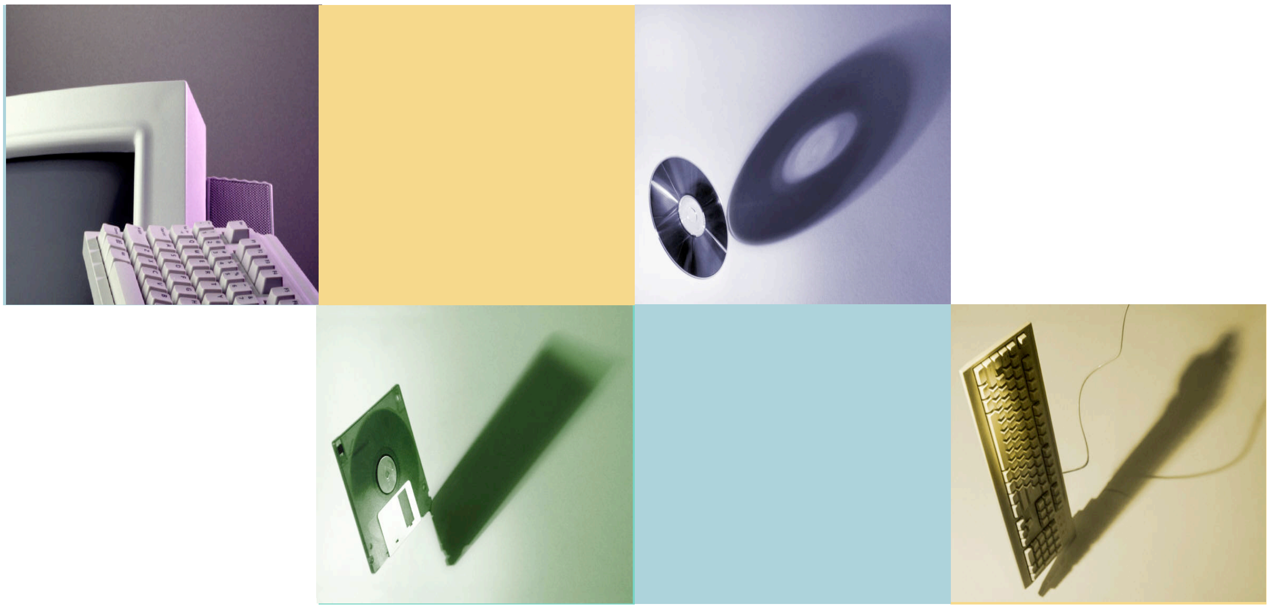
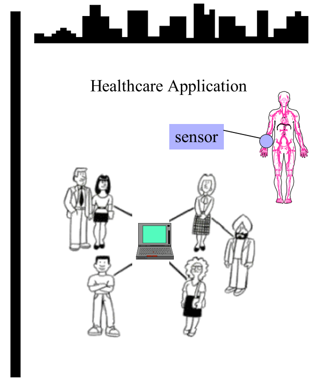
Protocol Design and Optimization for

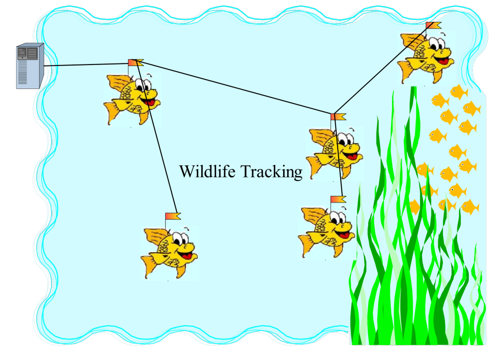


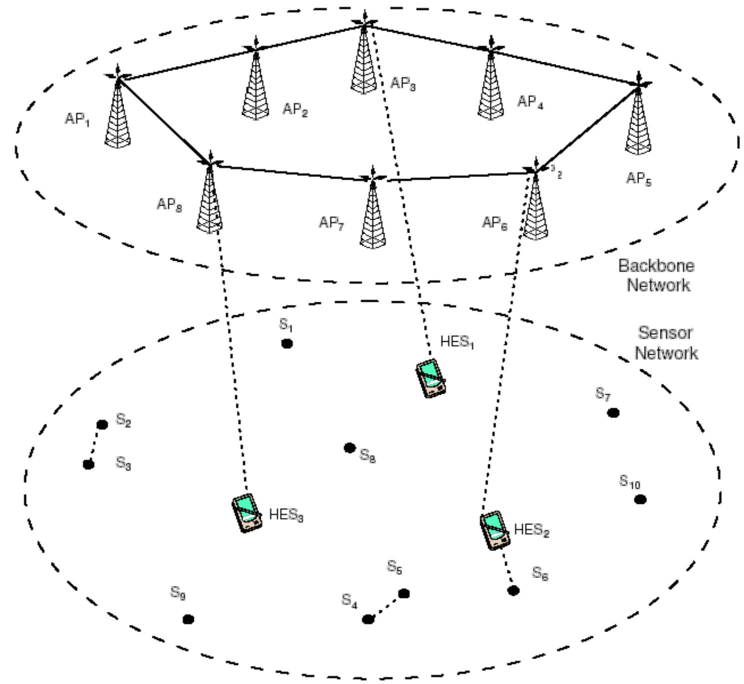
Yu Wang, **Hongyi Wu***, Feng Lin, and Nian-Feng Tzeng
Center for Advanced Computer Studies
University of Louisiana at Lafayette

Mobile Sensor Networks

- Applications:
  - Air quality monitoring
  - Flu virus tracking
  - Military …
- Two Layer Architecture
- Unique characteristics:
  - Nodal mobility
  - Sparse connectivity
  - Delay/fault tolerability
  - Limited buffer
- Challenge
  - Mainstream approaches of sensor networking do not work effectively.



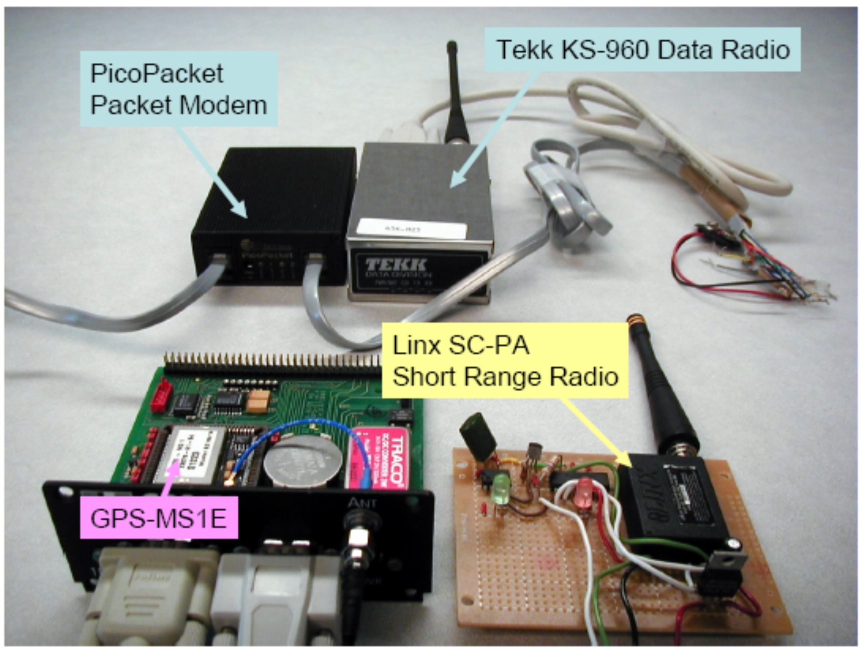




Delay/Fault-Tolerant Mobile Sensor Network (DFT-MSN)

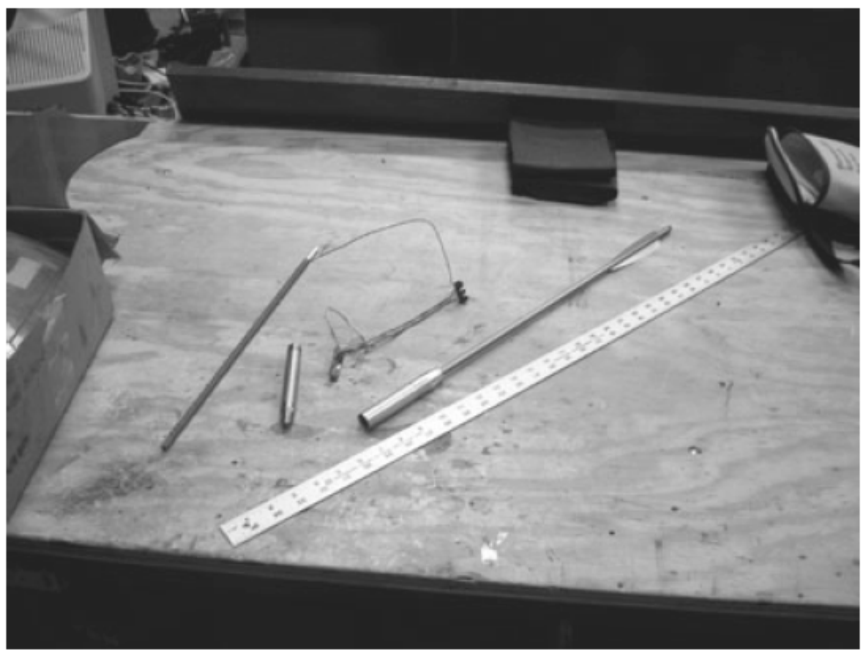
Related Work: ZebraNet

- ZebraNet employs the mobile sensors to support wildlife tracking for biology research.
- A position-aware and power-aware wireless system.
- A history-based approach for routing
  - Routing decision is made according to the node’s past success rate of transmitting data packets to the base station directly.



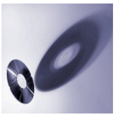
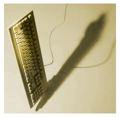
Shared Wireless Info-Station (SWIM)

- Where there is a Whale, there is a Way
  - Gathering biological information of radio-tagged whales
  - A sensor node distributes a number of copies of a data packet to other nodes so as to reach the desired data delivery probability.



Prior Studies (INFOCOM'06)

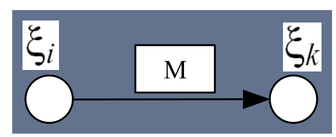
- A few questions to be answered:
  - What are the differences? Why is unique?
  - Any insights into the possible solutions?
- Studies of two basic approaches
  - Direct Transmission
    - M/G/1 Queuing Model
    - Lemma: service time is Pascal distributed
  - Simple Flooding
    - Analyze flooding overhead, delay, and delivery probability
- Fundamentally an opportunistic network
  - Communication links exist with certain probabilities
  - Replication is necessary for data delivery in order to achieve desired success ratio
  - Tradeoff: delivery ratio vs. overhead

Proposed Data Transmission Protocol

- Questions 1:
  - When and where to transmit data messages, when a communication link becomes available?
    - Direct Transmission: sink only
    - Flooding/SWIM: any sensors or sinks
    - ZebraNet: the sensor that meets sink more frequently
    - ➔ Define a new metrics to indicate the likelihood that a sensor can deliver data messages to the sink
  - Nodal Delivery probability: <u>Initial value</u>: 0
  - Update (EWMA):

$$\xi_i = \begin{cases} (1-\alpha)[\xi_i] + \alpha\xi_k, & \textit{Transmission} \\ (1-\alpha)[\xi_i], & \textit{Timeout}, \end{cases}$$



- $[\xi_i]$: delivery probability of sensor i before it is updated
- α: constant employed to keep partial memory of historic status
- ξ_k: delivery probability of node k

Proposed Data Transmission Protocol

- Questions 2:
  - Which messages to be transmitted (or dropped) first?
    - Not considered in existing solutions
    - ➔ Define a new metrics to indicate the importance of message
  - Fault tolerance: the probability that at least one copy of the message is delivered to sink by other sensors in the network. <u>Initial value</u>: 0 for a new message
  - Update:

Old fault tolerance degree

Nodal delivery probability

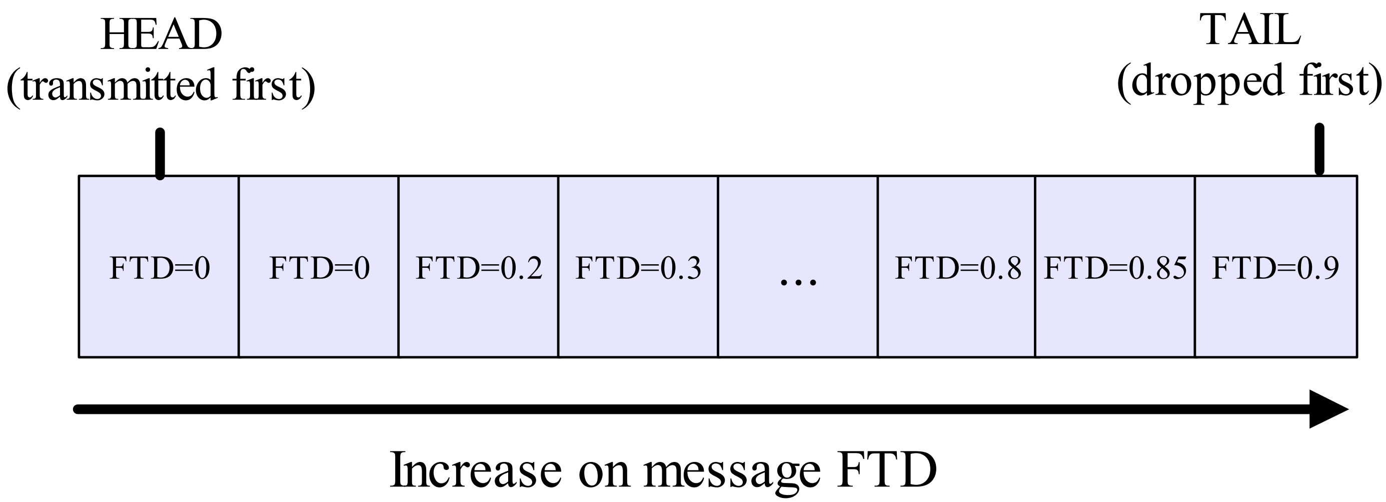
$$\mathcal{F}_{\psi_z}^{j} = 1 - (1 - [\mathcal{F}_i^{j}])(1 - \xi_i)\prod_{m=1,\ m\neq z}^{Z}(1 - \xi_{\psi_m})$$

Probability that at lease one other node can delivery the message

Probability that all the other … except node z, can not delivery the message

Queue Management

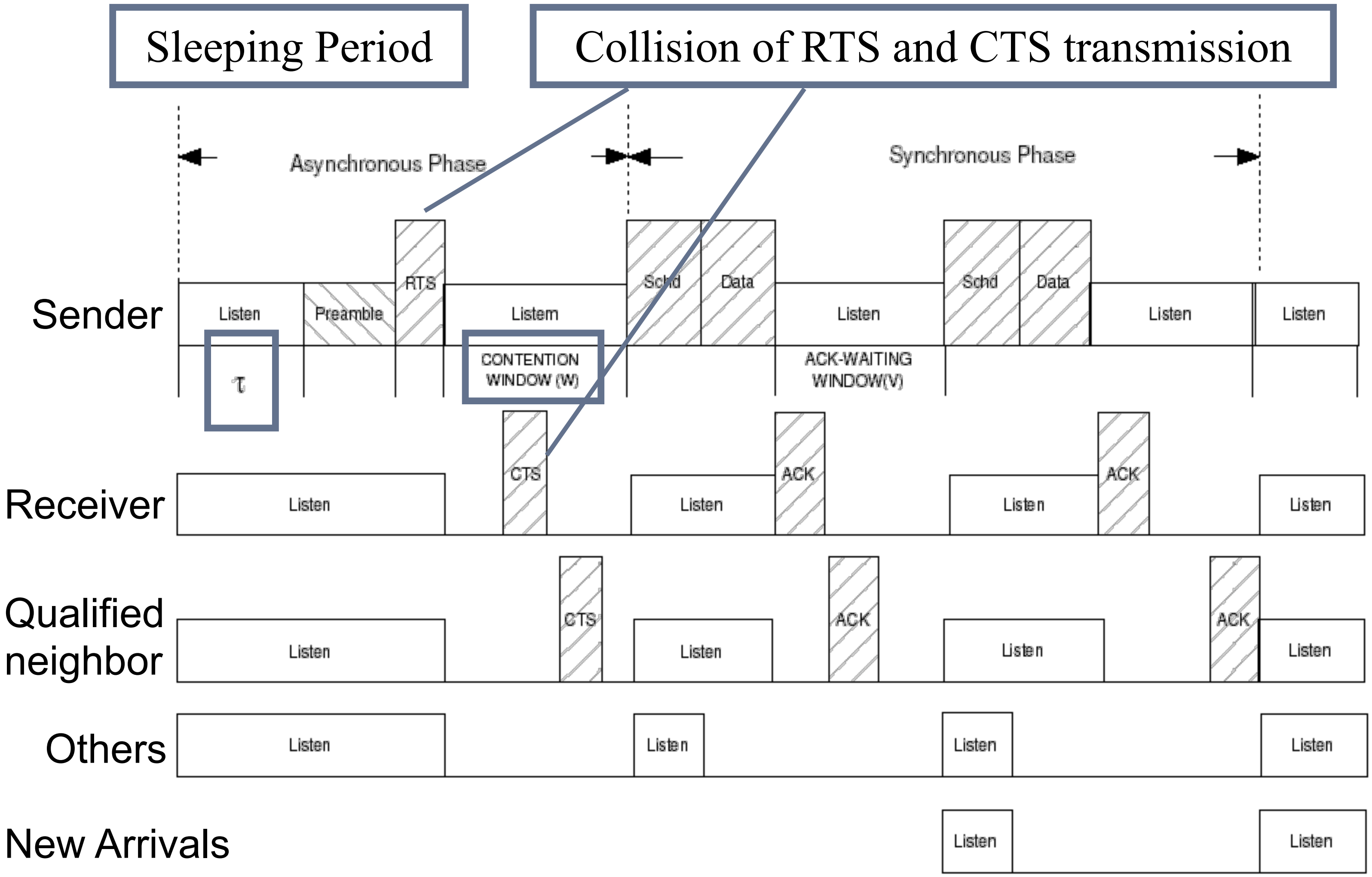
- The queue management scheme is based on message fault tolerance



Cross-layer Approach

- Without end-to-end connections, routing becomes localized and ties closely to Layer 2 protocols
- Two phases protocol
  - Phase I (asynchronous): a sender contacts its neighbors to identify a subset of appropriate receivers. Since no central control exists, the communication in the first phase is contention-based.
  - Phase II (synchronous): sender gains channel control and multicasts its data message to the receivers.
- Tradeoff: link utilization vs. energy efficiency.
  - Communication links are scarcest resources
  - Battery power of sensor nodes is also crucial

Two-Phase Data Delivery

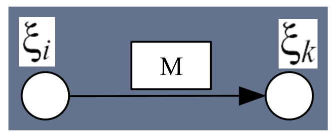


Protocol Optimization

- Periodic sleeping
  - Link utilization vs. energy consumption
  - Optimize sleeping period by two factors
    - Efficiency: likelihood to do a successful transmission upon waking up ➔ past success rate
    - Urgency: likelihood to lose important data if not wake up ➔ message fault tolerance and buffer space
  - Modeling and optimization

Protocol Optimization

- Collision Avoidance in RTS Transmission
  - Tune the listening period ➔
  - Minimize the collision probability of the node with lowest delivery probability

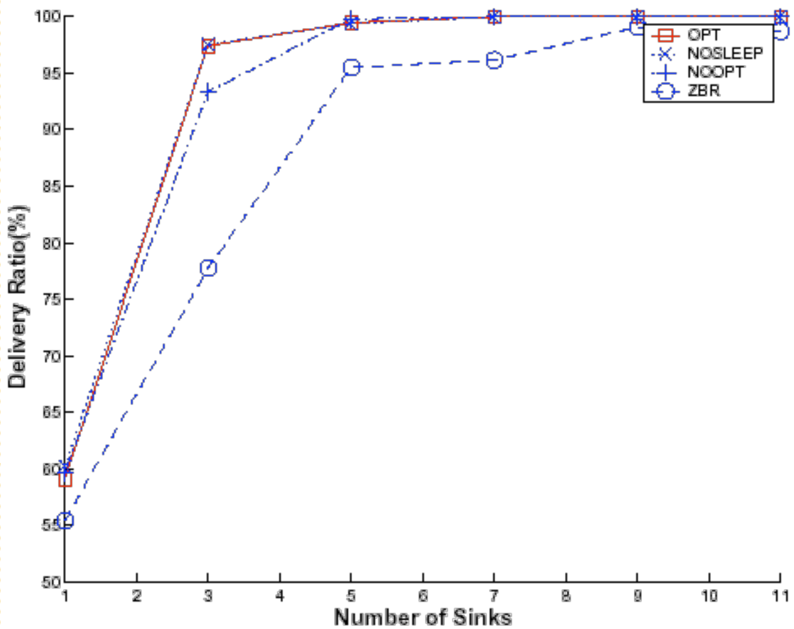


    - Allow node with lower delivery prob. to have a higher chance to win channel contention and become sender
    - A node chooses its RTS contention window reverse proportional to its nodal delivery probability
  - Model channel contention and derive collision probability

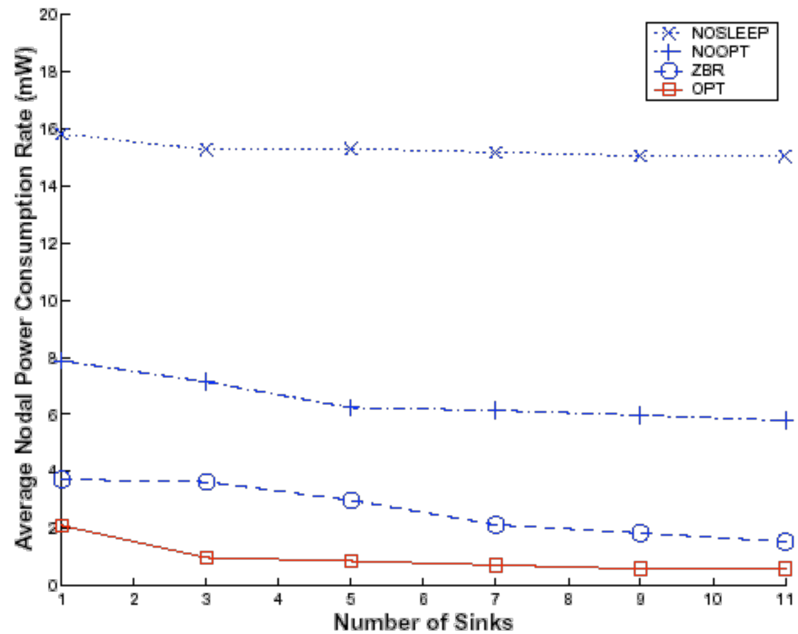
Protocol Optimization

- Collision in CTS Transmission
  - The node with higher delivery probability is more likely to be selected as receiver
  - CTS contention window is proportional to nodal delivery probability
  - Model contention and minimize collision probability

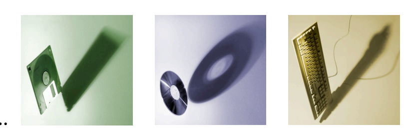
Simulation Results



(a) Delivery ratio.

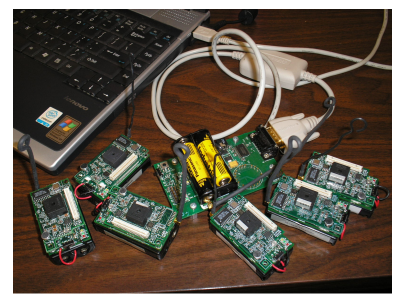


(b) Energy consumption



Summary and Other Work

- Proposed a two-phase cross-layer protocol for DFT-MSN
- Optimized the protocol parameters
- Done simulation to show its efficiency
- Other work
  - Different transmission schemes
    - Erasure-coding-based Approach
    - Cluster-based Data Delivery
  - Modeling
    - Generic Queuing Analytic Model
    - Mobility Modeling
  - Prototyping and Experiments



Questions?