Mobility patterns: implications on network parameters and handover

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Second Joint ERCIM eMobility and MobiSense Workshop

St. Petersburg, June 4th, 2013

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Overview

- Wireless networks → support to mobility

Layout

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

Overview

- Wireless networks → support to mobility

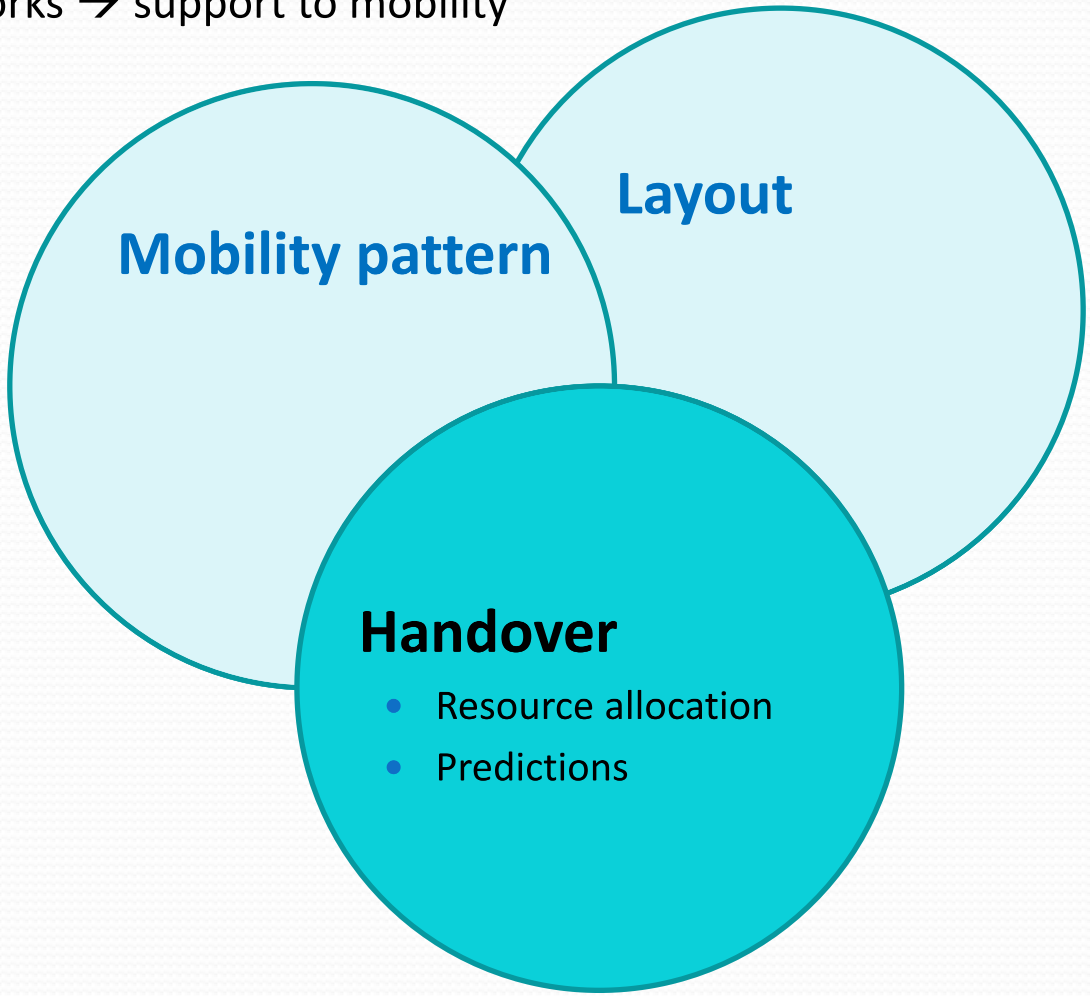
Mobility pattern

- User behaviour
- Real vs simulated patterns
  - RWP

Layout

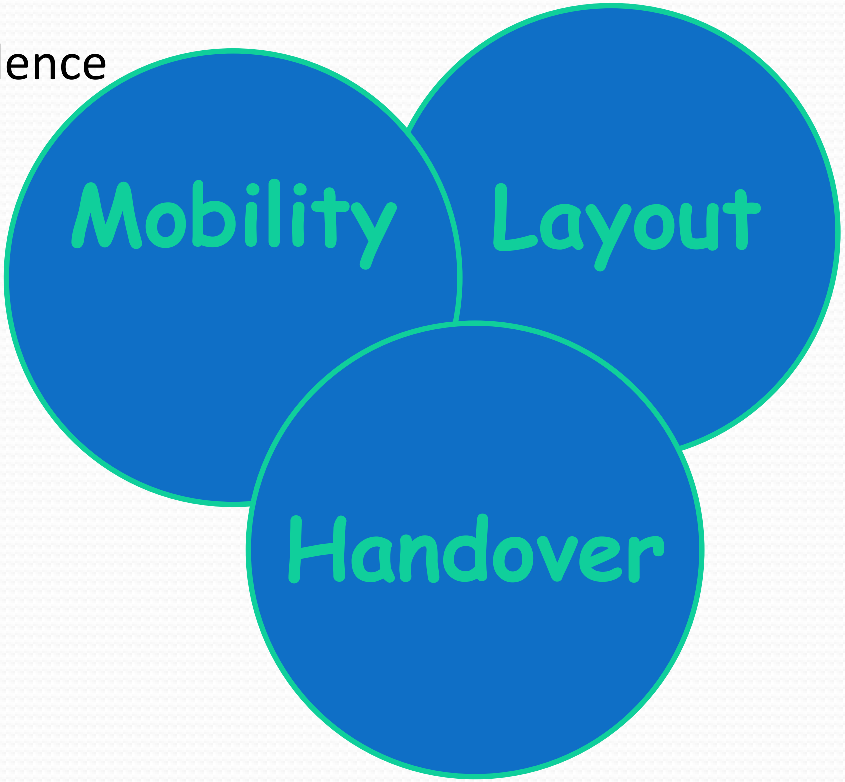
Overview

- Wireless networks → support to mobility



Outline

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

> Camp, T., Boleng, J., and Davies, V. "A Survey of Mobility Models for Ad-Hoc Network Research", *Wireless Communications and Mobile Computing*, vol. 2, pp. 483-502, Aug. 2002

  - 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
  - More recent studies from real traces → heavy-tail distribution

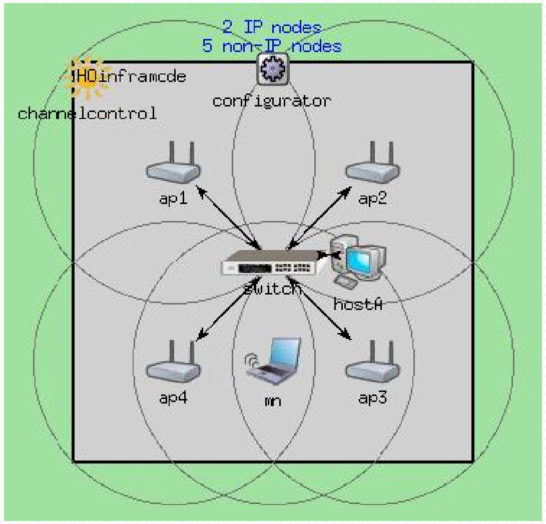
> Thajchayapong, S., Peha, J.M., "Mobility Patterns in Microcellular Wireless Networks", *IEEE Transactions on Mobile Computing*, vol. 5, no. 1, pp. 52-63, Jan. 2006

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

> E. Zola, F. Barcelo-Arroyo, "Impact of mobility models on the cell residence time in WLAN networks", *Proc. IEEE Sarnoff Symposium*, ISBN: 978-1-4244-3382-7, Princeton (USA), March 2009

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)

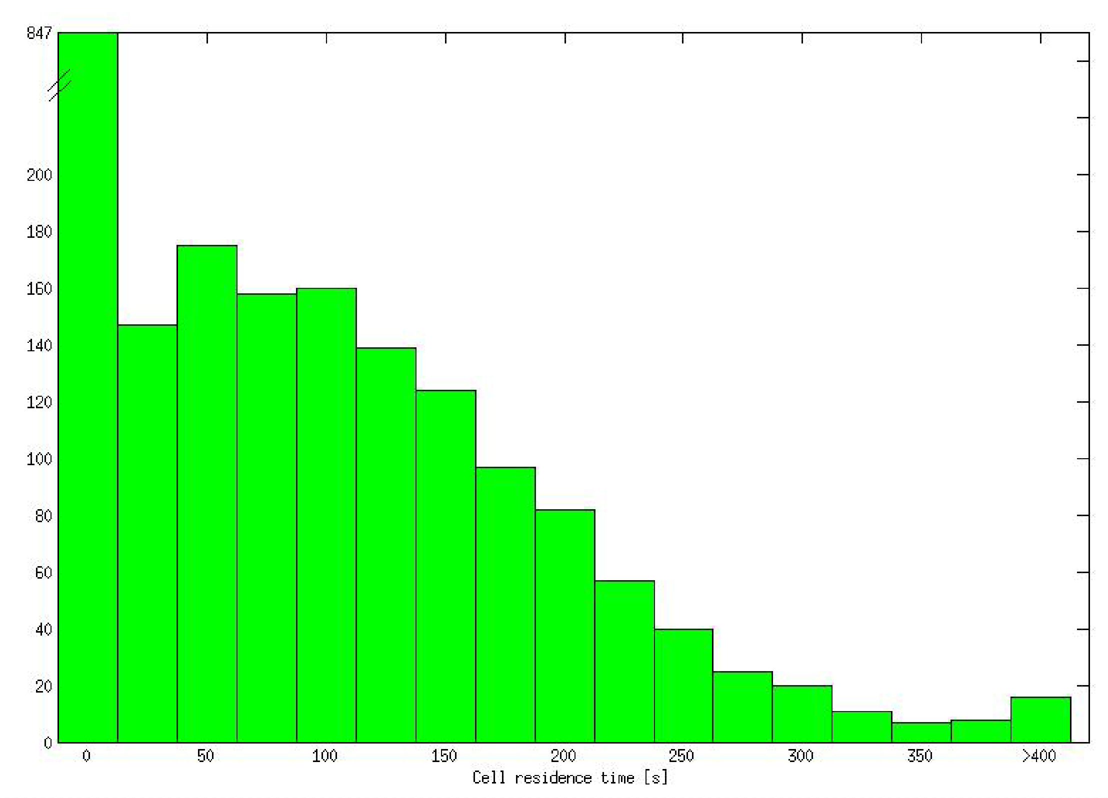


Cell Residence Time

- 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)

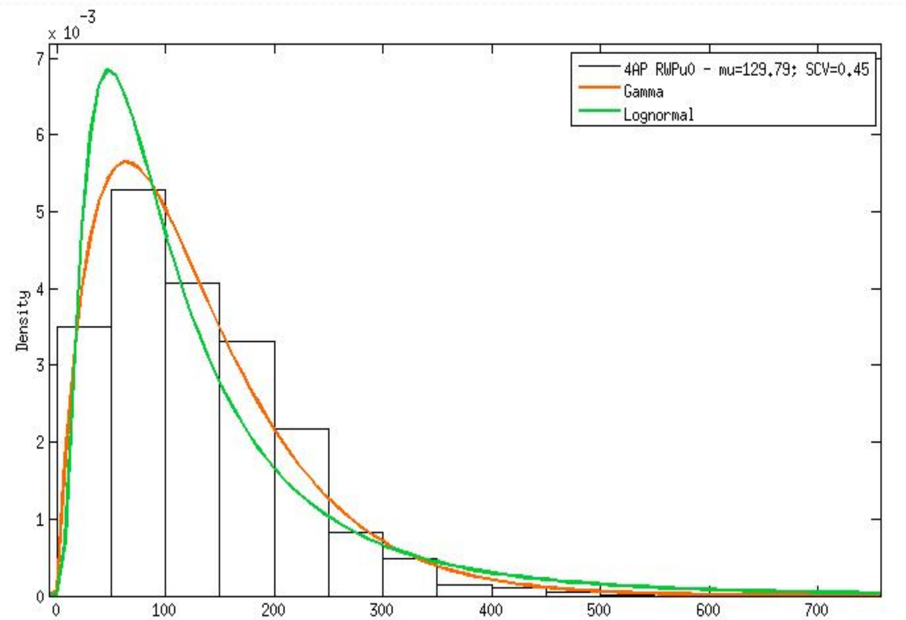
Statistical Distribution

- 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



		p-value Gamma	*p-value* Lognormal
4AP	***RWP***	0.99	0.85
	Gauss-Markov	0.83	0.83
8AP	***RWP***	0.96	0.99
	Gauss-Markov	0.42	0.99
16AP	***RWP***	0.74	0.74
	Gauss-Markov	0.57	0.99

Number of Handovers

	4AP	8AP	16AP
RWPu-0	10.96	6.34	4.92
RWPu-100	7.13	3.89	2.85
Gauss-Markov	7.05	6.79	7.37

- 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

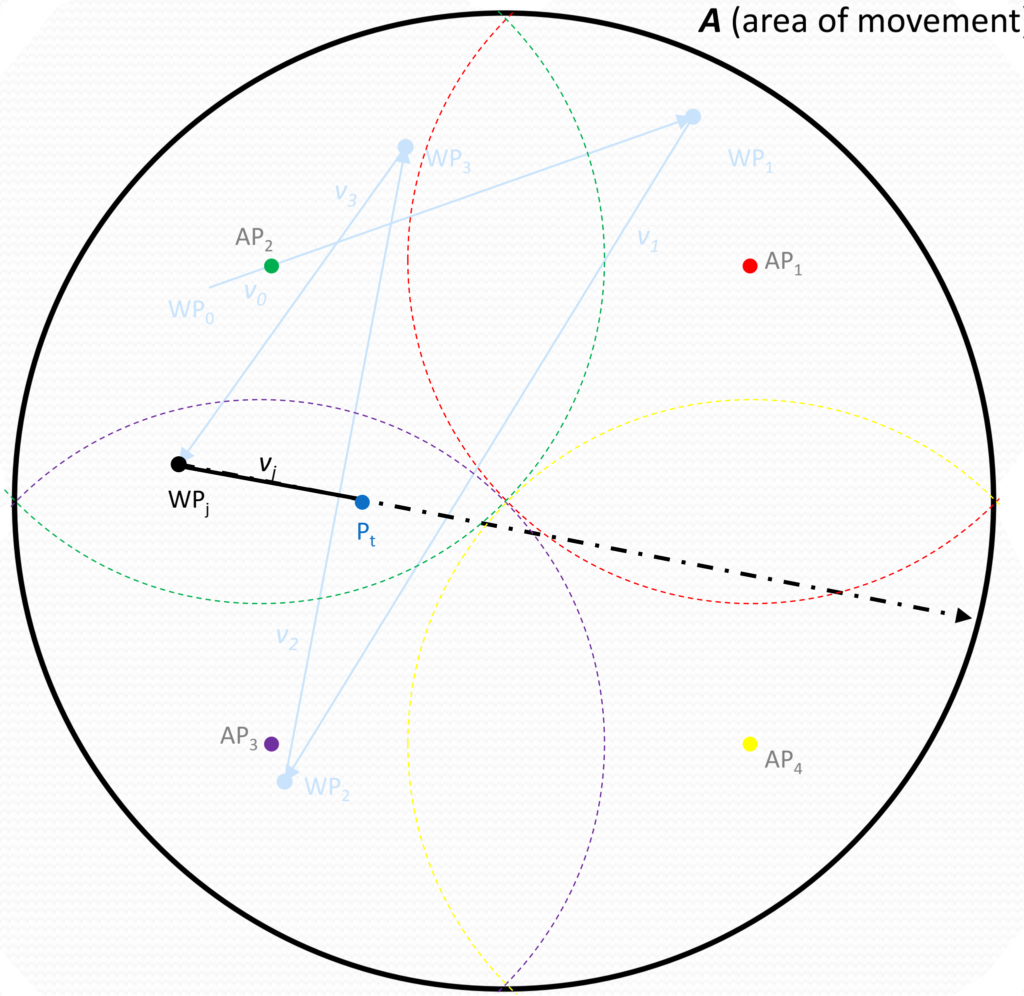
> Bettstetter, C., Hartenstein, H., and Pérez-Costa, X., "Stochastic Properties of the Random Waypoint Mobility Model", ACM *Wireless Networks*, vol. 10, no. 5, pp. 555-567, Sept 2004
>
> Hyytiä, E. And Virtamo, J., "Random Waypoint Mobility Model in Cellular Networks", *ACM Wireless Networks*, vol. 13, no. 2, pp. 177-188, 2007

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

> E. Zola, F. Barcelo-Arroyo, I. Martín-Escalona, "Forecasting the Next Handoff for Users Moving with the Random Waypoint Mobility Model", *EURASIP Journal on Wireless Communications and Networking, 2013:16,* January 2013

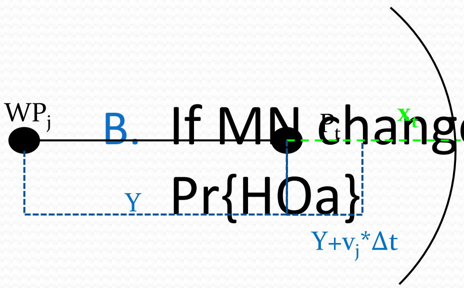
Problem Statement

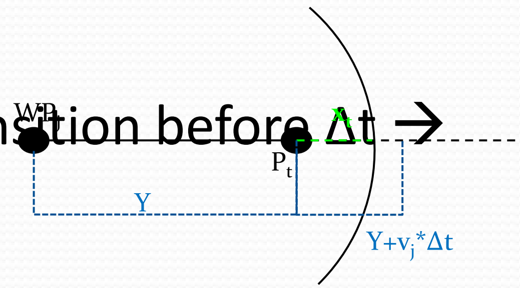
- Movements inside a circular area *A*
- APs are placed on a regular polygon inside *A*
- Ideal conditions (no fading, no noise)
- When the node is inside an overlapping area, the HO starts when the node exits the coverage area of the current cell
- A maximum of one change in transition may occur during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

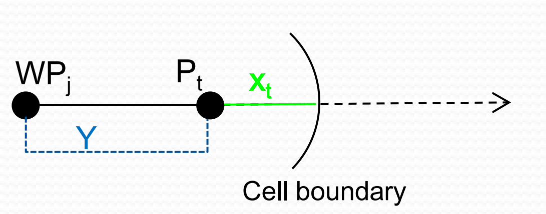


Probability of Handover

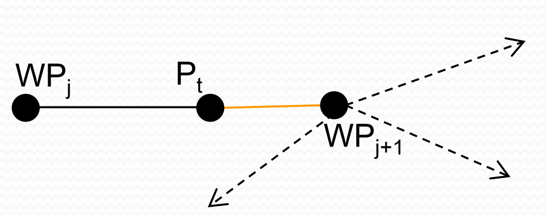
- Split the problem
  A. If MN changes transition after Δt → $v_j \cdot \Delta t \leq x_t$ (No HO) or $v_j \cdot \Delta t > x_t$ (HO)
  B. If MN changes transition before Δt → Pr{HOa}







Change in transition after Δt

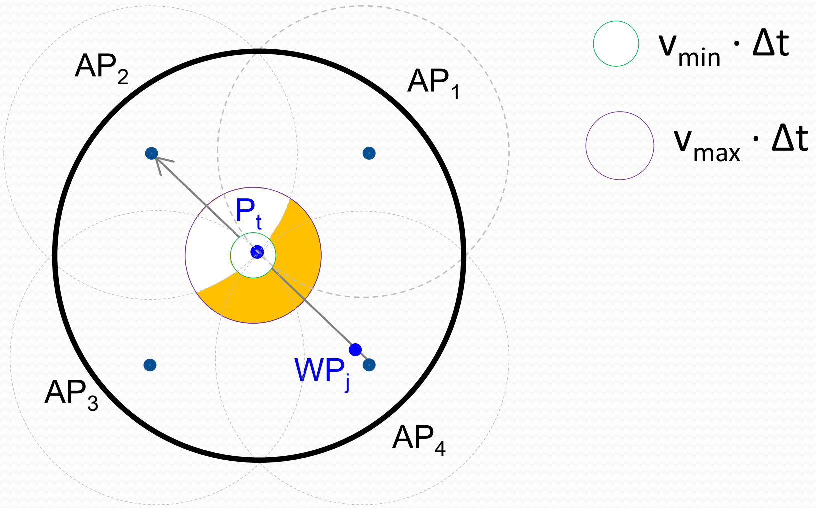


Change in transition before Δt

Pr{HO} = Pr{HO in Δt | change tr. after Δt} · Pr{change transition after Δt} + Pr{Hoa} · Pr{change tr. at tc<Δt}

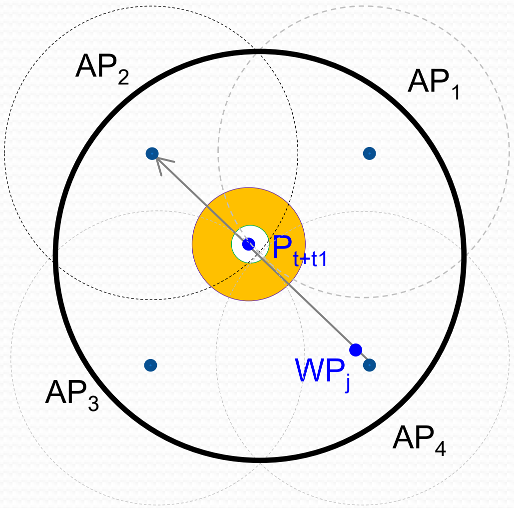
Example – Pr{HOa}

Time = t



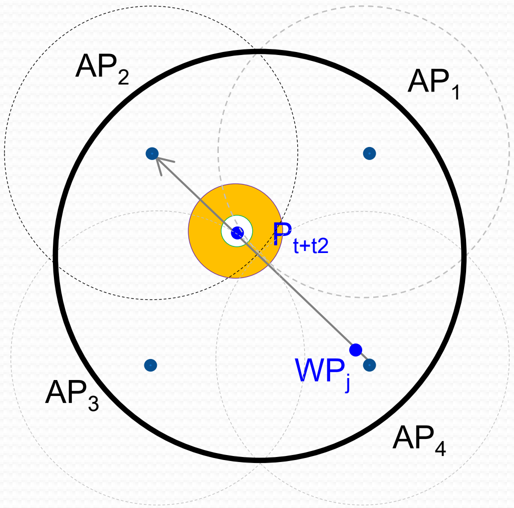
Example – Pr{HOa}

Time = t + 0.1/v_j



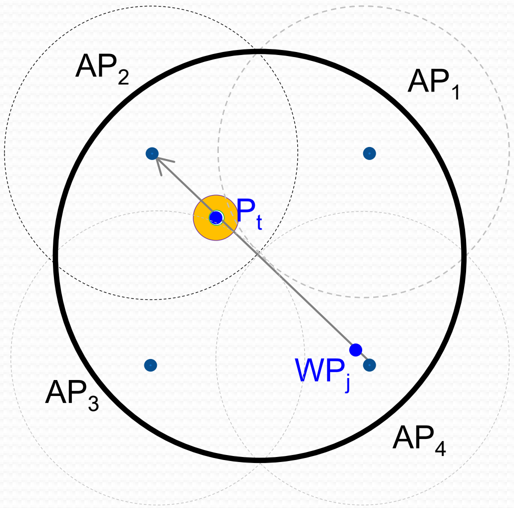
Example – Pr{HOa}

Time = t + 0.2/v_j



Example – Pr{HOa}

Time = t + Δt



Numerical vs Simulation

	Pr{HO1}	*Pr{HO2}*	*Pr{HO3}*	*Pr{HO4}*	*Pr{HO}*	*Pr{NOHO}*
1	0.83 0.64	0 (*) 0	0.83 0.58	0.06 0.02	1.72 1.24	98.28 98.76
2	0.62 0.46	97.43 98.08	0.62 0.49	0 (*) 0	98.68 99.02	1.32 0.98
3	0 (*) 0	0 0	0 0	29.94 26.20	29.94 26.20	70.06 73.80
4	99.90 99.65	0.02 0.08	0.04 0.11	0 (*) 0	99.96 99.84	0.04 0.16
5	0 (*) 0	0 0	0 0	0 0	0 0	100 100
6	0.75 0.35	0 (*) 0	0.78 0.44	0.01 0.00	1.54 0.79	98.46 99.21
7	0 (*) 0	68.20 70.76	2.04 0.96	8.99 6.27	79.23 77.98	20.77 22.02
8	0 (*) 0	90.43 93.66	2.48 1.20	3.31 2.40	96.22 97.27	3.78 2.73
9	0.02 0.01	0.14 0.06	0 (*) 0	81.18 84.87	81.34 84.94	18.66 15.06
10	0 (*) 0	19.59 25.30	5.35 3.21	11.21 14.50	36.15 43.00	63.85 57.00

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)

Kotz, D. And Essien, K., “Analysis of a Campus-Wide Wireless Network”, *ACM Wireless Networks*, vol. 11, no. 1-2, pp. 115-133, 2005

Henderson, T., Kotz, D. and Abyzov, I., “The Changing Usage of a Mature Campus-Wide Wireless Network”, *ACM Wireless Networks*, vol. 52, no. 14, pp. 2690-2712, 2008

Balanziska, M. and Castro, P., “Characterizing Mobility and Network Usage in a Corporate Wireless Local-Area Network”, in *Proc. MobiSys*, pp. 303-316, May 2003

Balachandran, A., Voelker, GM., Bahl, P., and Rangan, PV., “Characterizing User Behavior and Network Performance in a Public Wireless LAN”, in *Proc. SIGMETRICS*, pp. 195-205, June 2002

- Mobility trends in our university

E. Zola, F. Barcelo-Arroyo, M. López-Ramírez, “User behaviour in a WLAN campus: a real case study”, *Proc. Third ERCIM Workshop on* eMobility, pp. 67-77, Enschede (The Netherlands), 27-28 May 2009

E. Zola, F. Barcelo-Arroyo, “A comparative analysis of the user behavior in academic WiFi networks”, *Proc. of the 6th ACM PM2HW2N Workshop*, pp. 59-66, Miami Beach (Florida, USA), October 31-November 4, 2011

Cell Residence Time

Library building in main campus

	AP102	AP202
Mean	415.92 s (7 min)	294.67 s (5 min)
Median	86 s	66 s
Max Value	14339 s (~4 hours)	15558 s (4h 20m)
CV	2.99	3.38
Sample	1036	929

- **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

Library building in main campus

	AP102			AP202		
	Overall	No HO	HO	Overall	No HO	HO
Mean	415.92 (7 min)	**1479.80 (~25 min)**	272.6 (~5 min)	294.67 (5 min)	**631.50 (~10 min)**	258.99 (~4min)
Median	86	**218**	76	66	**136**	61
Max Value	14339 (~4 hours)	**14339 (~4 hours)**	10389 (~3 hours)	15558 (4h 20m)	**15558 (4h 20m)**	11976 (3h 20m)
CV	2.99	**1.80**	2.93	3.38	**2.75**	3.38
Sample	1036	**123 (11.87%)**	913 (88.13%)	929	**89 (9.58%)**	840 (90.42%)

- **No HO users**
  - Higher mean crt
  - More stable results

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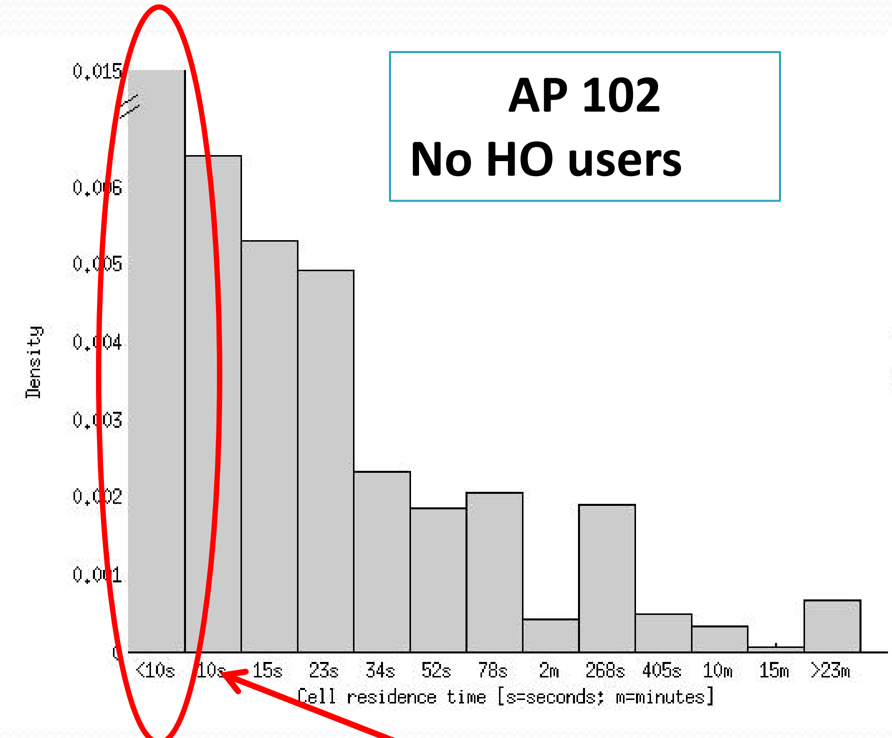
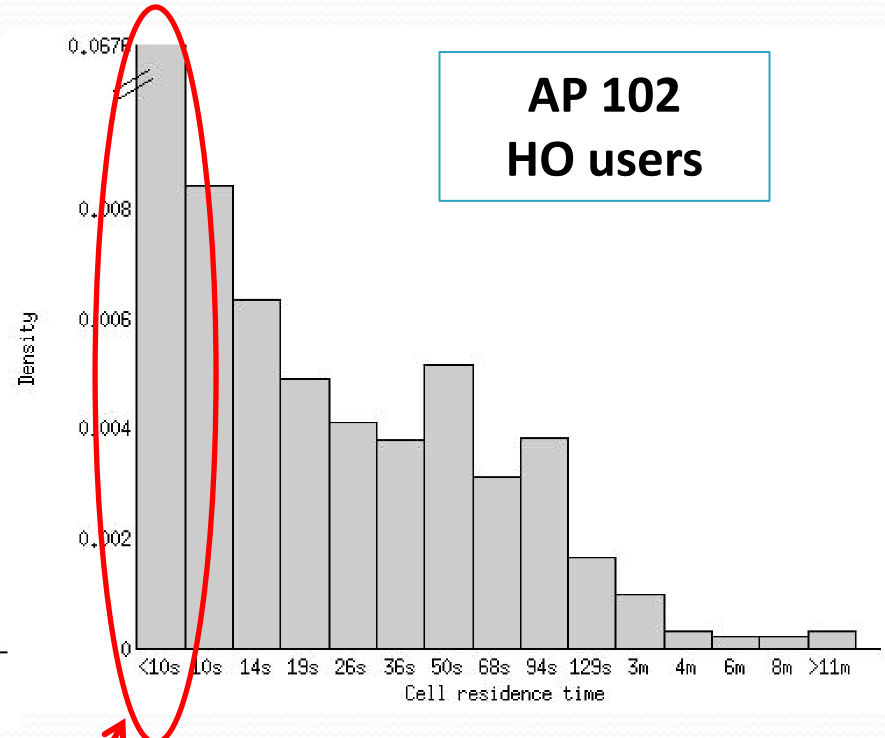
- No HO users
  - Higher mean crt
  - More stable results
- **HO users** (≈90% of the population)
  - Mean crt is 4.5 minutes
  - Still high CV

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

Ref.	Environment	Buildings	% of users up to 2 days:	50% of users connect up to [% of total days]:	10% of the users connect more than [% of total days]:
Our work	Campus	BRGF EDSE EETAC	53 35 24	5 10 15	31 51 59
[KO]	Campus		10	36	91
[MC]	Campus		11	25	75

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

[KO] D. Kotz, and K. Essien, "Analysis of a Campus-Wide Wireless Network," *Wireless Networks*, vol. 11, no. 1-2, January 2005, pp. 115-133
[MC] M. McNett, and G.M. Voelker, "Access and Mobility of Wireless PDA Users," *ACM Sigmobile Mobile Computing and Communications Review*, vol. 9, no. 2, April 2004, pp. 40-55

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Our work	Campus	BRGF EDSE EETAC	53 35 24	5 10 15	31 51 59
[BA]	Corporate network	Large Medium Small	24 22 38	12 27 30	67 63 60

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

[BA] M. Balazinska, and P. Castro, "Characterizing Mobility and Network Usage in a Corporate Wireless Local-Area Network," *Proc. of the 1st International Conference on Mobile Systems. Applications and Services* (MobiSys'03), ACM, New York, May 5-8, 2003, pp. 303-316

Conclusions

- Impact of Mobility Patterns on Teletraffic Variables
- Forecasting the Handover
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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?

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- Forecasting the Handover
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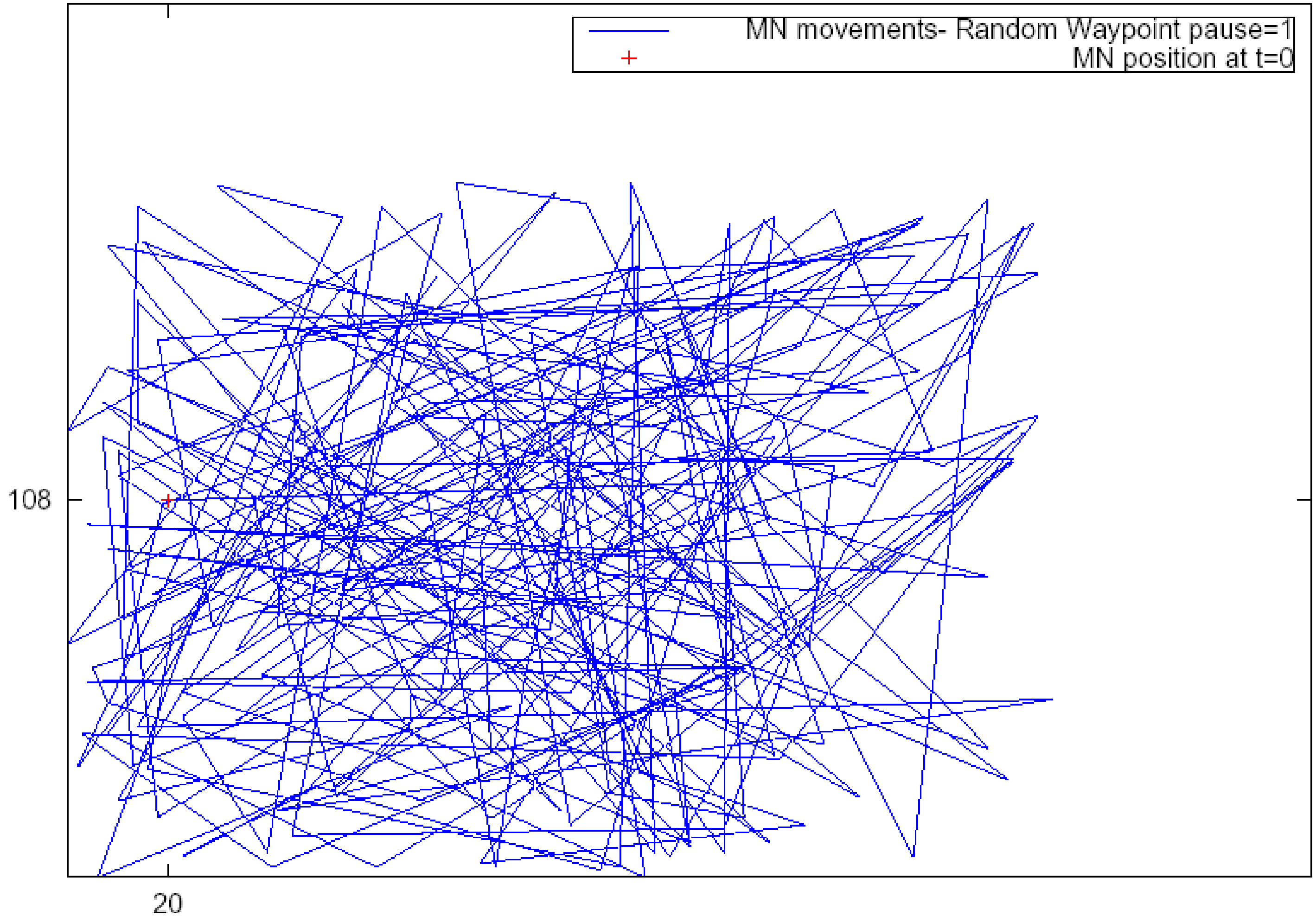
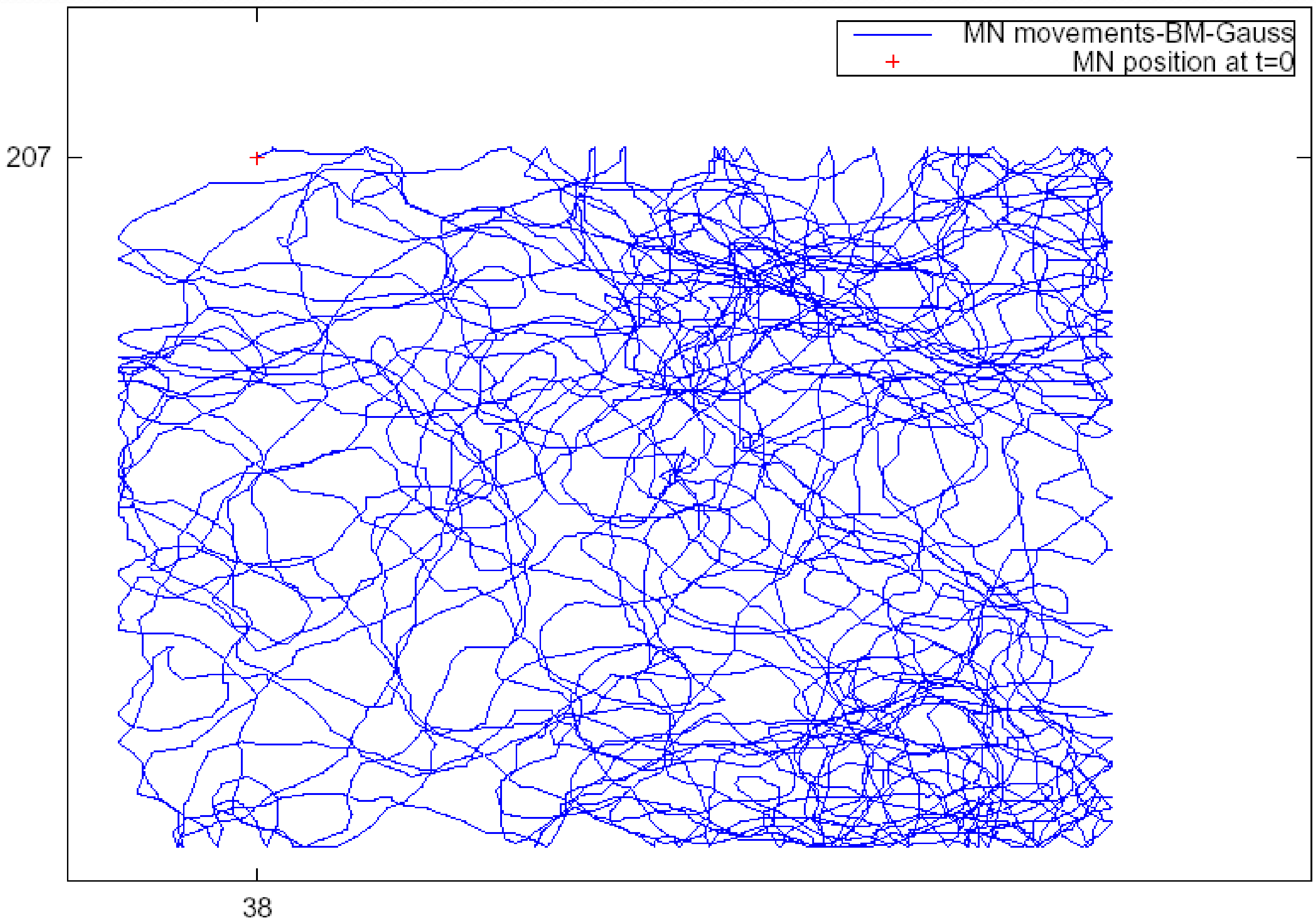
Mobility Models: RWP

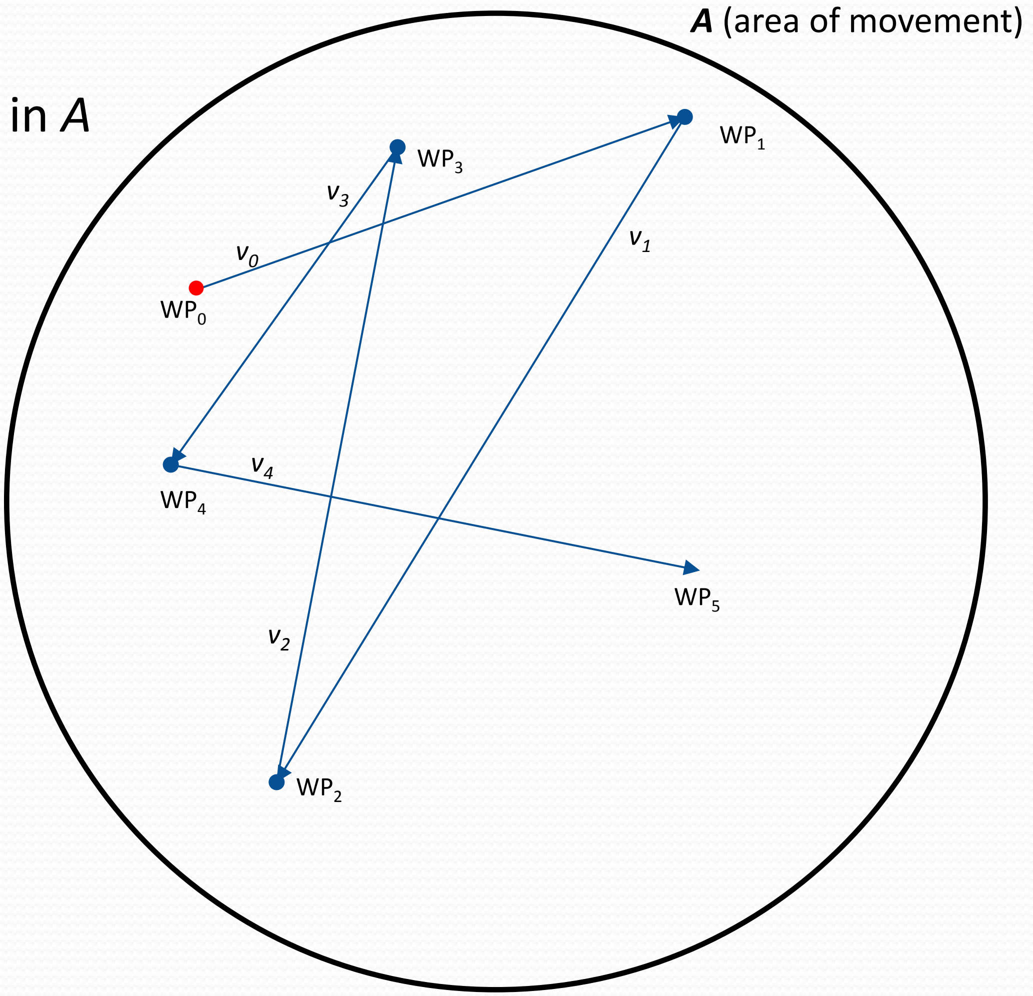


Mobility Models: Gauss-Markov



Random Waypoint

- Waypoints uniformly distributed in *A*
- Speed from uniform distribution $[v_{min}\,;\,v_{max}]$



Problem Statement

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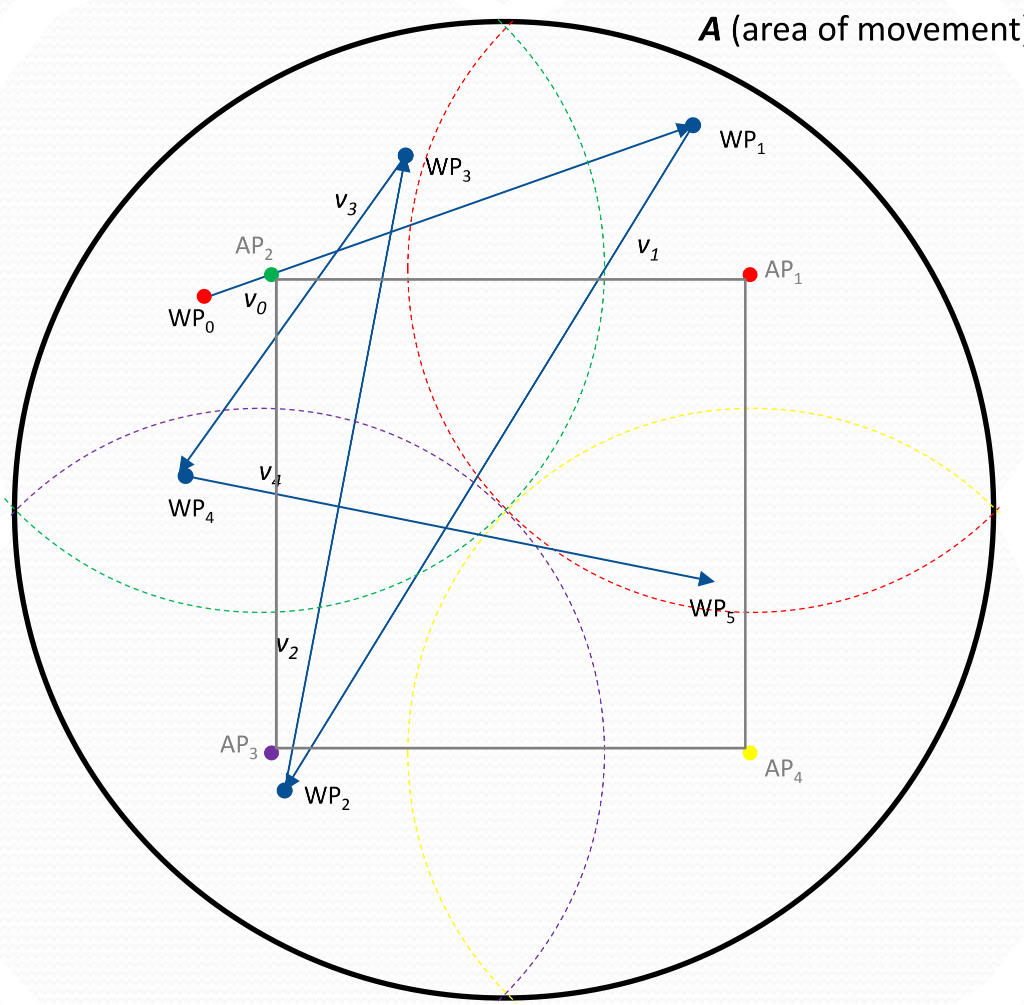
- APs are placed on a regular polygon inside *A*
- Ideal conditions (no fading, no noise)



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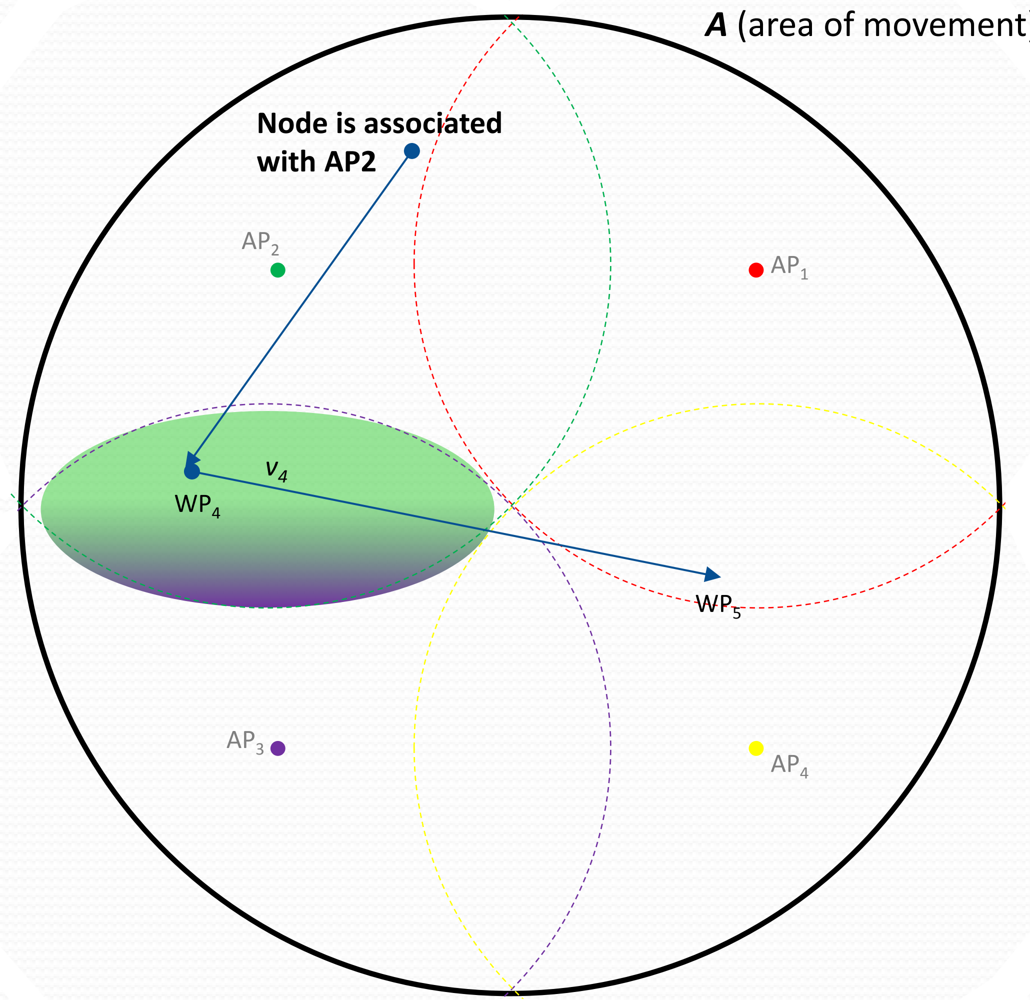
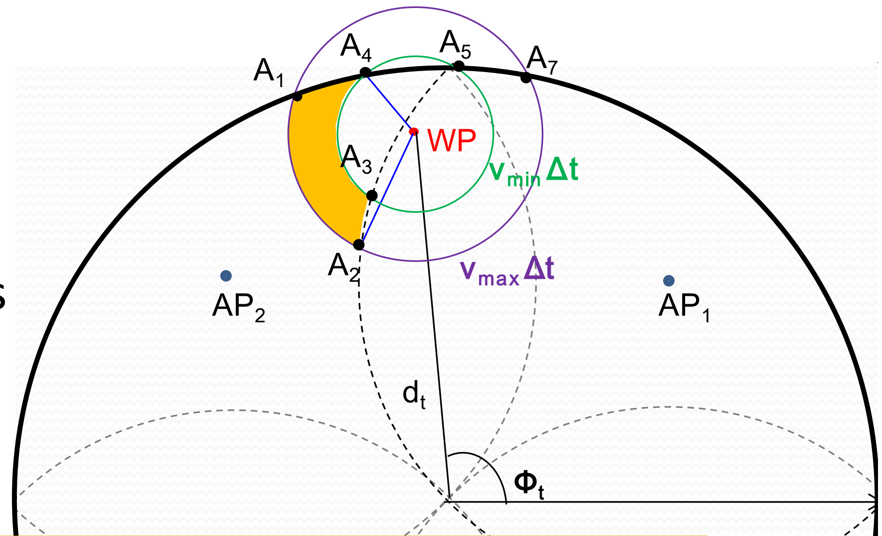


Probability of Handover

- If MN changes transition at tc < Δt → 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



$$Pr\{HOa|r=0\} = \int_{\theta A4}^{\theta A1} f_\Theta(\theta|d_t(0))\cdot\frac{d3(\theta,0)}{d3(\theta,0)}d\theta + \int_{\theta A1}^{\theta A3} f_\Theta(\theta|d_t(0))\cdot\frac{d1(0)}{d1(0)}d\theta + \int_{\theta A3}^{\theta A2} f_\Theta(\theta|d_t(0))\cdot\frac{d2(\theta,0)}{d1(0)}d\theta.$$

$$Pr\{HOa\} = \begin{cases} \int_0 Pr\{HOa|r\}\cdot f_R(r)dr & \text{if } x_t(\theta') < v_j\cdot\Delta t \text{ and } x_t(\theta') < x_A(\theta) \\ \int_0^{x_A(\theta)} Pr\{HOa|r\}\cdot f_R(r)dr & \text{if } x_t(\theta') \geqslant x_A(\theta) \end{cases}$$