Optimal Pilot Scheduling for Throughput Maximization over Wireless Channels: A Battle with Non-Monotonic Information Aging

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Background

Problem

- ❖ Pilots and data must take turns to be transmitted over a channel
- ❖ More pilots give better channel estimation **but at the cost of less resources for data**

Key Findings

- ❖ Throughput is a function of **Age of Information** (AoI) which is the time elapsed between the current time and the latest received sample

Why It Matters

- ❖ **Gives best performance** for adaptive communications including self-driving cars, GPS, sensor measurements, etc.

Model

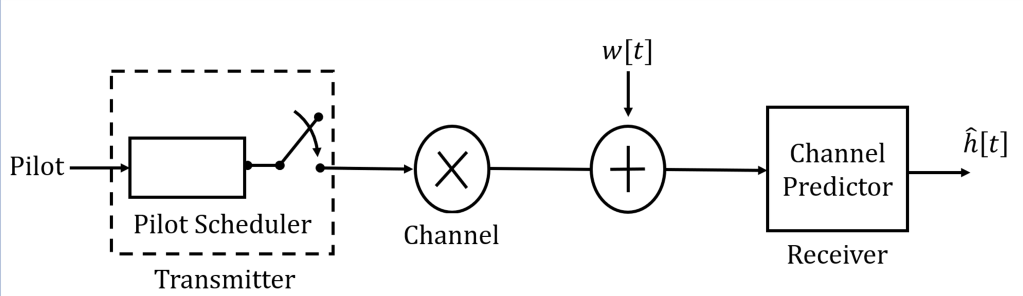

Figure 1: System model

- ❖ Pilot symbols do not age, and they are known at the receiver
- ❖ The optimal time to send another pilot is related to Gittins index

Methodology

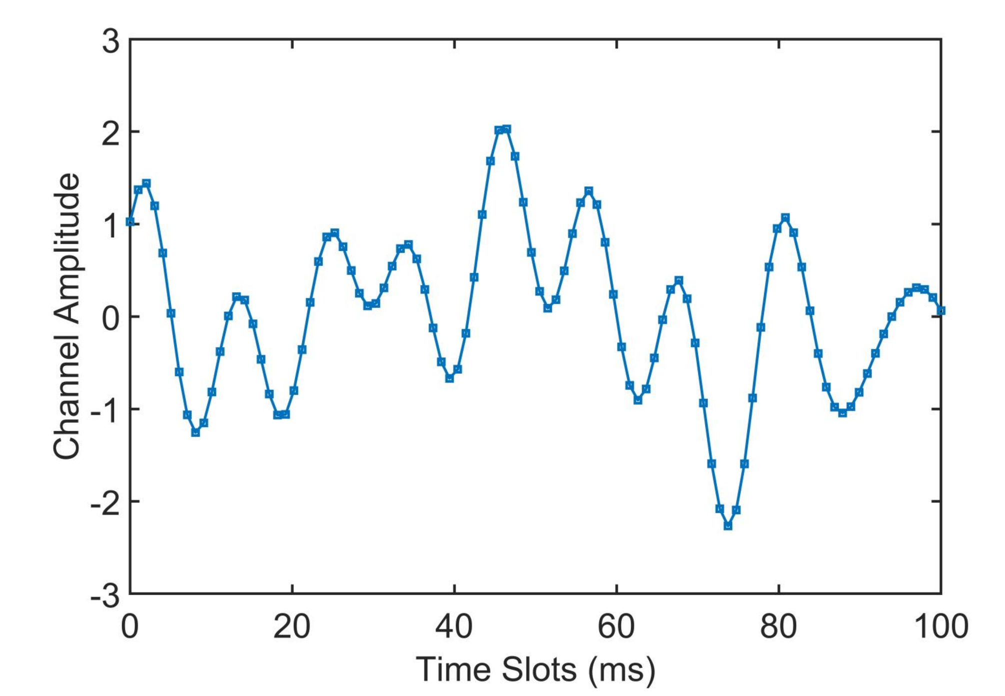

Figure 2: Time-varying channel model

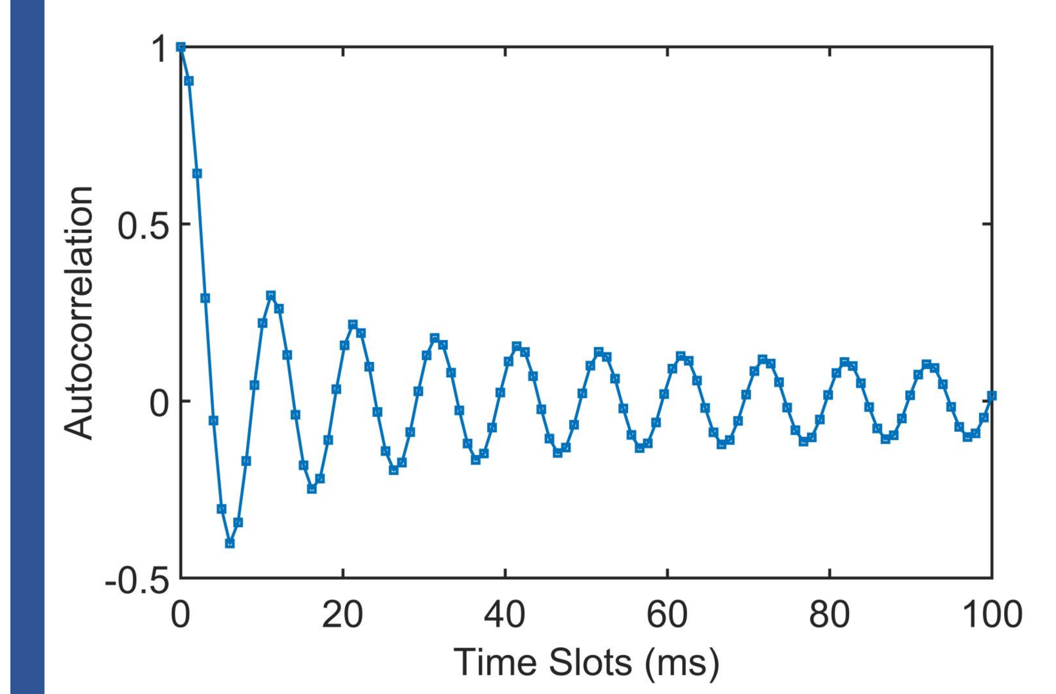

Figure 3: Jakes autocorrelation function

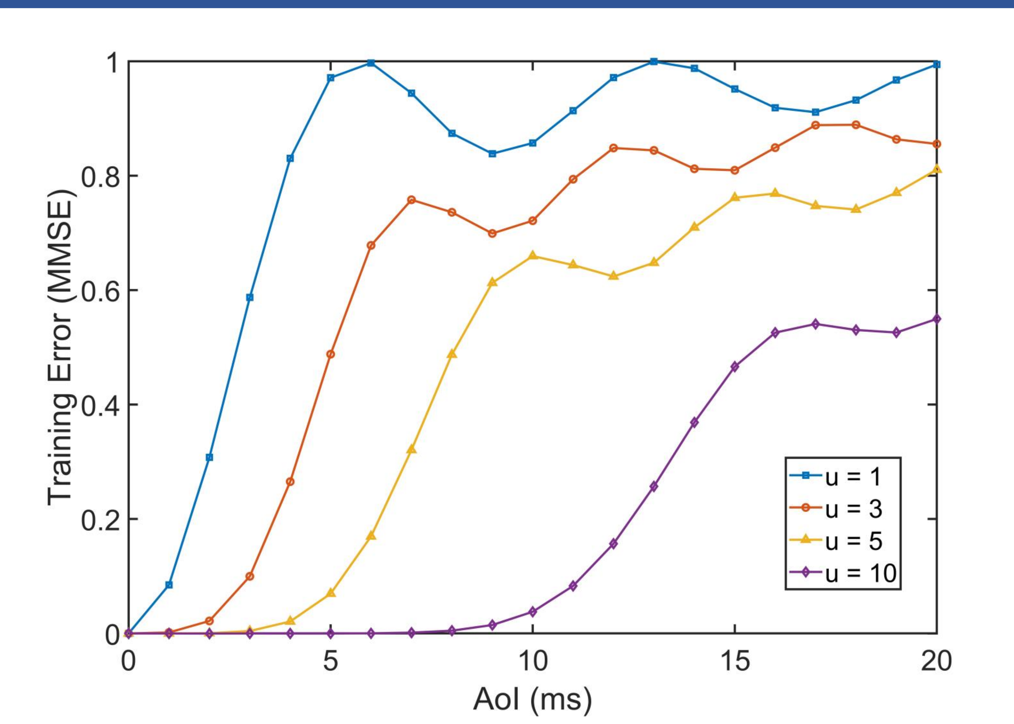

Figure 4: Channel state information (CSI) prediction error

Objective: Maximize goodput, an age utility function used as a metric for system throughput

Theorem: The optimal scheduling policy for sending pilots that maximizes the average age utility $u(t)$ for the system's goodput is given by:

$$S_{i+1} = S_i + T + Z(t)$$

$$\text{s.t. } Z(t) = \min_{z \in \mathbb{Z}} \{z \geq 0 : \gamma(z+T) \leq \beta\}$$

- ❖ T represents the system's **constant transmission time**
- ❖ $Z(t)$ represents the waiting time between when the sample is transmitted and when another sample is sent
- ❖ $\gamma(\Delta(t))$ represents the **Gittins index**

The optimal objective value is β which is the solution to the following equation:

$$\beta = \frac{\sum_{k=0}^{Z(t)-1} u(k+T)}{T + Z(t)}$$

The optimal time to send another pilot for better channel estimation, and hence improved throughput, is the earliest integer time that satisfies two conditions:

I. The previous pilot has been delivered by time t

II. The Gittins index **is not larger than the objective value β**.

Results

- ❖ This theorem **maximizes general non-monotonic functions of goodput** for fading wireless channels
- ❖ **Compare with** checking stock price: how often to check for accurate price measurement?

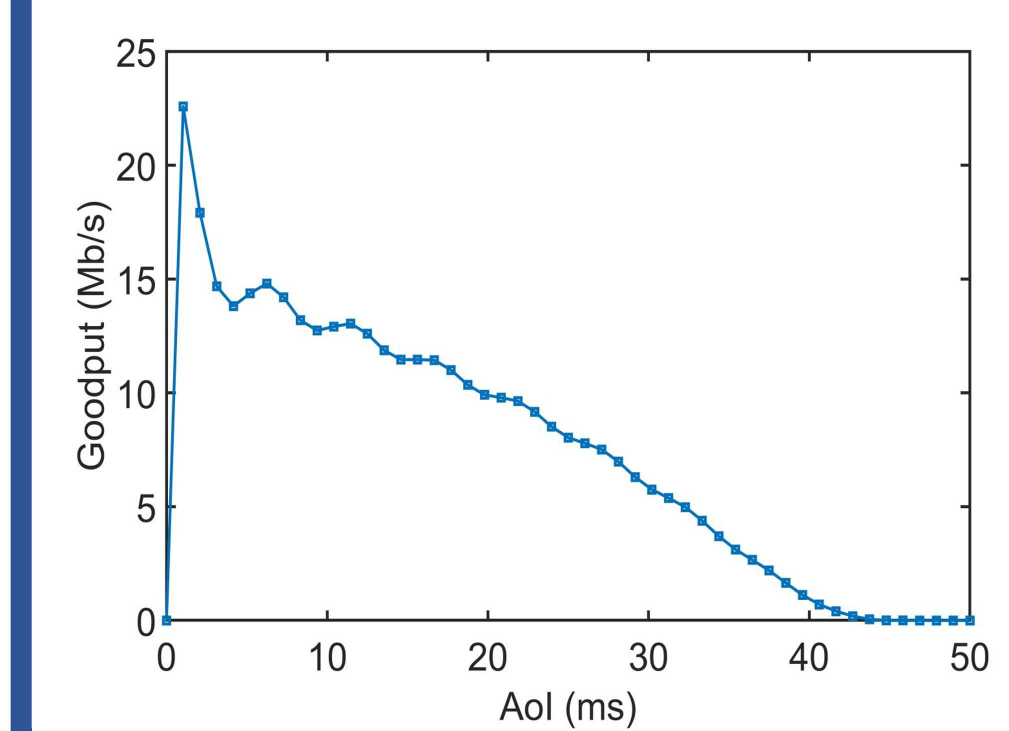

Figure 5: Non-monotonic goodput vs. AoI where the optimal time to send a pilot is when $\gamma(\Delta(t)) \leq \beta$

References

1. Y. Sun and B. Cyr, "Sampling for data freshness optimization: Non-linear age functions," in Journal of Communications and Networks, vol. 21, no. 3, pp. 204-219, June 2019.
2. K. T. Truong and R. W. Heath, "Effects of channel aging in massive MIMO systems," in Journal of Communications and Networks, vol. 15, no. 4, pp. 338-351, Aug. 2013.