
ELiMO: Eliminating Channel Feedback from MIMO



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MIMO Needs CSI Feedback

- MIMO beamforming provides high throughput for WiFi



Image from www.broadbandbuyer.com

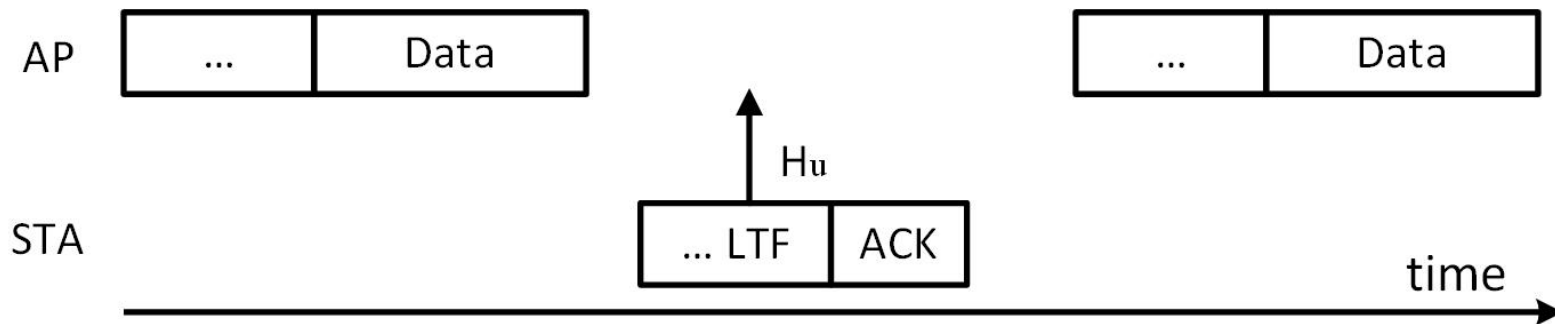


Image from www.howtogeek.com

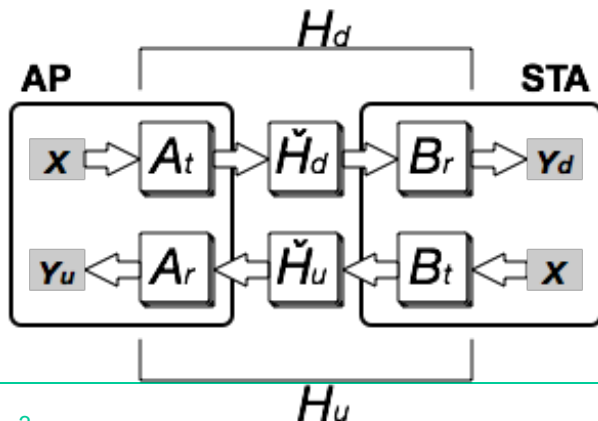
- To achieve high beamforming performance, feedback of Channel State Information (CSI) is needed.
- Implicit or Explicit CSI Feedback

Implicit CSI Feedback

- AP measures ACK's LTF from STA to get uplink CSI
- AP uses the **transpose** of uplink CSI as downlink CSI



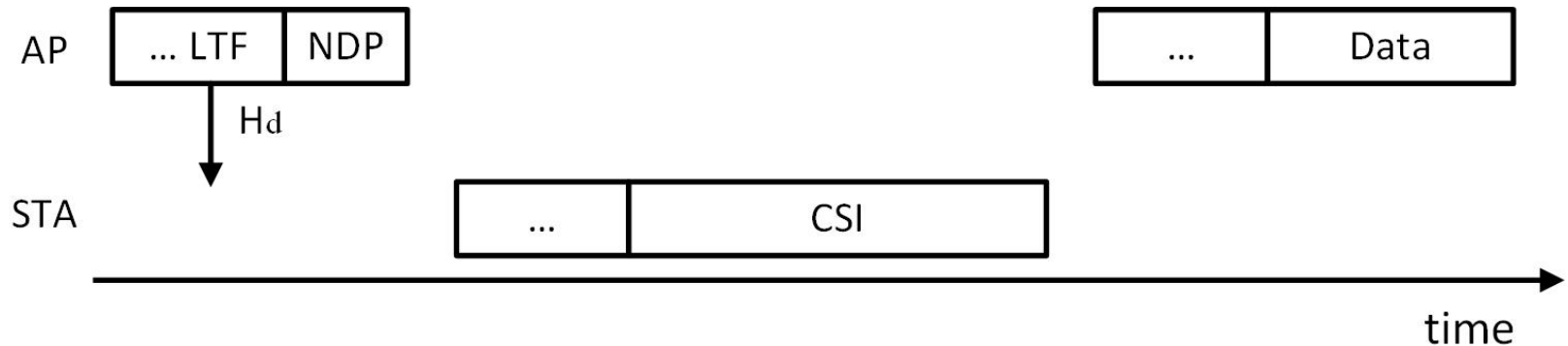
- Downlink CSI (H_d) and uplink CSI (H_u) are **not reciprocal**, leading to **low SNR**.



\check{H}_d and \check{H}_u : **over-the-air** channels
 H_d and H_u : **baseband-to-baseband** channels
 A_t , A_r , B_t , & B_r : **digital baseband** channels

Explicit CSI Feedback

- STA measures NDP's LTF to get downlink CSI
- STA sends measured downlink CSI to AP

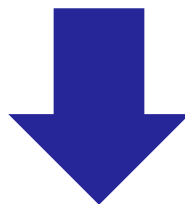


- Measuring and transmitting CSI introduce **high computation & communication overhead**

Eliminating CSI Feedback

■ Can we completely eliminate explicit CSI feedback?

- And achieve as high SNR as explicit CSI feedback
- With as low overhead as implicit CSI feedback



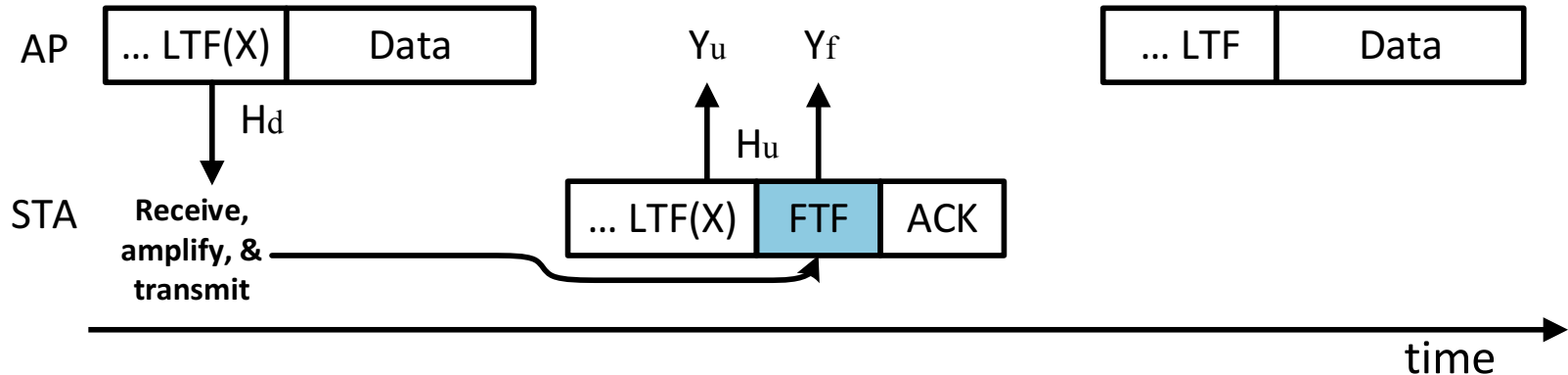
■ **ELIMO**: two-way CSI estimation for WiFi

- AP estimates downlink CSI without explicit CSI feedback
- STA does not send CSI to AP

Outline

- Introduction
- EliMO Two-way CSI Estimation
- EliMO Protocol Design
- Evaluation
- Conclusions

Two-way CSI Estimation



- Two-way CSI H_{tw} Estimation:

$$H_{tw} = \text{MMSE}(X, Y_f)$$

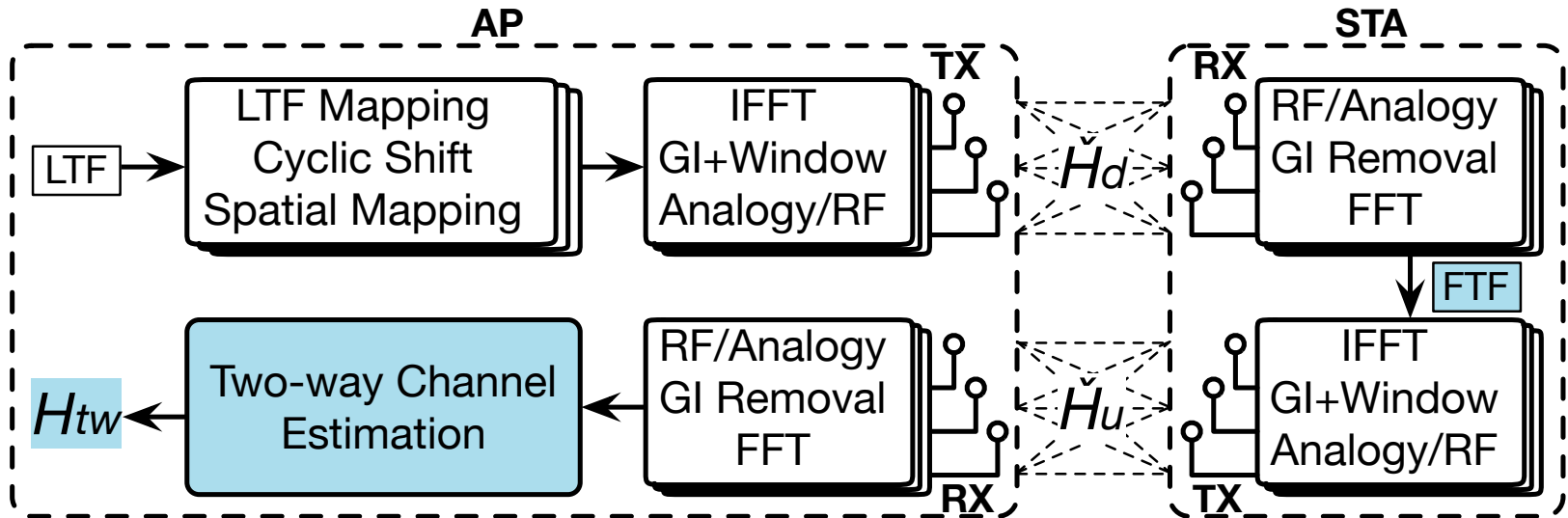
- Downlink CSI H_d Estimation:

$$H_{tw} = H_u H_d \Rightarrow H_d = (H_u)^+ H_{tw}$$

- Uplink CSI H_u Estimation:

$$H_u = \text{MMSE}(X, Y_u)$$

Block Diagram



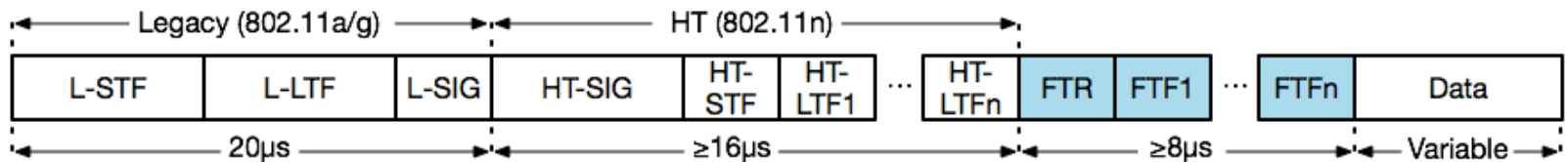
- STA only needs to amplify and send FTF to AP
- No need for STA to measure downlink CSI: **reduced computation**
- No need for STA to send CSI to AP: **reduced communication**

Outline

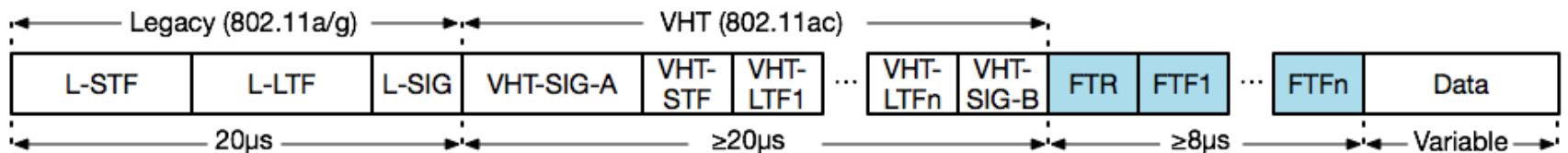
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Packet Format

- Implementing two-way CSI estimation in 802.11n/ac
 - FTF: Feedback Training Field, received signals of LTF
 - FTR: Feedback Training Request/Response

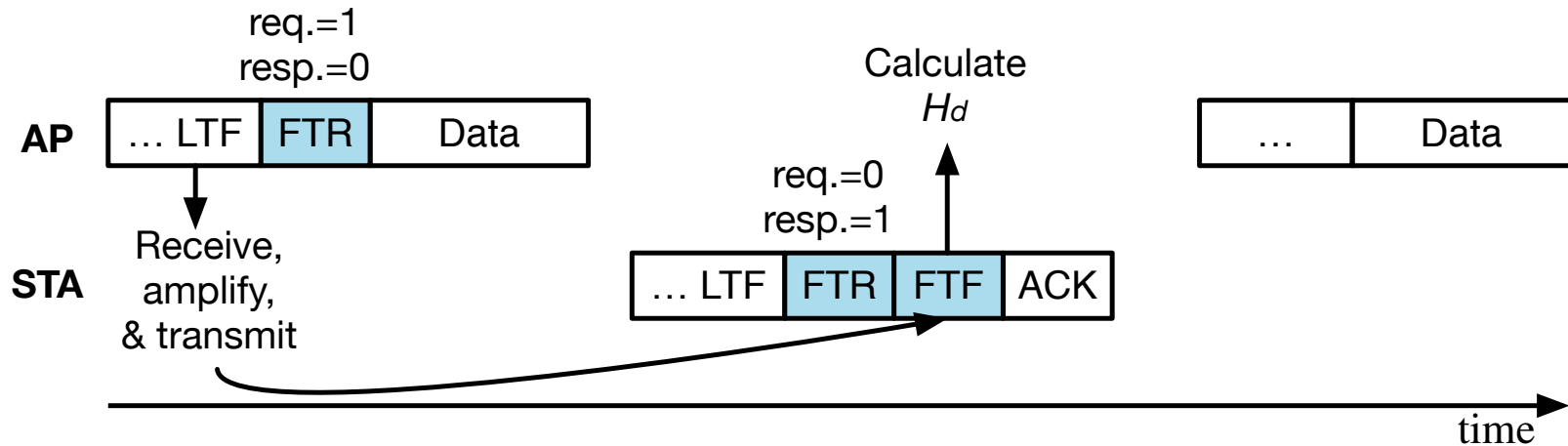


802.11n mixed mode packet



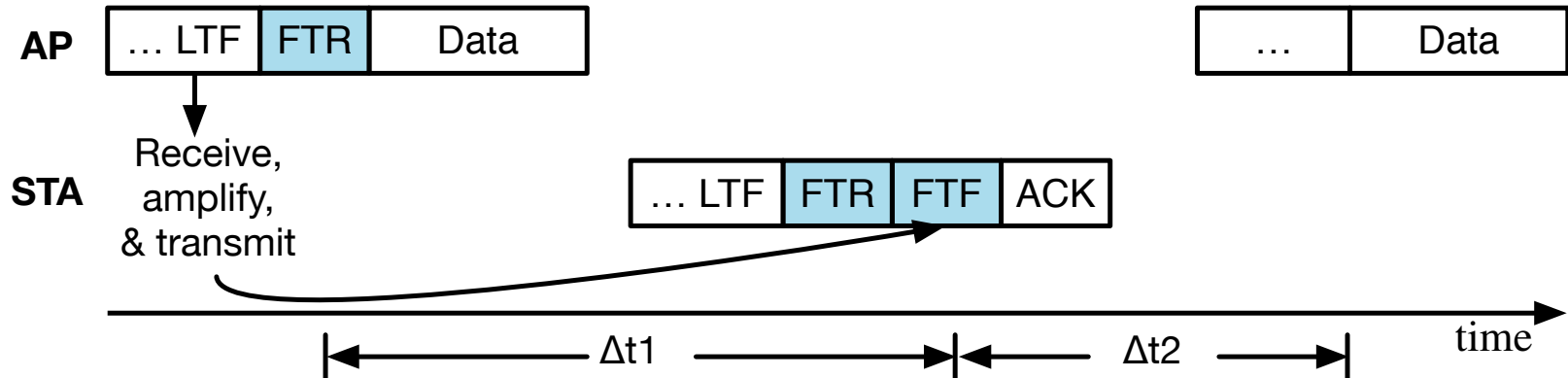
802.11ac packet

MAC Operation



- AP sends LTF and FTR to STA
- STA puts received LTF, amplify it, and put it in FTF
- STA sends LTF, FTR, and FTF to AP
- AP computes downlink CSI H_d , which is used for sending the next data packet

Dealing with Stale CSI



- Downlink CSI could be stale: $\Delta t_1 + \Delta t_2$ is too large
- AP sends NDP (w/ FTR) to request STA to measure downlink CSI, when
 - either similarity of two recent CSI measurements is smaller than 0.98
 - or the time from the previous ACK (Δt_2) is larger than 100ms

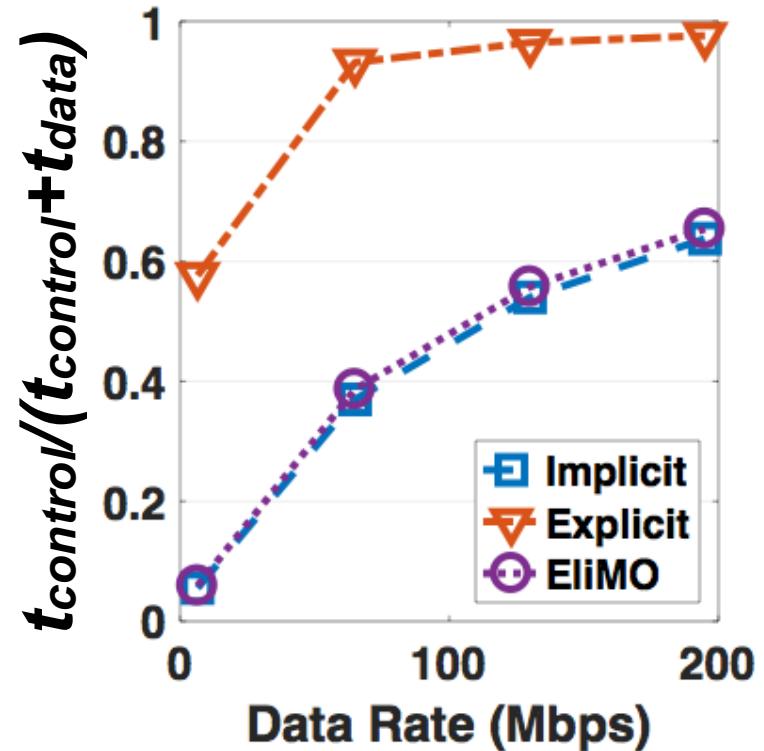
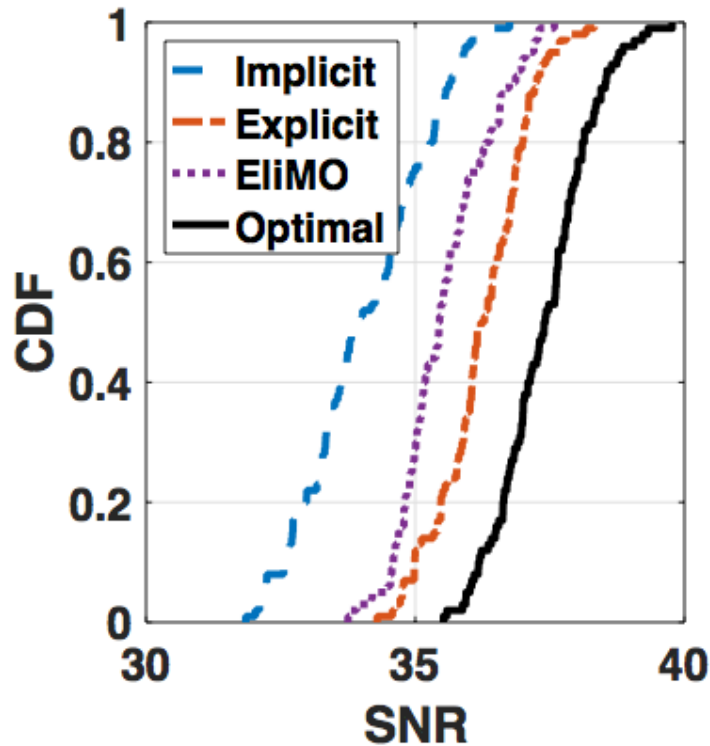
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Evaluation Setup

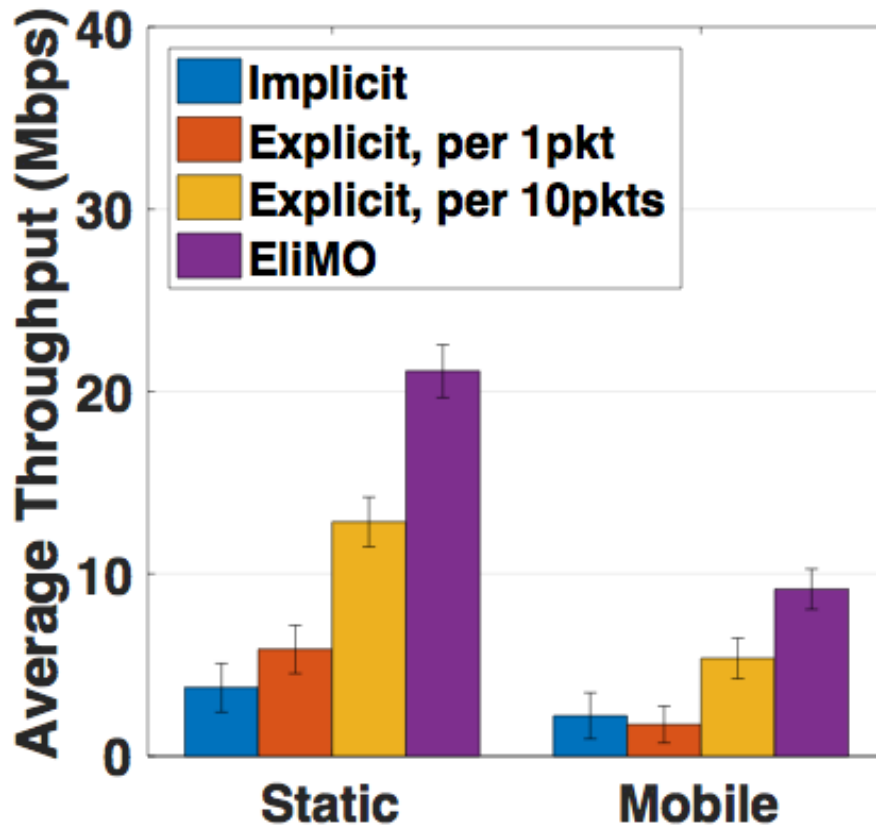
- AP & STA are laptops with Intel WiFi Link 5300 installed
 - The power signal of WiFi chipset can not be programmed to “amplify and transmit” in slide 7. So we use trace-driven simulation.
- Downlink/uplink CSI traces (H_d & H_u)
 - Frequency: 5GHz; channel width: 20MHz
 - AP: 3 external antennas;
 - STA: 3 internal antennas
 - Transmitting power: 17/15dBm for the AP/STA
- Scenarios
 - Static: both AP and STA are static
 - Mobile: the STA is randomly moving ($\sim 1.2\text{m/s}$); the AP is static

Evaluation: SNR & Overhead



ELiMO achieves **as high SNR** as explicit CSI feedback, with **as low overhead** as implicit CSI feedback

Evaluation: Throughput

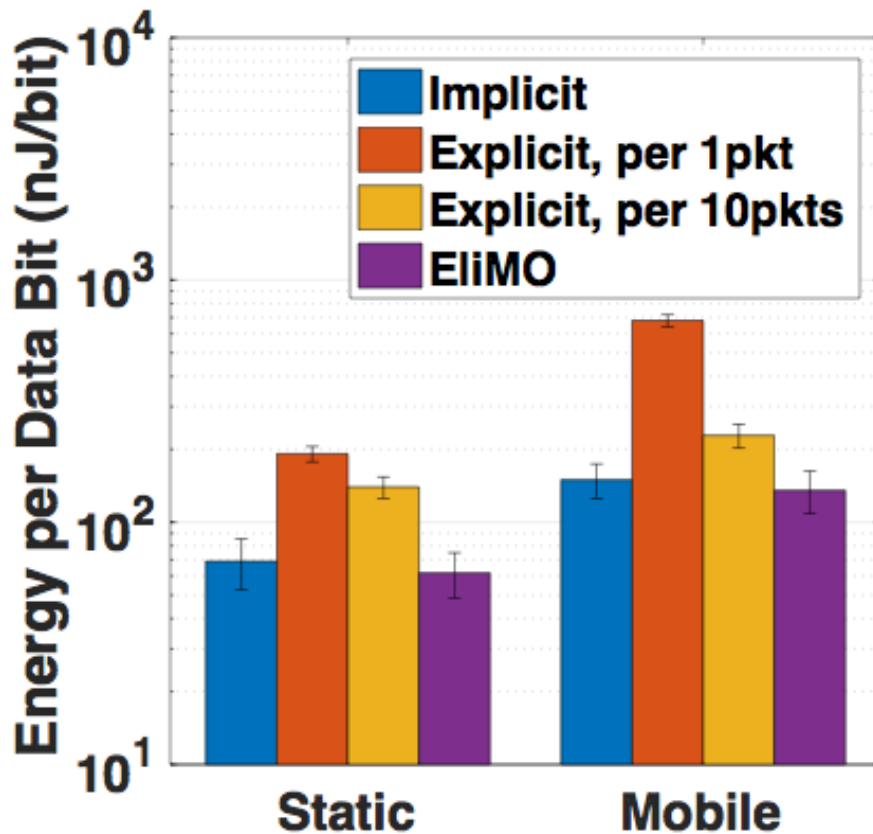


■ When static, EliMO's throughput is **5X/4X/1.7X** of "Implicit", "Explicit per 1pkt", and "Explicit per 10pkts".

➤ "Explicit per 10pkt" means one explicit CSI feedback for every 10 data packets

■ When mobile, these numbers are **3.6X/4.5X/1.4X**

Evaluation: Energy



■ When static, EliMO's energy consumption is **85%/30%/50%** of that of "Implicit", "Explicit per 1pkt", and "Explicit per 10pkts".

■ When mobile, these numbers are **90%/17%/57%**

Related Work

- Compressed CSI feedback, but still need CSI feedback
 - The same CSI for **multiple packets, subcarriers, and/or antennae**. [MobiCom'13]
 - **Less bits** to represent CSI [MobiCom'13]
 - **Less frequent** CSI feedback [CoNEXT'14]

- No CSI feedback
 - Echo-MIMO [IEEE TOSP'08] is similar to us, but not compatible with WiFi.
 - Narrow-band channels without frequency-selective effects
 - Over-the-air channels, not digital baseband channels
 - Pure theoretical analysis, not in a WiFi compatible protocol, not tested with real devices

Conclusions

- EliMO uses two-way CSI estimation and Feedback Training Field to accurately estimate downlink CSI without explicit CSI feedback.
- EliMO is WiFi compatible.
- EliMO significantly reduces computation, communication, and energy overhead for WiFi receivers.

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Thank You!