Application Development for Mobile and Ubiquitous Computing

3. Location-based Services

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Application Development

Mobile Business Applications

Cross-Platform Development

Mobile Web Applications
Android
iOS
Windows Phone

Mobile Middleware

Disconnected Operations
Mobile Databases
Location-based Services
Communication Mechanisms

Enabling Technologies and Challenges
The term location-based services [...] denotes applications integrating geographic location (i.e. spatial coordinates) with the general notion of services. Examples of such applications include emergency services, car navigation systems, tourist tour planning, or „yellow maps“ (combination of yellow pages and maps) information delivery. [J.H. Schiller und A. Voisard, Location-based services, Elsevier, 2004]

Location-based Services will allow mobile users to receive personalized and lifestyle-oriented services relative to their geographic location. [Open Mobile Alliance]
- Foundations
  - How to present the current position?
  - How to determine the current position?

- Positioning and Tracking Systems
  - Outdoor Positioning systems
  - Indoor Positioning and Tracking Systems

- Presenting Semantic Location
  - Geometric and Semantic Location Models
  - Query Types
  - Kinds of Location Models
How to represent the current position?

- **place, location** and **position** often used as synonyms, but they should be distinguished

  - **place**
    - denotes a geographic site in the real world
  
  - **location**
    - also referred to as logic/semantic location
    - semantic description of a spatial area (e.g. home or Albertplatz)
    - very important for organizing our “real-world” in everyday life
  
  - **position**
    - also referred to as spatial/geographic location
    - e.g. exact point in the Euclidean Space, i.e. two- or three-dimensional coordinate
    - indispensable for applications requiring precise location information

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Application Development - 3. Location-based Services  
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Spatial Positions

- spatial positions are based on reference systems

<table>
<thead>
<tr>
<th>Coordinate System</th>
<th>Geodetic datum</th>
<th>Projection (if location is presented on a map)</th>
</tr>
</thead>
</table>

- coordinate system
  - used for referencing a place via a position, i.e. via a vector of numbers called coordinates
  - coordinates relative to coordinate system

  - ellipsoid coordinate system to model locations on earth
Ellipsoid Coordinate System

- model of earth based on rotation ellipsoid, defined by two radii:
  - a – polar
  - b – equatorial

- two reference planes spanned by
  - a → vertical plane
  - b → horizontal plane

- position defined by means of latitude and longitude
  - degrees, minutes, seconds
  - one second for latitude is about 31 m
  - one second for longitude is between 0 and 31 m

degrees, minute: 51°11.3569’ N, 14°0.9562’ E
degrees, minute, second: 51°11’ 21” N, 14°0’ 57” E
- **Horizontal datum**
  - approximates the earth’s shape as reference ellipsoid
  - different optimized ellipsoids used for different regions
    - in Germany “Potsdam datum” for land surveying
      - based on displaced Bessel-Ellipsoid
      - reference point Rauenberg
    - World Geodetic System 1984 (WGS 84)
      - global geodetic datum
      - used in GPS

- **Vertical datum**
  - reproduces earth’s mean sea level as geoid
  - used for determination the height of a certain position
- mapping of three-dimensional coordinates to two dimensions
  - distortions (areas, angles, length)

- projection types
  - cylindrical
    - e.g. for see maps
    - WGS 84 / Pseudo-Mercator (EPSG:3857)

  - conical
    - e.g. for aviation maps

  - planar

How to determine the current position? Positioning vs. Tracking

- **Positioning** (client-based positioning)
  - device actively determines/calculates position itself
  - location information under control of located device
  - hardware and computing power at device required

- **Tracking** (infrastructure-based positioning)
  - device just sends signals
  - position determined by infrastructure, i.e. device is passively located
  - simple devices
  - location information not under control of located object
Technologies for Positioning - Cell ID

- Simplest form of positioning
- Based on signal and identifier of infrastructure component
  - E.g. MAC address of Wifi access point, cell id of GSM BTS, RFID
- Position is derived from position of infrastructure component with strongest signal
- Accuracy depends on cell size and/or amount of beacons
Lateration

- based on distances between device and reference points
- calculated e.g. by time of arrival (ToA) or signal strength
- positions of reference points have to be known
- 3D-positioning requires three reference points (trilateration)

Conceptual example for calculation of the distance using circular lateration

- calculation of signal propagation delay based on Time of Flight (ToF)
  - for instance ToF = 70 ms
- hence calculation of distance d based on speed of light c
  - \( d = \text{ToF} \cdot c = 70 \times 10^{-3} \text{ s} \cdot 3 \times 10^8 \text{ m/s} = 2,1 \times 10^7 \text{ m} = 21.000 \text{ km} \)
Technologies for Positioning - Angulation

- Based on angles between signals
  - referred to as angles of arrival
  - angle to reference point determined by means of special antennas
- Positions of reference points have to be known
- 3D-positioning requires three reference points (triangulation)

\[ \begin{align*}
\alpha_1 & \text{ at } (X_1, Y_1) \\
\alpha_2 & \text{ at } (X_2, Y_2)
\end{align*} \]
Both outdoor and indoor systems can be classified into

- **Stand-alone infrastructure**
  - dedicated infrastructure for positioning/tracking
  - e.g. satellite systems, infrared-based systems

- **Integrated infrastructure**
  - existing (communication) infrastructure also used for positioning/tracking
  - e.g. cellular systems, WLAN-based systems
advantages
- few environmental influences (e.g. weather)
- high accuracy (in the range of meters)
- global availability

disadvantages
- high costs, since for global availability many satellites are required
- enough signals have to be available for positioning
  - at least 4 signals (3 for positioning, 1 for time synchronization)
- usually no indoor positioning

example: GPS
- originally named NAVSTAR (Navigation System with Timing and Ranging)
- today known as GPS (Global Positioning System)
- consists of
  1. satellites
  2. control stations (observation of the satellites orbits)
  3. user devices
Global Positioning System (GPS)

- **Space Segment**
  - Min. 24 satellites on 6 orbits, i.e. 4 satellites per orbit
  - additional satellites for robustness
  - height = 20,200 km (medium earth orbit)
  - rotation frequency is 12 hours, i.e. satellites are at the same position each 24 hours
  - min. 5, max. 11 satellites visible from each point on earth

- **Control Segment**
  - a master control station (MCS)
  - an alternate master control station,
  - four dedicated ground antennas
  - six dedicated monitor stations.

[Roth, Ortsbezogene Anwendungen und Dienste]
Each satellite continually broadcasts two signals
- L1: 1575.42 MHz – C/A-Code and P/Y-Code
- L2: 1227.6 MHz P/Y-Code only
- Line of sight required between receiver and satellite

- C/A-Code (Coarse/Acquisition) – civil use:
  - position, orbit, time of transmission, correction and PNR
  - each satellite has a unique code called Pseudo Random Noise (PRN)

- P/Y- Code (Precision/encrypted) – military use
GPS Position

- **User segment**
  - GPS receivers for civil and military use

- **Position calculated based on lateration**
  - receiver determines time of flight (ToF) of four satellite signals
  - receiver-satellite range calculated using speed of light
  - three-dimensional position and clock deviation computed

- **Accuracy (Standard Positioning Service):**
  - average user range error (URE) of \( \leq 7.8 \text{ m (25.6 ft.)} \), with 95% probability

- **Sources of inaccuracy:**
  - incorrect clock synchronization
  - atmospheric errors,
  - multipath propagation
Main idea:
- improve GPS accuracy by means of correction data
- increases accuracy to 1-3 m

Assumption:
- errors correlated with local region

Principle:
- additional reference stations on earth's surface
- positions of reference stations are known
- reference stations permanently observe all visible satellites
- inaccuracies due to variability of satellite orbits and atmospheric errors are calculated based on known position of reference stations
  - Correction data calculated
Satellite-based augmentation systems (SBAS)
- Complement existing satellite navigation systems
- Several countries have implemented their own SBAS
- All systems comply with a common standard, i.e. they are all compatible

EGNOS
- ground network of 39 ranging and integrity monitoring stations (RIMS)
  - Receive satellite signals (GPS, GLONASS, Galileo)
- two mission control centres (MCC)
  - Calculate correction data for satellite path and signal propagation time
- six navigation land earth stations (NLES)
  - Send correction data to EGNOS satellites
- signal transponders on three geostationary satellites (two Inmarsat III and IV satellites and one SES ASTRA GEO satellite SES-5)
  - Propagate correction data to GPS devices using L1 frequency of GPS

EDAS - EGNOS Data Access Service
- terrestrial data service for data propagation, e.g. through an internet connection.
public class GpsActivity extends Activity {
/** Called when the activity is first created. */
@Override
public void onCreate(Bundle savedInstanceState) {
    super.onCreate(savedInstanceState);
    LocationManager lMgr =
            (LocationManager) getApplicationContext().getSystemService(Context.LOCATION_SERVICE);
    LocationListener lListener = new LocationListener() {
        @Override
        public void onLocationChanged(Location l) {
            TextView tv = new TextView(GpsActivity.this);
            tv.setText("lat: " + l.getLatitude() + "\nlon: " + l.getLongitude());
            setContentView(tv);
        }
    };
    lMgr.requestLocationUpdates(LocationManager.GPS_PROVIDER, 0, 0, lListener);
}
Further Satellite Systems

- **Globalnaya Navigationnaya Sputnikovaya Sistema (GLONASS)**
  - Russian satellite system
  - based on 24 planned satellites
  - no encryption, no selective availability
  - can be used, 21 satellites already in orbit (state 2010)

- **Galileo**
  - European project for civil satellite positioning system
  - goal: independence from American GPS system
  - compatible to GLONASS and GPS
  - GPS receivers reusable
  - 30 satellites planned
  - control stations (Munich GER, Fucino ITA)
Cellular Systems

- integrated approach based on existing infrastructure

**Advantages**
- low costs
- high availability
- works indoor and outdoor

**Disadvantages**
- lower accuracy
Example: GSM

- Positioning based on GSM cell ID
- Available from Home Location Register (HLR)
- Mobile Positioning System (MPS) by Ericsson to improve accuracy
  - Few changes of infrastructure; no changes of user devices

- Cell Global Identity (CGI) for identification of the cell
  - Uses GSM cell ID
- If sector-antennas used, position can be narrowed to segment of circle

- GSM based on FDMA and TDMA
- Exact timing required for the synchronization of uplink and downlink → Timing Advance (TA)
- Device calculates distance based on signal propagation time
- Can be used for positioning in combination with CGI

- Uplink Time Of Arrival (UL-TOA)
  - 4 base stations needed
- Measurement of signal propagation time at base stations
- Calculation of position based on lateration
- Accuracy 50 – 150m
- Position information stored in Mobile Positioning Center (MPC) → Tracking
Indoor Positioning/Tracking

- satellite or cell systems often not available in buildings or not accurate enough

- therefore other approaches required:
  1. GPS in buildings
     - pseudolites, repeater
  2. Stand-alone infrastructure approaches
     - infrared, ultrasonic, bluetooth (iBeacon), radio, audio, ...
  3. **Integrated infrastructure approach**
     - mainly Wifi
  4. Dead Reckoning
     - special devices, smartphone sensors
stand-alone infrastructure based tracking system
based on infrared (IR)
users carry badge sending specific user ID
IR-receivers in the rooms receive those signals
Cell ID is used to determine position
position of user is tracked by central server

problems:
- limited range of IR
- user’s position is position of IR-beacon which received the signal
- user does not get position information
Wireless Indoor Positioning System (WIPS)

- stand-alone infrastructure based **positioning** system
- based on infrared (IR)
- beacons installed in the rooms sending unique ID
- user’s badges receive signals of local beacons
- received beacon ID is sent to location server via WLAN
- server maps received beacon ID to semantic location which is sent back to the user

**advantage:**
- users knows their own position

**disadvantage:**
- integration of two wireless techniques
Further Systems

- **Active Bat**
  - stand-alone infrastructure based tracking system
  - based on ultrasonic
  - tracking by means of measured signal propagation time which is sent to the location server for processing
  - accuracy up to 10 cm

- **SpotOn**
  - stand-alone infrastructure based tracking system
  - based on radio signals
  - radio signals are able to pervade walls compared to infrared signals
  - strength of radio signal depends not only on distance (think of walls, ...)
    - accuracy of 3 m for WIPS
    - compensation of errors if more beacons available
  - variant: using RFID-tags (user carries tag, reader in rooms)
Wifi-based Positioning

- based on already installed WLAN infrastructure (that was installed for communication purposes primarily) → integrated infrastructure based positioning

- Passive Scanning for dynamic access point (AP) detection
  - APs periodical send beacons (timestamp, data rates, AP identifier)
  - period usually configured to tens or hundreds of ms
  - Receiver measures Radio Signal Strength (RSS) and Signal-to-Noise (SNR) ratio – available via network adapter API

- Active Scanning
  - Terminal can actively send a probe, all APs in range respond with beacon
  - APs can use probe for tracking

- Positioning by means of
  - Proximity sensing (Cell ID)
  - Lateration
  - Fingerprinting


- **Proximity sensing**
  - Position of terminal adopted from position of AP with highest signal quality (according to cell id)
  - Accuracy depends on density of APs
  - Usually hard to distinguish between floors and indoor/outdoor

- **Lateration**
  - Requires accurate information about AP positions
  - at least three access points have to be available
  - measurements are influenced by obstacles like walls, persons, orientation of device, multipath propagation, etc.
  - RSS not standardized, value depends on adapter implementation
  - Modern APs are able to adjust signal strength and channel
  - Accuracy depends on availability and constellation of APs and building structure
WLAN Fingerprinting

1st Phase: Radio Map Creation (Offline):
- Measurements of fingerprints at reference points -> stored in fingerprint DB
- Definition of reference points according to accuracy needs and building structure

2nd Phase: Radio Map Usage (Online):
- Fingerprint of current position is taken
- Search for closest matching reference point on radio map
- Position taken from that reference point or interpolated

Fingerprint
- Scan time: 16.11.2012 10:28:34
- Location: lat, lon, floor
- Visible Access Points:
  - AP1:
    - SSID: eduroam
    - MAC: 08:17:35:33:5f:80
    - Signal strength: -64
  - AP2
    - SSID: VPN WEB
    - MAC: 08:17:35:33:5f:81
    - Signal strength: -61
  - APn
    - ...

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Approaches for Fingerprinting

- **Empirical approach**
  - Deterministic Matching (RADAR):
    - Measuring of **RSS patterns** at reference points
    - **Mean value from several measurements** taken as fingerprint
    - Calculation of euclidean distance between current fingerprint and all fingerprints in radio map
      -> **position with smallest euclidean distance is current position**
      - Based on average RSS values, decreased accuracy
      - Whole DB has to be searched
  - Probabilistic Matching (Ekahau, Horus, Nibble, WhereMops):
    - Description of **variations of signal strength as probability distributions**
    - Often combined with joint **clustering – fingerprints with same set of APs** form cluster
    - Search by identifying the cluster, than application of probability distribution
      + Reduced computation overhead due to clustering
      + Increased accuracy due to probability distribution

- **Modeling approach (WhereMops)**
  - Usage of mathematical models for calculating radio propagation
    + Low effort for creating and maintaining the radio map
WLAN Fingerprinting - Implementation

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<tr>
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<th>Terminal-based</th>
<th>Terminal-assisted</th>
<th>Network-based</th>
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<tbody>
<tr>
<td>Scanning mode</td>
<td>passive</td>
<td>passive</td>
<td>active</td>
</tr>
<tr>
<td>Location of fingerprint DB</td>
<td>Mobile device</td>
<td>Fingerprint server</td>
<td>Fingerprint server</td>
</tr>
<tr>
<td>Position calculation</td>
<td>Mobile Device</td>
<td>Infrastructure</td>
<td>Infrastructure</td>
</tr>
</tbody>
</table>

[A. Küpper, Location-based services, John Wiley, 2005 (extended)]
Dead Reckoning

- starting with a reference point
- detect relative movements
- smartphone sensors can be used
  - accelerometer – step detection (distance)
  - magnetometer and gyroscope (orientation)
  - barometer (level changes)

issues
- even small errors lead to incorrect positions
- subsequent errors increase incorrectness
- orientation is biggest issues
- periodic recalibration with reference point required
Dead Reckoning Examples

Footprint Location Tracking
- at one shoe sender, at the other receiver
- additionally orientation and pressure sensors
- start position is known
- calculation of step length and rotation of feet to determine new position

TrackSense
- grid is projected onto and reflected from objects
- camera detects the lines using a custom edge detection algorithm
  - detection of walls and vertices
- three-axis accelerometer and magnetometer to determine which corner we are observing
- by triangulation distance and orientation to each point relative to the camera can be determined
## Comparision of Systems

<table>
<thead>
<tr>
<th>Name</th>
<th>Category</th>
<th>Positioning/Tracking</th>
<th>Mechanism</th>
<th>Medium</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>Satellite</td>
<td>Positioning</td>
<td>TOA</td>
<td>Radio</td>
<td>25 m</td>
</tr>
<tr>
<td>DGPS</td>
<td>Satellite</td>
<td>Positioning</td>
<td>TOA</td>
<td>Radio</td>
<td>3 m</td>
</tr>
<tr>
<td>Active Badge</td>
<td>Indoor</td>
<td>Tracking</td>
<td>COO</td>
<td>IR</td>
<td>Cell</td>
</tr>
<tr>
<td>WIPS</td>
<td>Indoor</td>
<td>Positioning</td>
<td>COO</td>
<td>IR</td>
<td>Cell</td>
</tr>
<tr>
<td>SpotOn</td>
<td>Indoor</td>
<td>Tracking</td>
<td>Signal strength</td>
<td>Radio</td>
<td>3 m</td>
</tr>
<tr>
<td>Active Bat</td>
<td>Indoor</td>
<td>Tracking</td>
<td>TOA</td>
<td>Ultrasonic</td>
<td>0.1 m</td>
</tr>
<tr>
<td>GSM</td>
<td>Network</td>
<td>Both</td>
<td>COO, AOA, TOA</td>
<td>Radio</td>
<td>Cell</td>
</tr>
<tr>
<td>MPS</td>
<td>Network</td>
<td>Both</td>
<td>COO, AOA, TOA</td>
<td>Radio</td>
<td>150 m</td>
</tr>
<tr>
<td>WLAN</td>
<td>Network</td>
<td>Positioning</td>
<td>RSS, SNR</td>
<td>Radio</td>
<td>2 – 10 m</td>
</tr>
</tbody>
</table>

TOA = Time of Arrival; COO = Cell of Origin; AOA = Angle of Arrival
IR = Infrared; MPS = Mobile Positioning Server / Center
WIPS = Wireless Indoor Positioning System
• position queries (e.g. Where is Alice?, In which room is Bob?)
  • some form of coordinates required
  • global and local reference systems possible

• nearest neighbor queries (What is the distance between Alice and Bob?)
  • some form of distance function required
  • extension with notion of path (not always direct physical distance)
    o e.g. How many bus stops between Alice and faculty building?
  • topological relation “connected to” required
  • different navigational tasks: shortest path or fastest path
  • calculation of path length including different attributes/weights

• range queries (Which persons are in room APB E008?)
  • all objects in a certain geographic area
  • topological relation “contains” required
    o for geometric coordinates it can be derived from known geometry
    o for symbolic coordinates explicit modeling required
Requirements for Location Models

- For supporting the different introduced query types we need a model of our environment → location model
- location models should model/have the following:
  - *object position*
  - *distance function*
  - *topological relation “connected to”*
  - *topological relation “contains”*
- location information can be represented in different formats
  - geometric coordinates → geometric models
  - symbolic coordinates → symbolic models

<table>
<thead>
<tr>
<th></th>
<th>absolute question</th>
<th>relative question</th>
</tr>
</thead>
<tbody>
<tr>
<td>geometric model</td>
<td>What are Alice coordinates?</td>
<td>What is the distance between Alice and Bob?</td>
</tr>
<tr>
<td>symbolic model</td>
<td>In what room is Bob located at?</td>
<td>How many bus stops are between Alice and the faculty of computer science?</td>
</tr>
</tbody>
</table>
Location Models

- Geometric Location Models
  - define places in form of coordinate tuples relative to reference coordinate system e.g. World Geodetic System 1984 (WGS-84)
  - mapping between coordinates of different reference systems possible
  - calculation of distances, overlapping's and inclusions of locations by means of geometric operations possible
    - topological relation “contains” implicitly available
    - topological relation “connected to” has to be explicitly modeled (e.g. as graph)

- Symbolic Location Models
  - coordinates usually do not have a meaning for humans
  - define places in form of abstract symbols
  - e.g. Cell ID in GSM, sensor identifiers in active badge system, room and street names
  - no distance and other topological relations implicitly defined
    ➔ additional information required
usage of symbolic names

- e.g. a building with several floors and rooms can be modelled like this

\[ L_{\text{building}} = \{L_{\text{floor1}}, L_{\text{Floor2}}, \ldots \} \]

\[ L_{\text{Floor2}} = \{2.002, 2.003, \ldots, 2.067\} \]

- "contains" relation defined by intersection of sets ( \( \{xyz\} \cap L = \{xyz\} \) )
- overlappings can be identified ( \( L1 \cap L2 \neq \emptyset \) )
- nearest neighbour and navigation
  - "connected to" relation can be defined by modelling pairs of connected locations
  - also simple (only qualitative) notion of distance possible
Symbolic: Graph-based Models

- symbolic coordinates define vertices $V$ of graph $G = (V, E)$
- "connected to" relation modelled by edges between vertices
- simple distance by calculation of "hops"
- weights for edges to model advanced distance notion
- no explicit "contains" definition
Hybrid Location Models

- combination of graph- and set-based modelling
  - combined symbolic model as basis (set and graph)
  - location model contains two parts

- combination of geometric and symbolic models
  - geometric information additionally stored in model (e.g. defined based on WGS84)
  - increases accuracy and precision for distances
  - arbitrary geometric figures can be used for locations and ranges
  - mapping between geometric and symbolic coordinates

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Application Areas

- provision location-based information
  - museum, city guide, shopping guide

- location-based search
  - buddy-finder
  - service search (post office, restaurant nearby)

- navigation systems

- tracking systems
  - mediation of incoming calls
  - alarm systems for children or elderly people
Summary

- large set of positioning systems
  - satellite based, cellular, local/indoor

- different types of location models
  - hybrid approach is preferable
    - supports all types of queries
    - enables mapping between geometric and symbolic coordinates
    - disadvantage: higher modelling effort, more data

- location-based services widely adopted
  - e.g. navigation systems or tourist guides

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