

Design of Wireless Sensor Networks with Censoring and On-Off Sensors Based on Mutual Information

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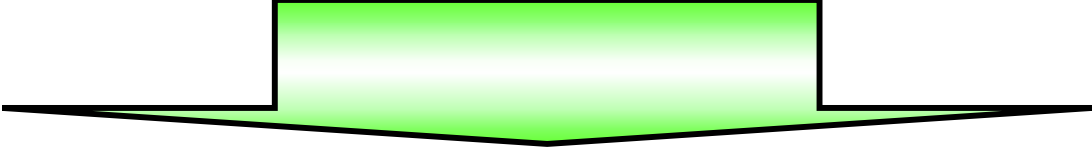
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Introduction

Sensor Networks

- Objectives : To obtain information about temperature, pressure, vehicle tracking, and so on
- Problems : Each sensor node is constrained by energy, memory, and computation



Innovative design techniques are required to use the energy efficiently under the constraints

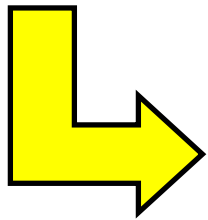


Introduction

Saving Transmission Energy

Censoring Sensor [1]: Sensor node transmits information only when it is informative

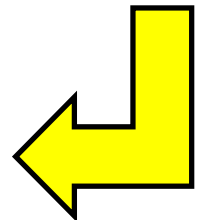
- Optimal censoring region was derived so that the detection probability was maximized [1]



Saving Observation and Transmission Energy

On-Off Sensor [2]: Sensor is either awake or asleep (on or off)

- Detection probability was evaluated in the sensor networks with censoring and on-off sensors [2]



Collaboration of censoring and sleeping plays a great role in saving more energy

[1] C. Rago, et al., *IEEE Trans. AES* . Vol. 32, No. 2, Apr. 1996

[2] V. V. Veeravalli, et al., in *Proc. of the sixth International Cnof. on Information fusion*, July. 2003



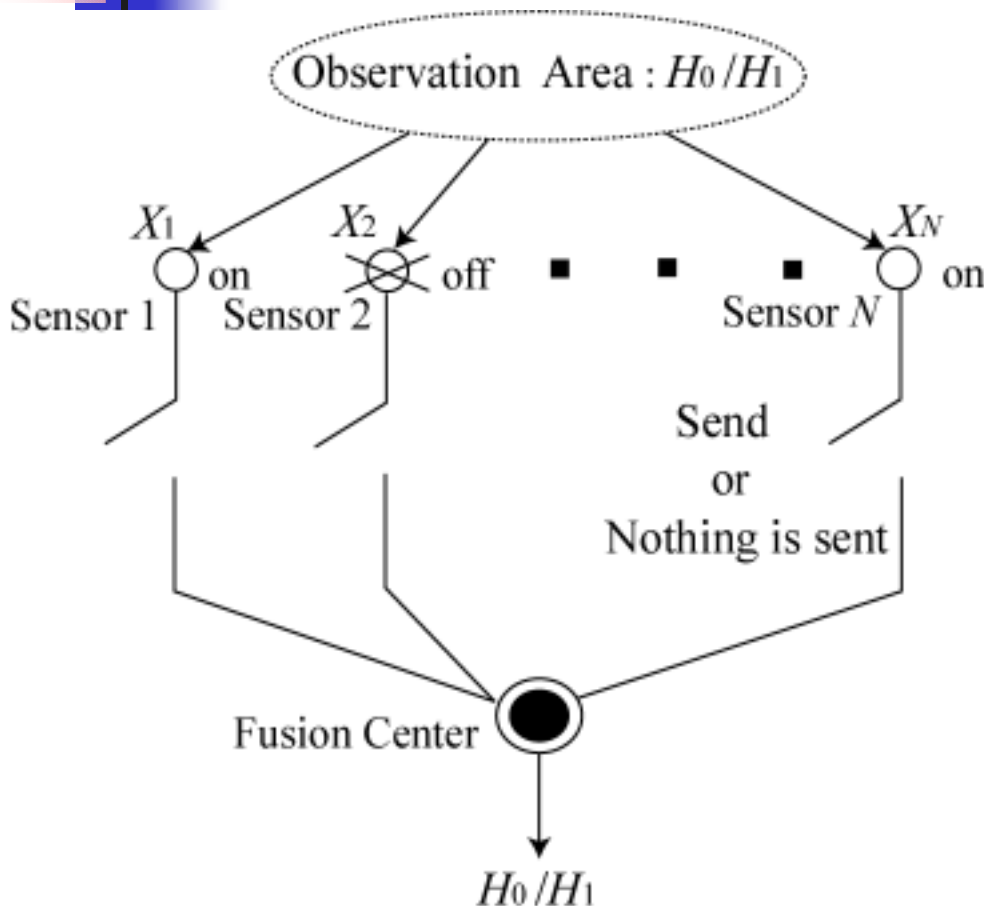
Objectives

We derive the **mutual information of a wireless sensor network** with N censoring and on-off sensors and one fusion center

Design Criteria : Maximum mutual information of sensor networks

- Under the constraint on the average power cost of each sensor, we derive the **maximum mutual information of the wireless sensor network**
- We derive the **optimum censoring and sleeping probabilities** with respect to the mutual information of the wireless sensor network

A Sensor Network Model with Censoring and On-Off Sensors



Target event : H_1
(with prior probability π_1)
Non-target event : H_0
(with prior probability $\pi_0 = 1 - \pi_1$)

- Each local sensor observes the **same environment**
- Sensor nodes can be off (sleep) with the **sleeping probability μ**
- X_i , $i = 1, 2, \dots, N$: the observation value of the i th local sensor
- Define the average of the censoring probabilities of the events : ρ

Fig. 1 A sensor network model with N censoring and on-off sensors

A Sensor Network Model with Censoring and On-Off Sensors

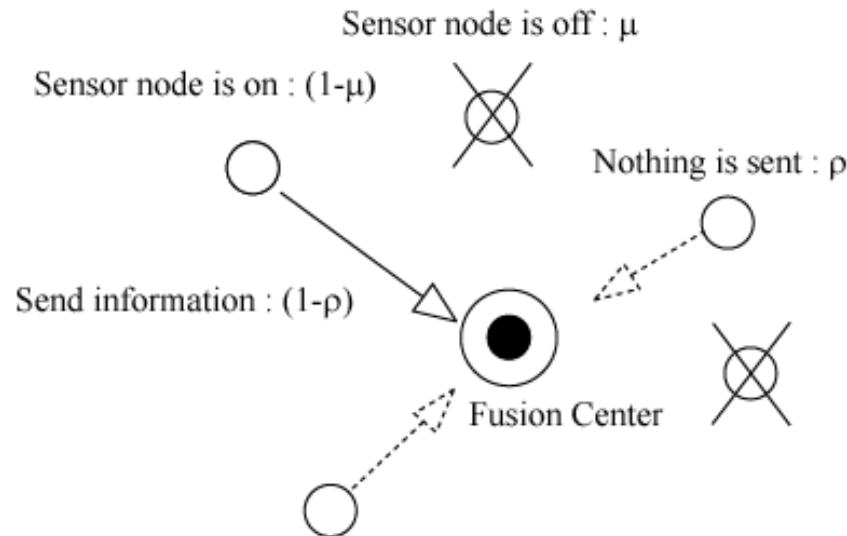
- We set a send region R_i and a censoring region \bar{R}_i at each local sensor
- Each local sensor i computes a likelihood ratio $\ell_i(X_i)$ of the observation value X_i

if
$$\begin{cases} \ell_i(X_i) \in R_i, & \ell_i(X_i) \text{ is sent to the fusion center} \\ \ell_i(X_i) \in \bar{R}_i, & \text{Nothing is sent} \end{cases}$$



Fusion Center makes a decision whether H_0 or H_1 occurs based on the likelihood ratio

A Sensor Network Model with Censoring and On-Off Sensors



- Sensor nodes perform one of the three operations

Sensor's operation	Probability
Not observe	μ
Observe but not transmit	$(1 - \mu)\rho$
Observe and transmit	$(1 - \mu)(1 - \rho)$

A Sensor Network Model with Censoring and On-Off Sensors

Average power cost of each sensor : C

Observe an event with probability $(1 - \mu)$ but not transmit information to the fusion center with probability ρ

$$C = \underbrace{(c_o + c_t)(1 - \mu)(1 - \rho)}_{\text{cost of observing and transmitting}} + \underbrace{c_o(1 - \mu)\rho}_{\text{cost of observing but not transmitting}}$$

Observe an event with probability $(1 - \rho)$ and transmit information to the fusion center with probability $(1 - \mu)$

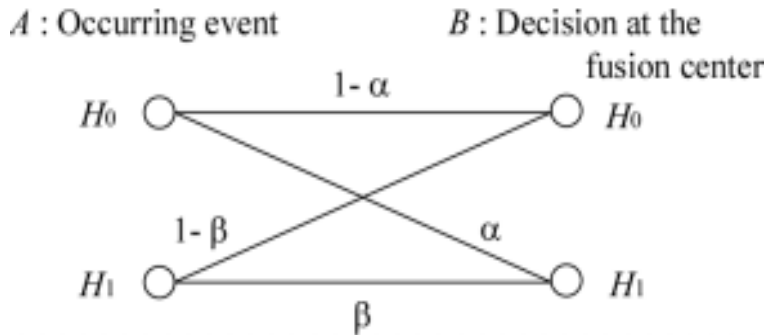
c_o : Observation Cost

c_t : Transmission Cost

➤ The ratio between transmission cost and observation cost : $\gamma = \frac{c_t}{c_o}$

Mutual Information of Sensor Network with Censoring and On-Off Sensors

- Model the sensor network as a **binary asymmetric channel**
- Compute mutual information of sensor network $I(A; B)$

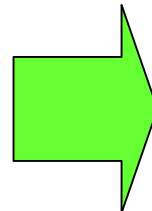


- α : Probability that fusion center makes a wrong decision H_1 when H_0 occurs
- β : Probability that fusion center makes a correct decision H_1 when H_1 occurs

Fig. 3 A binary asymmetric channel

- p_k : the probability that k out of N sensors are on
- $I_k(A; B)$: the mutual information of the sensor network when k sensors on

Expected mutual information
of the sensor network



$$E[I(A; B)] = \sum_{k=1}^N p_k I_k(A; B)$$



Numerical Results and Comparison

- Sensor network with $N = 10$ censoring and on-off sensors, and one fusion center
- Channel between each local sensor and fusion center is **ideal**
- Non – Target event : $H_0 : X_i \sim \mathcal{N}(0, 1)$
Target event : $H_1 : X_i \sim \mathcal{N}(1, 1)$
- Prior probability of target event is $\pi_1 = 0.1$
- Each local sensor employs **common and optimal censoring region** [2]
- Fusion center has knowledge of sleeping probability and prior probability of target event
- Ratio between transmission cost and observation cost : $\gamma = 1, 2, 10$



Numerical Results and Comparison

The average power cost of each sensor C is set to **unity**

TABLE I
Normalized Observation Cost and Normalized
Transmission Cost for

$\gamma = \frac{c_t}{c_o}$	Observation Cost : c_o	Transmission Cost : c_t
1	0.500	0.500
2	0.333	0.667
10	0.091	0.909

Numerical Results and Comparison

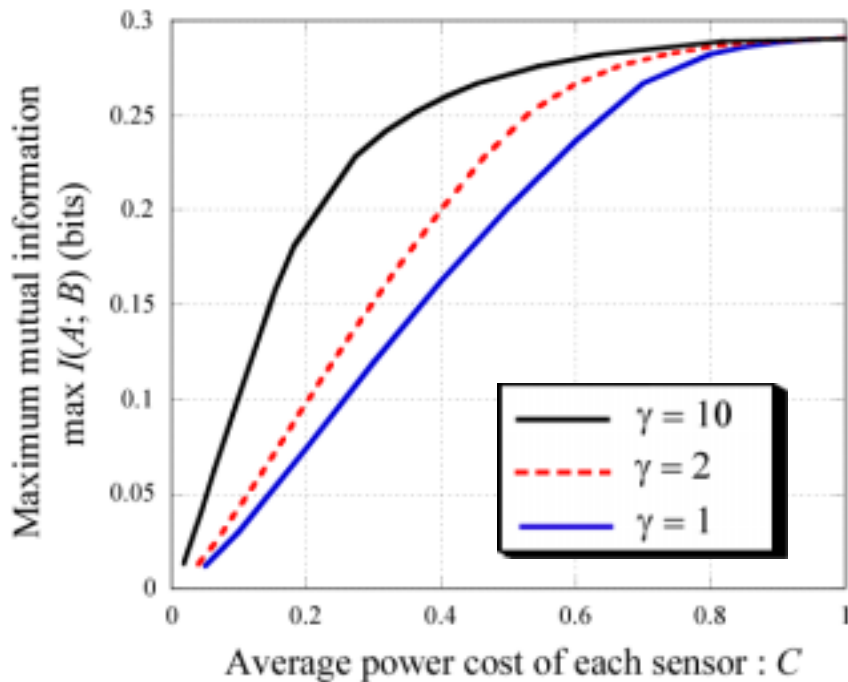


Fig. 4 Maximum mutual information of the sensor network for average power cost of each sensor ($N=10, \pi_1 = 0.1$)

- Largest mutual information can be achieved with $\gamma = 10$
- ✓ Sensor nodes always observe the event for $0.18 < C < 1$ in Fig. 5
- ✓ Sensor nodes transmit the information with the lowest censoring probability for $0.4 < C < 1$ in Fig. 6
- From Table I and Fig. 5, the larger the observation cost c_o becomes, the higher the sleeping probability is

Numerical Results and Comparison

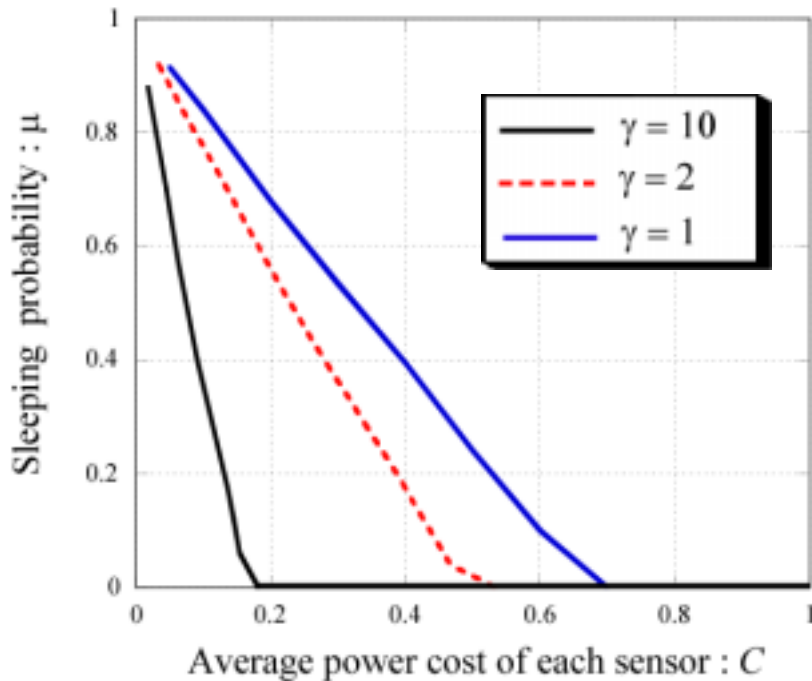
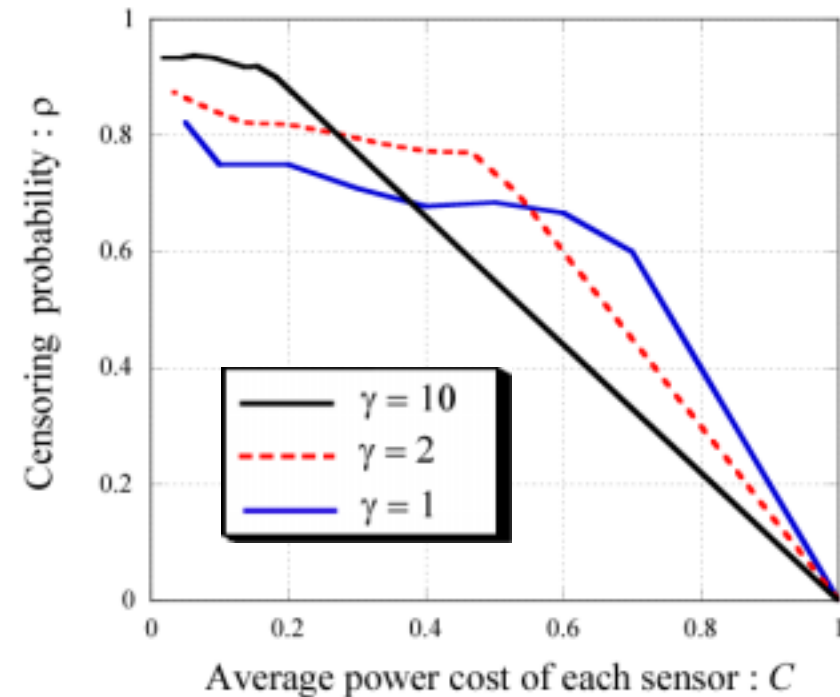


Fig. 5 Optimal sleeping probability for average power cost of each sensor ($N = 10$, $\pi_1 = 0.1$)

➤ From Figs. 5 and 6, the larger maximum mutual information of the sensor network can be obtained by censoring rather than by sleeping for large C

✓ When the available cost of the sensor node is not strictly limited, the best way to get the large mutual information of the sensor network is always observing an event

Numerical Results and Comparison



- From Fig. 5, when the cost available for each sensor node is large, that is, large C , we can design the energy efficient sensor network **by using censoring sensors only**
- From Fig. 5, when the available cost is limited, that is, small C , we can design the energy efficient sensor network **by using censoring and on-off sensors**

Fig. 6 Optimal censoring probability for average power cost of each sensor ($N = 10$, $\pi_1 = 0.1$)



Conclusion

We derived the **mutual information of a wireless sensor network** with censoring and on-off sensors and one fusion center under the constraint on the average power cost of each sensor

Design Criteria : Maximum mutual information of sensor networks

- **Based on maximum mutual information of sensor networks**, we can design very energy efficient wireless sensor networks by using censoring and on-off sensors