

## Graduate School Information Fair 2024

Adaptive Rate/Power Control with ML-based Channel Prediction for  
Optical Satellite Systems

## I. General Background

## Free-space Optics (FSO)

- **FSO**: is a line-of-sight technology using infrared frequency bands for data transmission in free space.
- **Benefits**: large bandwidth, high-speed connections, immunity to electromagnetic interference.

## FSO-based Vertical Networks

- **Vertical networks**: the use of satellites, high-altitude platforms (HAPs), and unmanned aerial vehicles (UAVs) to provide global high-speed connectivity.
- **Applications**: fronthaul/backhaul networks, post-disaster emergency communication, etc.

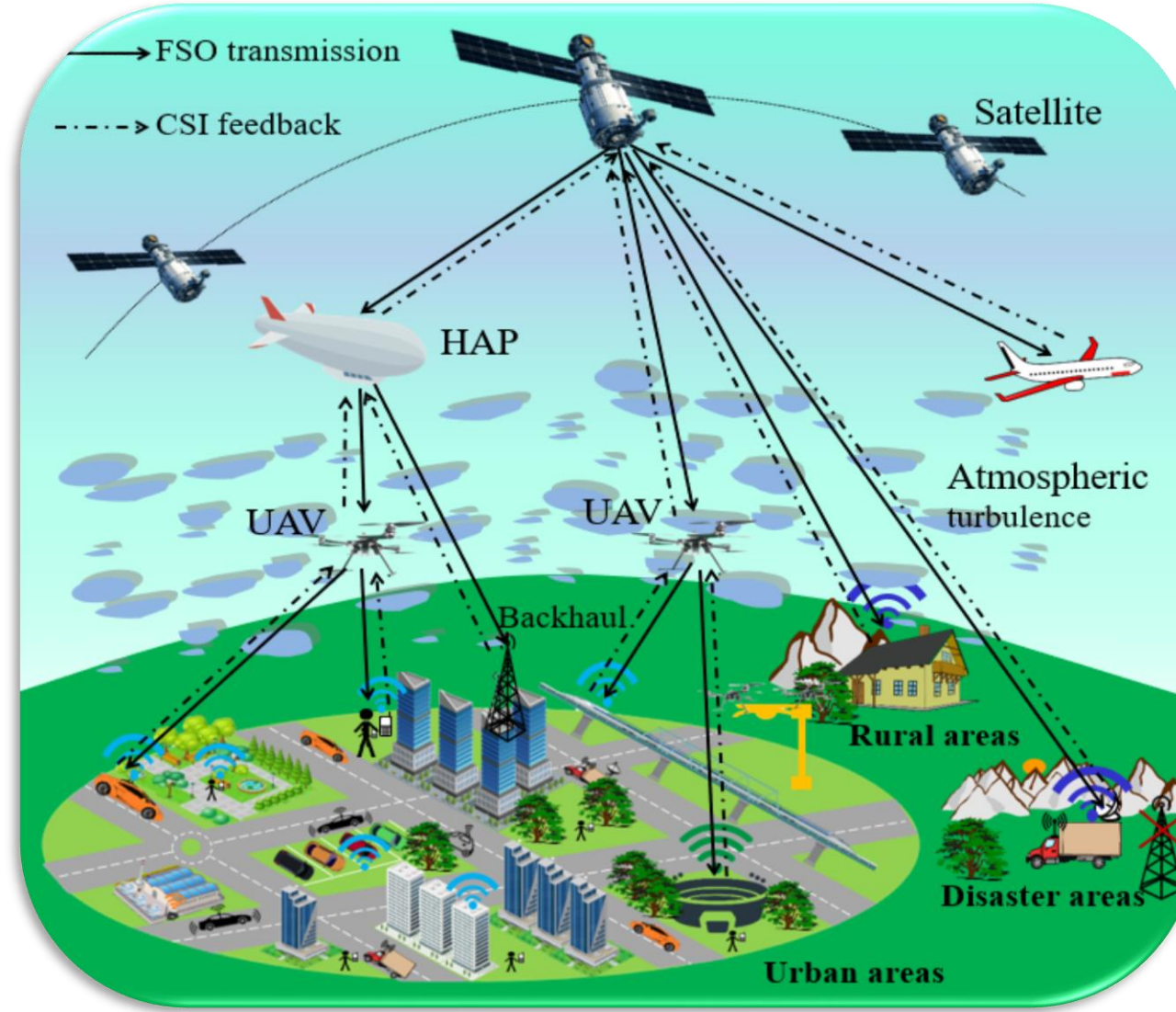


Fig. 1. FSO-based vertical networks.

## Challenges

**Critical Issue**: the *atmospheric turbulence* and *pointing misalignment* make the *FSO channel unstable*.

→ Channel state information (CSI) is required at the receiver side to adaptively choose proper parameters and settings for transmissions

**Challenge**: The *CSI tends to be outdated* due to the long distance of vertical networks, which degrades the system performance.

## II. Proposed Solutions

## Our Solutions

**Unstable channel**: We *adaptively change the transmitted power and transmitted rate* according to the current channel conditions. Figure 3 depicts an example with 6 modes and 25 states

- The rate varies for each mode, while the transmit power varies for each state
- To find the list of states → adopt the channel-state model as in [1]
- To find the list of modes → solve the optimization problem (1)

**Outdated CSI**: We *employ an echo state network (ESN) model* at the receiver (Fig. 2). It can forecast the future CSI beforehand to counteract the induced feedback delay [2]

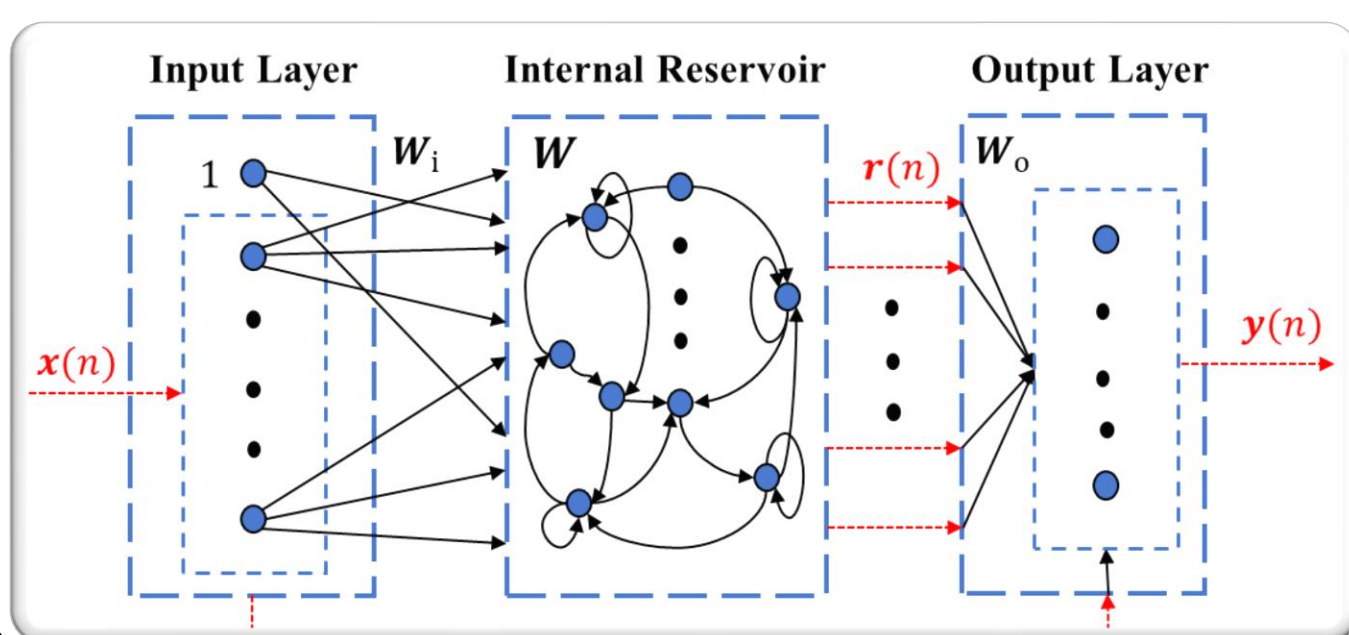
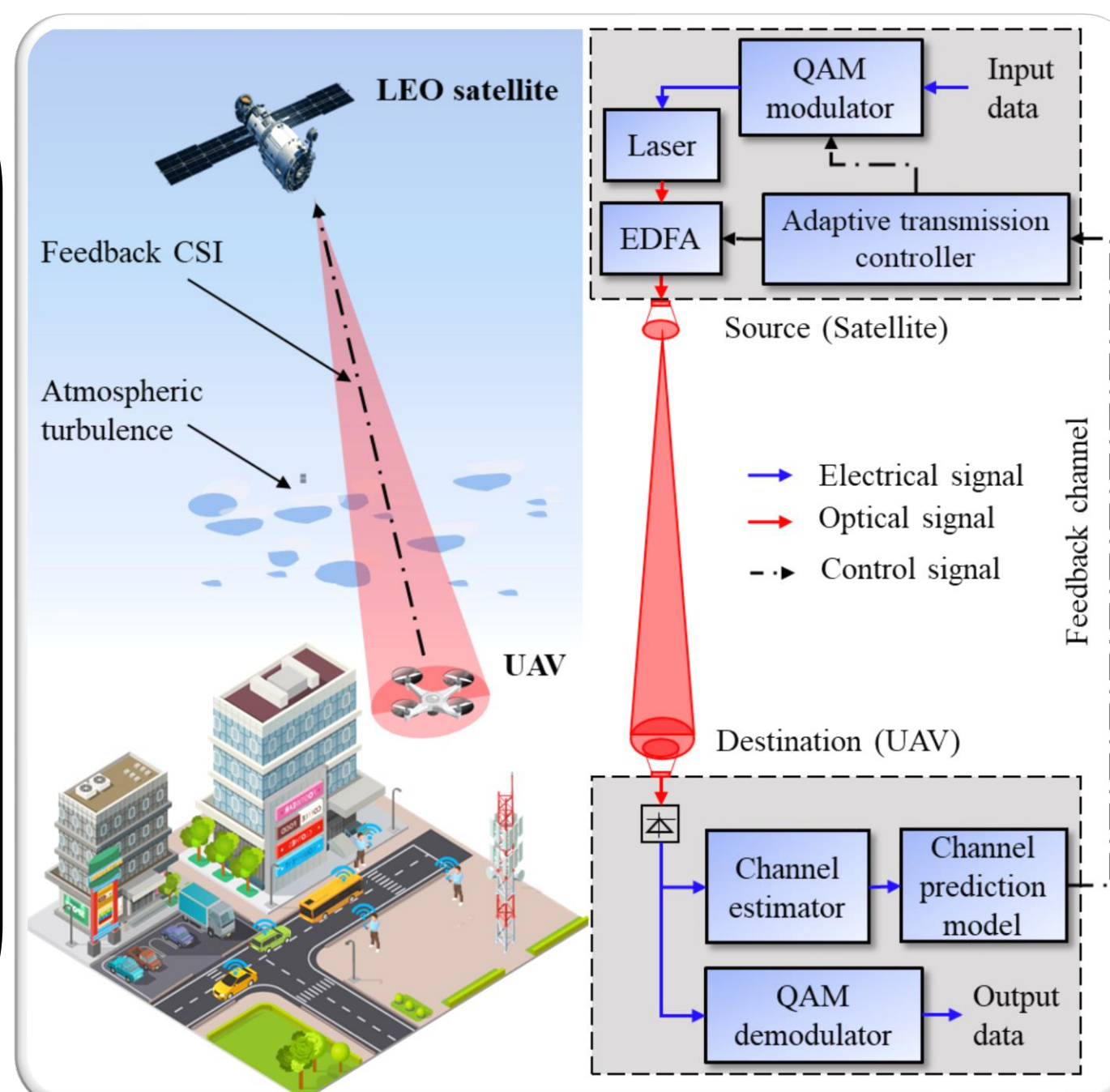


Fig. 2. A multiple-input/multiple-output ESN model



## Adaptive Rate/Power (ARP) Scheme

The ARP scheme aims to *achieve an average bit rate  $\bar{R}_b$  with minimum power consumption  $\bar{P}_t$*  under *several constraints*, including target outage probability  $\mathbb{P}_{out,tar}$ , target bit error rate  $\mathbb{P}_{e,tar}$ , and maximum transmit power  $\bar{P}_{t,max}$ . Hence, the optimization is formulated as

$$\min_{P_t(h), M(h)} \bar{P}_t = \int_0^\infty P_t(h) f_h(h) dh, \quad (1a)$$

$$\text{s.t.} \quad \bar{R}_b = \int_0^\infty R_s \log_2(K(h)) f_h(h) dh, \quad (1b)$$

$$\mathbb{P}_{out} \leq \mathbb{P}_{out,tar}, \quad (1c)$$

$$\mathbb{P}_e(h) \leq \mathbb{P}_{e,tar}, \quad (1d)$$

$$P_t(h) \leq P_{t,max}, \quad (1e)$$

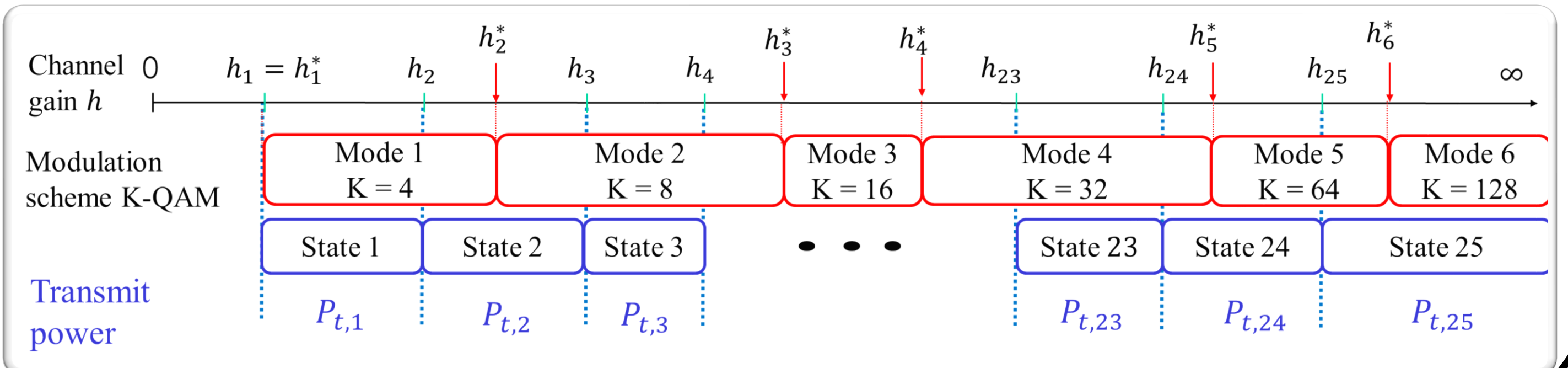


Fig. 3. An example of the adaptive rate/power system

## III. Numerical Results and Discussions

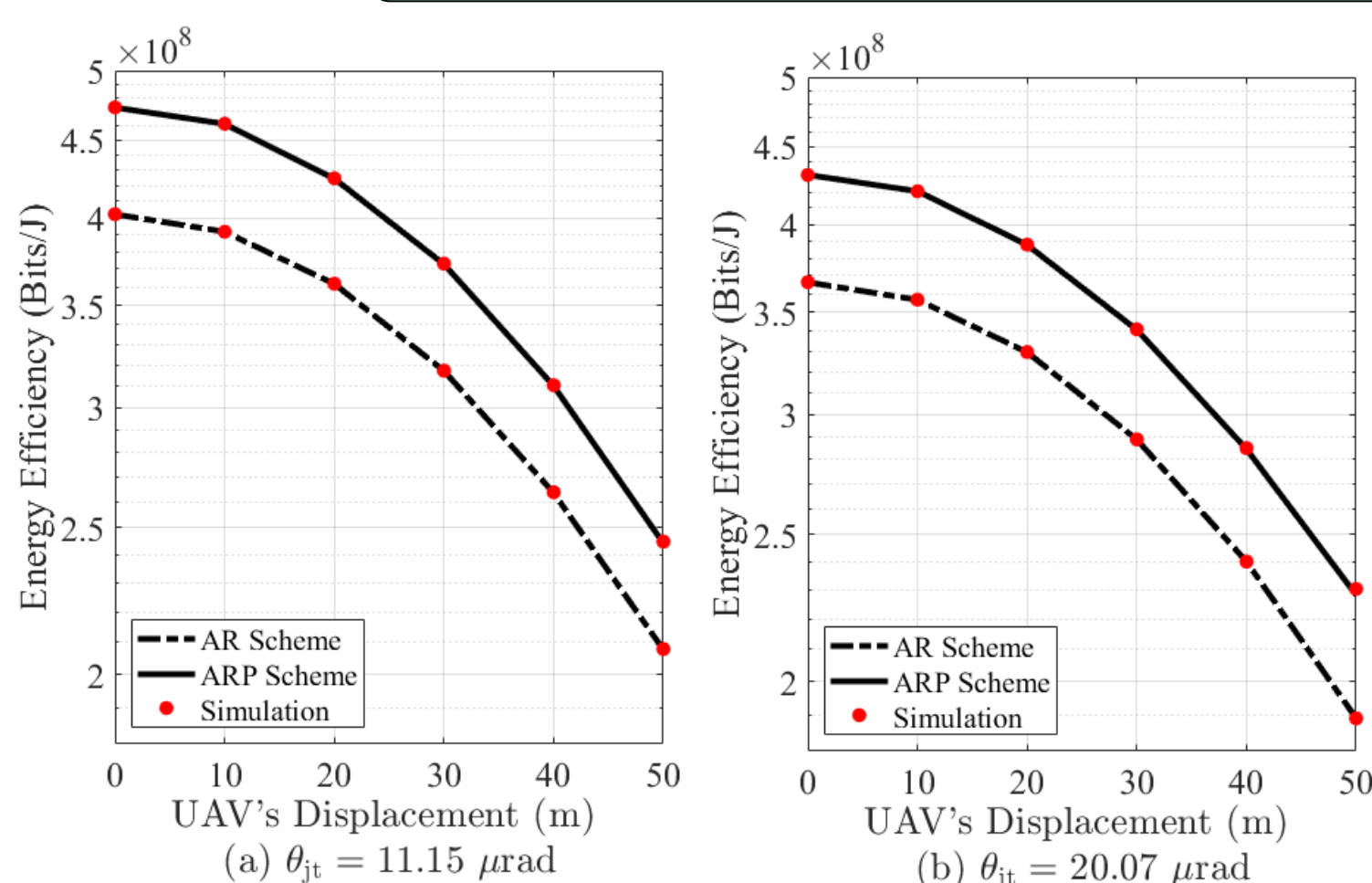


Fig. 4. Energy efficiency for different pointing error conditions.

*The ARP provides much better energy efficiency (EE) than the conventional adaptive rate (AR) scheme*

( $\theta_{jt}$ : jitter angle → indicates the intensity of satellite vibration)

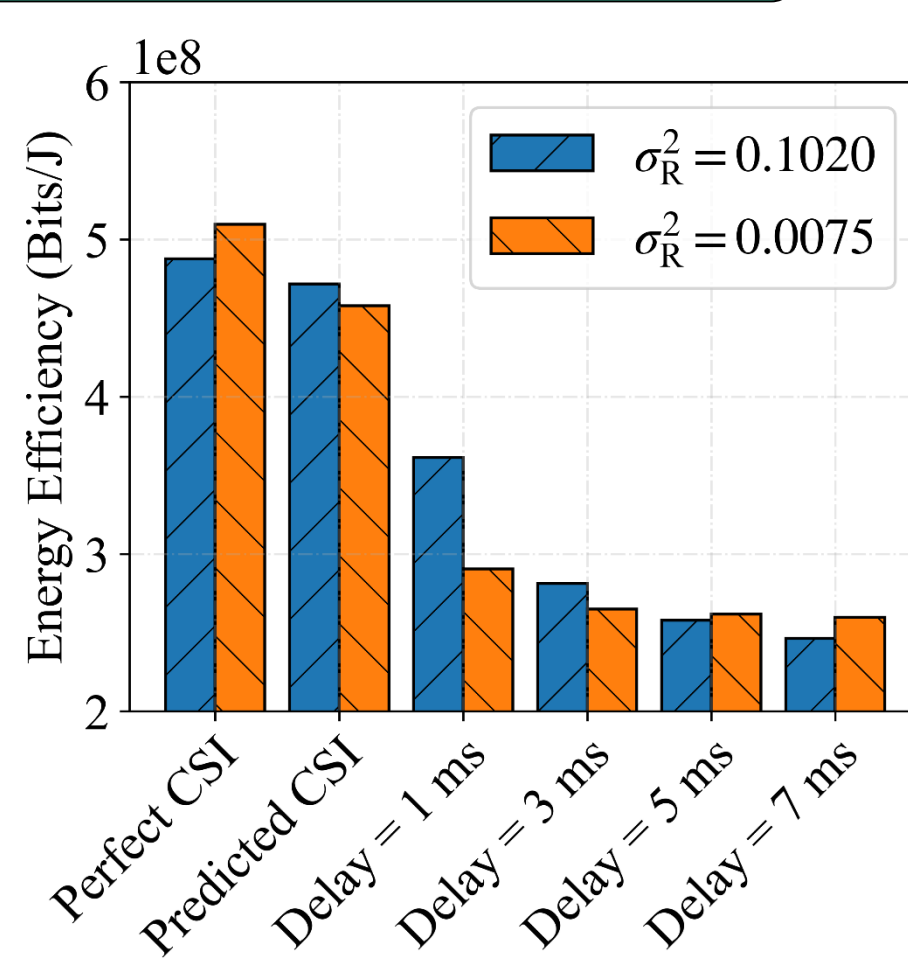


Fig. 5. EE with perfect, predicted, and outdated CSI

*Using predicted CSI offers very close EE compared to perfect CSI*

( $\sigma_R^2$ : Rytov variance → indicates the turbulence strength)

## IV. Conclusion

➤ By using the joint rate/power adaptation, the system's EE can be greatly improved.

➤ Using predicted CSI provides a considerable performance enhancement compared to delayed CSI. This confirms that channel prediction is vitally necessary for our adaptive rate/power system.

## References

- [1]. H. D. Le and A. T. Pham, "On the Design of FSO-Based Satellite Systems Using Incremental Redundancy Hybrid ARQ Protocols With Rate Adaptation," in *IEEE Trans. Veh. Technol.*, vol. 71, no. 1, pp. 463-477, Jan. 2022.
- [2]. T. V. Nguyen, H. D. Le and A. T. Pham, "Adaptive Rate/Power Control With ML-Based Channel Prediction for Optical Satellite Systems," in *IEEE Trans. Aerosp. Electron. Syst.*, vol. 60, no. 5, pp. 7498-7509, Oct. 2024.