Title
Energy Harvesting Support for Sensor Networking

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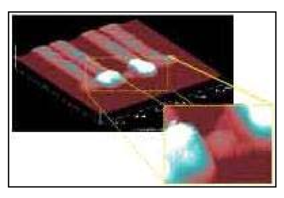
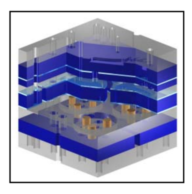
Introduction: Exploit Environmental Energy to Increase System Lifetime or Performance

Energy Harvesting

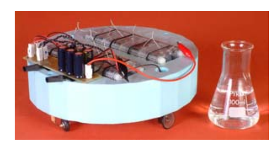
- **System life and performance can improve with extra energy**
- **Several harvesting technologies available/emerging**


Thermoelectric (DARPA,JPL, CalTech)


EM Direct Conversion Device (DARPA, ITN)


Micro-Hydraulic Transducer (DARPA, MIT)


Solar Cells


BioFuel, (IASL,UWE-Bristol)

- **Ultimate goal - Deployment of self-sustained sensor network**

Managing Environmental Energy

- **At the node level**
  i. Scale performance as per energy availability.
  ii. Schedule tasks optimally in space and time
- **At the network level**
  i. Distribute tasks to nodes with more energy
  ii. Choose communication routes that maximizes system lifetime

Problem Description: Sensor network has limited lifetime when running on batteries

- **Enable sensor nodes to scavenge energy from its environment.**
- **Need distributed method to learn the environmental energy opportunity and adapt global task sharing.**

Proposed Solution: Energy Harvesting Support for sensor network.

Harvesting Theory

Definition: E(t) is a *(ρ-σ_1-σ_2) source* if for all T:

$$\int_0^T E(t) \ge \rho T - \sigma_1 \quad \text{and} \quad \int_0^T E(t) \le \rho T + \sigma_2$$

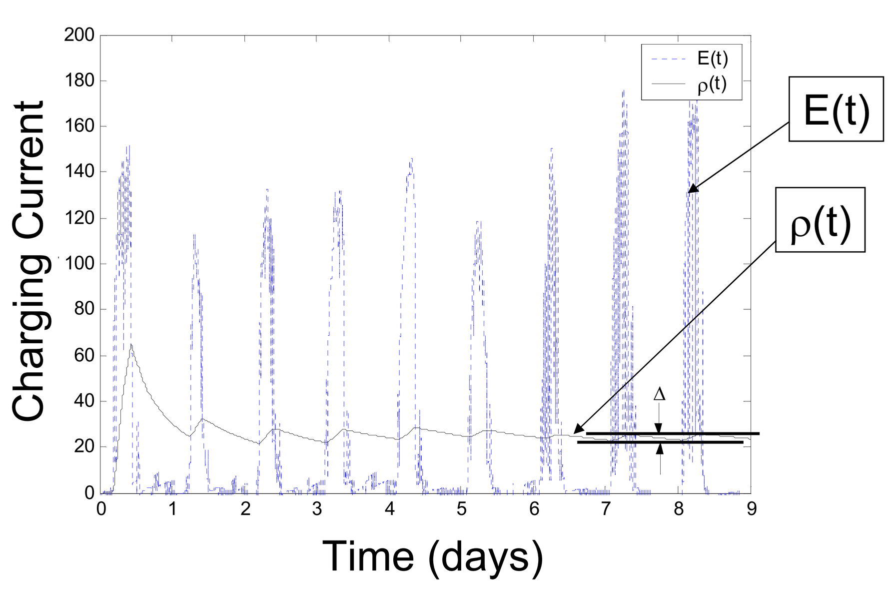
Theorem 1 (Optimal Achievable Performance): If

- a system is powered by a (ρ,σ_1,σ_2) source
- has energy storage capacity >= (σ_1+σ_2)
- operates at constant power level ρ

then it utilizes the energy source fully and can survive forever.

Theorem 2: Gives achievable performance when consumption rate not constant.

Single Server Harvesting

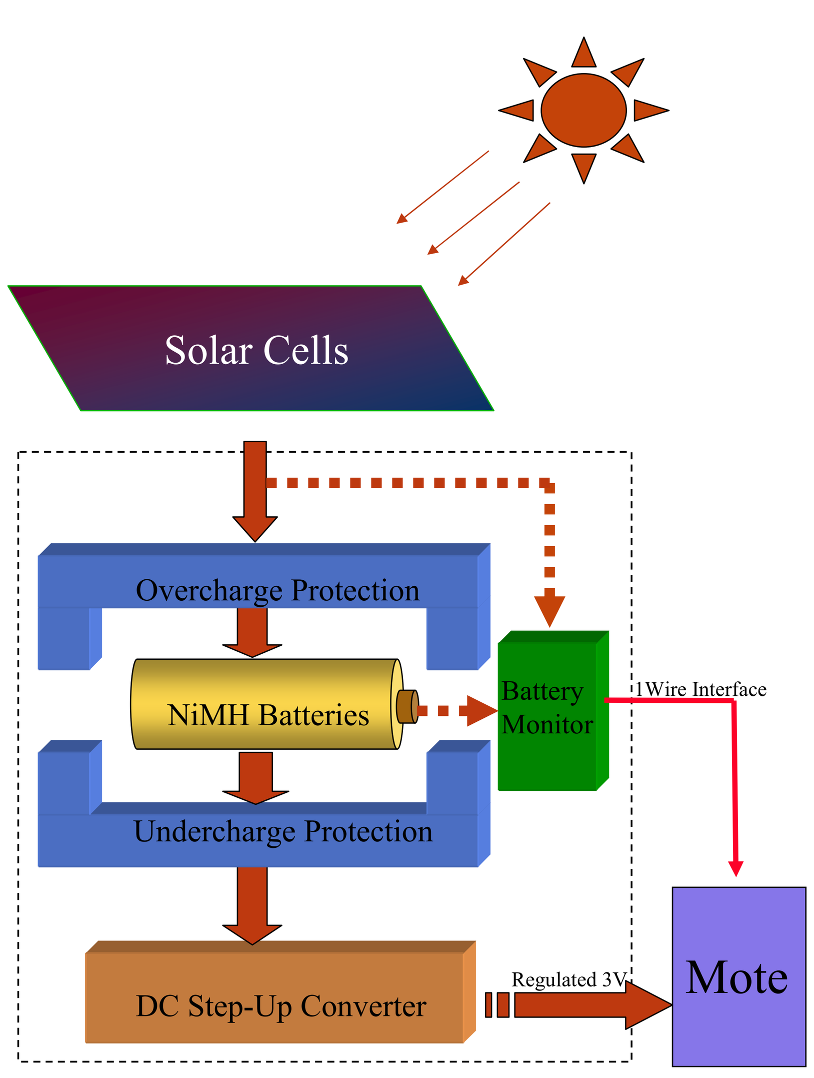


Achieve energy neutral operation

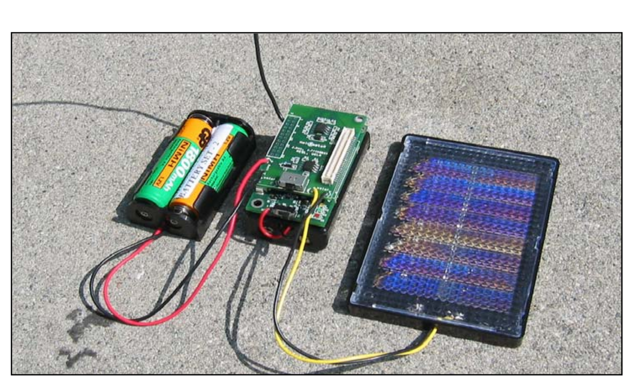
- Learn theorem parameters from initial data
- Various means for performance scaling: Sleep cycle, Dynamic Voltage Scaling, Radio range control
  - Mote hardware: sleep cycle

HeliomoteR

A integrated solar energy harvesting and storage device for sensor network



Heliomoter Hardware Block Diagram



Overcharge protection

- Disconnect solar cells when batteries have reached their full capacity.

Undercharge Protection

- Shut down DC Step-Up converter when batteries drawn below a present point

Battery Monitor

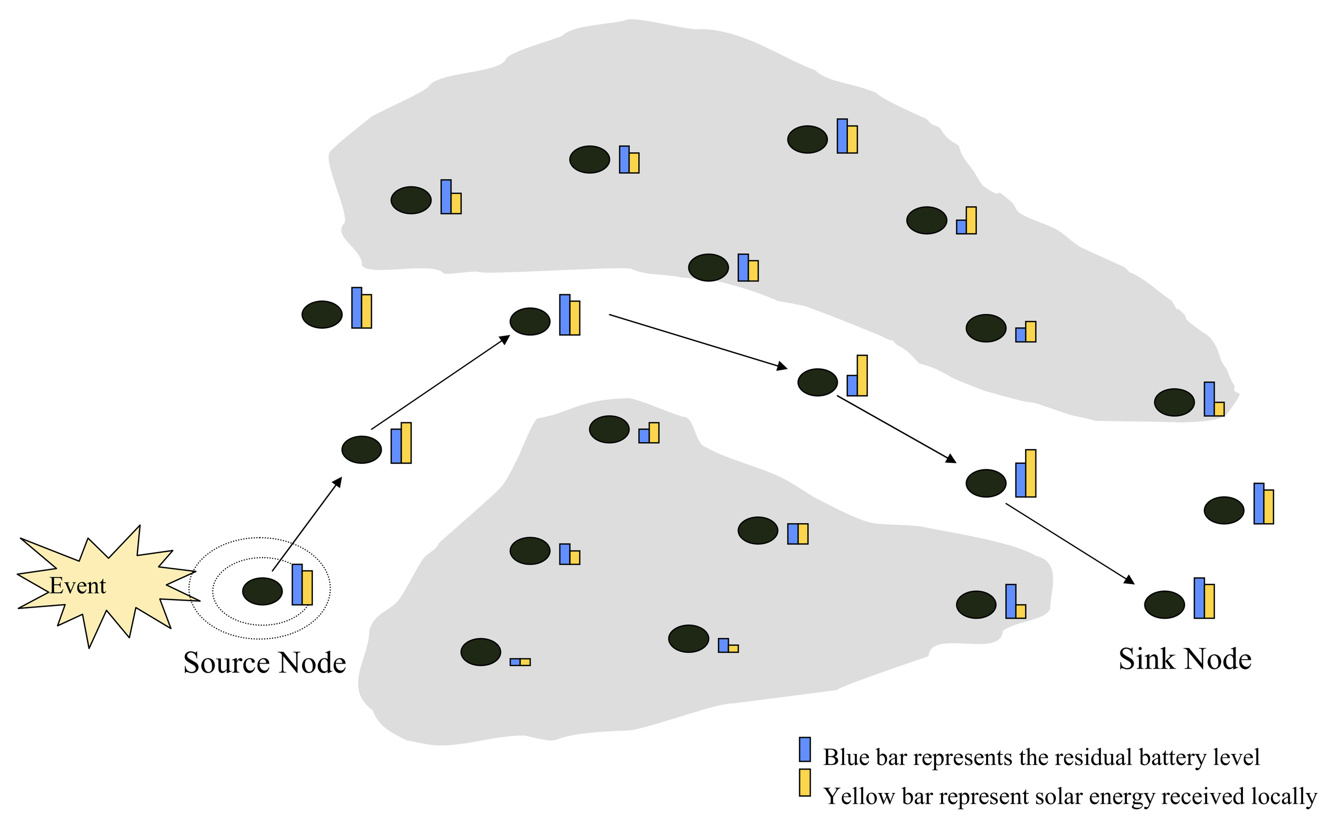
- Communicate residual battery status and solar energy info with host sensor node

DC Step-Up converter

- Provide a constant 3.0V output as per mote's operation requirement.

Environment Aware Routing

Utilize environmental information from Heliomoter to choose most energy-efficient routes

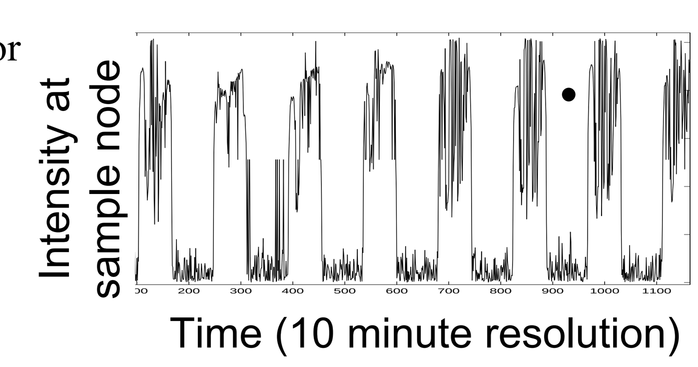


•A modified version of Directed Diffusion

- Knowledge about neighboring nodes are sent along with Interest message from sink
- Event data back to sink through nodes with highest energy.
- Next-hop decision made independently at nodes
- Nodes with higher harvesting potential are used first.

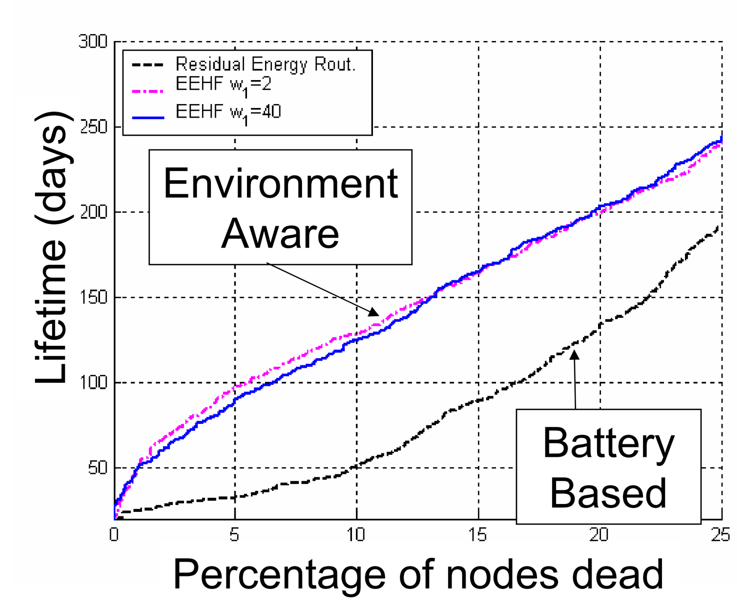
Simulation Studies

- Light distribution collected at James Reserve
  - Data: 10 minute resolution for 40 days
- Light data used off-line to simulate a distributed sensor network (in NESLsim)



Routing Results

- Route chosen based on environment and battery metric
- Avoids using nodes with no harvesting energy



Acknowledgements

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