Terrestrial GPS Augmentation with a Metropolitan Beacon System

Presentation to:

National Space-Based Positioning, Navigation, and Timing Advisory Board

10 December 2014

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Desired Characteristics

- Terrestrial GPS Augmentation:
  - » GPS-like signal structure, but not on, or near L1, L2, L5
  - » 3D positioning and time/frequency
  - » High reliability, encryption/authentication
  - » Coverage: rural, sub-urban, urban, indoor (high yield)
  - » Minimal device impact (cell phone/tablet): acceptance
    - Low power, first fix in seconds
  - » Passive: no network saturation, privacy
  - » Scalable: metropolitan areas / building structures
- Supports Applications:
  - » Consumer, E-911, First responder (blue force tracking etc.), Asset tracking, Time/Frequency Reference

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The E-911 Challenge

- FCC notice of proposed rulemaking (Feb. 2014)
  - » Majority of 911 calls come from wireless phones
    - CA: from 55.8% in 2007 to 72.7% in 2013
  - » Example: Fairfax, VA - September 2013, Up to 47% of wireless 911 calls did not include Phase II location information
    - Phase II (by 2019 – outdoor only): latitude and longitude
      - » Network: 100 m (67%), 300 m (90%)
      - » Handset: 50 m (67%), 150 m (90%)
  - » NPRM Accuracy: outdoor and indoor
    - Horizontal: 50 m (67% 2 yrs, 80%, 5 yrs)
    - Vertical: 3 m (67% 3 yrs, 80%, 5 yrs)
  - » Comment cycle closes Dec 17th, 2014

Public safety concern: "only identifies the city block"

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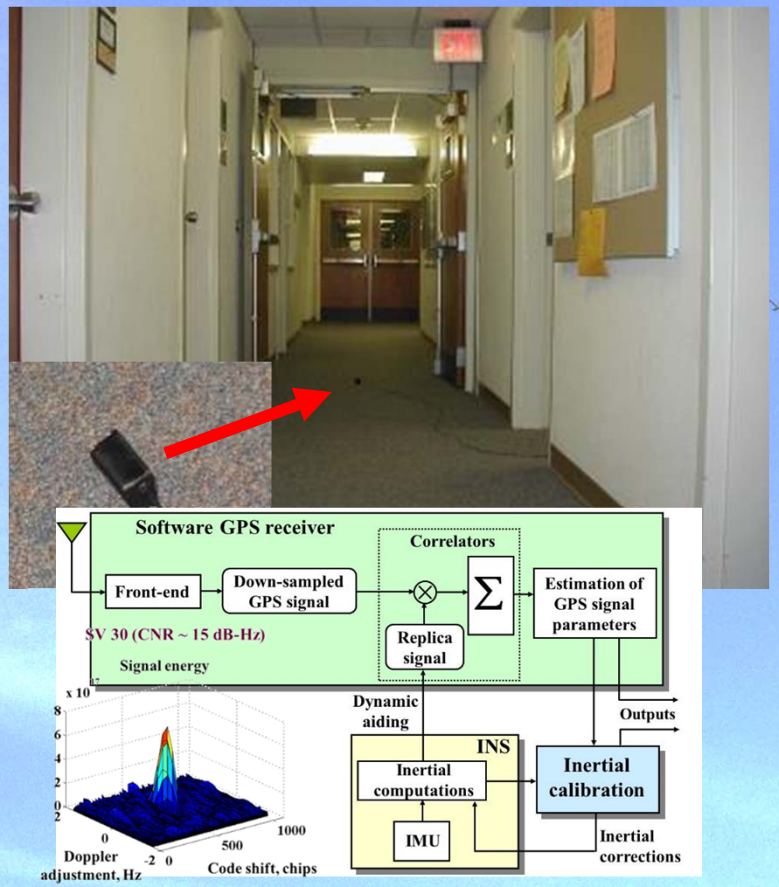
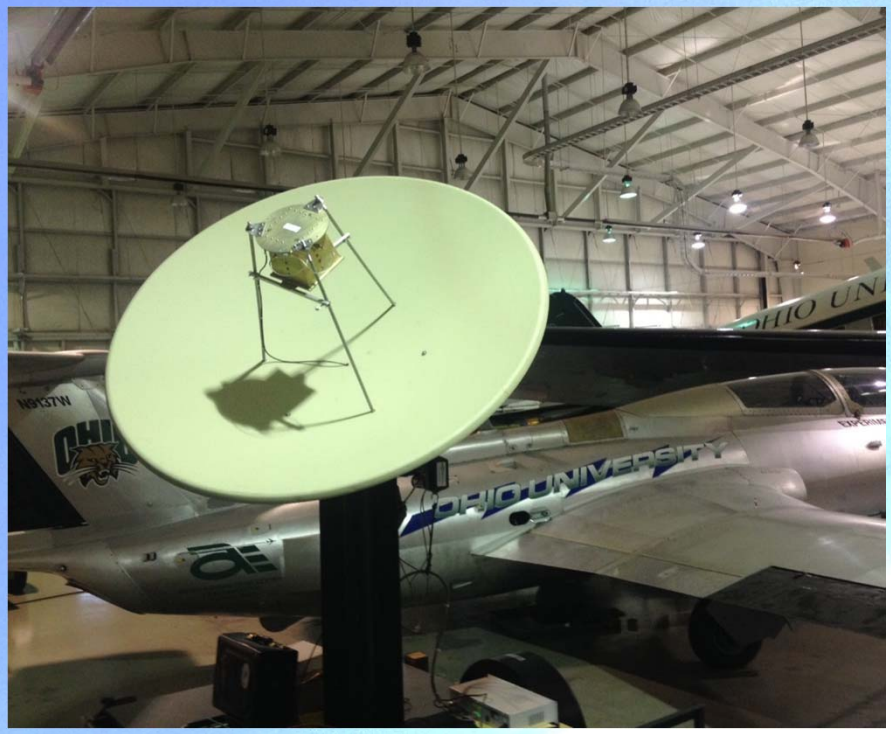
GPS Indoor

Indoor, 2nd floor of a 4-story steel/concrete building





- Key: oscillator, antenna, IMU, vector tracking, lots of processing power
- Works, but somewhat of an integration challenge

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6kcd#Õ

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  - »
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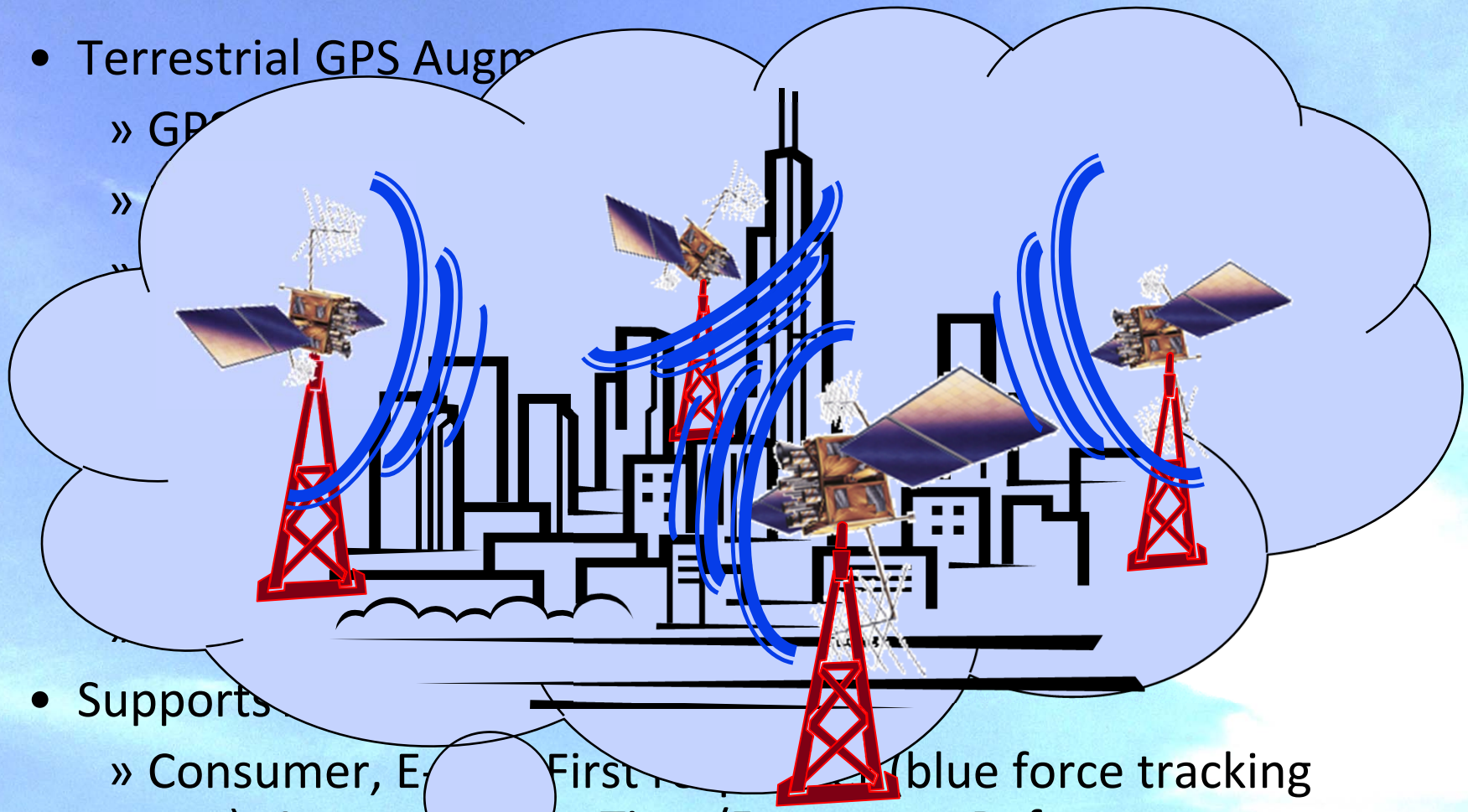

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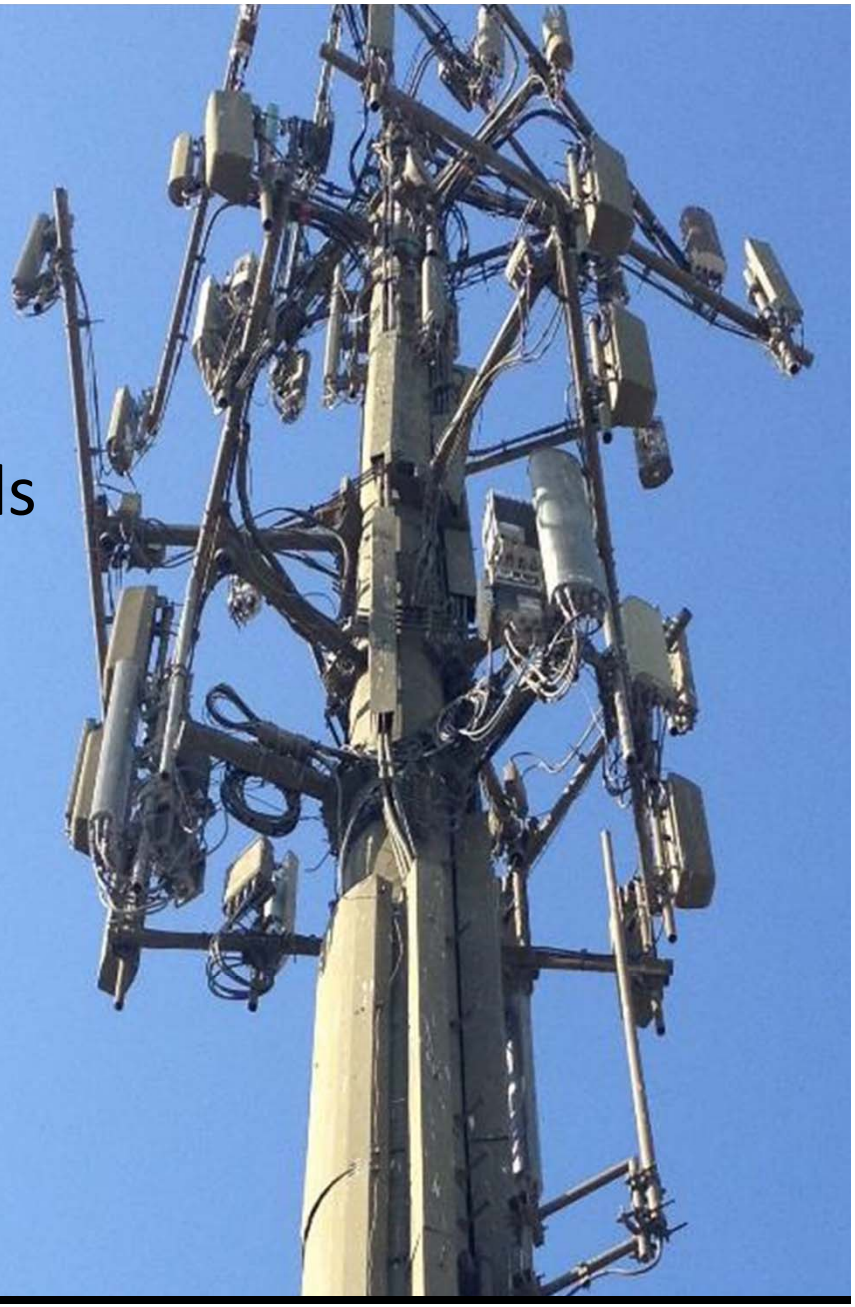
Trade Space

- Frequency:
  - » Stay out of L-Band (1-2 GHz)
  - » Nice if within cell phone bands (824-960 MHz, 1.7-2.7 GHz)
- Bandwidth: at least 2 MHz
  - » Multipath, C/A Code
- Geometry
- Power/Coverage
  - » Cellular network design
  - » Time-division multiple access for near-far mitigation



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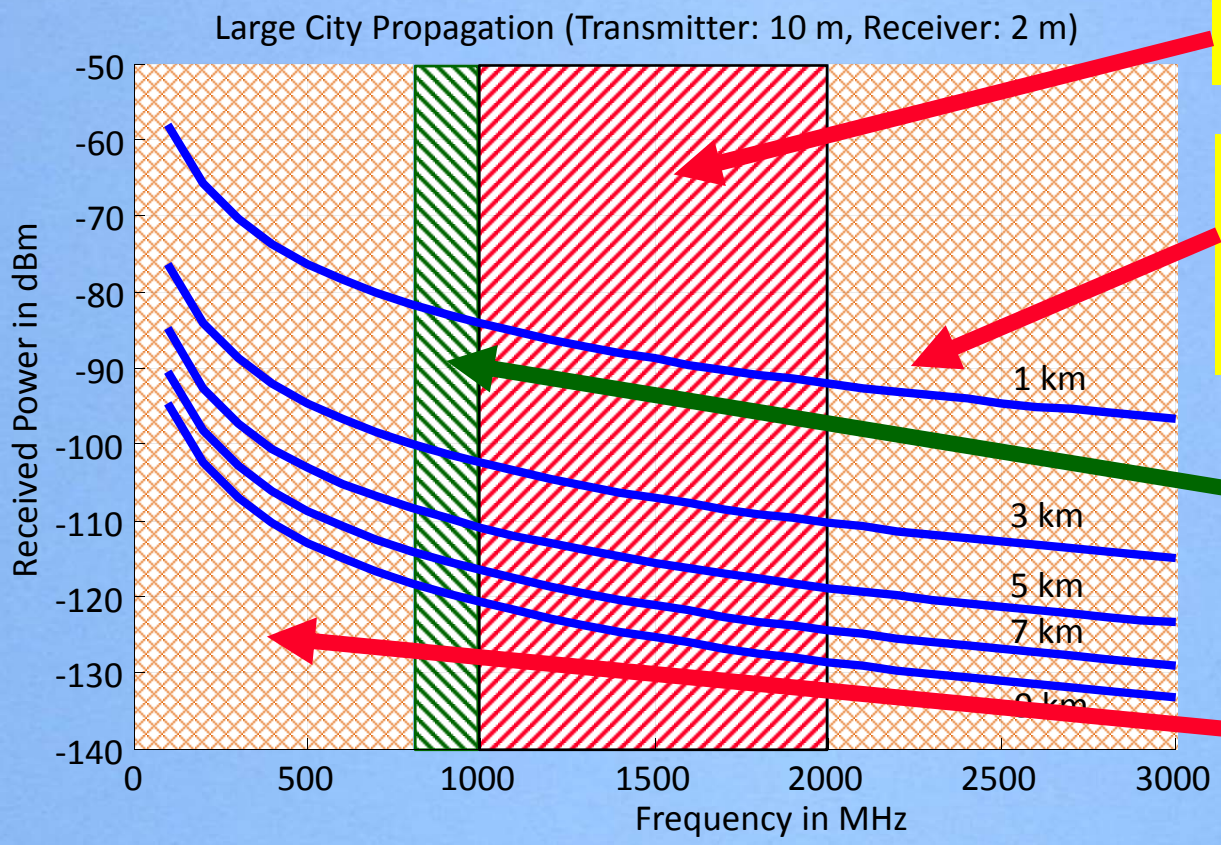
Urban Propagation

- Hata-Okumura Propagation Model [1]



Stay out of L-band

10 dB more loss: need 10 times more power

The green zone

Outside cellular bands

[1] Wireless Communications Systems, Second Edition, Andreas F. Molisch, John Wiley & Sons, Ltd.

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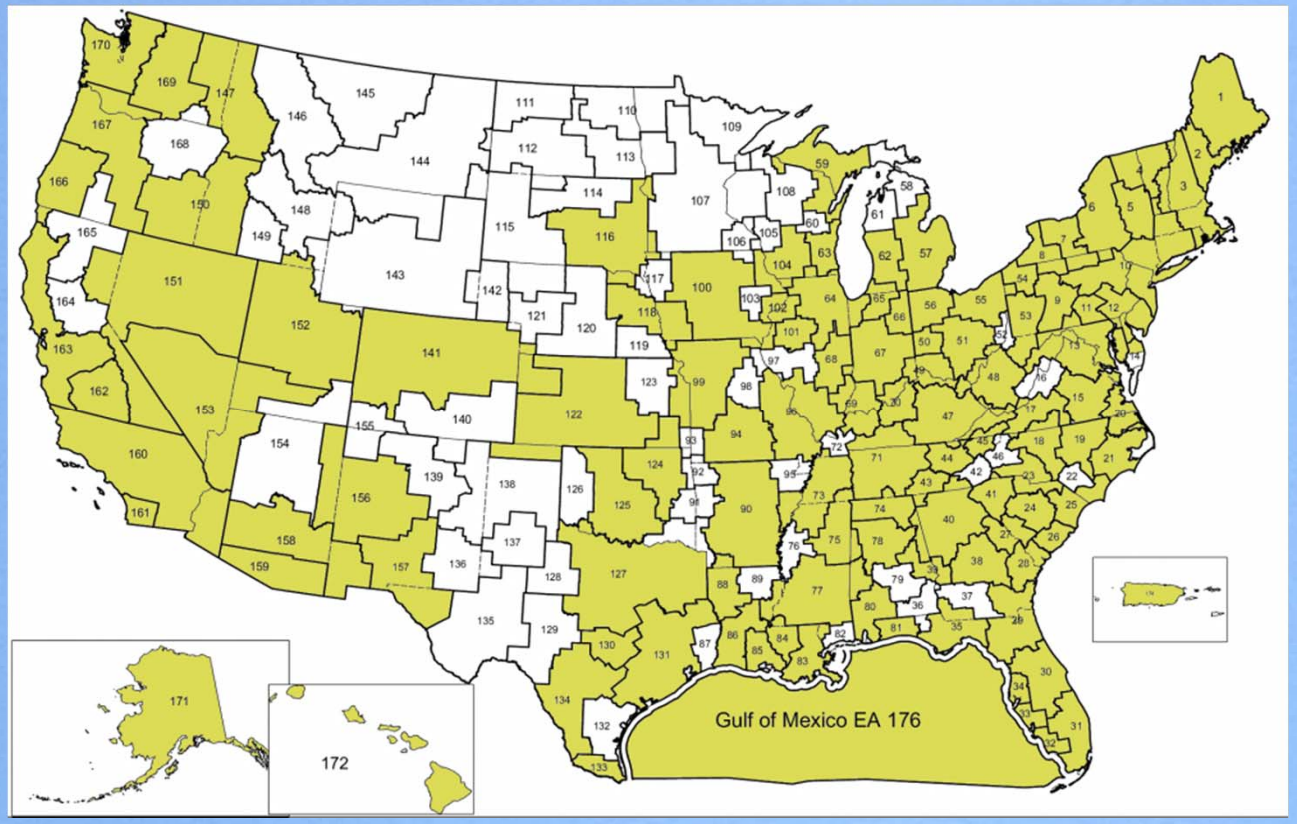
Spectrum: 919.75 – 927.5 MHz

NextNav M-LMS B&C Block Licenses



M-LMS licenses were auctioned on an EA basis.

- Cover over 93% of US POPs with 8 MHz of spectrum
- Spectrum licenses covering all major U.S. metros
- Spectrum footprint complements GPS
- ~900 sq miles coverage in the SF bay area

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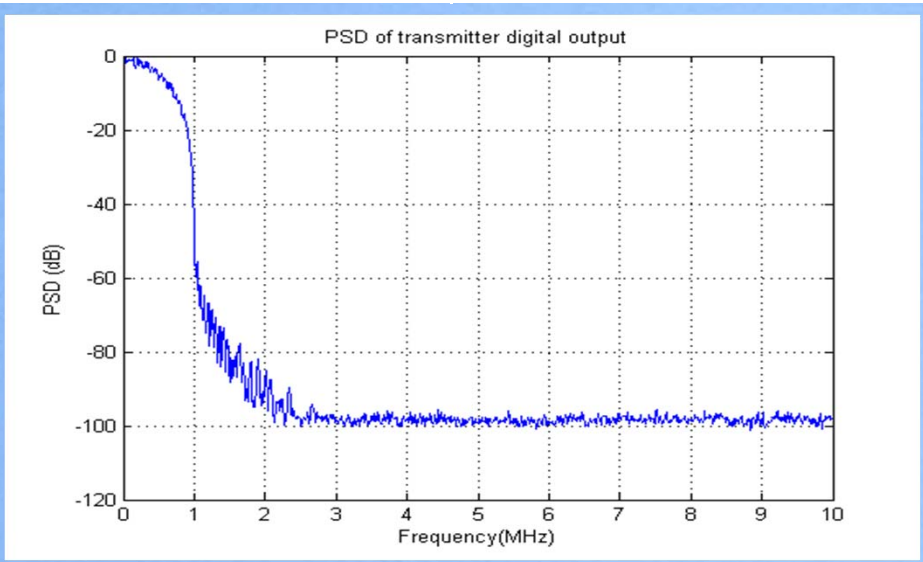
Spectral Characteristics

Parameter	Description [1]
Tx transmission type	Spread spectrum, pseudorandom codes (e.g. Gold Code)
Data	BPSK modulation: nav data bits (encryption/authentication)
RF Bandwidth	2.046 MHz
Tx center frequency	920.773 MHz to 926.227 MHz (tunable)
Tx power	30 W ERP (vertical polarization)



[1] NextNav Metropolitan Beacon System (MBS) ICD, Version G1.0, available from: www.npstc.org

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System Characteristics

- Fully redundant Master/Slave (per transmitter)
- Battery backup (per transmitter)
- Multiple transmit sites (system level redundancy)
- Current time/frequency performance:
  - » GPS/Rubidium timing loop (≈10^{-11}) for GPS smoothing, hold-over (incl. Rb coasting), and fine timing
  - » Common-view GPS time transfer between MBS beacons (2.5 ns)
- Under development (no GPS dependency):
  - » Two-Way Time Transfer (TWTT) between beacons
  - » Synchronization with USNO

$$t_{R,B} = t_{T,B} + cR = t_{T,A} - \Delta t_{A,B} + cR$$
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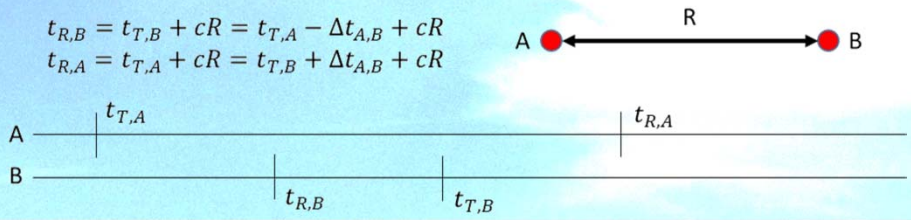

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3nrhshnmhnf˜#L ‘uhf‘shnm#‘mc#7hl hnf#$cuhmqx#%n‘qc
6kkcd#Áý

Timing/Frequency Performance

Mode	Rx Timing Performance[1]	Frequency Performance
GPS/Rb timing loop (Self-timed)	20-50 ns	Approaches Stratum-1 level (10^{-11})
Tuned Rb Coasting (GPS Outage)	< 100 ns (1 hr) < 1 µs (1 day)	Stratum-1 level up to 24 hrs, Stratum-2 (10^{-10}) up to 1 month
TWTT Sync with USNO, and Rb in a timing loop (backup to GPS disciplining)	20-50 ns	Approaches Stratum-1 level
TWTT between beacons (GPS Free; Rb core clock)	10-30 ns	Approaches Stratum-1 level

[1] This column illustrates an aggregate MBS timing receiver performance, deep indoors and under heavy multipath conditions. Beacons synchronized within 2.5 ns

Metropolitan Beacon System Performance

Communications Safety, Reliability and Interoperability Council ("CSRIC") Sponsored Blind Trials – 4Q12

Urban

San Francisco Financial District

Suburban

Santa Clara County

Rural

San Benito County

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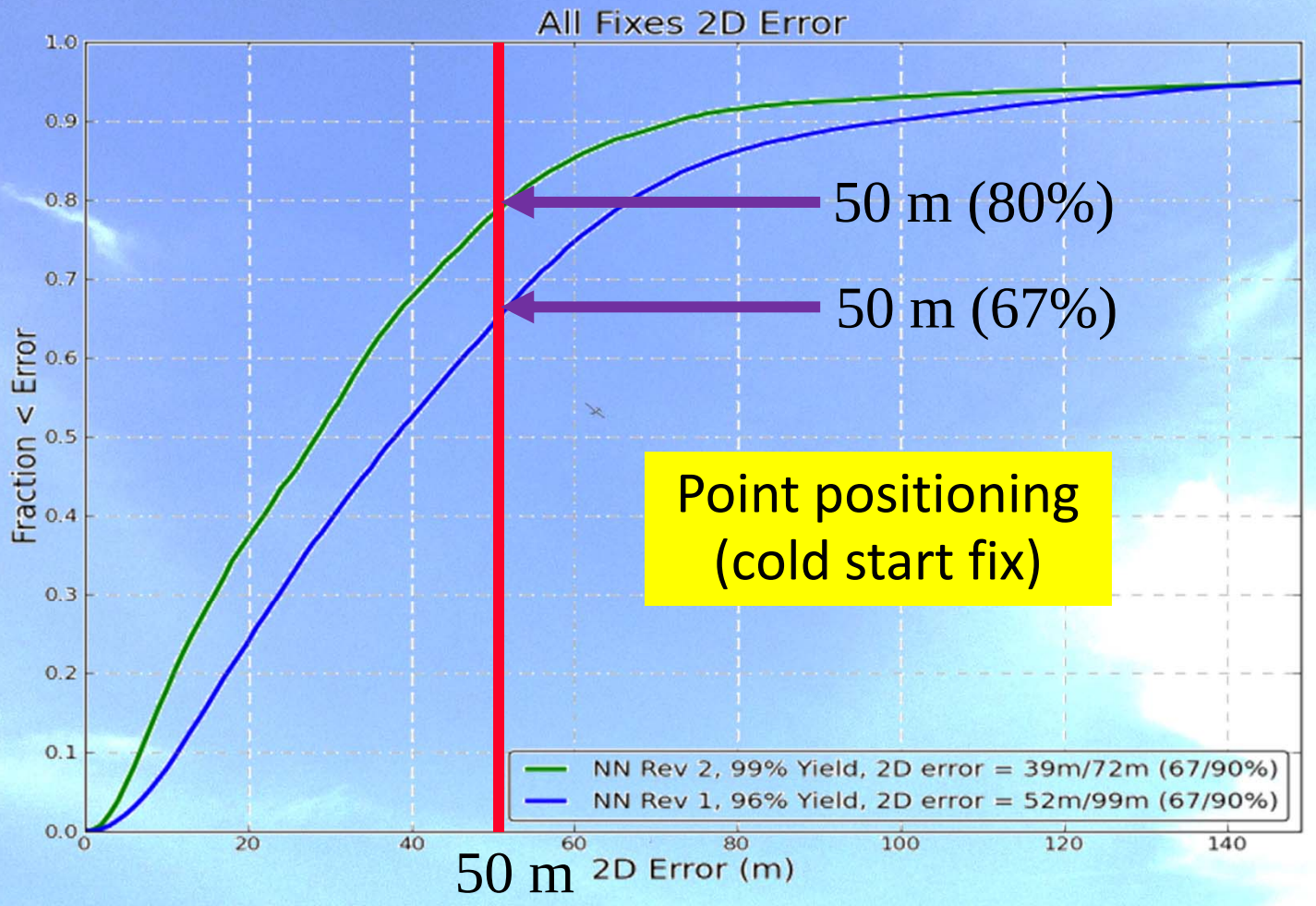
Horizontal Positioning Performance



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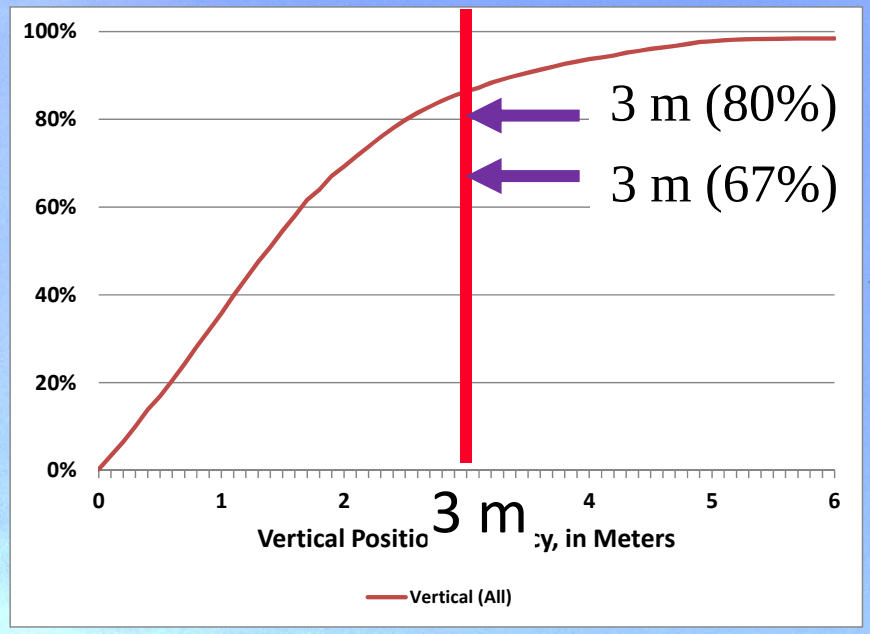
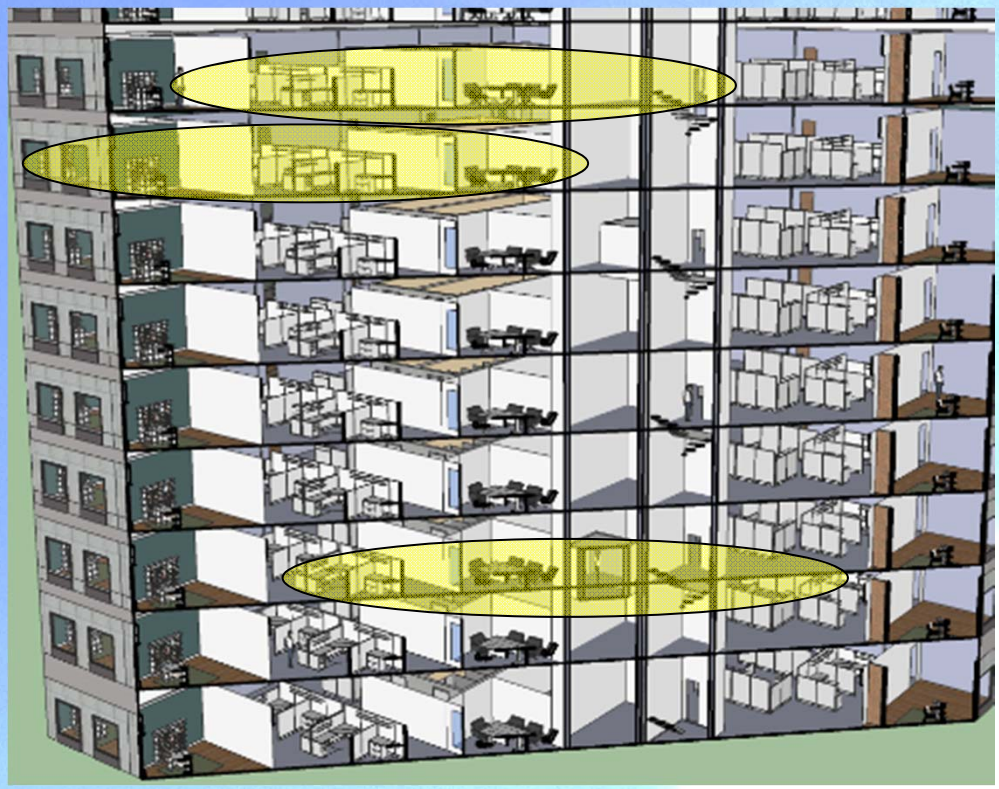
Vertical Positioning Performance

Vertical CDF (Rev 2 test Results)



Point positioning (cold start fix)



Note: building image is illustrative only, and does not represent an actual floor plan.

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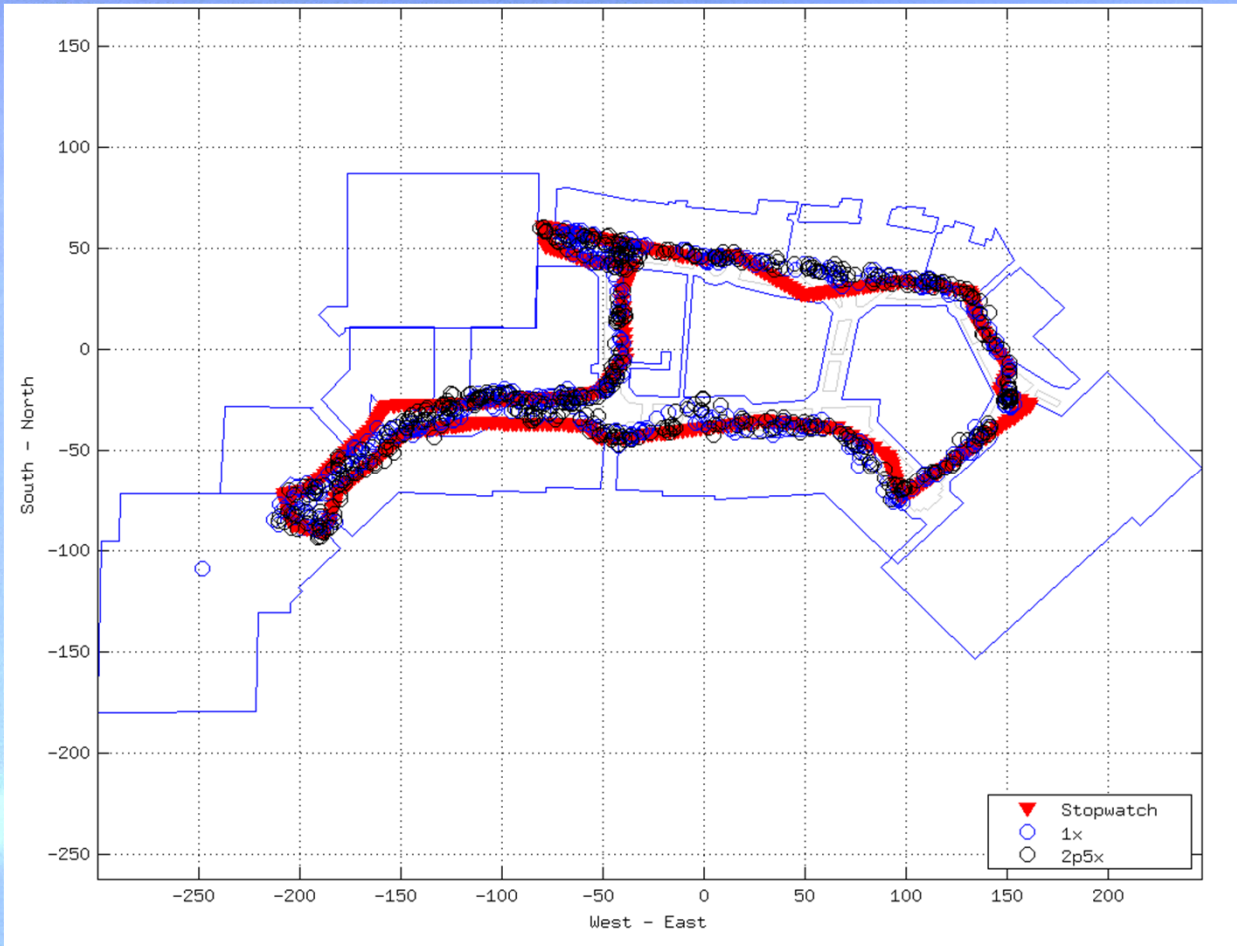
Persistently better than 10 m Accuracy



Walking User Experience: http://vimeo.com/90489380
password: WalkingDemo1

- E911 scenario is extremely limited (e.g.: Warm/Cold Start fix)
- In commercial and police/fire tracking additional benefits can be gained by Hot Start, Kalman filtering etc.
- This chart depicts tracking performance based on MBS systems – no additional signals or sensors (e.g. IMU, GPS etc.)
- Effectively provides “Room/Store-level/floor-level” context

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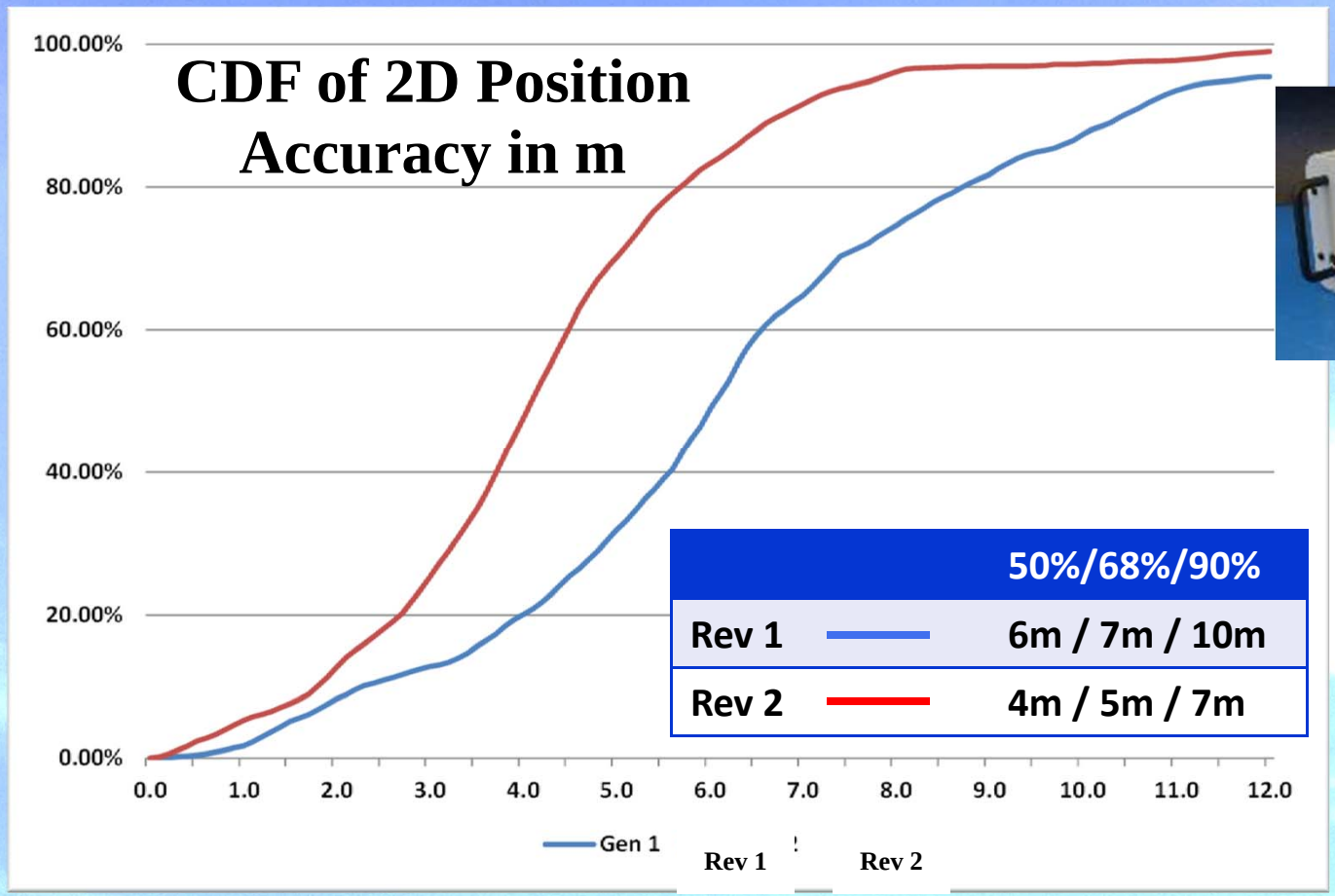
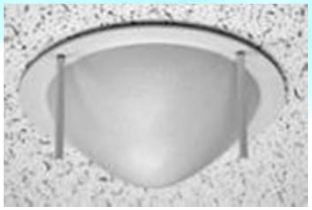
NextNav Local System Performance

Optimized for campus, mall, warehouse-like areas



	50%/68%/90%
Rev 1	6m / 7m / 10m
Rev 2	4m / 5m / 7m



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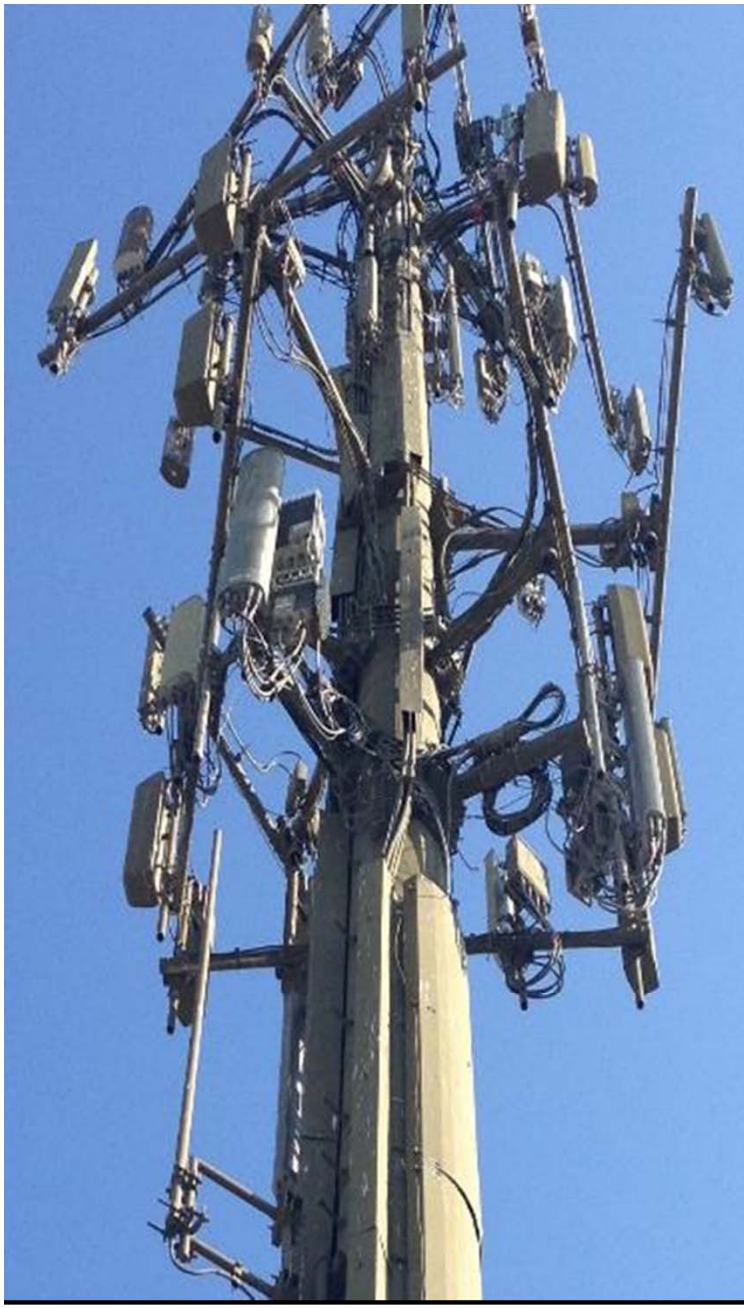
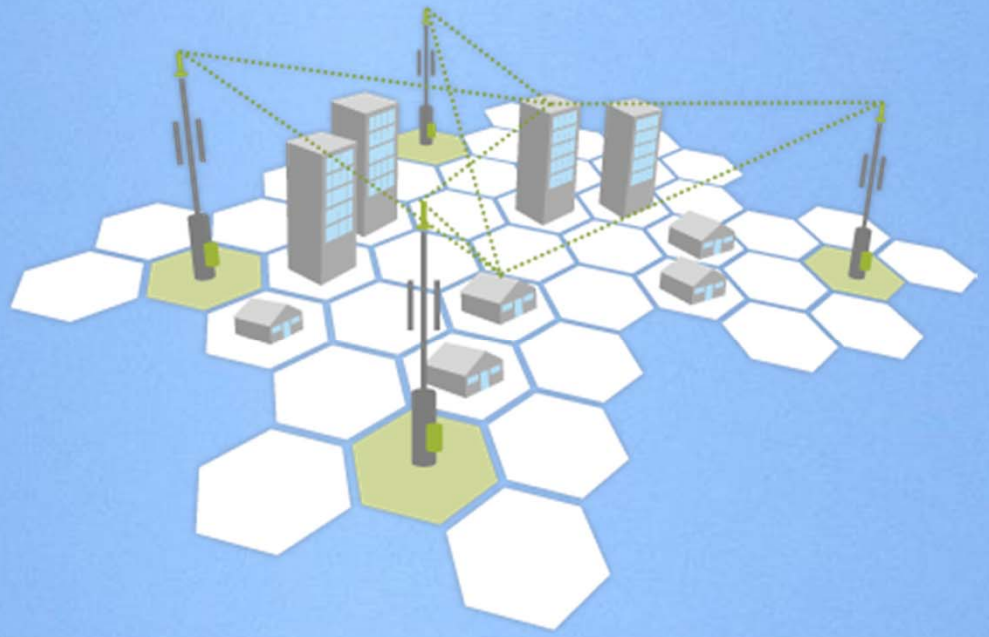


Conclusions

- GPS-like approach for user device integration
- Cellular-like approach for urban signal penetration



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