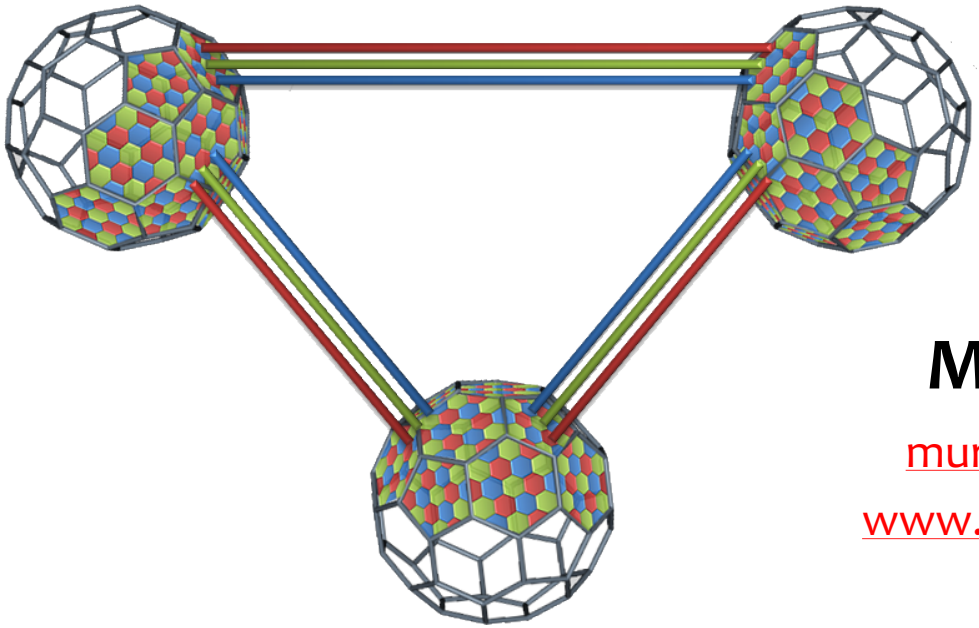
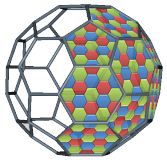
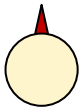
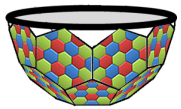
Multi-element Free-Space Optical Modules for Mobile Opportunistic Networking









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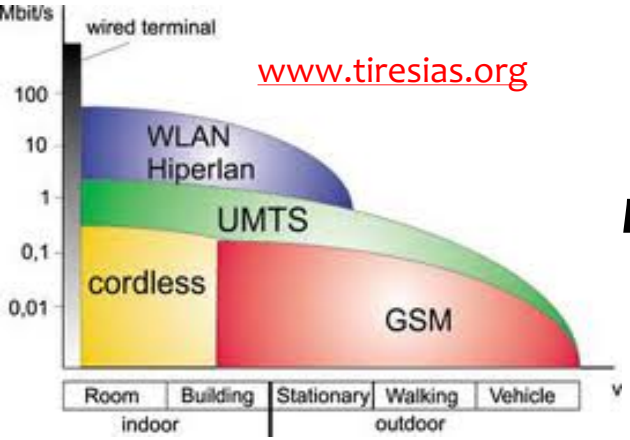
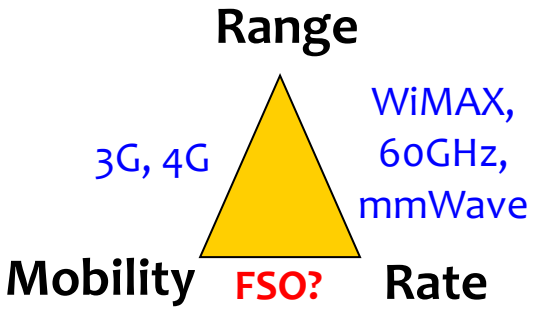
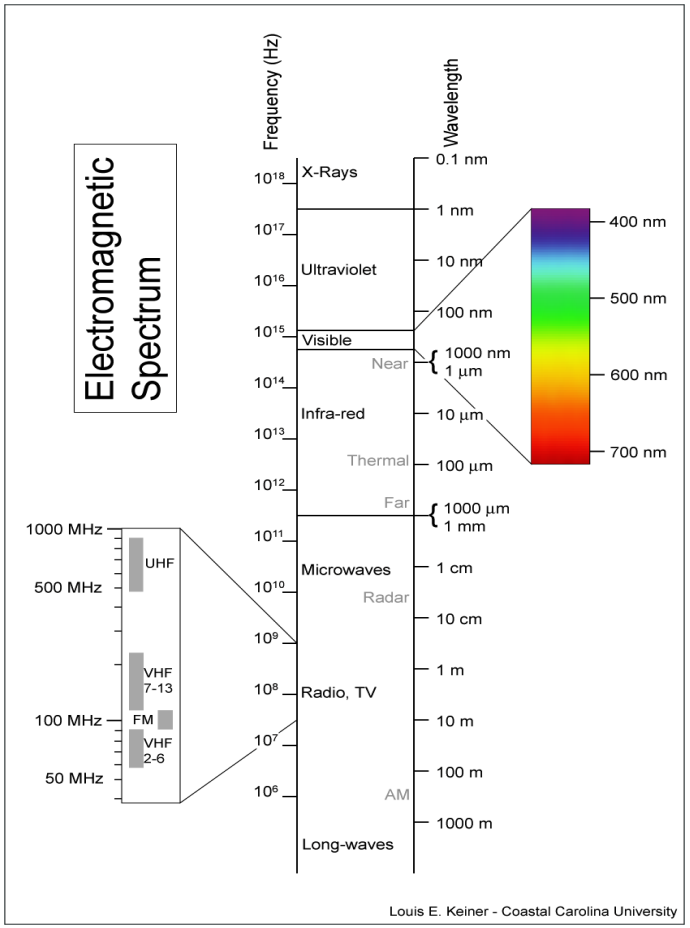
Wireless Spectrum Tradeoffs: Rate/Mobility/Range



www.tiresias.org



Have to Pick Two



- Licensed/unlicensed bandwidth available at higher frequency EM spectrum
  - Higher *rate* even with modest spectral efficiency
  - High *spatial reuse* due to highly directional signal propagation
- But, these EM regions are poorly suited for
  - *range*: small wavelength is absorbed too easily
  - *mobility*: line-of-sight alignment

KEY INSIGHT

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

HOW?

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

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

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FSO Modules: Spherical Designs

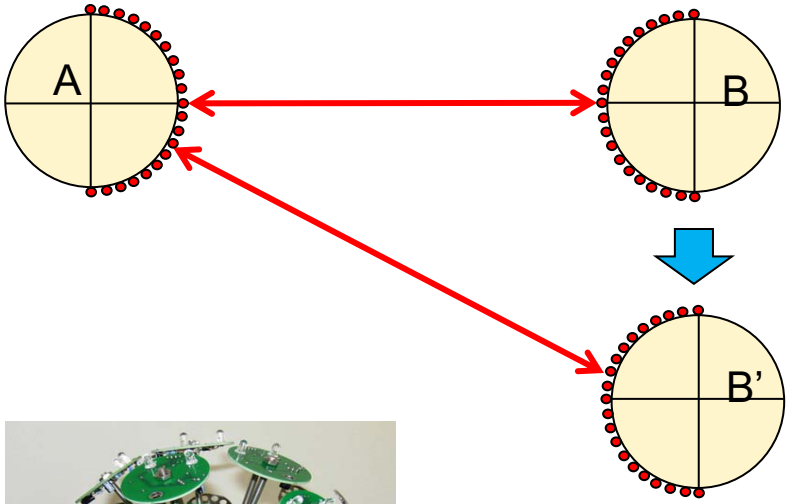
- How to handle mobility under LOS alignment requirement?

Mobile FSO =

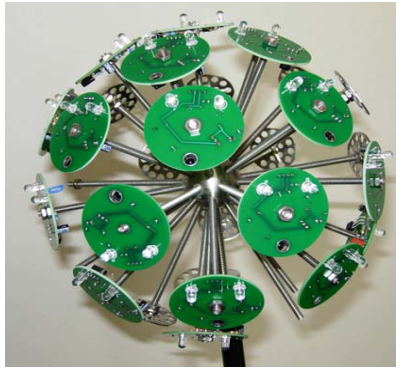
Directionality + Angular Diversity + **Electronic Steering**

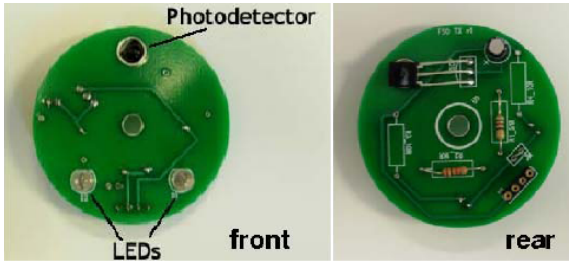
Multi-transceiver spherical FSO designs.

Need a distributed protocol for this!



Bidirectional LOS





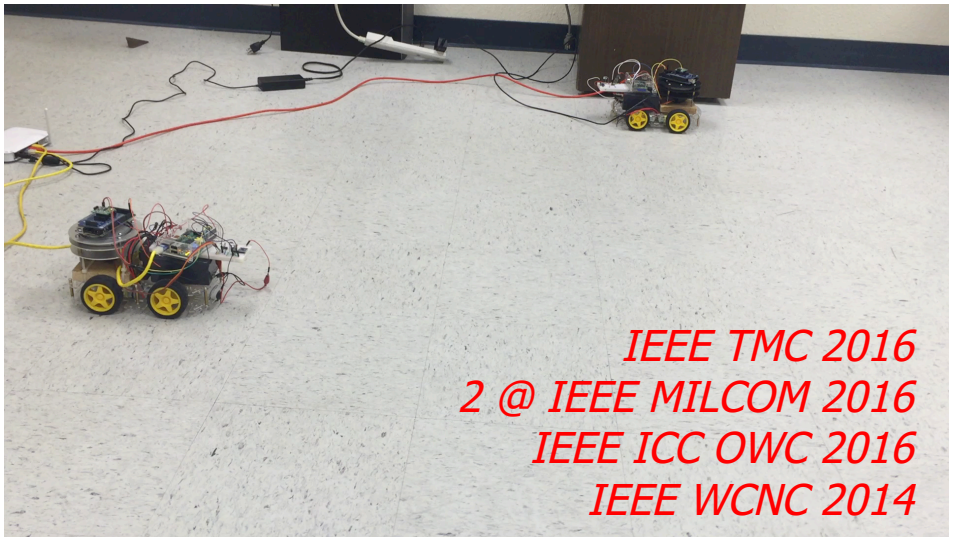
Ad Hoc Networks 2014
Ad Hoc Networks 2013

FSO Modules: Mechanical Steering

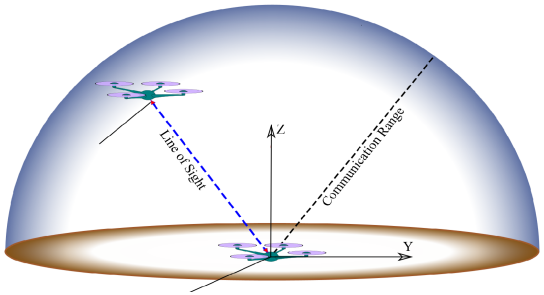
- Assumptions:
  - One transceiver on mechanically steerable head/arm
  - Equipped with Inertial Measurement Unit (IMU)
  - No radio or out-of-band channel
  - No GPS
- In-Band LOS Maintenance
  - Use the link itself to exchange

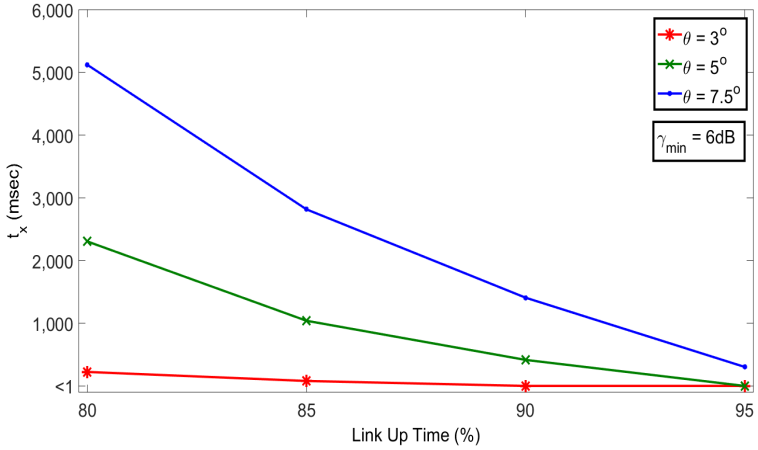
<Direction, Speed, Head Orientation>

  - Each node determines
    - Angular velocity of head
    - Direction of rotation
  - 2D: PackBots, UGVs, ships
  - 3D: UAVs, Google Balloons, FB solar drones



IEEE TMC 2016
2 @ IEEE MILCOM 2016
IEEE ICC OWC 2016
IEEE WCNC 2014





ACM MOBICOM HotWireless 2015

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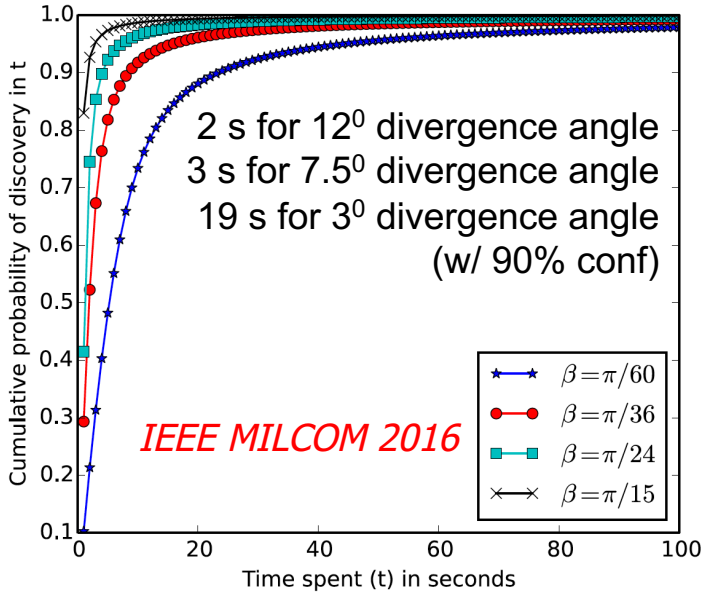
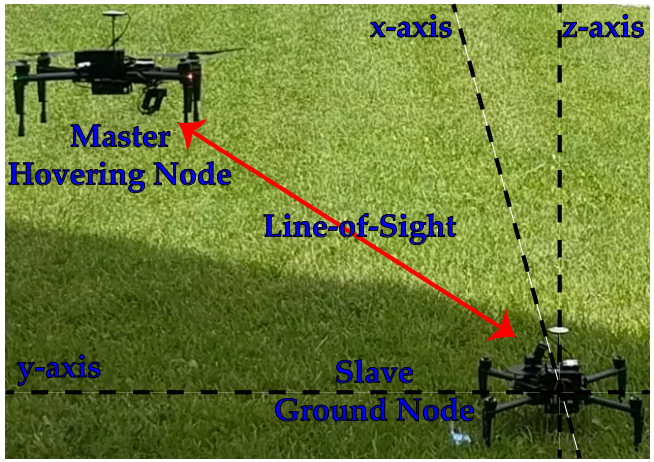
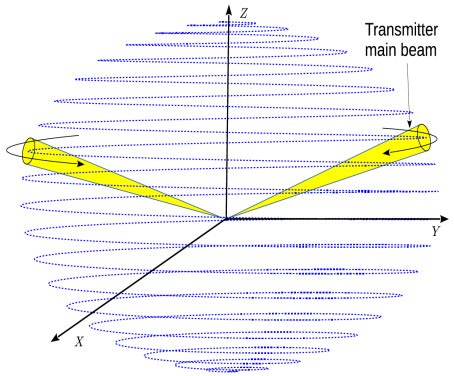
In-Band LOS Discovery

- 2D: Randomized rotation



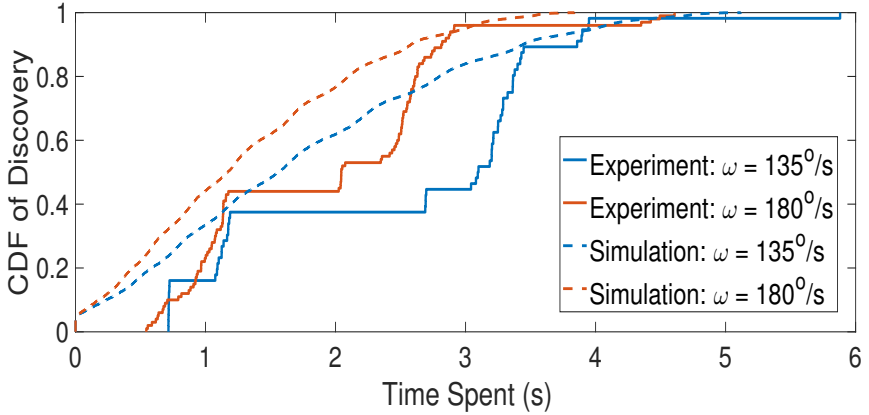


- 3D: Synch w/ RF at the start, then, rotate over a helix:

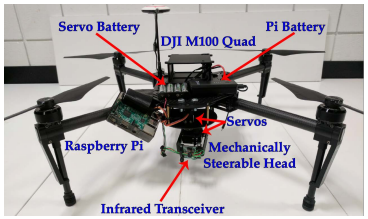


0.2 s for 12⁰ divergence angle
0.4 s for 7.5⁰ divergence angle
0.9 s for 5⁰ divergence angle
2.5 s for 3⁰ divergence angle
(w/ 90% conf)

IEEE MILCOM 2016



submitted to HotWireless 2017



3D: Still evaluating a totally in-band solution.

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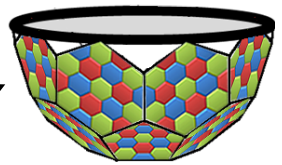
Future on Multi-Element FSO Modules

- Challenges
  - Miniaturized packaging and cooling issues
  - Seamless integration with legacy Wi-Fi
  - Flexible optoelectronics conformal to surfaces of mobiles
  - Discovery and maintenance of RF-independent FSO links

Revision to IEEE COMMAG
ACM MOBICOM VLCS 2016
ACM MOBICOM VLCS 2015
IEEE VTC 2015



- Opportunities
  - Integration with solid-state lighting
  - Localization w/ AoA detection
  - Uses in RF-challenged settings, e.g., PackBots in a battlefield, underground/underwater operations
  - Utilization of Troposphere for Internet access via a 3D mesh of UAVs equipped with FSO transceivers
  - Multi-laser modules for satellite communications, e.g., for CubeSat and Earth-to-Mars networks

IEEE/OSA JLT 2015
IEEE GLOBECOM OWC 2015
IEEE VTC 2015

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