11-9-2012

Communications and Energy-Harvesting in Nanosensor Networks

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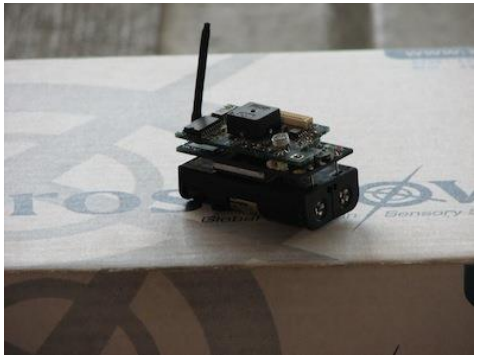
NSF Workshop on Biological Computations and Communications
November 9, 2012

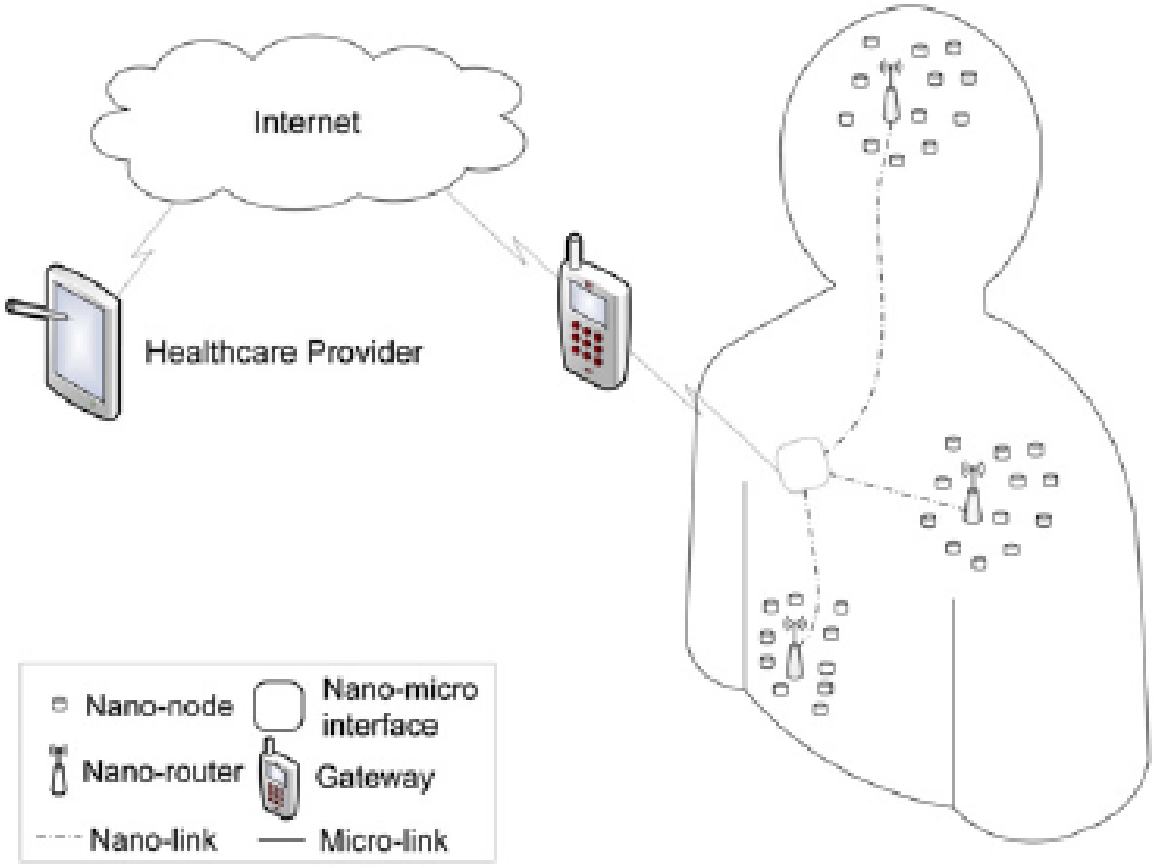
My Background

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

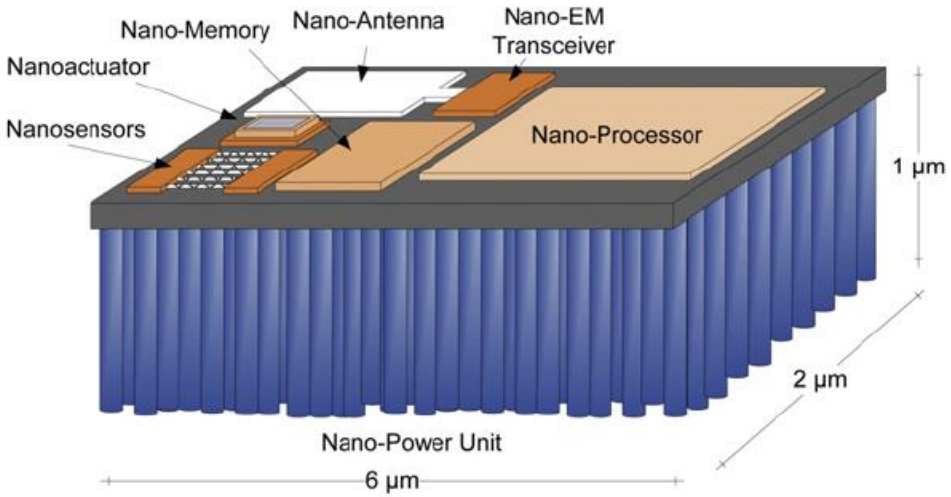
- Sensor Networks for Emergency Assistance
  - re-tasking existing sensor networks for use in emergency situations
  - investigating energy issues



Why Not Go Smaller?



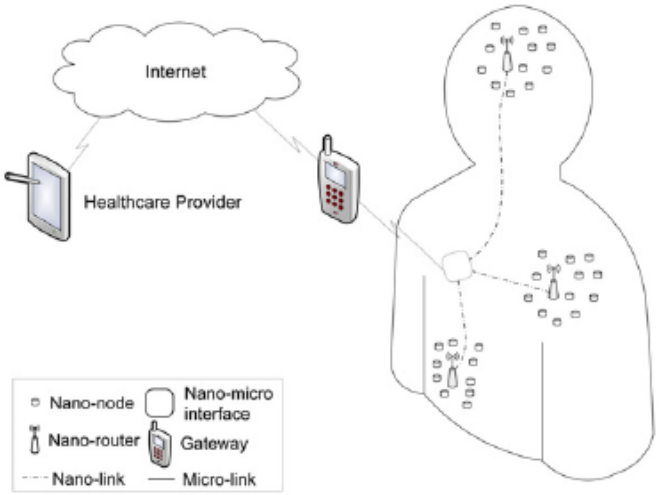
Nanosensor Networks

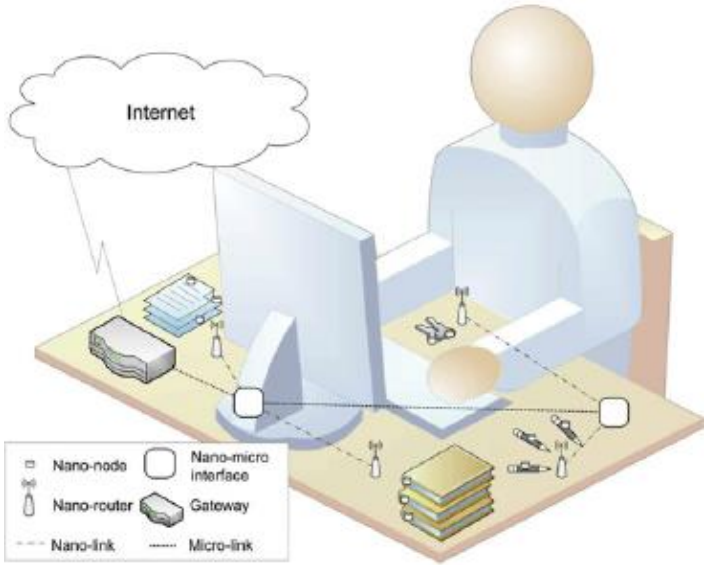


- Framework articulated by Ian Akyildiz's group at Georgia Tech
- Investigated network properties, coding, MAC protocols, energy harvesting
- We're just getting started, building on their work
  (many images from Akyildiz and Jornet)

Applications of Nanosensor Networks

- Biomedical
- Environmental
- Industrial and consumer goods

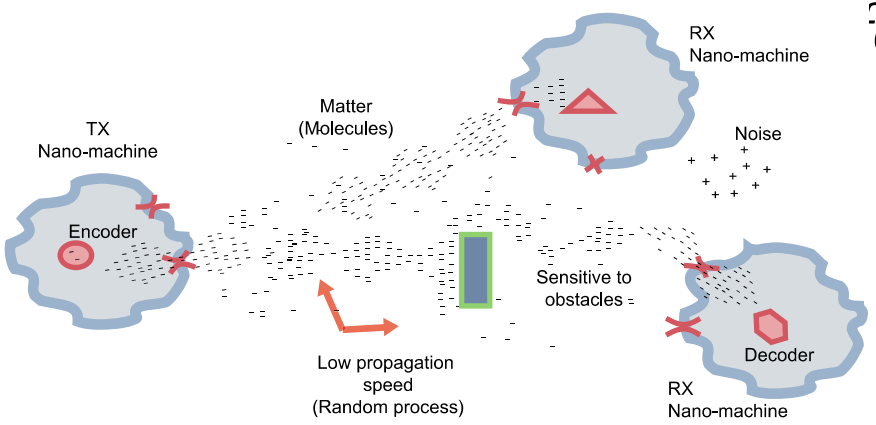




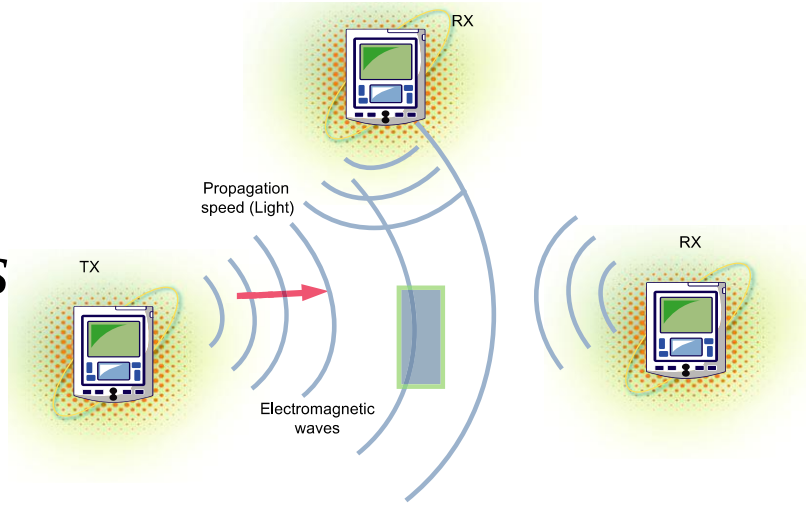
Nanosensor Networks

- Inspired by biological nanoscale networks

- Communication
  - molecular



focus



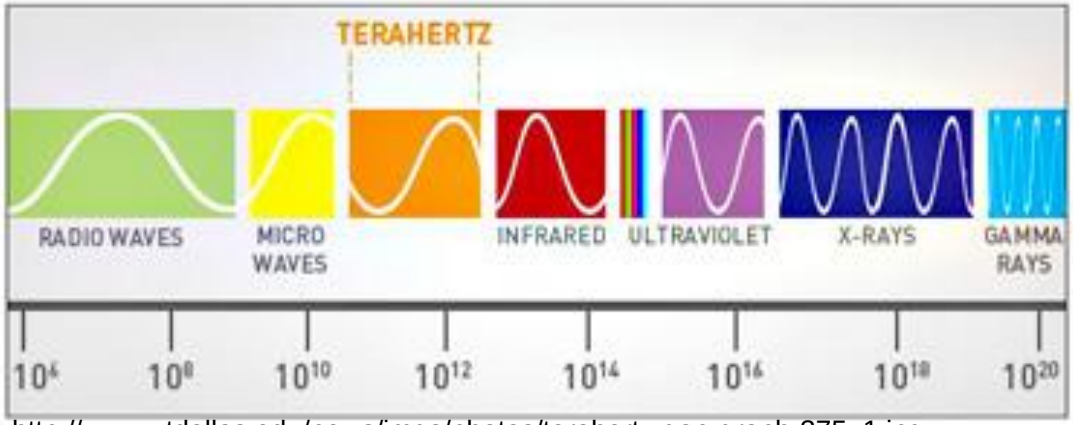
Electromagnetic Communication

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

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

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

Terahertz Band



http://www.utdallas.edu/news/imgs/photos/terahertz-gap-graph-375_1.jpg

- 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)

Jornet and Akyildiz
IEEE ICC, 2011

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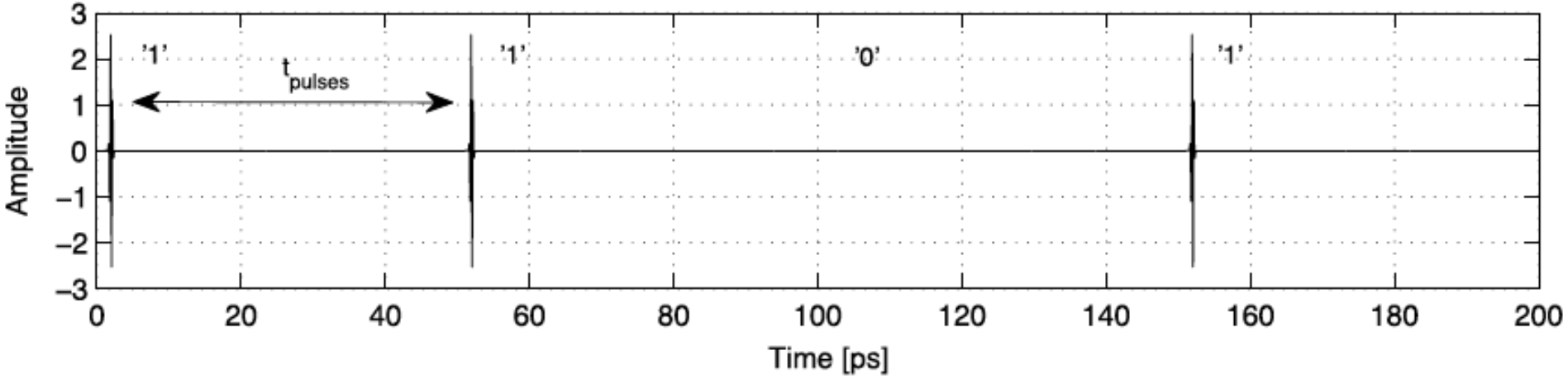
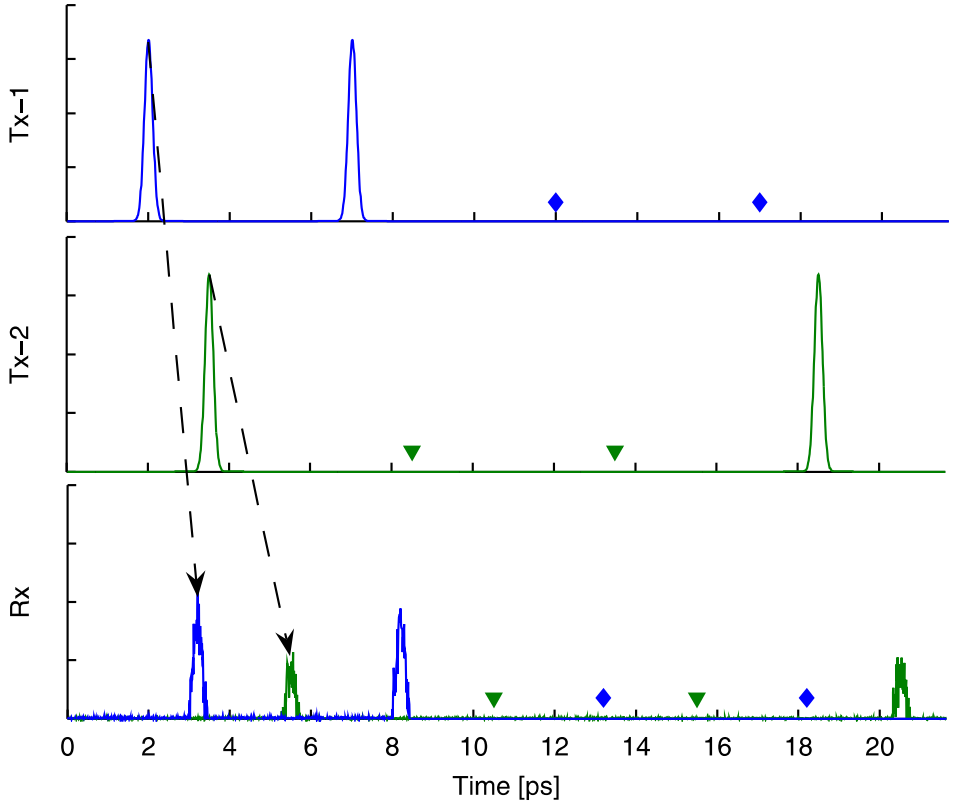


- Example Encoding
  - '1' - 100 fs (0.1 picosecond) pulse
  - '0' - silence
  - 50 ps between bits

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



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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

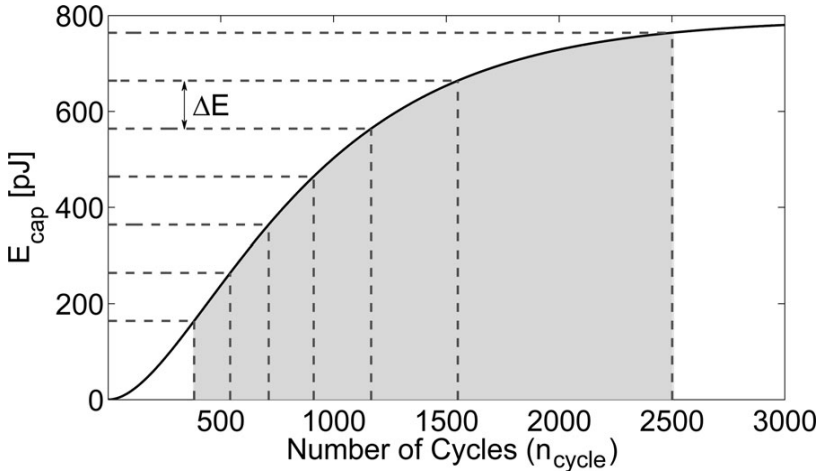
original (2 bits)	3-bit packet (weight = 0.25)
00	000
01	001
10	010
11	100

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

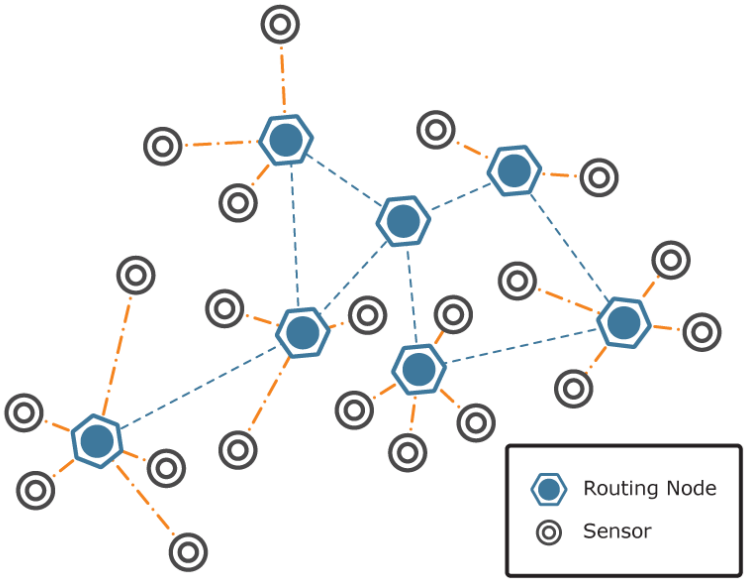
- Time to charge depends on vibration rate (needs 2500 cycles to charge)
  - A/C vents (50 Hz) =~ 50 sec
  - human heart beat (1 Hz) =~ 42 min
- Charging time is not linear
- Arrival of energy is not predictable in all scenarios



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 cm^2) need special multi-hop design

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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

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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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