Sensor Scheduling

EE228A
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Outline

- Motivation and Background
  - Sensor Network Application
- Problem Statement
- Model
- Simulation
- Conclusion
Motivation & Background

- Wireless Sensor Network Characteristics
  - Dense
  - Redundant
  - Large Scale
  - Battery Powered
Sensor Network Applications

- Monitoring
- Surveillance

Multiple sensors are triggered in near vicinity for estimation of a process
Estimation over Sensor Network

- Tracking: the more reporting sensors the better?

![Graphs showing tracking paths with different numbers of sensors: couple sensors vs. dozen sensors.](image)
Estimation over Sensor Network

• **Contention** for channel access among reporting sensors

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![Graph showing evader path and estimated path](image_url)
Problem Statement -- Goal

• Number of Reporting Sensors impacts
  – Application Performance: Estimation Accuracy
    Has not been addressed

  – Life time of Sensor Network:
    • transmission consumes most energy in sensor

Activate a subset of sensors to report while suppress the others.
Problem statement -- Background

- Multi-sensor Estimation using Kalman Filter

Process:

\[ x_{t+1} = A_t + w_t \]

Measurement:

\[ y_{i,t} = Cx_t + v_{i,t} \]

\[ y_t = \frac{\sum_1^N y_{i,t}}{N} \]

Bernoulli with probability distribution \( p_{y_{i,t}}(1) = \lambda_t(N) \)

For \( N = 2 \)

\[ y_t = \begin{cases} 
0 & \text{w/p } (1-\lambda_t(2))^2 \\
y_{1,t} & \text{w/p } \lambda_t(2)(1-\lambda_t(2)) \\
y_{2,t} & \text{w/p } (1-\lambda_t(2))\lambda_t(2) \\
y_{1,t}+y_{2,t} \over 2 & \text{w/p } \lambda_t(2)^2 
\end{cases} \]

Error covariance

\[ P_{t+1}^{(2)} = AP_tA' + Q - [\gamma_{1,t}(1-\gamma_{2,t}) + (1-\gamma_{1,t})\gamma_{2,t}]M_1(P_t) - \gamma_{1,t}\gamma_{2,t}M_2(P_t) \]

\[ M_1(P_t) = AP_tC'(CP_tC' + R)^{-1}CP_tA' \]

\[ M_2(P_t) = AP_tC'(CP_tC' + \frac{R}{2})^{-1}CP_tA' \]
Problem Statement -- Driver

- Multi-sensor Kalman Filter

Performance Criteria:

\[ g_{\lambda(N)}(X) = AXA' + Q - \sum_{n=1}^{N} \binom{N}{n} \lambda(N)^n (1 - \lambda(N))^{N-n} M_n(X) \]

where \( M_n(X) = AXC'(CXC' + \frac{R}{n})^{-1} CXA' \).

\( \lambda(N) \), the packet arrival probability is protocol dependent.

There is an \textbf{optimal} number of reporting sensors that gives the best performance.
Problem Statement -- Enabler

- Dominant MAC in WSN -- CSMA/CA
  - BMAC  Berkeley MAC
    - Provides basic CSMA access
    - Carrier sensing using Clear Channel Assessment (CCA)
    - Optional link level ACK, no link level RTS/CTS
  - IEEE 802.15.4 Low Rate Wireless Personal Area Network
    - Unslotted & slotted
    - The contention access period
**IEEE 802.15.4 MAC Unslotted**

**Notation:**
- **BE**: backoff exponent \( \in (\text{macMinBE}, \text{aMaxBE}) \)
- **CCA**: clear channel accessment
- **NB**: number of backoff stages \( \leq \text{maxMacCSMABackoffs} \)

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**Diagram Description:**
1. **CSMA-CA**
2. **NB = 0, BE = maxMinBE**
   - Delay for random(\(2^0 - 1\)) unit backoff periods
3. **Perform CCA**
   - Channel idle?\(\text{Y}\)
   - **NB = NB + 1, BE = max(BE + 1, aMaxBE)**
   - **NB = maxMacCSMABackoffs**
4. **Failure**
5. **Success**
MAC model assumption

- Single-hop star topology
- \( N \), fixed number of nodes within sensing range
- Each node always has packet ready for transmission
- Constant busy rate, \( c \)
- Ideal channel conditions
MAC Model

• Markov Chain Model of node State

  - Backoff counter decrements regardless of channel status
  - Starts sensing channel once counter becomes zero

  \{s(t), b(t)\}, backoff stage, position, with transition probabilities:

  \[
  \begin{align*}
  P\{s(t+1) = i, b(t+1) = k | s(t) = i, b(t) = k+1\} &= 1 & i \in [0,m] & k \in [CCA, W_i - 2] \\
  P\{s(t+1) = 0, b(t+1) = k | s(t) = i, b(t) = 0\} &= (1 - c) / W_0 & k \in [0, W_i - 1] \\
  P\{s(t+1) = 0, b(t+1) = k | s(t) = m, b(t) = 0\} &= 1 / W_0 & k \in [0, W_0 - 1] \\
  P\{s(t+1), b(t+1) = k | s(t) = i - 1, b(t)\} &= c / W_i & i \in [1,m] & k \in [0, W_i - 1]
  \end{align*}
  \]
Model Derivation

• The stationary distribution

\[ b_{i,0} = c^i b_{0,0} \]

\[ b_{0,0} = (1 - c) \sum_{i=0}^{m} b_{i,0} + cb_{m,0} = \frac{2(1 - 2c)(1 - c)}{(1 - c)(1 - c^{m+1}2^{m+1})W + (1 - 2c)(1 - c^{m+1})} \]

channel sensing probability

\[ \sum_{i=0}^{m} b_{i,0} \]

A node transmission probability

\[ p_{tr} = (1 - c) \sum_{i=0}^{m} b_{i,0} = (1 - c^{m+1})b_{0,0} \]

\[ = \frac{2(1 - 2c)(1 - c)(1 - c^{m+1})}{(1 - c)(1 - c^{m+1}2^{m+1})W + (1 - 2c)(1 - c^{m+1})} \]

(1)

The conditional collision probability

\[ c = 1 - (1 - p_{tr})^{N-1} \]

(2)

Solving the nonlinear fixed point equations to find \( P_{tr} \), node transmission probability,
Model

- **Node Successful Packet Transmission Probability** in an arbitrary (backoff) period

\[ \lambda(N) = p_{tr} (1 - p_{tr})^{N-1} \]

- **Find optimal number**

\[ N = \text{argmin} g_{\lambda(N)}(X) = AXA' + Q - \sum_{n=1}^{N} \binom{N}{n} \lambda(N)^n (1 - \lambda(N))^{N-n} M_n(X) \]

where \( M_n(X) = AXC'\left(CX'C' + \frac{B}{n}\right)^{-1}CXA' \).
Theoretical Results

- Successful Transmission Probability

![Graphs showing successful transmission probability with respect to the number of contending sensors.]

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Theoretical Result

- For a given process dynamics
Simulation

- Experiment Set-up (demo follows)
  - Target tracking in a surveillance field
  - 150 sensors randomly distributed
  - One case with all sensors reporting
  - One case with the optimal number sensors activated to and other suppressed from reporting
Future work

- Fairness
- Multi-hop
Conclusion and Acknowledgement

- Sensor scheduling/selection for optimal estimation performance over sensor network

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