Communications and Energy-Harvesting in Nanosensor Networks

Michele C. Weigle
Intelligent Networking and Systems Lab (iNetS)
Department of Computer Science
Old Dominion University
Norfolk, VA

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My Background

• Vehicular Networking
  – the use of vehicles as sensors to detect traffic incidents on the road

• Sensor Networks for Emergency Assistance
  – re-tasking existing sensor networks for use in emergency situations
  – investigating energy issues
Why Not Go Smaller?
Nanosensor Networks

- Framework articulated by Ian Akyildiz's group at Georgia Tech
- Investigated network properties, coding, MAC protocols, energy harvesting
- We're just getting started, building on their work (many images from Akyildiz and Jornet)
Applications of Nanosensor Networks

- Biomedical
- Environmental
- Industrial and consumer goods
Nanosensor Networks

- Inspired by biological nanoscale networks
- Communication
  - molecular
  - electromagnetic - our focus
Electromagnetic Communication

• Graphene-based nanoantenna
  – graphene nanoribbons (GNR) formed by unzipping carbon nanotubes (CNT)

• Radiates waves in the terahertz (0.1-10 THz) band

http://www.jmtour.com/images/NatureUnzippingImages/TubeUnzipping.png
Terahertz Band

- Supports very high transmission rates in the short range
  - up to a few terabits per second
  - distances below 1 meter
Pulse-Based Communication

• Not feasible to generate high-power carrier signal used in classical communications
  – motivates the need for pulse-based communication

• Femtosecond-long pulses ($10^{-15}$ second) proposed

• This introduces major changes in classical networking protocols
**TS-OOK**
(Time Spread On-Off Keying)

- **Example Encoding**
  - '1' - 100 fs (0.1 picosecond) pulse
  - '0' - silence
  - 50 ps between bits
TS-OOK Example

• With femtosecond pulses, probability of collision is almost non-existent
  – senders transmit when they have data ready

• With long inter-bit times, multiple senders can interleave transmissions
Communication and Power

• Max capacity of nano-battery - 800 pJ
• Transmission of single pulse - 1 pJ
• Reception of a single pulse - 0.1 pJ
Message Coding

- Encode the message such that there are more 0s transmitted than 1s
  - 0 is silence, costs no energy

- Code weight
  - average portion of 1s

- Lower code weight, more bits

<table>
<thead>
<tr>
<th>original (2 bits)</th>
<th>3-bit packet (weight = 0.25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>000</td>
</tr>
<tr>
<td>01</td>
<td>001</td>
</tr>
<tr>
<td>10</td>
<td>010</td>
</tr>
<tr>
<td>11</td>
<td>100</td>
</tr>
</tbody>
</table>
Energy Harvesting

• Nanosensors have the potential to harvest energy from their surroundings
  – solar, thermal, electromagnetic, vibration

• Vibration seems to be the best method for nanosensors

• Allows nanosensors to re-charge themselves
Energy Harvesting

- Time to charge depends on vibration rate (needs 2500 cycles to charge)
  - A/C vents (50 Hz) ≈ 50 sec
  - human heart beat (1 Hz) ≈ 42 min

- Charging time is not linear

- Arrival of energy is not predictable in all scenarios
Impact on Communication

• Energy harvesting phase is orders of magnitude larger than communication phase

• End-to-end delay significantly affected if forwarding nodes need to recharge before forwarding packet
Other Limitations

• Limited resources (memory, power) for storage and modulation

• Significant molecular absorption of pulses
  – expensive energy needed for retransmission
  – limited resources for error correction

• Dense network scenarios (100 nodes in 1 cm²) need special multi-hop design
Our Focus

• Model communications and energy-harvesting process

• Develop and evaluate strategies for coding, packet size, bit repetition, and packet retransmission to produce efficient and power-aware network transmissions

Joint work with PhD student Shahram Mohrehkesh and Dr. Stephan Olariu
Our Road Ahead

• We're just at the beginning of our investigation

• Development of customized protocol layers
  – pulse-based communication models
    • coding methods to send fewer 1s
    • error correction/detection methods: repetition, LDPC, hamming
  – energy harvesting-aware
    • MAC protocol
    • packet scheduling
    • packet formation
  – optimized model for throughput and delay, end2end delivery, reliability

• Development of simulation environment
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mweigle@cs.odu.edu
http://www.cs.odu.edu/inets

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