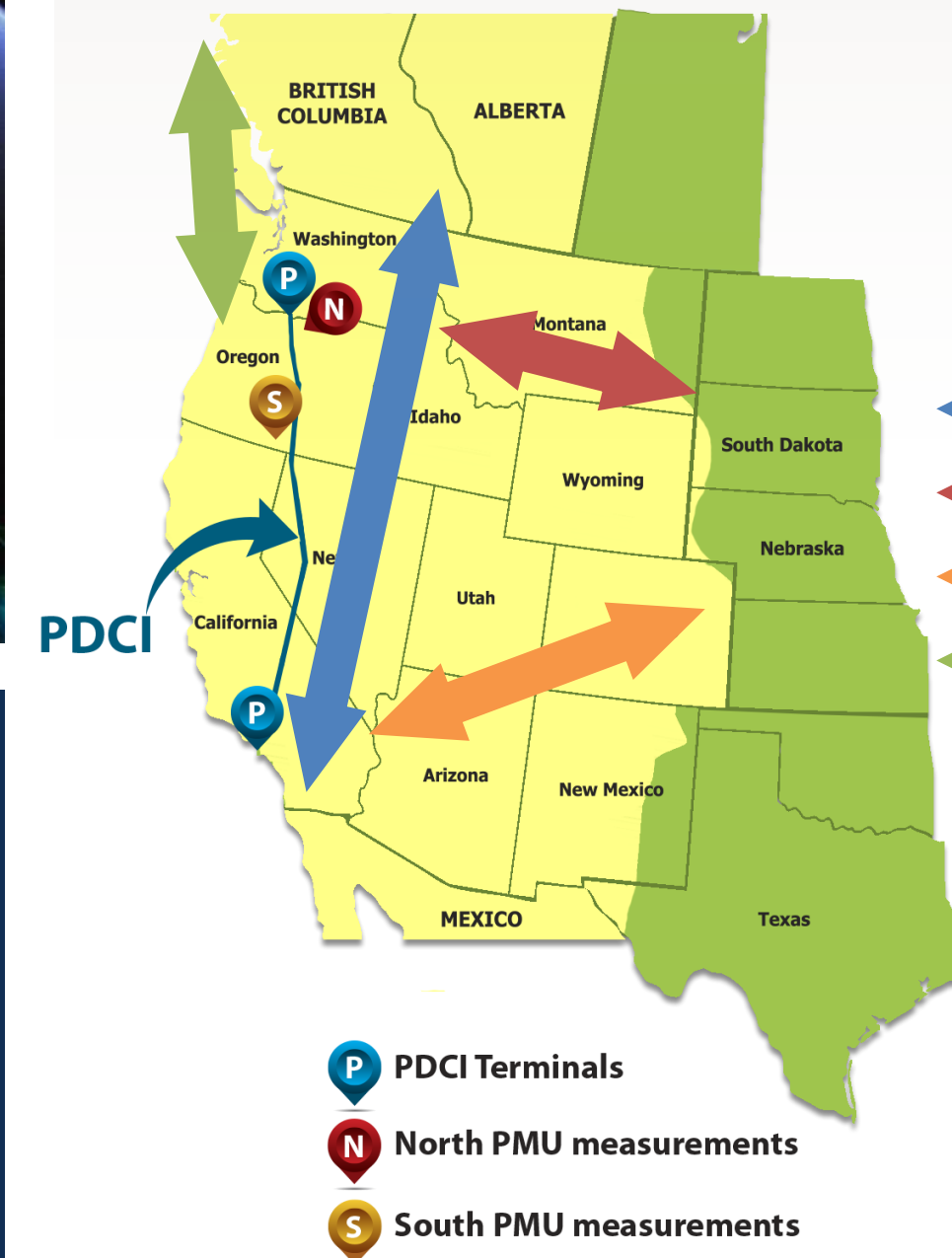


# Time Delay Definitions and Characterization in the Pacific DC Intertie Wide Area Damping Controller

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## Background

- Problem:** Inter-area oscillations in the Western Interconnection can cause system breakdowns
- Limits in power transfer (from north to south) were imposed to prevent such events



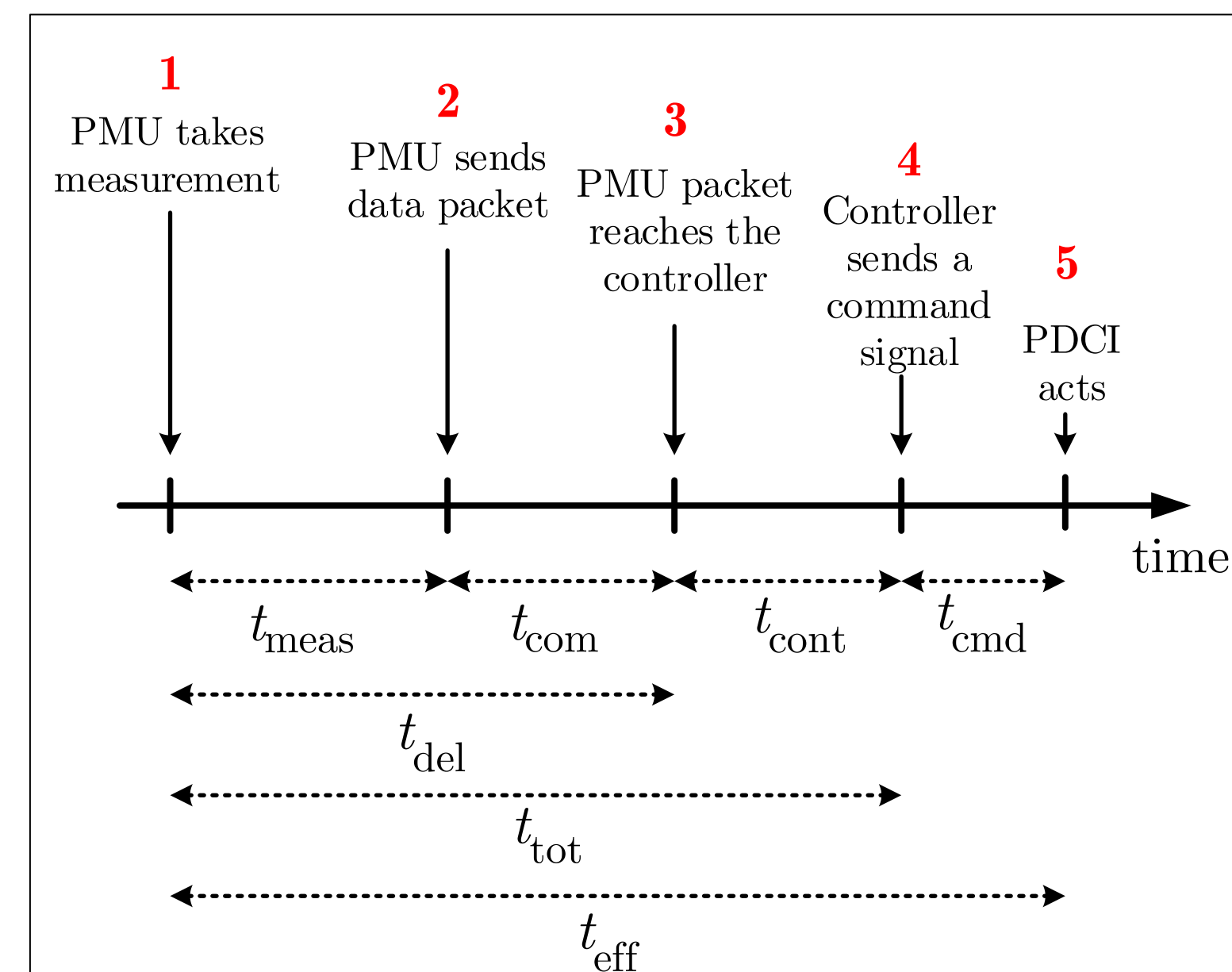
**Solution:** modulate the power transfer of the PDCI using wide area measurements from PMUs

**Philosophy:** “DO NO HARM” to the system under any condition

- Feedback signals for are streamed to the controller in accordance with the C37.118 standard using a UDP protocol (multicast) and are subject to **delay** in their transmission
- Goal is to define and determine latencies delays of all the components of an actual Wide Area Measurement System (WAMS)

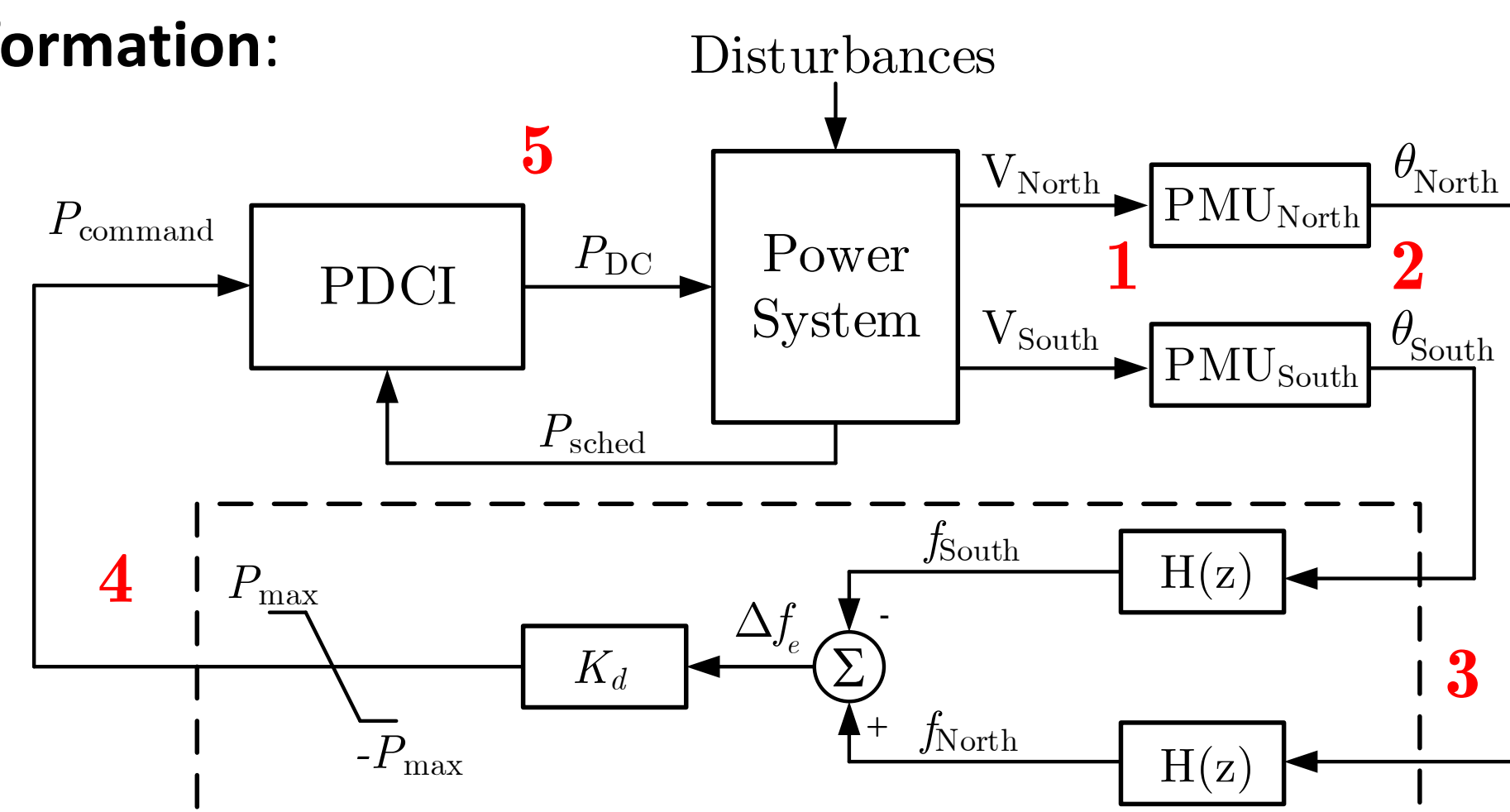
## Definitions of Delays

Classification of delays associated with the controller:



$t_{\text{meas}}$  – Measurement (PMU) Delay  
 $t_{\text{com}}$  – Communications (network) Delay  
 $t_{\text{del}}$  – Signal Delay  
 $t_{\text{cont}}$  – Control Processing Delay  
 $t_{\text{tot}}$  – Total Controller Delay  
 $t_{\text{cmd}}$  – Command Delay  
 $t_{\text{eff}}$  – Effective Delay

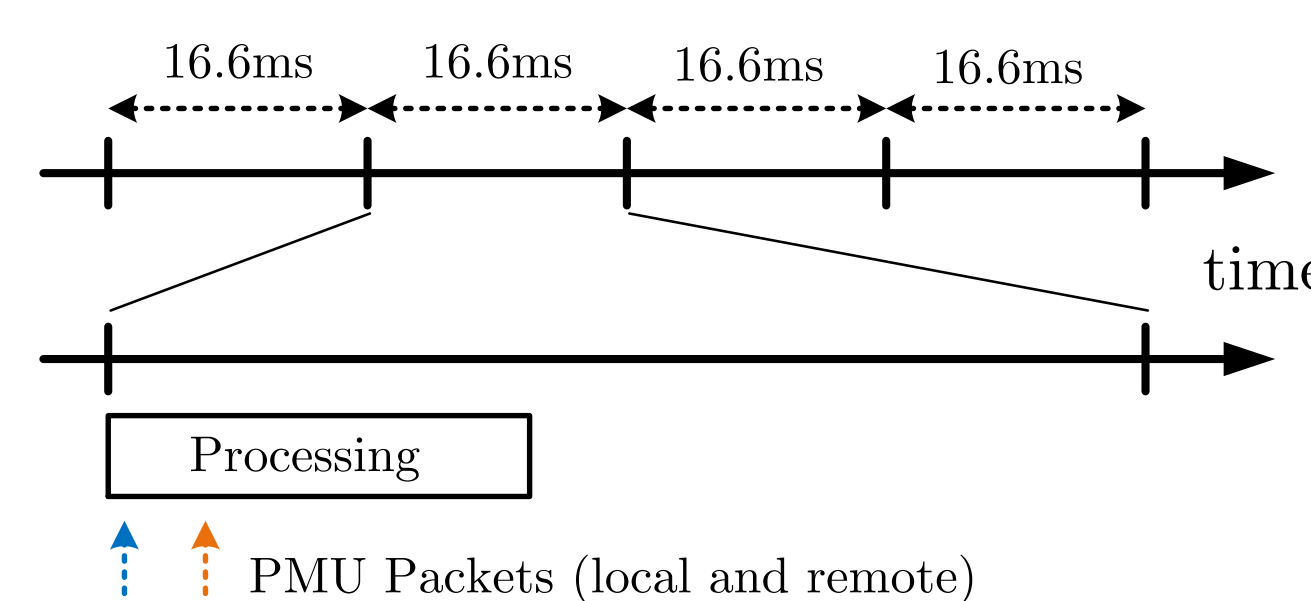
Time delays at different stages in the controller **flow of information**:



- Note:** controller used data directly from the PMUs without going through a PDC in order to reduce total delays
- Controller time-aligns the signals

## Controller processing action time window

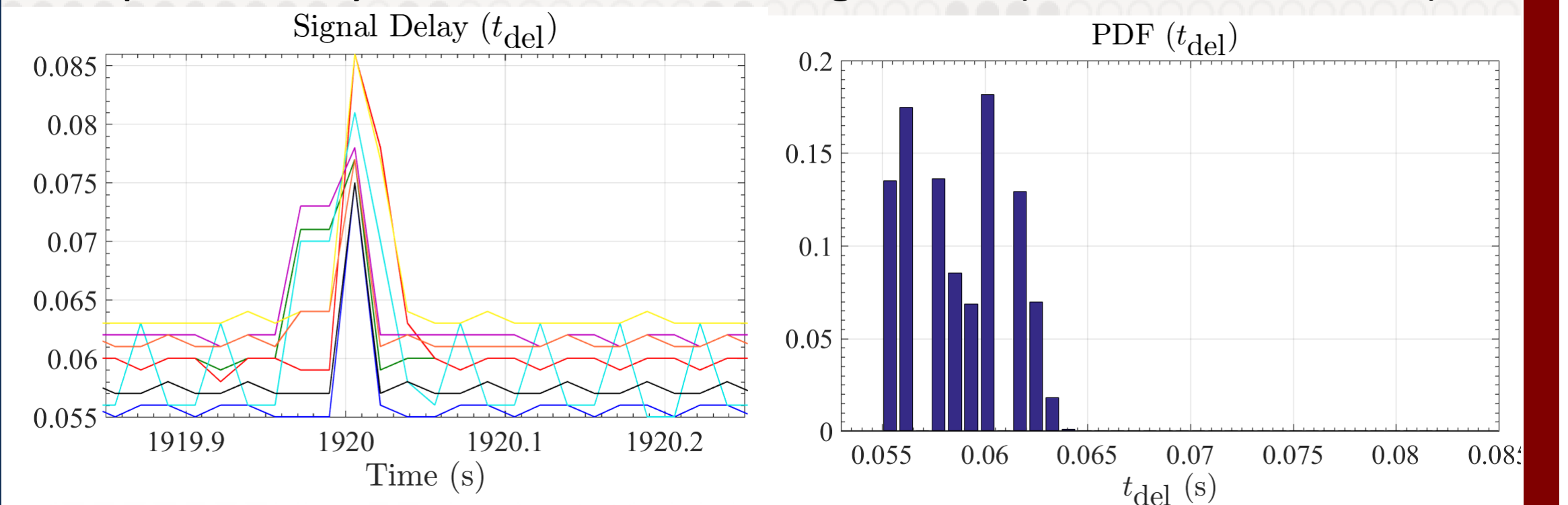
- Controller acts at the same reporting rate as the PMUs (60sps)
- Window is not synchronized with GPS time



## Measurements of Delays

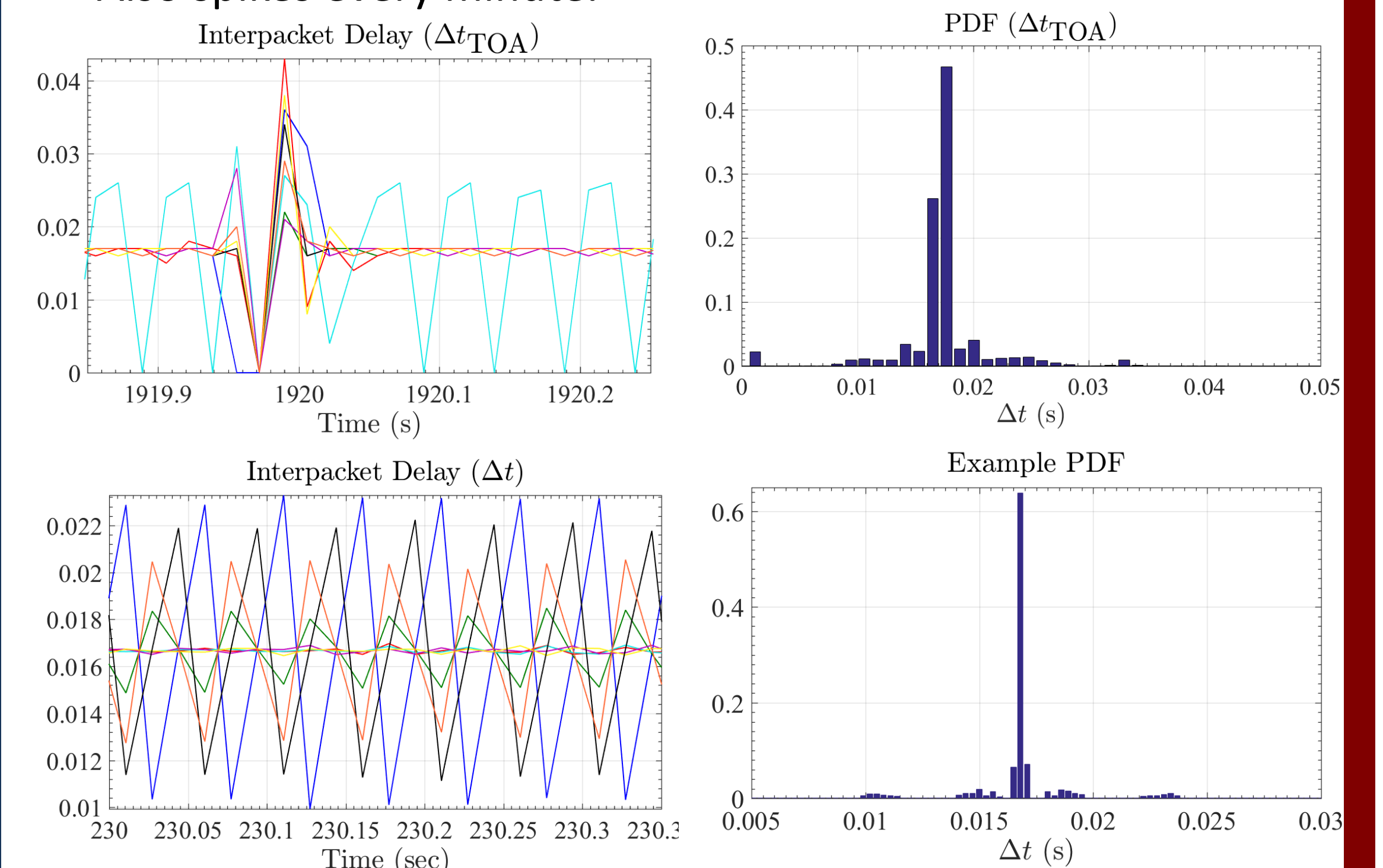
### Signal delay

- Average of 50 ms, range [55,88] ms.
- Spikes every minute due to config frame (C37.118 standard)



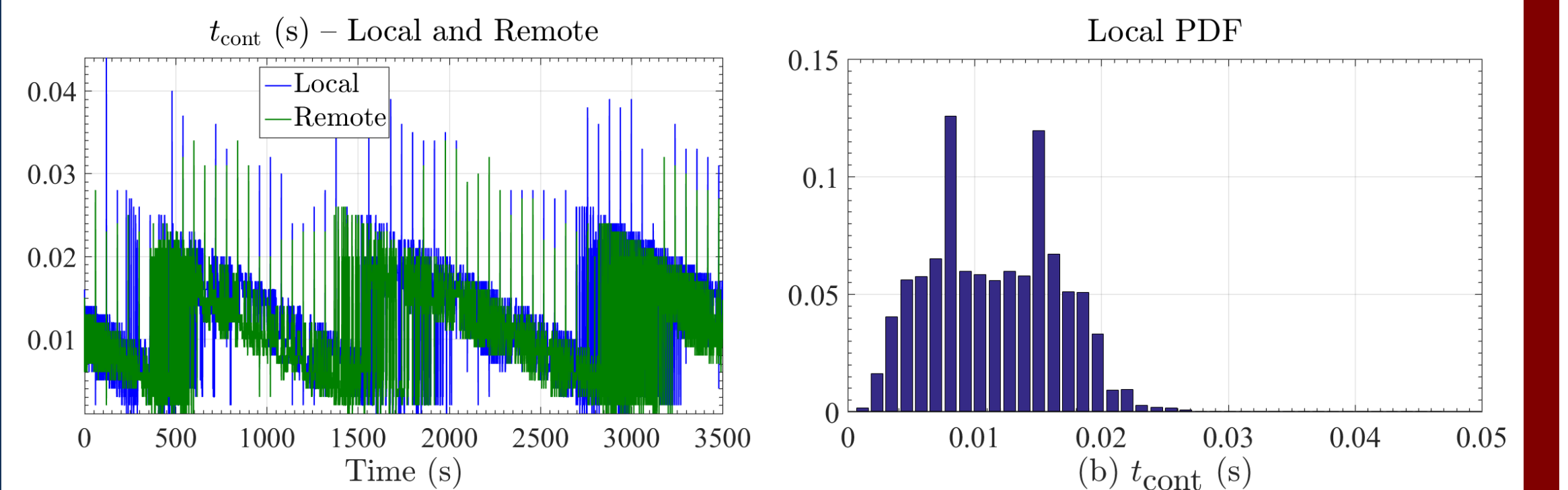
### Interpacket delay

- Average of 16.6ms.
- Sometimes has an oscillatory behavior.
- Also spikes every minute.



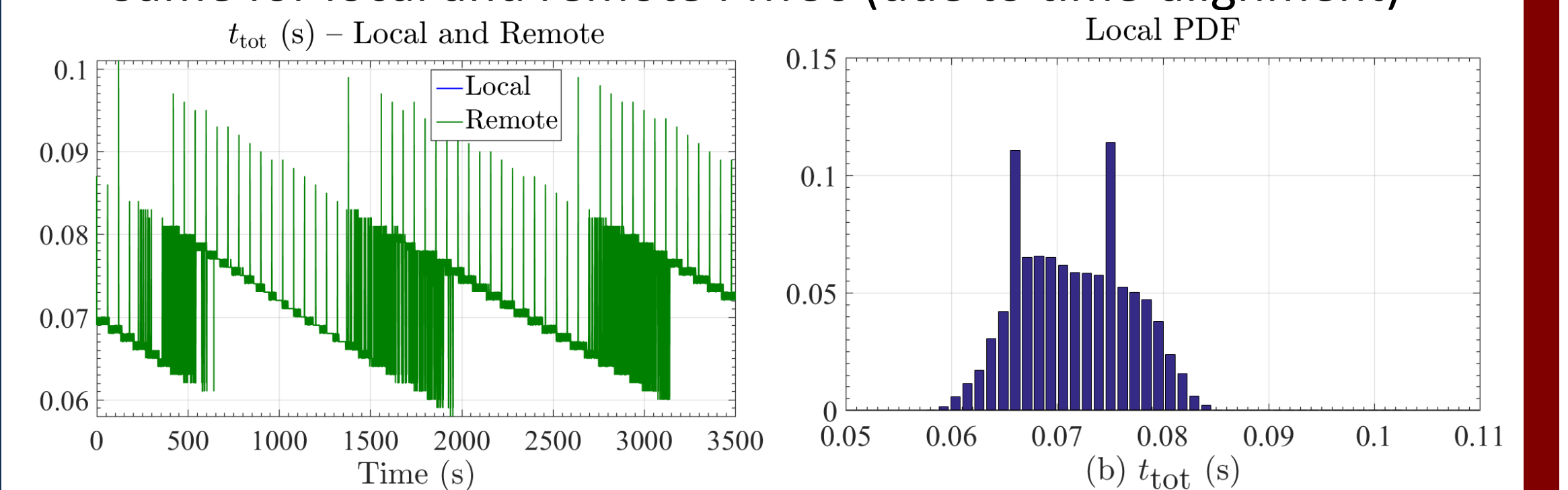
### Controller delay

- Average of 11ms, range [3, 22] ms.
- Different for local and remote PMU.
- It has a periodicity due to the drifting of the controller clock wrt to the GPS clock



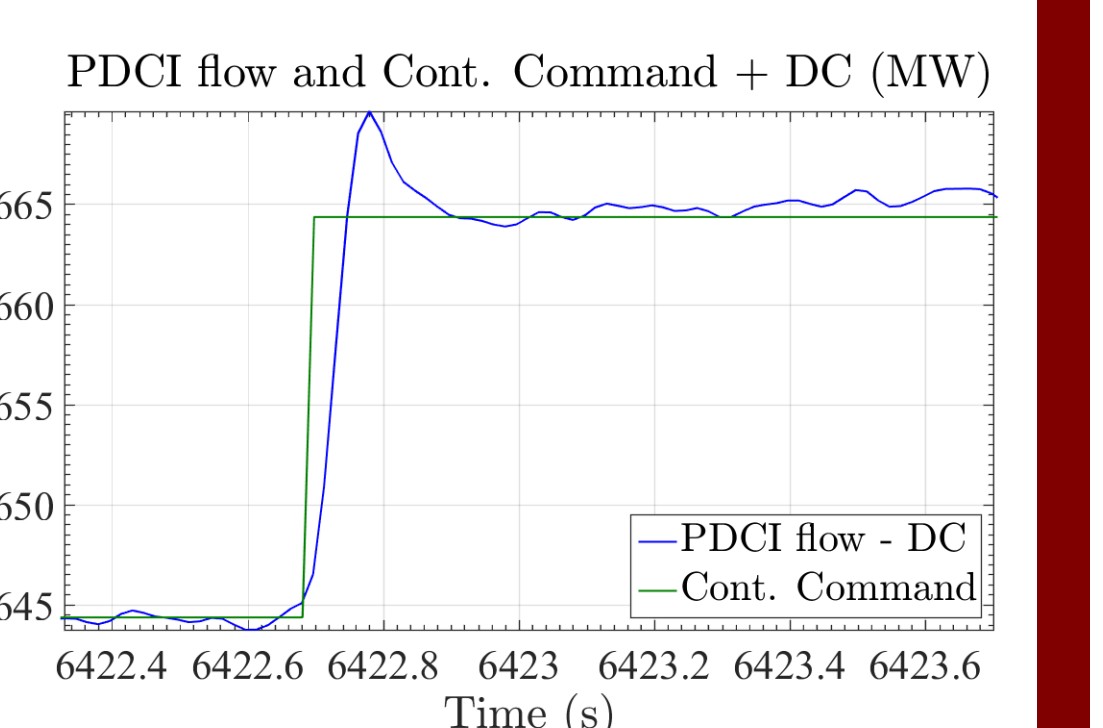
### Total Delay

- Average of 71ms. - same periodicity as controller delay
- Same for local and remote PMUs (due to time-alignment)



### Command Delay

- Estimated at 11 ms with system identification techniques



## Conclusions

- A classification of delays in a Wide Area Control System (WACS) was proposed
- Delay behavior was analyzed for each stage and components of the WACS
- Statistical analysis of each delay was performed
- Delays are within the limits to be used for real time control (max delay was determined at 113 ms and average of 81 ms)
- Data dropouts in the network is almost nonexistent



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