DISTORTION MINIMIZATION VIA ADAPTIVE DIGITAL AND ANALOG TRANSMISSION FOR ENERGY HARVESTING-BASED WIRELESS SENSOR NETWORKS

Yong Xiao, and Zhu Han, University of Houston

Zixiang Xiong, Texas A&M University

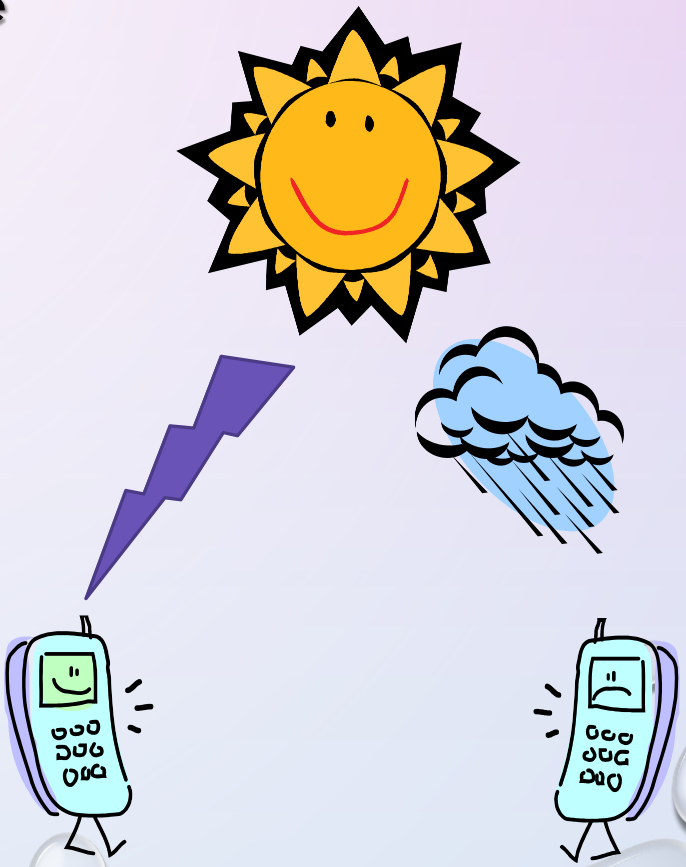
Dusit Niyato, Nanyang Technological University of Singapore

OUTLINE

- Introduction
- System Model and Problem Formulation
- Adaptive Digital and Analog Transmission
- Numerical Results
- Conclusions

INTRODUCTION: ENERGY HARVESTING

- Extracting energy from external source in natural environment such as solar power, wind energy, radio frequency energy, vibration power, etc.
- Main Challenges:
  - Environment is unstable, unpredictable and unreliable,
  - To achieve reliability guaranteed energy supply.



INTRODUCTION: ENERGY HARVESTING-BASED WIRELESS SENSOR NETWORKS

- Physical sources observed by wireless sensor networks are analog in natural and can have infinite number of possible values,
- It is known that the digital and analog transmission are energy efficient in the high or low power regime,
- Main challenge: How to dynamically optimize the wireless energy use to achieve the highest accuracy of the observed source signal with harvested energy.

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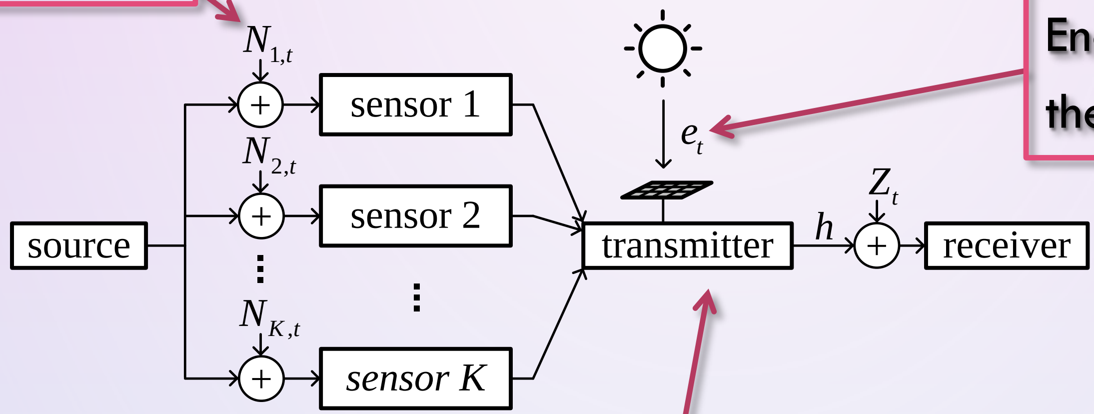
SYSTEM MODEL

Observation noise for each sensor

Energy harvested from the environment



Transmitter can process and transmit its observed signals using two methods:

- Digital Transmission,
- Analog Transmission (also called uncoded transmission).

PROBLEM FORMULATION

- Observation signal at sensor k

$$O_{k,t} = S_{k,t} + N_{k,t}.$$

- Combined observation signal sent by the transmitter

$$X_t = g\left(\boldsymbol{O}_1, \boldsymbol{O}_2, \ldots, \boldsymbol{O}_t\right)$$

- Signal received by the fusion center

$$Y_t = hX_t + Z_t.$$

- Causality constraints:

Battery capacity

Harvested energy

$$b_t = \min\{\bar{b}, (b_{t-1} + e_{t-1} - w_{t-1})\}$$

Energy for data transmission

PROBLEM FORMULATION

- We consider reconstruction distortion with the mean squared error criterion

$$D_t = \sum_{k=1}^{K} \mathbb{E}\left[\left(S_{k,t} - \hat{S}_{k,t}\right)^2\right]$$

- We seek a policy to minimize the long-term discounted distortion for energy harvesting-based wireless sensor networks

$$\mathbb{E}\left(\lim_{t\to\infty} \sum_{l=0}^{t} \rho^l D_l\right)$$

Discount factor

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DISTORTION ANALYSIS

- The minimum distortion that can be achieved by the digital transmission method is given by

$$D_t\left(s_t=\{d\}, w_t\right) \quad = \quad \frac{\sigma_S^2 \sigma_N^2}{\sigma_S^2 \log_2\left(1+\frac{h^2 w_t}{\sigma_Z^2}\right)+\sigma_N^2}.$$

Observation noise (σ_S^2)

Additive noise of sensor (σ_N^2)

- If the transmitter uses the analog transmission method, the optimal distortion that can be achieved is given by

$$D_t\left(s_t=\{a\}, w_t\right)= \frac{\sigma_S^2 \sigma_N^2}{K \sigma_S^2+\sigma_N^2}\left(1+\frac{\frac{K \sigma_S^2 \sigma_Z^2}{h^2 \sigma_N^2}}{\frac{K \sigma_S^2+\sigma_N^2}{\sigma_S^2+\sigma_N^2} w_t+\frac{\sigma_Z^2}{h^2}}\right)$$

ADAPTIVE DIGITAL AND ANALOG TRANSMISSION

- We model adaptive digital and analog transmission problem as a Markov decision process (MDP) consisting of
  - State: battery level
  - Action: Transmission method (digital or analog) and transmit power
  - State transition function calculated by

$$\Pr\left(b_{t+1}|b_t, a_t\right) = \begin{cases} \Pr\left(e_t = b_{t+1} - b_t + w_t|e_{t-1}\right), & \text{if } b_{t+1} < \bar{b}, \\ \sum_{e_t \in \Phi} \Pr\left(e_t|e_{t-1}\right), & \text{if } b_{t+1} = \bar{b}, \end{cases}$$

where

$$\Phi = \{e_t : \bar{b} - b_t + w_t \le e_t \le \bar{e}, \forall e_t \in \mathcal{E}\}.$$

AN OPTIMAL POLICY

- We can prove that the optimal policy π that decides the optimal action of transmitter is given by

Long-term expected distortion

$$a_t^* = \arg \min_{a_t \in \mathcal{S} \times \mathcal{W}} V(b_t, a_t).$$

where

Distortion in the current time

State transition function

$$V(b_t, a_t) = \hat{D}_t(a_t) + \rho \sum_{b_{t+1} \in \mathcal{B}} \Pr(b_{t+1} | b_t, a_t) V^*(b_{t+1}, a_{t+1}^*),$$

Discounted expected distortion in the future

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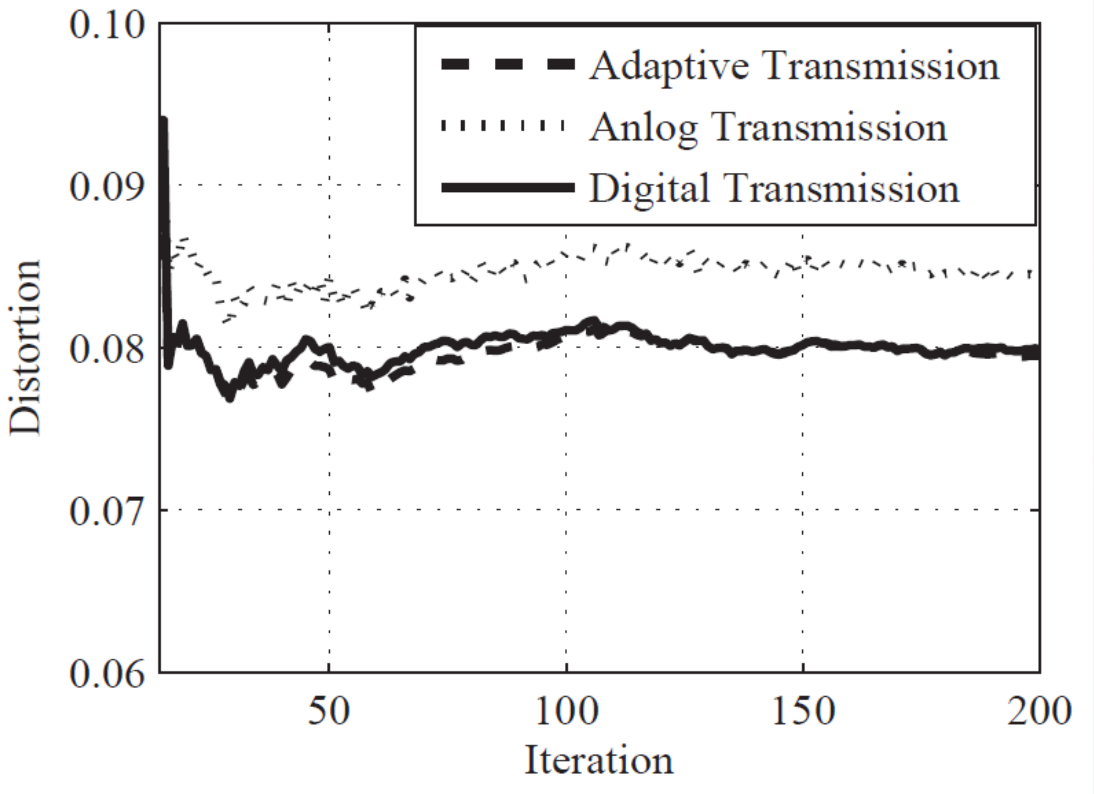
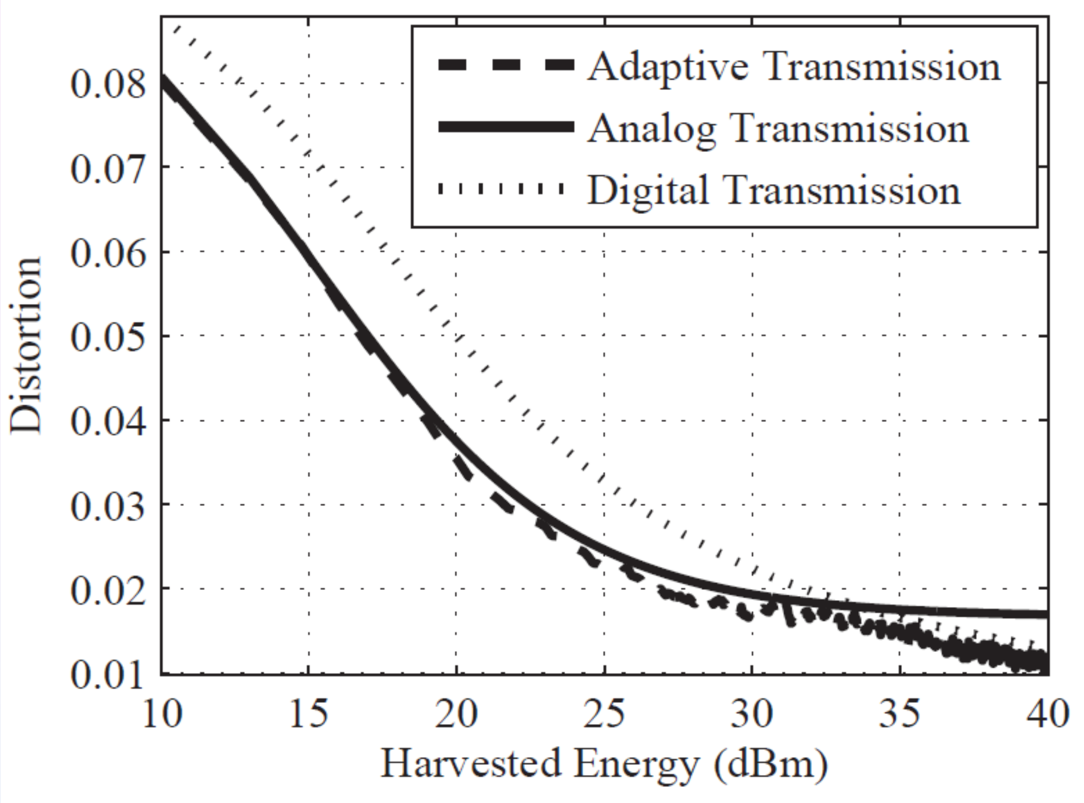
NUMERICAL RESULTS



Distortions of adaptive, digital and analog transmission methods under different iterations

NUMERICAL RESULTS



Distortions of adaptive, digital and analog transmissions under different amounts of energy that can be harvested by the transmitter.

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CONCLUSIONS

- We study optimal strategy that can minimize the distortion between the signal observed by the sensors and that recovered by a fusion center,
- A novel adaptive transmission method in which the transmitter can adapt its transmission method and transmit power according to the dynamics of the energy harvesting process.
- A MDP was formulated to derive the optimal policy to minimize the long-term discounted distortion

Any further question, please contact:

Dr. Yong Xiao

E-mail: xyong.2012@gmail.com

Homepage: https://sites.google.com/site/xyong2007/