TCIPG

Trustworthy Time-Synchronous Measurement Systems

Pulse Coupled Synchronization and Scheduling Protocol

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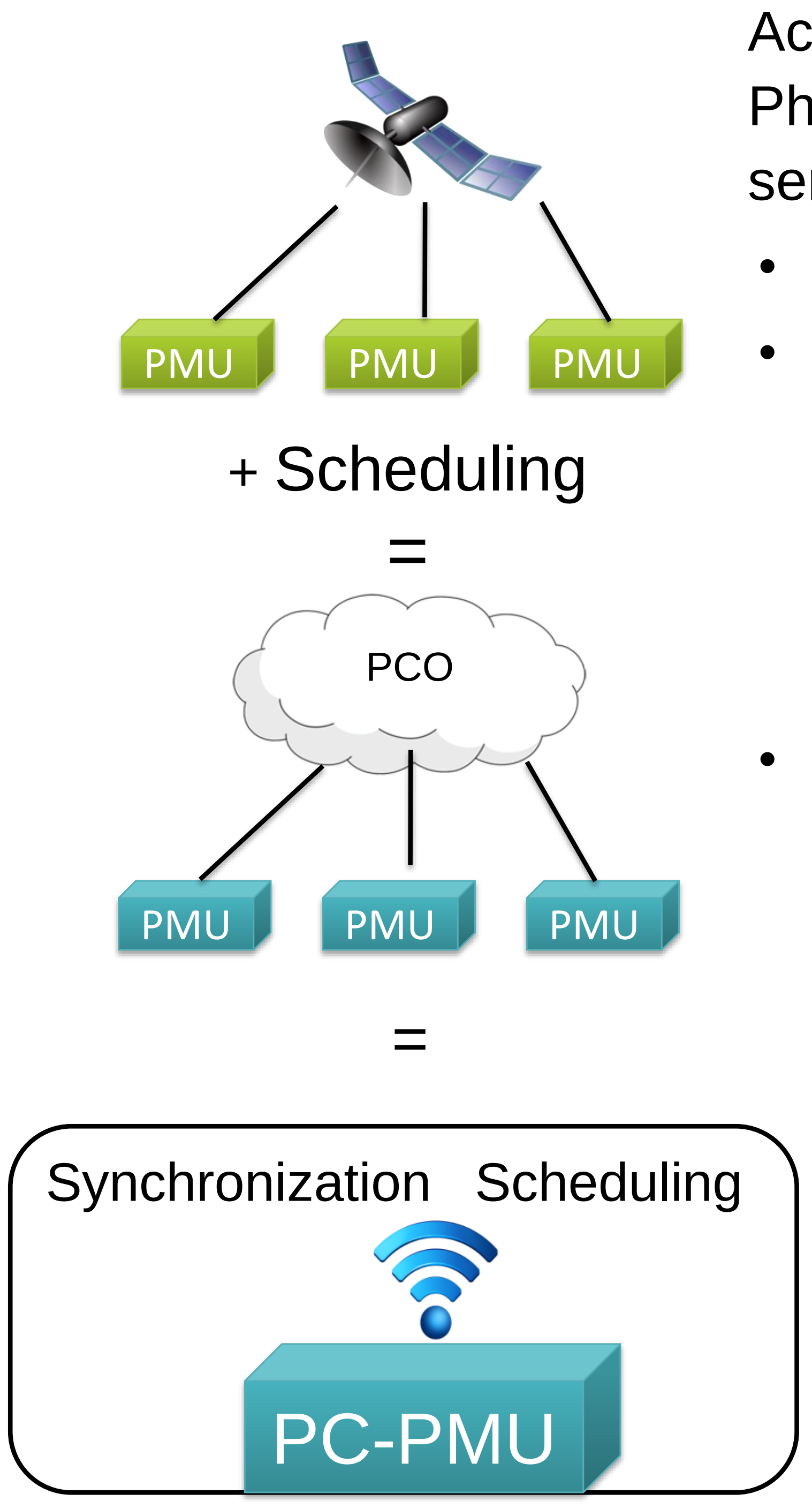
GOALS



Accurate network timing is required for Phasor Measurement Units (PMU) or other sensors.

- GPS spoofing is a threat.
- PTP & NTP:
  - Not encrypted (man in the middle attack).
  - Centralized (not scalable; central point of failure).
- PCO-Synchronization + Scheduling:
  - Resilient to node failures.
    - Self-healing (inspired by biological networks).
  - Physical-layer secure signaling.
  - Decentralized design → scalable.
  - Accurate timing due to time of flight estimation.
  - Application: monitor and control for the distribution grid.

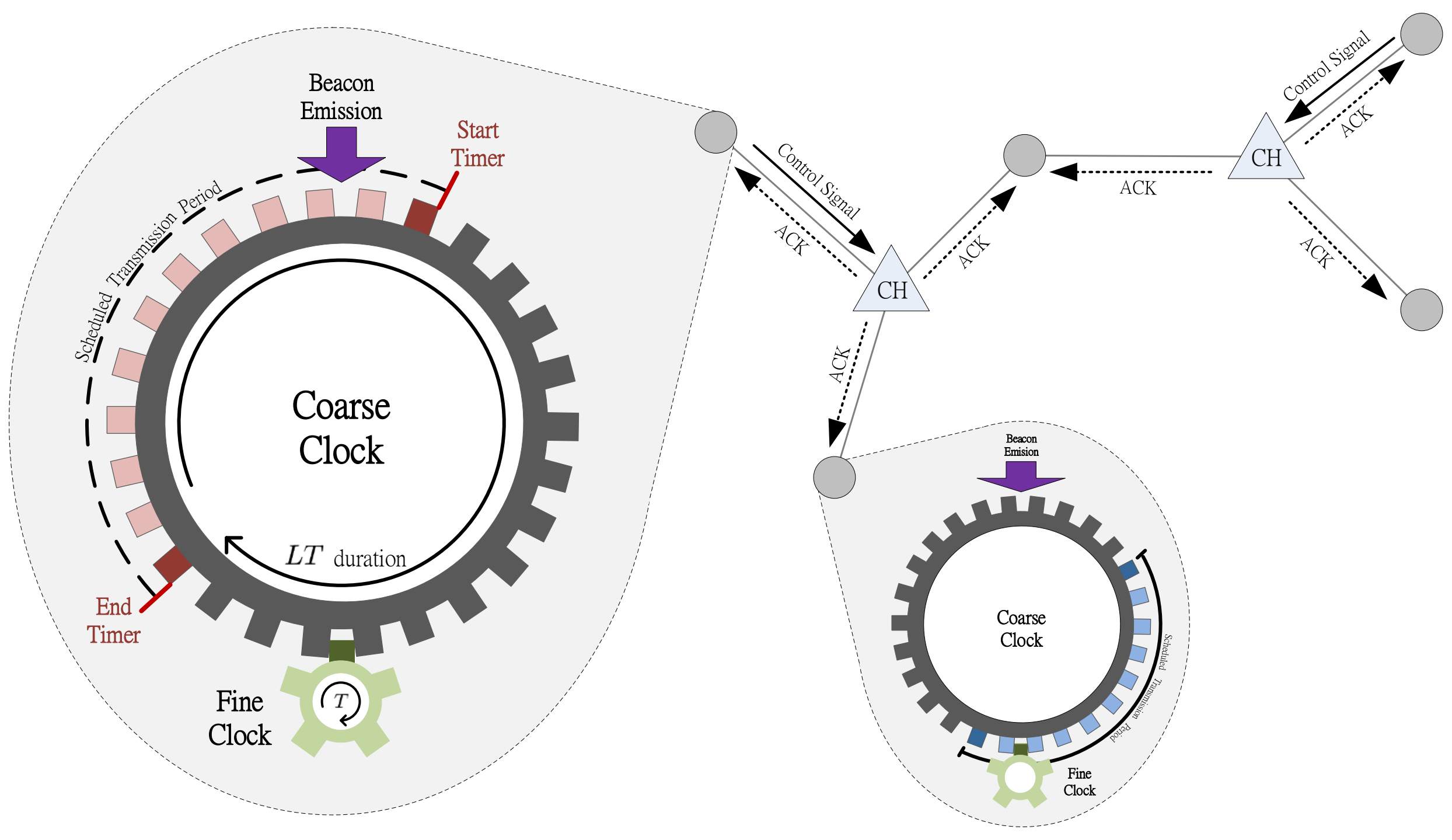
INTRODUCTION TO THE PULSESS PROTOCOL (PULSE-COUPLED SYNCHRONIZATION AND SCHEDULING)

Define start and end coarse clocks (length *L*) driven by the same fine clock.

scheduling synchronization

$$\Phi_v(t) = s_v(t) + \varphi_v(t) \pmod{L}$$

$$\Phi'_v(t) = e_v(t) + \varphi_v(t) \pmod{L}$$



- Each time a clock reaches *L*, it sends a pulse.
- Cluster heads (CH) in range spread the pulse locally by acknowledging it.

- The CHs adjust their own fine clocks, taking into account the estimated signal traveling time $\hat{t}_{v,c}$, i.e., when receiving the pulse at time $r_v^{(s)}$.

$$\hat{\varphi}_c = \varphi_c\left(r_v^{(s)}\right) - \frac{\hat{t}_{v,c}}{T}$$

$$\varphi_c\left(r_v^{(s)+}\right) = \begin{cases} \varphi_c\left(r_v^{(s)}\right), if\ 1 - \hat{\varphi}_c (mod\ T) \leq \delta_{ref} \\ \min\left((1+\alpha)\hat{\varphi}_c, 1\right) + \frac{\hat{t}_{v,c}}{T}(mod\ T), else \end{cases}$$

- The refractory period δ_{ref} is set based on the noise in time of arrival of a pulse: $$\delta_{ref} \propto \sigma^2_{v,c} = (SNR_{(v,c)} \cdot \bar{F}^2)^{-1}$$

  Thus, the accuracy depends on the signal-to-noise ratio of the link and mean squared bandwidth.

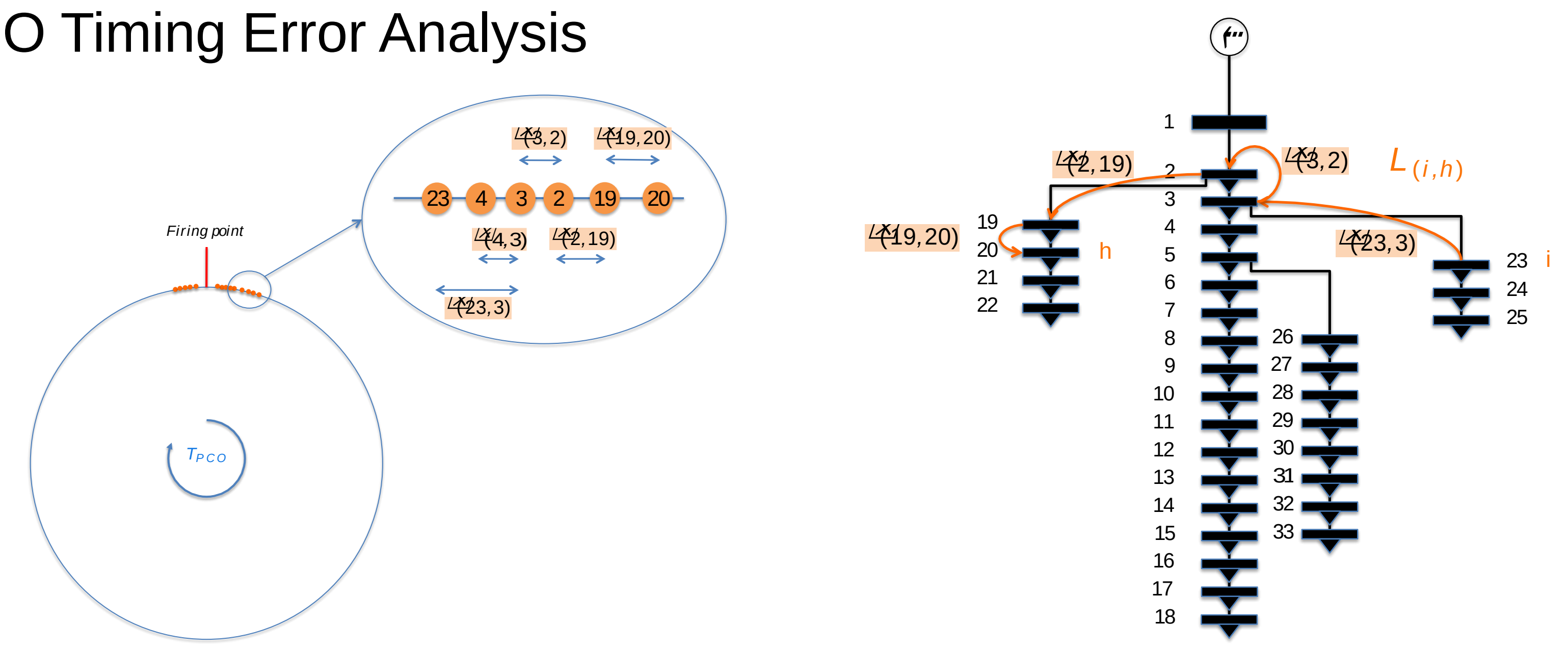
- Each **node** that receives an acknowledgment updates its fine clock analogously.
- In addition, when a node is receiving a start pulse from its successor, it updates its coarse clock.
- The update depends on the positions of the nodes' predecessors; the nodes' demand for communication, D_v; and an intended guard space, δ.

$$s_v^{target}(t) = \frac{(D_v + \delta)}{(D_v + 2\delta)} e_{pre(v)}(t) + \frac{\delta}{(D_v + 2\delta)} s_{suc(v)}(t)$$

$$e_v^{target}(t) = \frac{(D_v + \delta)}{(D_v + 2\delta)} s_{suc(v)}(t) + \frac{\delta}{(D_v + 2\delta)} e_{pre(v)}(t)$$

RESEARCH RESULTS

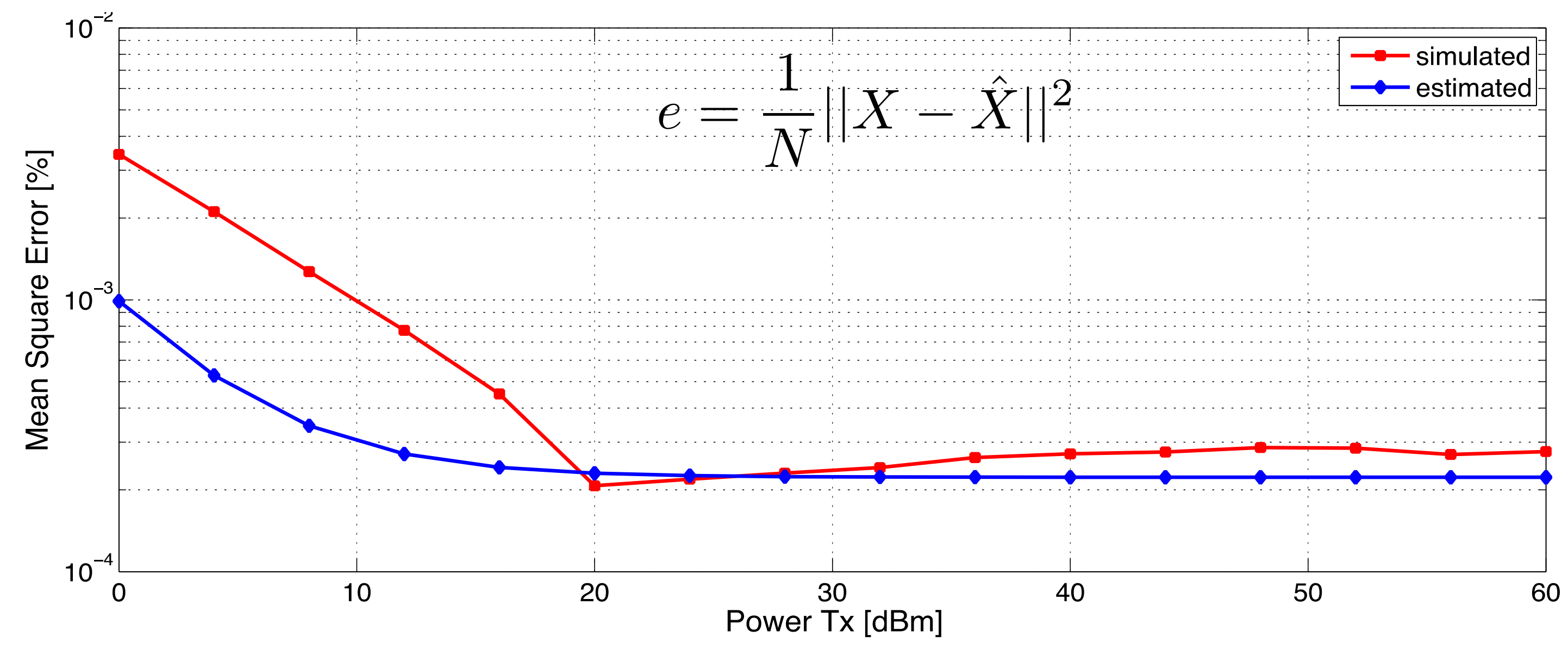
PCO Timing Error Analysis



Lemma (Convergence fixed point) $$\Delta\Phi_{(i,h)}(t) \underset{t\to\infty}{=} \sum_{(k,m)\in L_{(i,h)}} \tau_{(k,m)}$$

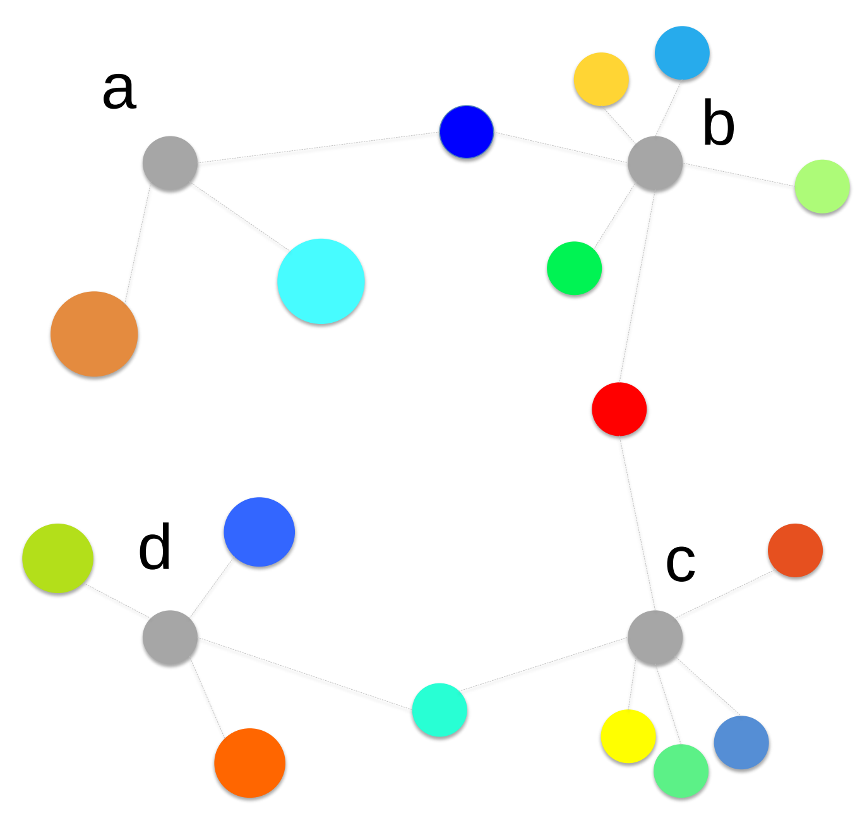
Simulation: *IEEE 33 bus, 1 PC-PMU per branch. Power-line communication (band around 300kHz +/- 100kHz). Losses on the line 40dB/km, average distance 100 m, coupling factor α=0.04, 170 iterations, transmission power 0-60dBm.*

Mean squared error 0.023%@30dBm

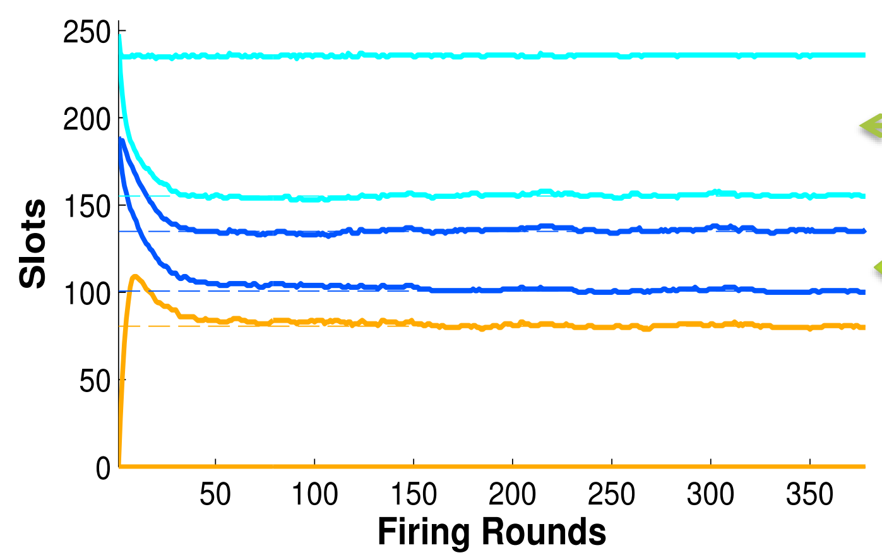


Scheduling convergence of PulseSS for clustered networks

Simulation: *4 clusters; each node has the same demand; 250 slots; 370 iterations; transmission power 30dBm; other parameters as above.*



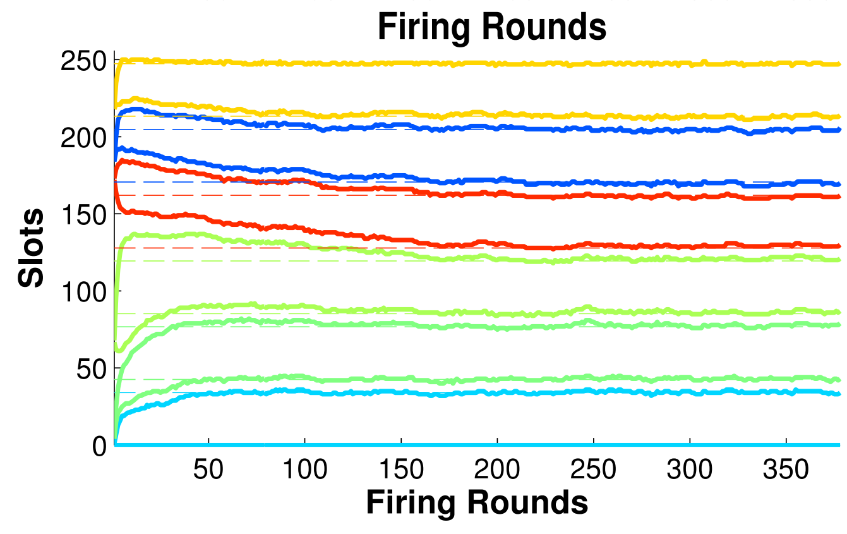
size of circle = scheduled communication time
gray circles = cluster head, have no comm. time



fills the space blue cannot take

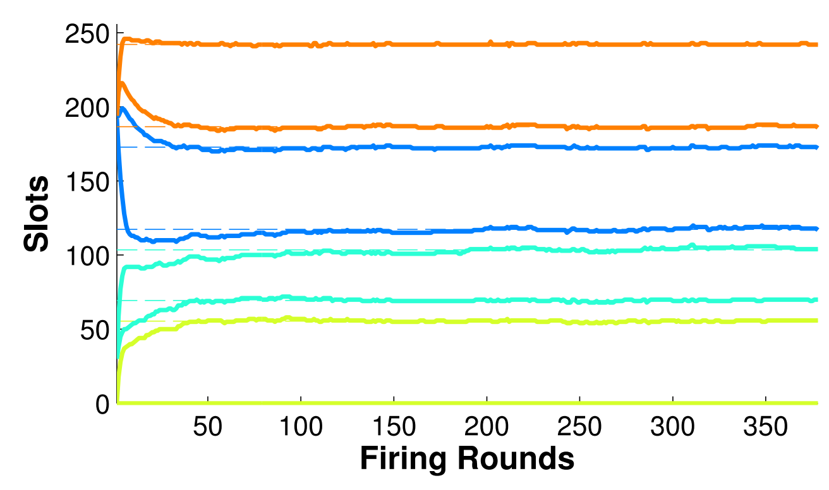
a

blue congested by b)

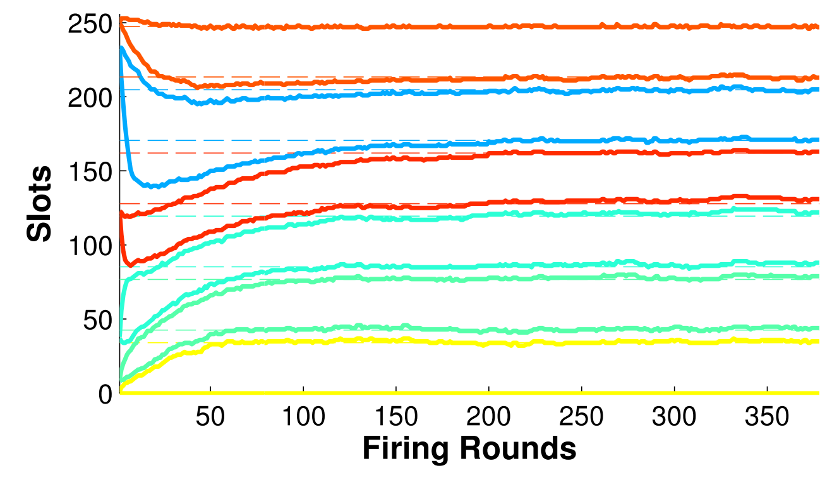


b

the simulation (solid line) converges to the theoretical value (dashed)



d



c

BROADER IMPACT

- A decentralized self-healing radio protocol to support synchronization and scheduling can reduce vulnerabilities due to possible spoofing and jamming of GPS signals and other master/slave network synchronization protocols.
- It can make NICS scalable and easy to deploy because of reliable timing and scheduling of information flow.

FUTURE EFFORTS

- Complete the analysis of convergence speed.
- Study compatibility of PulseSS as a wake-up radio.
- Develop and test the PulseSS hardware implementation.
  - Test with microcontroller running TinyOS.
  - Test with FPGA, allowing direct access to the physical layer.

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