IEEE COMMUNICATIONS SOCIETY

Technical Committee on Transmission, Access, and Optical Systems (TAOS)

Authors: Steve Hranilovic, Walter Cerroni and Mauro Biagi

Date/Time: Wednesday, May 6th, 2022 (11:00am-12:00pm EST)

Meeting Location: Before ICC 2022 – Online meeting due to COVID-19 emergency

Officers: Steve Hranilovic, Chair, hranilovic@mcmaster.ca
Walter Cerroni, Vice-Chair, walter.cerroni@unibo.it
Mauro Biagi, Secretary. Mauro.biagi@uniroma1.it

Meeting agenda:

1. Welcome and introduction
2. Approval of the GC 2021 TAOS Meeting Minutes
3. Conferences and Activities update
4. Notice: Upcoming Election of TAOS Secretary
5. 2021 TAOS Awards
6. Business arising from Members
7. Guest speakers
8. Adjourn

The meeting was called to order at 11:00a.m.

Participants (23)

- Moshen Abedi, Aalto University, Finland
- Nicola Andriolli, National Reserach Council of Italy, Italy
- Imran Shafique Ansari, University of Glasgow, Scotland
- Tarek Bejaoui, University of Cartaghe, Tunisia
- Abdelmoula Bekkali, TOYO Electric Corp, Japan
- Chedila Ben Naila, Nagoya University, Japan
- Mauro Biagi, University of Rome "La Sapienza", Italy

- Dajana Cassioli, University of L'Aquila, Italy
- Walter Cerroni, University of Bologna, Italy
- Jitender Deogun, University of Nebraska, USA
- Charles Depins, Ecole de Technologie Superieure, Montreal, Canada
- Alexis Dowhuszko, Aalto University, Finland
- Jaafar Elmirghani, University of Leeds, UK
- Rosario Giuseppe Garroppo, University of Pisa, Italy
- Fabrizio Granelli, University of Trento, Italy
- Nitin Gupta, National Institute of Technology, Hamirput, India
- Steve Hranilovic, McMaster University, Canada
- Ahmed Kamal, Iowa State University, USA
- Symeon Papavassiliou, National Technical University of Athens, Greece
- Roberto Rojas-Cessa, New Jersey Institute of Technology, USA
- Daniel So, University of Manchester, UK
- Eirini Eleni Tsiropoulou, University of New Mexico, USA
- Murat Yuksel, University of Central Florida, USA

1. Introduction

The meeting was held online due to the COVID-19 emergency that caused all IEEE events, including ICC 2022, to run on a teleconferencing platform. The Chair, Steve Hranilovic, welcomed all connected participants and presented the meeting agenda. A motion was made to approve the meeting agenda. Then the attendees briefly introduced themselves (see participant list above). The attached slides were presented by the Chair and discussed item-by-item.

2. Approval of the ICC 2022 TAOS Meeting Minutes

A motion was made by S. Hranilovic to approve the minutes of the previous meeting held online before ICC 2022. The draft of the minutes was previously made available on the TAOS website (http://taos.committees.comsoc.org/meetings) and distributed to the TAOS members through the mailing list. The motion was seconded by A. Kamal and the minutes were approved unanimously without further remarks.

3. Conference and activities update

The Chair recalls TAOS main activities involving symposia sponsorship and organization (ONS and GCSN ICC and Globecom). Furthermore, the Chair comments the recent results in terms of submission and acceptance of ONS and GCSN by noticing the reduction of the interest. After some rebounds the trend is still to have less number of submissions as well as the consequently number of accepted papers.

The Chair reported TAOS Co-Chair nominations for the following upcoming events:

- IEEE ICC 2022 (Seoul)
  - ONS: Steve Hranilovic (McMaster University, Canada)
  - GCSN: Fabrizio Granelli (University of Trento, Italy)
- IEEE Globecom 2022 (Rio de Janeiro)
  - ONS: Anas Chaaban (U. British Columbia, Canada)
  - GCSN: Eirini Eleni Tsiropoulou (U. New Mexico, USA)
- IEEE ICC 2023
  - ONS: Murat Yuksel (Univerity of Central Florida, USA)
  - GCNS : Taisir Elgorashi (University of Leeds, UK)
- IEEE Globecom2023
  - ONS: Nicola Andriolli (National Research Council of Italy, Italy)
  - GCNS : Emad Alsousa (University of Manchester, UK)

IEEE ICC2024
Nominations Pending

A discussion about call for papers with the goal of being broad in the topic and attract more submissions took place.
The Chair reminded that TAOS supports sponsorship of conferences that are related to the activities of TAOS-TC and indicated the conditions to obtain the sponsorship. Moreover, the Chair reminded also other kind of sponsorship that TAOS-TC can support, ranging from IEEE grade elevation to distinguished lecturer programs.

4. Notice: Upcoming Election of TAOS Secretary

The Chair informs the attendants that all the officers are approaching the end of the 2-year terms. The vice-chair will move to the position of chair and the secretary will move toward vice-chair position. Hence new election will take place for secretary position. Motivated people are encouraged to submit their candidature. The candidate must be a comsoc member and a member in good position with a good CV. Voting members are active members (who participated in at least 2 out of last 5 meetings).

5. 2021 TAOS awards

The TAOS Award sub-committee received nominations for “Outstanding Service Award” and “Best symposium paper award 2021” for ICC/Globecom symposia chaired by TAOS representative.

The Outstanding service award is delivered to Frabrizio Granelli, University of Trento, Italy

The TAOS-TC Best paper award 2021 goes to Mohsen Abedi, Alexis Dowhuszko, and Risto Wichman, authors of the paper entitled "*Visible Light Communications: A Novel Indoor Network Planning Approach"* presented at Globecom 2021, ONS.

6. Business arising from Members

Jaafar Elmirghani and Charles Despins presented the IEEE Sustainable ICT Initiative

7. Guest-speakers

Murat Yuksel, University of Central Florida, presented his contributions describing the current research. The talk is entitled "*Multi-Element Optical Wireless Modules for Mobile Networking and Lighting".*

8. Adjurn

The meeting was adjourned at 12:10pm.

Attachments: 1. Meeting Slides, 2. Talk slides

Transmission, Access and Optical Systems TC

Virtual Meeting for ICC 2022– May 6, 2022

Steve Hranilovic (Chair)

IEEE ComSoc™ IEEE Communications Society

IEEE Advancing Technology for Humanity

Attendance

- Please register your attendance at this meeting!
  - Link posted in chat

https://docs.google.com/forms/d/e/1FAIpQLSf8mVv_UREd20YiT4yX5G5aMqRhgXYNPNXF5PBUzZlOrf8YXw/viewform?usp=sf_link

Agenda

- Welcome and Introductions
- Approval of the Globecom 2021 TAOS Meeting Minutes (available online)
- Conferences and Activities update
- Notice: Upcoming Election of TAOS Secretary
- 2021 TAOS Awards
- Business Arising from Members
- Guest Speaker
- Adjourn

TAOS Officers for 2021-2022

As as January 2021

- Steve Hranilovic (Chair)
- Walter Cerroni (Vice-Chair)
- Mauro Biagi (Secretary)

Minutes approval

Meeting at IEEE Globecom 2021 November 17, 2021

- Available on the website: http://taos.committees.comsoc.org/meetings/

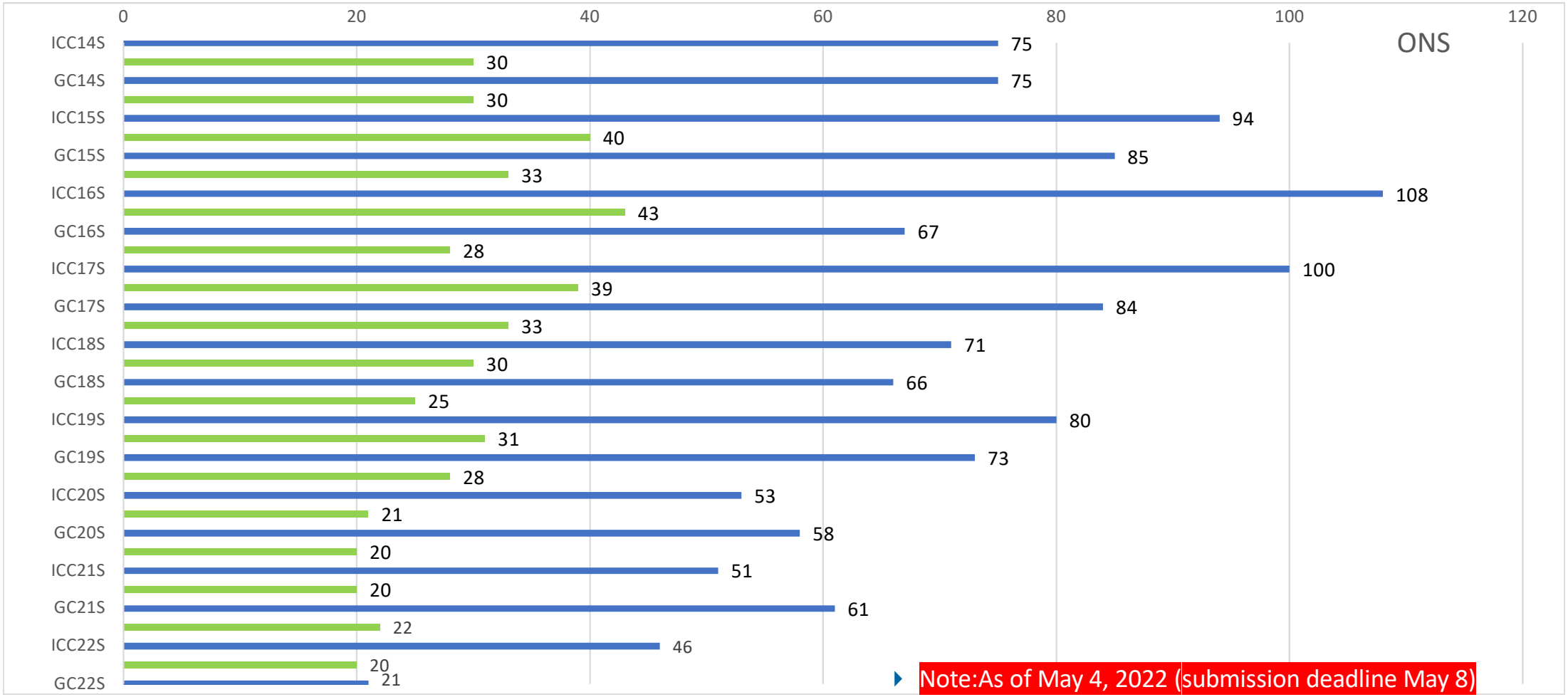
Update

Sponsored Symposia

- TAOS TC has consistently sponsored two symposia:
  - Symposium on *Optical Networks and Systems* (ONS)
  - Symposium on *Green Communications Systems and Networks* (GCSN)
- Moreover, TAOS TC technically endorses several other technical events
  - Co-located w/ ICC and GC, or many stand-alone
- ***Action:*** Our TC needs to coordinate with Symposium TPC Co-Chairs and update the topics to keep tracking hot-topics. e.g,
  - Writing of CfP
  - TPC nominations
  - New ideas!

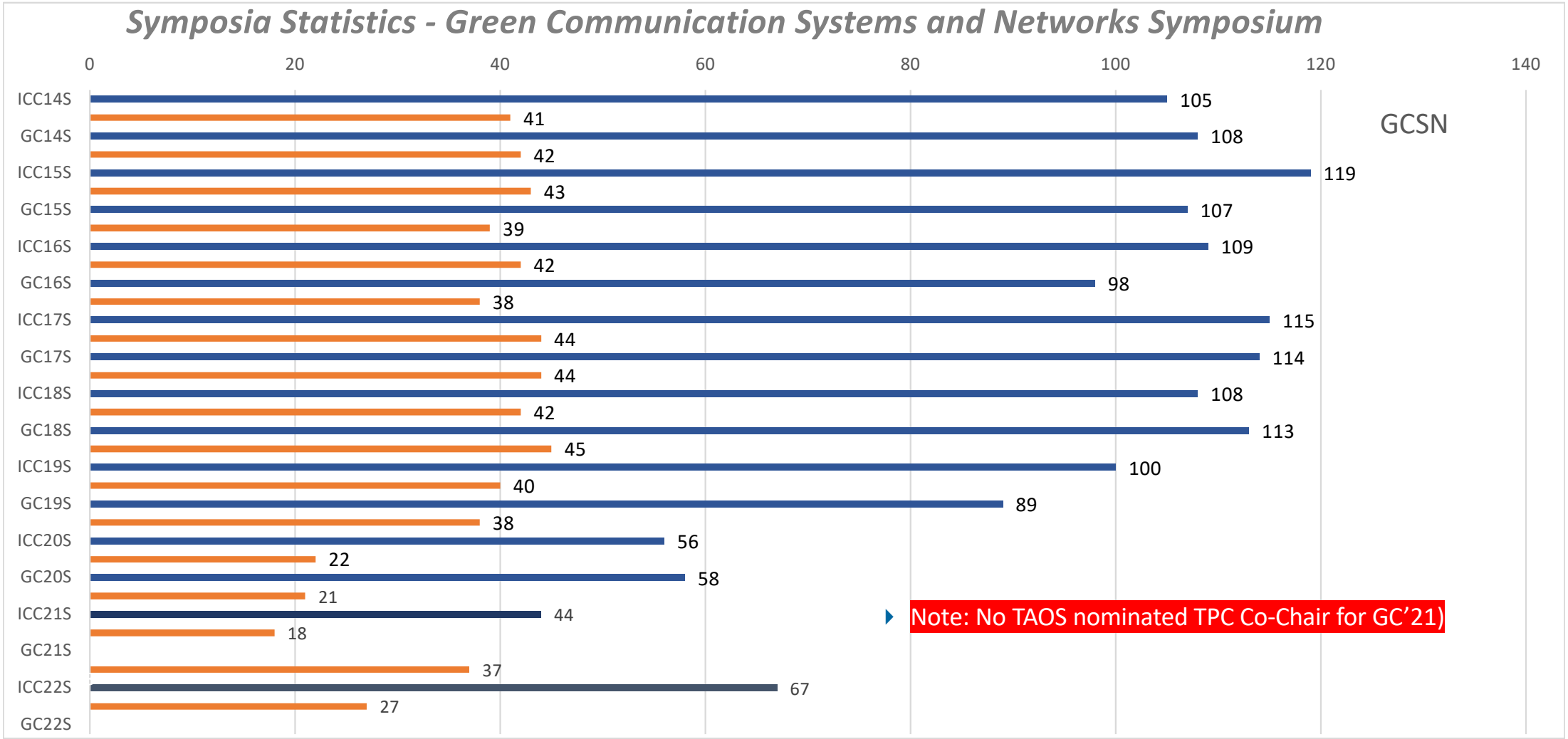
Highlights and Trends

Symposia Statistics - Optical Networks and Systems Symposium



Note:As of May 4, 2022 (submission deadline May 8)

Highlights and Trends



Conferences and Activities Update

Current & Upcoming Events

- IEEE Globecom 2021 (Madrid)
  - GCSN: *** no TAOS representative ***
  - ONS: Mauro Biagi (University of Rome Sapienza, Italy) and Jaafar Elmirghani (University of Leeds, U.K.)

- IEEE ICC 2022 (Seoul)
  - ONS: Steve Hranilovic (McMaster University, Canada)
  - GCSN: Fabrizio Granelli (University of Trento, Italy)

- IEEE Globecom 2022 (Rio de Janeiro)
  - GCSN: Eirini Eleni Tsiropoulou (U. New Mexico, USA)
  - ONS: Anas Chaaban (U. British Columbia, Canada)

Conferences and Activities Update

Upcoming Events

- IEEE ICC 2023 (Rome)
  - GCSN: Taisir Elgorashi (U. Leeds)
  - ONS: Murat Yuksel (U. Central Florida)

- IEEE Globecom 2023 (Kuala Lumpur)
  - GCSN: Emad Alsusa (U. Manchester)
  - ONS: Nicola Andriolli (National Research Council of Italy (CNR))

- IEEE ICC 2024 (Denver)
  - Nominations Pending

Notice: Upcoming Election of TAOS Secretary

- The term of the current slate of officers ends on December 31, 2022
- Per TAOS Policies and Procedures
  - On completion of the term, the TAOS Chair retires, the Vice-Chair steps up to the position of the Chair, the Secretary steps up to Vice-Chair and a new Secretary is elected.
  - TC officers (Chair, Vice-Chair, and Secretary) are elected for two-year terms.
  - Candidates for these positions are ComSoc members nominated by the TAOS steering committee.
- Call for candidates will be opened in early June 2022 and close end of September 2022
  - Active members are encouraged to put their names forward via email to Secretary (Mauro Biagi)
- Voting will be done electronically in October. Results made public November 2022.
- Voting is restricted to **Active TAOS Members**
  - Individuals that have attended (physically or virtually) two or more of the prior five regularly scheduled TC meetings.

2021 TAOS Awards

- Nominations received
  - Outstanding Service Award
  - Best symposium paper award for 2021 ICC/Globecom symposia chaired by a TAOS representative

- Selection made by the TAOS Awards Sub-committee
  - Walter Cerroni (University of Bologna, Italy) - Sub-committee Chair
  - Abdelmoula Bekkali (TOYO Electric Corporation, Japan)
  - Melike Erol-Kantarci (University of Ottawa, Canada)
  - Ahmed Kamal (Iowa State University, USA)
  - Daniel K. C. So (University of Manchester, UK)

2021 IEEE TAOS TC Outstanding Service Award

Fabrizio Granelli

2021 IEEE TAOS TC Best Paper Award

Presented at IEEE Globecom 2021 Optical Networks and Systems Symposium

Visible Light Communications: A Novel Indoor Network Planning Approach

- Authors: Mohsen Abedi, Alexis Dowhuszko, and Risto Wichman
- *The paper builds on solid theoretical foundations, which are very clearly explained and applied to a new application scenario related to indoor VLC coverage planning. The problem investigated has relevant practical applications and the proposed approach shows promising results.*
- *Link to the paper on IEEE Xplore: https://ieeexplore.ieee.org/document/9685571*

Business Arising

Input from TAOS TC Members

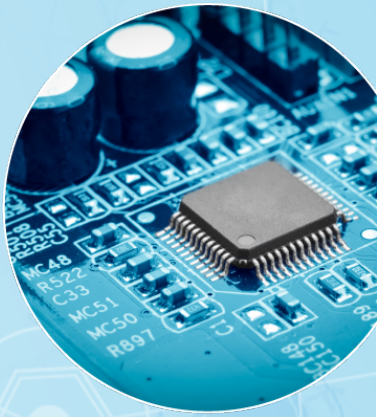
- IEEE Sustainable ICT Initiative
  - Jaafar M.H. Elmirghani, Charles Despins

- Feel free to follow up with any questions/comments at any time via email to officers

Guest Speaker

- Murat Yuksel
  - University of Central Florida

- Title: ***Multi-Element Optical Wireless Modules for Mobile Networking and Lighting***



Transmission, Access and Optical Systems TC

Thank you and see you at Globecom 2022!

- ***Please register your attendance at this meeting! (Link posted in chat)***

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Multi-Element Optical Wireless Modules for Mobile Networking and Lighting

Murat Yuksel

murat.yuksel@ucf.edu

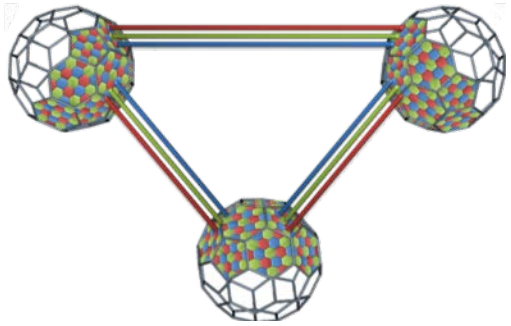
Networking and Wireless Systems Lab (NWSL)

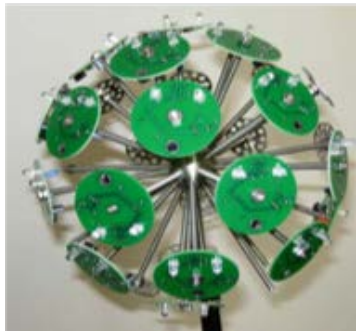
Electrical & Computer Engineering

Computer Science

College of Optics and Photonics (CREOL)

University of Central Florida, Orlando, FL 32816, USA





NWSL

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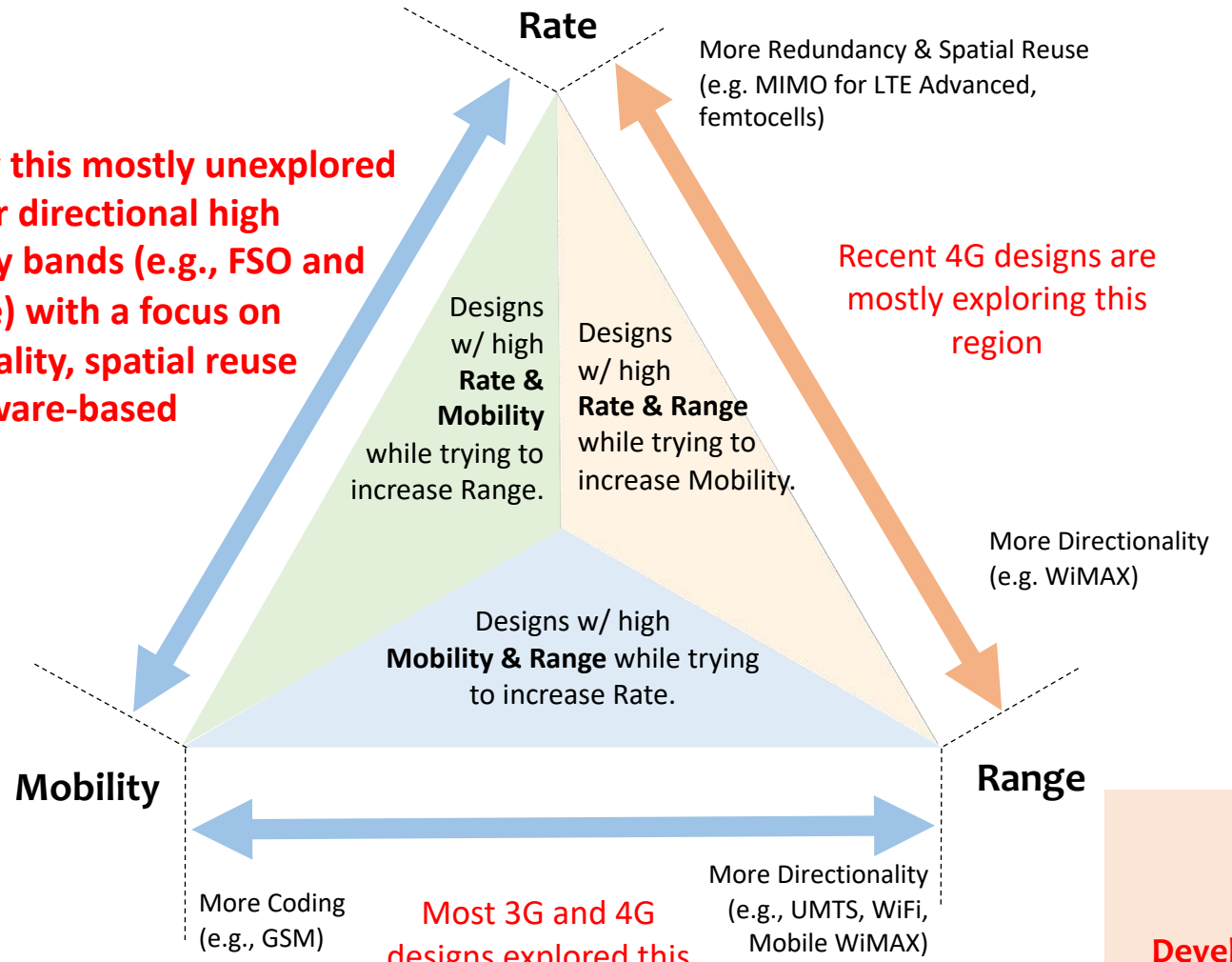
Collaborators and Sponsors

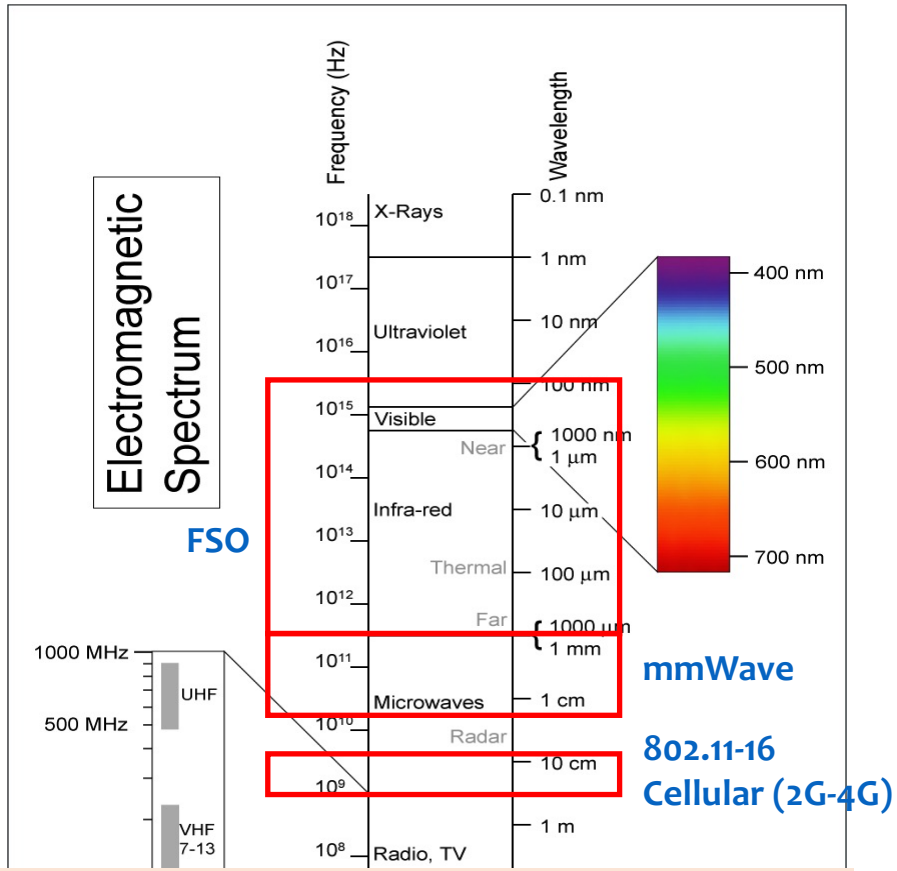
- Recent collaborators

- Sponsors

Wireless Spectrum Tradeoffs: Rate/Mobility/Range

We study this mostly unexplored region for directional high frequency bands (e.g., FSO and mmWave) with a focus on directionality, spatial reuse and software-based control.





KEY INSIGHT

Give up on range goals, focus on *rate* instead!

HOW?

Develop low-cost multi-element designs for opportunistic (ad-hoc) use.

***Handle mobility at higher layers* with limited support from PHY/MAC.**

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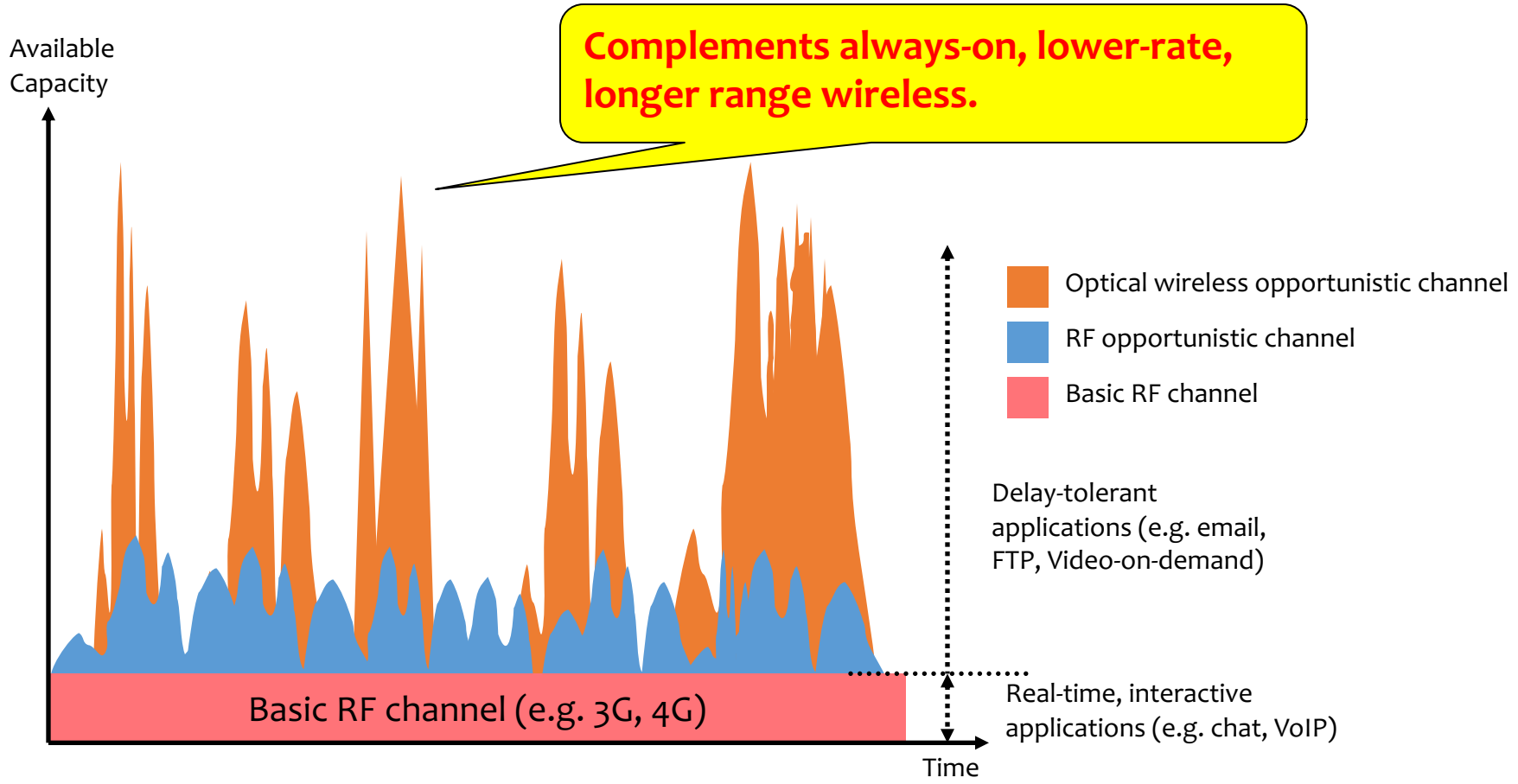
Opportunistic FSO (Optical Wireless) Channel

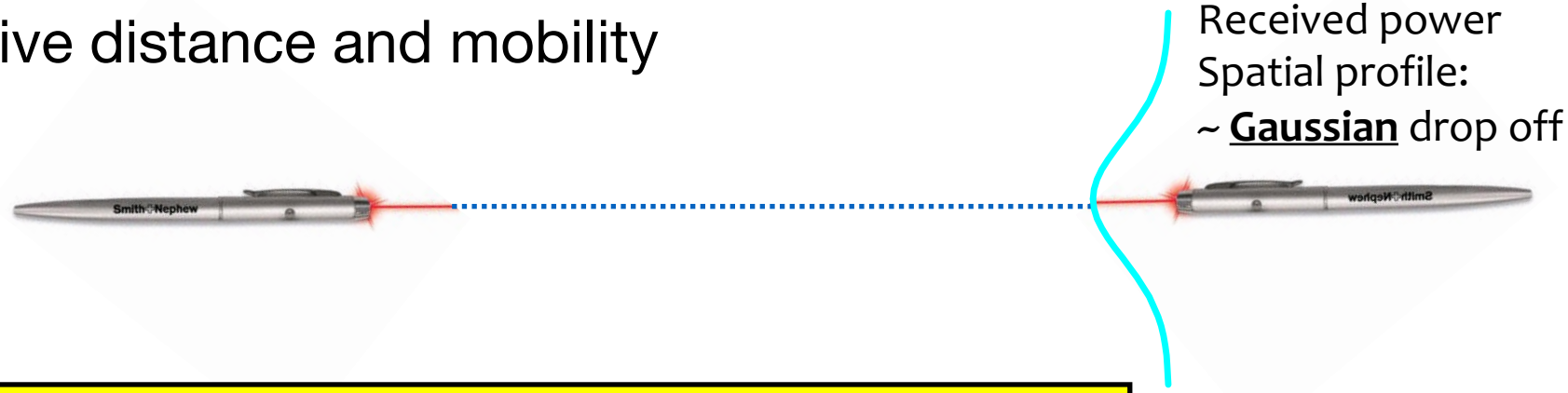


Optical Wireless: Why?

- **More secure:** Highly directional => low probability of interception
- **Small size and weight:** Dense packaging is possible
- **Very low cost** and **reliable** components
  - <60 cents a piece and <$5 per LED transceiver package + up to 10 years lifetime
- **Very low power** consumption (100 microwatts for 10-100 Mbps!)
  - Even lower power for 1-10 Mbps
  - 4-5 orders of magnitude improvement over RF
- Huge **spatial reuse** => multiple parallel channels for high bandwidth

FSO Issues/Disadvantages

- Limited range (no waveguide, unlike fiber optics)
- Need line-of-sight (LOS)
  - Any obstruction or poor weather (fog, heavy rain/snow) can increase BER in a bursty manner
- **Bigger issue:** Need tight LOS alignment:
  - LOS alignment must be maintained with mobility or sway!
  - Effects of relative distance and mobility



Can we reap FSO's benefits while solving these issues?

(Multi-element) FSO Modules

How to handle LOS alignment under mobility?

Software-Defined FSO Modules: Spherical Designs

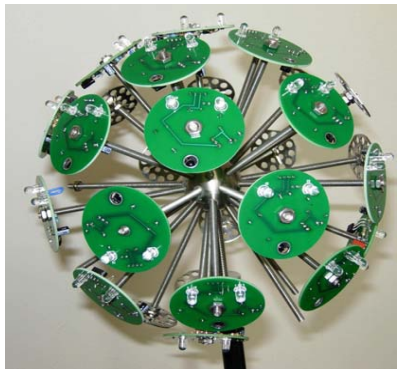
- How to handle mobility under LOS alignment requirement?

Software-Defined Mobile FSO =

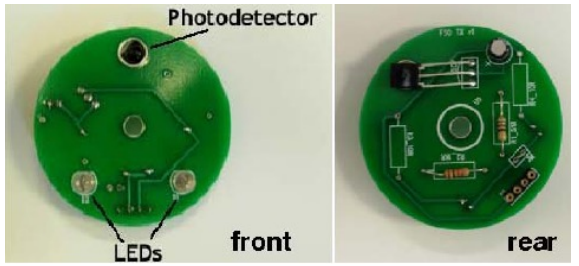
Directionality + Angular Diversity + **Electronic Steering**

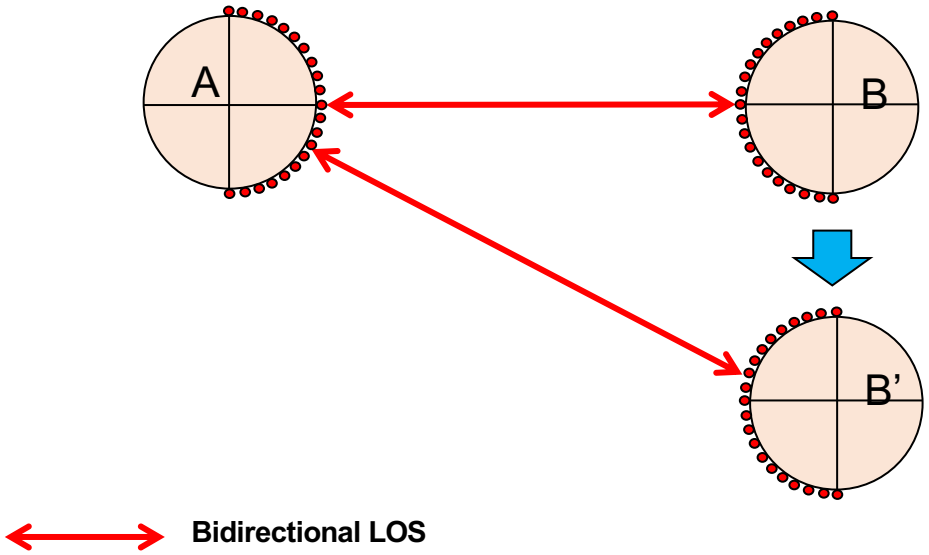
Multi-transceiver spherical FSO designs.

Need a distributed protocol for this!



Spherical Modules Tessellated w/ Many FSO Transceivers





- Multi-element spherical modules
- Angular diversity due to spherical packaging
- Designs conformal to surfaces
- Electronic steering of LOS alignment across many redundant FSO transceiver elements

Ad Hoc Networks 2013, 2014
IEEE ICC 2010

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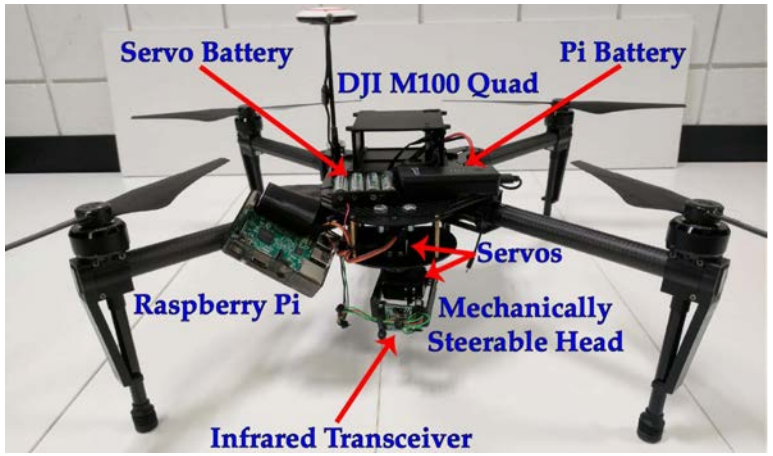
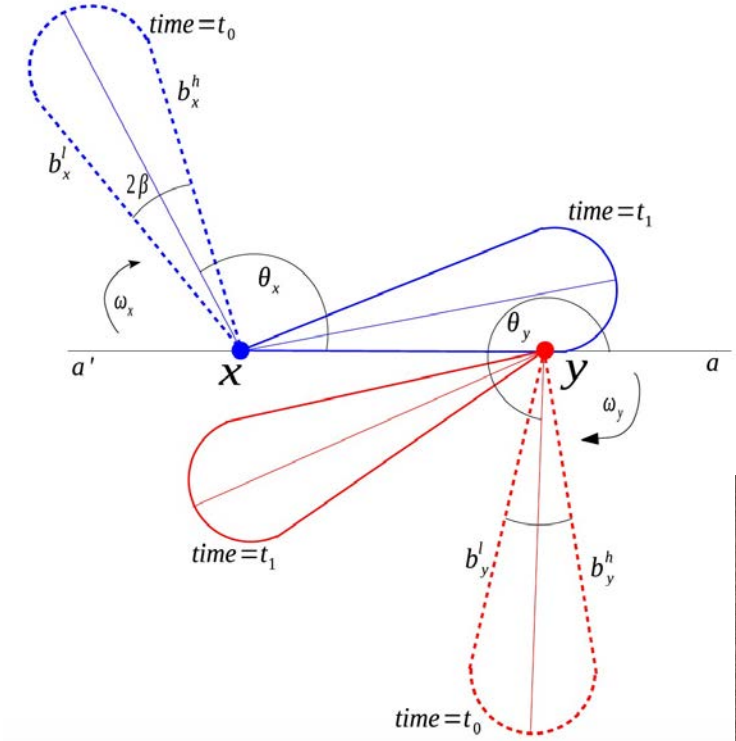
FSO Modules: Mechanical Steering

- Assumptions:
  - One transceiver on mechanically steerable head
  - Equipped with Inertial Measurement Unit
  - In-band: No radio or out-of-band channel
  - No GPS: Indoors or RF-challenged





- Can we **discover** and **maintain** the FSO link in
  - 2D: PackBots, UGVs, ships?
  - 3D: UAVs, Google Balloons, FB solar drones?

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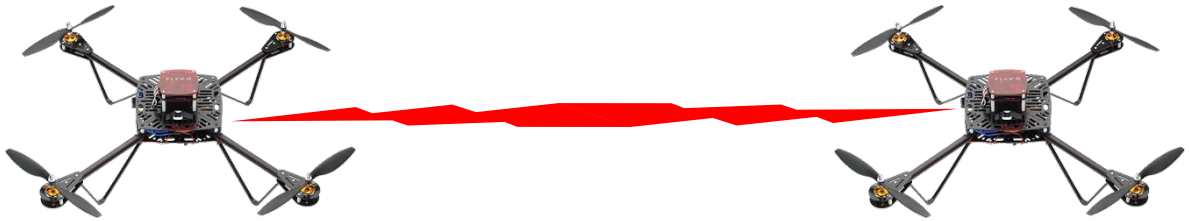
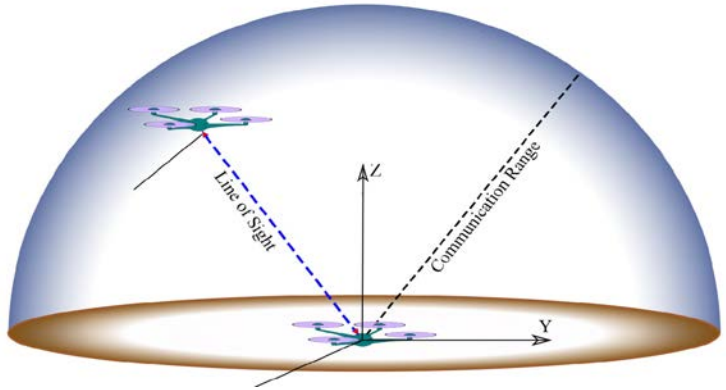
In-Band LOS Link Maintenance in 3D



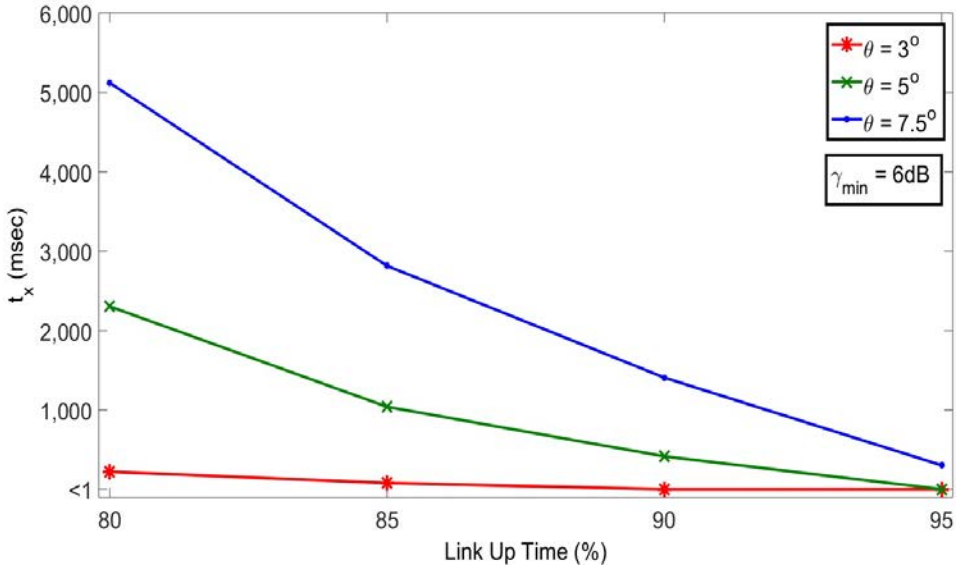
- Key Idea: Use the link itself to exchange at every t_x

<Direction, Speed, Orientation of the head>

- Then, each node can autonomously determine
  - Angular Velocity of head
  - Direction of Rotation



	Laser at Long Range	LED at Short Range
Speed	25 m/s	5 m/s
Range	2.5km	100m
θ	2, 2.25, 2.5 mrad	3°, 5°, 7.5°



Smaller tolerance to deviation → Smaller t_x

IEEE TMC 2017
IEEE MILCOM 2016
IEEE ICC OWC 2016
ACM MOBICOM HotWireless 2015
IEEE WCNC 2014

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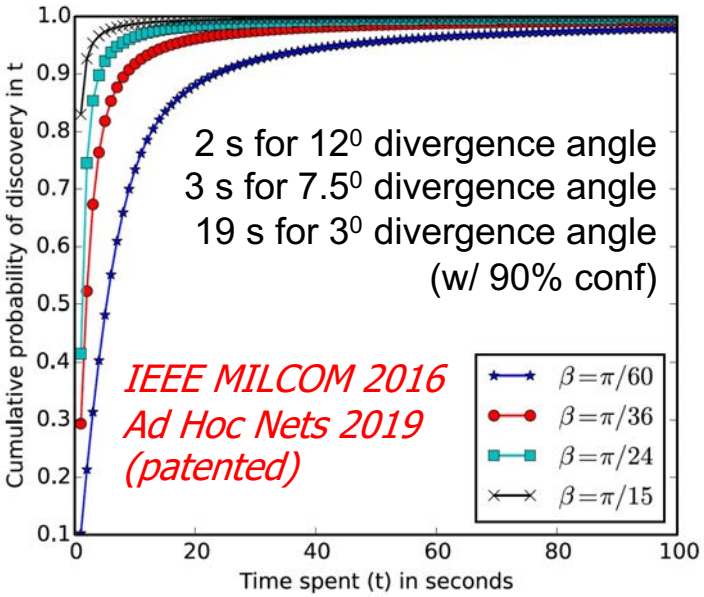
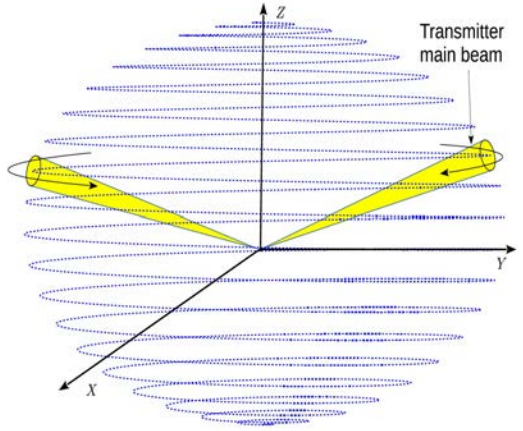
(Sort of) In-Band LOS Discovery

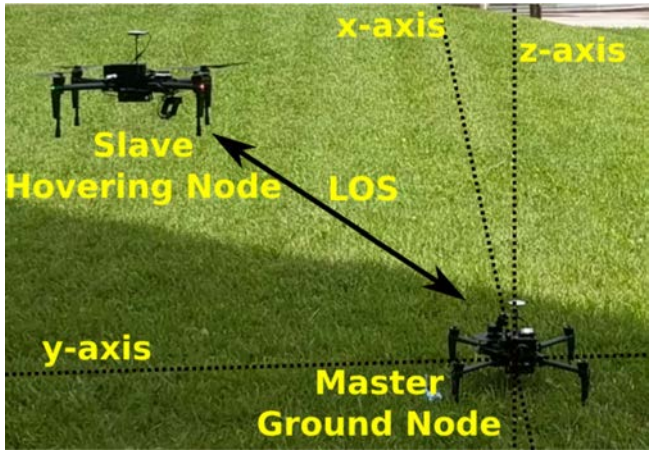
- 2D: Randomized rotation



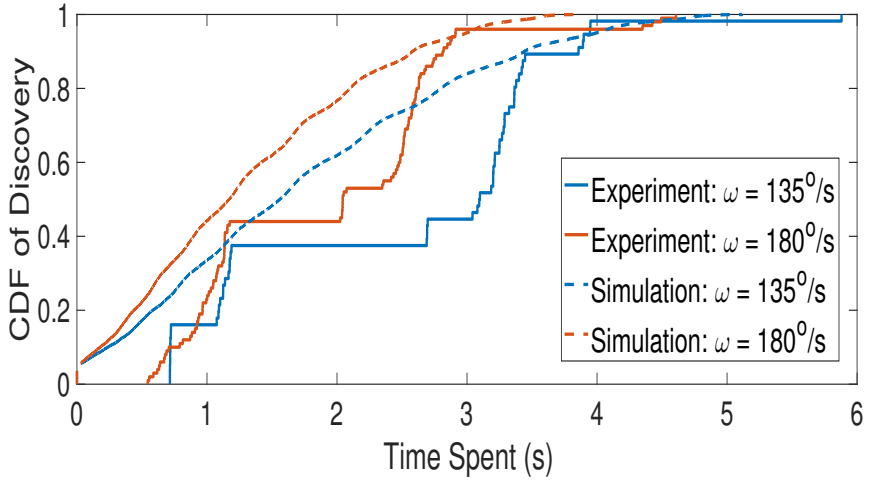
- 3D: Synch w/ RF at the start, then, rotate over a helix:



Snapshot of 3D discovery experiments



Discovery within a few seconds



0.2 s for 12⁰ divergence angle
0.4 s for 7.5⁰ divergence angle
0.9 s for 5⁰ divergence angle
2.5 s for 3⁰ divergence angle
(w/ 90% conf)

IEEE MILCOM 2016
ACM CoNEXT Student Workshop 2019
IEEE TMC 2019
Adhoc Networks 2019

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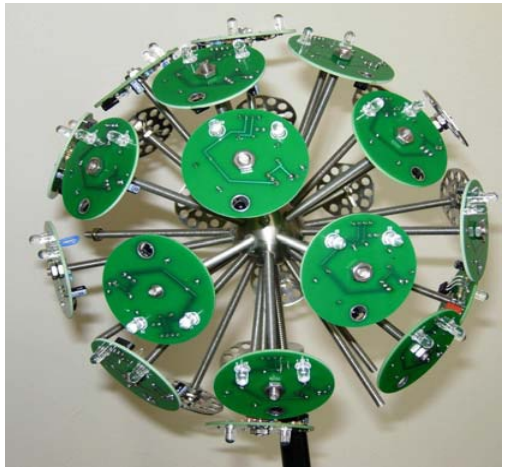
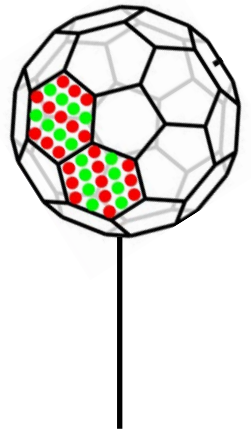
Future Work: FSO Modules

- Miniaturized packaging and cooling issues
- Flexible optoelectronics conformal to surfaces of mobiles



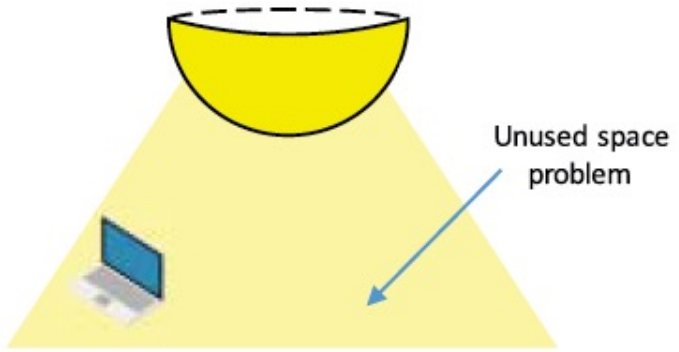


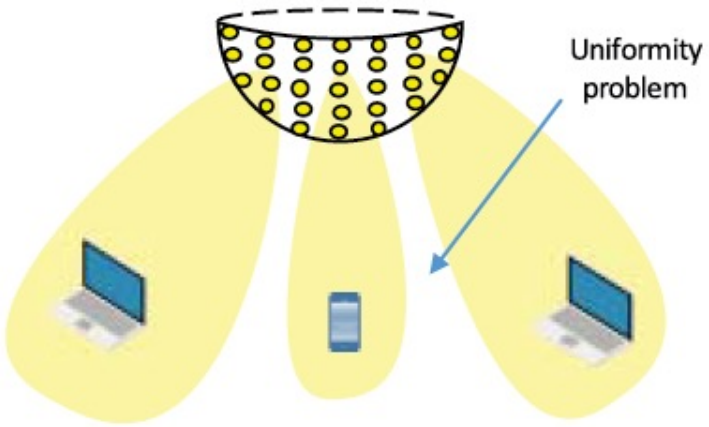
- Discovery and maintenance of RF-independent FSO links

Multi-element VLC Modules

How to handle mobility and lighting?

Multi-element Mobile VLC

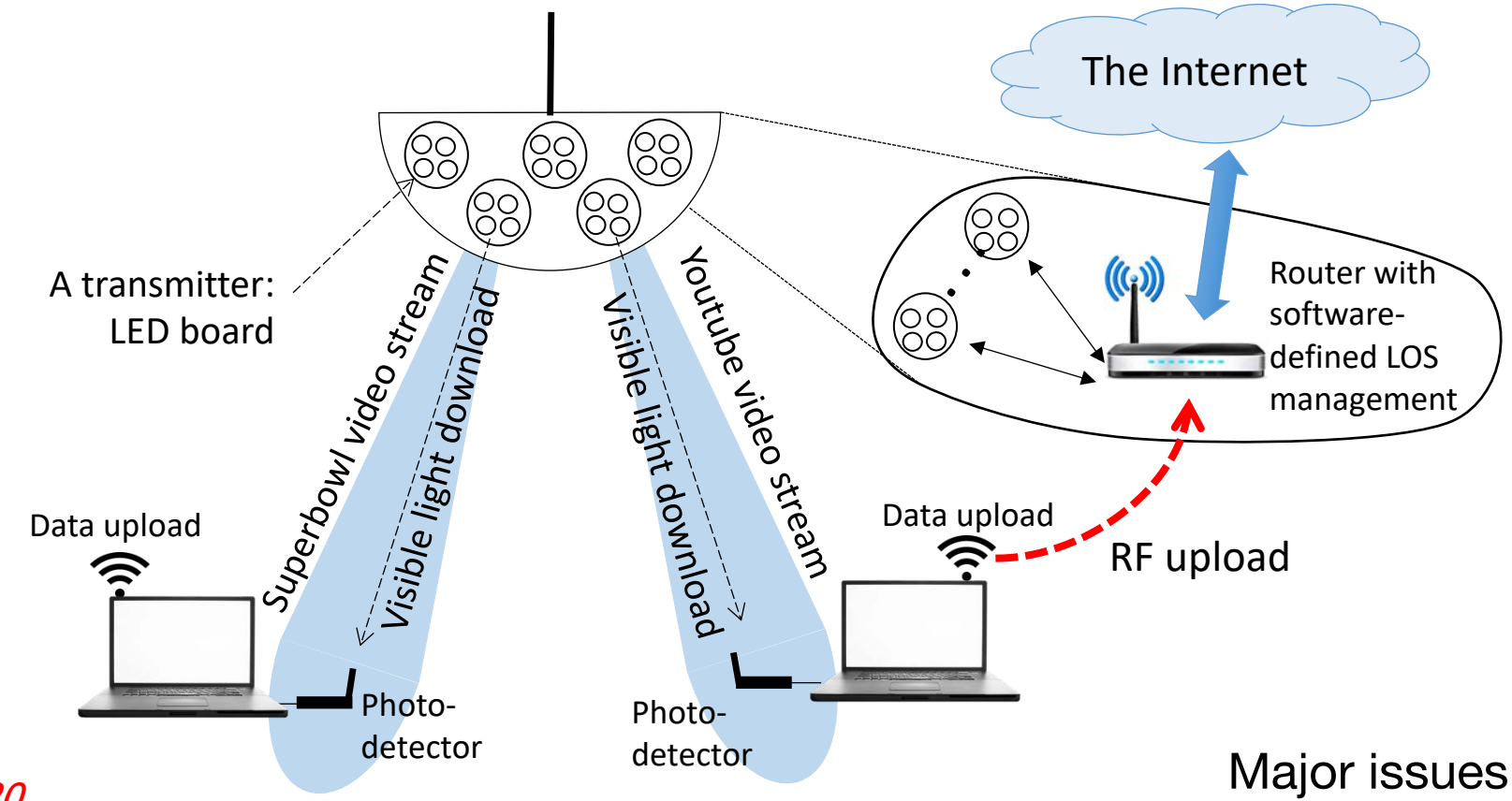




Single data stream
Large divergence – for smooth lighting

Multiple data streams
Narrow divergence – for higher spatial reuse
Spherical structures – to retain smooth lighting

Multi-element VLC Architecture



IEEE TCCN 2020
IEEE LANMAN 2019
IEEE COMMAG 2018
ACM MOBICOM VLCS 2016
ACM MOBICOM VLCS 2015
IEEE VTC 2015

Major issues:

- VLC receiver for mobiles
- Uniformity of lighting
- LED-mobile association

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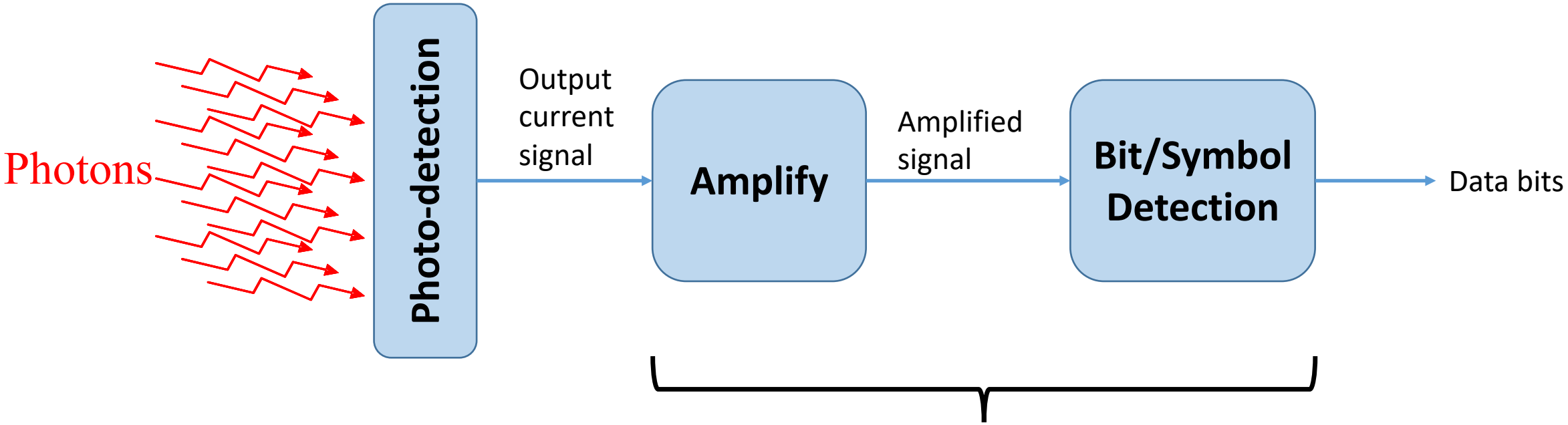
VLC for Mobiles

- Existing VLC solutions use receivers with large FOV but a small aperture area.
- Small aperture area allows high speed reception.
- But, can easily be blocked by a finger!

- How can we increase the reception aperture area while keeping the reception rate high?
- How to design robust receivers?

VLC Receiver Design



We re-worked this part while increasing the photo-detection aperture area.

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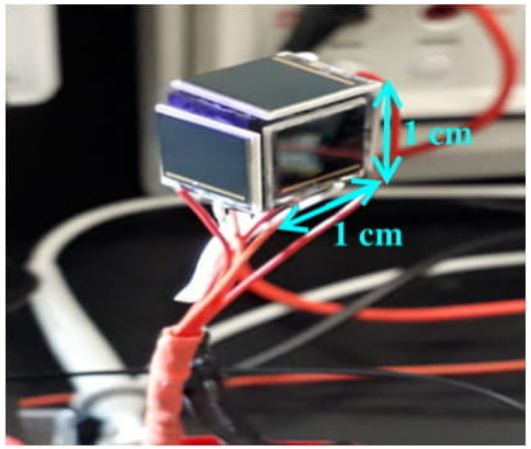
VLC Receiver Design: Photo-detection

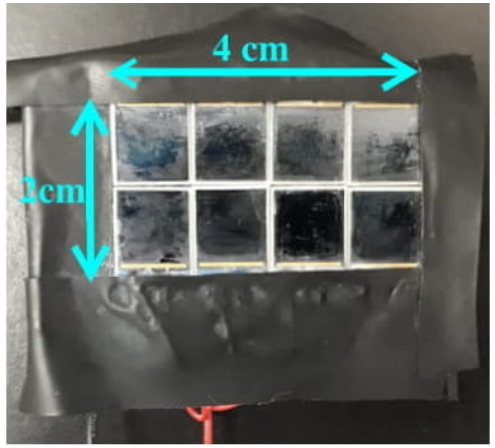
- Each APD
  - Has 1cm^2 aperture area
  - Costs $50
- 5-8 APDs
- Can be arranged conformal to the surface of the mobile device

IMPORTANT CHARACTERISTICS OF FDS1010

Specifications	
Wavelength Range, λ	$350 - 1100$nm
Peak Responsivity, $max[\mathcal{R}(\lambda)]$	0.725A/W
Active Area per PD, A	100mm^2
Rise/Fall Time, t_r/t_f ($V_B = 18V$)	18ns
Dark Current ($V_B = 18V$)	80μA
Capacitance, C_J ($V_B = 18V$)	169.2pF
Maximum Tolerable Reversed Biased, $V_{B,max}$	25V
Maximum Output Photocurrent, I_o	10mA
Maximum Optical Input Power, $P_{i,max}$	10mW



(a)



(b)

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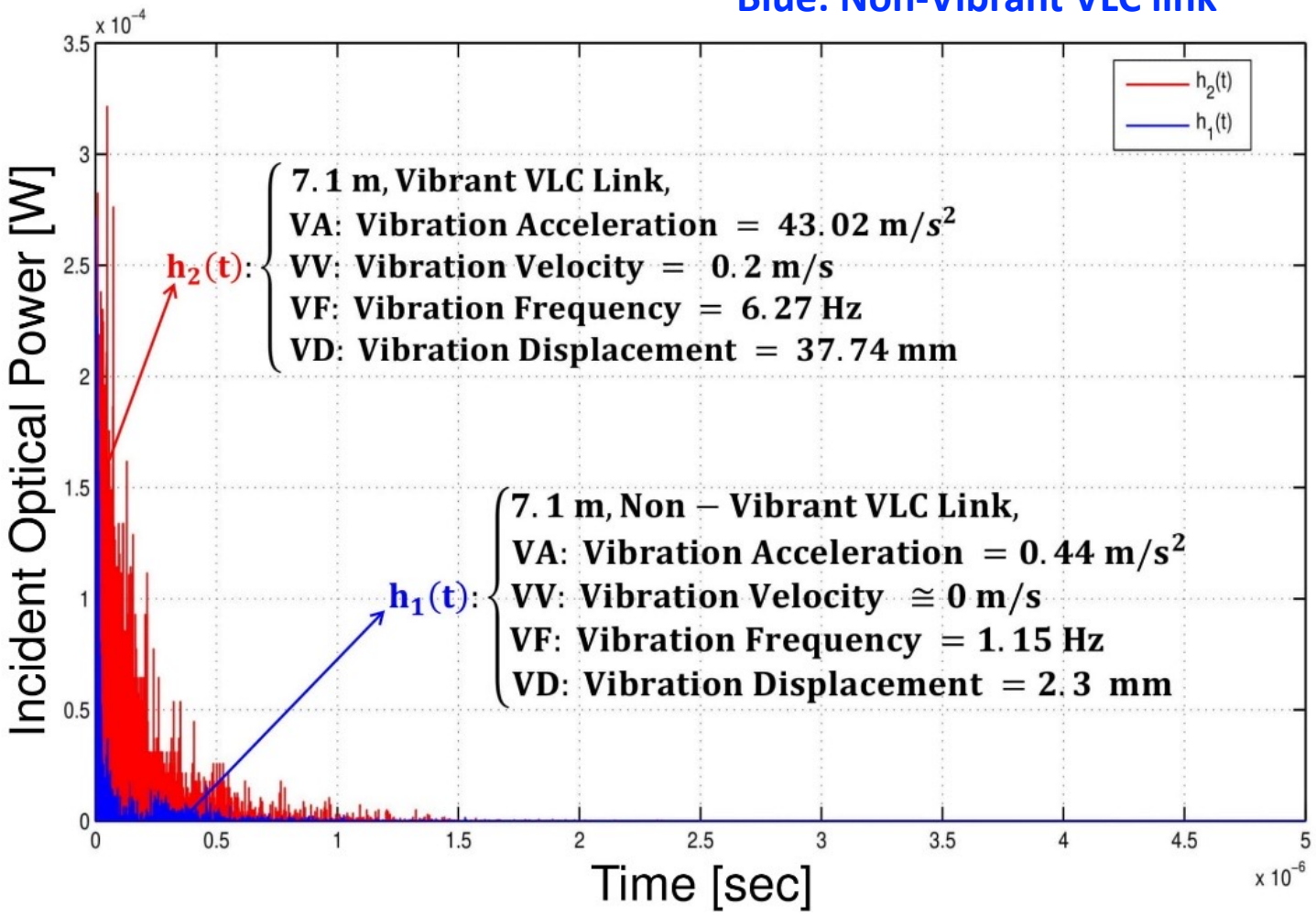
Delay Spread from Vibration

- Vibration characterizations:
  - speed of 0.2 m/s
  - acceleration of 43.02 m/s^2
  - displacement of 37.74 mm
  - and frequency of 6.27 Hz
- Max delay spread in vibrant VLC link ≈ 312 ns
  - ~10 times reflection in the room

~2.5 times oscillation over ~4cm displacement

Red: Vibrant VLC link

Blue: Non-Vibrant VLC link



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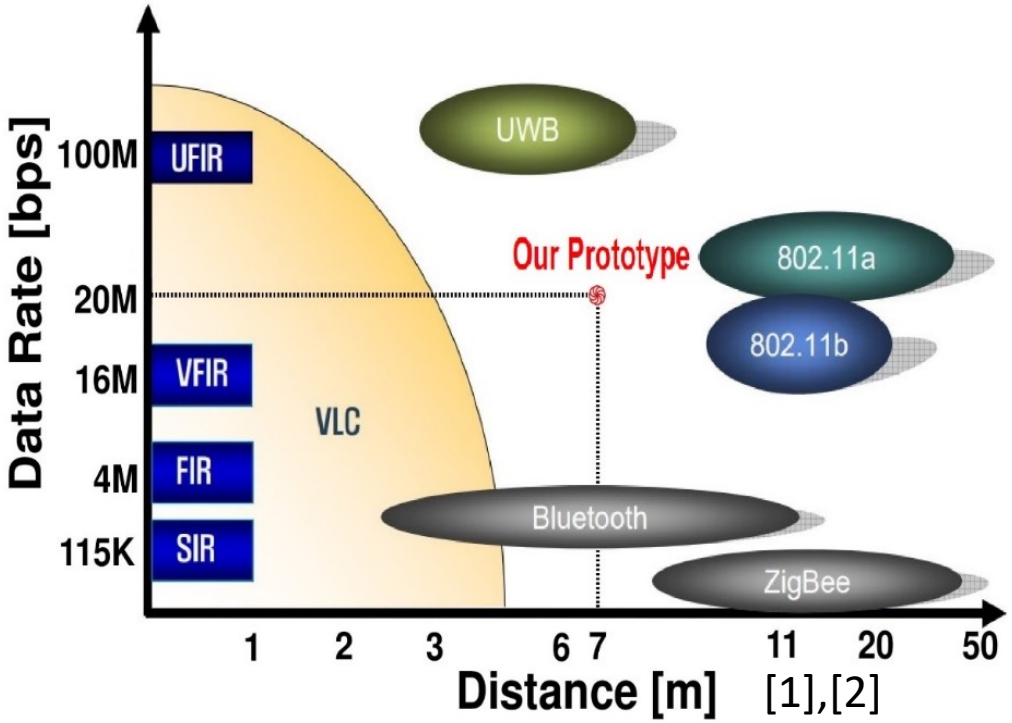
VLC System Performance

- Max Range $\approx 7\ m$
- Max BW $\approx 20 - 26\ MHz$

	R	BW	FOV	Packet Loss Rate
Our Prototype	7.1 m	20 MHz	360°	10^{-6}
Pure LiFi-X [23]	1.8 m	42 MHz	60°	$\approx 3.4 \times 10^{-5}$
[21]	2.4 m	10 KHz	10°	10^{-2}
[20]	50 m	50 KHz	75°	3.2×10^{-4}
Thorlabs [24]	0.45 m	12 MHz	150°	$\approx 10^{-4}$



[1],[2]

IEEE/OSA JLT 2020
IEEE ICC 2019
USPTO patent

[1] E. T. Won, D. Shin, D. Jung, Y. Oh, T. Bae, H.-C. Kwon, C. Cho, J. Son, D. O'Brien, T.-G. Kang, and T. Matsumura, IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs): Visible Light Communication: Tutorial, 2018.
[2] S. Rajagopal, R. D. Roberts , and S. Lim, "IEEE 802.15.7 visible light communication: modulation schemes and dimming support," IEEE Communications Magazine, vol. 50, no. 3, pp. 72–82, March 2012.

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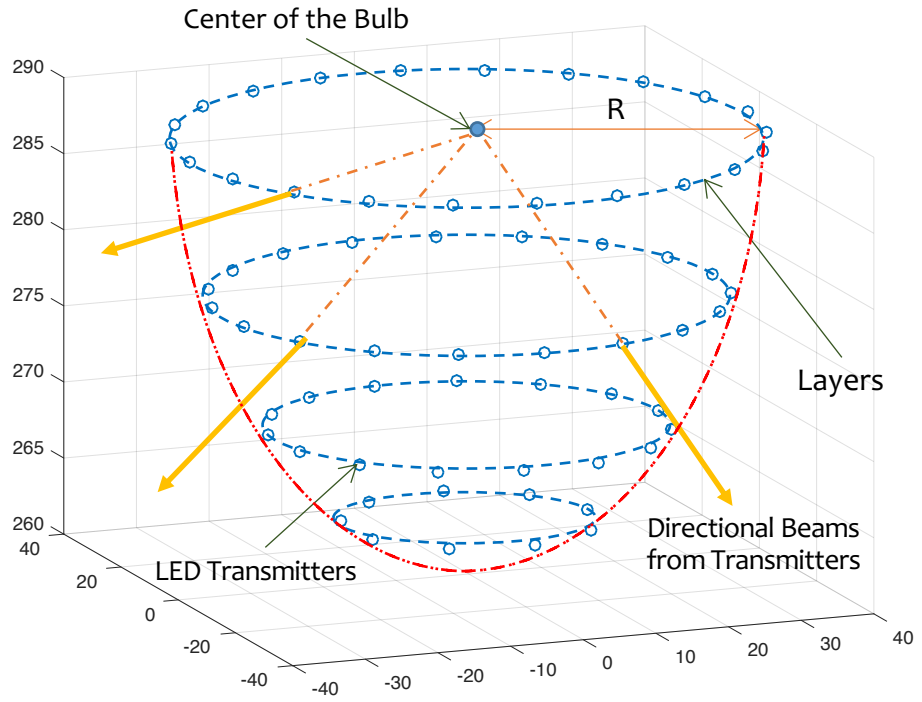
VLC for Many Mobiles

How to associate VLC beams to mobile users and tune them

-- while having “good” illumination?

Hemispherical Bulb

- The LEDs are mounted on the bulb
- Multiple LEDs can be assigned to a particular user but no LED is assigned to more than 1 user
- A variable, ϵ_{mu} , defines the association between LED m and User u



$$\epsilon_{mu} = \begin{cases} 1, \text{if LED } m \text{ is associated with user } u. \\ 0, \text{otherwise.} \end{cases}$$

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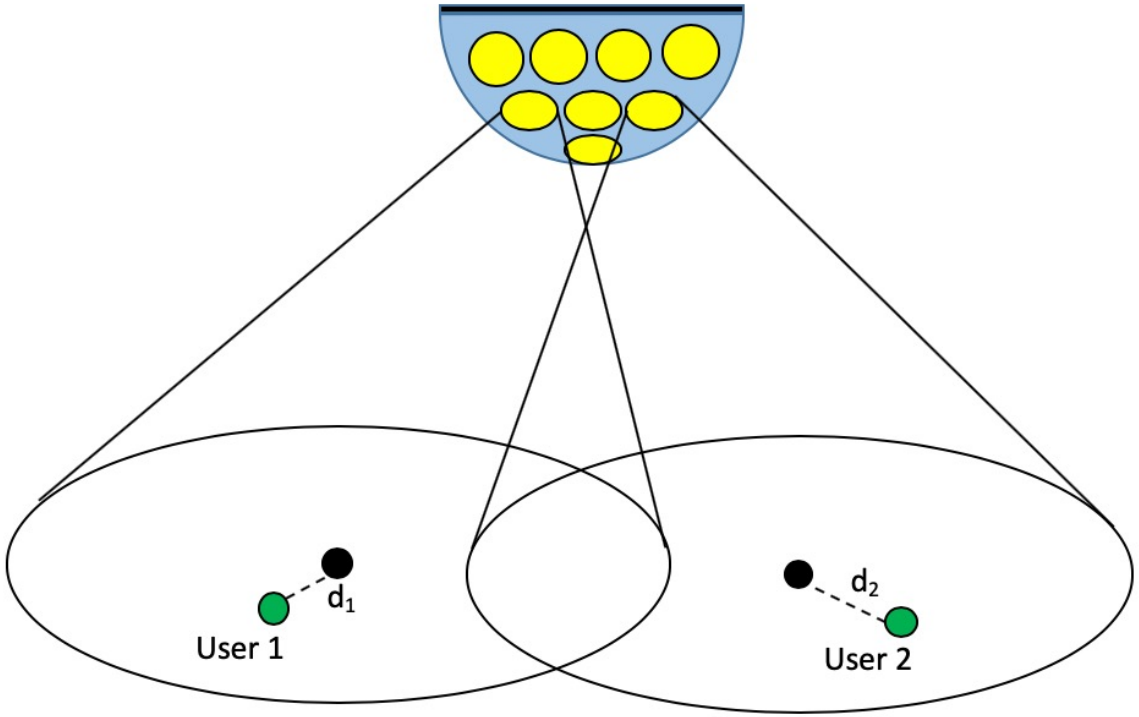
Problem and Solution

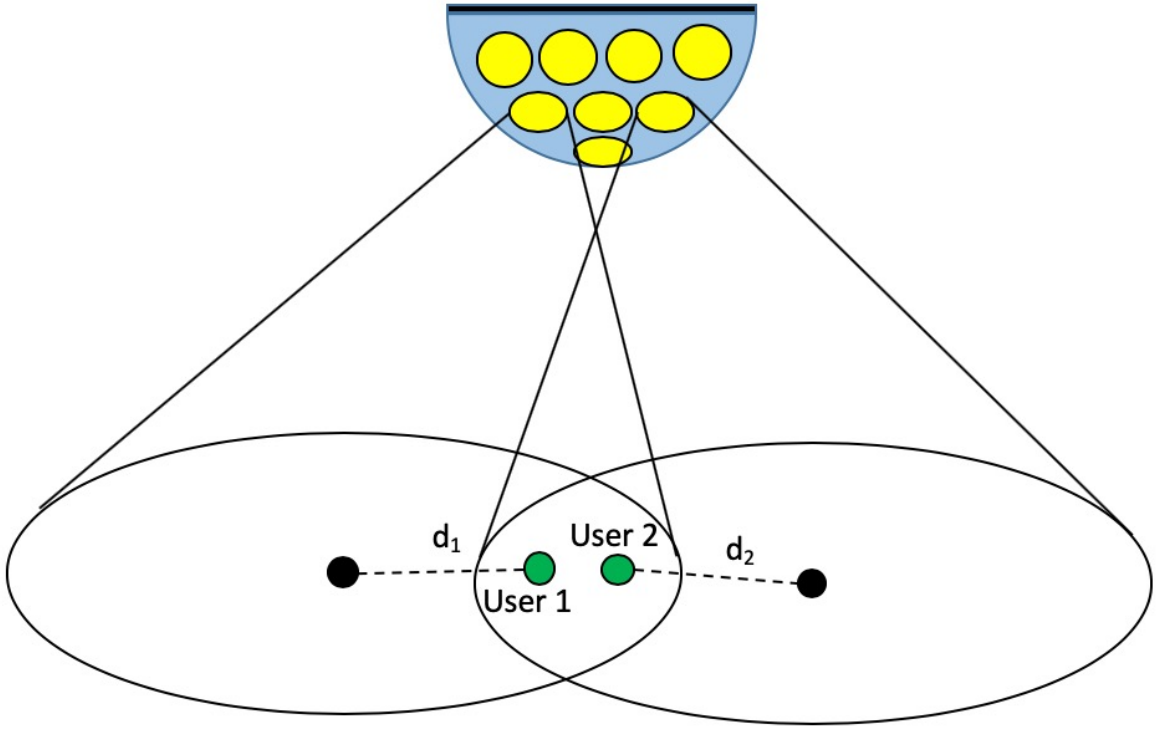
- Things to optimize:
  - Total power consumption of the system: There can be a large number of IoT devices in the network
  - Data rates of each user in the system: Ensuring a minimum data rate for each IoT device is critical
  - Illumination uniformity: We also should not forget about the lighting quality!

- Our proposed two-stage heuristic solution
  - First stage: A 'Nearest User Assignment' (**NUA**) approach is implemented to determine the value of ϵ_{mu}
  - Second stage: Using the LED-user associations from the value of ϵ_{mu} found in stage 1, we optimize the LEDs' power allocations

NUA: Example Cases



Good case: Low interference, stronger signals



Bad case: High interference, weaker signals

IEEE LANMAN 2019
IEEE TCCN 2020

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Future/Ongoing Work: VLC

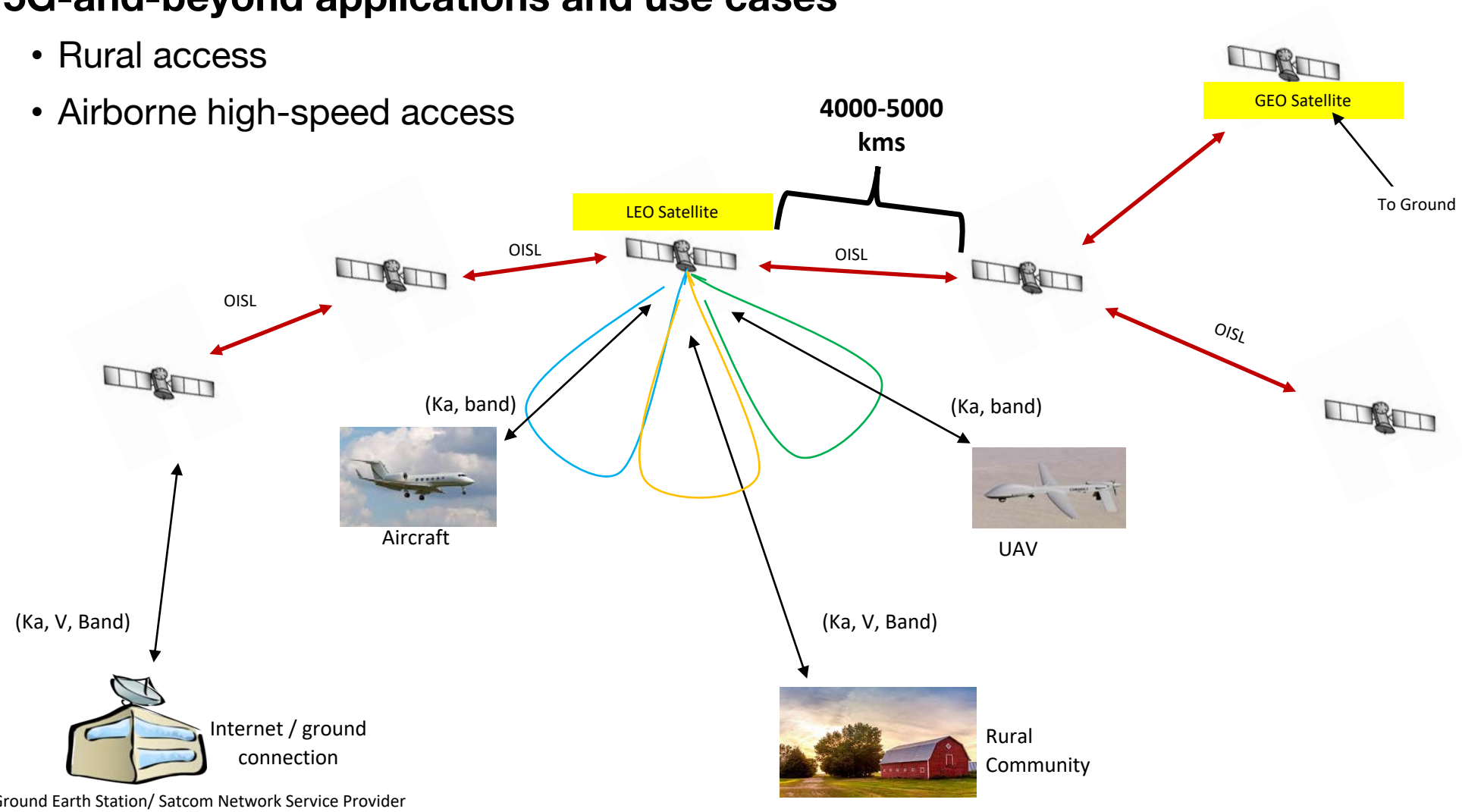
- VLC receiver
  - Removing FPGAs out of the way: Integration with laptops or smartphones
  - Scaling the aggregate aperture area at the receiver:
    - Detect and merge
    - Advanced learning methods
- VLC channel modeling
  - Further understanding of the VLC channels in a casual office/indoor setting: Shakes, human movements, reflections
- Multi-element Bulb
  - Larger room size with more users (as in airports or hospitals)
- VLC architecture
  - What would the mirrors do?

Multi-element FSO for Space

How to handle mobility and extreme conditions?

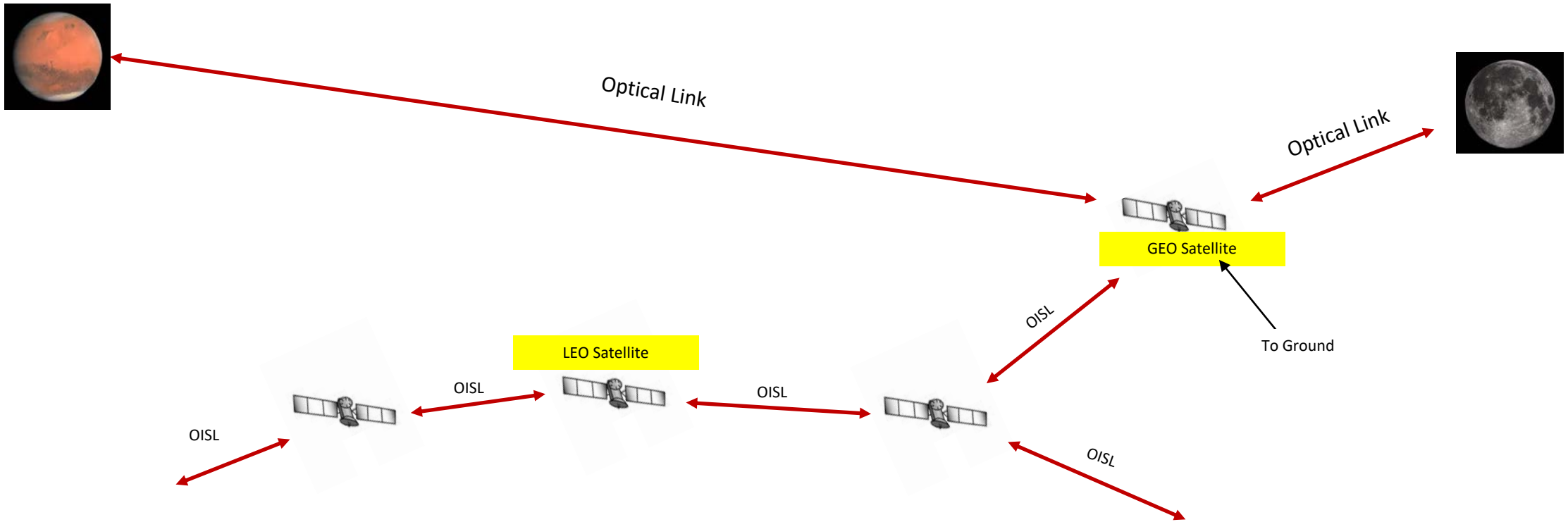
Optical Networking in Space

- **5G-and-beyond applications and use cases**
  - Rural access
  - Airborne high-speed access



Optical Networking in Space

- **5G-and-beyond applications and use cases**
  - Rural access
  - Airborne high-speed access
  - Inter-planetary access



Optical Networking in Space

	Current State	Future State
Satellite-to-Earth	RF (Ka, Ku, E) GEO/MEO satellites 35-270 ms latency 100 Mbps	RF/FSO hybrid Many ground stations to circumvent atmospheric conditions FSO on 1000s of LEO satellites → 1-7 ms latency 100 Gbps
Satellite-to-satellite	RF or non-existent GEO-MEO: ~25,000 km	OISL: laser, OOK, ~1,550 nm LEO-LEO: ~5,000 km
Satellite-to-Moon/Mars	RF a few Kbps	RF/FSO Several Mbps

Optical Networking in Space

- **General requirements**
  - Very long ranges (1000s of kms)
  - Small form factor aperture (10s of cms)
  - Low weight (a few kgs)

} Legacy RF technologies are insufficient

- **General desires**
  - High bandwidth (MHz to GHz)
  - Low power consumption
- **Challenges**
  - Mobility – pointing & acquisition and line-of-sight are required
  - Receiver Sensitivity – photon starvation at too long distances
  - Atmospheric Conditions – must attain robust link via atmospheres of different sorts
  - Wild Radiation and Temperatures – opto-electronics robust to harsh radiation and temperatures are needed

Thank you!