An Architecture for a Power-Aware Distributed Microsensor Node

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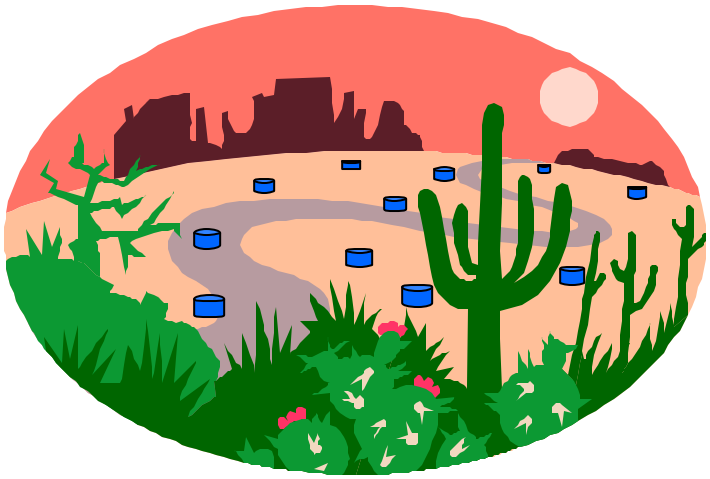
Distributed Microsensor Networks

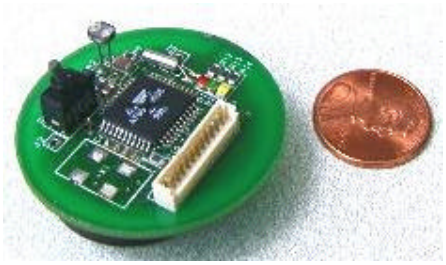


An alternative to macrosensors

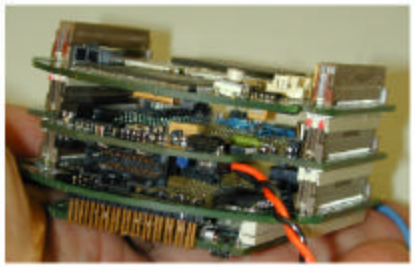
- Small, ubiquitous, easily deployed nodes
- Collaborative data gathering, *ad hoc* networking for fault-tolerance
- Battery replacement not an option:

How to achieve months/years of operation from a single battery?

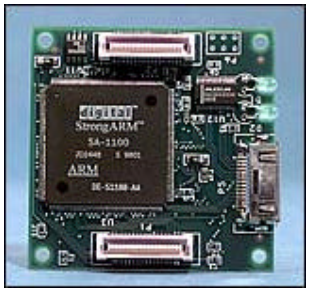
- **Some prototype nodes under active research:**



Smart Dust



PicoRadio



WINS

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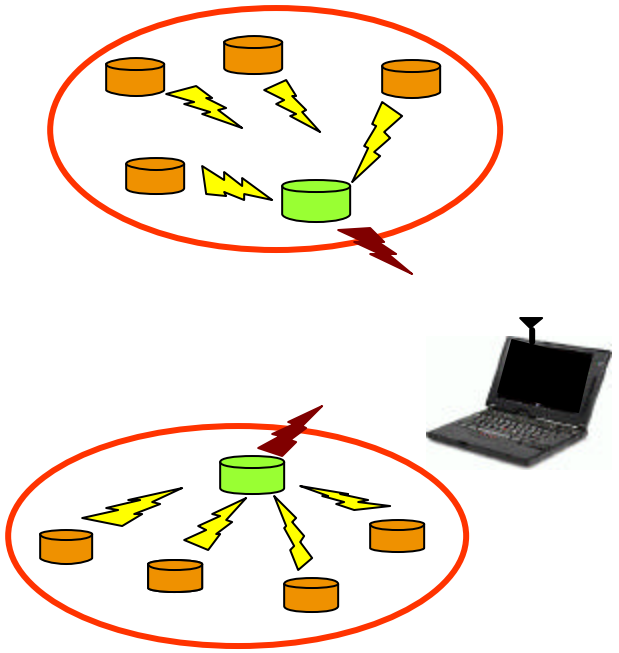
Operational Characteristics

- **Event driven**
  - Low duty cycles
- **Low bandwidth**
  - bits/sec to kbits/sec
- **High Spatial Density**
  - 0.1 nodes/m^2 to 20 nodes/m^2
- **Short transmission distances**
  - 5-10m typical (< 100m)



- **High operational diversity:**

...from network roles

- **Sensor**
- **Relay**
- **Data aggregator**

...from the environment

- **Event arrival rate/type**
- **Ambient noise**
- **Signal statistics**

...from user demands

- **Tolerable latency**
- **Result SNR**
- **Pr(Detection)**

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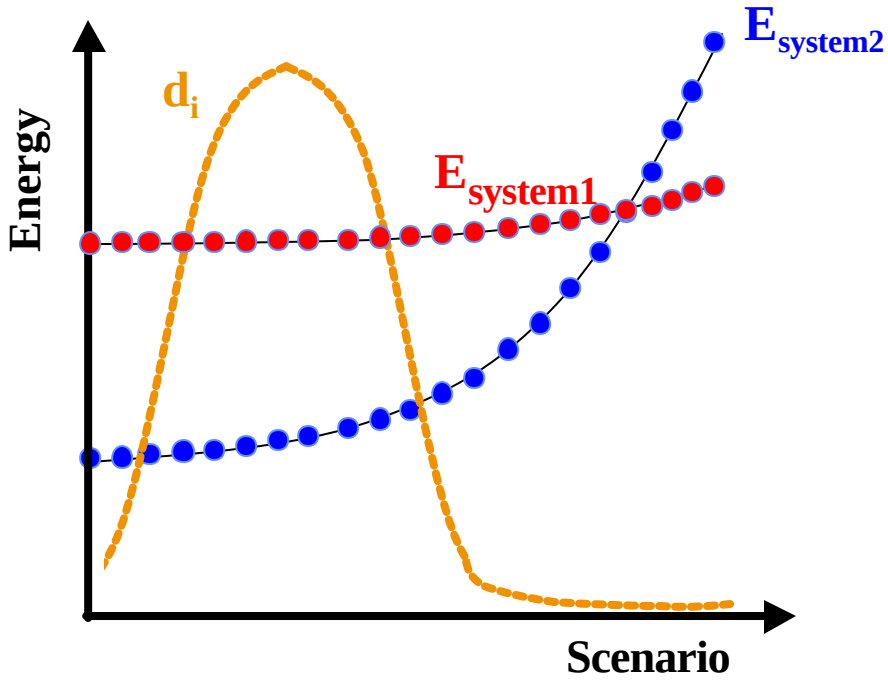
Characterizing Diversity

- ***Scenario:*** **the space of possible operating points**
- ***Scenario distribution:*** **quantifies diversity as a distribution d_i**
- ***Energy curve:*** **E_{system} characterized for each operating point**



Power-aware systems have a low $E_{system}d_i$ product

A Power-Aware Sensor Node

Low-Power Design

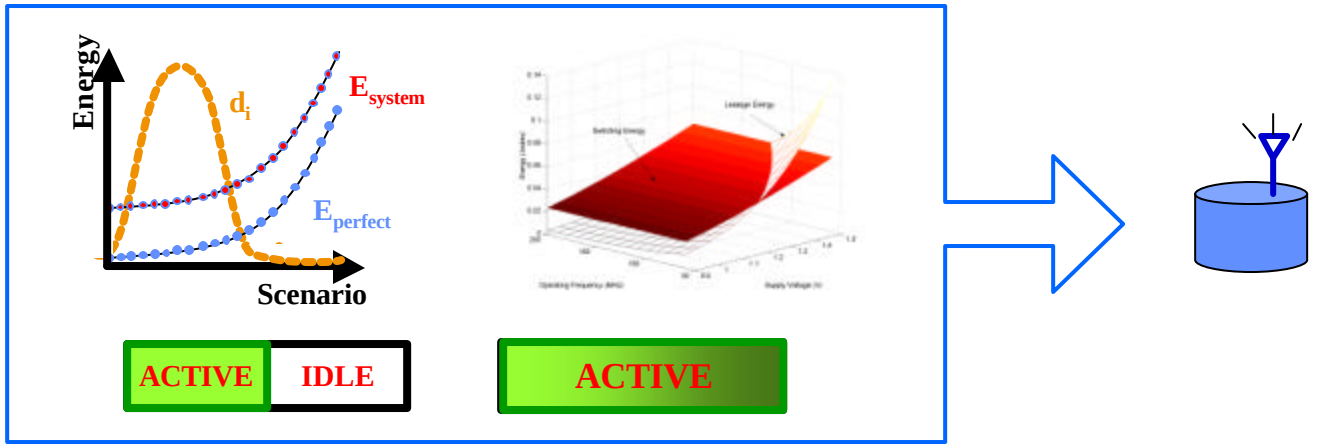
- Component-by-component optimization
- Reduction of worst-case power dissipation

Power-Aware Methodologies

- Graceful energy scalability across a diversity of operating conditions
- Energy-quality trade-offs
- Collaboration across levels of the system hierarchy

MIT mAMPS: Adaptive Multi-Domain Power-Aware Sensors

A sensor node that demonstrates power-aware methodologies



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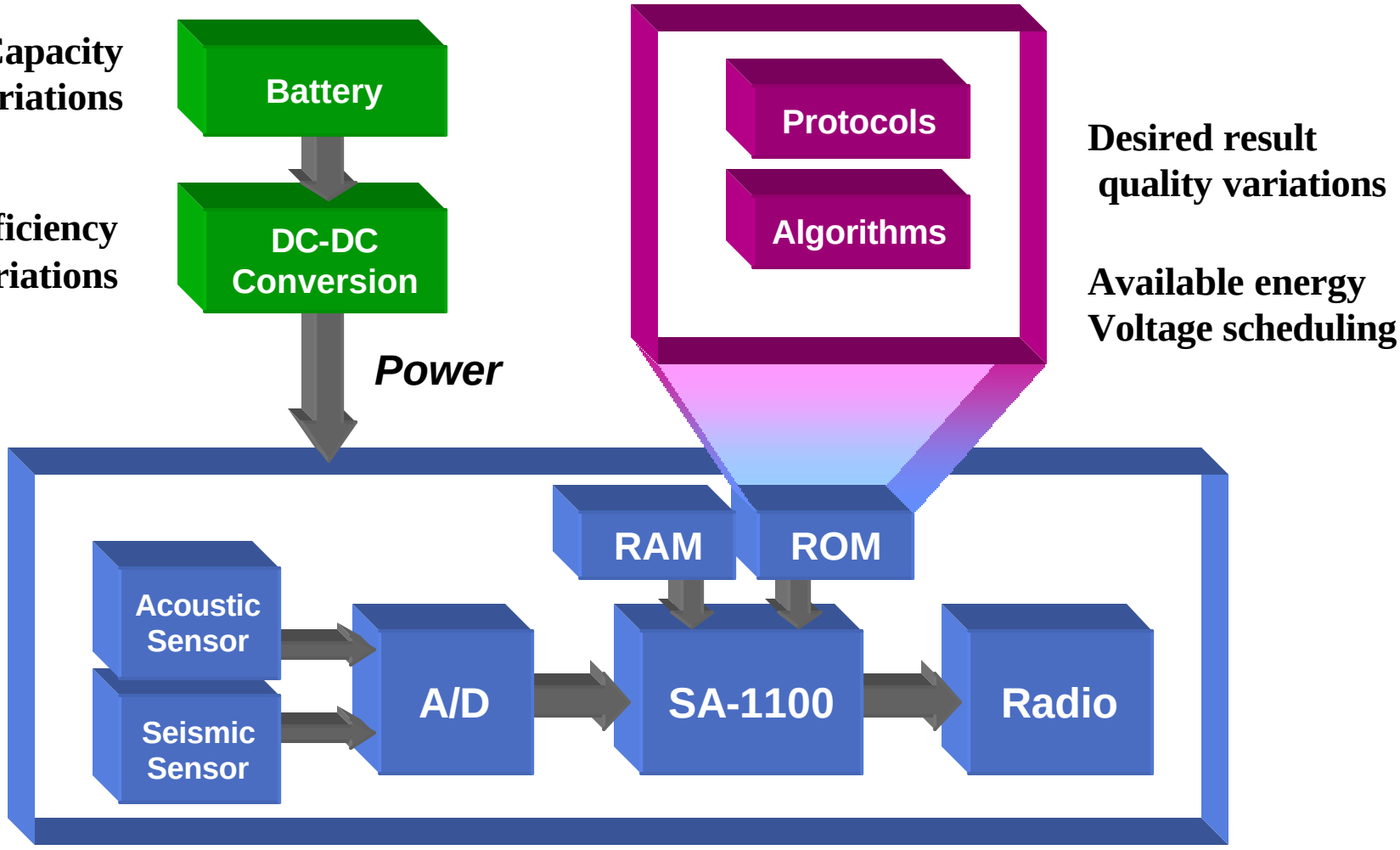
Power-Aware Node Architecture



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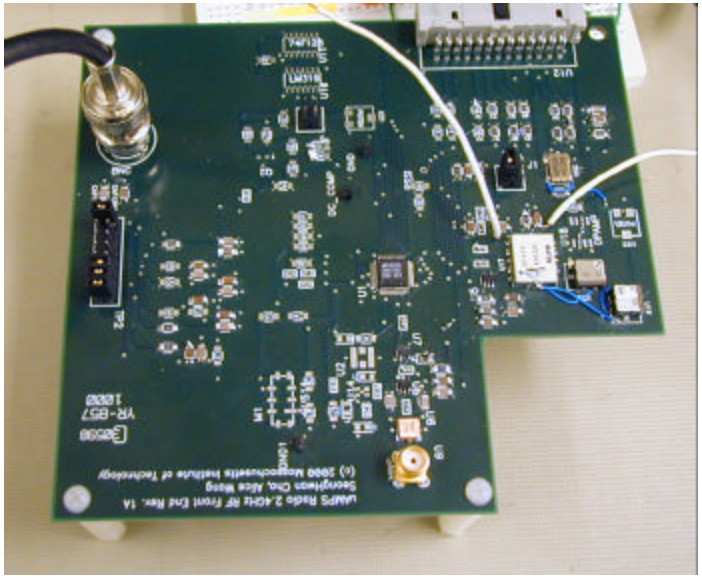
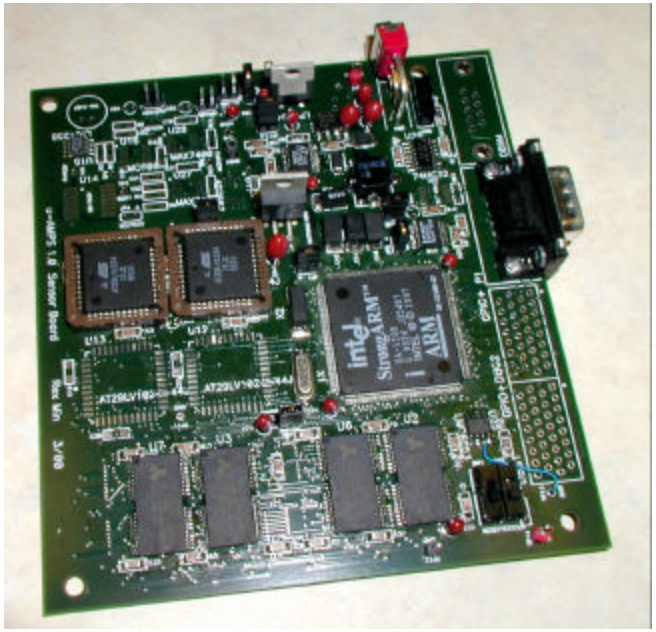
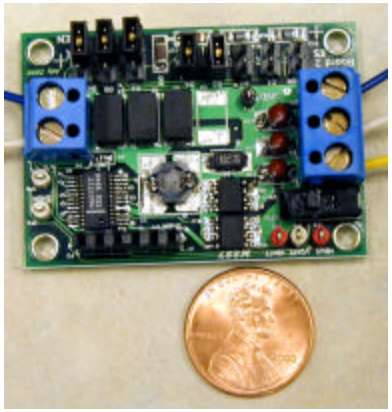
Node Prototype



radio baseband



sensor/processor board



miniaturized DVS control
(Nathan Ickes)

- **Version 1 prototype with COTS components**
- **Advanced iterations will feature custom chipsets**

Power-Aware Methodologies

- **Idle mode:** deepest possible shutdown with minimum overhead
  - **Leakage current control**
  - **Radio duty cycles**
  - **Sleep state assignment**

- **Active mode:** scalability in energy consumption exploits node's operational diversity
  - **Dynamic voltage scaling**
  - **Energy-quality scalable algorithms**
  - **Variable-strength error correction**
  - **Current profiles for maximum battery capacity**

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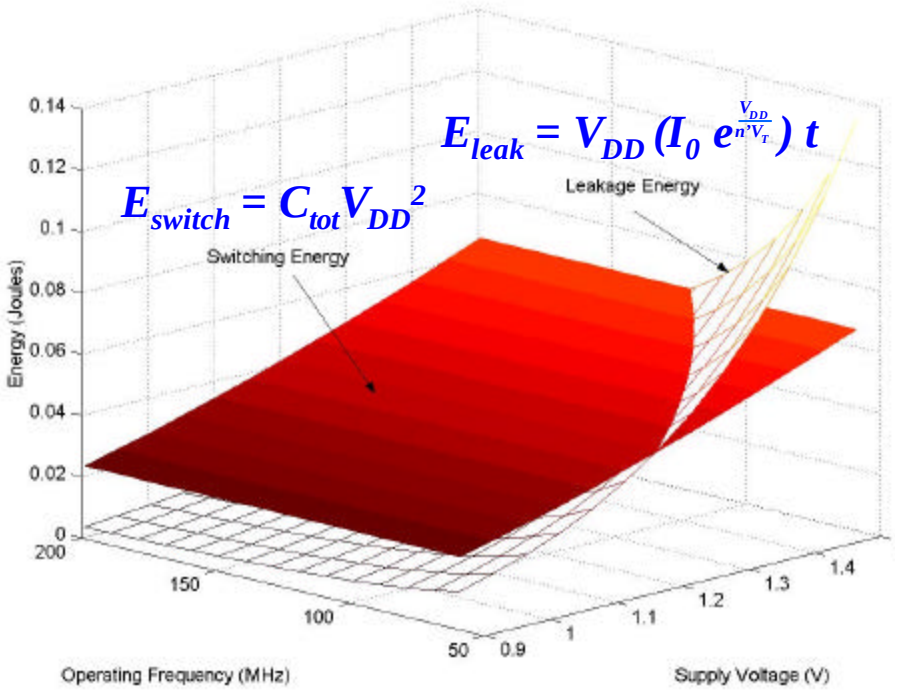
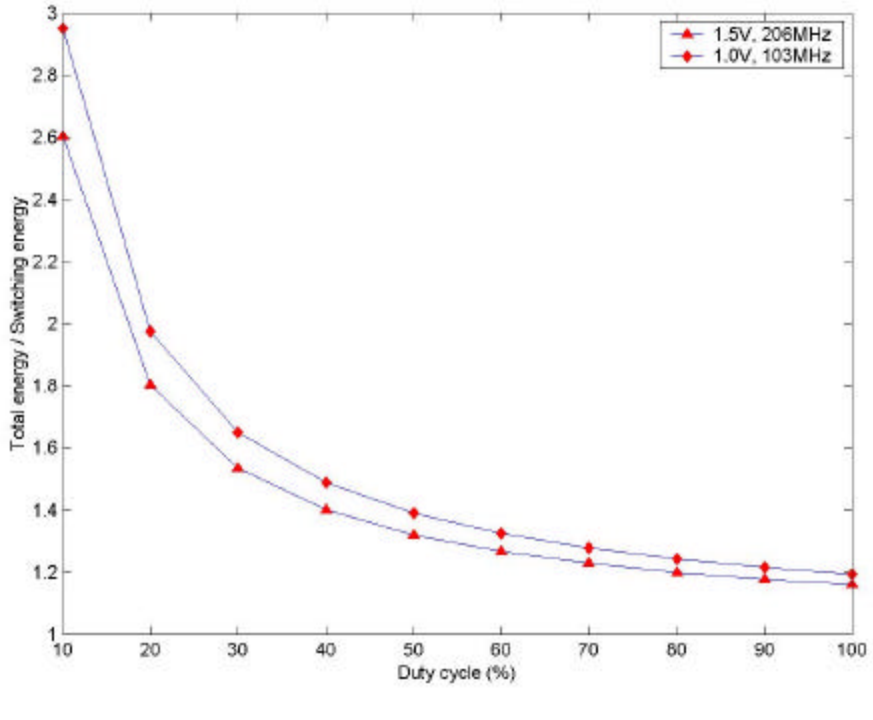
Idle Mode: Leakage Current Control





Measurements from SA-1100

- **Leakage dominates switching energy for low duty cycles**
- **A major concern for event-driven sensor operation**

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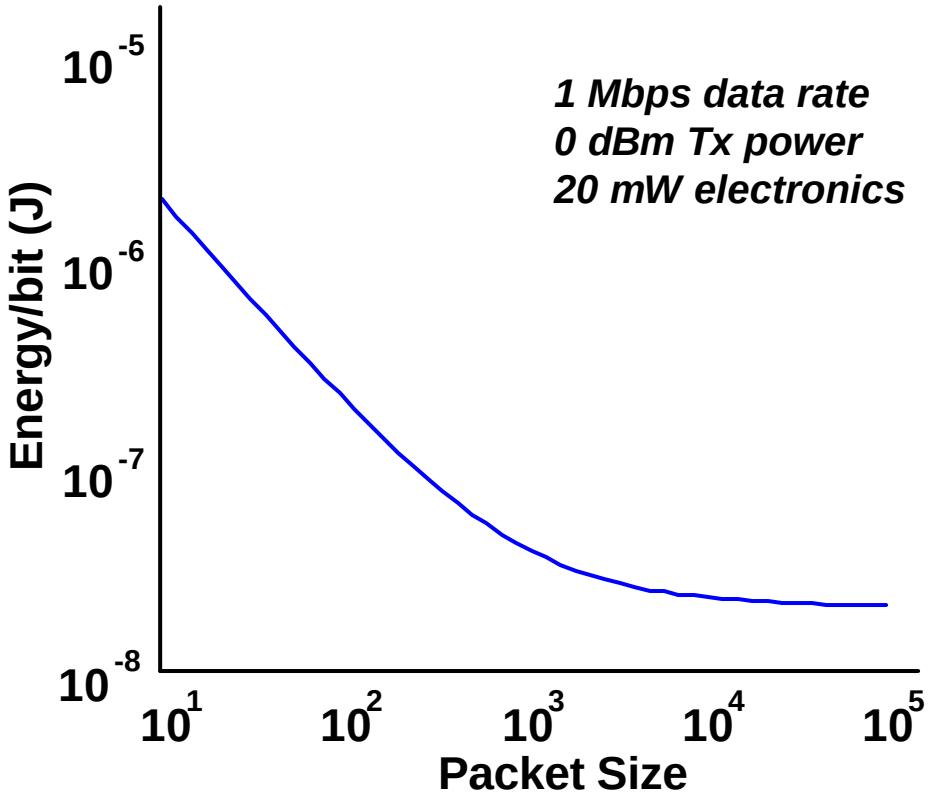
Radio Considerations



- **Startup energy can dominate transmission energy for short distances and packets**
  - **Demands power-aware network protocols**
  - **Favors buffering if latency is tolerable**

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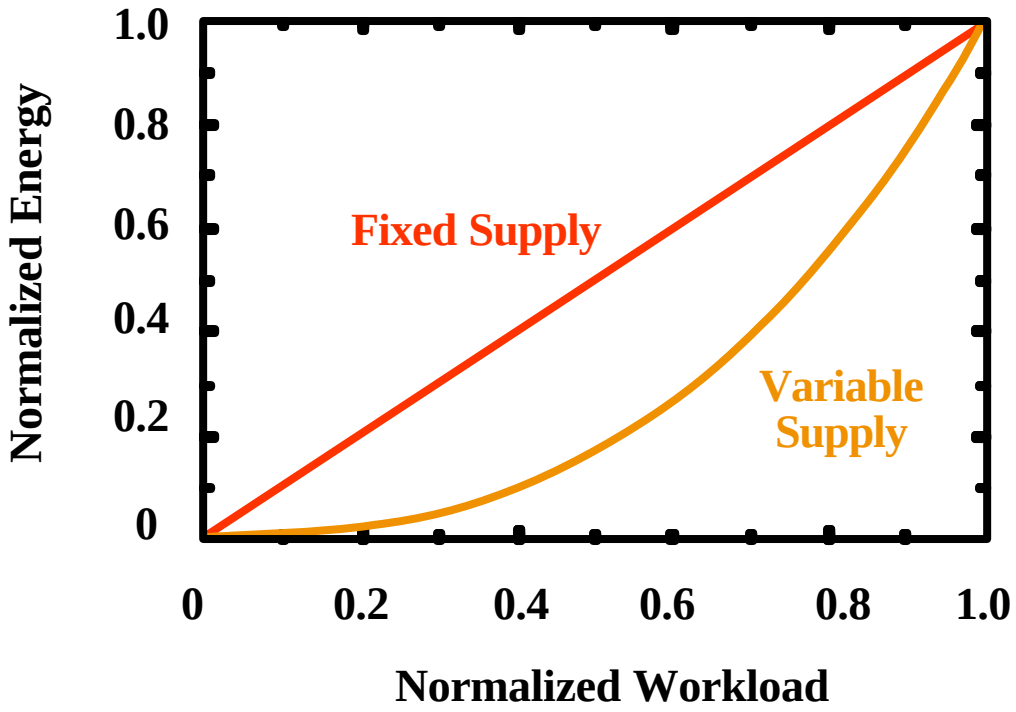
Active Mode: Dynamic Voltage Scaling

Fixed Power Supply

Variable Power Supply

$$E_{FIXED} = \frac{1}{2} C V_{DD}^2$$

$$E_{VAR} = \frac{1}{2} C (V_{DD}/2)^2 = E_{FIXED} / 4$$



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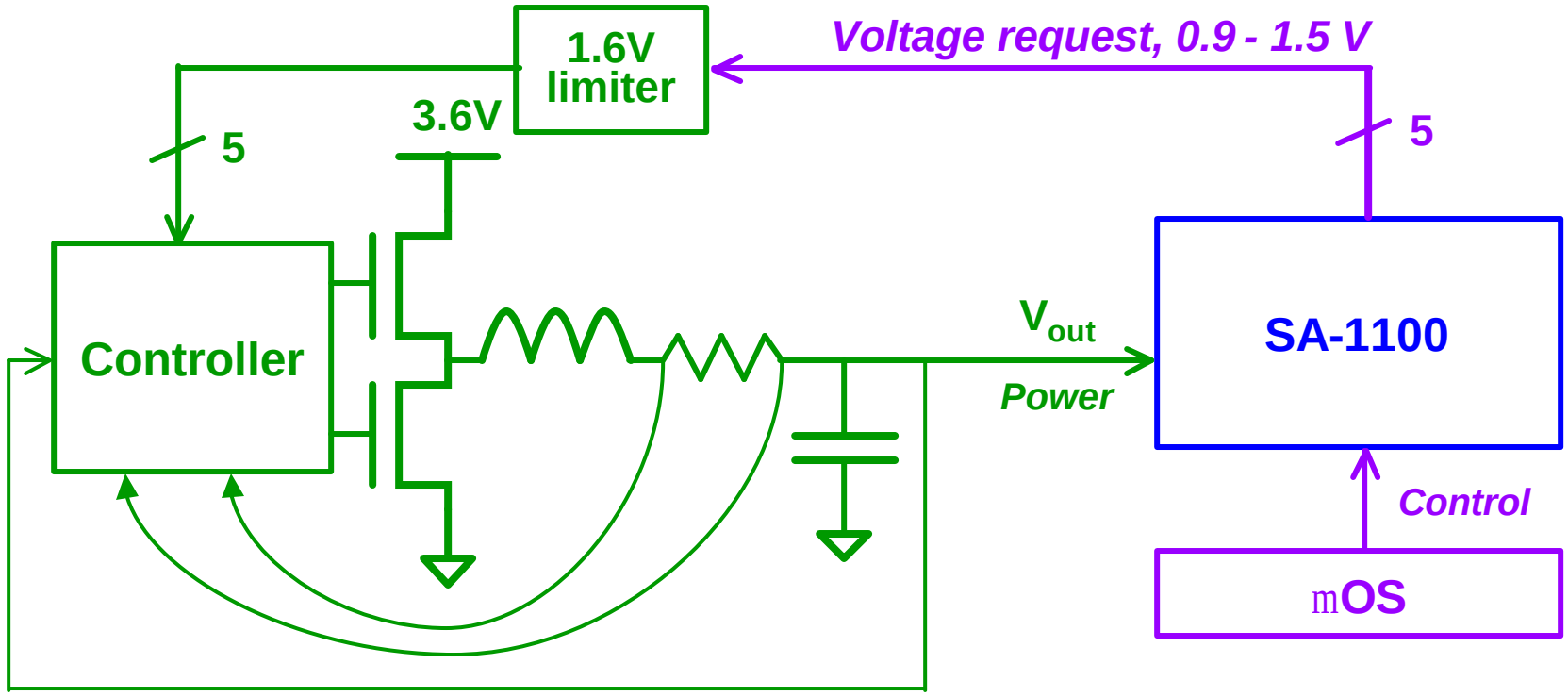
DVS Implementation

SA-1100 requests a voltage appropriate for its clock frequency



digitally adjustable DC-DC converter powers SA-1100 core

mOS selects appropriate clock frequency based on workload and latency constraints

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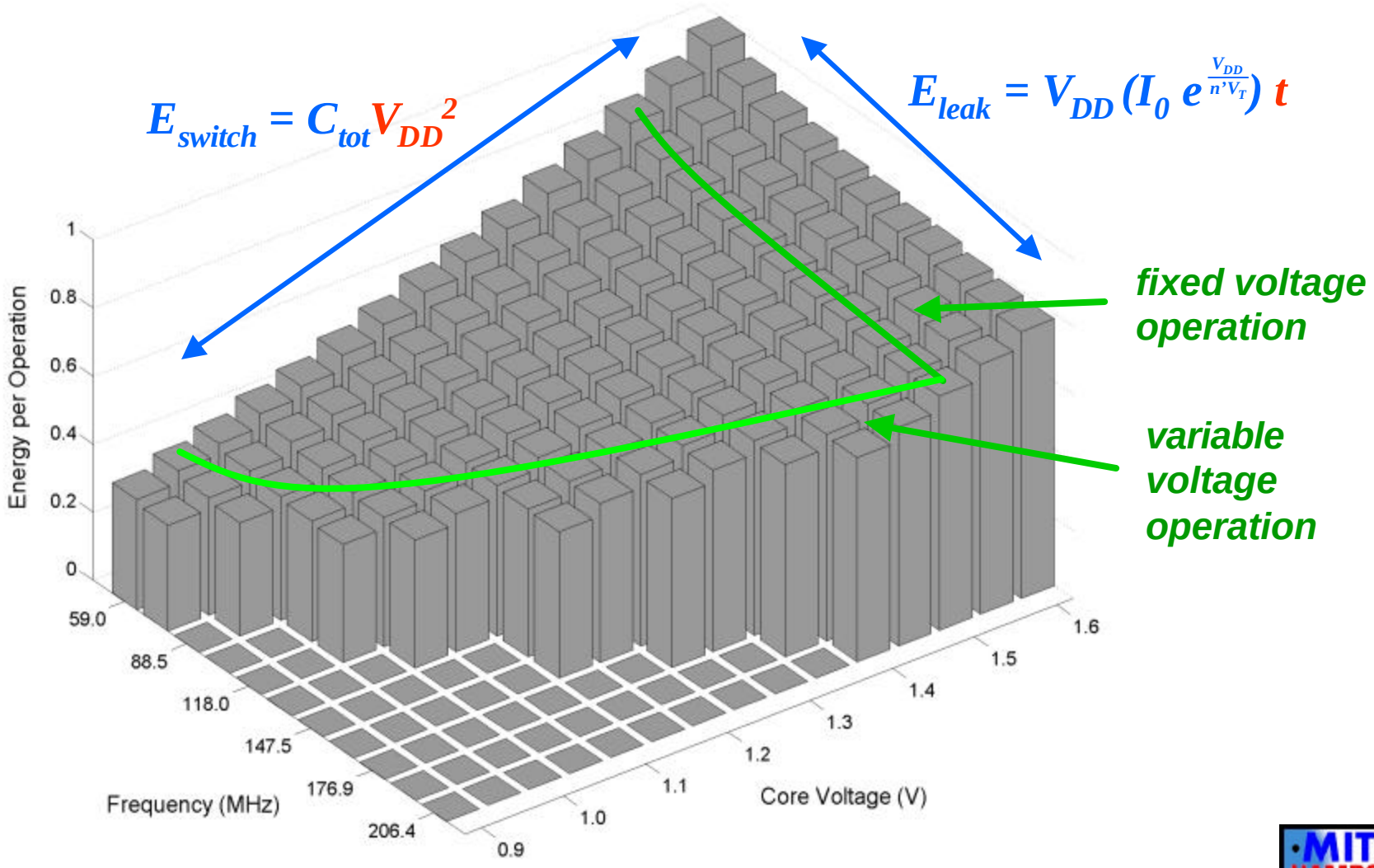
Energy Characterization of SA-1100

- Energy *per operation* at full processor utilization



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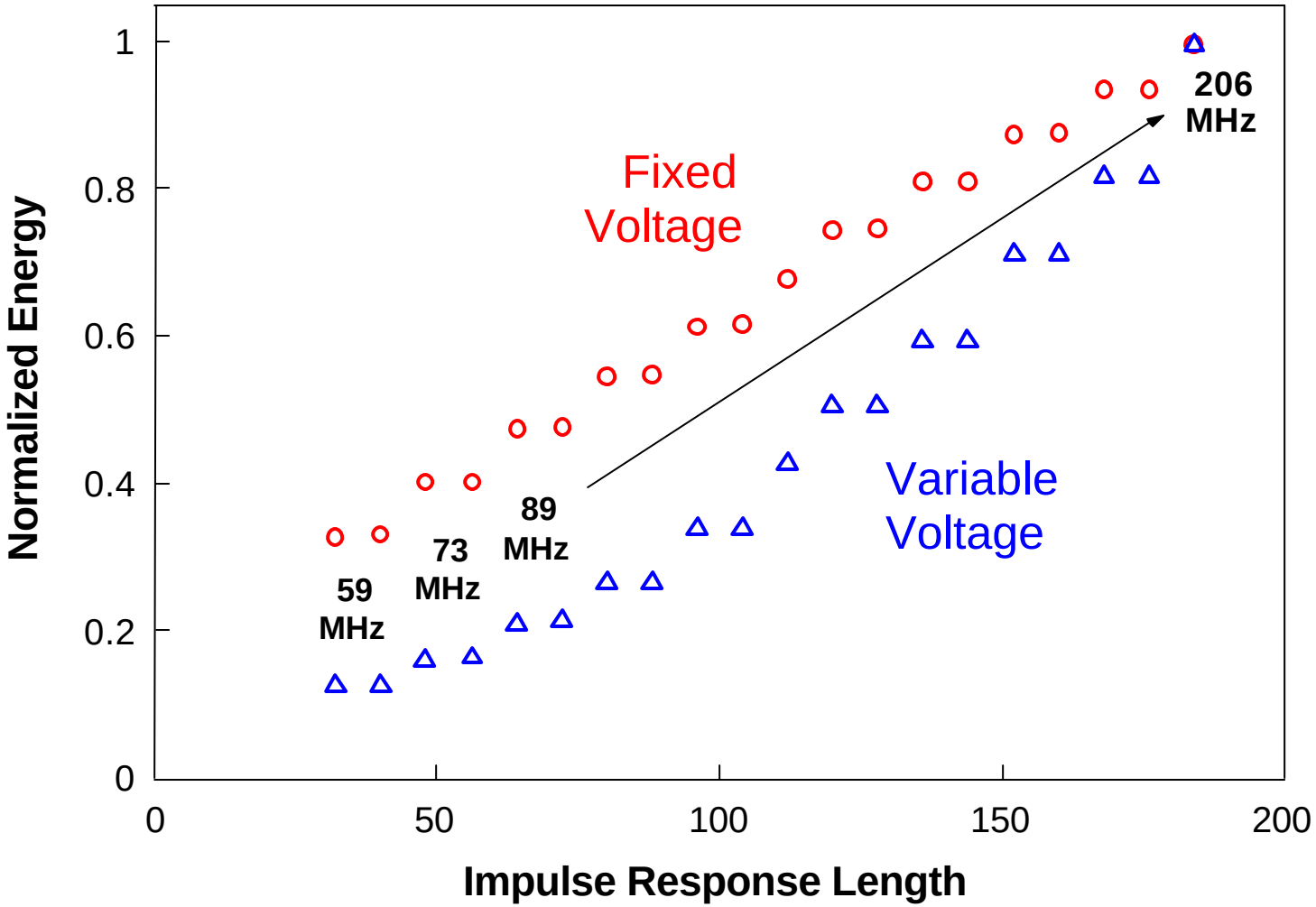
Application: Energy-Scalable Digital Filter

- **Processor workload proportional to filter length**
- **mOS adjusts clock frequency (and voltage) with workload**



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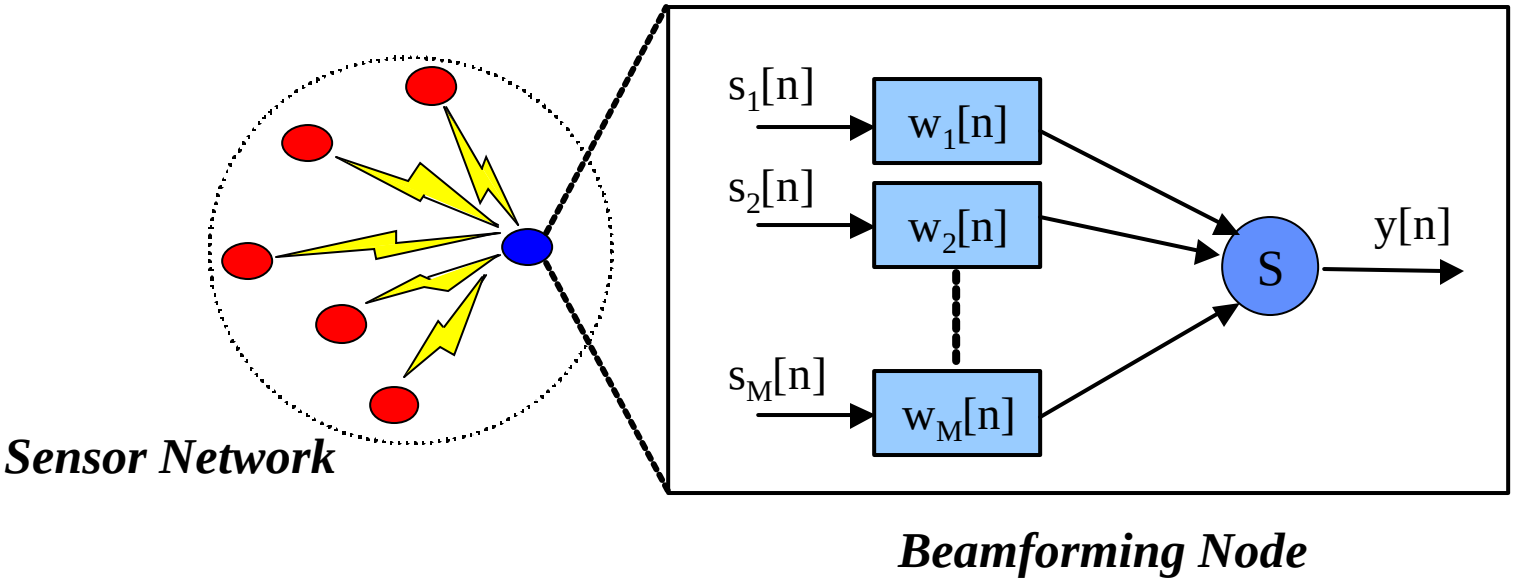
Algorithmic Considerations: Beamforming



- **Data aggregation from multiple sensors into a single, high-SNR result**
  - Data redundancy removed => less network transmission
  - Energy-scalable: vary the number of input signals to beamformer
  - How is quality affected?

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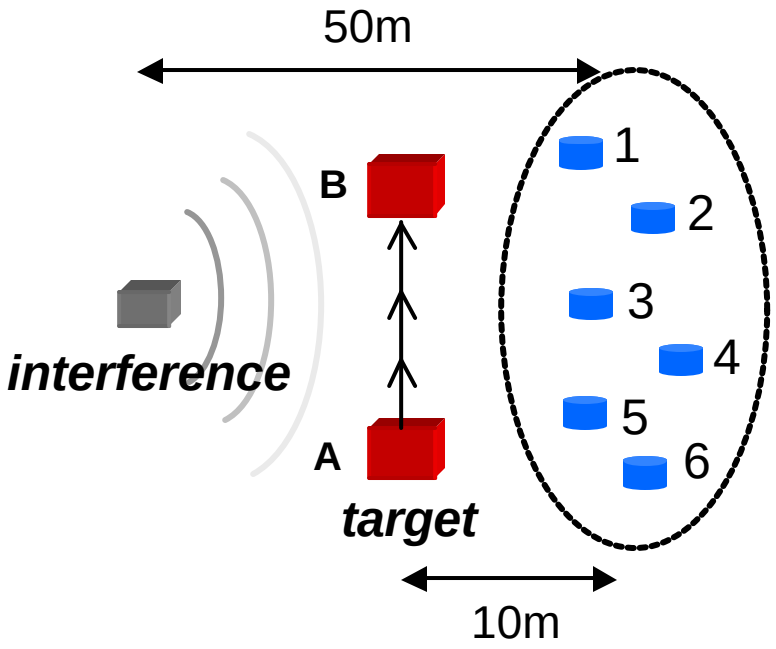
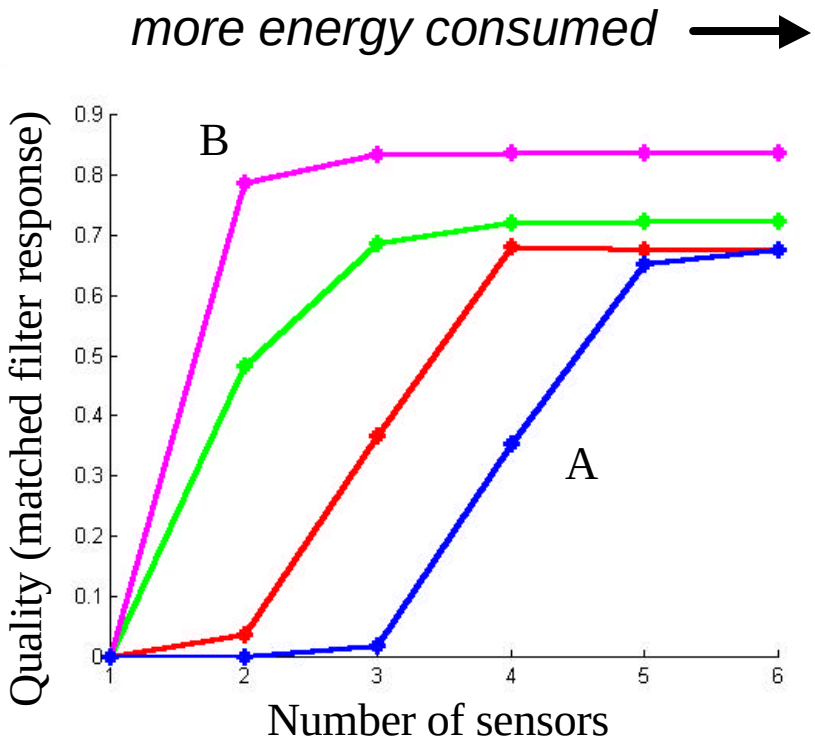
Beamforming Example





Example scenario with sensor cluster, target, and interference source

LMS Beamforming in order (choosing sensors 1...*N*) leads to energy-quality variations with source location

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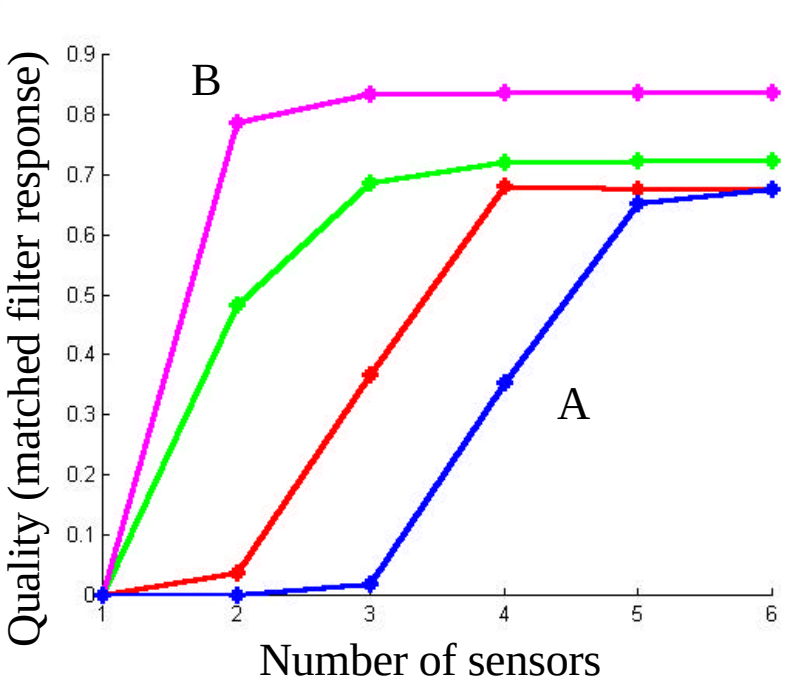
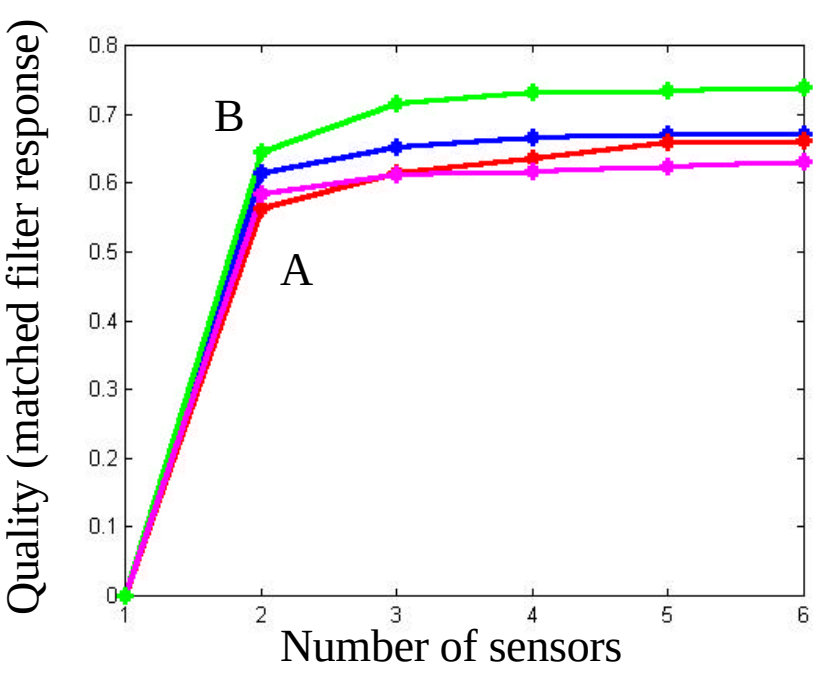
Power-Aware Transformation

- ***Most significant first* transformation improves energy-quality characteristics**
  - Quicksort signals by their SNR; beamform with strongest signals
  - Low overhead transformation: 0.44% overhead for 2-sensor (worst) case



Before



After

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Conclusions

- **Power-awareness means...**
  - **Graceful energy-quality scalability at all levels**
  - **Hardware-software collaboration to save energy**
  - **Accounting for the unique power dissipation characteristics of the target application**
- **For a long lifetime, microsensor nodes must be power-aware**

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