Mobility patterns: implications on network parameters and handover

Enrica Zola
Second Joint ERCIM eMobility and MobiSense Workshop
St. Petersburg, June 4\(^{th}\), 2013
Overview

- Wireless networks → support to mobility

Layout

- Network planning
- Min. coverage
- Higher density for capacity
Overview

- Wireless networks → support to mobility

**Mobility pattern**
- User behaviour
- Real vs simulated patterns
  - RWP

**Layout**

St. Petersburg – June 4th, 2013
Overview

- Wireless networks → support to mobility

Mobility pattern

Layout

Handover
- Resource allocation
- Predictions

Mobility patterns: implications on network parameters and handover St. Petersburg – June 4th, 2013
1. Impact of mobility patterns on teletraffic variables
   - Number of handovers and cell residence time in different scenarios and with different mobility patterns

2. Forecasting the handover for RWP users

3. User behaviour in real WLANs
   - Analysis of the cell residence time
   - How much are they mobile?
   - Comparison with similar studies
Impact of Mobility Patterns on Teletraffic Variables

- Impact of Mobility Patterns on Teletraffic Variables
- Forecasting the Handover
- User Behaviour in Real WLANs
- Conclusions
Motivation

- Importance of choosing an appropriate mobility model for a given network performance evaluation
  

- Special interest on the impact of mobility models on routing in MANETs

- For simplicity, many authors assumed the cell residence time (crt) to be exponentially distributed
  

- Impact of the mobility model on crt and number of handover
  
Simulation setup

- Simulation with *Omnet + INET Framework*

- Different layouts in a square area
  - 4, 8 or 16 Access Points (AP)
  - Full coverage with minimum nº of APs and overcoverage for high capacity

- Different mobility models
  - One memory-less mobility pattern (*RWP*)
  - One with memory (*Gauss-Markov*)
  - Pedestrian users (speed among 0.7 and 2.0 m/s)
Cell Residence Time

- With more APs
  - Mean cell residence time (crt) decreases for all models
  - Higher stability for RWP
  - Higher variability for Gauss-Markov patterns
- With higher speed
  - Mean crt decreases
    - Not for Gauss-Markov 4AP scenario
  - More stability
    - Not for Gauss-Markov
- Smoother changes in the movements → higher variability in the statistics (crt)
Statistical Distribution

- Histogram of the cell residence time for 4AP scenario and RWP
  - High concentration of very short values (< 5 s)
  - Pdf can be a combination of two distributions
- Same pattern for the other scenarios
Goodness of Fit Test

- Crt > 5 seconds
- MLE to estimate the parameters for the two distributions
- Kolmogorov-Smirnov GOF test (α=5%)
  - Higher $p$-value = better fit

\[
\begin{array}{c|cc|cc}
\text{ } & \multicolumn{2}{c|}{\text{Gamma}} & \multicolumn{2}{c}{\text{Lognormal}} \\
\hline
\text{4AP} & \text{RWP} & 0.99 & \text{Lognormal} & 0.85 \\
 & \text{Gauss-Markov} & 0.83 & & 0.83 \\
\hline
\text{8AP} & \text{RWP} & 0.96 & \text{Lognormal} & 0.99 \\
 & \text{Gauss-Markov} & 0.42 & & 0.99 \\
\hline
\text{16AP} & \text{RWP} & 0.74 & \text{Lognormal} & 0.74 \\
 & \text{Gauss-Markov} & 0.57 & & 0.99 \\
\end{array}
\]
Number of Handovers

<table>
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<tr>
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<th>8AP</th>
<th>16AP</th>
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<tbody>
<tr>
<td>RWPu-0</td>
<td>10.96</td>
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<td>2.85</td>
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<tr>
<td>Gauss-Markov</td>
<td>7.05</td>
<td>6.79</td>
<td>7.37</td>
</tr>
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</table>

- Average number of handovers *per hour and AP*
- With a higher number of AP
  - RWP: decreases
  - BMGauss: very stable
Forecasting the Handover

- Impact of Mobility Patterns on Teletraffic Variables
- Forecasting the Handover
- User Behaviour in Real WLANs
- Conclusions
Motivation

• Interest in mobility prediction to aid the HO process + RWP largely used in simulation and extensively studied
  • Mathematical expressions for: transition length and time; cell change rate; mean arrival rate

• Analytical framework for forecasting the handover
• Probability that, within a given interval, a user will perform a handover
  • To which of the neighbouring cells?

---


Problem Statement

- Movements inside a circular area $A$
- APs are placed on a regular polygon inside $A$
- Ideal conditions (no fading, no noise)
- When the node is inside an overlapping area, the HO starts when the node exits the coverage area of the current cell
- A maximum of one change in transition may occur during $\Delta t$
- Current position $P_t$ at time $t$ is known
- Position and time of last waypoint are known
Probability of Handover

- Split the problem
  
  A. If MN changes transition after $\Delta t \rightarrow v_j \cdot \Delta t \leq x_t$ (No HO) or $v_j \cdot \Delta t > x_t$ (HO)

  B. If MN changes transition before $\Delta t \rightarrow Pr\{HOa\}$

  $Pr\{HO\} = Pr\{HO \text{ in } \Delta t \mid \text{ change tr. after } \Delta t\} \cdot Pr\{\text{change transition after } \Delta t\} + Pr\{Ho\} \cdot Pr\{\text{change tr. at } tc<\Delta t\}$
Example – \( \text{Pr}\{\text{HOa}\} \)

Time = \( t \)

\[ \text{AP}_1 \quad \text{AP}_2 \quad \text{AP}_3 \quad \text{AP}_4 \]

\[ \text{WP}_j \]

\[ \text{Min} \cdot \Delta t \quad \text{Max} \cdot \Delta t \]
Example – $\Pr\{\text{HOa}\}$

Time = $t + 0.1/v_j$
Example – $\Pr\{\text{HOa}\}$

Time = $t + 0.2/v_j$
Example – \( \text{Pr}\{\text{HOa}\} \)

\[
\text{Time} = t + \Delta t
\]
## Numerical vs Simulation

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<th></th>
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<th>$\text{Pr}{\text{HO3}}$</th>
<th>$\text{Pr}{\text{HO4}}$</th>
<th>$\text{Pr}{\text{HO}}$</th>
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<tr>
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<td>57.00</td>
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User Behaviour in Real WLANs

- Impact of Mobility Patterns on Teletraffic Variables
- Forecasting the Handover
- User Behaviour in Real WLANs
- Conclusions
**Motivation**

- Research on the use of the WLAN in real environments
  - **Different scenarios**: campus-wide universities, corporate networks, conference rooms, ...
  - Data collected from 1999 to 2004 (OLD)


- Mobility trends in our university


### Cell Residence Time

<table>
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<tr>
<th></th>
<th>AP102</th>
<th>AP202</th>
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<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>415.92 s (7 min)</td>
<td>294.67 s (5 min)</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>86 s</td>
<td>66 s</td>
</tr>
<tr>
<td><strong>Max Value</strong></td>
<td>14339 s (~4 hours)</td>
<td>15558 s (4h 20m)</td>
</tr>
<tr>
<td><strong>CV</strong></td>
<td>2.99</td>
<td>3.38</td>
</tr>
<tr>
<td><strong>Sample</strong></td>
<td>1036</td>
<td>929</td>
</tr>
</tbody>
</table>

- **Very high concentration of short crt**
  - Median: 1 to 1.5 minutes

- **New analysis**
  - No HO users: users connected to only one AP per day
  - HO users: users connected to different APs per day
Cell Residence Time

<table>
<thead>
<tr>
<th></th>
<th>AP102</th>
<th></th>
<th>AP202</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
<td>No HO</td>
<td>HO</td>
<td>Overall</td>
</tr>
<tr>
<td>Mean</td>
<td>415.92 (7 min)</td>
<td>1479.80 (~25 min)</td>
<td>272.6 (~5 min)</td>
<td>294.67 (5 min)</td>
</tr>
<tr>
<td>Median</td>
<td>86</td>
<td>218</td>
<td>76</td>
<td>66</td>
</tr>
<tr>
<td>Max Value</td>
<td>14339 (~4 hours)</td>
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<td>10389 (~3 hours)</td>
<td>15558 (4h 20m)</td>
</tr>
<tr>
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<td>1.80</td>
<td>2.93</td>
<td>3.38</td>
</tr>
<tr>
<td>Sample</td>
<td>1036</td>
<td>123 (11.87%)</td>
<td>913 (88.13%)</td>
<td>929</td>
</tr>
</tbody>
</table>

- No HO users
  - Higher mean crt
  - More stable results
### Cell Residence Time

#### Library building in main campus

<table>
<thead>
<tr>
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<th>AP102 Overall</th>
<th>AP102 No HO (7 min)</th>
<th>AP102 HO (~5 min)</th>
<th>AP202 Overall</th>
<th>AP202 No HO (5 min)</th>
<th>AP202 HO (~10 min)</th>
<th>AP202 HO (~4 min)</th>
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<td>294.67</td>
<td>631.50 (~10 min)</td>
<td>258.99 (~4 min)</td>
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<td><strong>Median</strong></td>
<td>86</td>
<td>218</td>
<td>76</td>
<td>66</td>
<td>136</td>
<td>61</td>
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<td>14339 (~4 hours)</td>
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<td>15558 (4h 20m)</td>
<td>11976 (3h 20m)</td>
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<td><strong>CV</strong></td>
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<td>2.93</td>
<td>3.38</td>
<td>2.75</td>
<td>3.38</td>
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<tr>
<td><strong>Sample</strong></td>
<td>1036</td>
<td>123 (11.87%)</td>
<td>913 (88.13%)</td>
<td>929</td>
<td>89 (9.58%)</td>
<td>840 (90.42%)</td>
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</table>

- **No HO users**
  - Higher mean crt
  - More stable results
- **HO users** (≈90% of the population)
  - Mean crt is 4.5 minutes
  - Still high CV
Cell Residence Time

- Density function
  - High concentration of very short **crt**
  - Even for “No HO users”
Analysis in different buildings

- Mobility inside each building is low
  - Also observed in other campuses
- Many devices never associate to more than one AP during the day
- Active devices unevenly distributed across APs
  - Some APs often deal with a high number of users simultaneously associated with them, while others are usually idle
- Users on a small campus are more likely to reappear on different days (higher fidelity)
Activity Trends Comparison

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Environment</th>
<th>Buildings</th>
<th>% of users up to 2 days:</th>
<th>50% of users connect up to [% of total days]:</th>
<th>10% of the users connect more than [% of total days]:</th>
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<tbody>
<tr>
<td>Our work</td>
<td>Campus</td>
<td>BRGF</td>
<td>53</td>
<td>5</td>
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<td></td>
<td>11</td>
<td>25</td>
<td>75</td>
</tr>
</tbody>
</table>

- Very different behaviour in same environment
- The distribution in [KO] is roughly uniform between one and 77 days


Activity Trends Comparison

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<td>Medium</td>
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<td></td>
<td></td>
<td>Small</td>
<td>38</td>
<td>30</td>
<td>60</td>
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</tbody>
</table>

- Very similar behaviour in corporate network
  - At UPC, students do not spend the night inside the Campus

Conclusions

- Impact of Mobility Patterns on Teletraffic Variables
- Forecasting the Handover
- User Behaviour in Real WLANs
- Conclusions
Conclusions (I)

- Network planning benefits from the knowledge of users’ movements
  - An analytical framework has been proposed in order to predict future associations for users moving with one of the most used mobility models (RWP)
    - The error in the prediction is always very low
    - The prediction may be used in order to allocate resources and facilitate the handover task
  - Real traces show low mobility but high number of handovers (short crt) and uneven distribution among the APs
Conclusions (II)

- The mobility pattern has key consequences on the traffic properties
  - Smoother mobility patterns mean higher cell residence time (i.e. Gauss-Markov) and higher variability
  - The HO behaviour of Gauss-Markov pattern is very stable compared to the RWP
  - Cell residence time as a combination of two distributions
    - Very short connections
      - Also observed in real traces
    - Another distribution depending on the mobility pattern
Questions?

- Impact of Mobility Patterns on Teletraffic Variables
- Forecasting the Handover
- User Behaviour in Real WLANs
- Conclusions
Mobility Models: RWP

MN movements - Random Waypoint pause=1
MN position at t=0
Mobility Models: Gauss-Markov
Random Waypoint

- Waypoints uniformly distributed in $A$
- Speed from uniform distribution $[v_{min}; v_{max}]$
Problem Statement

- Movements inside a circular area $A$
- APs are placed on a regular polygon inside $A$
- Ideal conditions (no fading, no noise)
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- APs are placed on a regular polygon inside $A$
- Ideal conditions (no fading, no noise)
- When the node is inside an overlapping area, the HO starts when the node exits the coverage area of the current cell
- A maximum of one change in transition may occur during $\Delta t$
Probability of Handover

- If MN changes transition at \( tc < \Delta t \rightarrow Pr\{HOa\} \)
  - At the WP, a new speed and a new WP are chosen
  - Area with all the possible positions that the node may reach when it changes transition
  - Orange area → handover

\[
Pr\{HOa| r = 0\} = \int_{\theta A_4}^{\theta A_1} f_{\Theta}(\theta|d_t(0)) \cdot \frac{d3(\theta, 0)}{d3(\theta, 0)} d\theta + \int_{\theta A_1}^{\theta A_3} f_{\Theta}(\theta|d_t(0)) \cdot \frac{d1(0)}{d1(0)} d\theta + \\
\int_{\theta A_2}^{\theta A_3} f_{\Theta}(\theta|d_t(0)) \cdot \frac{d2(\theta, 0)}{d1(0)} d\theta.
\]

\[
Pr\{HOa\} = \begin{cases} 
Pr\{HOa|r\} \cdot f_{R}(r)dr & \text{if } x_t(\theta') < v_j \cdot \Delta t \text{ and } x_t(\theta') < x_A(\theta) \\
Pr\{HOa|r\} \cdot f_{R}(r)dr & \text{if } x_t(\theta') \geq x_A(\theta)
\end{cases}
\]

Forecasting the handover