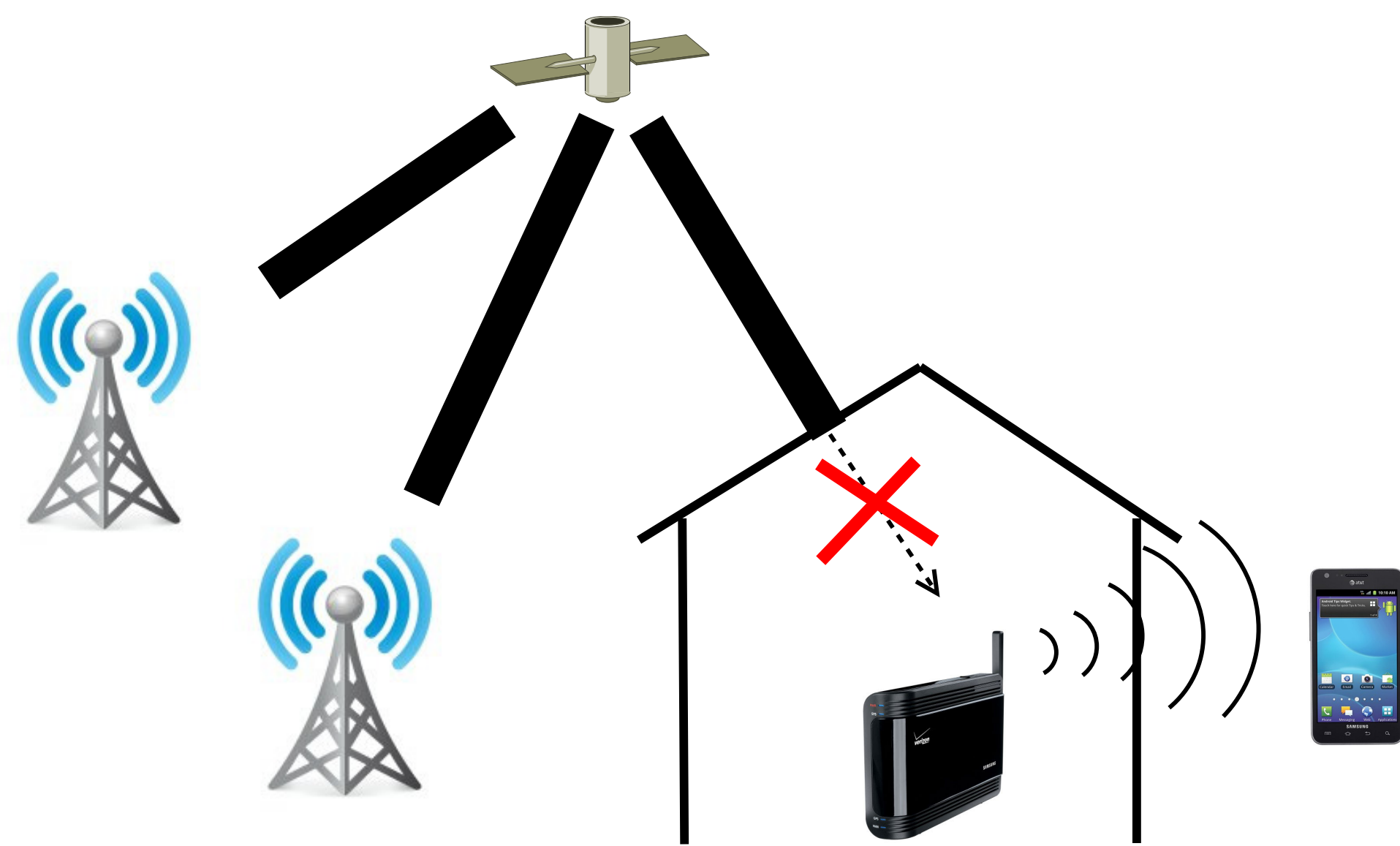


## THE PROBLEM

Femtocells must be synchronized with the cellular network and also be self-locatable

- GPS is typically used to achieve this
- **Problem:** GPS signals attenuate 30–50 dB indoors



## FEMTOCELL REQUIREMENTS

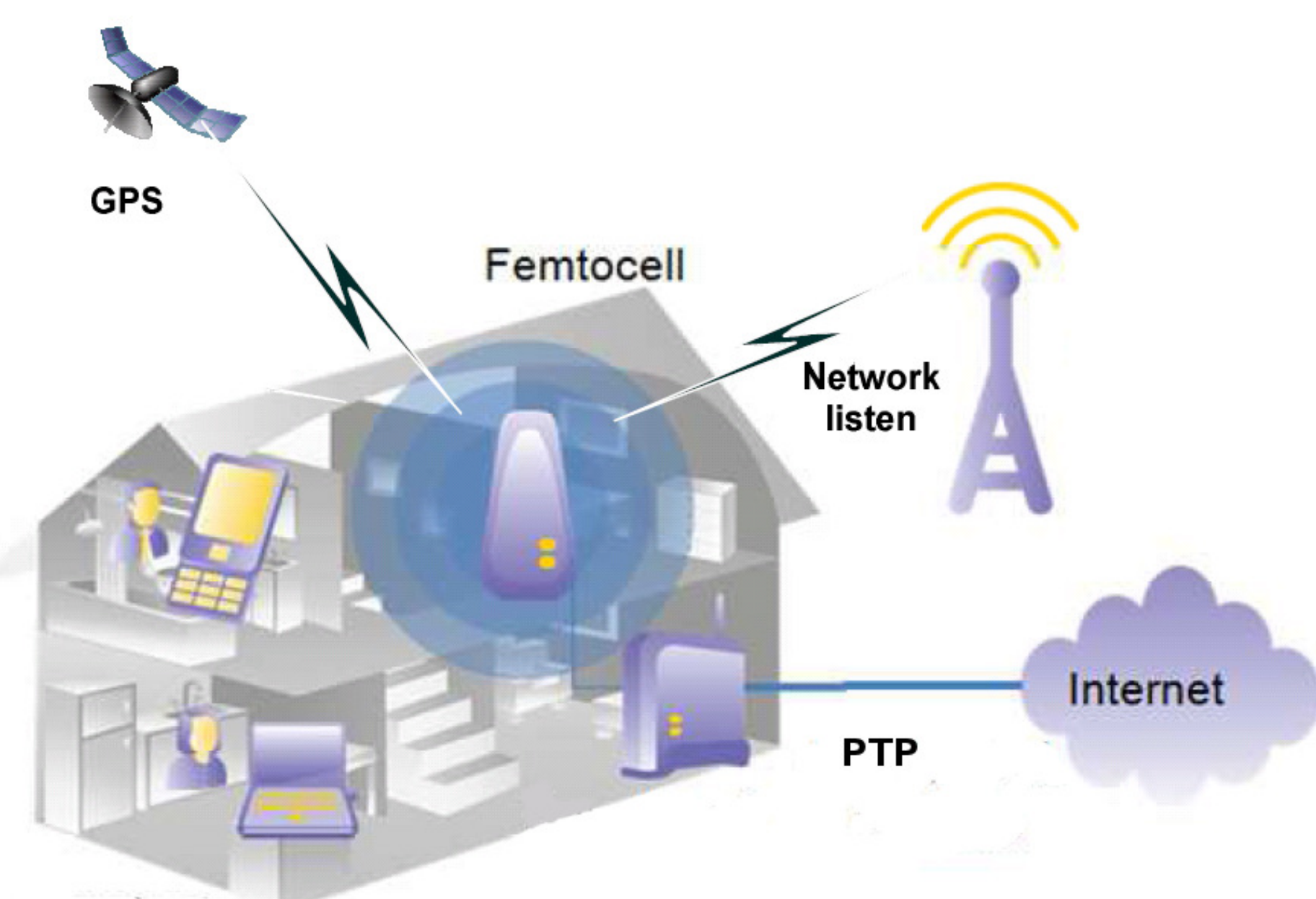
Synchronization Requirements:

Standard	Time	Frequency
CDMA2000	10 $\mu$ s	100 ppb
GSM	N/A	100 ppb
WiMAX	1 $\mu$ s (TDD)	8 ppm
LTE	3 $\mu$ s (TDD)	250 ppb
WCDMA	2.5 $\mu$ s (TDD)	250 ppb
TD-SCDMA	2.5 $\mu$ s	100 ppb

Location Requirements: E911, Spectrum Licensing

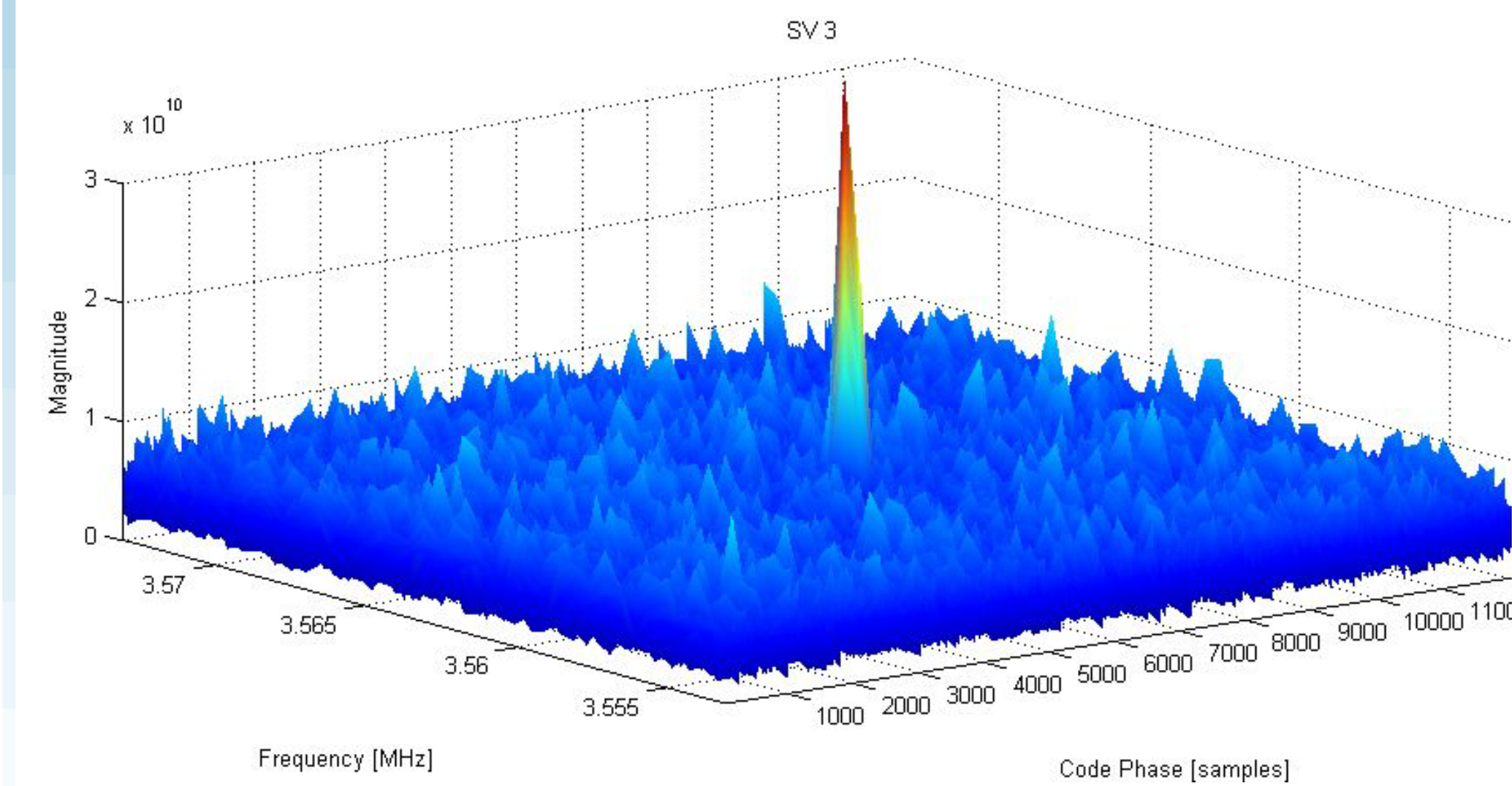
## SOLUTIONS

1. Cellular Network Listen
2. Precision Time Protocol (IEEE 1588)
3. Global Positioning System (GPS)



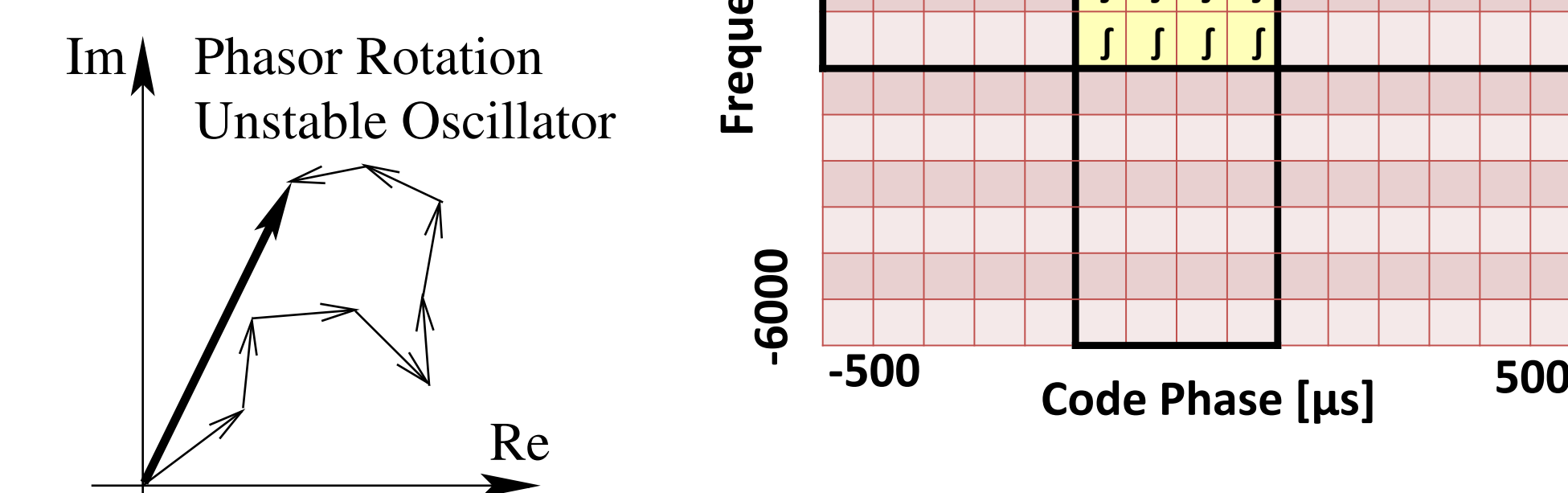
## GPS SEARCH SPACE

GPS acquisition includes a 2-dimensional search over frequency (doppler) and code-phase (time)



## STANDALONE GPS LIMITATIONS

1. Large search space
2. Femtocell clock limits coherent integration time



## TCON-ENABLED FEMTOCELL

**Tightly-Coupled Opportunistic Navigation (TCON)** is a strategy for exploiting the **frequency stability, transmit location, and timing information** of non-GPS “signals of opportunity” to assist GPS-synchronized femtocells in weak-signal environments. A femtocell can use TCON to:

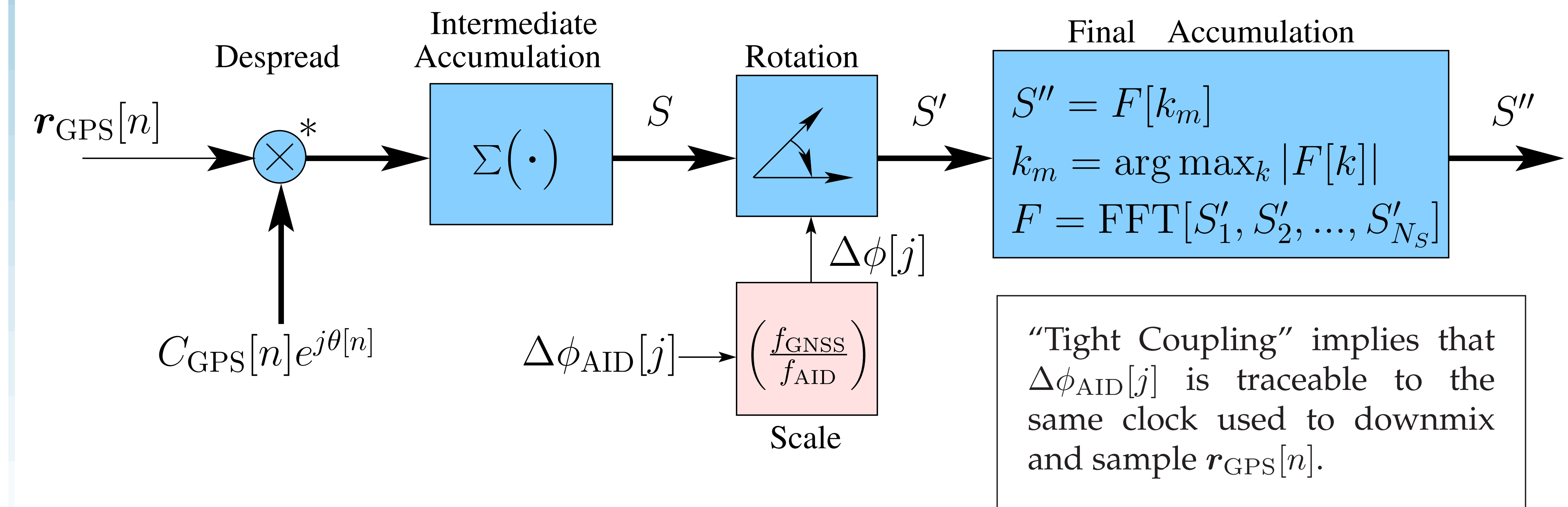
1. Constrain its search space
2. Increase its coherent integration time  $\rightarrow$  frequency stability transfer

## SIGNALS OF OPPORTUNITY



## FREQUENCY STABILITY TRANSFER MODEL

Frequency stability transfer is the exercise of compensating for the local oscillator’s phase instability by applying phase corrections derived from a tightly coupled stable aiding signal:



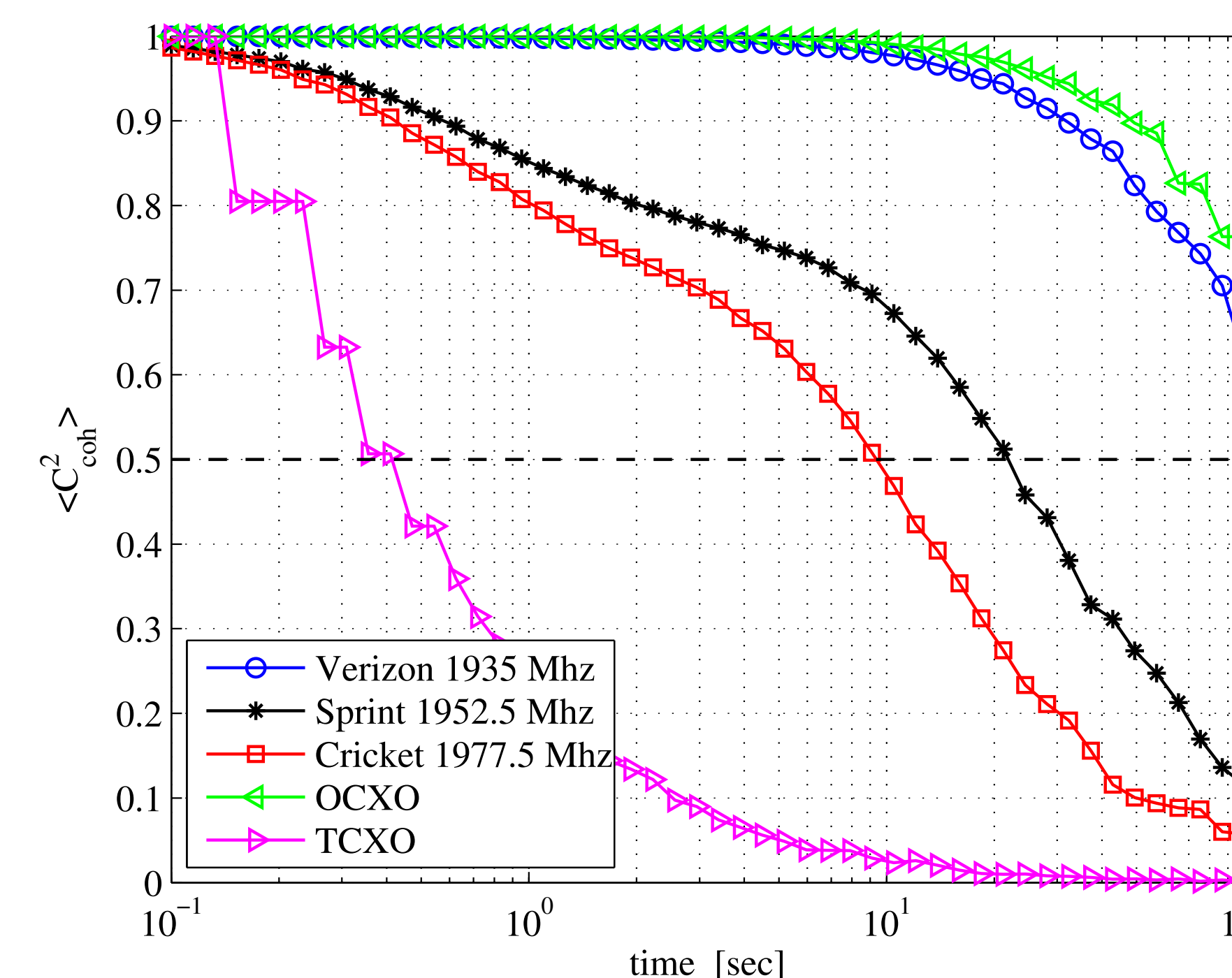
## RESULTS: CDMA-BASED TCON FOR FEMTOCELLS

Mean and Standard Deviation of CDMA Frequency Error

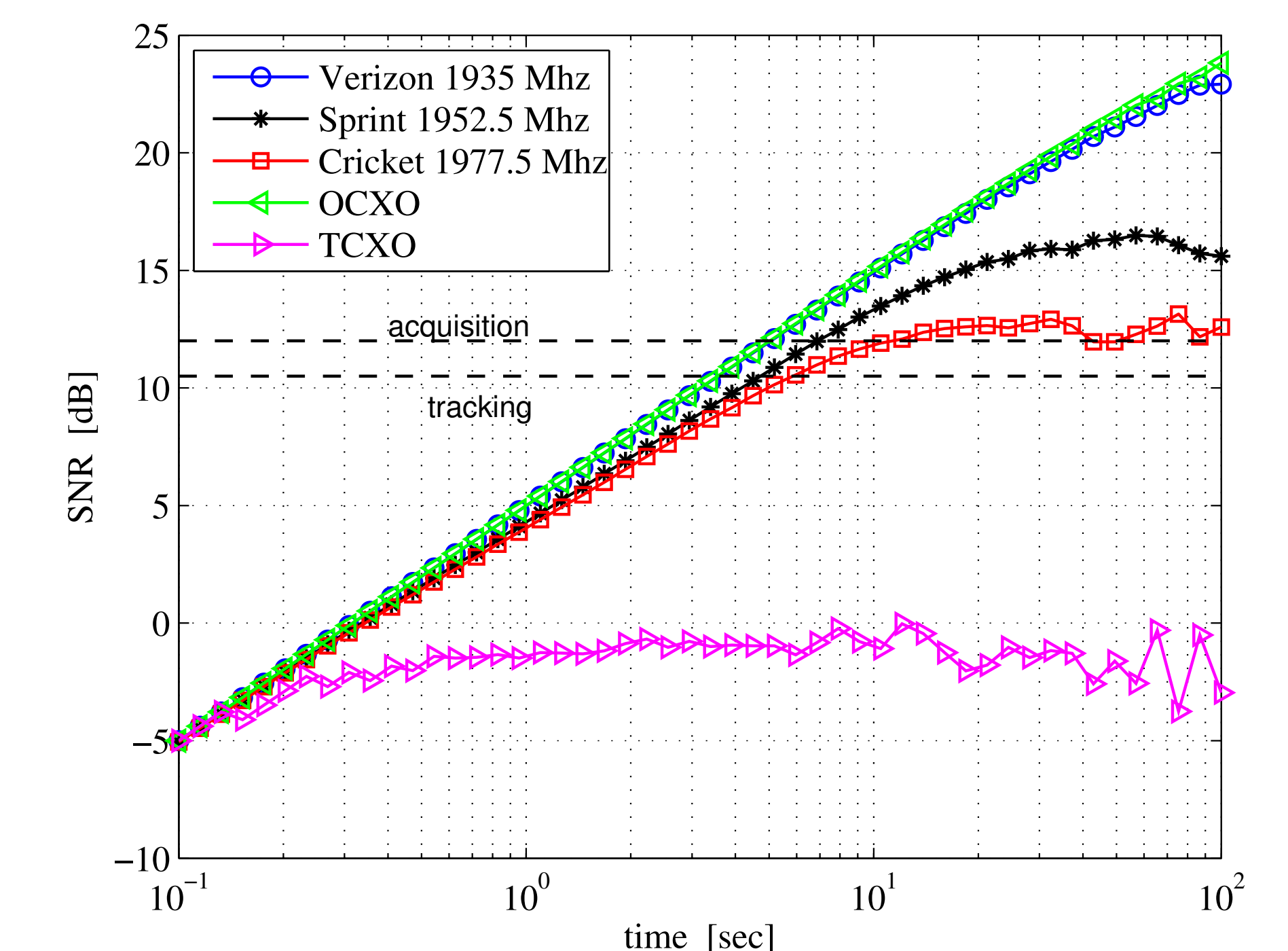
Carrier	Freq. [Mhz]	Mean [Hz]	Std. Dev. [Hz]
Verizon	1935	0.006	0.012
Sprint	1952.5	-0.001	0.038
Cricket	1977.5	0.100	0.058

Mean and Standard Deviation of CDMA Timing Offset

Carrier	Freq. [Mhz]	Mean [ $\mu$ s]	Std. Dev. [ $\mu$ s]
Cricket	1977.5	3.773	0.031
Verizon	1935	2.968	0.016
Sprint	1952.5	40.745	0.035



Mean-squared coherence of the TCXO-, OCXO-, and CDMA-driven carrier phase estimates



Pre-detection SNR for TCXO-, OCXO-, and CDMA-generated carrier phase estimates for an assumed  $C/N_0 = 5$  dB-Hz.

## CONCLUSION

By harnessing the frequency and time information of CDMA signals, a TCON-enabled femtocell can acquire and track GPS signals down to **5 dB-Hz**. This would allow the synchronization and localization of femtocells in **90% of residences**.

## REFERENCES

[1] K.M. Pesyna, K.D. Wesson, R.W. Heath, T.E. Humphreys. “Extending the Reach of GPS-assisted Femtocell Synchronization and Localization Through Tightly-Coupled Opportunistic Navigation” to appear in the *IEEE 2nd Intl. Workshop on Femtocell Networks, Globecom, December 2011*