BreadCrumbs: Forecasting Mobile Connectivity

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Outline

1. INTRODUCTION
2. Connectivity Forecasting
   1. Mobility model
   2. Prediction
3. USING COLLIE FOR LINK ADAPTATION
4. CONCLUSION

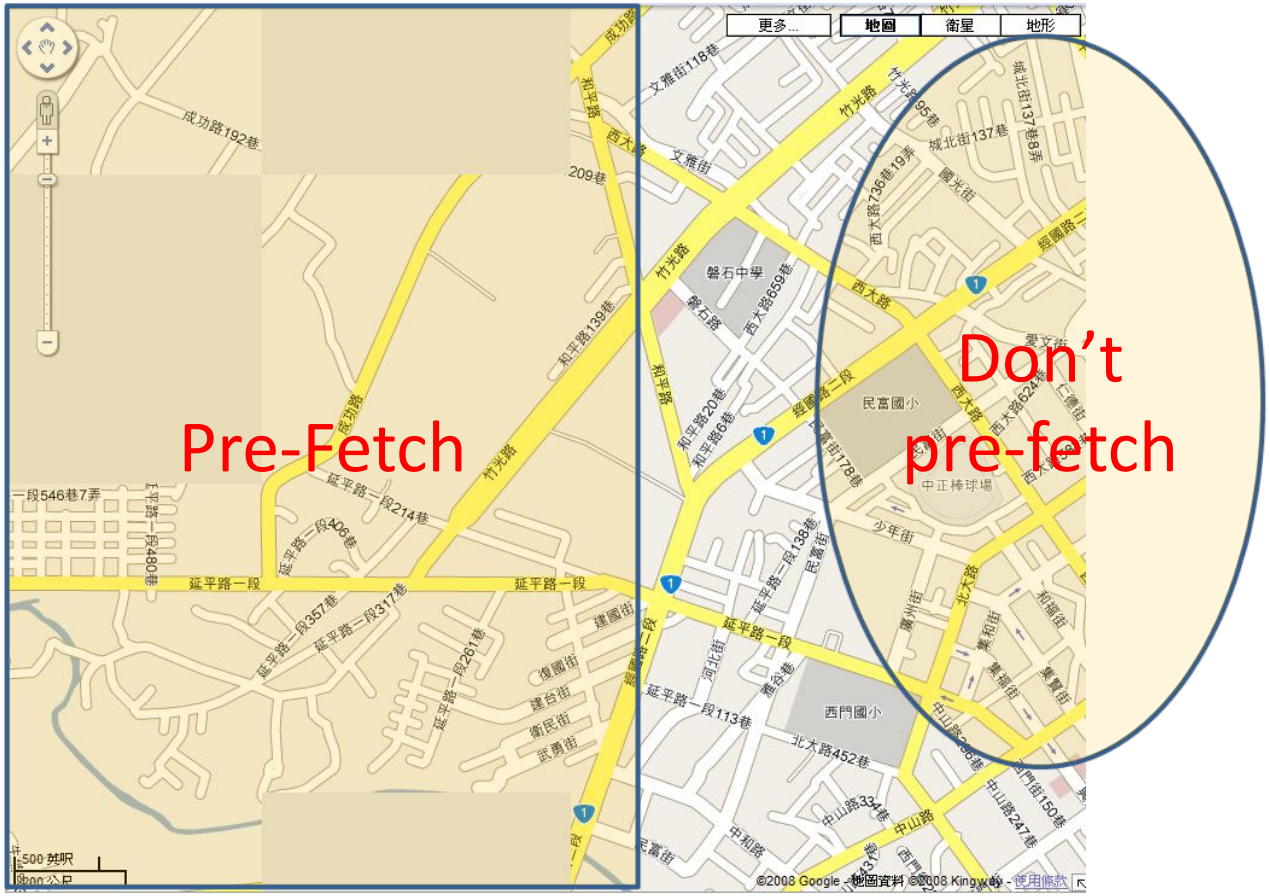
Introduction

- We observe that people are creatures of habit.

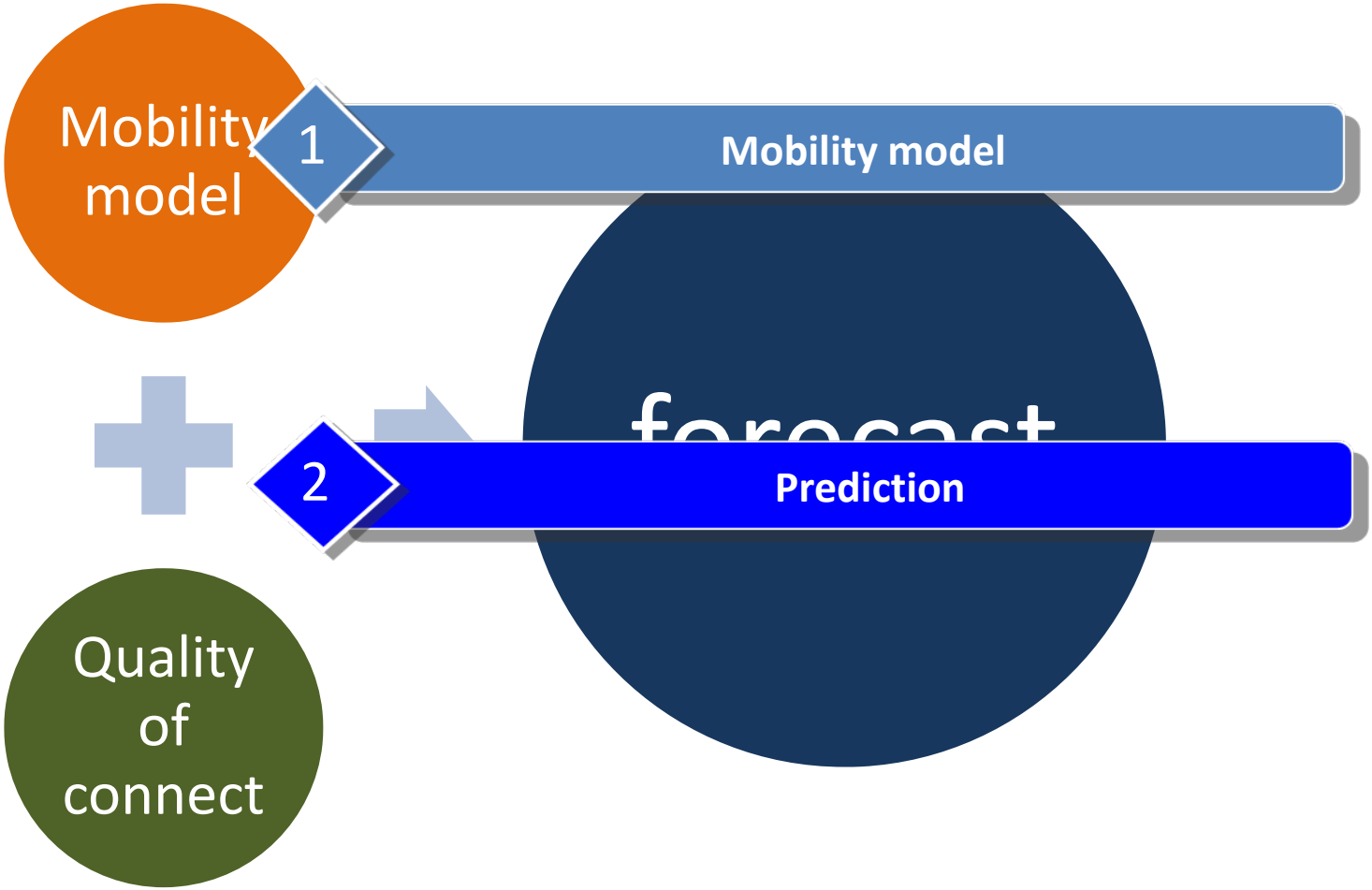
- *The aim of BreadCrumb is to improve the application-level for mobile device by connectivity forecasts.*

Introduction

Introduction



CONNECTIVITY FORECASTING



Mobility model

- Evaluation found a second-order Markov model

$$\mathbf{x}^{(0)} = \begin{bmatrix} 1 & 0 \end{bmatrix} \qquad P = \begin{bmatrix} 0.9 & 0.1 \\ 0.5 & 0.5 \end{bmatrix}$$

Sum=1

$$\mathbf{x}^{(1)} = \mathbf{x}^{(0)} P = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} 0.9 & 0.1 \\ 0.5 & 0.5 \end{bmatrix} = \begin{bmatrix} 0.9 & 0.1 \end{bmatrix}$$

Example:

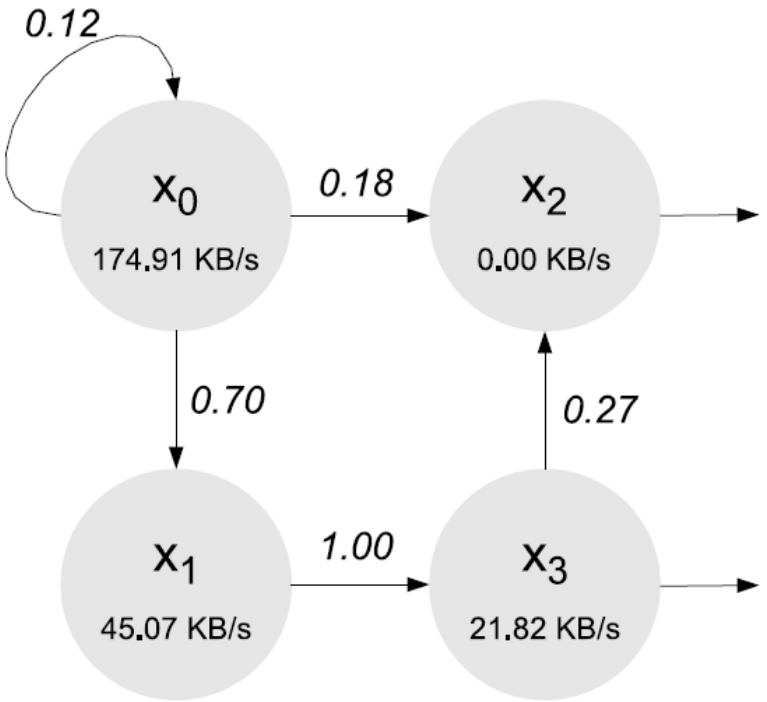
nth-order Markov Example

1st-order matrix

Note	A	C#	Eb
A	0.1	0.6	0.3
C#	0.25	0.05	0.7
Eb	0.7	0.3	0

2nd-order matrix

Note	A	D	G
AA	0.18	0.6	0.22
AD	0.5	0.5	0
AG	0.15	0.75	0.1
DD	0	0	1
DA	0.25	0	0.75
DG	0.9	0.1	0
GG	0.4	0.4	0.2
GA	0.5	0.25	0.25
GD	1	0	0



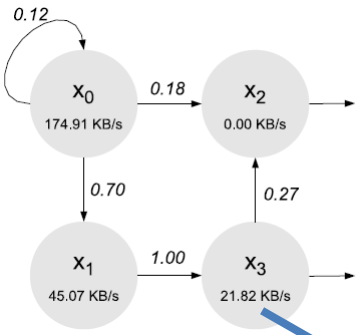
Define state

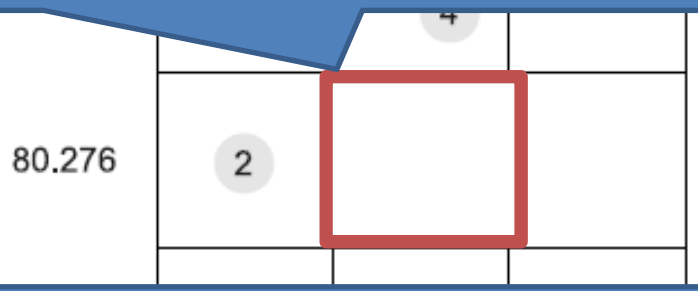
- Building fundamental block by geographic coordinates .
- A 0.001 $^{\circ} \times 0.001^{\circ}$ *grid square is 110 m* $\times$ *80 m.*
- Markov chain where a state transition fires every τ *seconds.*

Example:

Define state

A 0.001°×0.001° grid square is 110 m×80 m.





These transitions occur every τ seconds.

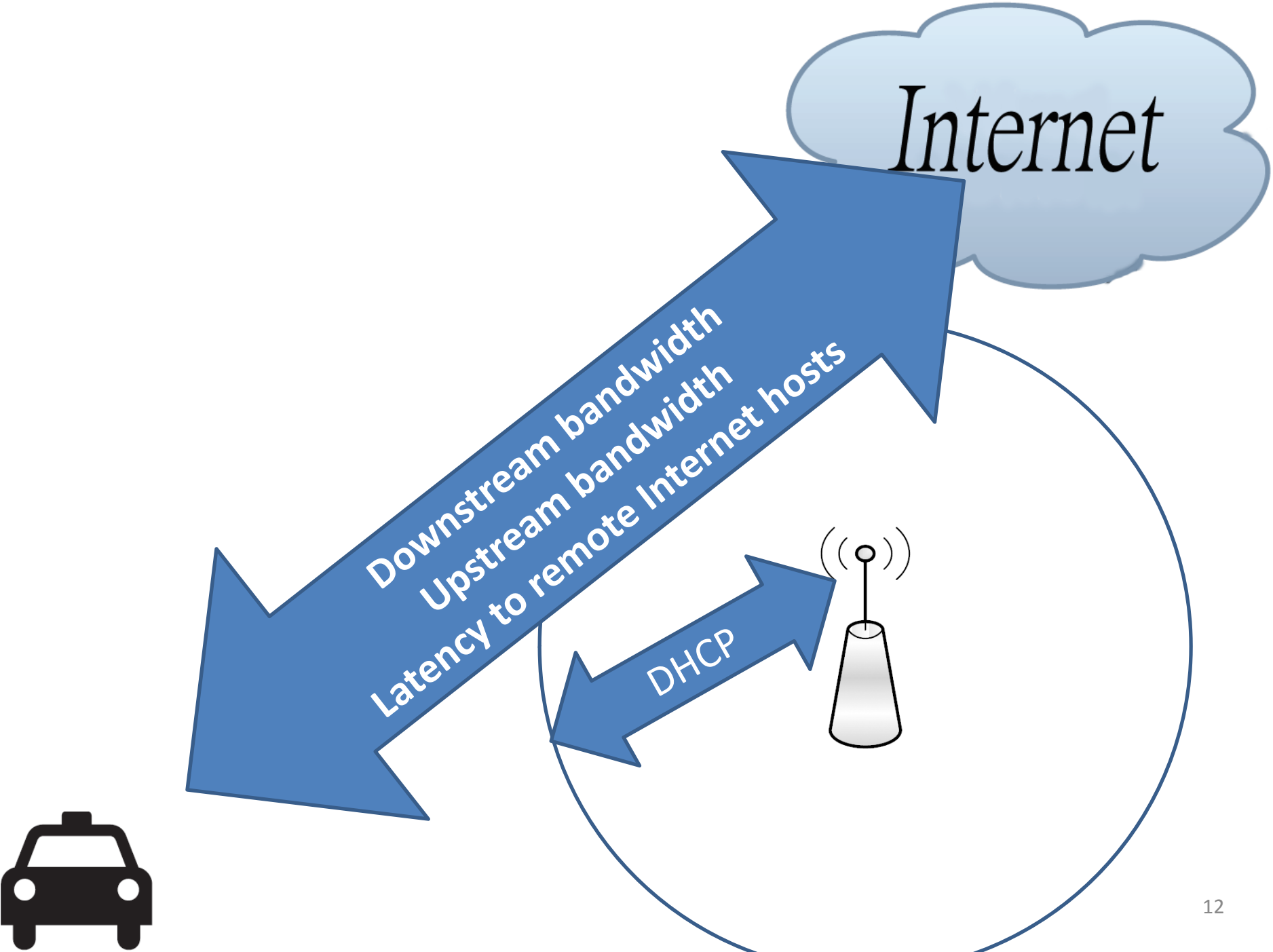
-80.747 -80.746 -80.745

State	Last GPS	Current GPS
1	—	(80.275,-80.747)
2	(80.275,-80.747)	(80.276,-80.747)
3	(80.276,-80.747)	(80.277,-80.746)
4	(80.277,-80.746)	(80.277,-80.746)
5	(80.277,-80.746)	(80.277,-80.745)

Forecasting Future Conditions

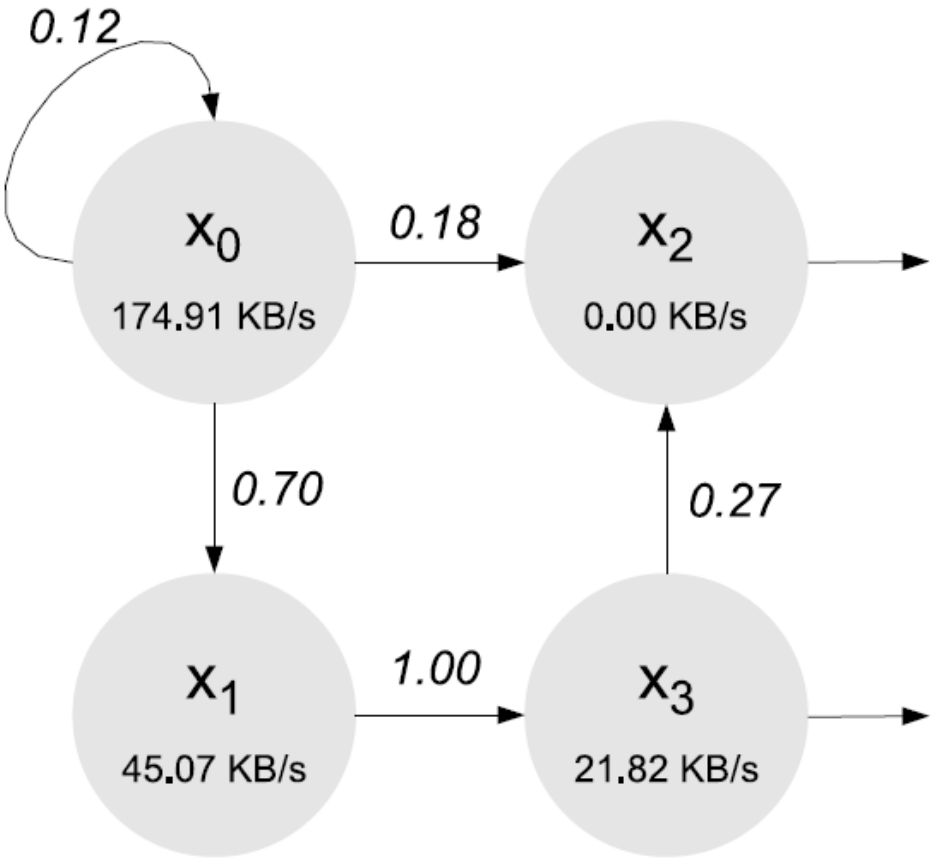
- How to combine data with the predictions of the mobility model.

- Build an AP quality database by Virgil.


Internet
Downstream bandwidth
Upstream bandwidth
Latency to remote Internet hosts
DHCP

Example – one step

the model transition period τ



State of best bandwidth

- This model considers what network quality is to be forecast

BBW (state x)

$best \leftarrow 0.00$
foreach $ap \in \{$APs previously seen at state $x\}$
  if $ap.bandwidth > best$
    $best \leftarrow ap.bandwidth$
return $best$

(a) Best bandwidth algorithm

Connectivity forecasts

CF (state x_i, int $steps$)

if $steps \leq 1$

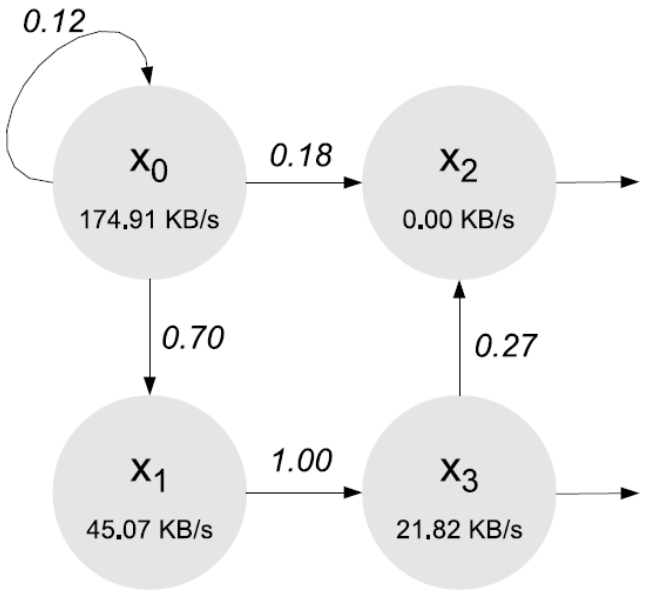
return $\sum_{\forall j}\{p_{ij} \cdot \mathrm{BBW}(x_j)\}$

else

return $\sum_{\forall j}\{p_{ij} \cdot \mathrm{CF}(x_j, steps - 1)\}$

(b) Connectivity forecast algorithm

Example:



$$\mathrm{CF}(x_0, 1) = \sum_{\forall j} p_{0j} \cdot \mathrm{BBW}(x_j)$$

$$\begin{aligned}\mathrm{CF}(x_0, 1) &= p_{00} \cdot \mathrm{BBW}(x_0) + p_{01} \cdot \mathrm{BBW}(x_1) + p_{02} \cdot \mathrm{BBW}(x_2) \\ &= 0.12 \cdot 174.91 + 0.70 \cdot 45.07 + 0.18 \cdot 0.00 \\ &= 52.54\ KB/s\end{aligned}$$

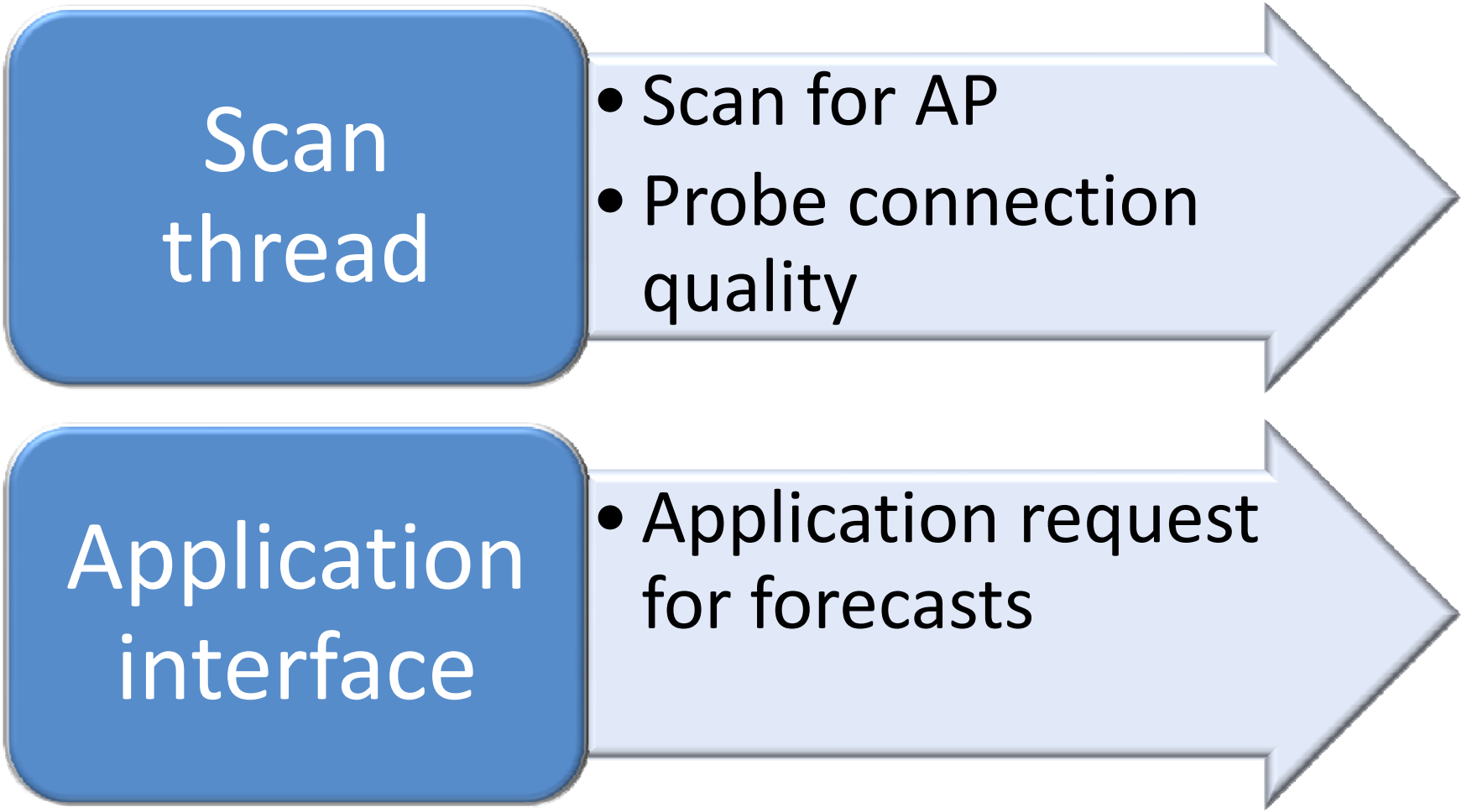
$$\begin{aligned}\mathrm{CF}(x_0, 2) &= \sum_{\forall j} p_{0j} \cdot \mathrm{CF}(x_j, 1) \\ &= p_{00} \cdot \mathrm{CF}(x_0, 1) + p_{01} \cdot \mathrm{CF}(x_1, 1) + p_{02} \cdot \mathrm{CF}(x_2, 1)\end{aligned}$$

Connectivity forecasts

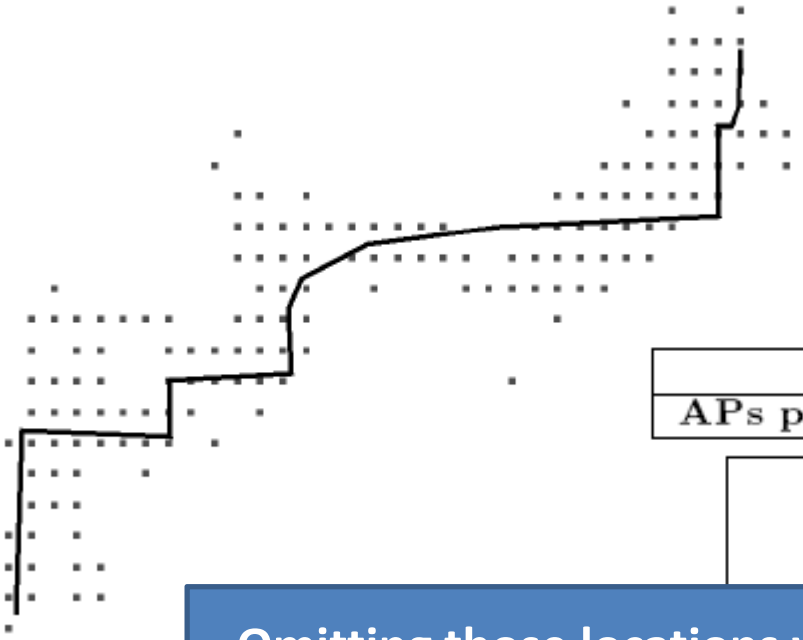
- Bread-Crumbs calculates this forecast as the weighted sum of the best bandwidth.

- If *steps is greater than one, connectivity forecasts are calculated* recursively.

Implementation



Implementation



Time: train 1 week and evaluation 1week
Period : 10s

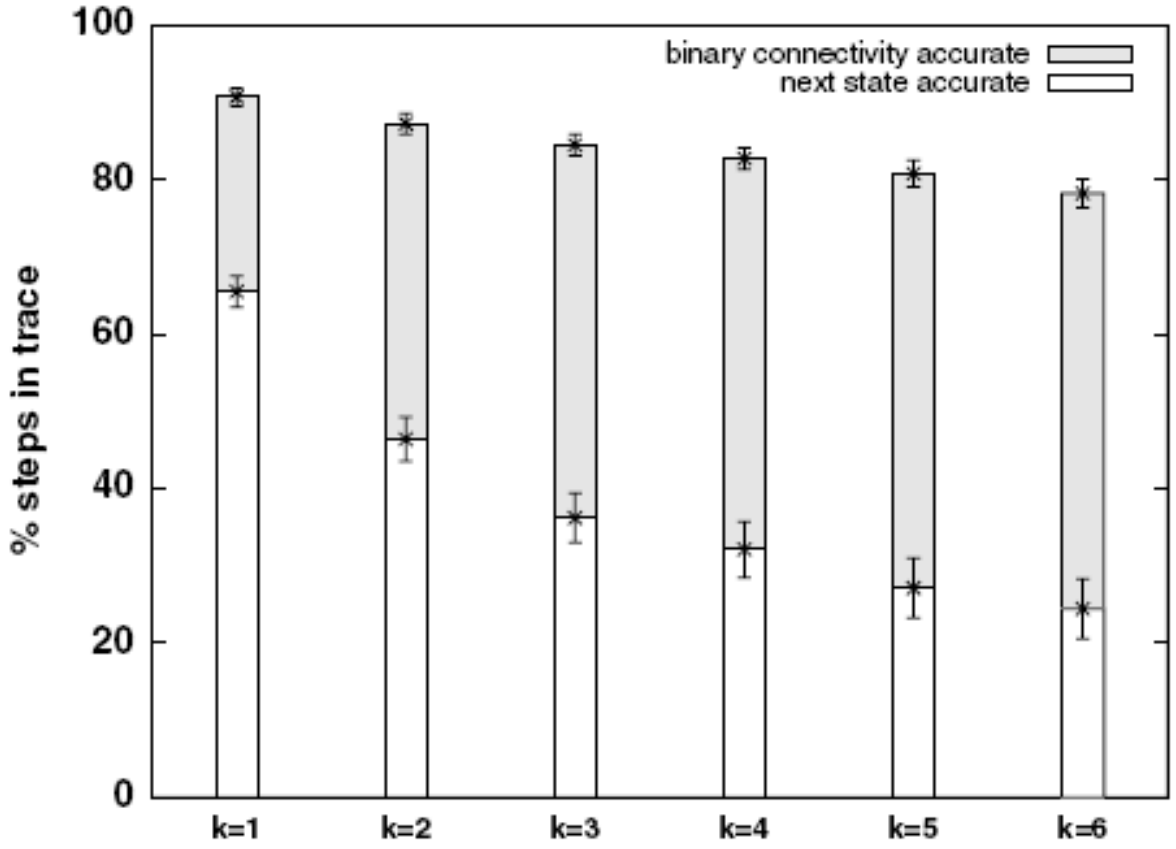
	mean	σ	max	min	n
APs per scan	10.23	7.73	32	0	5227

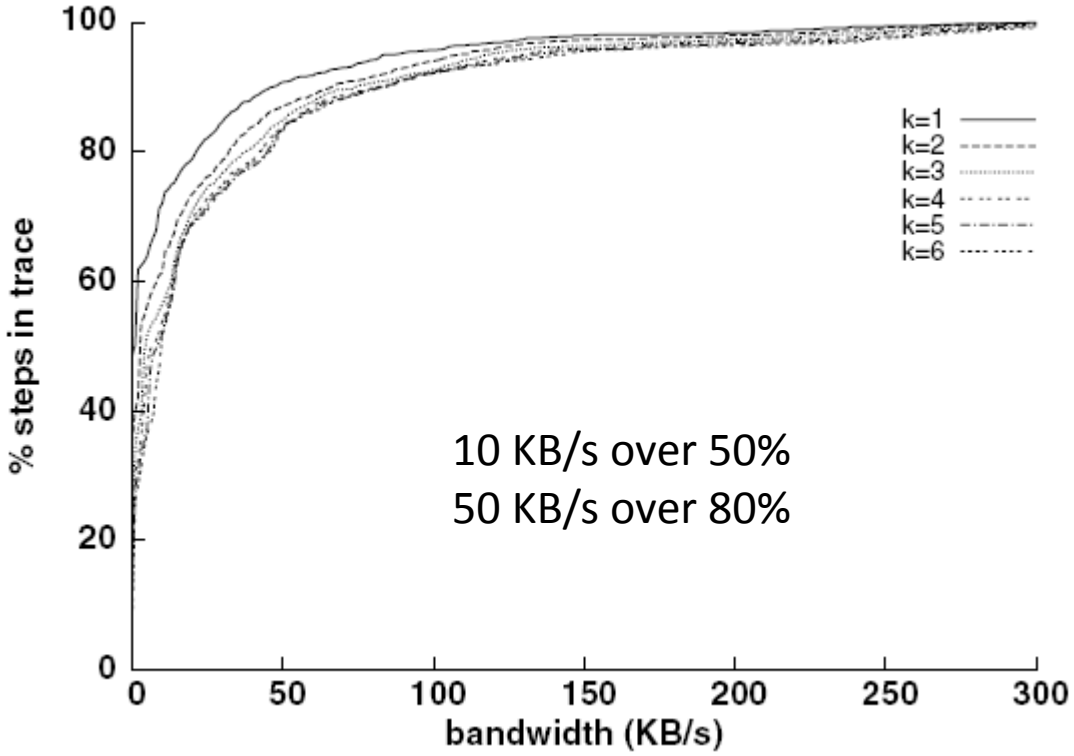
unique APs	1621
open APs	282 (17.40%)
encrypted APs	1339 (82.60%)

Omitting those locations where no encountered AP had a probed bandwidth greater than zero

	mean	σ	max	min	n
down BW	68.38	114.41	385.54	0.00	110
down non-zero	123.30	129.74	385.54	0.29	61
up BW	33.98	49.85	241.66	0.00	110
up non-zero	64.44	52.44	241.66	4.10	58

Implementation

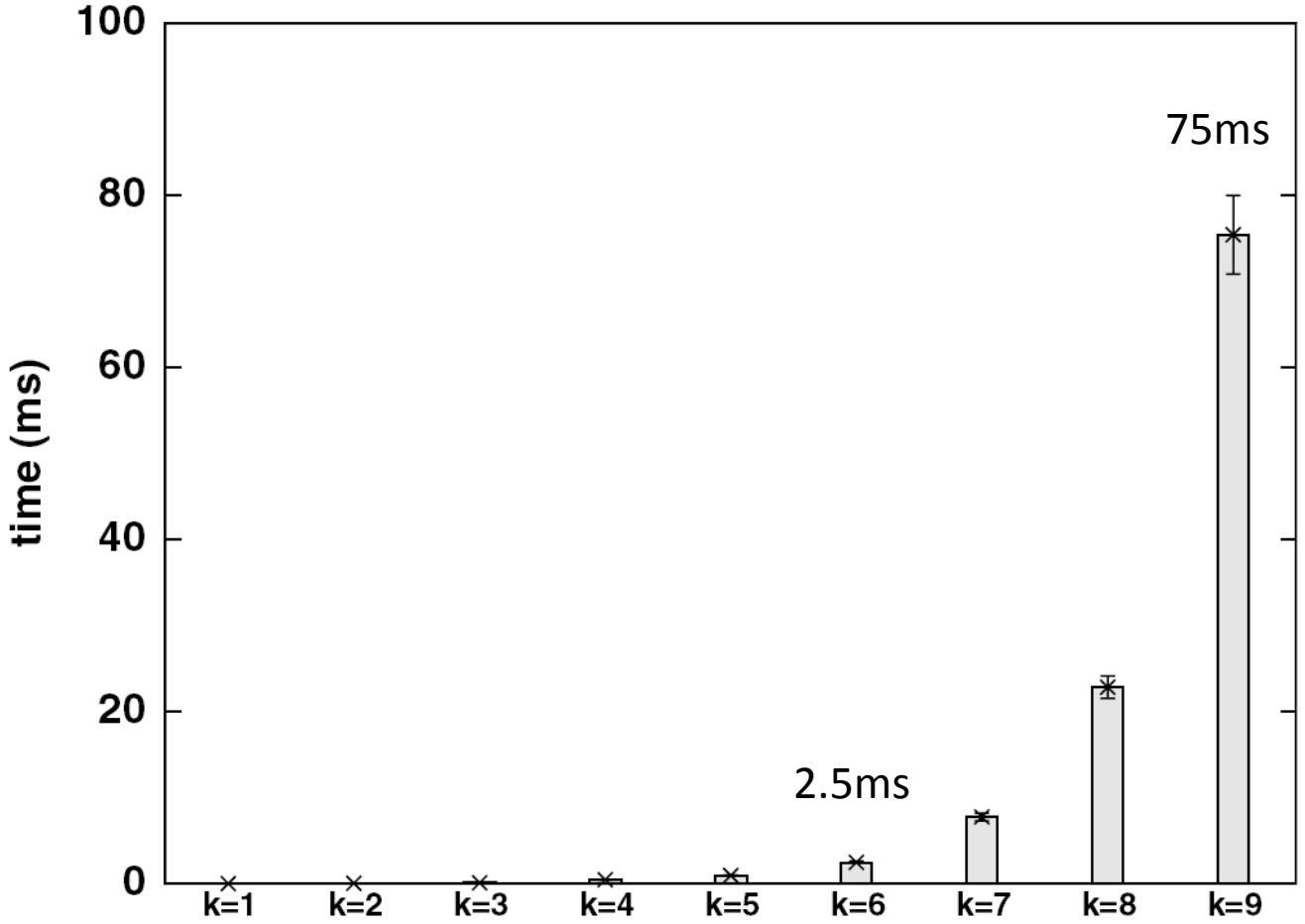



100
80
60
40
20
0
% steps in trace
0
50
100
150
200
250
300
bandwidth (KB/s)
k=1
k=2
k=3
k=4
k=5
k=6
10 KB/s over 50%
50 KB/s over 80%

Overhead

states in model	652
model size	27984 bytes (42.92 B/state)
test results	1335
test DB size	92132 bytes (69.01 B/entry)

Overhead



Conclusion

- Focus on how connectivity changes over time.
- BreadCrumbs maintains a personalized mobility history.
- It also probe the application-level quality.
- It could apply to more application.