

Energy Harvesting-Based Green Wireless Communication Systems

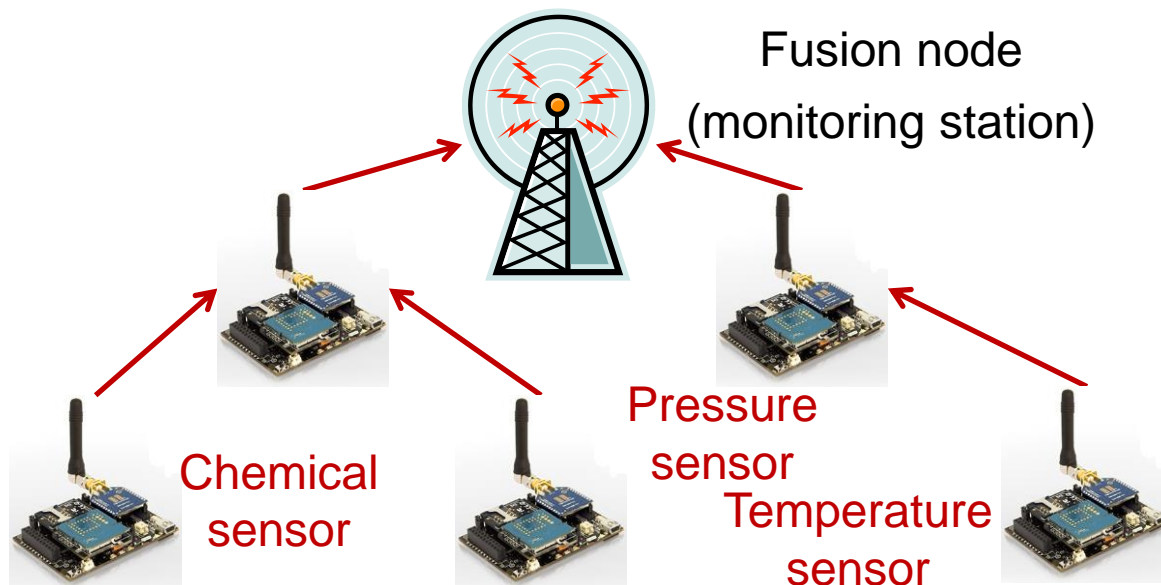
Neelesh B. Mehta

Outline

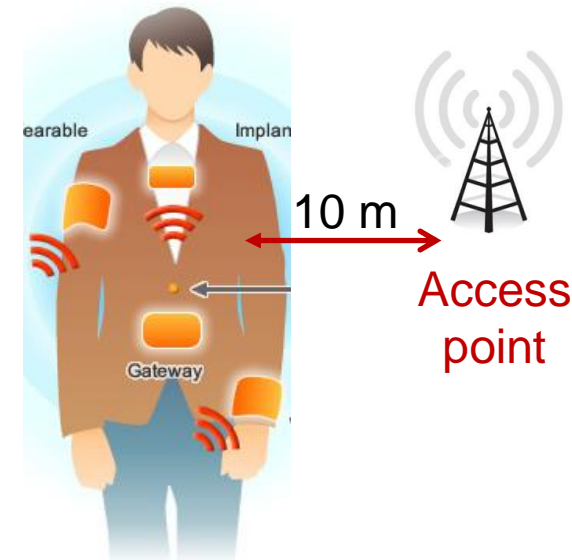
- A motivating application
- Energy harvesting overview
- Two research problems
- Looking ahead: Challenges

Wireless Sensor Networks

- Network of nodes that sense & communicate sensed data to a common fusion node over a wireless link
- Nodes are off the power grid, battery-powered
- **Challenge: Limited lifetime**



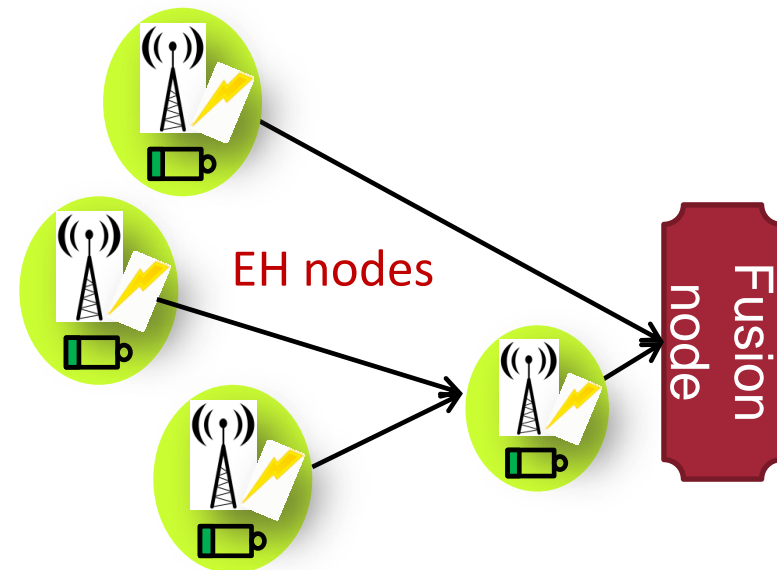
Implanted and wearable sensors



[Image sources: tecnorevolucion.blogspot.com, renesas.com]

Energy Harvesting (EH) Wireless Network

- Network in which nodes harvest energy from the environment
 - Uses **renewable** energy sources, e.g., solar, vibration, wind, thermoelectric effects
- Can store harvested energy in a supercapacitor or battery
- Harvested energy for sensing, processing, and communication

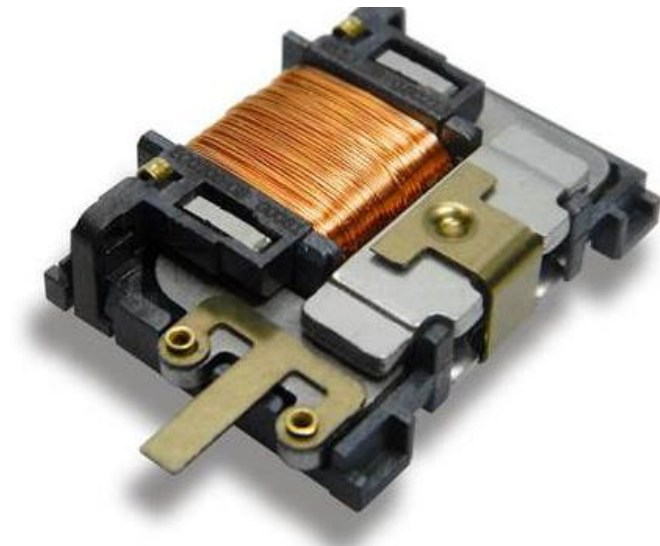
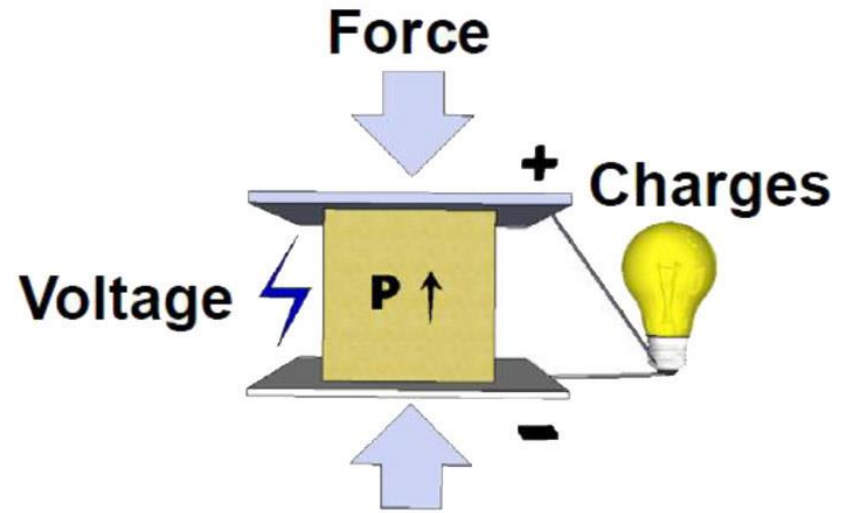


Energy harvesting promises perpetual, green, and high performance operation

Examples of Energy Sources

Piezo-electric

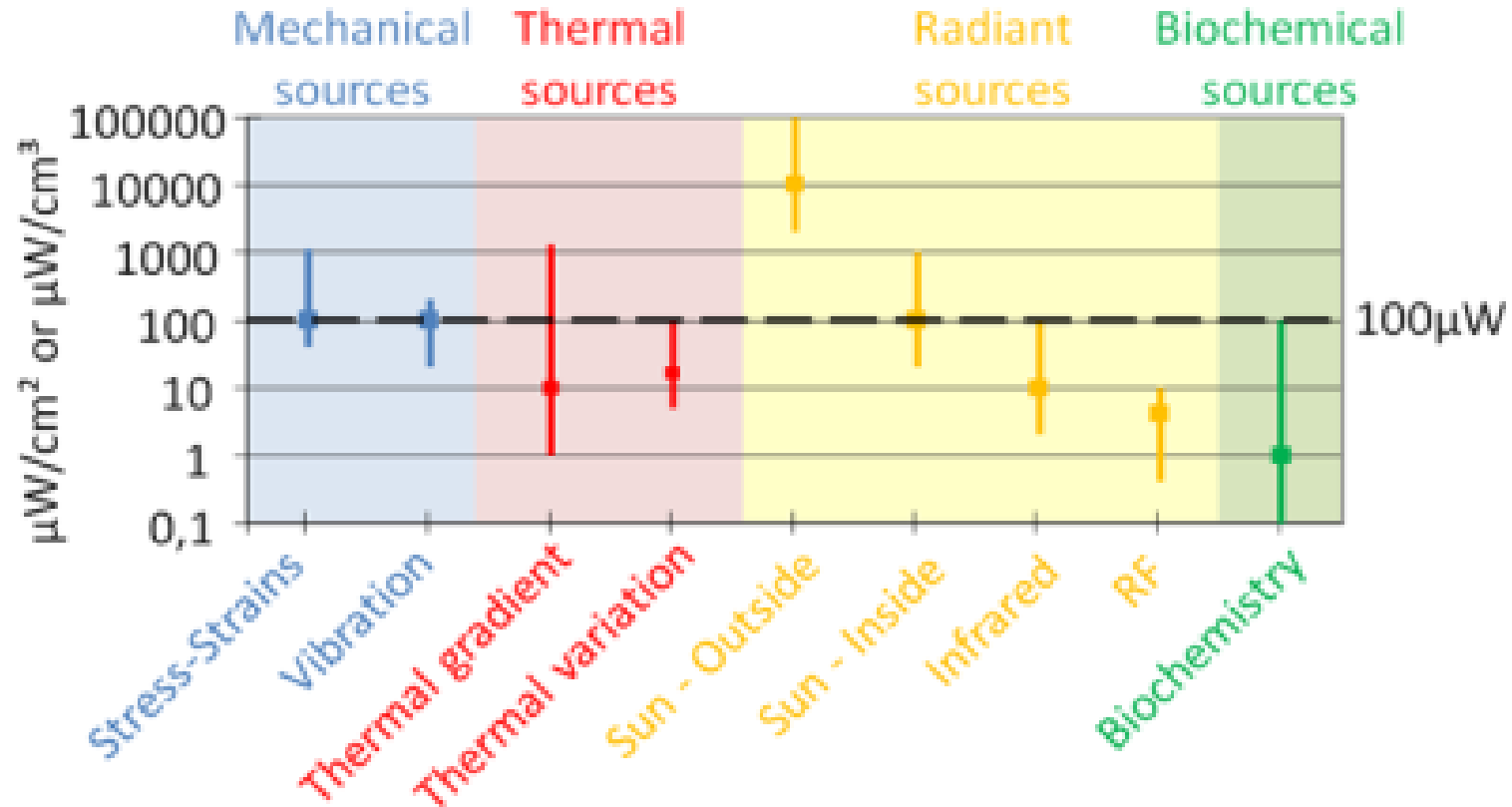
Converts mechanical strain into electrical energy



Mechanical energy

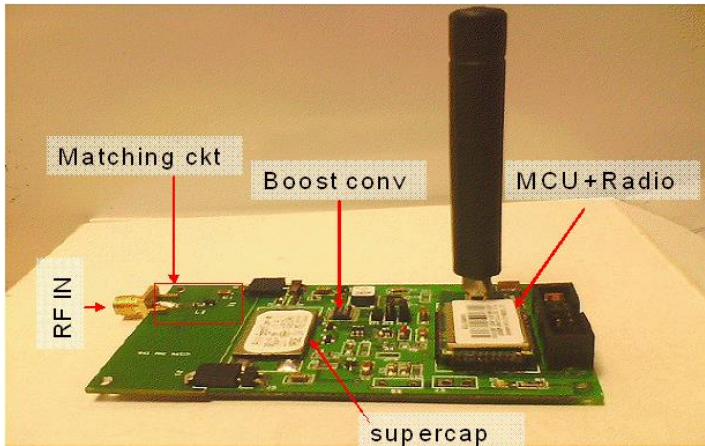
Change the magnetic flux of core within a coil, which induces a current through the coil

How Much Energy Can Be Harvested?



- Ballpark range of energy harvesting: 10-100 $\mu\text{W}/\text{cm}^3$

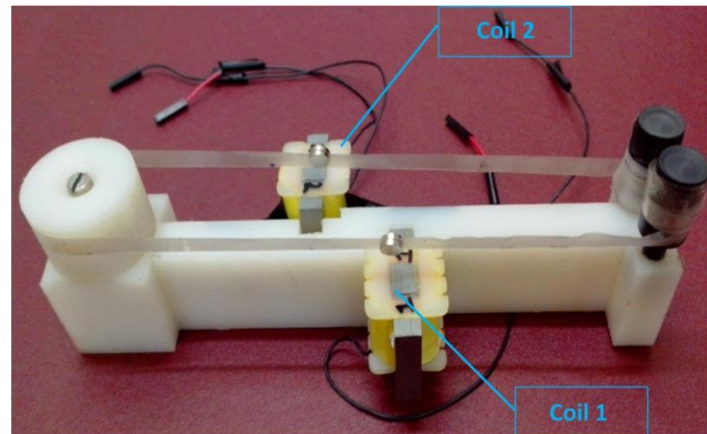
EH Prototypes (From ZENLab @ IISc)



1. RF energy harvester (μW)



2. Hydroelectric harvester (W)



3. Windbelt harvester (mW)

Implications on Communication System Design

Traditional design goals

- Minimize energy consumption. Maximize lifetime

New design goals for EH systems

- Energy harvested can be sporadic/random
- Judicious usage of harvested energy
 - Too conservative: Wastes harvested energy
 - Too aggressive: Node lacks energy when it needs it in future

Need an energy-efficient system designed to handle sporadic and low amounts of harvested energy

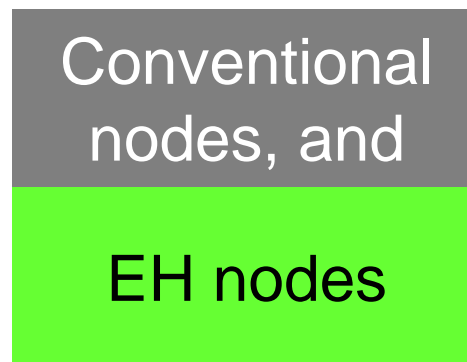
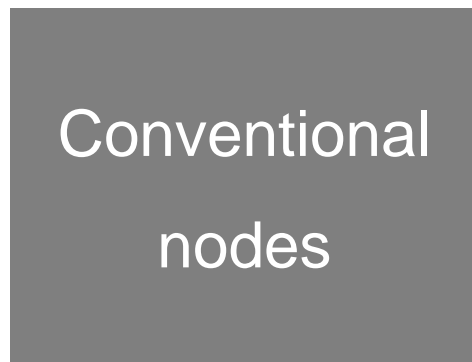
Two Research Examples

1. Hybrid wireless sensor networks
2. EH relay networks

Conventional

Hybrid wireless networks

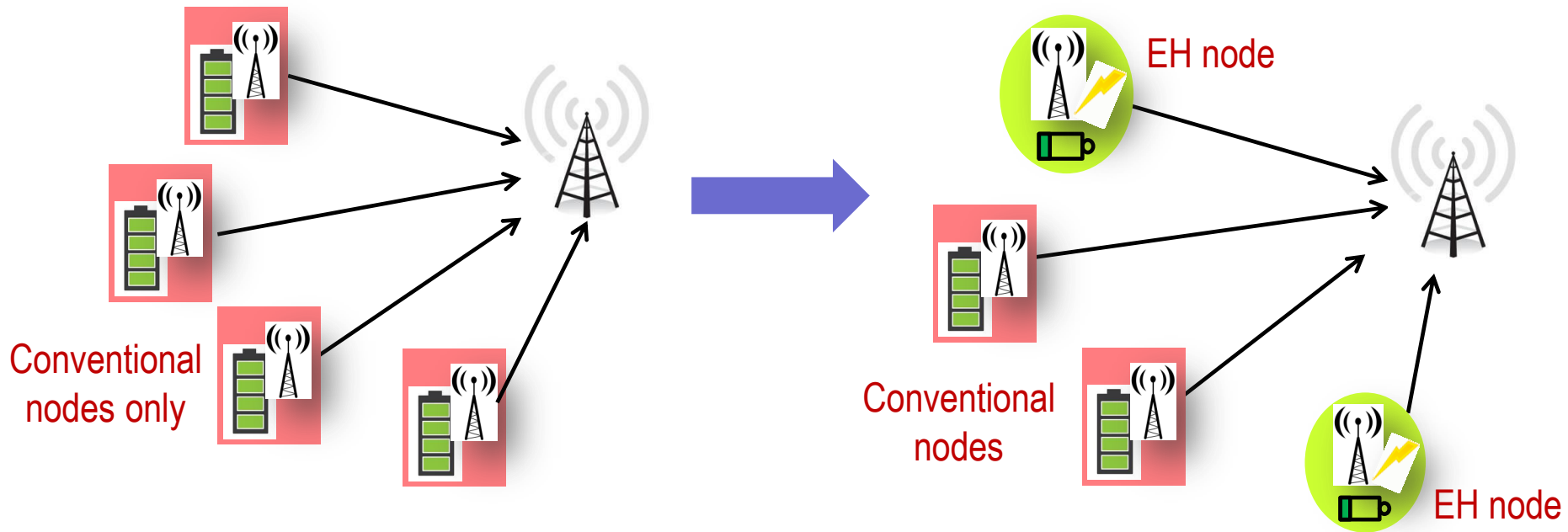
EH relay networks



1. Why Hybrid Sensor Networks?

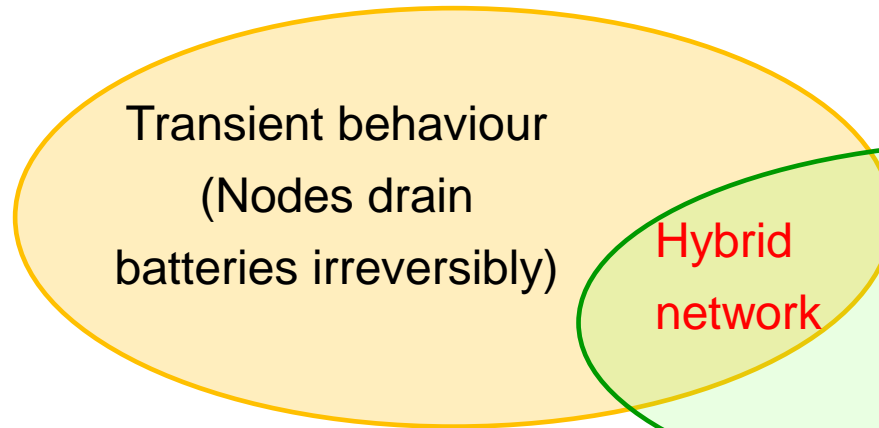
Consists of a mixture of conventional pre-charged battery-powered sensor nodes and EH sensor nodes

- Gradually upgrade legacy sensor network deployments
- Cost considerations: EH is likely to be more expensive



How to Evaluate a Hybrid Wireless Network?

Conventional wireless sensor network



All-EH wireless sensor network

Steady state behaviour
(EH node has energy with some probability)

Disparate measures for evaluating performance

Lifetime based

- When do enough nodes die?

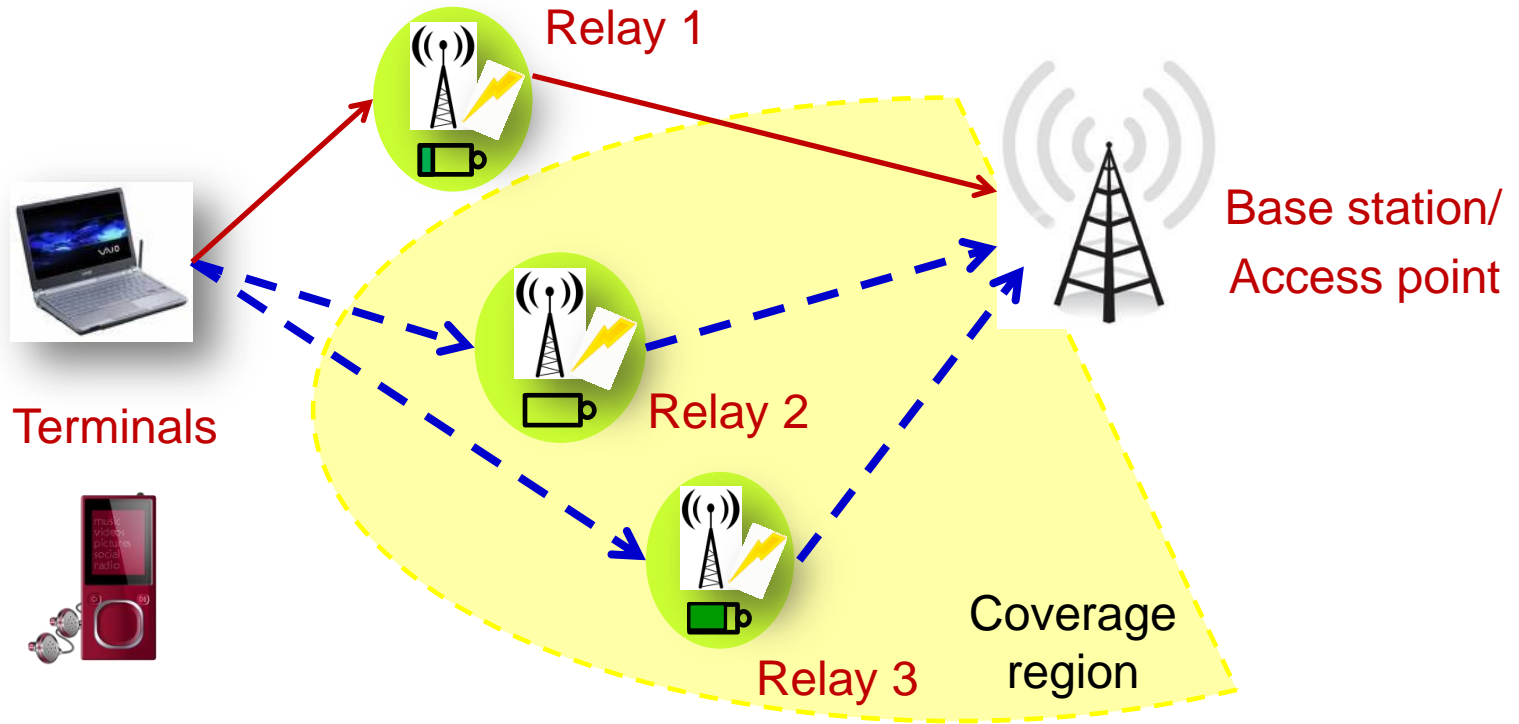


Steady state based

- What fraction of nodes, on average, have energy?

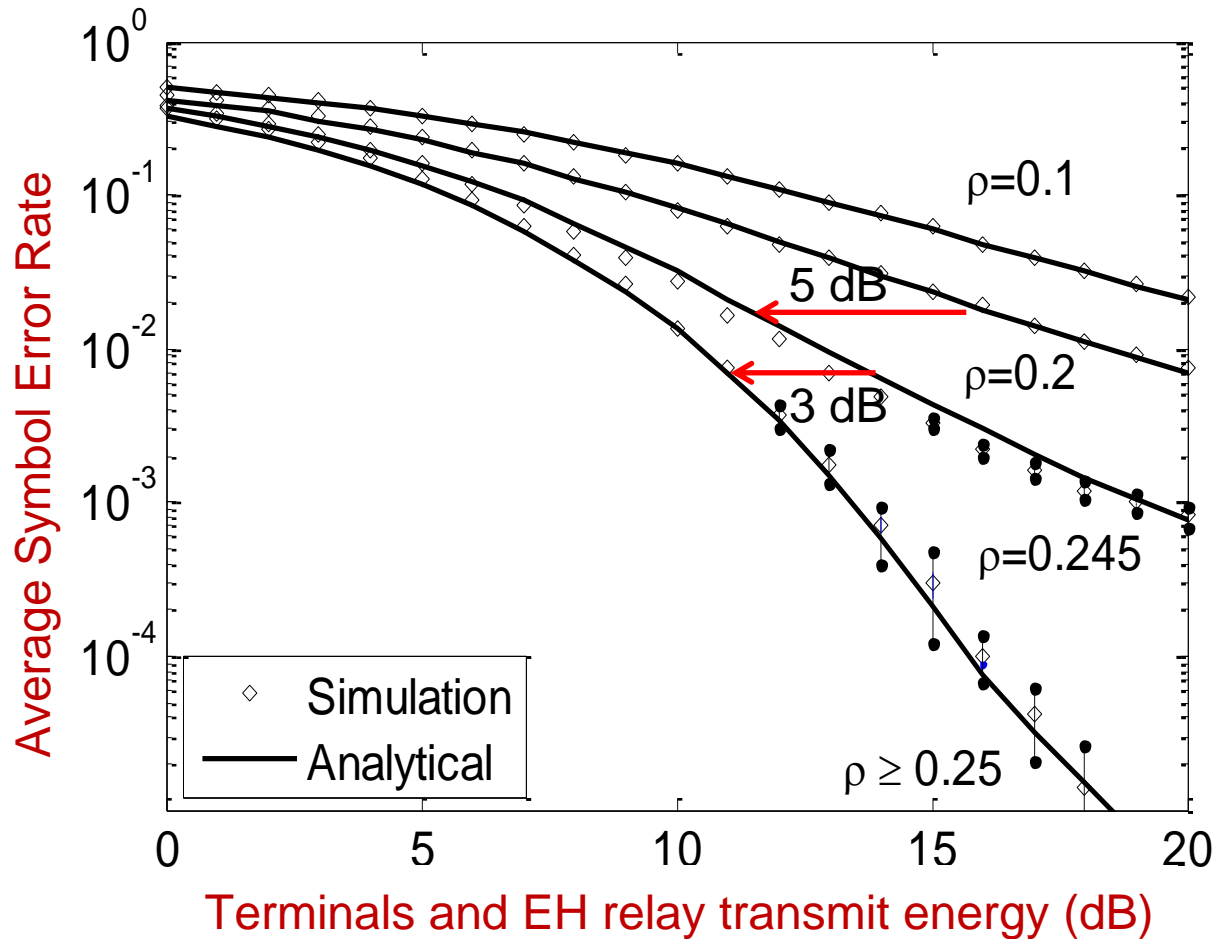
Need new performance measures to evaluate hybrid networks

2. Energy Harvesting Relays



- Relays help forward signals between access point and terminals
- But, relays expend energy in forwarding data
 - EH relays are the solution to this problem

Effect of Transmit Power Setting



ρ : Probability energy is injected

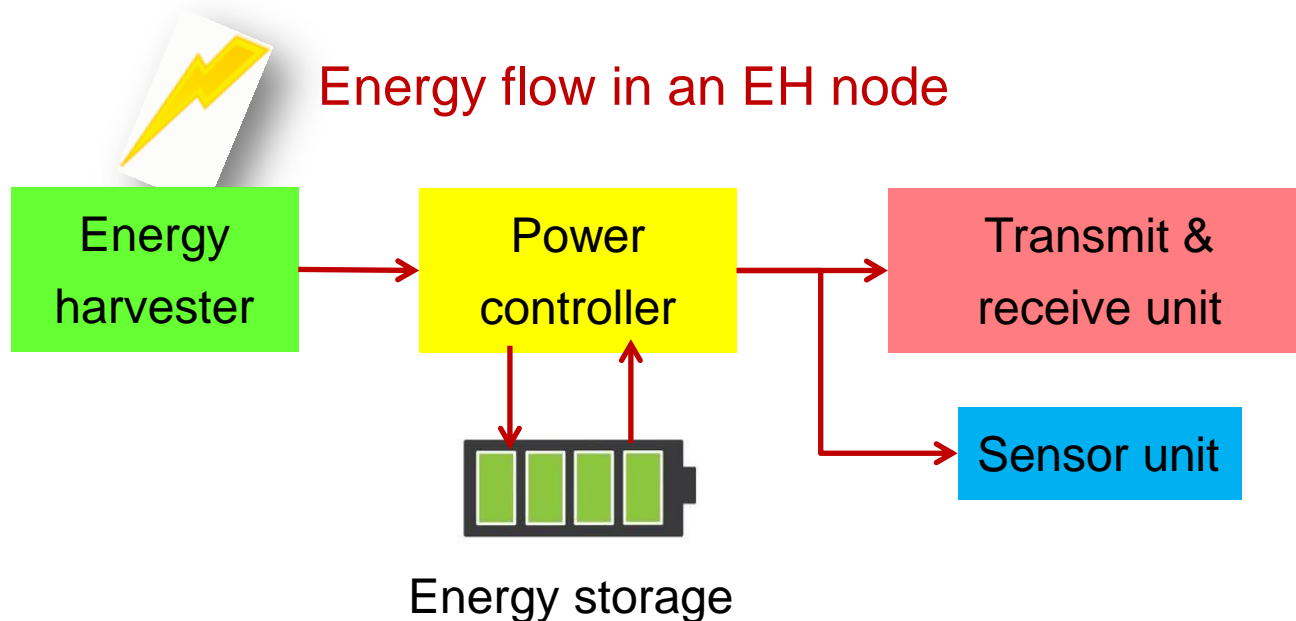
- Energy savings with EH relays are significant
 - 3 dB = 50% savings

Summary

- Energy harvesting nodes are forever!
- Variety of applications and growing interest
- Design focus changes from conserving as much energy as possible to judiciously utilizing harvesting energy
 - New design trade-offs arise
 - New algorithms needed

Challenges: Hardware

1. Improve efficiency of energy harvester
2. Energy-efficient power controller to output a clean voltage
3. Ultra-low power electronics
 - Energy harvested can be scarce



Challenges: System Design

1. Need to handle randomness in energy harvested and energy consumed
2. Energy-aware estimation algorithms
 - Intelligence embedded in the EH nodes: Aggregate data en route to the fusion node
 - Energy-aware: Role played by a node depends on how much energy it is harvesting

