Communicating with Energy Harvesting Transmitters and Receivers

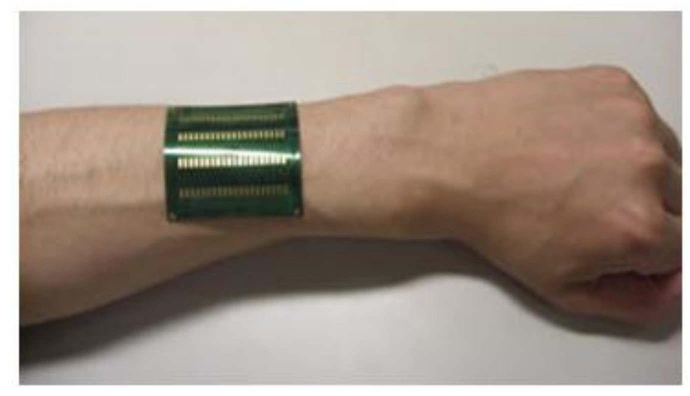
KAYA TUTUNCUOGLU and AYLIN YENER

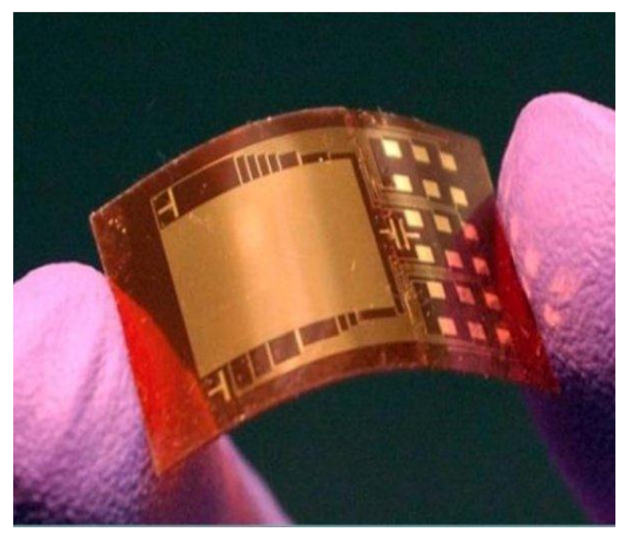
Energy Harvesting in Wireless Communications

Wireless networking with energy harvesting nodes:

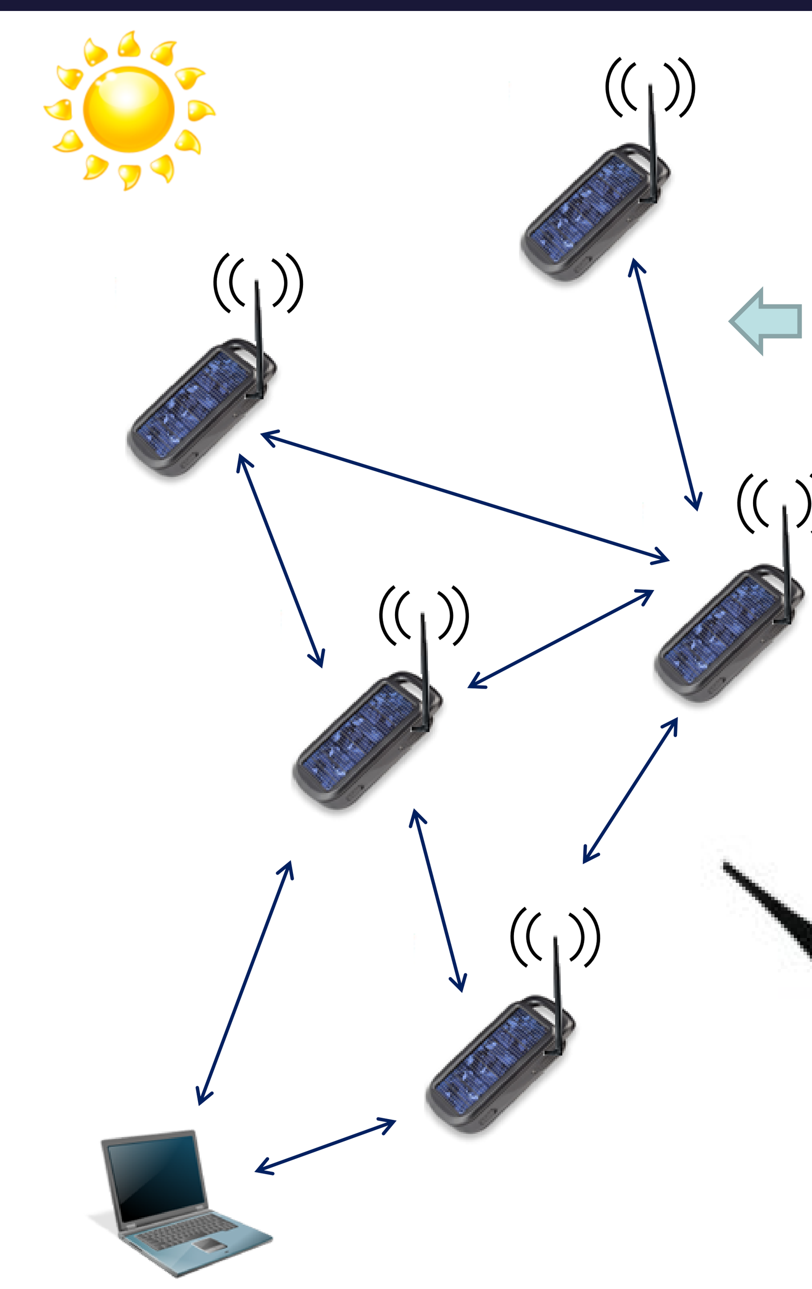
- Green, self-sufficient nodes,
- Extended network lifetime,
- Smaller nodes with smaller batteries,
- Very limited and varying energy.

Fujitsu's hybrid device utilizing **heat or light.**





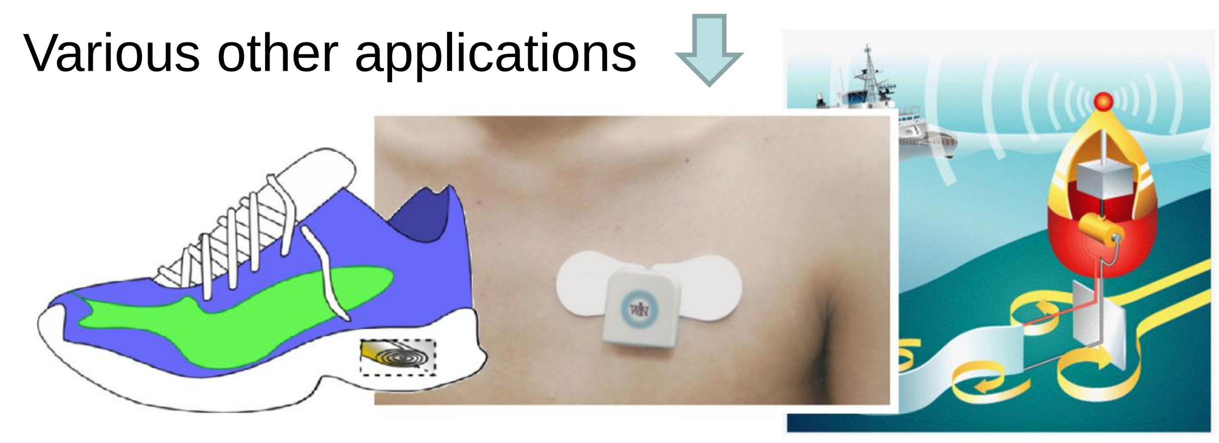
- Nanogenerators built at Georgia Tech, utilizing **strain**



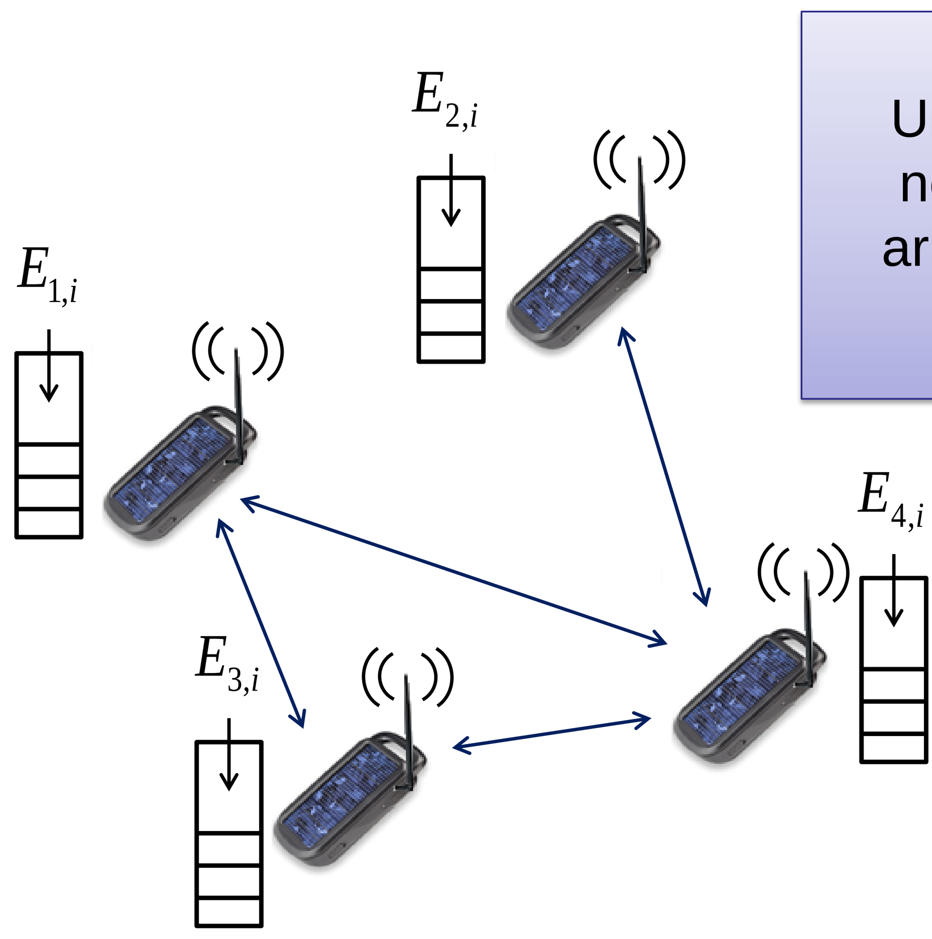
Wireless sensor networks

Green communications

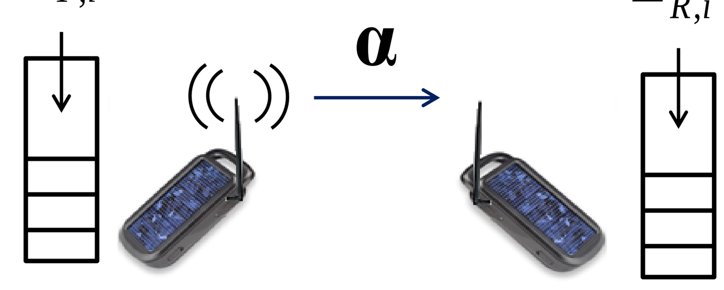
Various other applications



System Model and Energy Feasibility



Unifying model for any network topology with arbitrary utility function.
$f(p_1, p_2, \ldots, p_n, \boldsymbol{\alpha})$



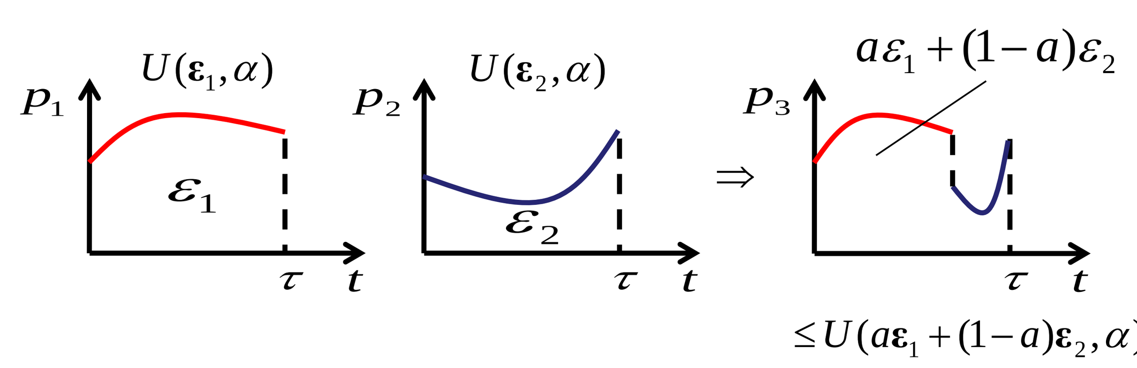
$f(p_T, p_R, \boldsymbol{\alpha})$

- **Energy Causality:** $\sum_{k=0}^{n} E_{j,k} - \int_0^{t'} p_j(t)dt \geq 0 \qquad n\tau \leq t' \leq (n+1)\tau$
- **Battery Capacity:** $\sum_{k=0}^{n} E_{j,k} - \int_0^{t'} p_j(t)dt \leq E_{j,\max} \qquad n\tau \leq t' \leq (n+1)\tau$

Optimal Transmission Policy

Average utility maximization problem

$$\max_{\mathbf{p}(t)} \frac{1}{T}\int_0^T f(\mathbf{p}(t),\alpha)dt, \qquad s.t. \quad \mathbf{p}(t) \in \mathfrak{P}$$

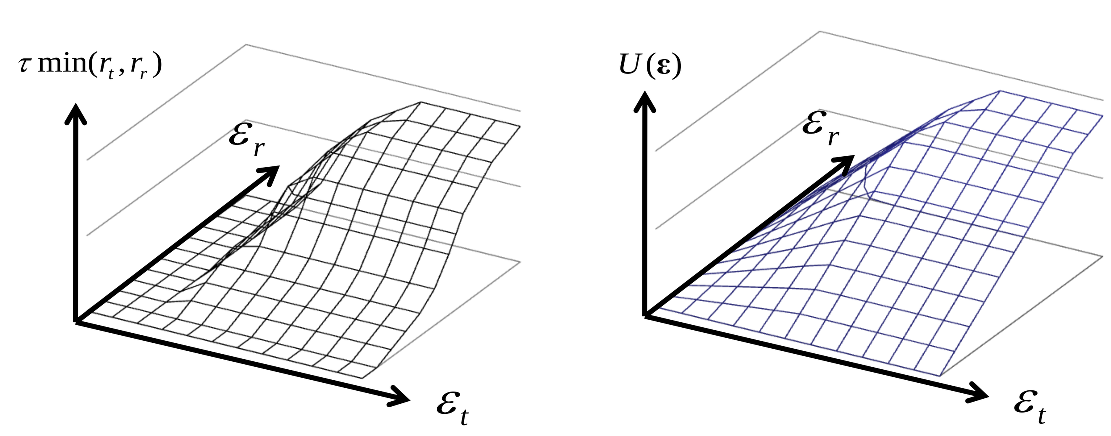


Simplifying the problem

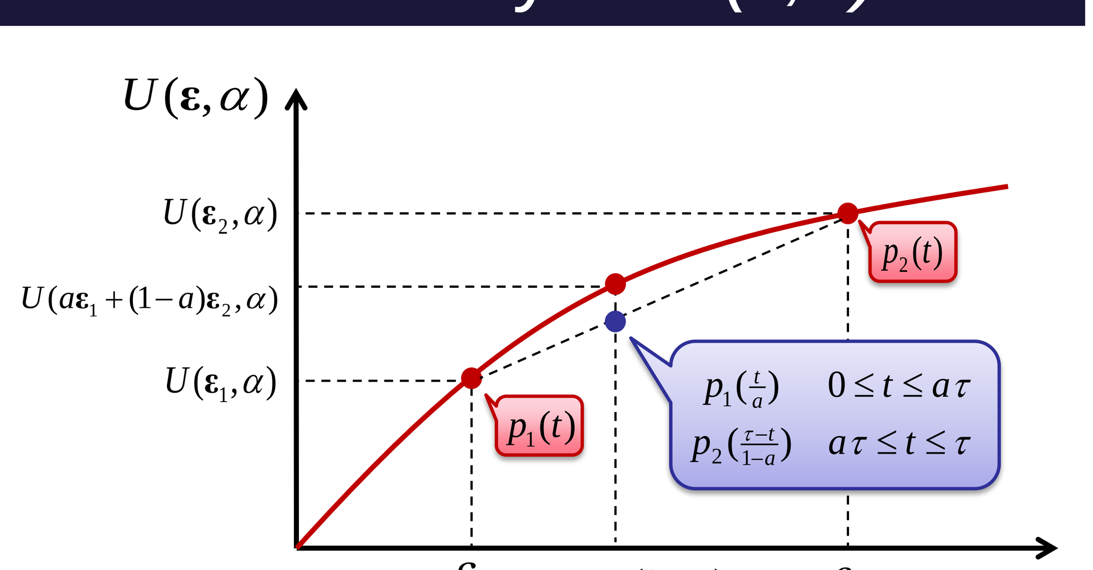
$$U(\boldsymbol{\varepsilon}_i,\alpha_i) = \max_{\mathbf{p}(t)} \int_{i\tau}^{(i+1)\tau} f(\mathbf{p}(t),\alpha_i)dt \qquad \text{(Inner Problem)}$$
$$s.t. \quad \varepsilon_{j,i} = \int_{i\tau}^{(i+1)\tau} p_{j,i}(t)dt, \qquad \forall j$$

$$\max_{\boldsymbol{\varepsilon}_i} \frac{1}{T}\sum_{i=1}^{N} U(\boldsymbol{\varepsilon}_i,\alpha_i) \qquad \text{(Outer Problem)}$$
$$s.t. \quad 0 \leq \sum_{k=0}^{n} E_{j,k} - \varepsilon_{j,k} \leq E_{j,\max}, \qquad \forall j,n$$

Concavification for EH Tx-Rx pair



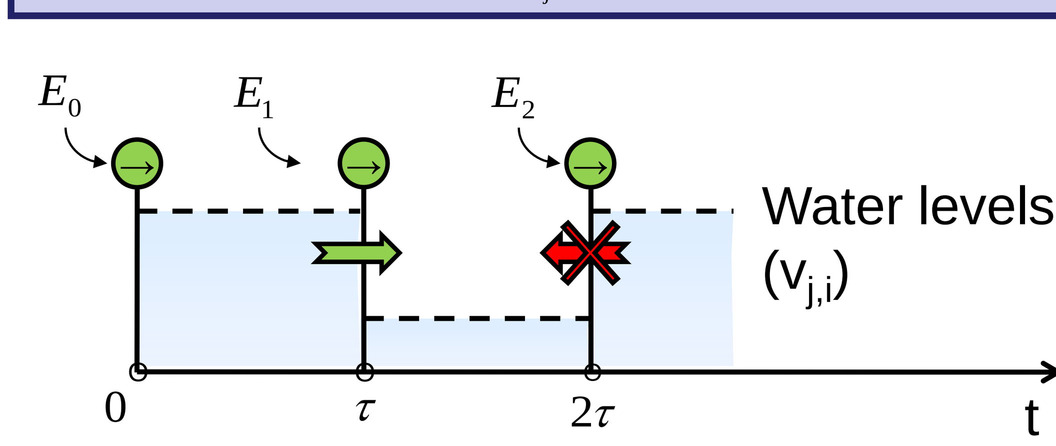
Concavity of $U(\varepsilon,\alpha)$



Generalized Water-Filling

- Water-filling with generalized water levels:

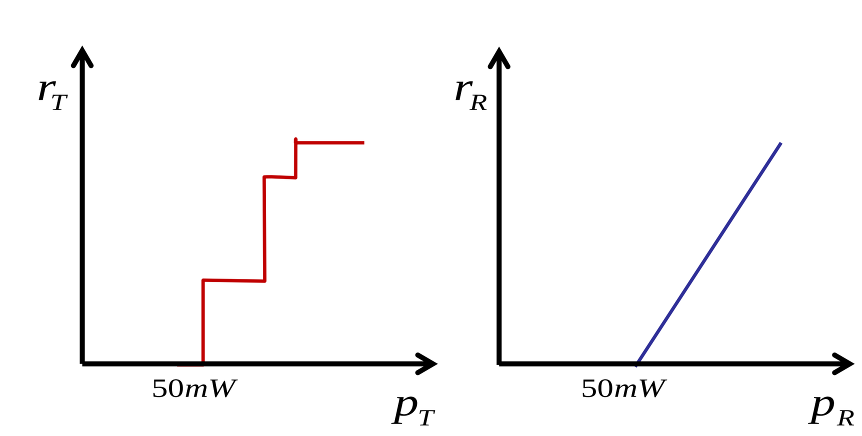
$$v_{j,i} = \frac{\partial}{\partial \varepsilon_j} U(\boldsymbol{\varepsilon},\alpha_i)\Big|_{\varepsilon_j} = \sum_{j=i}^{N} (\lambda_j - \mu_j) - \eta_i$$



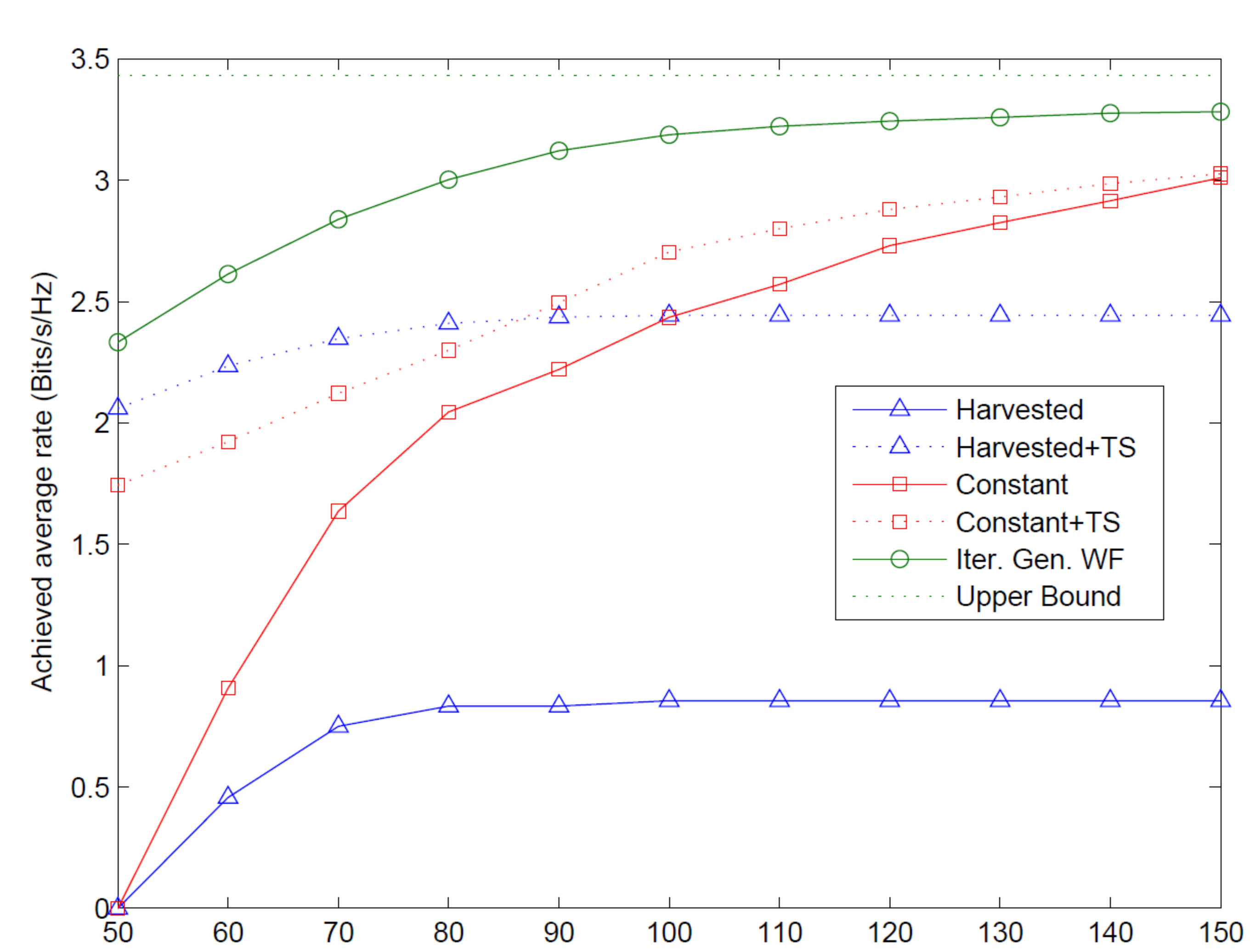
Water levels ($v_{j,i}$)

Simulations

- EH Transmitter w/ adaptive modulation
- EH Receiver w/ linear storage cost



- Both nodes with 50mW base power
- Harvests *iid*, ~U[0,100mW]



This work is supported by NSF Grant #0964364