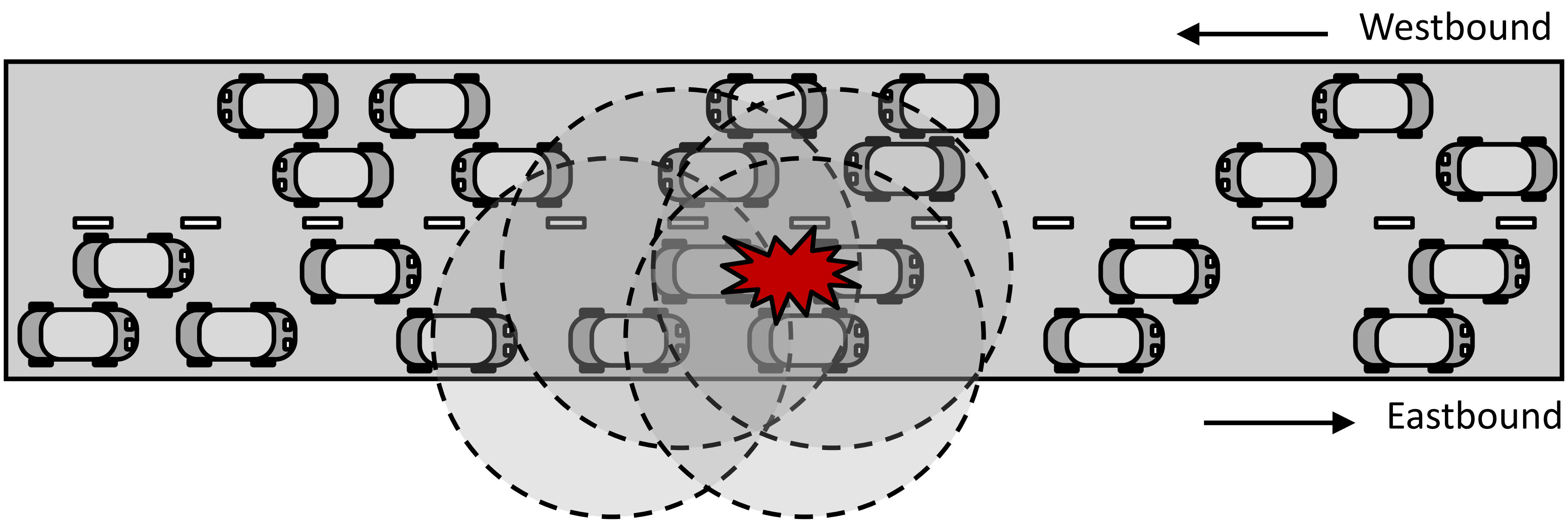


Optical Communications for Peer to Peer Vehicular Communications [Agarwal]



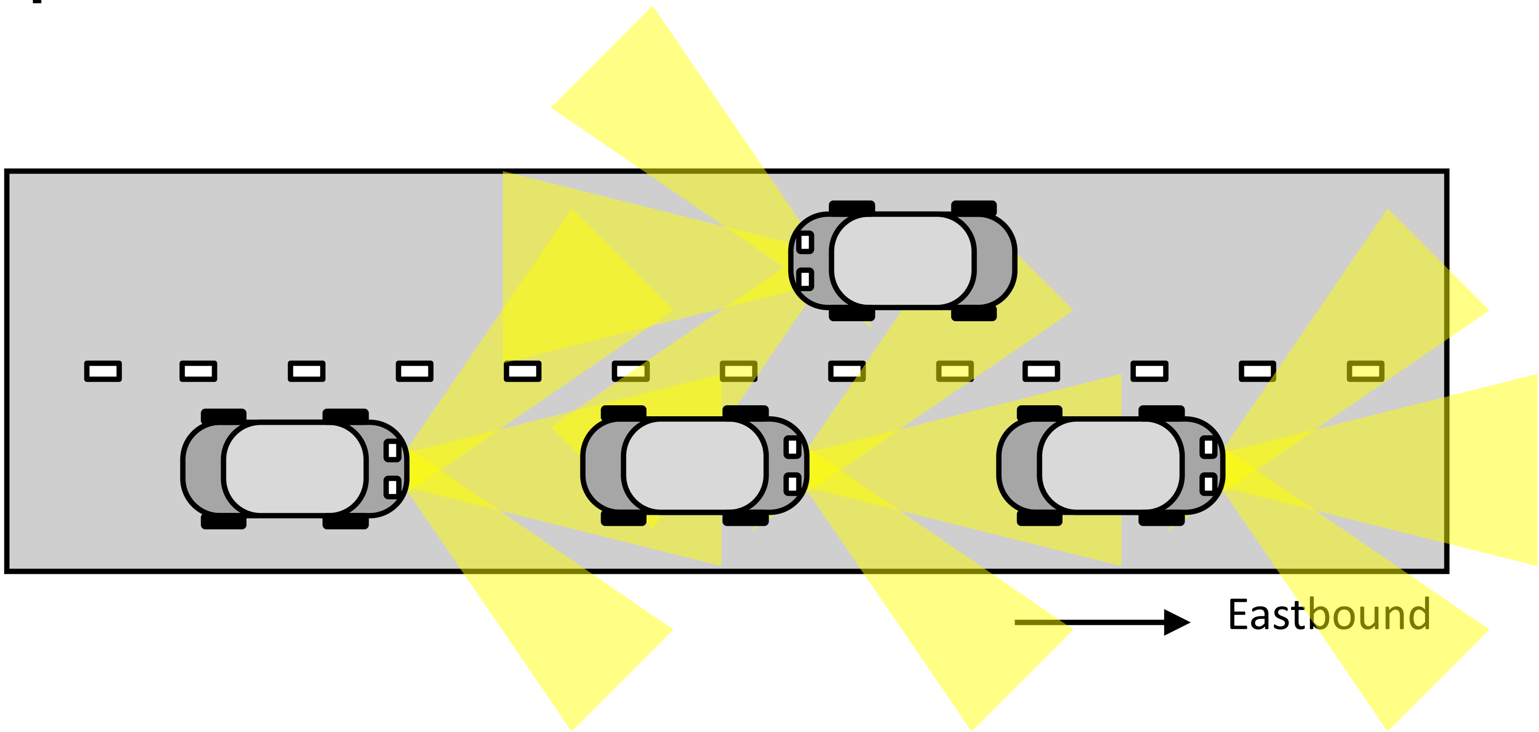
Safety applications, convenience

Broadcast Storm Problem with Omnidirectional Communications



Packet collisions due to state sharing and omnidirectional antennas

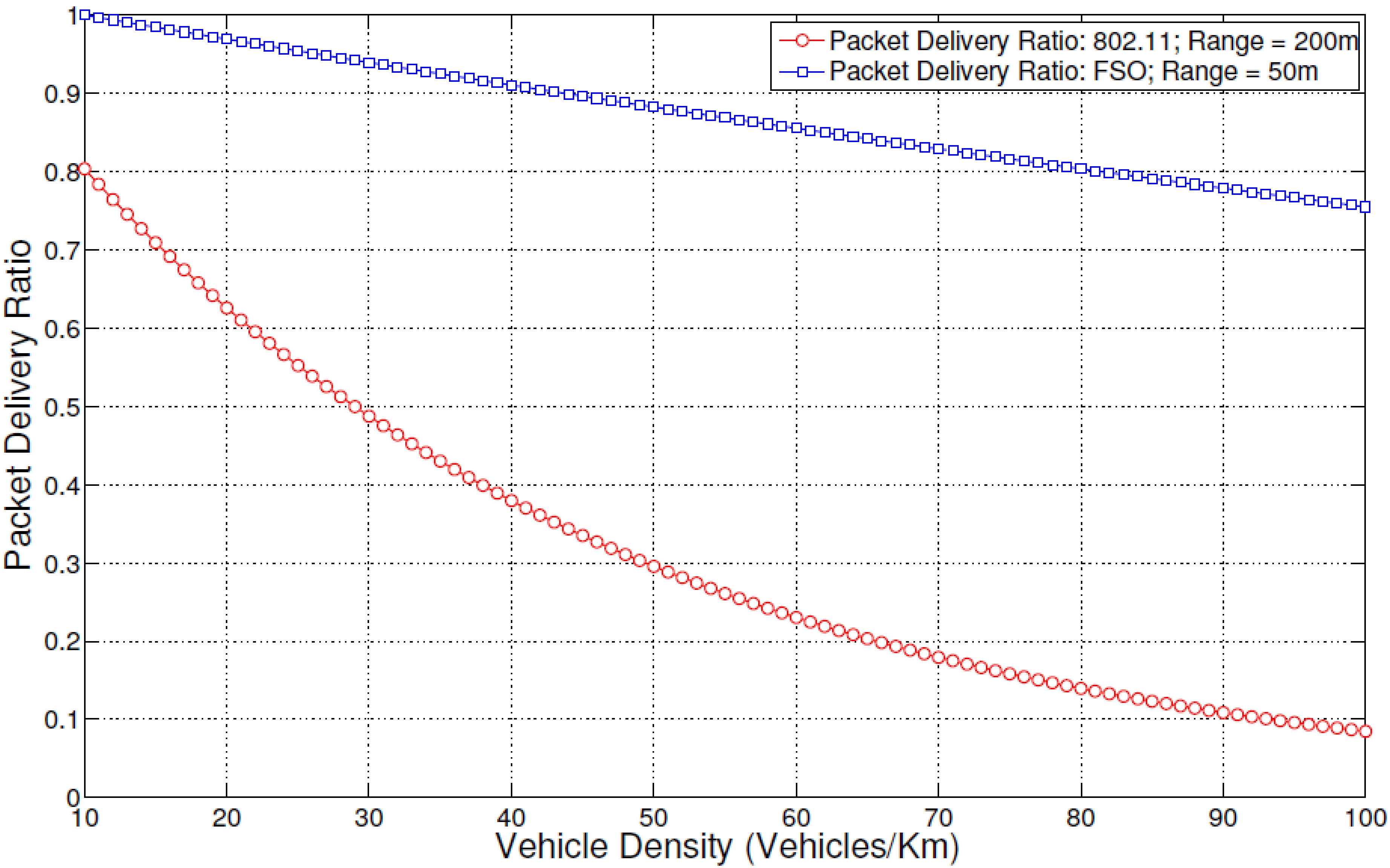
Mitigation with Directional Antennas/ Optical Communications [Agarwal]



Short range, directional, limited LOS: Optical!

Packet Delivery Ratio Vs Vehicular Traffic Density [Agarwal]

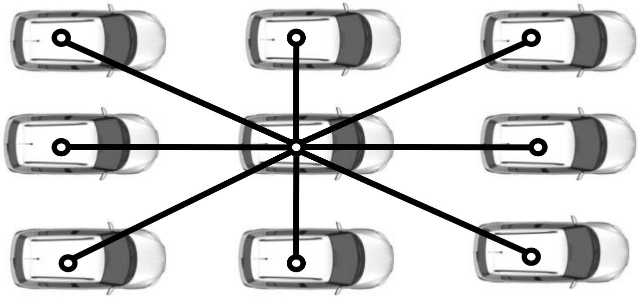
Increasing traffic density implies increasing number of nodes in the network, thereby increasing contention for the shared wireless channel. Thus, the packet delivery ratio, or ratio successful transmissions to total transmissions, decreases.



Exploring use of CMOS Imagers at Receiver

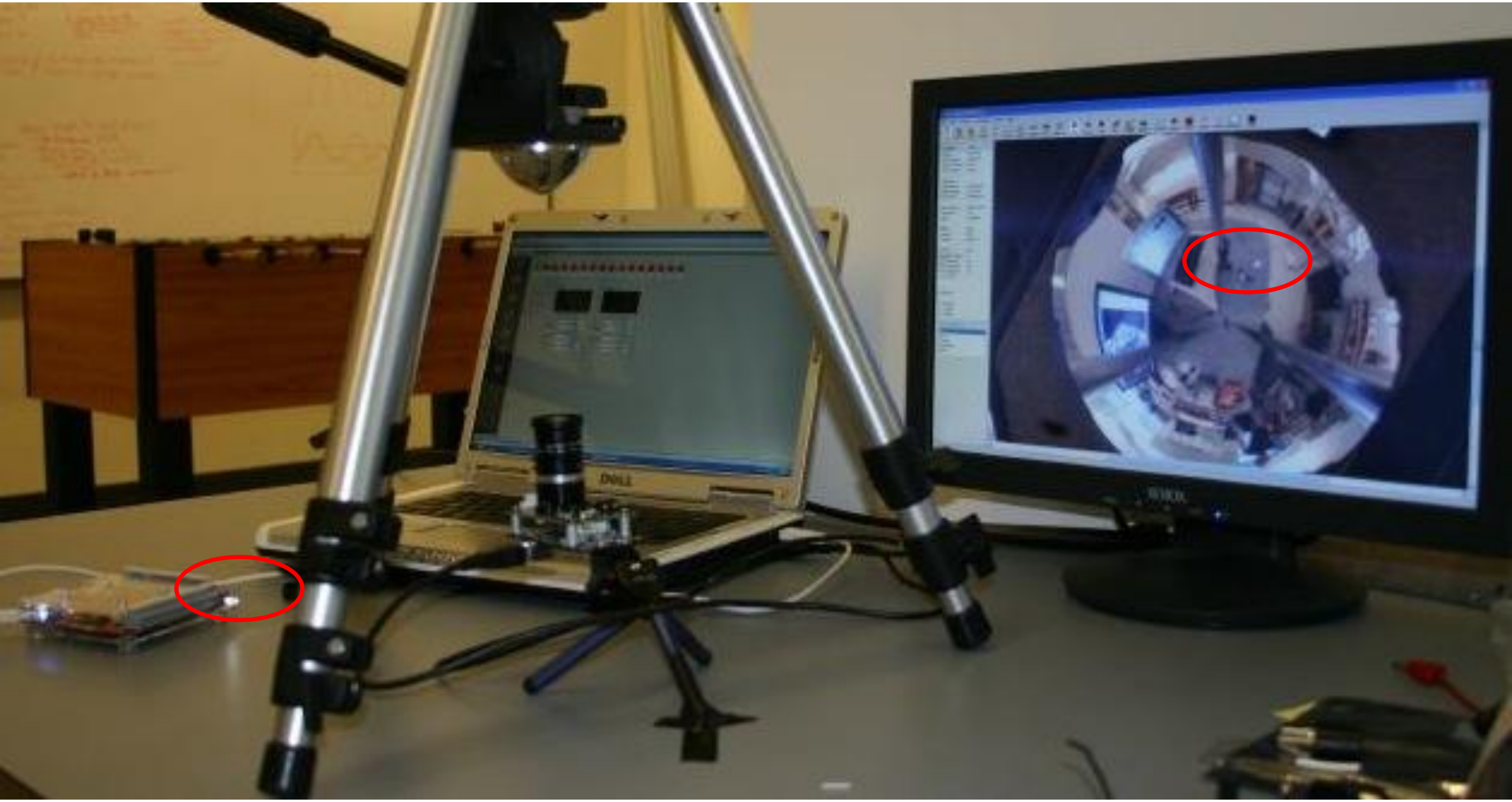
Omnidirectional Mirror

CMOS imager

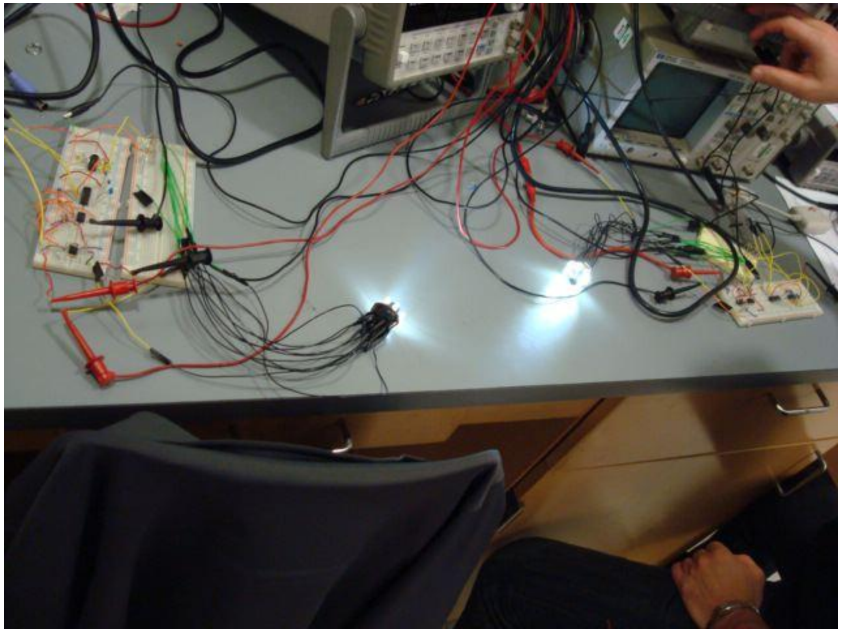


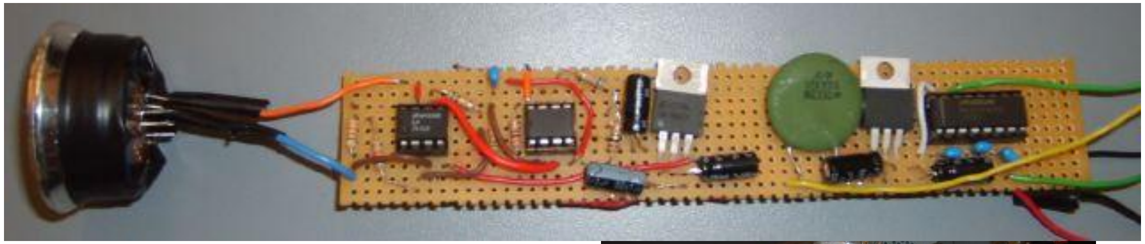
Use windowing capability of
Image array to isolate and
Track signal in 360 deg view

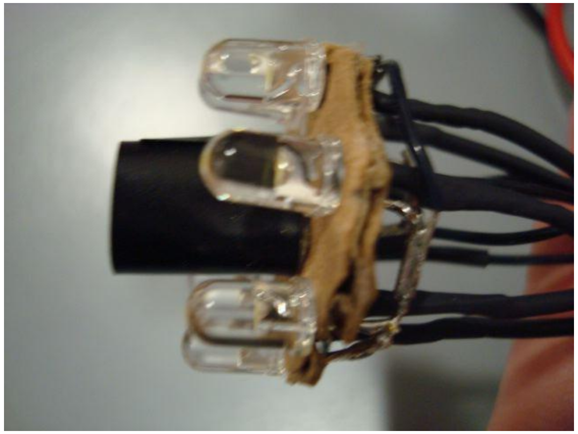
LED Tracked in 3 Dimensions



Prototype Indoor VLC Transceivers [Shah et al.]

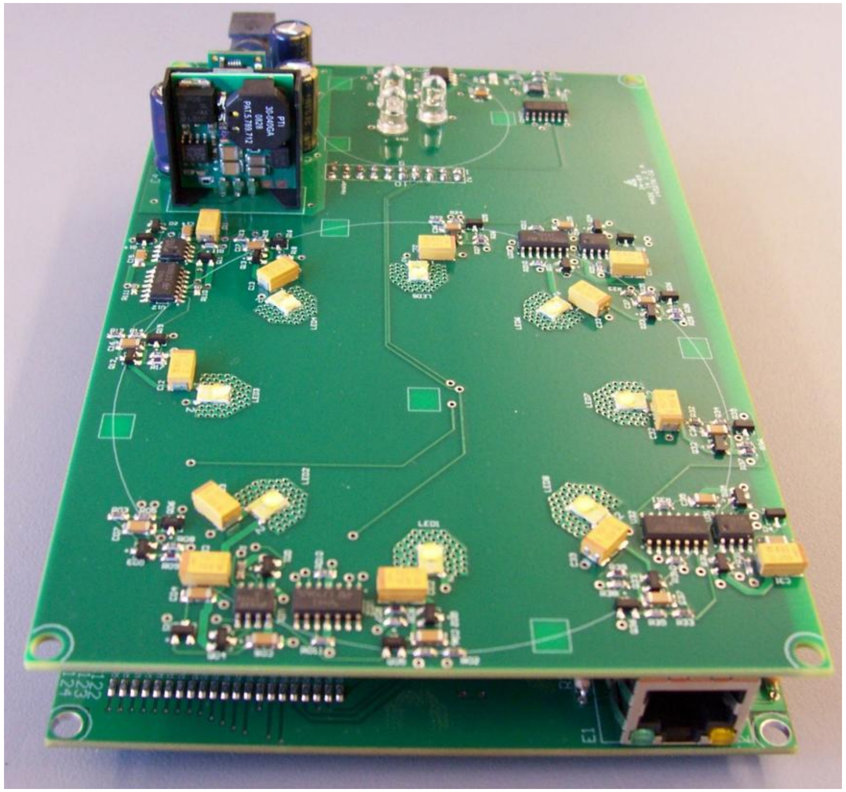




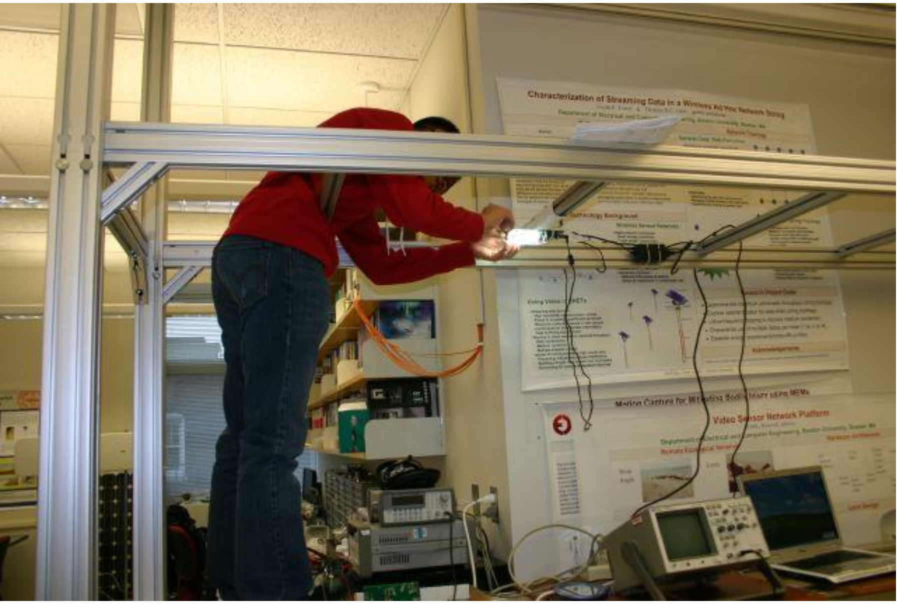


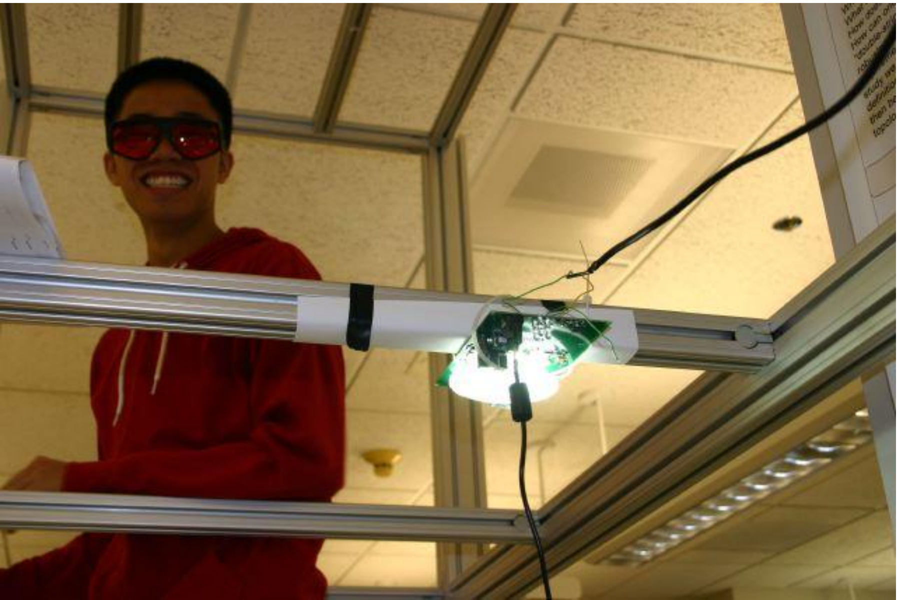
Two-Board TX/RX [Chau, Ryan, Shah, Rich, Nadeau, Brown]

- LEDs and LED driver circuit
  - Satisfy high current switching requirement
  - Power supply requirement
- Ethernet interface and protocol engine (FPGA)



Testbed and V.2 prototype





V.2 prototype in lighting cage

V.2 prototype with installed diffuser

Summary

- Smart Lighting: An opportunity to embed VLC
  - Many opportunities – niche and broad-based
  - Dual use: networking where there is illumination
  - Goal of networking with ‘net zero’ energy increase
  - Active community developing VLC
  - Unique opportunity to integrate novel materials and device packaging for increased performance in dual use
- But some challenges
  - With a Dual-Use ‘lighting’ model, need to balance different goals
  - We’re not developing in a vacuum: RF is the incumbent
  - Need participation by industry for adoption
- Check out the posters!

Smart Lighting Team at Boston Univ.