TCIPG

Trustworthy Time-Synchronous Measurement Systems

Pulse Coupled Oscillators Network Time and Access Protocol

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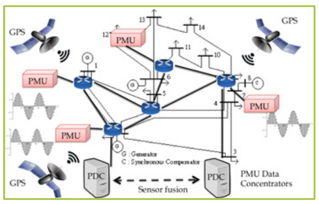
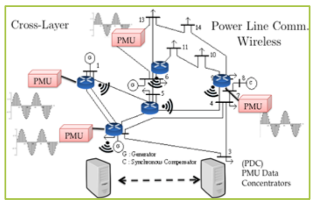
GOALS

- Provide scalable primitives for accurate network timing for Networked Industrial Control Systems (NICS).
- Provide coordination mechanisms for scheduling (important for protection schemes in the grid).
- Attain those goals with a decentralized design.
- Create a design inspired by the biological pulse coupled oscillators (PCO) model, feature properties of natural swarms, such as:
  - Scalable designs.
  - Physical signaling and timing estimation accuracy.
  - Self-healing, adaptive.
  - Decentralized (ad hoc networks).





FUNDAMENTAL QUESTIONS/CHALLENGES

- PCO primitives can lead to two useful emergent behaviors:
  - **Synchronization**
    - Nodes are attracted to fire a beacon signal in unison as long as they are in a connected graph.
    - Potentially useful to establish common timing.
    - Are the synchronization speed and accuracy sufficient for accurate phasor measurement unit (PMU) synchronization?
    - Is the protocol robust to attacks and failures?
  - **De-synchronization**
    - Nodes are attracted to fire their beacons in a daisy chain.
    - Useful to establish a wake-up or collision-free access schedule (Time Division Multiplexing).
    - Is the scheduling protocol mindful of hidden and exposed terminal problems?
    - Is it sufficiently fast in adapting to a changed environment?
    - Is it efficient in sharing resources?
  - Can we have a control plane that provides both Network Time and Access control via PCO and harmonize communications in Networked Industrial Control Systems (NICS)?

RESEARCH PLAN

- Combine PCO primitives into a PCO Network Timing and Access Protocol (PCO-NTAP) to attain two goals:
  1) Accurate and secure timing.
  2) Reliable, deterministic, conflict-free access.
- PCO NTAP protocol design compatible with master/slave communications (e.g., Remote Terminal Units and Intelligent Electronic Devices) orchestrated by application layers such as DNP3 or Modbus.
  - Routing topologies: multiple coexisting clusters and trees.
- Analyze the convergence and efficiency (rate for shared networks).
- Analyze the timing accuracy.
- Introduce security measures (signal scrambling and intrusion detection).
- Design a prototype of the PCO-NTAP.
  - Wake-up radio, separating control + synchronization from the data plane and making it back-compatible with other radios used in NICS.

RESEARCH RESULTS

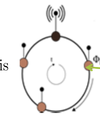
PCO synchronization and De-synchronization basics

- State of the clock $\Phi_i(t)$ - the node fires when $\Phi_i(t)=1$

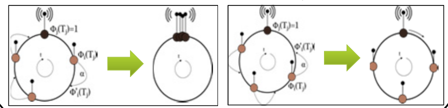
$$\Phi_i(t) = \left(\frac{t}{T_{\mathrm{PCO}}} + \phi_i\right) \bmod 1$$

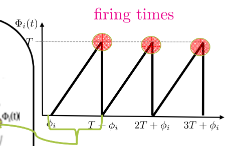
- If a firing is detected at time t_f the PCO update is

$$\Phi_i^+(t_f) = ((1+\alpha)\Phi_i(t_f) \bmod 1)$$



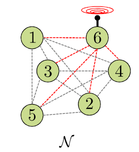
Excitatory $\alpha > 0$ — Inhibitory $\alpha < 0$





Clock cycle and state of node i

Mesh Networks



PCO Network Time and Access Protocol – PCO NTAP

- Each node and cluster-head has an internal timer ($u \in \mathcal{V} \cup \mathcal{C}$):

$$\Phi_u(t) = (t - \phi_u)\frac{L}{T} \pmod L$$

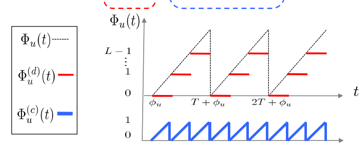
- Timer evolutions can be decomposed into discrete and continuous parts

Scheduled by PCO Desync

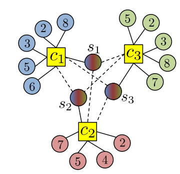
$$\Phi_u(t) = \lfloor \Phi_u(t) \rfloor + (\Phi_u(t) \pmod 1)$$

$\Phi_u^{(d)}(t)$, $\Phi_u^{(c)}(t)$

Aligned by PCO sync

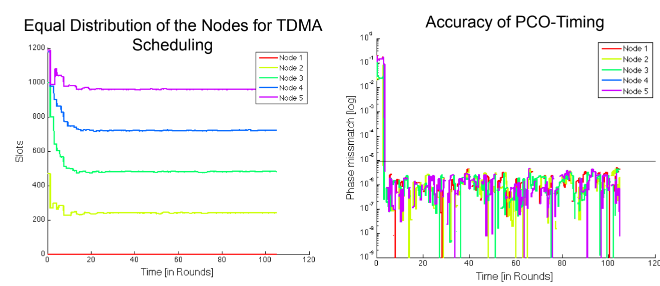


clustered networks (master/slave configurations)



Main results: Convergence analysis of PCO NTAP.

- Even if in conflict, nodes settle to locally fair schedules [Ashkiani '12].
- Confirmed by numerical simulations.



N=5 nodes are placed randomly in a 2D-plain of r=1. Signal-travel-time is assumed to be the speed of light with added normalized Gaussian time error N(0, 10-5). Number of slots is set to L=1200.

Example: Frame duration<= 1/60 sec., PCO slot=1/60/L (e.g., 14 μsec.).
Time Error Variance with 6dB of SNR and 20MHz of bandwidth ~6.2797e-16.
While the simulation has noise variance 1.9600e-15. Distance error negligible below 10 m.

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 study of the timing accuracy.
- Consider tree topologies for the communication.
- Study compatibility of PCO-NTAP as a wake-up radio.
- Develop and test the PCO-NTAP hardware implementation.

Ashkiani, S., Scaglione, A. IEEE 50th Annual Allerton Conference on Communication, Control, and Computing, pp.1551-1558, Oct. 1-5, 2012.

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