LECTURE 8:
HUMAN MOBILITY AND MOBILE NETWORK DATA

Amnir Hadachi, PhD.
hadachi@ut.ee
What can mobile network data offers:

- Understanding human mobility

- Study statistical properties of human mobility or some particular group of people
  - Building mobility models
  - Building models capturing population movement behavior under specific events or conditions.
  - Spread of biological and mobile viruses.
HUMAN MOBILITY AND MOBILE NETWORK DATA

(INTRO)

• If we know how the people behave we will be able to guess their movement intentions in advance and react consequently.

  – Pervasive computing (automatic detection of home and work etc)

  – Location based services

  – Detect unusual behaviours
HUMAN MOBILITY AND MOBILE NETWORK DATA

(INTRO)

• The interest of identifying areas where people spend most of their time during the week, weekend, and also major routes used, etc
  – Urban planning
  – Traffic forecasting
  – Intelligent transportation systems
Summary:

- Understand how people move
  - Spatio-temporal analysis
  - Most visited location
  - Etc

- Use mobility knowledge to estimate or predict the future destinations.
  - Mobility Prediction
HUMAN MOBILITY AND MOBILE NETWORK DATA

MOBILE NETWORK DATA
Most of the people carry all the day a mobile phone.

The amount of data collected by mobile operators

- Mobile phone devices enable massive data collection
Mobile Data:

- From the device
  - Many methods to obtain information in Android API
  - Not so easy in iOS
- From the network
  - Operators: knows to which cell you are connected too, if you are making a call or receive call, sms, etc.

- GPS:
  - Best Accuracy
  - High battery drain
  - Limited coverage
- WLAN:
  - Lower accuracy
  - Lower battery drain
  - Limited coverage
- GSM:
  - Lowest accuracy
  - Lowest battery drain
  - Worldwide coverage
**Mobile phone network data**

- **Events-driven mobile phone network data**
  Data generated by the interaction between the device and the network.

- **Network-driven mobile phone network data**
  Data generated by the interaction between the network and the device.
Events-driven mobile phone network data
- Communication (Call Detail Record)
  - Originating User ID
  - Terminating User ID
  - Type of communication (Call, SMS,…)
  - Length of the call
- Internet usage (IP Detail Record)
  - User ID
  - Type of website
  - Time event
  - Number of bytes transmitted
- Cellphone tower (associate the events to the towers)
Network-driven mobile phone network data

- Mobility location update
  - Cell based information
  - Generated when the phone moved to another area
  - Data:
    - User ID
    - Occurrence time of the event
    - Location area and cellphone tower where it has moved to

- Handover
  - Generated when a phone involved in a call and moves between two cell areas
  - Data:
    - User ID
    - Time of event
    - Cellphone tower where it has moved from and to
Mobile Network architecture:

**MS**: Mobile Station – Mobile Phone+SIM
**BSS**: Base Station Subsystem
**BTS**: Base Transceiver Station - Tower with radio transponders attached
**BCS**: Base Station Controller – Provides bi-directional signaling and traffic channels between MS and NSS
**TC**: Transcoder -
**NSS**: Network Switching Subsystem (MSC, HLR or VLR) – manages communication between mobile-to-mobile and mobile to land-line phone calls.
HUMAN MOBILITY AND MOBILE NETWORK DATA
(MOBILE NETWORK DATA)

Mobile Subscriber:

- Phone with an attached SIM card
  - IMEI code identifies the particular phone
  - IMSI code identifies the particular SIM card

- Additionally each subscriber has a MSISDN
  - the actual phone number
HUMAN MOBILITY AND MOBILE NETWORK DATA

(MOBILE NETWORK DATA)

Cell Tower:

- Each tower belongs to a service area (Location ID, Site ID)
- Each tower has multiple directed transmitters attached (Cell ID), typically 3
Multiple towers together for strong coverage of the particular area:

- 3-sector cell tower
  - 120° per sector

- 3 sectors
  - 1 channel per sector

- 3D view of monopole
  - 3-sector cell tower

Illustration by: George Ou
HUMAN MOBILITY AND MOBILE NETWORK DATA
(MOBILE NETWORK DATA)

• Very important fact, used in further research: cell coverage regions (sites) are defined by multiple transmitters of different towers.
* Cell tower does not mean center of the coverage region (site)
HUMAN MOBILITY AND MOBILE NETWORK DATA
(MOBILE NETWORK DATA)

EXAMPLE 8.1: Basic Network
**Transmitters types:**

- **Macro cell**
  - Diameter $\geq 10\text{km}$
  - Power up 6W

- **Micro cell**
  - Diameter up to 1km
  - Power up to 1W

- **Pico cell**
  - Indoor cell, used in tunnels, large buildings

- **Selective cell**
  - Tiny directed sector
  - Use to cover narrow, but heavily loaded regions (roads, streets)

- **Umbrella cell**
  - Introduces cell hierarchy based on traffic speed
  - Has large coverage, serves fast traffic
  - Offloads other cells, so they server slow traffic
MS are moving across different service areas and cells generating events that are processed by operator
HUMAN MOBILITY AND MOBILE NETWORK DATA
(MOBILE NETWORK DATA)

- Static data (operators have them by default):
  - Home Location Register (HLR)
    - Register of all subscribers (customer) of particular operator. Contains IMSI, MSISDNs and other service contract related preferences.
- Collected data:
  - Triggered by silent activities in Cell Network:
    - Visitor Location Register (VLR)
    - Temporal storage attached to each service area
    - Reduces the amount of queries to HLR
    - Contains IMSI, MSISDN, Location area …
  - Triggered by calling, mobile internet and other active usage:
    - Call Detail Records (CDR)
**HUMAN MOBILITY AND MOBILE NETWORK DATA**

**CDR:**

- **Call detail records (CDR)**—Data records that contain information about each call that was processed.

- **Call management records (CMR)**—Data records that contain quality of service (QoS) or diagnostic information about the call. Also referred to as diagnostic records.
EXAMPLE 8.2: CDR data

For our research we only interested in the following fields:

- Subscriber IMSI
- Subscriber IMEI
- Location ID
- Identifies cell tower of service area
- Cell ID
- Identifies particular transmitter
- Start Time
- End Time
HUMAN MOBILITY AND MOBILE NETWORK DATA
(MOBILE NETWORK DATA)

VISITOR LOCATION REGISTER (VLR):

- Location Updates
  - Location Area Change
    - When switching between BSC
  - Periodic Location Update
    - Confirm the presence of MS (keep-alive)
  - IMSI Attach
    - SIM card change, power on the phone
  - Cell change during calls
For our research we only interested in the following fields:

- Subscriber IMSI
- Subscriber IMEI
- Location ID
- Identifies cell tower of service area
- Cell ID
- Identifies particular transmitter
- Event Type
- Event Timestamp

### TABLE 5: Overview of data stored in location registers

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SECTION</th>
<th>HLR</th>
<th>VLR</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMSI</td>
<td>2.1.1</td>
<td>M</td>
<td>M</td>
<td>P</td>
</tr>
<tr>
<td>International MS ISDN number</td>
<td>2.1.2</td>
<td>M</td>
<td>M</td>
<td>P</td>
</tr>
<tr>
<td>TMSI</td>
<td>2.1.3</td>
<td>-</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>IMSI</td>
<td>2.1.4</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Mobile Station Category</td>
<td>2.3.1</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Authentication key</td>
<td>2.3.2</td>
<td>M</td>
<td>M</td>
<td>T</td>
</tr>
<tr>
<td>RAND/SRES and Kc</td>
<td>2.3.3</td>
<td>M</td>
<td>M</td>
<td>T</td>
</tr>
<tr>
<td>Cipher Key Sequence Number</td>
<td>2.4.1</td>
<td>M</td>
<td>M</td>
<td>T</td>
</tr>
<tr>
<td>MS roamingnumber (Note 1)</td>
<td>2.4.2</td>
<td>M</td>
<td>M</td>
<td>T</td>
</tr>
<tr>
<td>Location area Id</td>
<td>2.5.1</td>
<td>M</td>
<td>M</td>
<td>P</td>
</tr>
<tr>
<td>VLR number</td>
<td>2.5.2</td>
<td>M</td>
<td>M</td>
<td>P</td>
</tr>
<tr>
<td>MSC number</td>
<td>2.5.3</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Roaming restriction</td>
<td>2.5.4</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>HLR number</td>
<td>2.5.5</td>
<td>M</td>
<td>M</td>
<td>P</td>
</tr>
<tr>
<td>Provision of bearer service</td>
<td>2.5.6</td>
<td>M</td>
<td>M</td>
<td>P</td>
</tr>
<tr>
<td>Provision of teleservice</td>
<td>2.5.7</td>
<td>M</td>
<td>M</td>
<td>P</td>
</tr>
<tr>
<td>BC allocation</td>
<td>2.5.8</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Subscription restriction</td>
<td>2.5.9</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Provision of supplementary service</td>
<td>2.6.1</td>
<td>M</td>
<td>M</td>
<td>P</td>
</tr>
<tr>
<td>CUG interlock code</td>
<td>2.6.2</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>CUG index</td>
<td>2.6.3</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Per call basis subscription</td>
<td>2.6.4</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Notification to calling party</td>
<td>2.6.5</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>User-to-user signalling service ind</td>
<td>2.6.6</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>CUG facility</td>
<td>2.6.7</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Preferential CUG facility</td>
<td>2.6.8</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Barring incoming calls within CUG</td>
<td>2.6.9</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Barring outgoing calls within CUG</td>
<td>2.6.10</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Maximum number of conferences</td>
<td>2.6.11</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Control of barring services</td>
<td>2.6.12</td>
<td>C</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Hunt group access selection order</td>
<td>2.6.13</td>
<td>FS</td>
<td>FS</td>
<td>FS</td>
</tr>
<tr>
<td>Forward-to number</td>
<td>2.6.14</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Registration status</td>
<td>2.6.15</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>No reply condition timer</td>
<td>2.6.16</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Call barring password</td>
<td>2.6.17</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Activation status</td>
<td>2.6.18</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>IMSI detached flag</td>
<td>2.6.19</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Radio Confirmation Indicator</td>
<td>2.6.20</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>HLR Confirmation Indicator</td>
<td>2.6.21</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>MSRN flag</td>
<td>2.6.22</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Check Supp. Services flag</td>
<td>2.6.23</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Access priority class</td>
<td>2.6.24</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Handover Number</td>
<td>2.6.25</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Messages Waiting Data</td>
<td>2.6.26</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Messages Waiting Flag</td>
<td>2.6.27</td>
<td>C</td>
<td>C</td>
<td>T</td>
</tr>
</tbody>
</table>

Note 1. See section 3.2.4.1

See section 3 for explanation of M,C,T and P in table.
Generalizing the records of CDR and VLR, leaving only:

- \{ uid: \{ imsi, imei \},
  timestamp,
  CGI: \{ MNC,MCC,LAC,CI \},
  event type \}

- In order to preserve privacy IMSI and IMEI are replaced with random unique ID, called token
- Finally the data is ordered and grouped by time, archived into daily export TAR.
Geographical coordinates regarding:
- Cell Towers
- Cells
- Cell coverage areas

are organized in a document called "Cell Plan".

Example:

Header =

\{ "CGI", "Coverage Area", "Tower ID Longitude", "Tower ID Latitude", "Site ID" \}

Record =

\{ "MCC-MNC-LAC-CI", "POLYGON(((x1,y1),(x2,y2),...,(xn,yn)))", "X.xxxxx", "Y.yyyyy", "Site-N" \}
Cell coverage area:

- Cell plan is not stable
  - New cells are attached and the old ones are taken away
  - Cell IDs are not assigned continuously
  - The free cell ID can be assigned to new cells

Consequence

Results in location updates from unknown cells
Results in rapid location changes on significant distances
Cell coverage area behaviour by design:

- Cell coverage might change, dependent on current load (amount of subscribers).

- Traversing the same route geographically will not result in the same sequence of visited cells.

What happens to the customer?

Already loaded towers may in turn offload to other, nearby towers.

A failed cell tower offloads calls to nearby towers.
Mobile network data and mobility:

- Only events driven by active phone usage are collected.
- Silent keep alive events and other location updates might not be present at all in exported data (operators' decision).

- Cell hoping
  - Rapid change of cells without actual movement. A result of “dynamic cell coverage” and depends on average load.

No phone usage might result in no events.
Absence of events does not mean absence of mobility.

We need to distinguish actual movement from hoping.
HUMAN MOBILITY AND MOBILE NETWORK DATA

MOBILE NETWORK DATA AND MOBILITY
HUMAN MOBILITY AND MOBILE NETWORK DATA

From Coverage area to Trajectories:

\[ A = \{a, b, c, d, e\ldots\} \]

From physical trace to network domain trace:

\[ T_c = abce \]
HUMAN MOBILITY AND MOBILE NETWORK DATA
(MOBILE NETWORK DATA)

Physical movement features:

- Length of routes
- Coverage area
- Speed …

Network domain movement features:

In mobile network symbolic domain there is no coordinates
HUMAN MOBILITY AND MOBILE NETWORK DATA
(MOBILE NETWORK DATA)

- In mobile network domain: number of cell changes
  - the improvement is done by using towers coordinate
  - And extract the polygon coverage area
  - Problem: the coverage area is changing depending to other factors such weather
    plus other effect not related to the movement like ping pong handover.

Record:
  - User ID
  - Event: call / texting / etc
  - CellID (coverage area ID)

Location area:
  - CellID
  - Polygon (coverage area shape)
  - Centroid (latitude, longitude)

Cell based Trajectory
Movement qualification:

**VISITATION FREQUENCY**

- Physical domain → How many times does the user visit a location/region?
- Mobile network domain → How many times does the user visit each cell tower?
HUMAN MOBILITY AND MOBILE NETWORK DATA
(MOBILE NETWORK DATA)

Movement qualification:

Diversity of visited location

Distribution of the total number of different cells per hour
Movement qualification:

- Diversity of visited location
- Amount of movement
Movement qualification:

- Diversity of visited location
- Amount of movement
- Visitation frequency: Cell Trajectory
Movement qualification:

- Diversity of visited location
- Amount of movement
- Visitation frequency:
  - Cell Trajectory
- Visitation frequency:
  - User’s events
Movement qualification:

PERIODICITY

- Physical domain → Do the user make the same routes daily/weekly/monthly?
- GSM domain → How much time does it go by between consecutive visits to the same cell?
  - Problem: ping-pong handover effect have special importance in this measurement.
Clustering Users periodicity movements

- leading eigenvalue
- multilevel
- walk trap
Cell phone subscribers mobility prediction using enhanced Markov Chain algorithm*

Problematic:

- Network-driven Data
- Extract Trajectory (Cell Based)
- Predict The Next Cell Location Area
HUMAN MOBILITY AND MOBILE NETWORK DATA
(CASE STUDY)

System Architecture:

- Network-driven data
- Extract Trajectories
- Filtering
- Historical Database
- Training process
- MC Algorithm
- Input data
- Prediction Output
Filtering Process:

- **Time filter**
  - Defining the period and the weekdays for a user trajectory

- **Ping pong handover filter**
  - Is when the users start switching randomly and several times between two neighbouring cells.

- **Gap filter**
  - Splits the trajectory where the delay between subsequent visits is longer than two hours.
Markov Chain Algorithm:

- Global Prediction Algorithm
- Local Prediction Algorithm

Enhancement: Association rules
- Universal behaviour rule
- Temporal rule
Markov Chain Algorithm:

By Applying the association rules:

- Global universal prediction algorithm (GUPA)
- Local universal prediction algorithm (LUPA)
- Global temporal prediction algorithm (GTPA)
- Local temporal prediction algorithm (LTPA)
HUMAN MOBILITY AND MOBILE NETWORK DATA
(CASE STUDY)

Markov Chain Algorithm:

Terminology:

Cellular Network $\Psi$ is the set of cells $c_i$ that cover an area with connectivity $\Phi$ is the set of all the users in the database

User’s Trajectory $T = c_1 \rightarrow c_2 \rightarrow \ldots \rightarrow c_{n-1} \rightarrow c_n$ where
Markov Chain Algorithm:

- Second order Markov process
- Discrete states are the cells of the cellular network
- Transition probability:

\[ P_g(c_{n+1}|c_{n-1}, c_n) = \frac{M(c_{n-1} \rightarrow c_n, c_{n+1})}{\sum_{c \in \Psi} M(c_{n-1} \rightarrow c_n, c)} , \]

- Where,

\[ M(c_{n+1} \rightarrow c_{n-1}, c_n) \] is the number of transition of the mobile user from cell \( c_n \) to \( c_{n+1} \) knowing that the user was before in \( c_{n-1} \)
Markov Chain Algorithm:

LPA

• First order Markov process
• Transition probability:

\[ P_i(c_{n+1} / c_n) = \frac{N(c_n, c_{n+1})}{\sum_{c \in \Psi} N(c_n, c)} \]

• Where,

\[ M(c_{n+1} \rightarrow c_{n-1}, c_n) \] is the number of transition of the mobile user from cell \( c_n \) to \( c_{n+1} \).
Markov Chain Algorithm:

**GUPA**

- Second order Markov process
- Transition probability:

\[
P_{ug}(c_{n+1} / c_{n-1}, c_n) = \frac{\sum_{\Phi} M_v(c_{n+1} \rightarrow c_{n-1}, c_n)}{\sum_{\Phi} \sum_{c \in \Psi} M_v(c_{n+1} / c_{n-1}, c_n)}
\]

- Where,

\(M_v\) is the triple transition count \(M\) for user \(v \in \Phi\)
Markov Chain Algorithm:

**LUPA**

- First order Markov process
- Transition probability:

\[
P_{ul}(c_{n+1} | c_n) = \frac{\sum_{\Phi} N_v(c_n, c_{n+1})}{\sum_{\Phi} \sum_{c \in \Psi} N_v(c_n, c)}
\]

- Where,

   \( N_v \) is the number of transition

   \( N \) for user \( v \)
Markov Chain Algorithm:

**GTPA**

Time Window:

\[ c_i \Rightarrow (b_{i-1}, e_{i-1}) \]

Window interval is defined:

\[ \delta t = [e_{n-1} - \beta, b_n + \beta] \]

\[ \beta \] is the extension parameter
HUMAN MOBILITY AND MOBILE NETWORK DATA
(CASE STUDY)

Markov Chain Algorithm:

**GTPA**

Second order Markov process

Transition probability:

\[
P_{tg}(c_{n+1}/c_{n-1}, c_n) = \frac{M(c_{n+1} \rightarrow c_{n-1}, c_n / F([e_{k-1}, b_k], \delta t))}{\sum_{c \in \psi} M(c_{n+1} \rightarrow c_{n-1}, c / F([e_{k-1}, b_k], \delta t))}
\]

Where,

\[M(.... / F(k))\] is the number of triple transition filtered by the predicate F that refers to the transition being tested through index k.

The target F ensures that time interval is not empty

\[F(d_1, d_2) = d_1 \cap d_2 \neq \emptyset\]
HUMAN MOBILITY AND MOBILE NETWORK DATA
(CASE STUDY)

Markov Chain Algorithm:

**LTPA**

- First order Markov process
- Transition probability:

\[
P_{il}(c_{n+1} / c_n) = \frac{N(c_n, c_{n+1} / c_{k,k+1} = c_{n,n+1} \land F([e_k, b_{k+1}], \delta t))}{\sum_{c \in \Psi} N(c_n, c_{n+1} / c_{k,k+1} = c_{n,n+1} \land F([e_k, b_{k+1}], \delta t))}
\]

- Where,

\[
N(c_n, c_{n+1} / c_{k,k+1} = c_{n,n+1} \land F([e_k, b_{k+1}], \delta t)) \text{ is the number of transition filtered from } c_n \text{ to } c_{n+1} \text{ with respect to } F.
\]
HUMAN MOBILITY AND MOBILE NETWORK DATA
(CASE STUDY)

Testing and Results:

Strategy adopted:

- Unitary Test
- Test following Markov structure:
  - (GPA + LPA)
  - (GUPA + LUPA)
  - (GTPA + LTPA)
- Test different combinations:
  - (GPA + LUPA)
  - (GPA + LTPA)
  - (GUPA + LPA)
  - (GUPA + LTPA)
  - (GTPA + LPA)
  - (GTPA + LUPA)
HUMAN MOBILITY AND MOBILE NETWORK DATA
(CASE STUDY)

Testing and Results:

**EVALUATION CRITERIA:**

\[
\% \text{Correct Predictions} = \frac{\text{number of correct predictions}}{\text{Total number of the users}} \times 100
\]

\[
\% \text{Wrong Predictions} = \frac{\text{number of wrong predictions}}{\text{Total number of the users}} \times 100
\]

\[
\% \text{Failure} = \frac{\text{number of failure}}{\text{Total number of the users}} \times 100
\]

\[
\text{Localization ratio} = \frac{\text{number of correct predictions}}{\text{Total number of attempts to predict}} \times 100
\]
HUMAN MOBILITY AND MOBILE NETWORK DATA  
(CASE STUDY)

Testing and Results:

<table>
<thead>
<tr>
<th>Dataset: Test1</th>
<th>%Correct Predictions (%)</th>
<th>%Wrong Predictions (%)</th>
<th>%Failure (%)</th>
<th>Localization ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPA</td>
<td>81.46</td>
<td>6.25</td>
<td>12.29</td>
<td>52.82</td>
</tr>
<tr>
<td>LPA</td>
<td>53.98</td>
<td>23.76</td>
<td>22.26</td>
<td>18.63</td>
</tr>
<tr>
<td>GUPA</td>
<td>34.44</td>
<td>61.34</td>
<td>4.22</td>
<td>0.61</td>
</tr>
<tr>
<td>LUPA</td>
<td>17.58</td>
<td>82.4</td>
<td>0.02</td>
<td>0.07</td>
</tr>
<tr>
<td>GTPA</td>
<td>95.67</td>
<td>0.36</td>
<td>3.97</td>
<td>90.57</td>
</tr>
<tr>
<td>LTPA</td>
<td>66.6</td>
<td>10.02</td>
<td>23.39</td>
<td>38.41</td>
</tr>
</tbody>
</table>
HUMAN MOBILITY AND MOBILE NETWORK DATA
(CASE STUDY)

Testing and Results:

<table>
<thead>
<tr>
<th>Dataset: Test2</th>
<th>%Correct Predictions (%)</th>
<th>%Wrong Predictions (%)</th>
<th>%Failure (%)</th>
<th>Localization ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPA</td>
<td>9.57</td>
<td>2.25</td>
<td>88.18</td>
<td>17.9</td>
</tr>
<tr>
<td>LPA</td>
<td>53.87</td>
<td>23.8</td>
<td>22.33</td>
<td>18.43</td>
</tr>
<tr>
<td>GUPA</td>
<td>28.75</td>
<td>52.19</td>
<td>19.06</td>
<td>0.5</td>
</tr>
<tr>
<td>LUPA</td>
<td>18.18</td>
<td>81.81</td>
<td><strong>0.01</strong></td>
<td>0.07</td>
</tr>
<tr>
<td>GTPA</td>
<td>2.7</td>
<td><strong>0.05</strong></td>
<td>97.25</td>
<td><strong>36.48</strong></td>
</tr>
<tr>
<td>LTPA</td>
<td>6.6</td>
<td>2.85</td>
<td>90.55</td>
<td>12.61</td>
</tr>
</tbody>
</table>
Testing and Results:

MARKOV TEST AND DIFFERENT COMBINATIONS:
Testing and Results:

**MARKOV TEST AND DIFFERENT COMBINATIONS:**
HUMAN MOBILITY AND MOBILE NETWORK DATA
(CASE STUDY)

Testing and Results:

MARKOV TEST AND DIFFERENT COMBINATIONS:
Conclusion:

- The testing showed:
  - Best combination for Markov structure is GTPA+LPA

- However:
  - The accuracy of the approach is not that high when it comes to unknown users.

- To make it better:
  - Test some other predicting algorithms that we can add to the system such as particle filter or particle Kalman.
THANK YOU FOR YOUR ATTENTION

— Intelligent Transportation Systems - MTAT.08.040 - Lecture 8