Cognitive Sensor Networks with Primary QoS Constraints

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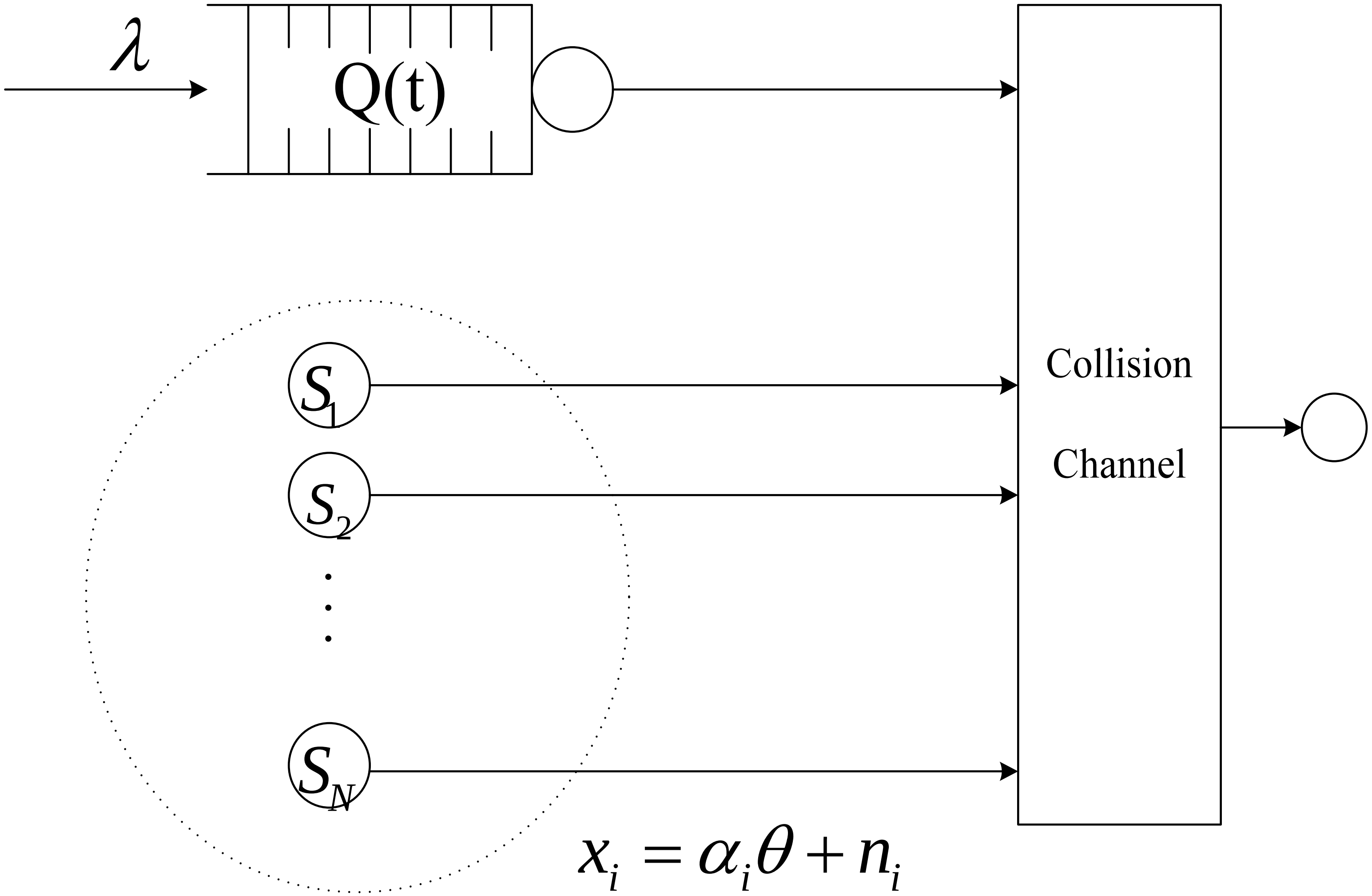
Introduction

- Sensor networks may be operated in a bandwidth licensed for use of a primary system
- A primary link coexists with a secondary distributed network of sensors reporting to a fusion center

System Model



$$x_i = \alpha_i \theta + n_i$$

System Model (Cont.)

- Detection to the primary activity
  - Interference to the primary user inevitably takes place due to sensing error (miss detection)
  - Each sensor of the network attempts to detect the primary activity to determine whether to transmit or not
- Random access
  - Employ slotted ALOHA

System Model (Cont.)

- Collision model
  - Primary or secondary node succeeds in transmission if only if one transmission takes place
- Estimator at the fusion center
  - Best Linear Unbiased Estimation (BLUE)
- Quality-of-Service constraints (QoS)
  - Defined as the maximum average delay of primary packets

Problem Formulation

- The goal of the our work
  - Design a transmission strategy (probability of error) so as to minimize the accumulated estimation error at the fusion center under Quality-of-Service (QoS) constraints on the primary activity
- The optimization problem
  - Objective function

$$\min_{p} \; Var_{av}(\hat{\theta})$$

  - The Quality of Service (QoS) constraint

$$D(p) \leq D_{\max}$$

Problem Formulation (Cont.)

- The BLUE is adopted at the fusion center

$$\mathrm{Var}\left(\hat{\theta}\right)=\left[\boldsymbol{\alpha}^{\mathrm{T}}\mathbf{R}^{-1}\boldsymbol{\alpha}\right]^{-1}=\left(\sum_{i=1}^{T}\frac{\alpha_i^2}{\sigma_i^2}\right)^{-1}=\frac{1}{\delta_T}$$

- If sensor succeeds in transmission

$$\mathrm{Var}\left(\hat{\theta}\right)=\frac{1}{\delta_T+\delta_i}$$

- If no sensor succeeds in transmission

$$\mathrm{Var}\left(\hat{\theta}\right)=\frac{1}{\delta_T}$$

Problem Formulation (Cont.)

- **The average MSE**

$$\mathrm{Var}_{av}\left(\hat{\theta}\right)=\sum_{i=1}^{N}P_i\frac{1}{\delta_T+\delta_i}+\left(1-\sum_{i=1}^{N}P_i\right)\frac{1}{\delta_T}$$

where

$$P_i=p_i(1-p_{fa,i})\prod_{j\neq i}\left(1-p_j(1-p_{fa,i})\right)$$

Problem Formulation (Cont.)

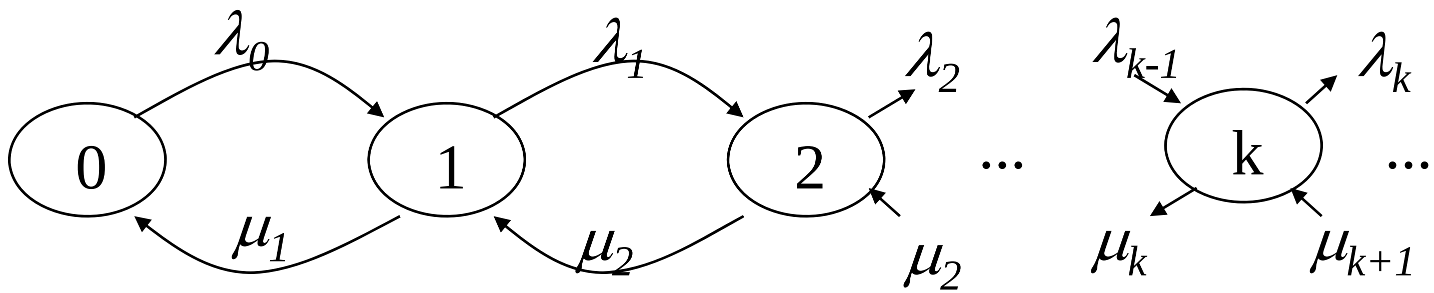
- The delay of the primary user

$$D(p) = \frac{1-\lambda_p}{\bar{\mu}_p - \lambda_p}$$

$$\bar{\mu}_p = \prod_{i=1}^{N}\left(1-p_{md,i}\right) + \sum_{V \subseteq N}\left(\prod_{j \in V} p_{md,j}\left(1-p_j\right)\right) \times \left(\prod_{j \neq V}\left(1-p_{md,j}\right)\right)$$

Problem Formulation (Cont.)

- The system can be modeled as a Birth-Death Markov chain



Simulation Results

❑ Assumptions

- **All the sensors attempt to transmit with the same probability**
- **All the sensors are under the same probability of miss detection and probability of false alarm.**

❑ Solution

- **We can obtain a unique optimal transmission probability**

$$p_{opt} = \begin{cases} \dfrac{1}{N\left(1-p_{fa}\right)}, & D_{\max} \geq D\left(\dfrac{1}{N\left(1-p_{fa}\right)}\right) \\ D^{-1}\left(D_{\max}\right), & D_{\max} < D\left(\dfrac{1}{N\left(1-p_{fa}\right)}\right) \end{cases}$$

where $D^{-1}(*)$ is the inverse function of $D(p)$

Simulation Results (Cont.)