THE UNIVERSITY OF TEXAS AT AUSTIN
RADIONAVIGATION LABORATORY

WNCG Wireless Networking & Communications Group

Extending the Reach of GPS-assisted Femtocell Synchronization and Localization through Tightly-Coupled Opportunistic Navigation

Ken Pesyna, Kyle Wesson, Robert Heath Jr., Todd Humphreys

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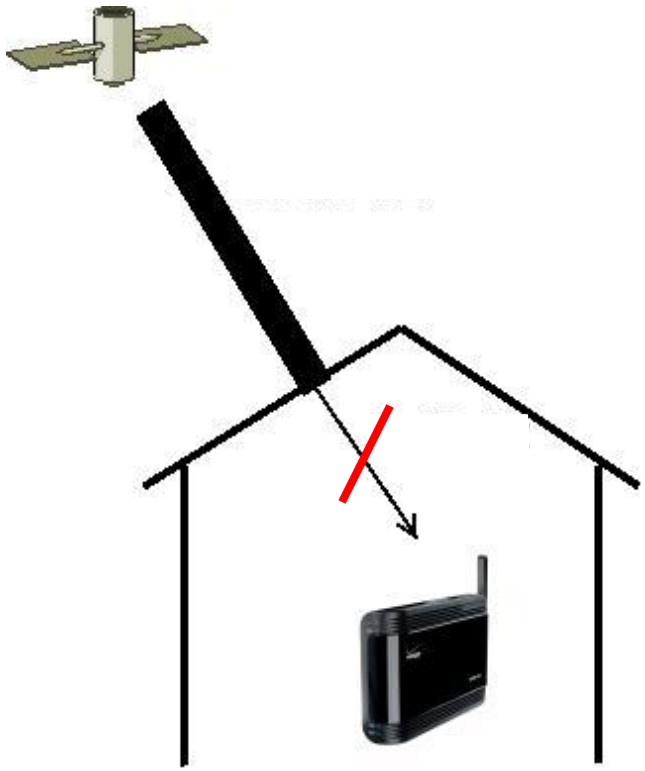
Why Synchronization & Localization?

- Ensure reliable handover
- Reduce interference
- Operate within licensed spectrum
- Locate emergency calls

Synchronization and Localization are key requirements for femtocells

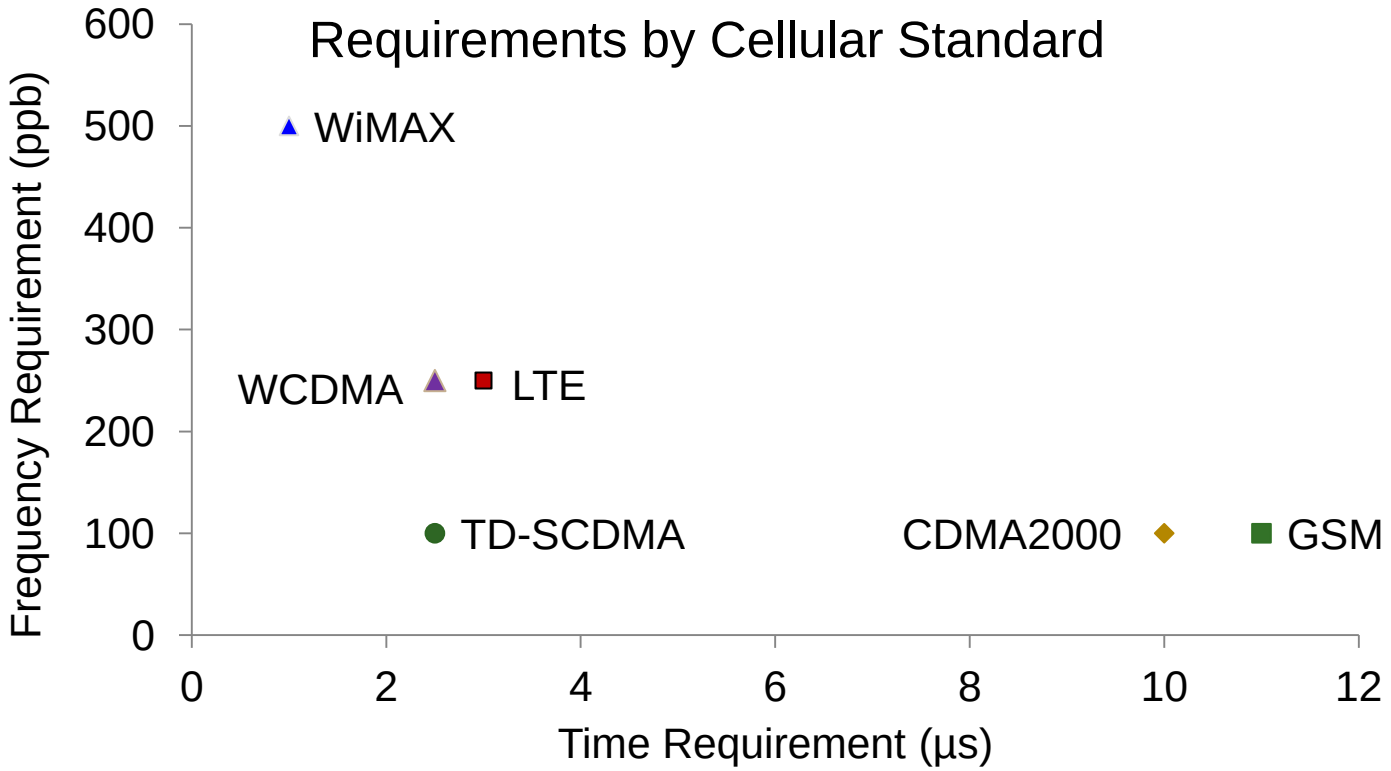
Challenges of Satellite-based Synchronization

- Femtocells placed indoors
- GPS signals weak: -155 dBW
- Up to 45 dB penetration loss



Time and Frequency Requirements

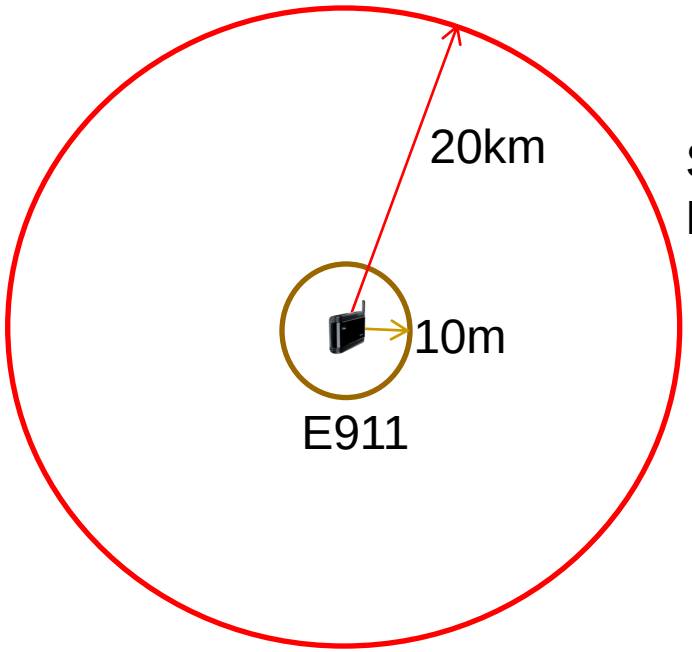
- Minimum synchronization requirements [Rakon]:



These are very stringent requirements!

Location Requirements

- Spectrum licensing & operator control
- Emergency caller location identification (E911)

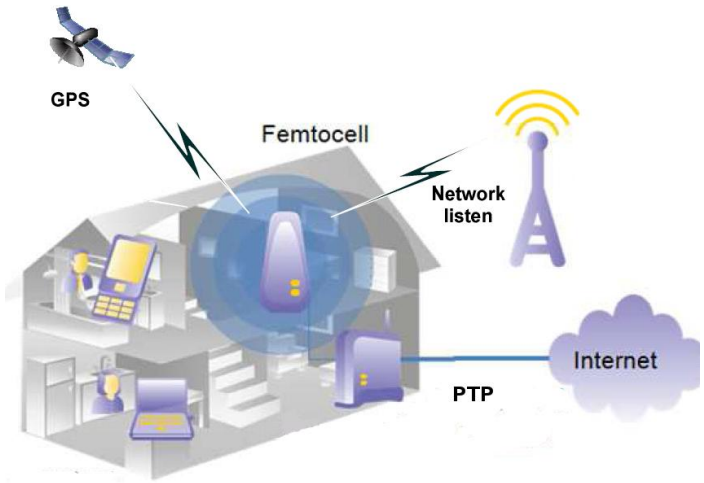


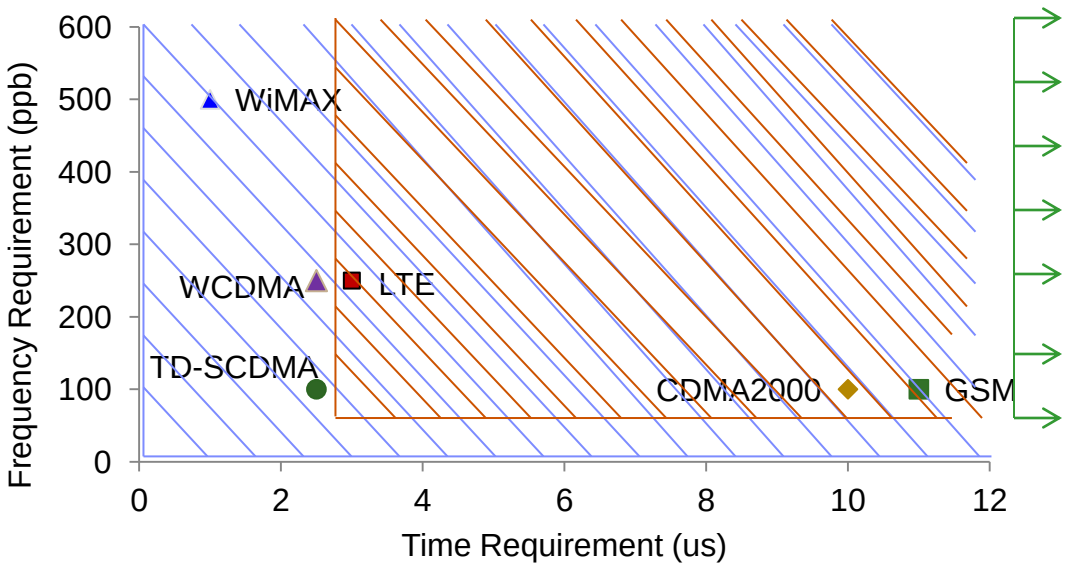
Spectrum Licensing

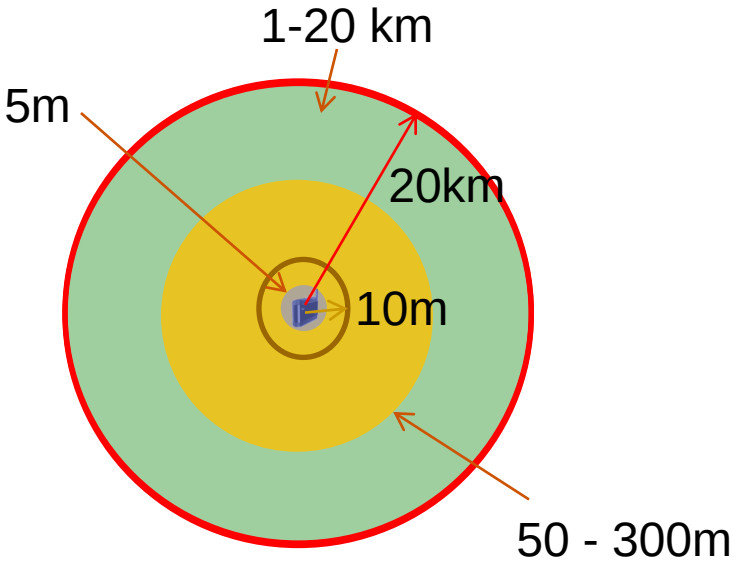
Challenging!
Big Issue: E911

Prior Work

- Precision time protocol (PTP) [Eidson02]
- Cellular network listen [Edwards08]
- GPS-based solutions [Lewandowski99, Smith09]

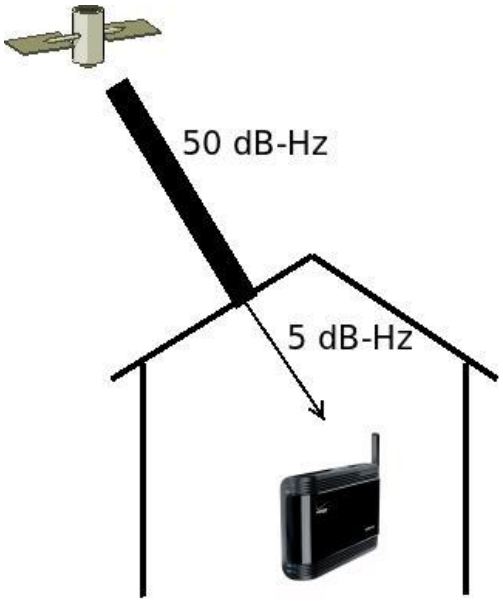






Challenges of GPS

- High signal sensitivity is required to acquire GPS signals indoors
  - 5 dB-Hz to cover 90% of residences
- Sensitivity attainable today:
  - State-of-the art via EGPS/AGPS is 14 dB-Hz [RoDuJaGra08]



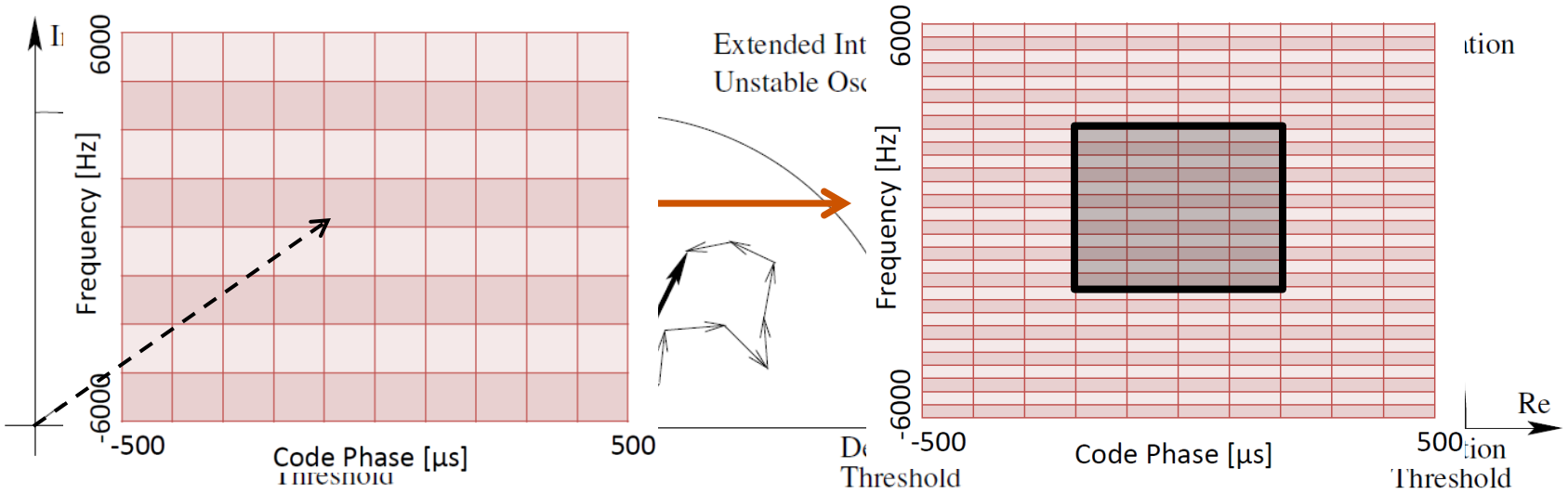
Goal: Close this 9 dB gap

Closing the 9 dB gap: Requirements

- Coherently integrate GPS signal over extended interval
  1. Local oscillator drifts

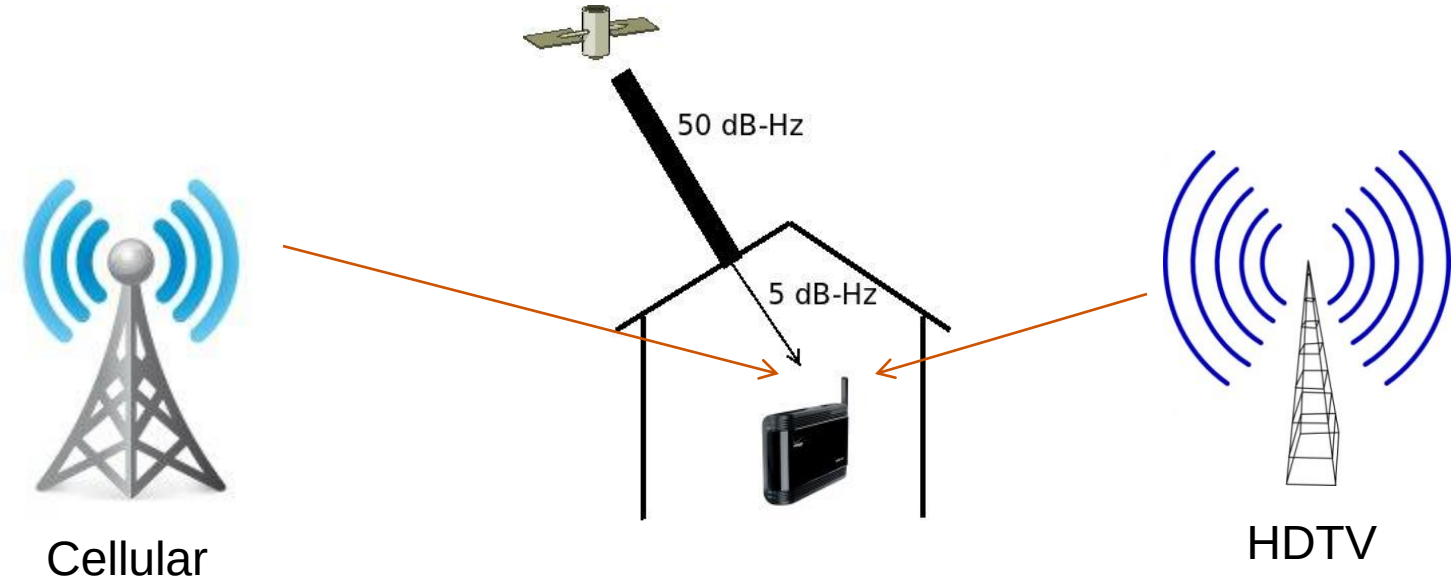
     → This requires a more stable oscillator
  2. # of time-frequency search cells explodes
     - Increases probability of false alarm

     → The search space must be reduced

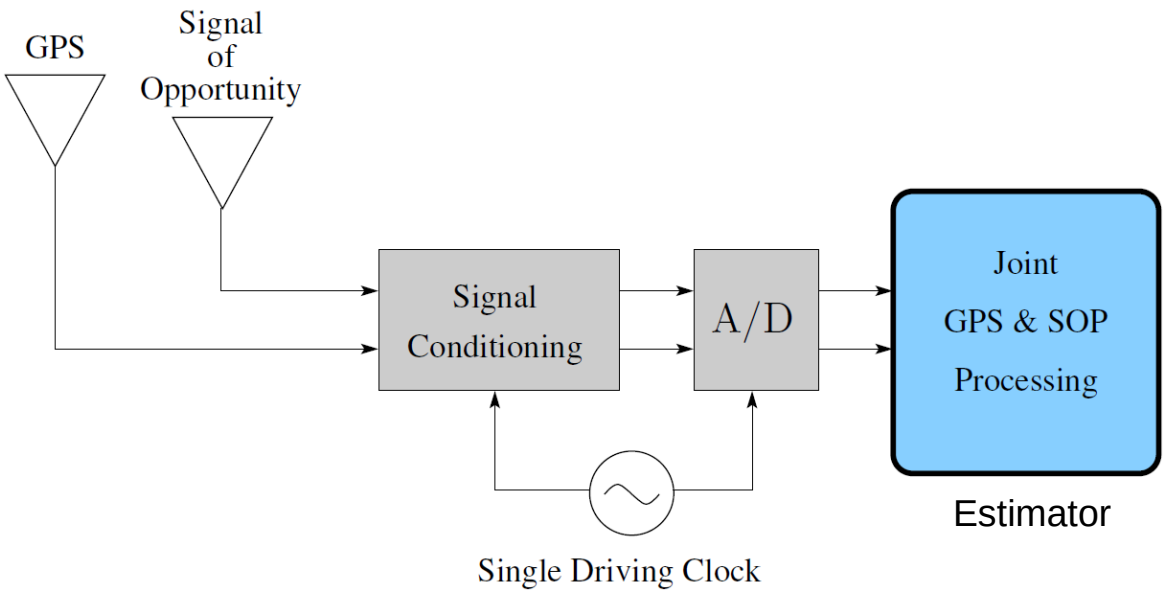


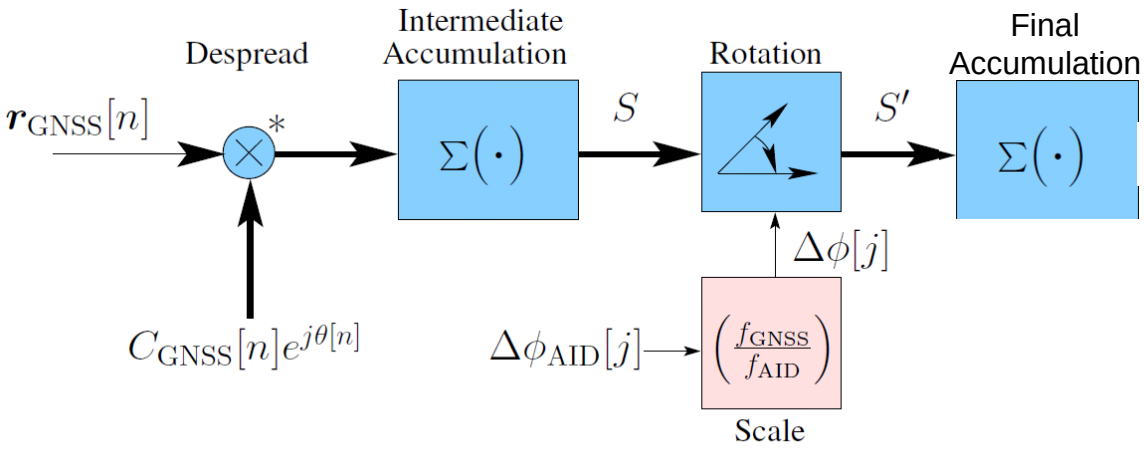
Proposed Solution: Tightly-Coupled Opportunistic Navigation

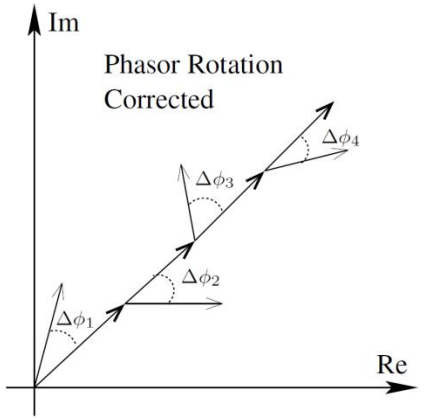
- Use ambient radio "signals of opportunity":
  - Stabilize femtocell's local oscillator
  - Narrow the GPS search space



Tightly-Coupled Opportunistic Navigation

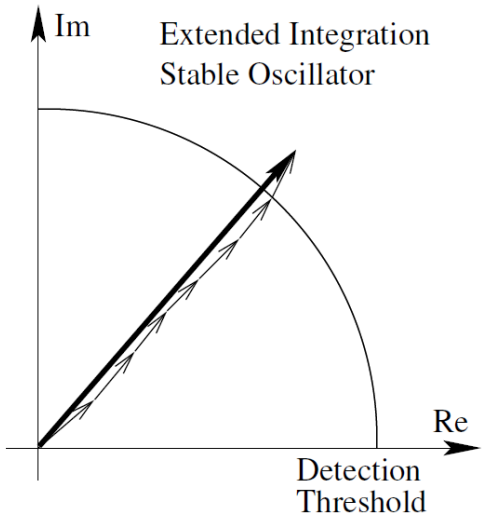


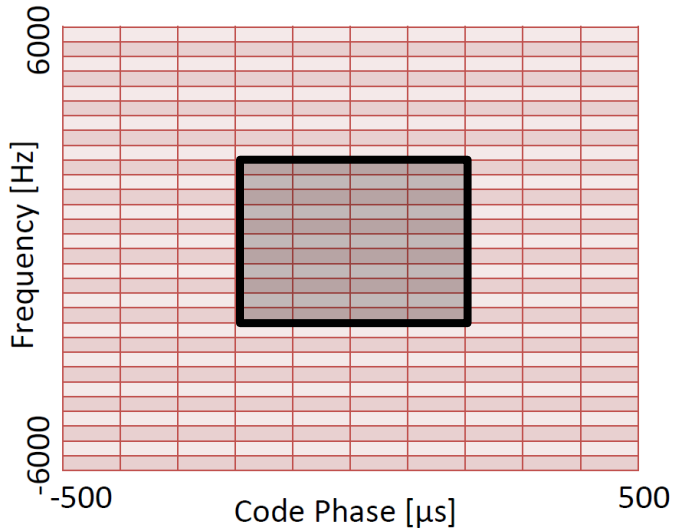




Benefits of Proposed TCON

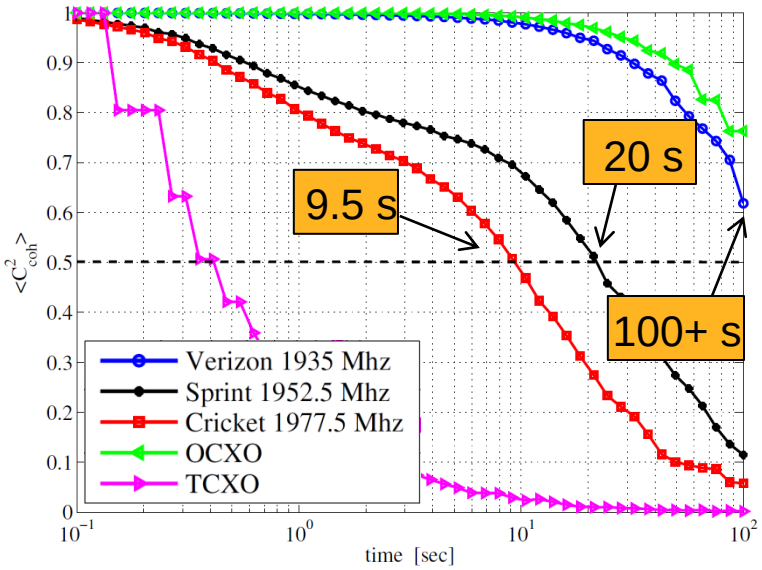
1. **Frequency stability transfer**
   - Correct its local clock variations to allow extended integration
2. **Search space contraint**
   - Aiding of precise time and frequency information
   - Decreases time & frequency uncertainty





Ambient Signal Analysis

- Analyzed ambient CDMA signals
- Extremely stable and synchronous
  - Signals remain stable beyond 9 seconds
  - Time synchronized to 4 μs (2 of 3)
  - Frequency accurate to 0.3 Hz



Mean-squared Coherence vs Time

Carrier	Mean [μs]	Std. Dev. [μs]
Cricket	3.773	0.031
Verizon	2.968	0.016
Sprint	40.745	0.035

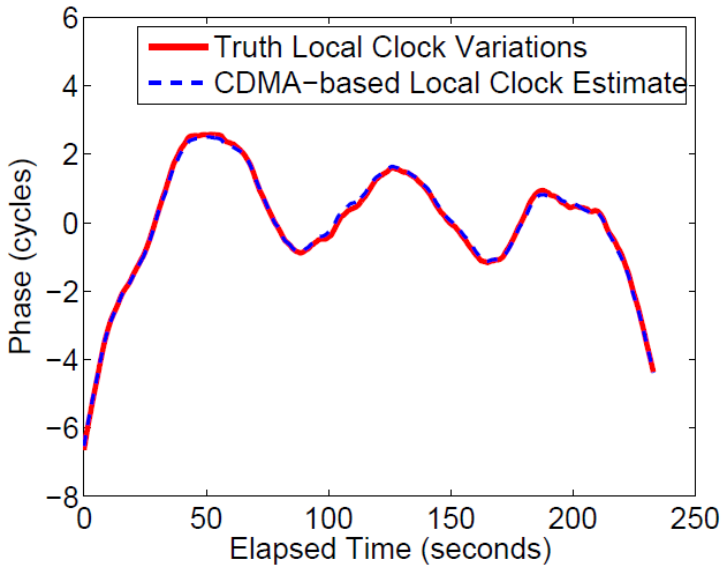
CDMA Signal Timing Offset from GPS Time

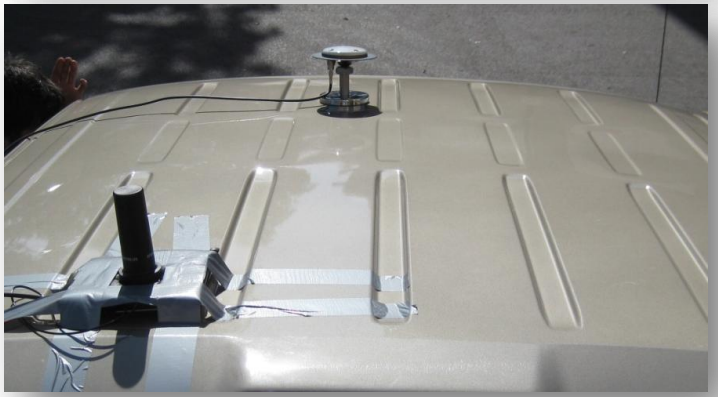
Carrier	Mean [Hz]	Std. Dev. [Hz]
Verizon	0.006	0.012
Sprint	-0.001	0.038
Cricket	0.100	0.058

CDMA Signal Frequency Error

Field Demonstration

- Cellular CDMA signals recorded in Austin, TX
- TCON used to estimate the local clock variations using only CDMA signals





Conclusions

- Synchronization is required for femtocell operation
- Location is required to meet FCC regulations
- Existing approaches may not meet requirements
- Propose TCON to exploit other available signals
- Increases the GPS-sensitivity of the femtocell
  - → GPS meets the syncrhonization requirements
  - → Allows femtocells to be located further indoors

Conclusions

- Requirements to acquire a 5 dB-Hz GPS signal:
  - Coherent integration time of 7 seconds
  - Time certainty to within 6 μs of GPS time
  - Frequency certainty to within 0.5 Hz
- TCON achieves the needed gain in sensitivity
- Femtocells synchronized indoors using GPS

Questions?