Efficient Distributed Sensing using Adaptive Censoring-based Inference

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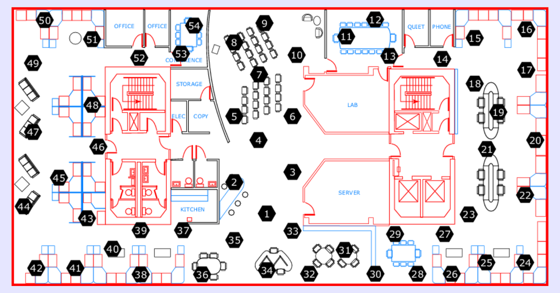
Distributed Information Fusion Under Uncertainty and Communication Constraints

- Important to maintain accurate situational awareness for a variety of cooperative multi-agent missions
  - Key to many other decision making problems, e.g. distributed planning
  - Challenging in dynamic, uncertain, communication-constrained environments
- **Problem**: How compute distributed parameter estimates in presence of uncertainties and **communication constraints**?
  - What is correct? ⇒ centralized Bayesian estimate
  - Various types of uncertainties
  - Limited communication/computation resource

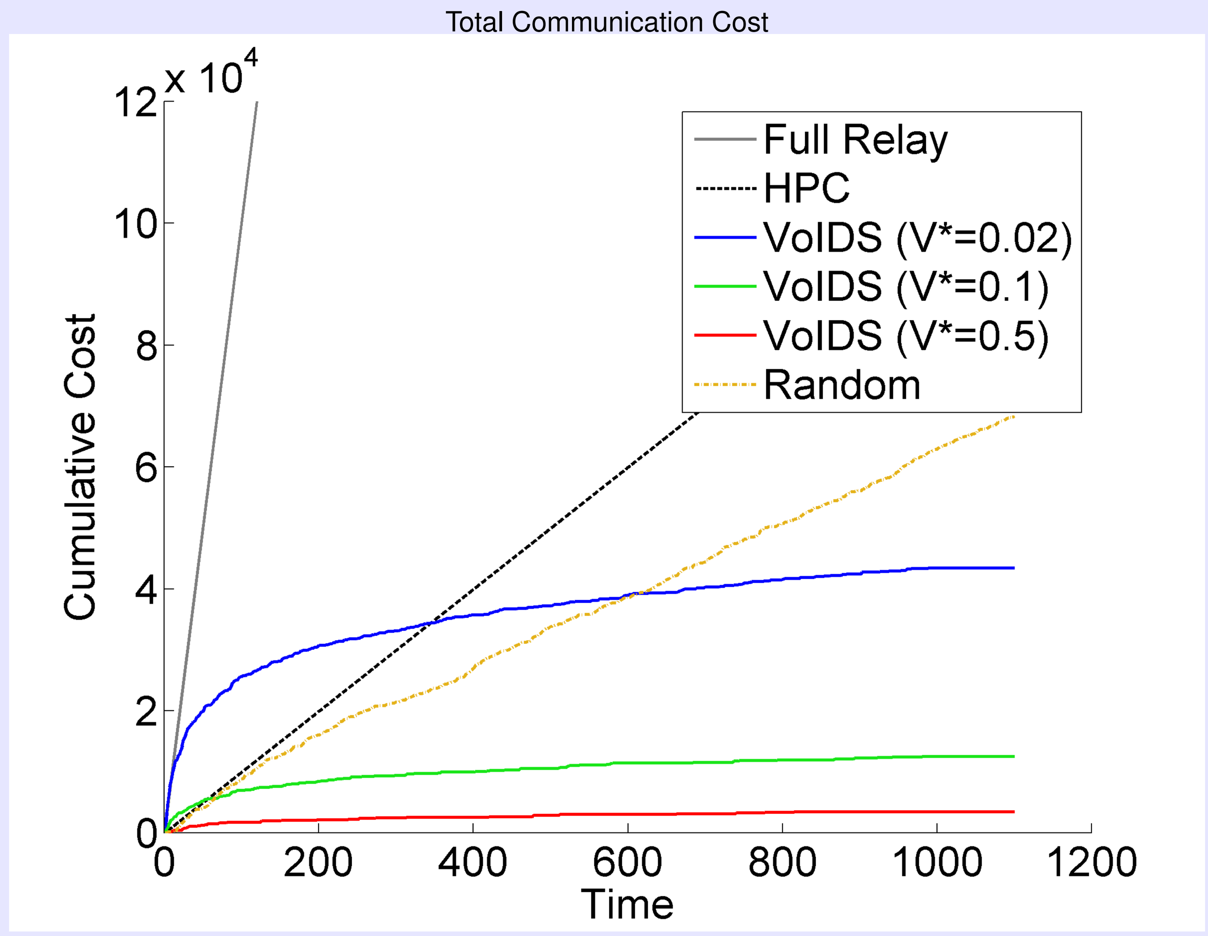


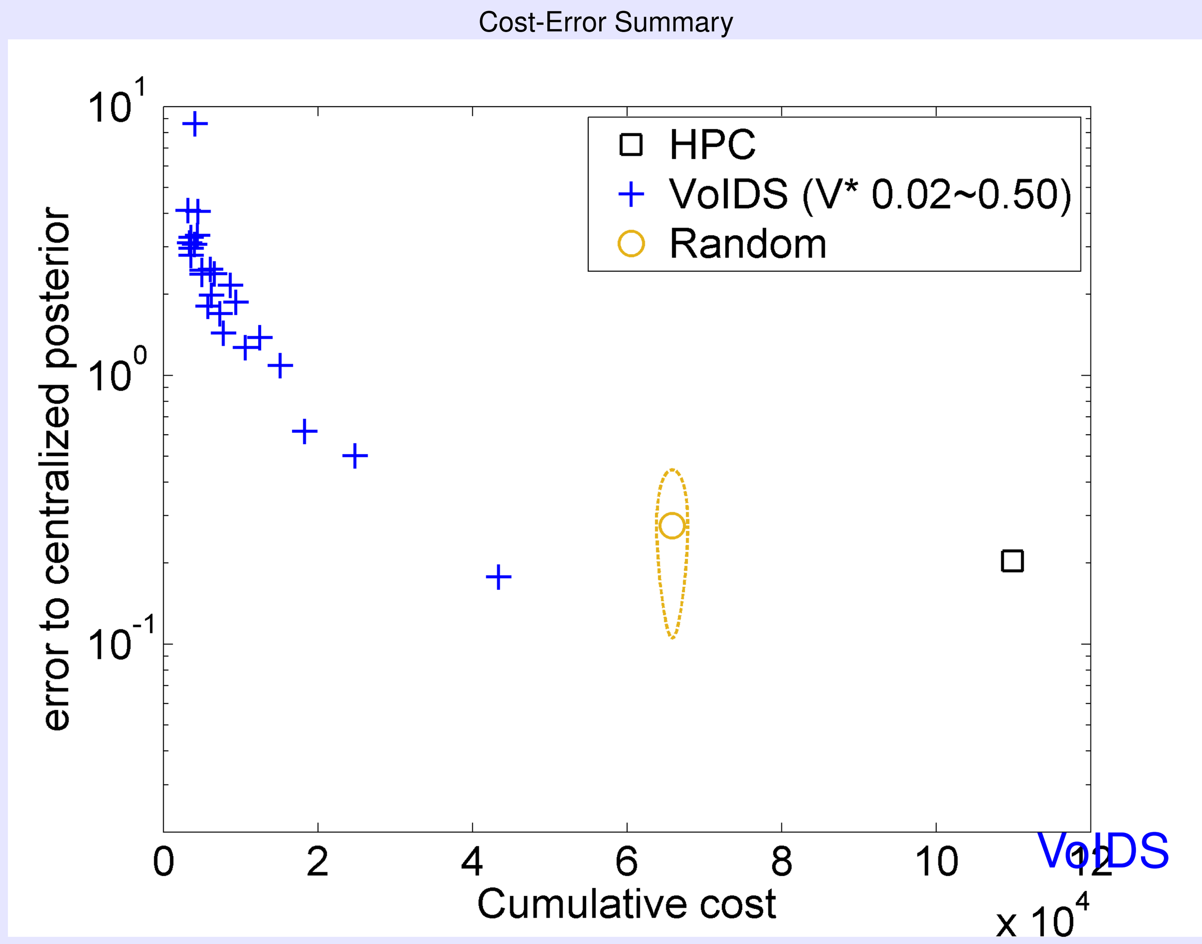
How efficiently handle large data volume collected over distributed nodes?

- **Key features needed:** accurate, scalable, communication efficient

Simulation Results

- Same Poisson arrival rate estimation on slide **??**, $V^* \in [0.02, 0.5]$





- For given V^*, comm. cost initially grows quickly then levels off
  - Little known initially, so most new measurements declared informative
- Communication drops in later stages, error cannot be reduced further ⇒ **dynamic** trade-off between cost and accuracy
- How **balance** communication load between early/later stages?

Existing Methods

- All measurements are broadcast or relayed by all agents to all other agents ⇒ baseline Full-Relay (FR)
  - Comparable to centralized Bayesian estimation
  - Inefficient: communication cost very high (well known)
- Distributed inference with graphical models [**? ? ? ?**]
  - Communication cost lower than FR, can work for arbitrary distributions
  - Not easily scalable to cyclic graphs
- Can employ **censoring**
  - Differentiate informative measurements from uninformative ones.
  - Censor uninformative measurements/sensors
- Consensus based fusion
  - Comm. cost lower than FR, but all agents communicate at all times
  - Dynamic network topology can lead to bias ⇒ hard to censor agents
- Random Broadcast (random censoring of agents)
  - Communication cost reduced by increasing probability of censoring.
  - No bias since all agents have chance to communication
  - Longer time to convergence since frequency of communication reduced

Our Method: Efficient Distributed Inference

- Value of Information realized Distributed Sensing (VoIDS)
  - Sensors do not communicate measurements all the time
  - Differentiate between informative and uninformative sensors
  - Relax restrictions on network topologies
- Will show that this works well, but censoring threshold is somewhat arbitrary and impacts communication cost/performance
- Developed Adaptive VoIDS (A-VoIDS) [**?**]
  - Better balance between communication cost and inference error

Bayesian Update

- Bayesian update

$$p(\theta|z,\omega) = \frac{p(z|\theta)p(\theta|\omega)}{\int p(z|\theta)p(\theta|\omega)\,d\theta}$$

  - ω: hyperparameters of the prior
  - θ: parameters to be estimated
- Posterior may not have closed form solution
- Approximate inference methods often used (e.g. Markov Chain Monte Carlo (MCMC) [**?**]), but still slow and costly
- In case of exponential family, **closed from solution** exists ⇒ efficient Bayesian inference

Exponential Family and Conjugate Prior

- **Exponential Family**

$$p(\mathbf{x}|\theta) = \exp\left\{\theta^T T(\mathbf{x}) - A(\theta)\right\}$$

  - under measurement $\mu(x)$
  - $T(\mathbf{x})$: sufficient statistics; $A(\theta)$: log partition
- **Conjugate prior**

$$p(\theta|\omega,\nu) = \exp\left\{[\omega,\nu]^T[\theta, -A(\theta)] - \Lambda(\omega,\nu)\right\}$$

  - under measurement $h(x)$
  - ω, ν: hyperparameters of the prior; Λ: log partition of conjugate prior

Adaptive VoI Realized Distributed Sensing (A-VoIDS)

- Control frequency of communication by **adjusting V^* in response to communication load**
- Much better utilization of available communication bandwidth
  - If many nodes are informative, increase V^* to reduce communication load,
  - If low communication load decrease V^* to increase accuracy

$$V^* = \begin{cases} \gamma_1 V^* & \bar{C}[t-l+1:t] < c \\ \gamma_2 V^* & \bar{C}[t-l+1:t] \geq c \end{cases}$$
$$\gamma_1 > 1, \quad 0 < \gamma_2 < 1$$

  - $\bar{C}[t-l+1:t]$: average number of active agents during $[t-l+1:t]$
  - c: desired communication cost in a step, user-defined
  - γ_1: gaining rate of V^*, user-defined
  - γ_2: loosing rate of V^*, user-defined

Exponential Family and Conjugate Prior

- brief text

Summary

- brief text

Refs