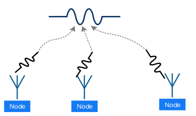
Experimental Demonstration of Nanosecond-Accuracy Wireless Network Timing Synchronization

Marcelo Segura, S. Niranjayan, Pei-Lan Hsu, Andreas Molisch and Hossein Hashemi
Ming Hsieh Department of Electrical Engineering

Motivation

Distributed beam-forming using an array of wirelessly self-synchronized nodes.



Challenges

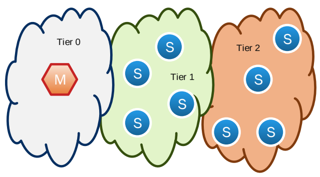
- Accurate wireless synchronization of carrier's frequencies, phases and absolute times (e.g., sub-nanosecond for GHz carriers).
- Scalability to large distributed networks.
- Maintaining synchronization in dynamic environments and in the presence of multipath.

Past work

- Synchronization accuracy equaling duration of packet or cyclic prefix.
- Previous algorithms neglect fast re-timing and/or propagation delay differences.

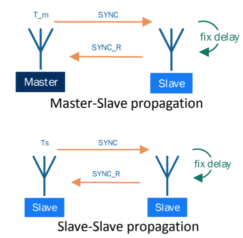
Algorithm Overview

Create Time Virtual Network



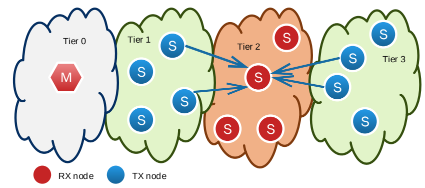
1-Master starts the association procedure using a CSMA/CA protocol.
2-Slaves with SNR > SNR_{th} recognize the Master.
3-Every node belongs to an even or an odd tier.

Round Trip Delay Measurement



All propagation delays are estimated and stored for all neighbor nodes.

Blinking Algorithm



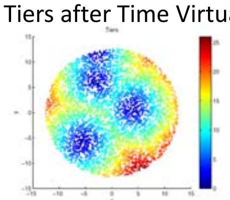
$\{t_k^e\}_{k=1}^N$ Measured TOA
$\{\tilde{t}_k^e\}_{k=1}^N$ Estimated TOA
$\{t_k^e - \tilde{t}_k^e\}_{k=1}^N$ Offset from neighbors
$\sum_{k=1}^N w_k(t_k^e - \tilde{t}_k^e)$ Correction function

1-Rx nodes estimate their neighbors' TOAs according to their local clocks.
2-Rx nodes calculate the offset using the previously saved round trip delay values.
3-Using the correction function every node adjusts its timer.
4-This re-timing process is repeated every 2 τ_b (blinking time). At any given time, all nodes in alternate tiers serve as transmitters or receivers.

Network synchronization is achieved through consensus

Simulation Results

Tiers after Time Virtual Network Creation

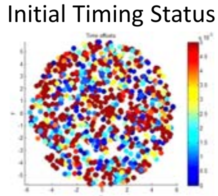


Simulation Setup

- Master nodes N_m=5.
- Slaves nodes N_s=5000.
- Node radius coverage 50m
- 2D Poisson spatial spread
- Coverage 1.118Km

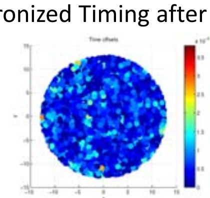
Simulation Results
26 Tiers created in the TVN.

Initial Timing Status



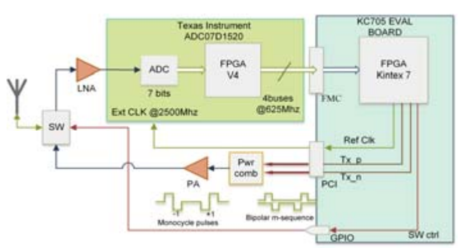
Timing error (us)

Synchronized Timing after Blink algorithm



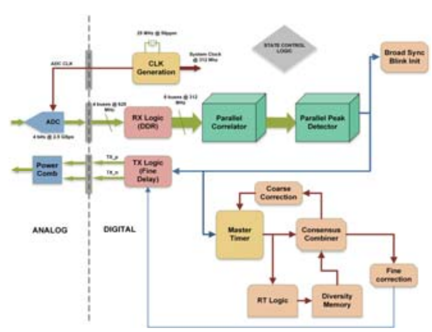
Timing error (us)

Hardware Implementation



TX: Ultra-wide band pulses are generated in the FPGA.
RX: Received waveform directly digitized via ADC.

System Architecture



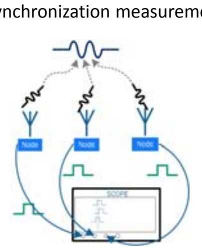
Measurement Setup

Indoor

Outdoor

Experimental Results

Synchronization measurement



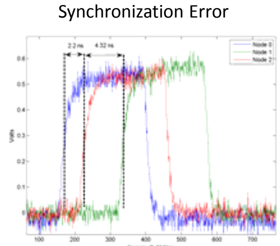
Distance between nodes

	Master-N0	N0-N2	N2-N1
Indoor (LOS)	1	1.8	2.4
Indoor (NLOS)	0.9	1.6	1.7
Outdoor	1.9	3.7	4.5
Simulation	3	5.4	7.5

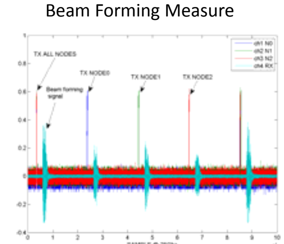
Statistical Analysis

	Indoor(LOS)		Indoor(NLOS)		Outdoor	
	Node 0	Node 1	Node 0	Node 1	Node 0	Node 1
Mean (ns)	0.118	0.886	0.820	2.812	1.554	2.822
Std. dev. (ns)	3.316	3.358	3.412	3.211	3.011	3.002

Synchronization Error



Beam Forming Measure



Absolute timing synchronization within 3 ns is experimentally demonstrated for both indoor and outdoor static environments

Future and Ongoing Work

Enhance timing synchronization accuracy to <100 ps. Enable operation in multipath & dynamic environments. Develop low-cost/low-power CMOS chip for timing synchronization. Demonstrate distributed beam-forming up to GHz carrier frequencies.

Sponsors:
ONR JCREW EW S&T
Ming Hsieh Institute at USC

References

[1] M. Segura et al., "Experimental Demonstration of Nanosecond-Accuracy Wireless Network Synchronization," *IEEE International Conference on Communications*, submitted for publication.
[2] S. Niranjayan, A. F. Molisch, "Ultra-wide Bandwidth Timing Networks" in *IEEE Int. Conf. on Ultra-Wideband*, 2012 pp 51-56.

Contacts: mjsegura@usc.edu / peilan.hsu@usc.edu / molisch@usc.edu / hosseinh@usc.edu Nov 2014