Energy and Delay: Network Optimization in Cyber-Physical Human Sensing Systems

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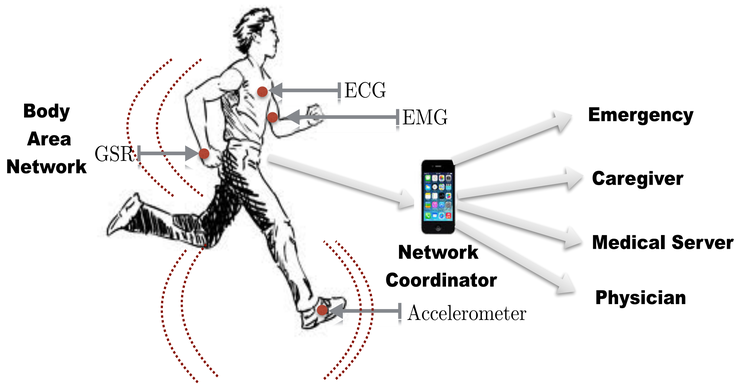


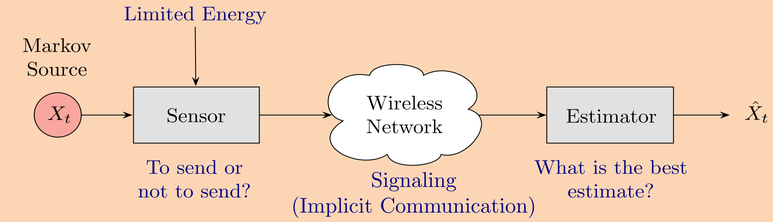
Cyber-Physical System
coupling **bio-sensors** on people and **wireless networks**

Goals
Real-time monitoring health and behavior
Feedback via adaptive and personalized interventions

Design challenges
Sensors & data **heterogeneity**
Sensors & coordinator **energy constraints**
Sensing & communication are **state dependent**

Networked decision systems
New decision-making problems involving
the joint design of **sensing**, **communication** and **control**

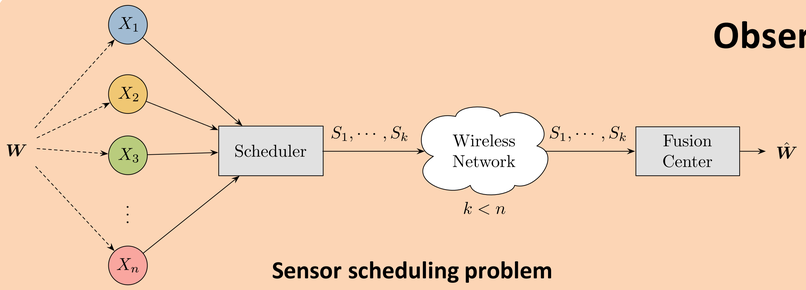
Previous work: min-max estimation with signaling



$$\underset{(\gamma,\eta)\in\Gamma\times\mathrm{H}}{\text{minimize}} \quad \mathcal{J}(\gamma,\eta)=\max_{X_{1:T}}\left\{\max_t |X_t-\hat{X}_t|\right\}$$

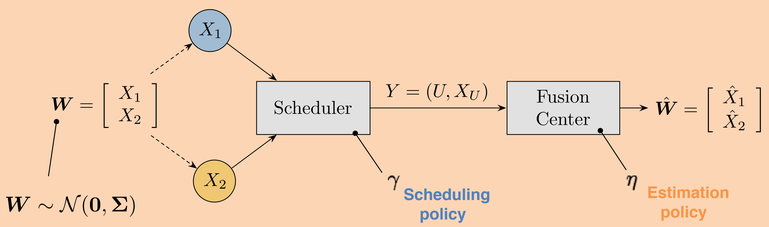
Main result[1]
The globally optimal transmission strategy is an energy-based threshold rule and the globally optimal estimate is the most recently received source value

Observation-driven sensor scheduling for networked estimation



Sensor scheduling problem

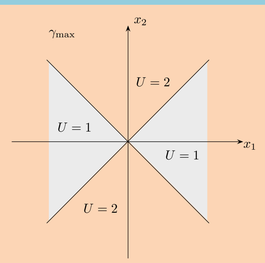
Choose k out of n sensors such that the expected distortion between $\boldsymbol{W}$ and $\hat{\boldsymbol{W}}$ is minimized

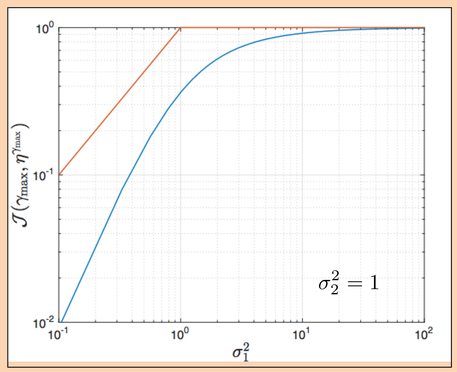


$$\underset{(\gamma,\eta)\in\Gamma\times\mathrm{H}}{\text{minimize}} \quad \mathcal{J}(\gamma,\eta)=\mathbf{E}\left[(X_1-\hat{X}_1)^2+(X_2-\hat{X}_2)^2\right]$$

Main result[2]
Person-by-person optimality of max-scheduling for independent and correlated Gaussian observations

Send the measurement with largest magnitude





Performance comparison in the independent Gaussian case

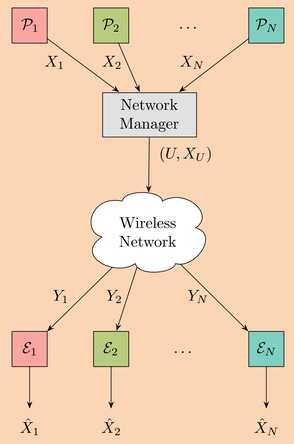
$$\bar{\mathcal{J}}(\sigma_1^2,\sigma_2^2)=\min\{\sigma_1^2,\sigma_2^2\}$$

"Open-loop" sensor scheduling

$$\mathcal{J}(\gamma_{\max},\eta^{\gamma_{\max}})=\mathbf{E}\left[\min\left\{X_1^2,X_2^2\right\}\right]$$

Observation-driven sensor scheduling

Multi-source and multi-receiver case with unicast networking



$$\underset{(\gamma,\eta)\in\Gamma\times\mathrm{H}}{\text{minimize}} \quad \mathcal{J}(\gamma,\eta)=\mathbf{E}\left[\sum_{i=1}^{N}\|X_i-\hat{X}_i\|^2+c\cdot\mathbf{1}(U\neq 0)\right]$$

$$\gamma_{\max}(x)=\begin{cases}0, & \text{if } \|x_i\|\leq\sqrt{c},\ i\in\{1,\cdots,N\}\\ \arg\max\limits_i \|x_i\|, & \text{otherwise}\end{cases}$$

$$\eta_i^{\text{mean}}(y_i)=\begin{cases}x_i, & \text{if } y_i=(i,x_i)\\ \mathbf{E}[X_i], & \text{otherwise}\end{cases} \qquad i\in\{1,\cdots,N\}$$

Main result[3,4]
Global optimality of max-scheduling for independent symmetric unimodal observations

Future work

- Extend to sequential estimation problems
- Design of observation-driven schedulers for arbitrarily correlated sources
- Close the cyber-physical control loop
- Explore connections with dimensionality reduction

Publications

[1] Gagrani, Yi, Rasouli & Nayyar, *Remote estimation with worst-case guarantees* (in prep.)
[2] Vasconcelos & Mitra, *Observation-driven sensor scheduling*, IEEE ICC 2017
[3] Vasconcelos, Nayyar & Mitra, *Optimal scheduling strategies in networked estimation*, IEEE CDC 2017
[4] Vasconcelos, Gagrani, Nayyar & Mitra, *An optimal sensor scheduling strategy for sequential networked estimation with constrained transmissions* (in prep.)