Positioning Technologies for GPS-Challenged Locations

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Agenda

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2. Indoor Positioning Challenges
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Why Mass-Market Indoor Positioning?

- Over 400,000 E911 calls are placed from wireless devices – every day
  - Over 34% of all households, and 50% of rental households, lack a land line
  - Without verbal assistance, first responders can not be dispatched unless the device can be located

- Smartphones are increasingly relied on to augment the perception of their users
  - Outdoor navigation has been “solved” by GPS
  - Some information is available virtually instantly – but position indoors, on an accurate map, remains a general estimate

- The economic opportunity of indoor positioning is extraordinary
  - Location-based mobile advertising is expected to exceed $7Bn in the U.S. by 2016
  - Smartphones are now part of consumers’ purchase cycle – 44% of local searches on a smartphone lead to a purchase, and mobile commerce is expected to reach $30Bn by 2016

- Enterprise applications, including workforce management, public safety services, and M2M applications increasingly demand indoor positioning capabilities
  - Mass-market features such as ubiquitous coverage and high performance are just as desirable, and useful, for enterprise applications
Existing E911 Rules (Outdoor)
In a Complex Interior Floor Level Accuracy is Necessary
The Fundamental Indoor Positioning Challenge

The GPS signal is too weak for reliable indoor positioning.
Related Issues

• Indoor environments are complex and require very high accuracy

• Localized solutions do not provide pervasive reliability or availability
  – Imagine if turn-by-turn directions for your car only worked in every other neighborhood

• Network architecture, signal attenuation and multi-path increase the difficulty of deploying a wide-area solutions

• Cost considerations have, so far, prevented the deployment of dedicated positioning systems outside of specialized enterprise applications
  – Infrastructure expense
  – Receiver complexity
  – Coverage scale
Positioning Technology State of Affairs

There is no reliable, high-precision solution where mobile devices are used today.

Areas of Use

- Urban Canyon
- Outdoors
- Indoors

Accuracy

- GPS
- Wi-Fi
- Cell-ID
- A-GPS + AFLT

The missing piece....
Technologies

• Cell ID and its derivatives
• Cellular infrastructure-based trilateration techniques – AFLT, U-TDOA and O-TDOA
• RF Fingerprinting
• WiFi and BlueTooth-based positioning
• Sensor fusion
• Selected emerging technologies
  – Magnetic field characterization
  – Visual location technologies
  – Other satellite-based systems (e.g., Boeing / Iridium)
Location Techniques: Cell ID

**Cell Tower**

- 2 – 10km

**Cell Sector**

- 2 – 10km

**Centroid of Cell Sector**

- 1 – 5 km

Pros:
- Always available
- Fast TTFF
- Something is better than nothing

Cons:
- Poor accuracy
- No height information

\( X = \text{reported position} \)
Location Techniques: U-TDOA, AFLT and O-TDOA

Pros:
- Service indoors and in urban areas
- Fast TTFF
- Better than Cell ID
- Can be combined with GPS in some cases

Cons:
- Poor geometry
- Poor siting of infrastructure
- Poor synchronization
- No height capability
- DAS uncertainty
RF Fingerprinting

Pros:
- Service indoors and in urban areas
- Fast TTFF
- Better than Cell ID
- Can be combined with GPS in some cases

Cons:
- Constant maintenance
- SON network considerations
- Accuracy limited by granularity and age of direct calibration
WiFi and Bluetooth Based Positioning

Pros:
- Service indoors and in urban areas
- Fast TTFF
- Can be very accurate

Cons:
- Managed infrastructure is very expensive
- Unknown location of transmitters
- No control over infrastructure
- Very high site density required for very high accuracy
- High variability in performance
- Coverage varies
Sensor Fusion

• Sensor do not provide positioning information, but can be used in conjunction with other radiolocation technologies

• Key principle is using information from gyros, accelerometers and compass to assist in track determination

• With persistent radio information, sensors have been demonstrated to be able to correct a track for a short time duration
  – Detects motion and prevents large jumps in position
  – Radio inputs can assist in preventing the significant drift associated with consumer-grade sensors over short horizons

• Requires a good initial starting positioning – sensors are of no use in determining absolute location, only offsets
## Technology Summary

<table>
<thead>
<tr>
<th>Technology</th>
<th>Status</th>
<th>Issues</th>
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</thead>
<tbody>
<tr>
<td>GPS</td>
<td>Mature</td>
<td>• Doesn’t work indoors!</td>
</tr>
<tr>
<td>Cell ID</td>
<td>Mature</td>
<td>• Extremely coarse accuracy</td>
</tr>
<tr>
<td>Cellular trilateration</td>
<td>Mature</td>
<td>• Synchronization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Site characterization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Coverage and capacity considerations (e.g., DAS, overall architecture)</td>
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<tr>
<td></td>
<td></td>
<td>• Multipath</td>
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<tr>
<td></td>
<td></td>
<td>• Accuracy</td>
</tr>
<tr>
<td>RF Fingerprinting</td>
<td>Mature</td>
<td>• High maintenance costs / unstable performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Accuracy</td>
</tr>
<tr>
<td>WiFi / BlueTooth</td>
<td>Mature</td>
<td>• Very high infrastructure costs associated with highest performance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Unmanaged systems have insufficient accuracy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Coverage considerations</td>
</tr>
<tr>
<td>Sensor Fusion</td>
<td>Emerging</td>
<td>• Doesn’t provide absolute location, only can condition a track</td>
</tr>
</tbody>
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NextNav Overview

• NextNav is a network services provider deploying a nationwide system to provide reliable, high-precision positioning information in urban and indoor environments

• Owned assets and wide-area architecture provide defined technology evolution path and certainty of service availability

• Experienced team has a long and successful history in network deployment, operations and location technology, and has raised billions in capital

• Backed by Columbia Capital, Telcom Ventures and Goldman Sachs, well-funded investors with rich domain expertise
What Is The Ideal Solution?

- High accuracy in urban and indoor environments
- High reliability, high yield and pervasive coverage (ubiquitous scale)
- Low time to first fix and reduced power drain
- On-device location computation (personal privacy)
- Minimal device, core network impact and application impact

A network of high-power GPS satellites on the ground would satisfy all of these requirements
**NextNav Metro Overlay Deployment**

**Performance Advantage**
- Precise location in urban and indoor environments
- Accurate vertical position (1-3m)
- Fast time to first fix
- Dependable “carrier-grade” performance

**Broadcast Beacons**
- Low-power, highly synchronized
- Encrypted signal
- Broad coverage from minimal sites
- No backhaul, small form factor
- Operate on licensed spectrum

**Core Network**
- Utilizes existing PDE, SUPL elements
- Modifications to support NextNav information
- Similar to “Standalone GPS Mode” call flows

**Receivers**
- Firmware upgrade to “typical” GPS chipsets
- Minimal handset integration cost
- On-device computation of location
- Reduced power consumption

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Challenges of Terrestrial Positioning Transmitters

• Deployment Challenges
  – Radio planning for coverage and DOP
  – Leasing, Zoning and Permitting, Construction and Maintenance

• Timing accuracy
  – 1ns ↔ 1 ft
  – Calibration of hardware delays including field terminated cables
  – Calibration of precise lat/long/alt of the transmit antenna
  – Timing synchronization between the beacons
  – Antenna selection
  – Antenna siting
  – Variations across temperature
  – Ageing
  – Part to Part variations

• Data or Dedicated Positioning Service (PRS on LTE)?

• Near – far issues

• VDOP
Challenges of Terrestrial Positioning Receivers

• Yet Another Radio Receiver (YARR) on the handset?
• Co-existence with powerful radios adjacent in frequency and space
• Computational challenges w.r.t power consumption
• Multipath Challenges
  – Resolvability
  – Availability of LoS path
  – Discern between correlation side lobes and multipath peaks
  – Early path estimation algorithms
  – Time-varying multipath
Measurement data from the field
Correlation function amplitude for various scenarios
Some challenging real-world correlation functions
Histograms of range errors
Range error histogram at a high elevation/outdoor Rx location

- Histogram
- Range error (m)

Legend:
- Tx 1
- Tx 2
- Tx 3
- Tx 4
- Tx 5
- Tx 6
- Tx 7
- Tx 8
- Tx 9
- Tx 10
- Tx 11
- Tx 12
- Tx 13
- Tx 14
- Tx 15
- Tx 16
- Tx 17
- Tx 18
- Tx 19
- Tx 20
- Tx 21
- Tx 22
- Tx 23
- Tx 24
- Tx 25
- Tx 26
Indoor Accuracy Performance

- Results across suburban/urban environment
  - Offices
  - Hotels
  - Malls
  - Homes
- Indoor results only
- ~100 locations and 5,000 data points

CDF

Z-D position error (m)

50%/ 68%/ 90%

Metropolitan - Indoor (20m/ 26m/ 47m)
Floor-Level Height Accuracy

NextNav is building the nation’s first high precision, real time barometric pressure calibration network
Summary

• NextNav is deploying a revolutionary wide-area positioning system
  – Fully managed network brings high-precision, reliable location indoors
  – Underlying technology requires minimal chipset and device integration
  – Encrypted signals allow management of access to technology
  – Shared network allows multiple customers, for different services (e.g., E911, commercial)

• Mobile services and devices are increasingly dependent upon location
  – Advertising is following data traffic to mobile platforms, but with remarkable new capabilities in “aware” user terminals
  – Location is being embedded in commerce and popular social networking applications; it could be embedded in nearly ALL mobile applications

• Public Safety has recognized that the existing standards for E911 location accuracy are inadequate

• NextNav brings “carrier grade” ubiquity, reliability and accuracy to location