Location & Its Infrastructure:

towards dm-scale real-time consumer equipment

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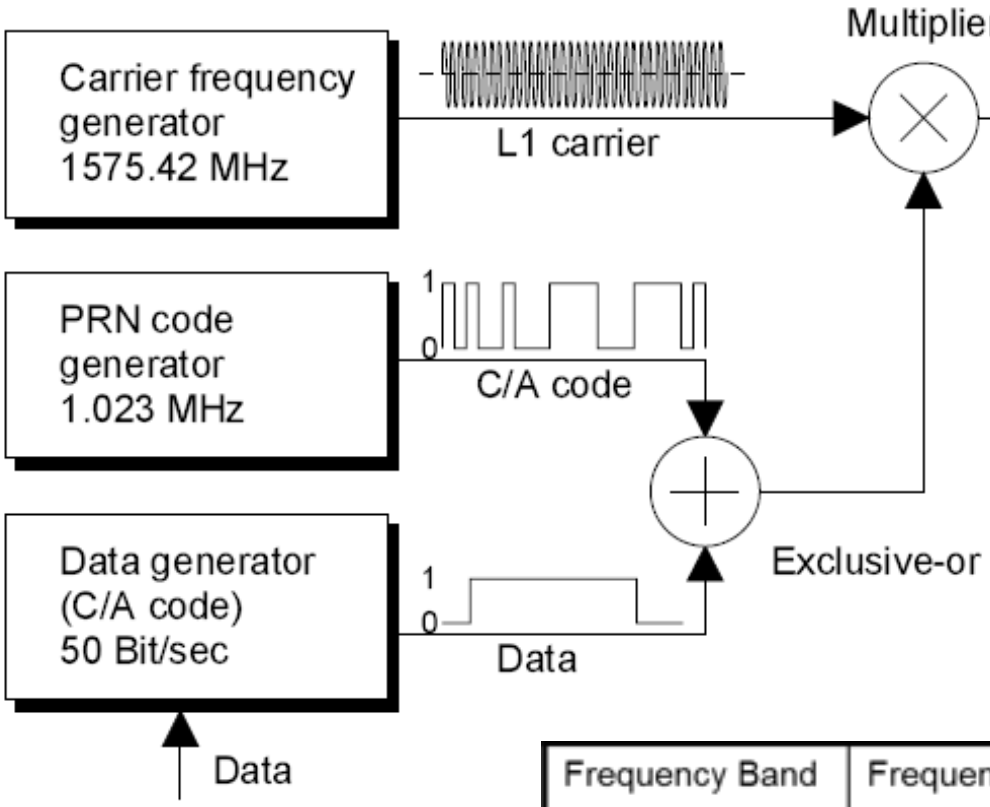
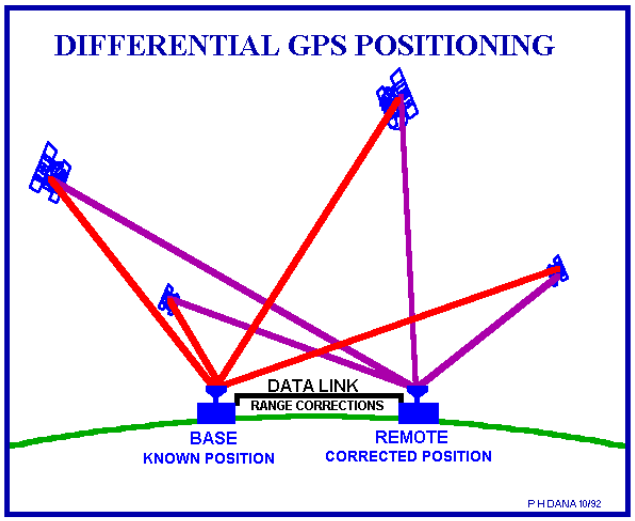
New Observables in Computing:
Sensor Networks, Cyber-Physical Systems

- Almost all computing was based on 'storage' as an observable
- Then 'time' happened
  - Real-time Systems
- Temperature, humidity, motion, proximity, …
  - Sensor Networks, Cyber-physical Systems
- All physical phenomena are inherently local
  - Computing did have virtual mobility, sensors made it local (virtual versus physical places)
- Computational Observables are events or states that can in principle be detected by the programmer
- Mobility creates new observables
  - new hiddens (e.g., communication failure)
  - new security needs and opportunities (mobility across location, administrative domains).

Infospatial Objects

GPS 101





Frequency Band	Frequency	Wavelength (meters)	Expected accuracy (m)
L1	1575.43 MHz	0.190	0.0019
C/A	1.023 MHz	293	2.93

Location Infrastructure:
Accuracy, Determinism, Cost

- Who takes the measurement, who calculates the position?
  - (radar versus radio), server side finger-printing, client side Δ
  - From UltraS, IR, UWB radios (5-50cm) to TV signals, powerline, WiFi, Cellular (1m-100m)
- GPS infrastructure
  - Recreational, Navigational: 3m-10m. Consumer equipment bottomed out at 1-3m. (lane accuracy)
- Many forms of augmentation,.. to survey applications
  - First lock: 30-40 seconds, locking error: C/A 3m, P-code: 30 cm, atm. can add +/- 15m
  - DGPS with radio beacon assists: 1-3m, WAAS: 2m. Simple correctional data on position error.
  - RTK require RX capable of processing carrier-phase
  - AGPS (Cell, WiFi, IMU): many players to AGPS: 3GPP, OMA
- GPS Augmentations: many but real-time is a challenge/WIP
  - NDGPS – Ground-based augmentation (coast guard), USCG beacons sending RF signals
  - WAAS – Satellite based (air force): grid of 5x5 continental stations, 2 master stations
  - CORS – NOAA tied to National Spatial Reference Systems
  - Global Differential GPS (GDGPS) – JPL for real-time positioning, tied to TDRSS
  - IGS – International GNSS Service (one hour latency bound from measurement to broadcast)
- Commercially: SiRFstarV (Quad-GNSS+MEMS+AGPS), iOS (C/A + Cell Δ + WiFi), GLOBALCORS using iCORs

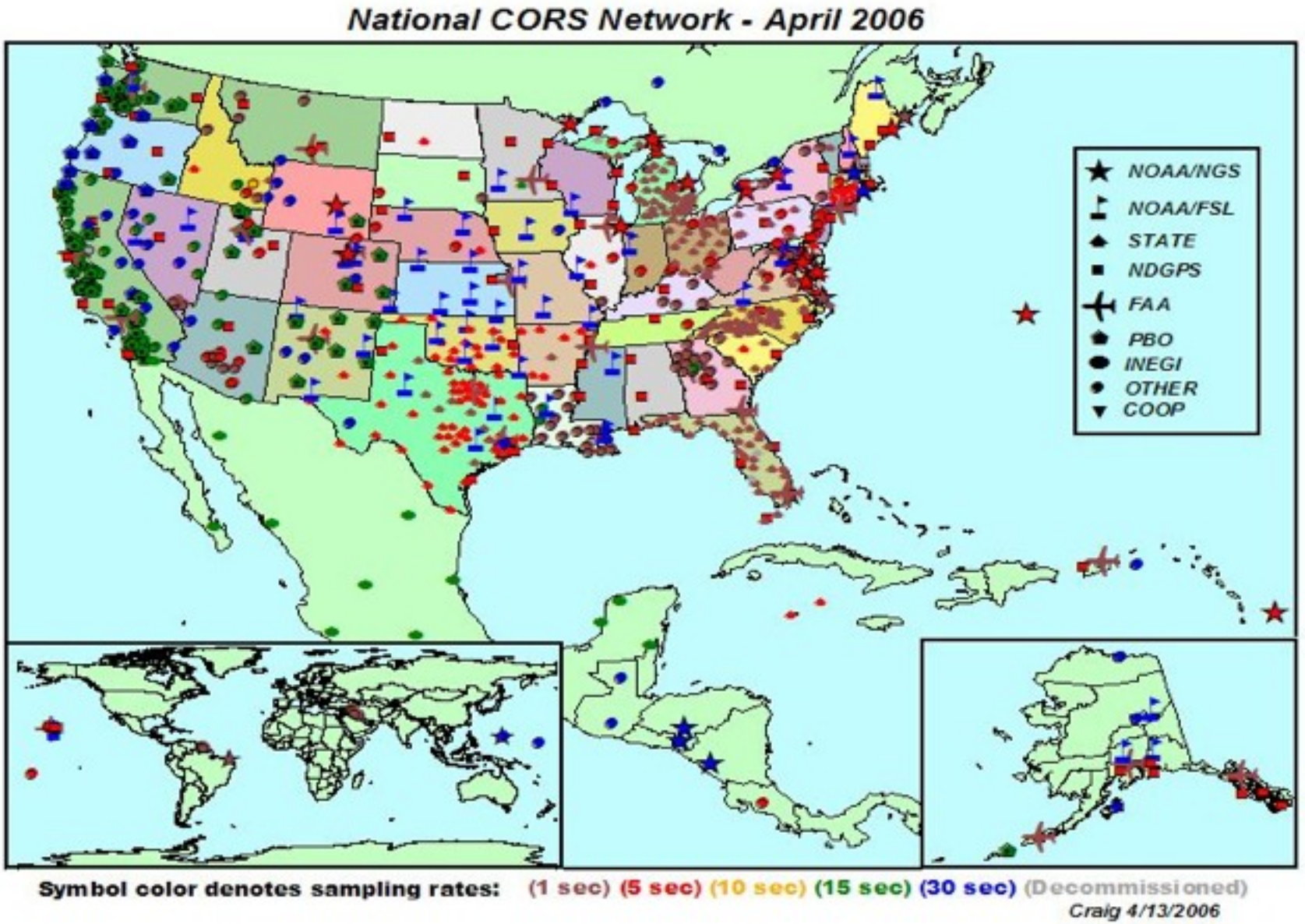
Sub-dm real-time consumer is on the horizon.

Getting to Sub-dm
in Real-time Consumer Equipment

- Assisted by reference stations, rowers and cooperative infrastructure
  - DGPS: L1 corrections, range: 200-400km, meter level accuracy, few seconds, continental coverage
  - RTK – single base-station : L1 code, L1/L2 carrier corrections, range: 10-15 km, cm level accuracy, < 1 second delay, regional and local coverage.
- Not a new idea here: systems implementation may be
  - Stream corrections over the internet (RAW, RTCM, RTCA, SP3, RINEX)
  - NTRIP (RTCM via IP) – generic stateless protocol on HTTP/1.1 (RTCM-104)
  - Internet RTK using NRTIP demonstrated at 3cm/8cm (H/V) at 95% @GNSS'04.
  - SWEPOS at 1m accuracy using DGPS: correctional data on FM radio at 300 bytes/sec
  - Reference stations: Virtual versus Broadcast
    - One reference station works as a central unit collecting data from all stations in the network. Billable.
- Dm accuracy in real-time can be used for
  - Land surveying, Remote sensing, Hydrography, Machine control (precision agriculture), Emergency response, Asset inventory, Structural integrity monitoring, Atmospheric monitoring, weather forecasting, Tsunami and volcanic warning systems.

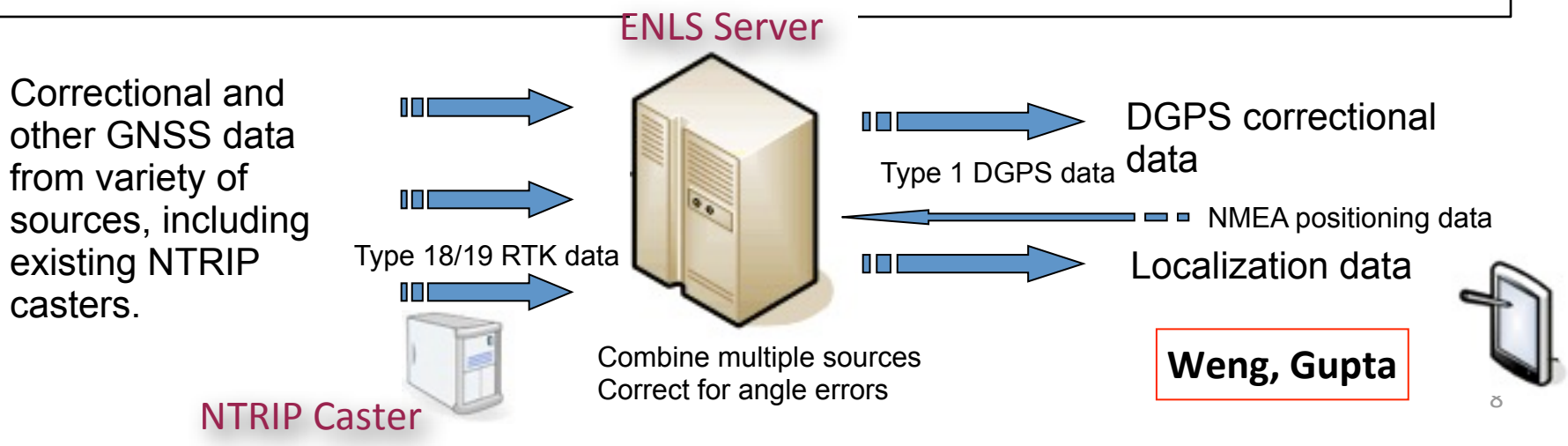

GPS Satellites
Barrow
Kotzebue
Fairbanks
Bethel
Anchorage
Cold Bay
Juneau
Auburn
Billings
Fremont
Salt Lake City
Longmont
Palmdale
Albuquerque
Fort Worth
Houston
La Paz
Puerto Vallarta
Honolulu
Iqaluit
Winnipeg
Farmington
Aurora
Olathe
Oberlin
Goose Bays
Gander
Nashua
Ronkonkoma
Leesburg
Memphis
Hampton
Jacksonville
Miami
San Juan
Merida
Mexico City
Tapachula
GEO Satellite
GEO Satellite
Wide-area Reference Station (WRS)
New WRS's
Wide-area Master Station (WMS)
Ground Earth Station

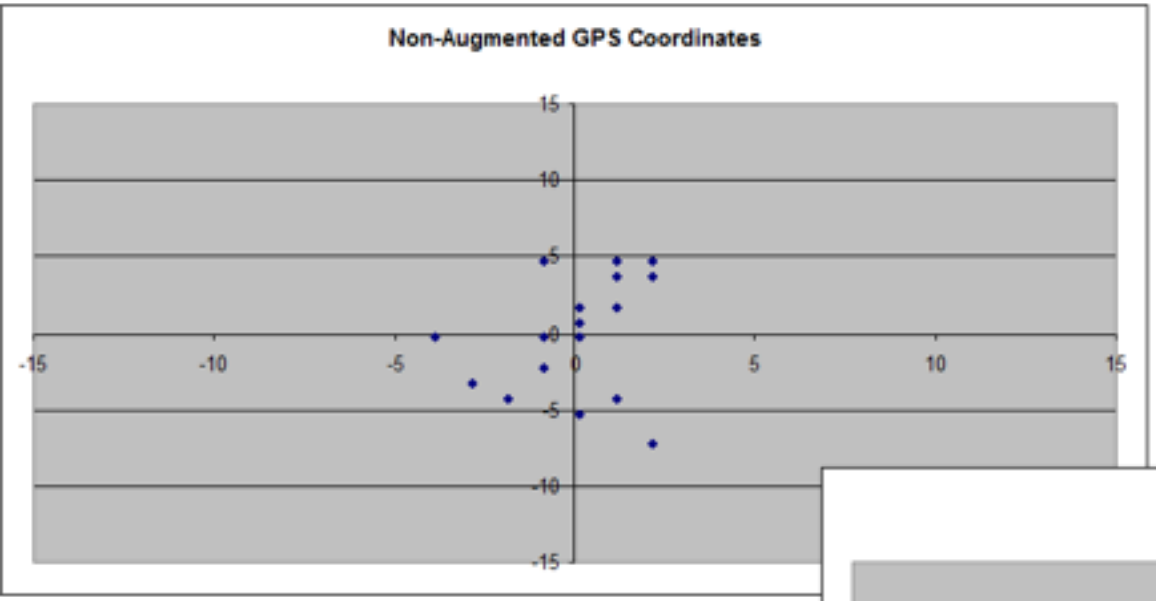
Continuously Operating Reference Stations

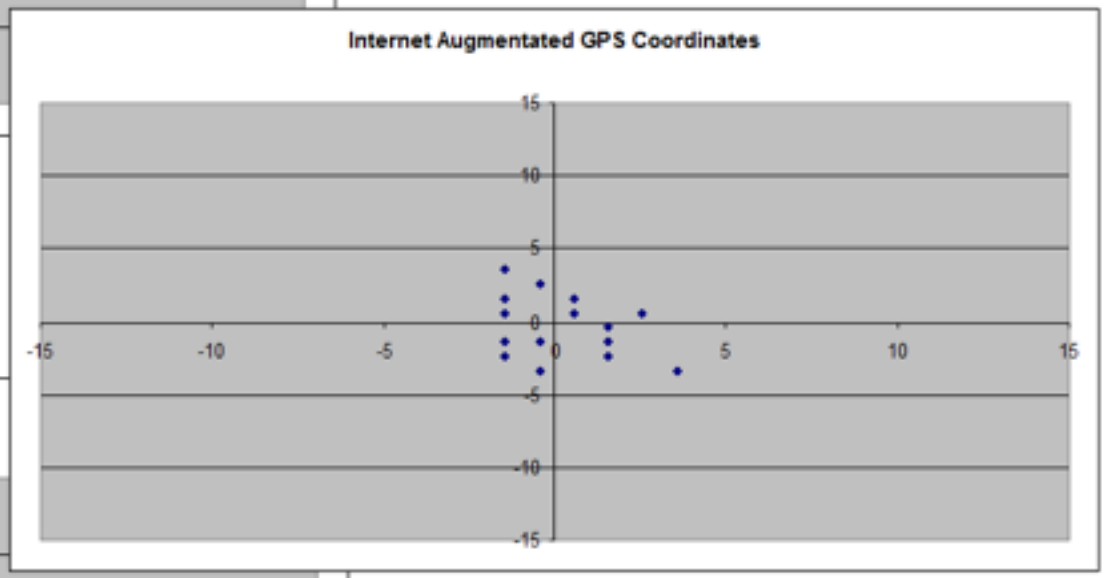


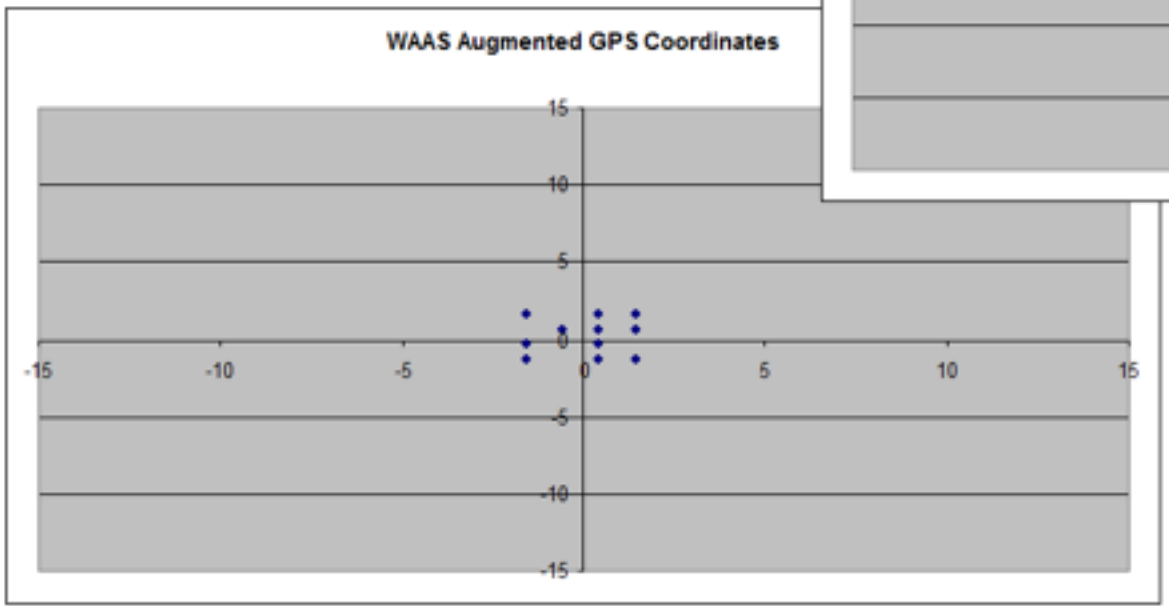
Enhanced Network Localization Services (ENLS)

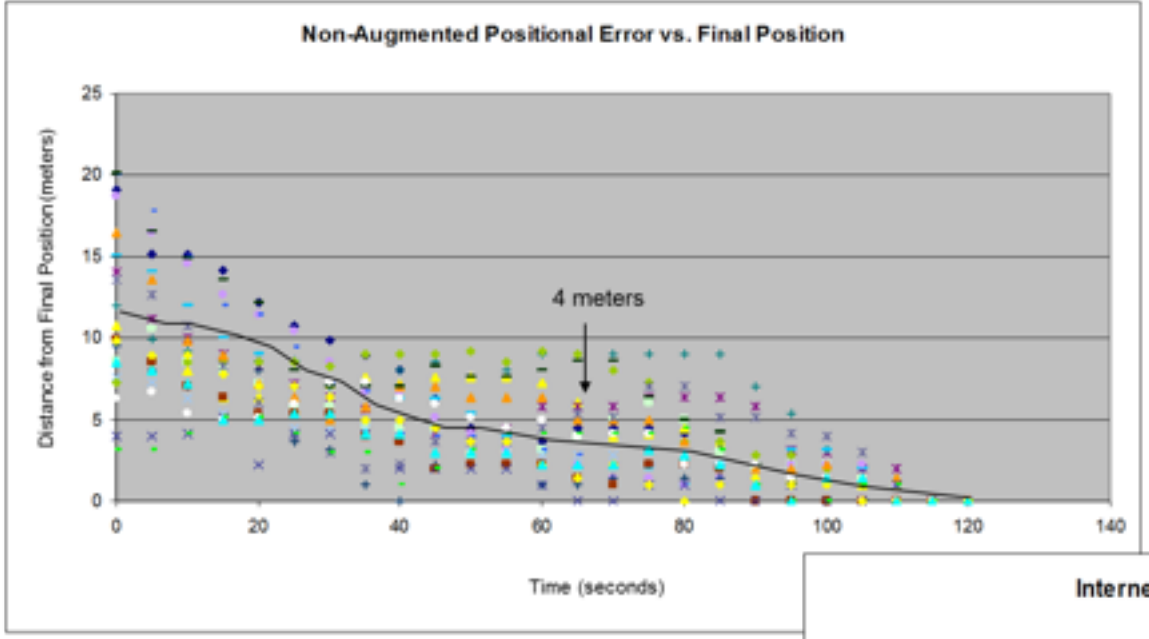
- ENLS provides a platform for delivery of localization services to end users.
- Two types of services:
  - Augmentation based services – deliver improved differential corrections over network from existing correction services, though VRS for DGPS and AGPS streams.
  - Localization based services – deliver localization information, such as transformed coordinates or GNSS data.
- APIs allow new modules to be written and incorporated with the ENLS server.
- Modules use network communication via TCP/IP ports to pass data. This allows for a more scalable infrastructure
- IPv6 embedded with localization information.
- Current project and implementation at enls.ucsd.edu.

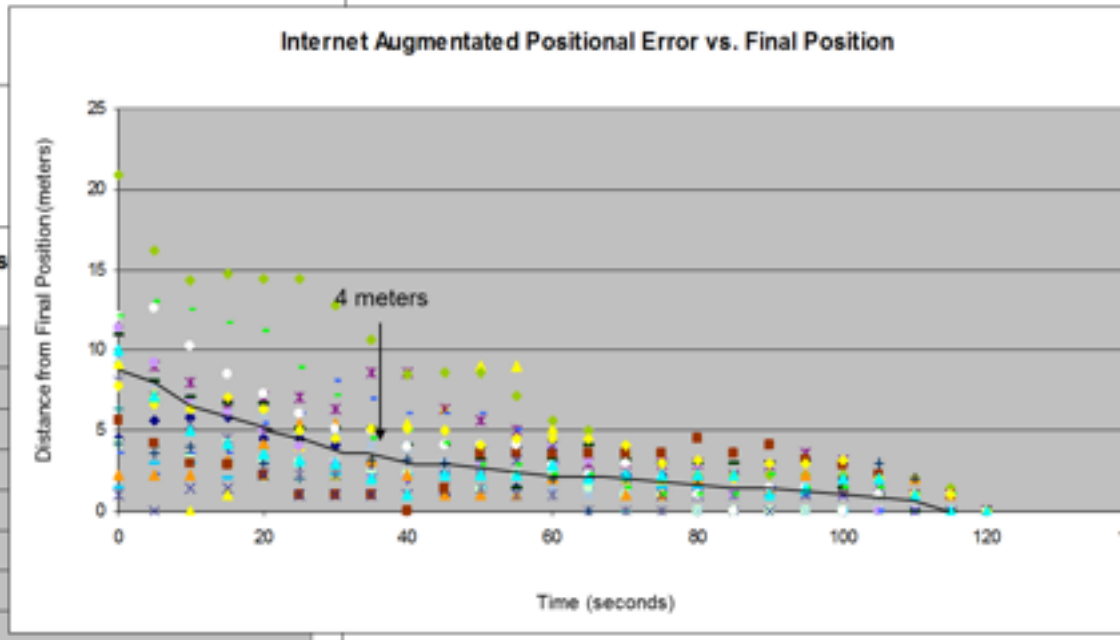



Non-Augmented GPS Coordinates
15
10
5
0
-5
-10
-15
-15
-10
-5
0
5
10
15


Internet Augmentated GPS Coordinates
15
10
5
0
-5
-10
-15
-15
-10
-5
0
5
10
15


WAAS Augmented GPS Coordinates
15
10
5
0
-5
-10
-15
-15
-10
-5
0
5
10
15


Non-Augmented Positional Error vs. Final Position
Distance from Final Position (meters)
25
20
15
10
5
0
4 meters
0
20
40
60
80
100
120
140
Time (seconds)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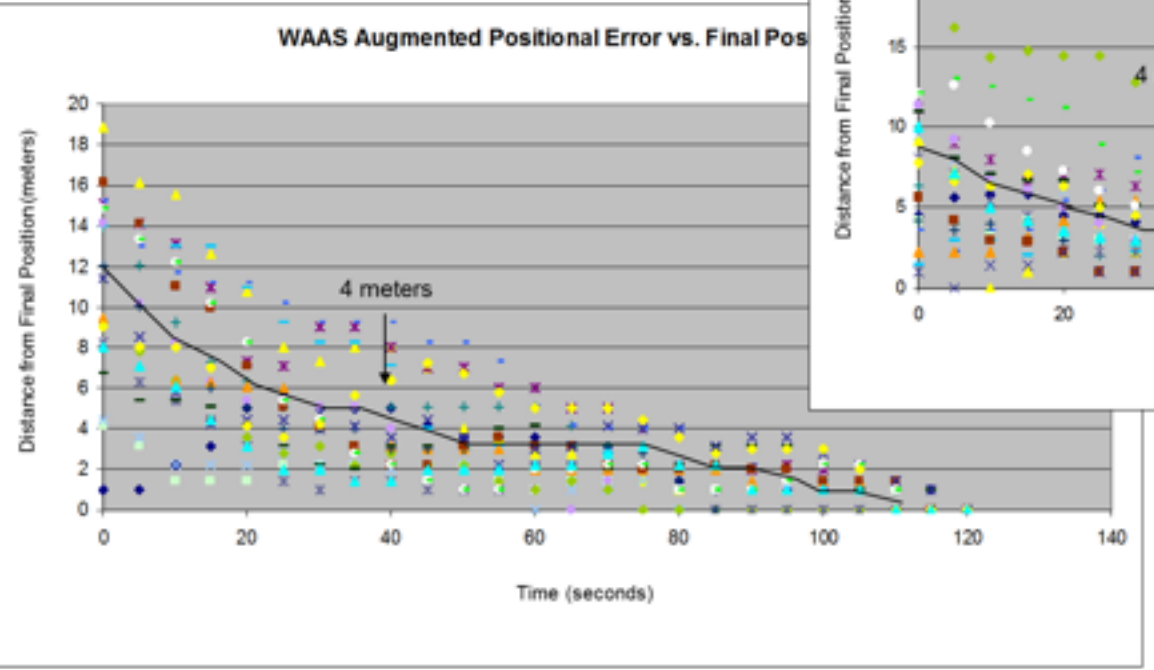
25
20
15
10
5
0
4 meters
0
20
40
60
80
100
120
Time (seconds)


WAAS Augmented Positional Error vs. Final Pos
Distance from Final Position (meters)
20
18
16
14
12
10
8
6
4
2
0
4 meters
0
20
40
60
80
100
120
140
Time (seconds)

Thoughts

- Consumer localization technologies have reached a (temporary?) plateau (automotive, application level): cultural problem?
  - Tremendous possibilities as we move to cm/dm real-time starting with networked DGPS at sub-meter.
- What role will Spatial Computing play in our lives in 2020?
- New observable that serves as
  - Organizer for contextual information
    - E.g., seamless interaction, continued operation across devices & spaces.
  - Authentication (ID), Security (Access control), Privacy (Spoofing)
  - A new root of trust (ROT) to ensure enforceable policies and observable violations. (part of shared secret, as a cryptographic key?)
- What are the most compelling transformative opportunities?
  - CPS-type applications driven by Spatio-Temporal Events.