Emerging Challenges: Mobile Networking for “Smart Dust”

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Overview

- Focus
- Hardware
- Challenges
- Technology
- Applications
- Related Project
- Conclusions
Focus

• Large scale network of Wireless sensors are becoming more and more plausible

• Networking and application layers are needed to make such a system usable.
Hardware

• Can now integrate sensing, communication, and power supply into an inch-scale device. (off-the-shelf)

• 3 technologies leading this advance:
  – Digital circuitry
  – Wireless communications
  – Micro ElectroMechanical Systems (MEMS)
Key Challenges

- Must consume extremely low power
- Must communicate at average bit rates measured in kilobits p/sec
- Must operate in high volumetric densities

- How?
  - Needs ad hoc routing
  - Media Access solutions
Smart Dust mote

Fig. 2. Smart dust mote, containing microfabricated sensors, optical receiver, passive and active optical transmitters, signal-processing and control circuitry, and power sources.
Energy

• Total Stored energy is on the order of 1 J
  – If that is consumed continuously over a day, then the dust mote power consumption cannot exceed roughly 10mW

• Solar cells could gain about 1 J per day in the sun

• Energy-optimized microprocessors user about 1 nJ per 32-bit instruction
  – Bluetooth burns about 100nJ per bit transmitted
  – Picoradios target 1nJ/bit – which will allow billions of operations per Joule
Ultra-low power: RF or Optical

• RF cons:
  – Extremely short-wavelength transmission
  – Energy Issues
    • Difficult to reduce to such low power consumption

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

- 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)
Achieves several kilobits per second over hundreds of meters in full sunlight

At night it should extend to at least a kilometer
Line-of-sight?

- Receiver is fairly omni-directional (forget about it)

1. With one CCR a mote has about a 10% chance of being able to transmit to BTS
   - Equip it with several CCRs

2. Distribute an excess number of motes (expecting many to not be able to communicate)

3. Steer the Beam in the right direction
MAC protocol

- Sensor-MAC (S-MAC)
- Etiquette Protocol
- CSMA for Sensor Networks
- Z-Mac
Passive and Broadcast-oriented techniques

• A single wide beam from BTS can simultaneously probe many dust motes

• Motes transmit in short-duration burst signals
  – similar to cell phones

• BTS grants channels to requesting nodes

• There are as many channels as resolvable pixels at the BTS
Applications

- Used to record data for meteorological, geophysical or planetary research

- Environments where wired do not work
  - (semiconductor processing chambers, rotating machinery, wind tunnels, anechoic chambers)

- Biological:
  - Measure movements, habits, and environments of insects and small animals

- Military:
  - (passage of vehicles, perimeter surveillance, chemicals)
Operate in Ensembles

• Sensors can specialize in certain signatures and combine for more useful information
  – A change in temperature may not mean much
  – A change in sound level probably doesn’t tell us enough
  – Movement could mean many things

• The combined array through P2P could determine that a vehicle just pulled up with at least 2 men
Why is Ad hoc needed?

• The centralized/passive scheme is most power efficient way to communicate.

• Line-of-sight (again)
  – The mote will have to use Ad hoc if line-of-sight to BTS is not possible
  – Requires 4 phase handshake

• Standard routing algorithms like RIP, OSPF, and DVRMP assume bidirectional and symmetric links
  – New routing algorithms must be able to deal with unidirectional and/or asymmetric links
Related Projects

- **Factoid Project** at Compaq Palo Alto Western Research Laboratories

- **Wireless Integrated Network Sensors (WINS) Project** at UCLA

- **Ultralow Power Wireless Sensor Project** at MIT
Summary and Conclusions

- “Smart Dust” has described 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.

- Opened up leads into 3 main future work focuses:
  1. New routing algorithm to deal with unidirectional
  2. A p2p collision avoidance scheme to deal with dynamic networks
  3. A Beam-steering algorithm