Pulsar: Wireless Propagation-Aware Clock Synchronization

Adwait Dongare, Anthony Rowe
Carnegie Mellon University

Award # CNS-1329644

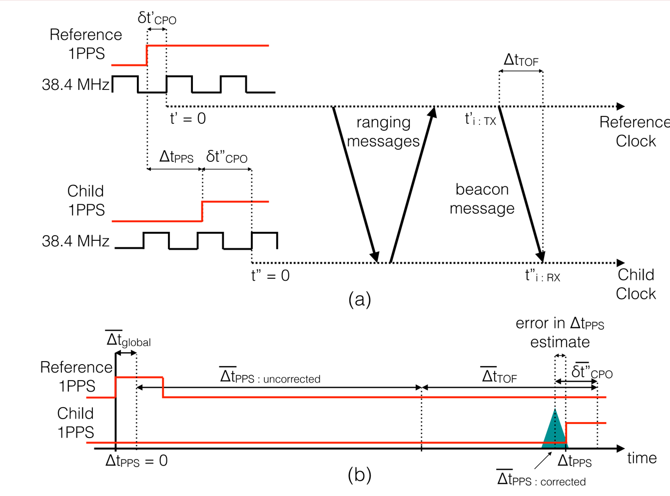
Introduction

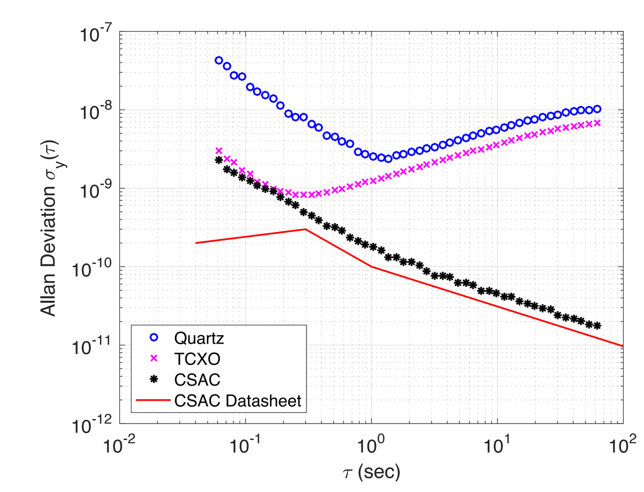
- Development of next-generation wireless systems using platforms like software-defined radios requires better than 5 nsec clock synchronization ideally decoupled from MAC layer for communication
- Existing solutions like GPS, IEEE 1588 PTP, etc cannot scale to wireless, indoor environments with the required accuracy.
- The ideal wireless time synchronization platform operates on very stable clocks and very wide bandwidth for lowest clock errors and best range resolution.

Challenges with Nanoseconds

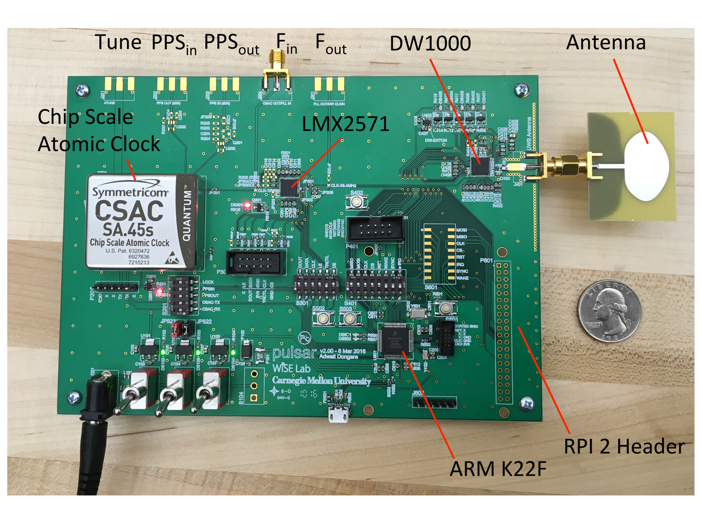
Nanosecond-scale time measurements have to consider:

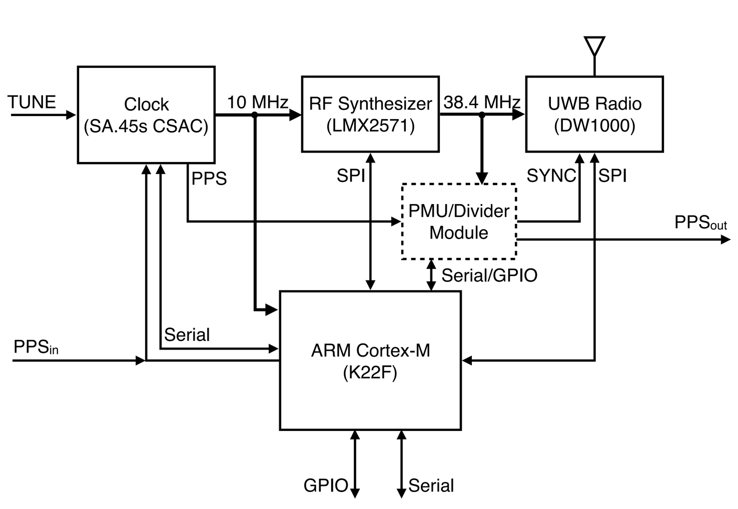
- *Propagation time* for speed-of-light communication that scales with distance
- Clock stability, quantified by *Allan deviation*, that determines oscillator limits and synchronization messaging rate
- Accuracy of message timestamps dependent on bandwidth, algorithms and signal quality
- Digital *I/O discretization errors* introduced by sampling only on clock edges
- *Clock Phase Offset* i.e delay between event trigger and actual start of clocks





Platform

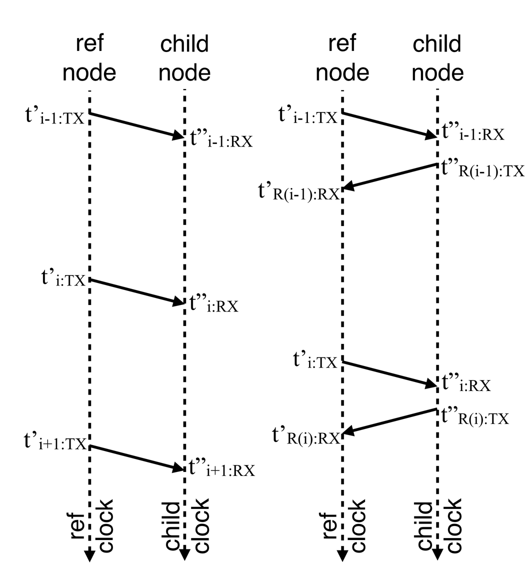




Pulsar hardware platform:

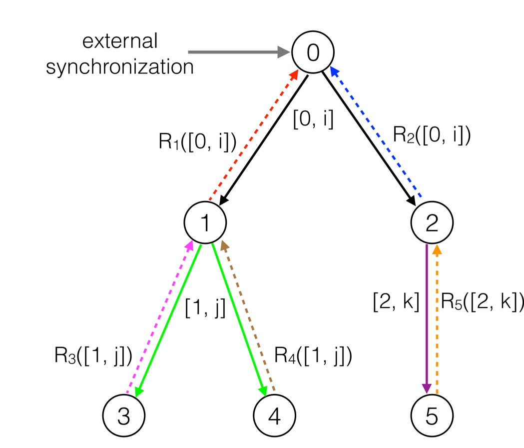
- **Output:** Standard *10 MHz* & *1PPS* to SDR, etc.
- SA.45s CSAC for stable timing allows > 1 sec message rates
- LMX2571 PLL to bridge CSAC and radio clock domains, has < *1 nsec jitter* after lock
- DW1000 UWB radio for *wireless messaging* and *sub-nsec timestamps*
- *Kinetic K22* ARM Cortex-M4 processor manages peripherals and protocols using FreeRTOS tasks
- Can synchronize with *external GPS* receivers over PPS input

Clock-Synchronization Protocol

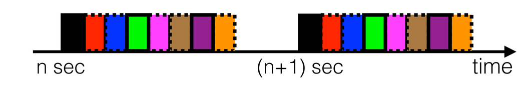


Wireless UWB message timestamps to estimate frequency, phase and time-of-flight w.r.t. reference node

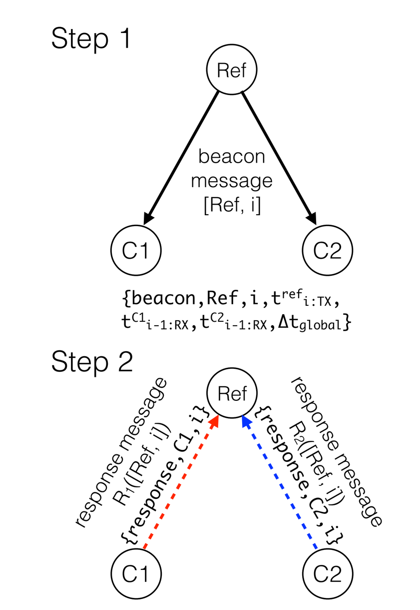
3 Stage Synchronization Protocol



Stage 1: Generate spanning tree for time distribution



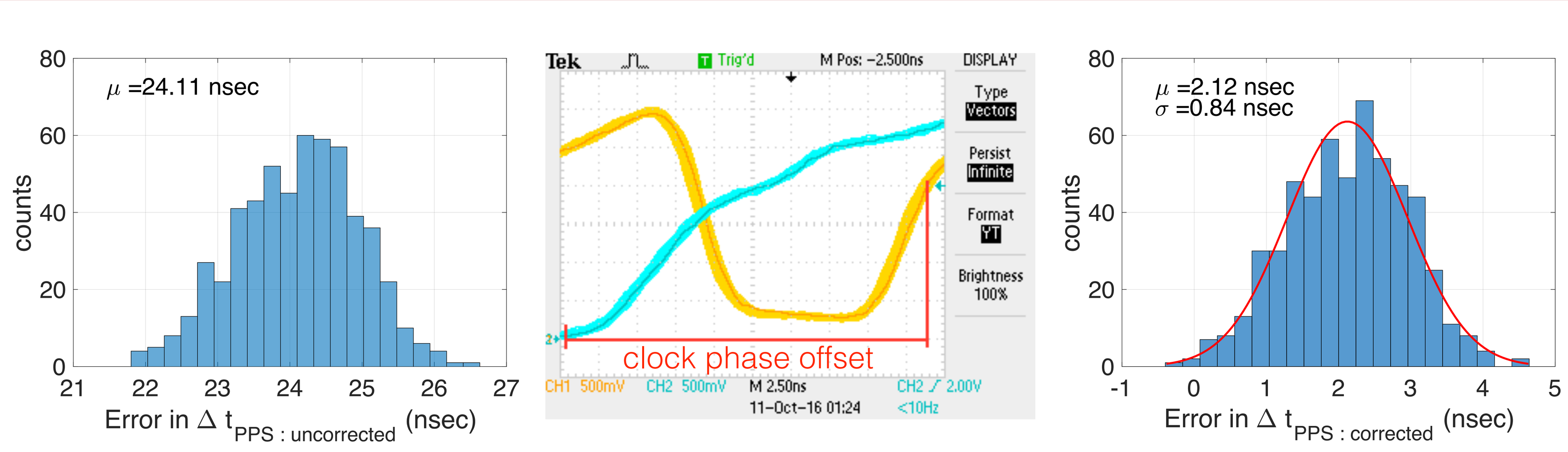
Stage 2: Generate TDMA schedule for messaging



Stage 3: Per-hop reference-child synchronization using beacon and response messages

Only child nodes discipline clocks. Start as listen-only. Send responses after frequency lock.

Evaluation



(a) (b) (c)

- Proof-of-concept protocol achieves frequency lock under 3 parts in 10^{10} (very close to Allan deviation predicted limit)
- Raw phase estimate (a) doesn't account for time-of-flight and other errors
- Clock Phase Offset (b) has < *1 nsec of jitter* after lock. Can be measured by precise PMU and compensated.
- Clock synchronization after corrections (c) *better than 5 nsec per hop* with $\mu = 2.12$ nsec & $\sigma = 0.84$ nsec (under error bounds for individual components)

Discussion & Conclusion

- Pulsar platform provides better than 5 nsec synchronization directly usable by higher-level applications
- CSAC improves robustness and long-term clock stability. Lower cost system may be developed with higher message passing rate.
- Sophisticated time synchronization schemes can be easily adapted and tested on the Pulsar platform for scalability, fault-tolerance, etc.
- Link quality directly affects time synchronization. With UWB communication, timestamp & ranging jitter is an easy-to-compute metric for link quality.

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