E911 Mobile Location Technologies and Location-Aware Services

Peter Wang
Nokia Research Center

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OUTLINE

• FCC E-911 LOCATION MANDATE & VERIFICATION

• MOBILE LOCATION TECHNIQUES
  – Network-Based Techniques
  – Handset-Based Techniques

• MOBILE LOCATION APPLICATIONS
  – System management Enhancement
  – Location-Aware Services

• CONCLUSIONS
FCC WIRELESS E-911 MANDATE (1/4)

• **Network-based Solutions:**
  – Not require any SW/HW modification to the handset

• **Handset-based Solutions:**
  – Requires some SW/HW modifications to the handset

• Operators have to report their plans for implementing E911 location, including the technology by November 9, 2000.
FCC WIRELESS E-911 MANDATE (2/4)

- Requirement for network-based methods:
  - Accuracy: 100m 67% of calls, 300m 95% of calls

Ref.: Guidance on carrier reports on implementation of wireless E911 phase II ALI, CC Docket No. 94-102
FCC WIRELESS E-911 MANDATE (3/4)

- Requirement for handset-based methods:
  - Accuracy: 50m for 67% of calls, 150m for 95% of calls

ALI (Automatic Location Identification)

<table>
<thead>
<tr>
<th>Year</th>
<th>25% new handset ALI-capable</th>
<th>50% new handset ALI-capable</th>
<th>100% new handset ALI-capable</th>
</tr>
</thead>
</table>
FCC WIRELESS E-911 MANDATE (4/4)

- Pending Waiver for E-OTD methods:
  - Accuracy: 100m for 67% of calls, 300m for 95% of calls before Oct. 1, 2003.
  - Accuracy: 50m for 67% of calls, 150m for 95% of calls after Oct. 1, 2003.

Carrier introduce ALI-capable handset

- 50% new handset
- 100% new handset
- 95% handset ALI-capable

<table>
<thead>
<tr>
<th>Time</th>
<th>50% new handset</th>
<th>100% new handset</th>
<th>95% handset ALI-capable</th>
</tr>
</thead>
</table>
- Accuracy: 50m for 67% of calls, 150m for 95% of calls after Oct. 1, 2003.
FCC GUIDELINE FOR E-911 LOCATION VERIFICATION (1/2)


certainty \( (x \geq x_r, \ y \geq y_s ; n, r, s, p_1, p_2) = \\
\sum_{i=0}^{r-1} \sum_{j=i}^{s-1} \binom{n}{i} \binom{n-i}{j} p_1^i (p_2 - p_1)^{j-i} (1 - p_2)^{n-j}

- \( n \) is the number of measurements
- the \( r^{th} \) and \( s^{th} \) largest measurements are \( x_r \) and \( y_s \)
- \( p_1 \) is 0.67 and \( p_2 \) is 0.95
- \( x \) and \( y \) are the percentile points associated with probabilities \( p_1 \) and \( p_2 \)
FCC GUIDLINE FOR E-911 LOCATION VERIFICATION (2/2)

Location-error samples for comparison with FCC required threshold for 67% and 95% (at the 90% confidence level)

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Pairs of Test Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>((x_{47}, y_{60}))</td>
</tr>
<tr>
<td>70</td>
<td>((x_{53}, y_{70}))</td>
</tr>
<tr>
<td>80</td>
<td>((x_{60}, y_{80})) or ((x_{63}, y_{79}))</td>
</tr>
<tr>
<td>90</td>
<td>((x_{67}, y_{90})) or ((x_{68}, y_{89}))</td>
</tr>
<tr>
<td>100</td>
<td>((x_{74}, y_{100})) or ((x_{75}, y_{99}))</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ordered Samples</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5…</th>
<th>74…</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurements(m)</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>19</td>
<td>22</td>
<td>50</td>
<td>150</td>
</tr>
</tbody>
</table>
CARRIERS E-911 LOCATION METHODS

121 Carriers are reported to FCC Docket No. 94-102
(Update to Nov. 15, 2000)

<table>
<thead>
<tr>
<th>Method</th>
<th>Network-based</th>
<th>Handset-based</th>
<th>AGPS</th>
<th>E-OTD</th>
<th>TBD</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Carriers</td>
<td>35</td>
<td>27</td>
<td>14</td>
<td>9</td>
<td>36</td>
</tr>
</tbody>
</table>

Current Status (March, 2003):
AT&T, Cingular: U-TDOA
T-Mobile: EOTD(GSM)
Verizon, SprintPCS, Nextel: AGPS
E-911 CALL DISTRIBUTION

- Call distribution data published

<table>
<thead>
<tr>
<th>Market</th>
<th>Urban - %911</th>
<th>Suburban - %911</th>
<th>Rural - %911</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston</td>
<td>1</td>
<td>73</td>
<td>26</td>
</tr>
<tr>
<td>Tampa</td>
<td>4</td>
<td>61</td>
<td>35</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>6</td>
<td>69</td>
<td>25</td>
</tr>
<tr>
<td>Kansas City</td>
<td>3</td>
<td>60</td>
<td>37</td>
</tr>
<tr>
<td>Columbus</td>
<td>5</td>
<td>75</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Urban - %911</th>
<th>Suburban - %911</th>
<th>Rural - %911</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>68</td>
<td>28</td>
</tr>
</tbody>
</table>
MS LOCATION TECHNIQUES (1/3)

- Network-Based Location Techniques
  - Network-based TOA Method
  - Network-based AOA Method
  - Network-based Fingerprinting Method
MS LOCATION TECHNIQUES (2/3)

- Handset-Based Location Techniques
  - E-OTD (Enhanced Observed Time Difference) Method
  - IPDL/AFLT (Idle Period Down Link/Advanced Forward Link Trilateration) Method
MS LOCATION TECHNIQUES (3/3)

• Assisted-GPS method
LOCATION ESTIMATION ALGORITHM

- Hyperbola method
**DOWNLINK LOCATION SIMULATOR (1/2)**

- The simulation model is comprised of five core blocks

1. **The network pattern**
   - Each BS is located at the center of a hexagon
   - The true MS locations are randomly selected to lie within the cell

2. **BS-transmitted pilot signals**
   - The pilot signal is modulated with spreading code/Walsh code and then is spread by a long scramble code/pilot PN

3. **The channel model**
   - Based on the specifications set forth in t1p1.5, it was used to help study location accuracy in GSM systems
4. The receiver correlator

- The coherent correlation is carried out on a selected number of symbols at short time periods over which the channel is stationary.
- The correlation at the different time periods are non-coherently combined.
- The power of the intra-cell interference depends on the signal to intra-cell interference ratio (SIIR).
- The Inter-cell interference is defined as the transmitted energy of neighboring cells to the MS receiver.

5. The algorithm for timing measurement and MS location estimation

- Peak detection
- Location estimation algorithm
CDMA IP-DL AND AFLT MODELS

BS Transmitter

Others Channels

Spreading Code

Pilot symbols

Long Scrambling Code/Pilot PN

Filter

p(t)

S

BS1

Path Loss

Idle Period

0

Channel Model

MS Receiver

Spreading Code

Long Scrambling Code/Pilot PN

Pilot symbols

Filter

p(t)

S

DS2

BSn

AWGN

Measurement of timing

Timing meas.

peak det.

Avg.

correlation
SIMULATION RESULTS (1/2)

- WCDMA with idle period = 0.667 ms and correlation length = 6.67 ms
SIMULATION RESULTS (2/2)

- CDMA2000 with idle period = 0.667 ms and correlation length = 6.67 ms
DOWNLINK LOCATION SUMMARY

• SIMULATION RESULTS

  – Longer Coherent Integration and Idle Period Improve MS Location

  – However, Channel Stability Restrains a Longer Coherent Integration

  – Idle Period of the Serving BS Pilot Transmission May Effect System Capacity
GPS LOCATION BACKGROUND

Satellite Geometry
NLOS CORRECTION METHOD (1/3)

Range Residues in the NLOS Situation

Assume $c >> a$

\[ a = \frac{h}{\sin \phi} \quad b = \frac{h \cos \theta}{\sin \phi} \]

Range Residue = \[ a - b = \frac{h (1 - \cos \theta)}{\sin \phi} \]
NLOS CORRECTION METHOD (2/3)

NLOS Correction Concept

- True mobile locations on every grid
- Estimated location including NLOS
- Measured GPS location

Estimated location including NLOS

True mobile locations on every grid

Corresponding to the Measured GPS location

Location Zone

Building
NLOS CORRECTION METHOD (3/3)

1. The Direction Cosine for a Satellite Location

\[ ue = \cos(EL) \times \sin(AZ) \quad un = \cos(EL) \times \cos(AZ) \quad uu = \sin(EL) \]

2. The Geometry Matrix

\[
H = \begin{bmatrix}
ue \_ sat & 1 & un \_ sat & 1 & uu \_ sat & 1 \\
uu \_ sat & 1 & \text{...} & \text{...} & \text{...} & 1 \\
ue \_ sat & 1 & \text{...} & \text{...} & \text{...} & 1 \\
\end{bmatrix}
\]

3. The least Squares Solution

\[
\begin{bmatrix}
\Delta x \\
\Delta y \\
\Delta z \\
\end{bmatrix} = \left[ H^T \ H \right]^{-1} H^T \left[ R_i \right]
\]

\[\Delta x = x\_\{\text{GPS predicted}\} - x\_\{\text{true location}\}\]
\[\Delta y = y\_\{\text{GPS predicted}\} - y\_\{\text{true location}\}\]
\[\Delta z = z\_\{\text{GPS predicted}\} - z\_\{\text{true location}\}\]
NLOS CORRECTION SIMULATION

Propagation Environment 2
NLOS GPS LOCATION SUMMARY

• NLOS Location Error
  – Obstacle Building Height
  – Mobile and Obstacle Building Distance
  – Satellite Geometry
LOCATION ACCURACY vs. APPLICATIONS

- **GSM: E-OTD**
  - MS based/assisted
  - commercial
  - active/passive

- **3G: IP-DL**
  - MS based/assisted
  - commercial
  - active/passive

- **GPS**
  - NW assisted
  - commercial
  - active/passive

- **CI**
  - commercial
  - active

Applications:
- **Navigation**
- **Security services**
  - E911, 1-800-roadside
  - Fleet management and tracking
- **Information services**
  - where is the nearest
  - Tariff applications
  - city zone/home zone

**Tariff applications**
- city zone/home zone

**Information services**
- where is the nearest

**Navigation**

**Accuracy**
- 10m
- 100m
- 1 km
- 10 km
MS LOCATION IN APPLICATION DOMAIN

- Content
  - Media broadcast
  - Advertising
  - Location Based Services

- Pervasive computing
  - Data collection
  - Data distribution
  - Embedded systems

- Connectivity and Messaging
  - Voice
  - SMS

- Interactive applications
  - Internet
  - Intranet
  - e-Commerce
ADVENTAGE OF LOCATION SERVICES

On-line Recommendation, consultancy
• End-user pays a fee for the service (transaction based, monthly fee)

Proposal
• Advertising driven
• Free for the end-user

Data overload
• Free of charge

Location Based Services

Knowledge

Information

Data

Current Internet Search machines

Yahoo.com
LOCATION COMMERCIAL APPLICATIONS (1/2)

• System Management Enhancement
  – Adaptive Horizontal/Vertical Handover
    • Using the history of signal strength and MS location information to reduce the unnecessary handoff and maintain the QoS
  – User Behavior Modeling
    • Tracking mobility patterns and user distribution to improve the system management and control
  – Efficient Early Channel Reservation
    • Using MS current location and MS location profile to dynamically allocate channel based on call admission scheme and QoS requirement
  – Optimized Cell Sectorization
    • Optimizing the transmit power and antenna beam directivity to reduce multi-user interference
LOCATION COMMERCIAL APPLICATIONS (2/2)

• Location-Aware Services
  – Tracking Services
    • Fleet management, elderly people and children who need support of others, car navigation and real-time user's location
  – Tariff Services
    • providing tiered services for home zone/office zone with low cost calls
  – Value Added Services
    • requesting the nearest ATM, cheapest gas station, location-based Internet services, local broadcasting, and local traffic information
  – Commercial Safety
    • Emergency roadside assistance, nearest doctor and medical clinic
  – Connecting Services
    • Making friends with location information such as instant messaging services
EXAMPLE OF MS LOCATION APPLICATION

- ADAPTIVE HANDOFF METHOD
- EARLY CHANNEL RESERVATION SCHEME
ADAPTIVE HANDOFF METHOD (1/2)

• Handoff Condition

\[
x(n) > T_{\text{add}} \Rightarrow \text{add A}
\]

\[-x(n) > T_{\text{add}} \Rightarrow \text{add B}
\]

\[
x(n) < T_{\text{drop}} \Rightarrow \text{drop A}
\]

\[-x(n) < T_{\text{drop}} \Rightarrow \text{drop B}
\]

Where \( x(n) = \text{RSS}_A(n) - \text{RSS}_B(n) \)

\[ T_{\text{add}} = -1\,\text{dB} \text{ and } T_{\text{drop}} = -2\,\text{dB} \]
ADAPTIVE HANDOFF METHOD (2/2)

- Average RF Signal Strength in Each Grid Size

The time constant \( \tau = \frac{P_1 P_2}{\text{mobile speed}} \)
ADAPTIVE HANDOFF RESULTS (1/3)

- Probability of Handoff vs. BS in Active Set (Different $T_{add} / T_{drop}$)
  - Applying Fixed and Adaptive Handoff Thresholds

![Handoff vs. BS Graph]

- Probability of Handoff vs. BS in Active Set (Different $T_{add} / T_{drop}$)
ADAPTIVE HANDOFF RESULTS (2/3)

- Handoff Probability – (MS is moving from BS_A to B)
ADAPTIVE HANDOFF RESULTS (3/3)

- Outage Probability – (MS is moving from BS_A to B)
ADAPTIVE SOFT HANDOFF SUMMARY

• Trade-off between Handoff Probability and BS in Active Set
• Trade-off between Handoff Probability and Outages
• Trade-off between BS in Active Set and RSS
• Fix versus Adaptive Soft Handoff
EARLY CHANNEL RESERVATION (1/6)

Future mobility path prediction
EARLY CHANNEL RESERVATION (2/6)

Network manages three mobiles requesting bandwidth reservation in cell “T”

Mobile #1 heading prediction
Mobile #2 heading prediction
Mobile #3 heading prediction
Schematic Diagram for Early Channel Reservation

- **MS**
  - Basic location registration
  - Lempel-Ziv filtering

- **MSC**
  - Prediction Engine
  - Trigger

- **BS**
  - Air Interface
EARLY CHANNEL RESERVATION (4/6)

Trajectory of User Movement
EARLY CHANNEL RESERVATION (5/6)

Histogram for 75% Guarantee on Mobility Support
EARLY CHANNEL RESERVATION (6/6)

Histogram for 95% Guarantee on Mobility Support
CONCLUSIONS

• TIME LINE OF FCC E-911 MANDATE
• GUIDELINE OF FCC E-911 LOCATION VERIFICATION
• DESCRIBED MS LOCATION TECHNIQUES
  – Network-Based Techniques
  – Handset-Based Techniques
• EXPLORED LOCATION COMMERCIAL APPLICATIONS
  – System Management Enhancement
  – Location-Aware Services