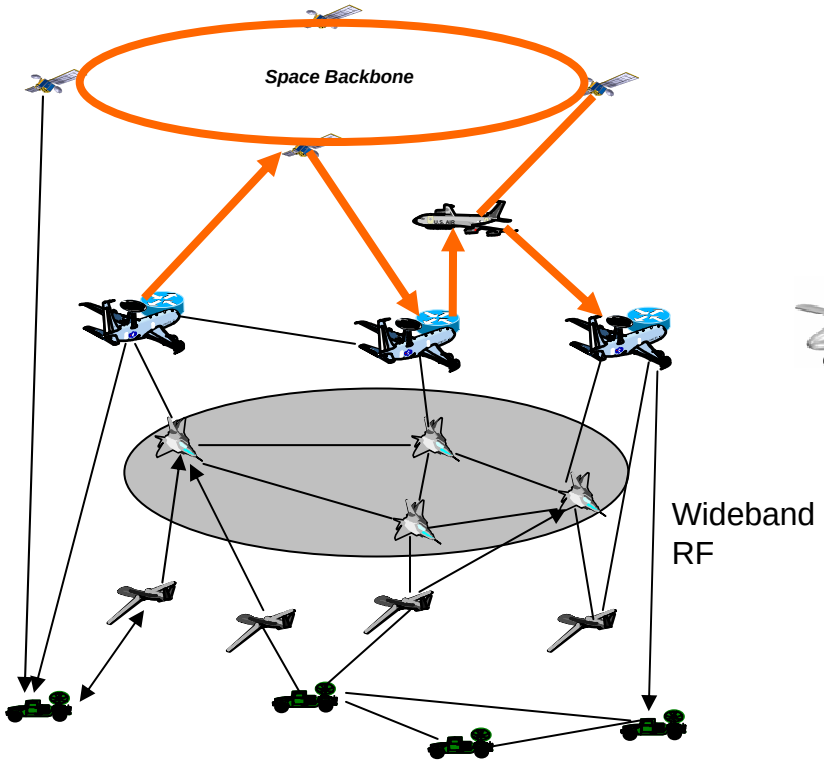
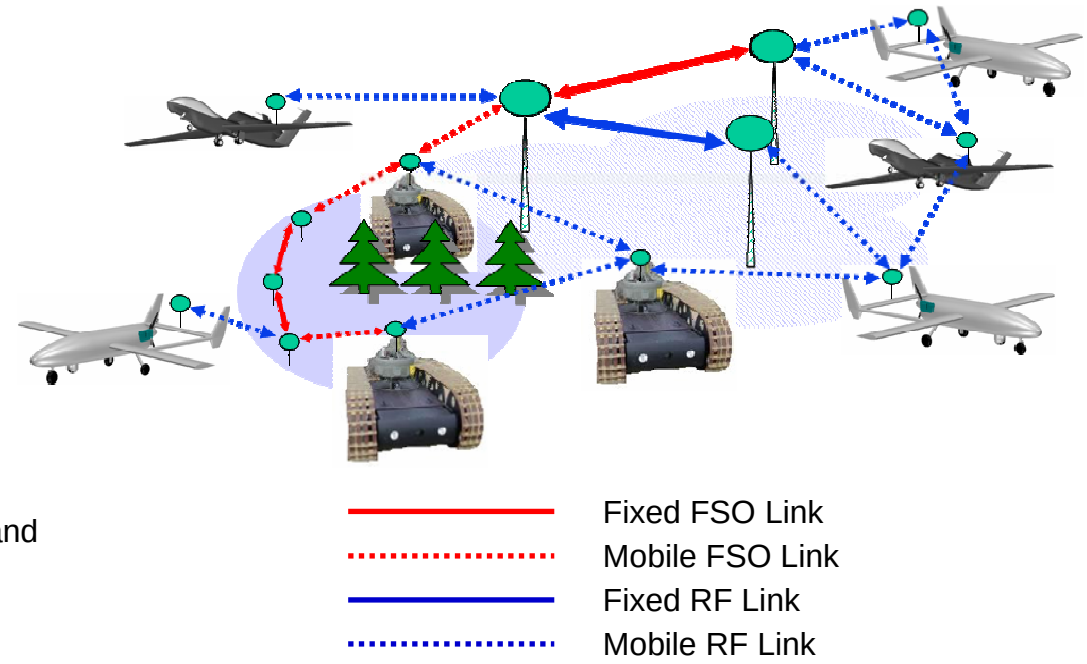
Free-Space-Optical Mobile Ad-Hoc Networks (FSO-MANETS)



Multi-Tier Ground-Airborne-Satellite Ad-Hoc Networks



FSO Ad-hoc Networking in the Lower Altitude Levels of the Hierarchy, e.g. Networks of UAVs

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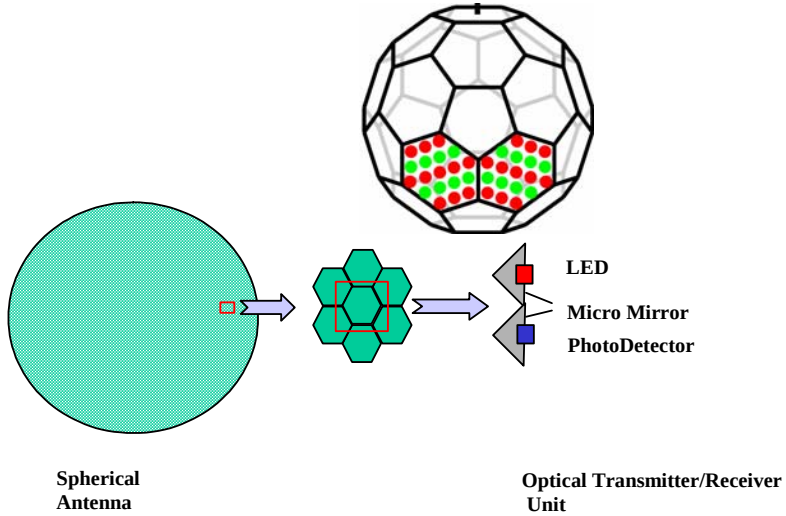
FSO-MANETS Vision

Initial 3-d FSO prototypes with auto-alignment circuitry



Design of 3-d FSO antennas

Free-Space-Optical Communications

- High bandwidth
- Low power
- Directional – secure

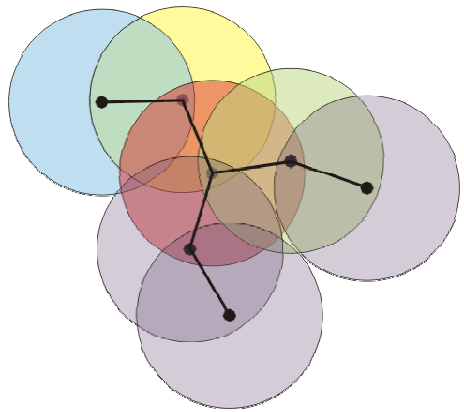
Mobile Ad-Hoc Networking

- Mobile communication
- Auto-configuration

Free-Space-Optical Mobile Ad-Hoc Networks

- Spatial reuse and angular diversity in nodes
- Electronic auto-alignment
- Optical auto-configuration (switching, routing)
- Low-power and highly secure
- Interdisciplinary, cross-layer design

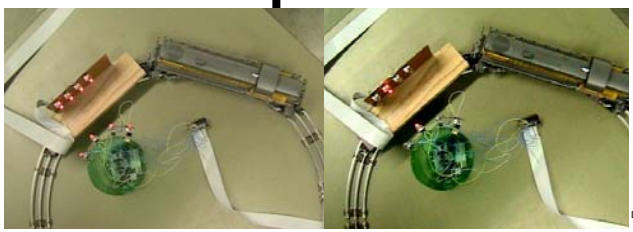
Bringing optical communications and ad-hoc networking together…

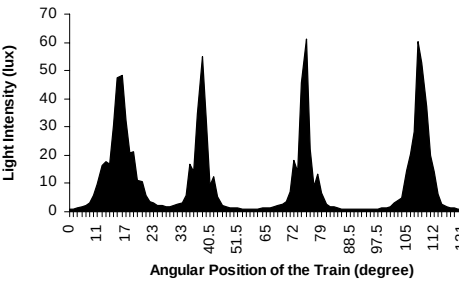


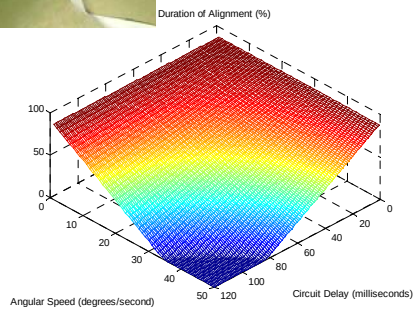
- 802.1x with omni-directional RF antennas
- Less reliable
- High-power – typically the most power consuming part of laptops
- Low bandwidth – typically the bottleneck link on a path
- Very error-prone
- Less secure – very vulnerable to interception

Legacy RF MANETS

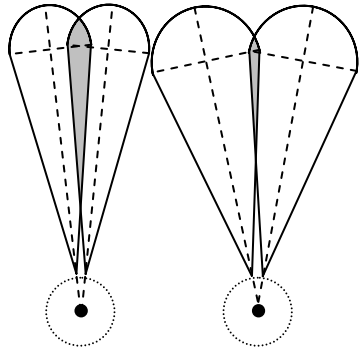
FSO-MANETS: Technical Motivations





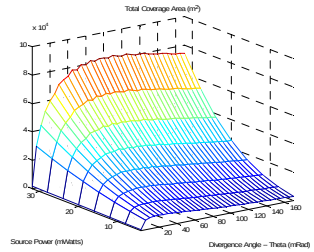


Initial tests show high tolerance to mobility

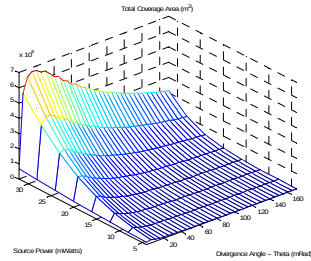


Design I **Design II**

Optimal coverage and interference (shaded) areas for different divergence angles are achieved by different number of transceivers.

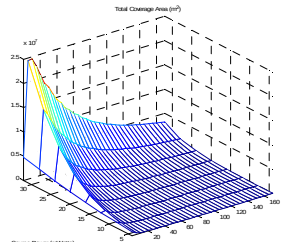


Visibility = 0.2km



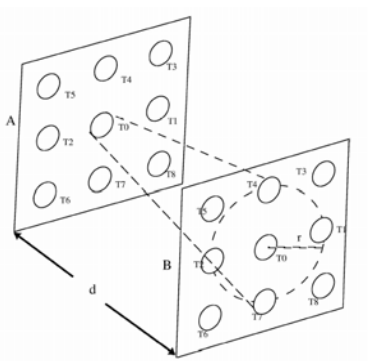
Visibility = 6.2km

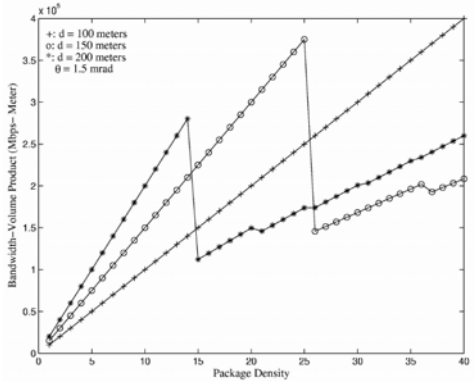
Coverage area of an FSO node with radius 20cm and transceivers' radius 2.4cm under different weather conditions.



Visibility = 20.2km

Dense packaging and long ranges are attainable





Two multi-element arrays in alignment Bandwidth-Volume Product (BVP)

Ultra-high-bandwidth through multi-element 2-d FSO array designs

FSO Advantages:

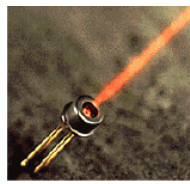
- High-brightness LEDs (HBLEDs) and VCSELs are **very low cost** and **highly reliable** components
  - 35-65 cents a piece, and $2-$5 per transceiver package + up to 10 years lifetime
- **Very low power** consumption
  - 4-5 orders of magnitude improvement in energy/bit compared to RF, e.g. 100 microwatts for 10-100 Mbps!
- Huge **spatial reuse** => multiple parallel channels for huge bandwidth increases due to spectral efficiency
- **More Secure:** Highly directional + small size & weight => low probability of interception (LPI)

FSO Issues:

- Need line-of-sight (LOS); and alignment of LOS

Huge potential advantages with low-cost solutions to FSO issues

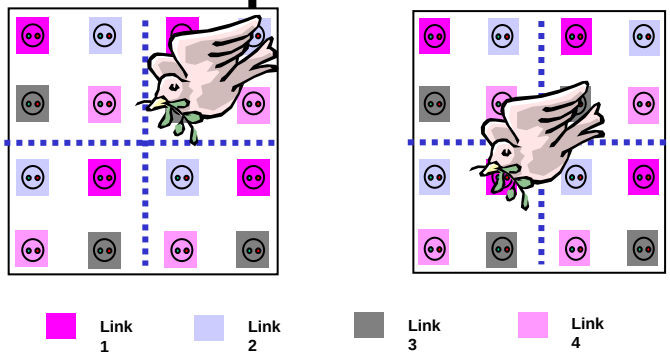
VCSELs…



IrDAs…

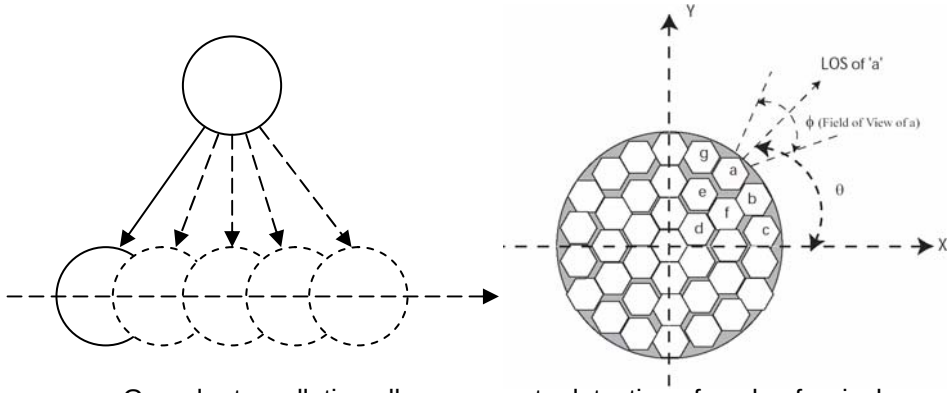
LEDs…

FSO-MANETS: Technical Innovations



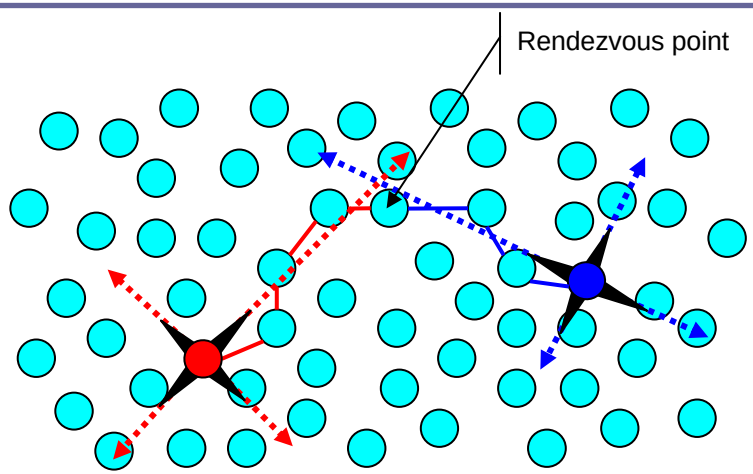
Potential to perform a combination of real-time, space-time, and multi-path FEC coding techniques at FSO-aware link layers.

Multi-Scale Space-Time FEC Coding and Multi-Path FEC Link Layer Methods



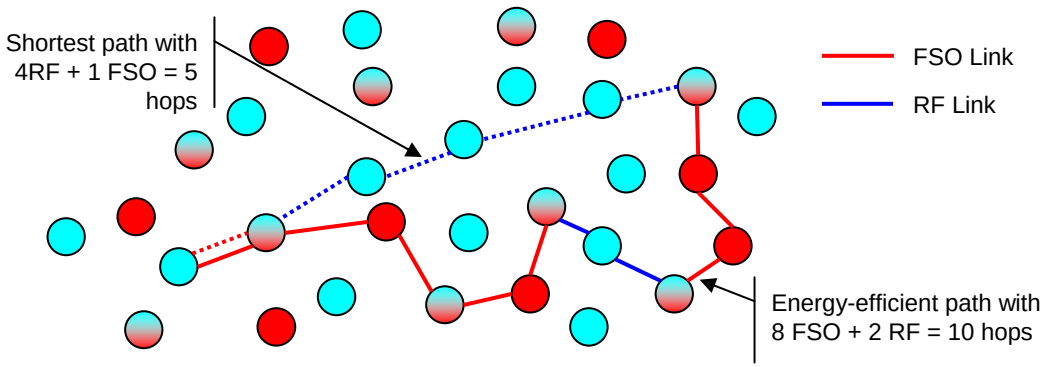
Granular tessellation allows accurate detection of angle of arrival.

FSO-based localization system with granular tessellation of transceivers



The source and destination sends probe packets at North-South and East-West directions based on their local sense of direction.

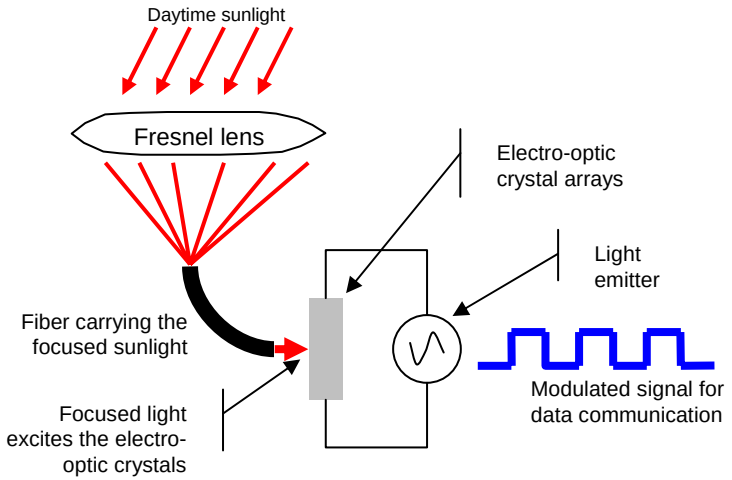
Orthogonal/Directional Routing using FSO nodes



Even though the route will be longer in number of hops, FSO links may be preferable due to their energy-efficiency.

Energy-Efficient Routing in a Hybrid FSO/RF Network

FSO-MANETS: Technical Innovations

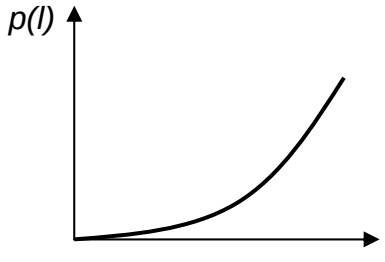


Sunlight-based FSO Communication Device Design

- Multi-hop FSO is better in bit-error-rate (BER) and power consumption performance, but cost of additional hops balances the power gains.
- This optimization problem can be formulated as a regular economic diminishing returns phenomenon:

$$\min_{n} \left\{ np\left(L/n\right) + nc \right\}$$

L – end-to-end link length
n – number of hops
c – monetary cost of deploying an extra repeater



Transmission power per bit is a strictly increasing function of the p length.

Power-Optimal Cost-Effective FSO Network Designs

SUMMARY

- ***Cross-layer*** wireless network protocols (e.g. localization, routing) that leverage unique properties of FSO such as power efficiency and directionality.
- ***Interdisciplinary*** work on both hardware and software aspects of the FSO-MANETs.
- We propose to research, design, and develop building blocks for FSO-MANETs, such as:
  - FSO-based network components, buffering and queuing methods that remedy intermittent mobile connectivity
  - multi-scale space-time FEC techniques that compute and insert FEC packets online into the data traffic stream,
  - scalable location management protocols using FSO structures,
  - power-optimal cost-effective multi-hop FSO network designs,
  - orthogonal/directional routing and energy-efficient routing protocols that use features of FSO
  - sunlight-based FSO components that reduces data transmission power consumption,
  - and lab setup of an auto-configuring FSO-MANET.