Emerging Challenges: Mobile Networking for "Smart Dust"

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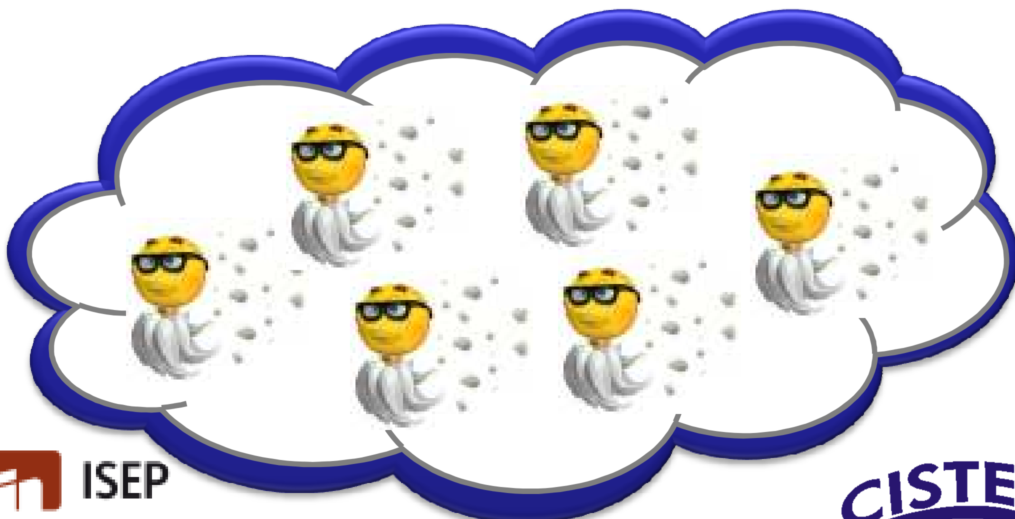
Outline

- Smart Dust Idea
- Ultra low power: RF/optical
- Corner Cube Retro Reflector
- Free space optical networks
- Mobile networking challenges
- Mobile networking opportunities
- Applications
- Summary and conclusions

What is Smart Dust?



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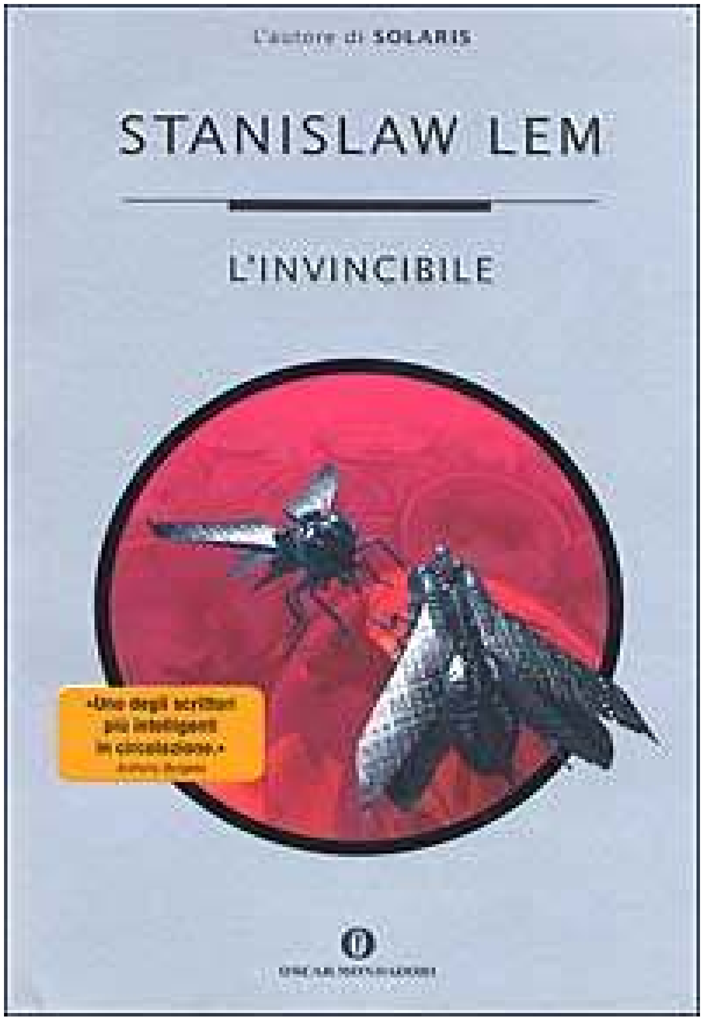
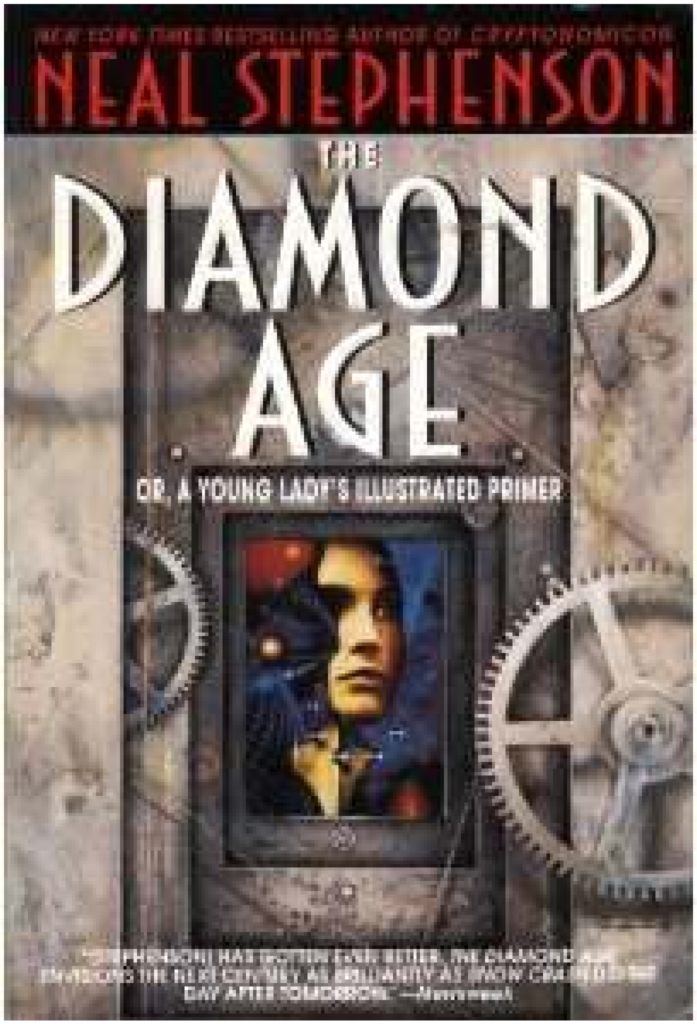
Smart Dust Idea

Berkeley´s Smart Dust project (Professors Pister and Kahn)



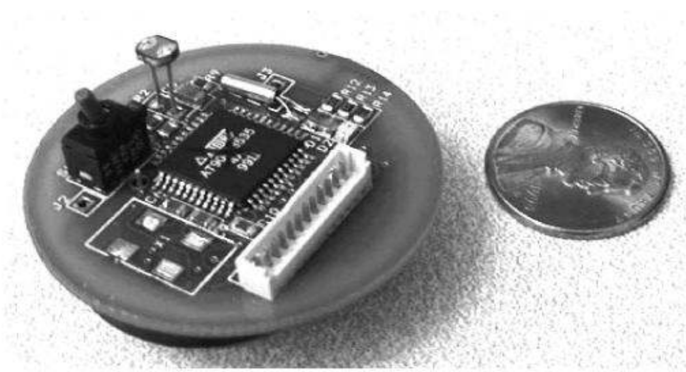
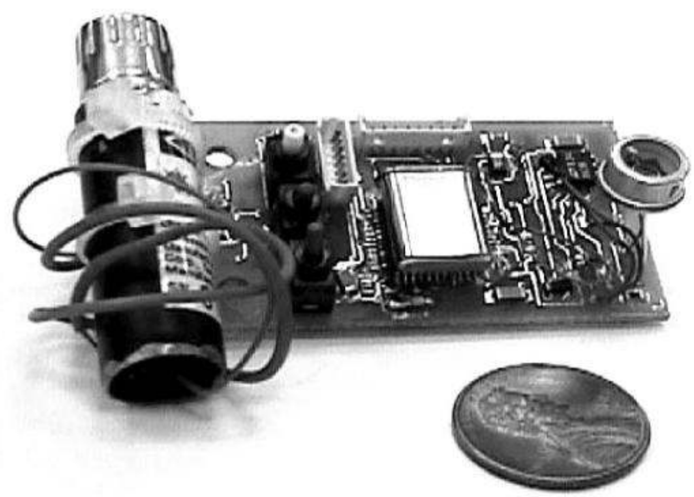


Introduction

- Integrate sensing, communication, and power supply

- Digital circuitry
- Wireless communications
- Micro ElectroMechanical Systems (MEMS).

} reduction in size, power consumption and cost

Smart Dust Technology

- Main concern

  Networking and applications challenges

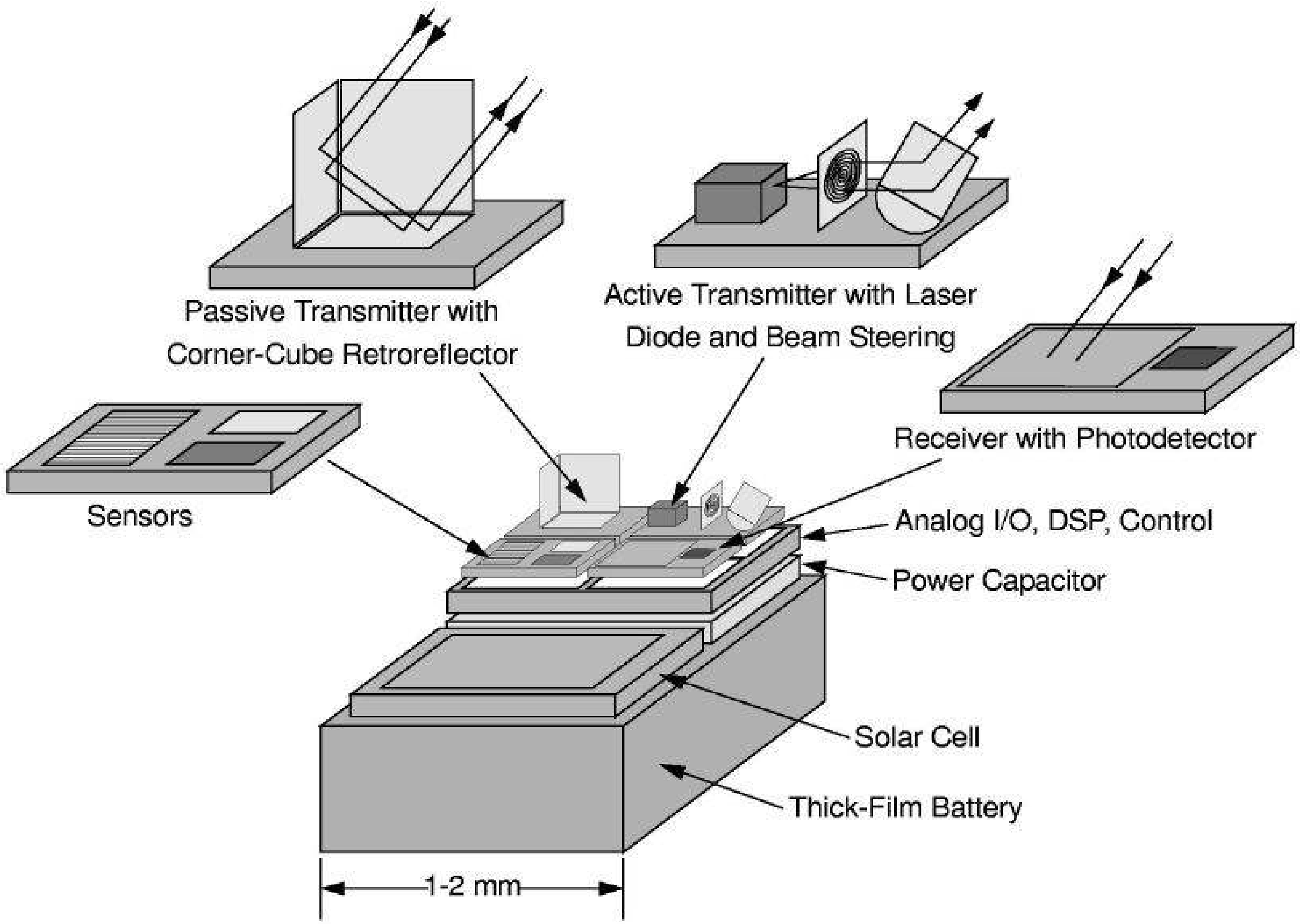
  Requirements: low power, low data rate, high volume

  Solution: novel routing and MAC

- Major challenge:

incorporate all functions while maintaing requirements

Smart Dust Technology



- ✓Microfabricated sensors
- ✓Optical receivers
- ✓Passive and active optical transmitters
- ✓Signal processing
- ✓Control circuitry
- ✓Power sources

Energy

- Total Stored energy is on the order of 1 J

- Solar cell gains about 1 J per day in the sun and 1mJ per day with room light.

- Energy-optimized microprocessor uses about 1 nJ per 32-bit instruction

- Networking challenge: allocate energy
  - Sensing
  - Computation
  - Transmission

Ultra-low power: RF or Optical

- Critical challenge: communication architecture (RF/optical)

- RF cons:
  - Extremely short-wavelength transmission
  - complex circuitry and so difficult to reduce power consumption

- Optical Cons:
  - Line-of-sight needed (within a few tens of degrees)

Optic Pros

- Low energy per bit (simple baseband circuitry, no modulator/active bandpass filters/demodulator)

- High antenna gain can be achieved with very low power

- A base-station can decode simultaneous transmissions with *Space-division multiplexing*

- Passive optical transmission
  - No optical power needed

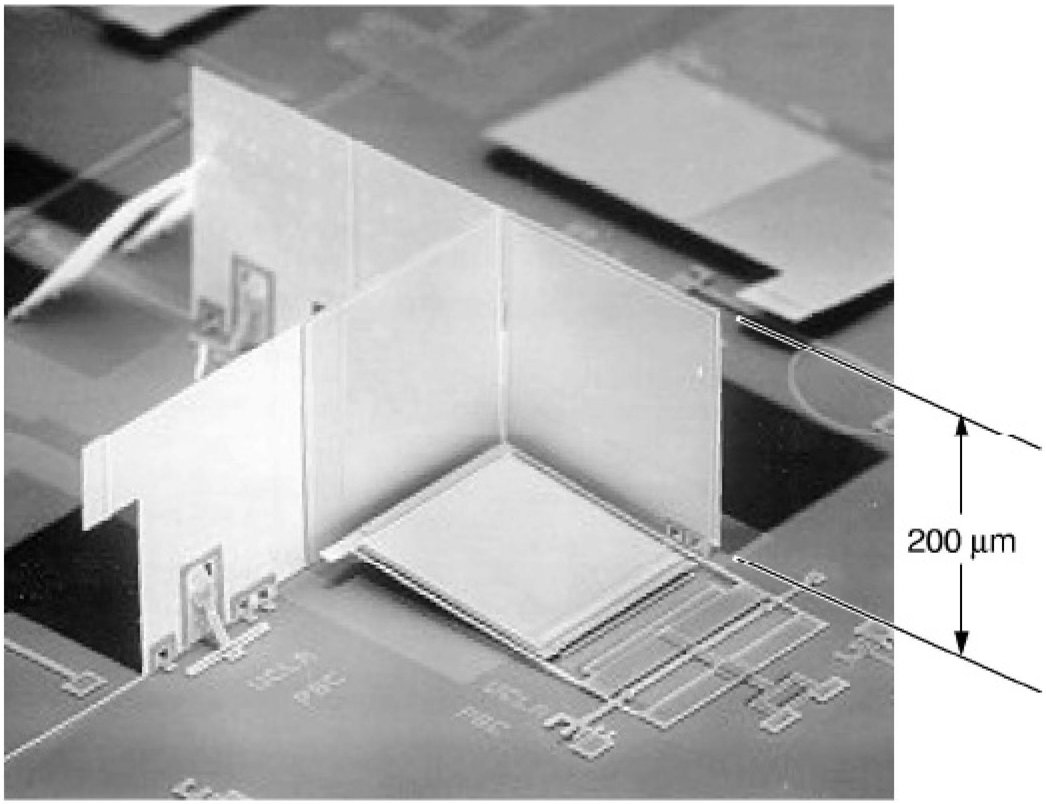
- Corner-Cube Retroreflector (*CCR*)

Corner-Cube Retro Reflector

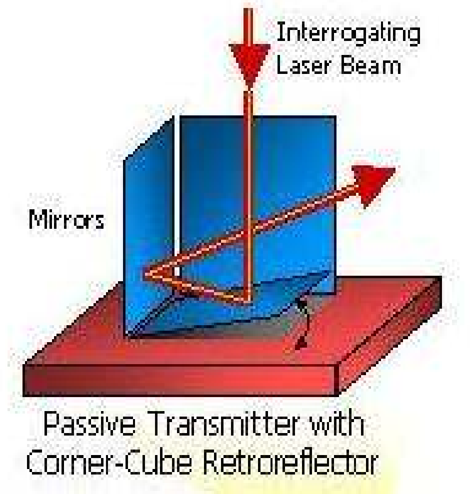
- To supply signals without any power

- It comprises three perpendicular mirrors of gold-coated polysilicon

- CCR includes an electrostatic actuator deflects on of the mirrors at kilohertz rates.



CCR-Passive (1/2)



- Transmit without light source
- Uninterrupted line-of-sight path
- Directional (directly to the BTS)
- Emerging more Omni-directional by use of several CCRs in different directions

CCR-Passive (2/2)

- BTS contains a laser to *illuminates* area of dust nodes

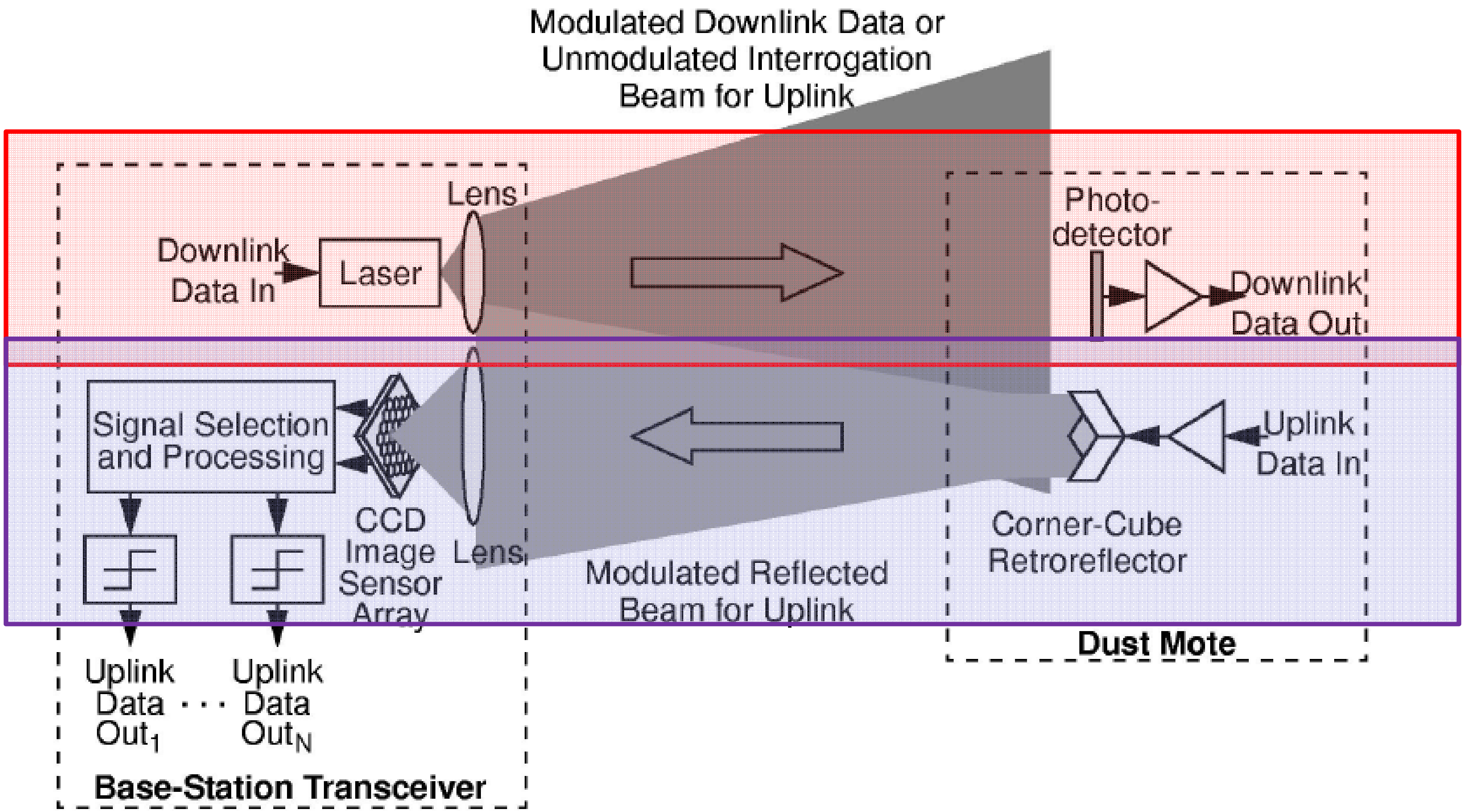
- Modulated beam contain downlink data + commands to wake up and Query

- Non modulated beam transmit uplink by CCRs

- Uplink achieves several kbps + hundreds of meter in full sunlight

- Design is simple

Free space optical network



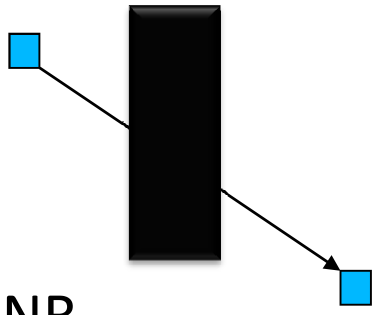
Mobile Networking Challenges

1- Requirement of uninterrupted line-of-sight path

2- Directional characteristics of active and passive transmitters

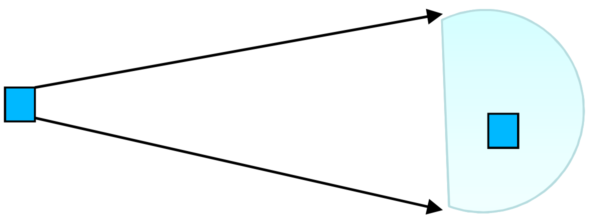
3- trade-off b/w bit rate, energy per bit, distance and directionality

Line-of-sight



- Smart dusts require unbroken links for reliable transmission
- Transmitted beam with small angular spread -> high SNR
- Specular reflection may not increase the angular spread -> proper alignment of specular reflector
- Diffuse reflection scatters energy over a range of angles
- Non-line-of-sight mote to BTS communicate multihop. Increases latency and forces to use active transmitters.
- Floating dust motes transmit intermittently when line-of-sight exists

Link Directionality (1/2)



Beam angular spread should match the dust field.

Mote´s receiver has an omnidirectional photodetector

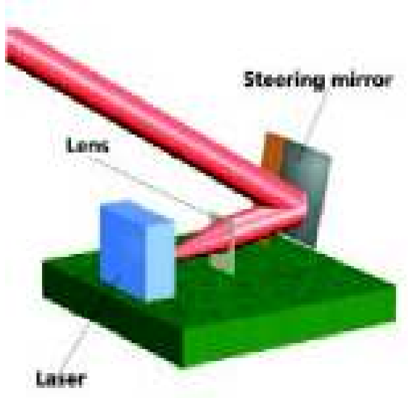
Passive with CCR reflects light in a few tens of degree

With one CCR, possibility of transmitting to BTS is 10% , increases by using several CCRs in different directions.

Link Directionality (2/2)

- Active dust mote transmitter based on laser diode.

- Beam steering to send beam to a desired direction.



- Dust mote transmitter and receiver have different angular spread.

- Link directionality lead to hidden node problem during medium access

Trade-offs

- Should provide many trade-offs

- One critical metric is SNR: governs the possibility of bit error.

$$SNR = C.\frac{E_b^2 R_b A^2}{N_0 d^4 \phi^4}$$

$$E_b \propto R_b^{-1/2}$$

$$P_t = \frac{E_b}{R_b}$$

$$SNR = C.\frac{P_t^2 A^2}{N_0 R_b d^4 \phi^4}$$

$$P_t^2 \propto R_b . d^4$$

$$R_b \propto d^{-4}$$

E_b	Transmitter energy
P_t	Transmitter power
R_b	Bit rate
A	Receiver collection area
N_0	Receiver noise power
d	Link transmission distance
ϕ	Transmitter beam angular spread

Mobile Networking Opportunities

1- perform read-out from large volume of sensors in small area

2- use a mixed active and passive approach using demand access

Parallel read-out

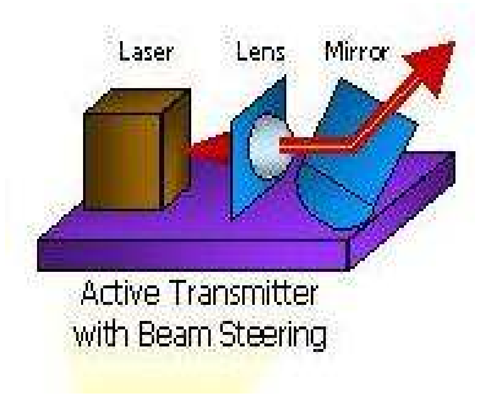
- BTS transmitter scatters a single beam to dust motes

- BTS receiver gets the multiple reflected beams from motes as they are sufficiently separated

- BTS receiver sweeps three dimensional space covered by it to collect reflected beams

Demand access

- Suitable demand access combines active communication (low latency) and passive communication (low power)



- Use active transmitter when they have data to send. BTS detects the signals and send probe to that geographical area. Mote uses passive transmitter to respond the probe with a modulated beam.

Applications

- Attach to objects or float in the air
- Motes record sensor readings and report them with optical communication
- In some apps motes send directly and passively to BTS and in some apps peer-to-peer active b/w motes and relay to BTS
- BTS maybe in distance of tens meters to kms.

Applications

- Used in civilian and military apps. Deploy to record geophysical or planetary research. Perform measurement in environments were wired are not used.

- In biological research, monitor movement, habits and environment of insects and small animals.

- In military research, monitor hostile. Acoustic, vibration, or magnetic sensors detect vehicles.

Multi sensor behaviour

- Deploy mixture of sensors and self organize

- Specialized to detect certain signature: motion, heat, sound. One sensor detects event and notifies neighbors.

- Sensing function do intelligent process. Detects intruder, distinguish b/w human and animal. Integrate motion and thermal sensor readings.

- **Complex**: increase scan rate to get higher resolution signature or dedicate energy to a narrow band or specific direction.

- **Challenge**: Max detection probability and resolution while min power consumption

Why is Ad-hoc needed?

Two ways to make these systems: centralized and ad-hoc

In centralized, motion and heat motes communicate directly with BTS in a passive way while having most power efficient way.

In a line-of-sight blockage, use active transmitter and ad-hoc technique to communicate with other motes and BTS.

Multihop routing is challenging because of laser directionality. It doesn´t scatter to all directions. Two way communication of motes is unlikely.

Why is Ad-hoc needed?

Assume static arrangement: in a **discovery algorithm**, each node know its ID and set of directions pointing at.

In discovery phase, a mote broadcasts to all in the direction. E.g. one mote says I am ID1 and I am pointing to (x,y). Other hearing says I am ID2 and pointing to (i,j), ***heard*** ID1 pointing at (x,y).

Routings like OSPF, RIP, DVRMP are for bidirectional and symmetry links. Not suitable for smart dust with unidirectional and asymmetry link.

Technology approach

- Possible solution: use MEMS technology for on-board inertial navigation.

- When sensors lose line-of-sight, then BTS send probe with the info of their location and their neighboring location.

- The on-board inertial combined with location information assist orientation.

Summary and Conclusions

- *"Smart Dust" an inexpensive way* to setup small low power sensors which can communicate to a central BTS and/or each other

- Attacked the line-of-sight issue with 3 possible Solutions
    1. *use more CCRs*
    2. *distribute excess motes*
    3. *steer the beam in a right direction*

- Opened up leads into two main future work focuses
    1. *New routing algorithm to deal with unidirectional*
    2. *A Beam-steering algorithm*

Thanks!