Networks Structure and Dynamics
12. Dynamic networks driven by human mobility

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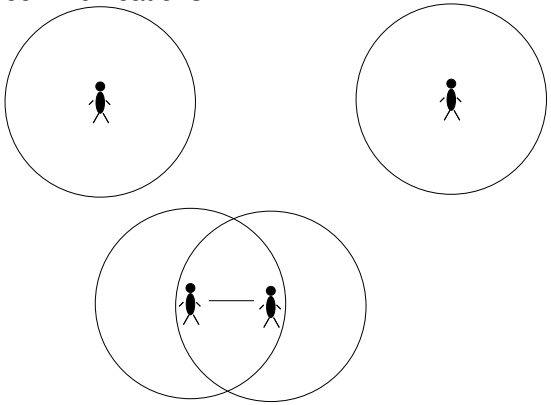
Object under study

Human-contact networks

Mobility modify the proximity between users, hence wireless communications



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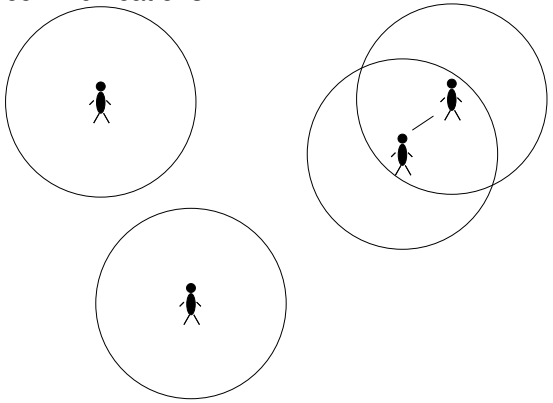


Motivations

Ad-hoc communications: transmission hop-by-hop

- Reduce the cost (eg. broadcast)
- Extreme events (eg. earth quake)
- Military applications

Virus propagation

Radio proximity $\leftrightarrow$ physical proximity

Outline

Efficiency?

Capacity:

- for a pair source/destination: the amount of data (bits) that can be transmitted (per sec.)
- of the network: average capacity for a random pair source/destination

Need to model:

- who communicates with whom?
  - when
  - how many times (frequecy)
- which protocol of communication?

Point-to-point

For each packet, the source waits until it meets the target.

Advantage:

Drawbacks :

Point-to-point

For each packet, the source waits until it meets the target.

Advantage:

simple

Drawbacks :

Time to send the paquet?

Flooding protocol

Each node send all its packets to all the nodes it meets

Avantages

Drawbacks

Flooding protocol

Each node send all its packets to all the nodes it meets

Avantages

- time to reach every one: proxy for a lower bound in terms of times required for the transmission

Drawbacks

- Waste of memory
- Interference

Two-hop relay

Each source transmits its packets to the first node it meets:

- either directly to the target
- either to a relay

Each relay waits until it meets the target

Avantages/drawbacks

Protocol used in an article. Detailed later

Static nodes

[Gupta, Kumar, 2000]

Settings:

- n nodes are randomly placed on a disc whose surface is 1.
- the nodes don't move
- for each source: one destination is randomly chosen
  one sends an infinity of packets

Results

- Capacity in $cte/\sqrt{n \log n}$ possible
- Capacity in $cte/\sqrt{n}$ impossible

Discussion

Discussion

The capacity desceases while the number of nodes increases
$\longrightarrow$ the more the number of nodes, the less the efficiency

Discussion

Important theoretical result
What happens if:

- nodes moves?
- pattern of communication changes?
  (who wants to communicate with whom)

With mobile nodes

[Grossglauser, Tse, 2002]

Settings:

- The nodes move in a disc whose surface is 1.
- $X_i(t)$: position of i at time t.
- Uniform distribution over the disc
- One node $\longrightarrow$ one destination
- One sends an infinity of packets

First idea

Each pair source/destination is infinitly often close
$\longrightarrow$ direct communications when *distance* $<$ *threshold*

Problem

Better compromise: impossible to reach $1/\sqrt{n}$

First idea

Each pair source/destination is infinitly often close
$\longrightarrow$ direct communications when *distance* $<$ *threshold*

Problem

- high threshold $\rightarrow$ lot of interferences
  few communication at the same time
- short threshold: short distances $\rightarrow$ needs to wait for longer

Total capacity low in both cases

Better compromise: impossible to reach $1/\sqrt{n}$

Second idea: relay

At each time step: one chooses randomly θn sources
($\theta < 1$, parameter)
the other nodes are receptors

2 modes

- if t odd: each source sends its packet to the closest receptor
  - either the destination
  - either a relay (unique)
- if t even: each source sends a relayed packet, if possible.
  - transmission only to the destination

Results

The capacity of each pair is constant

Discussion

Important theoretical result:

Discussion

Important theoretical result: the mobility plays a great impact

Only one relay: surprising?

Discussion

Important theoretical result: the mobility plays a great impact

Only one relay: surprising?

The modelling of the mobility assumes a trajectory:

- stationnary
- uniformly distributed on the disc
- independant in regards to the nodes

$\longrightarrow$ each node has the same probability to meet the destination

Is it a reallistic model?

Outline

Measuring the mobility

How to measure mobility?
Very difficult

A good proxy

Record all possible radio communications

Two types of data

- Connection to *access points*
- Measuring contacts between radio badges (often *iMotes*)

Contact and inter-contact duration times

For radio badges networks:

Contacts duration times

How long two nodes stay in contact

Inter-contact duration times

How long before two given nodes meets again

$\longrightarrow$ Distribution

Format

Format (used also for PW

```
1 2 23 34
1 2 45 46
...
23 25 1 3
...
```

Each line `n1 n2 td tf`: contact between nodes `n1` and `n2`

- beginning at time `td`
- endint at time `tf`

Sorted by pairs of nodes, then by time

Contacts and inter-contacts durations

- Contact duration: `tf - td`
  (for each line)
- Inter-contacts duration:
  `td` of one line - `tf` of preceding line + 1
  (for two lines related to the same nodes)

Dataset

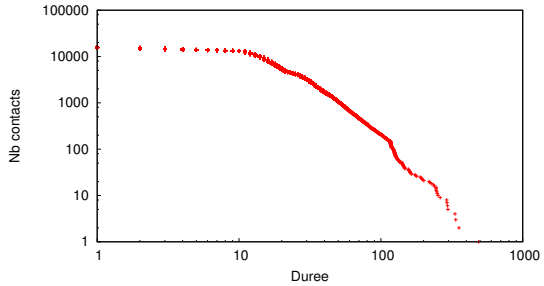
[Tournoux, Leguay, Benbadis, Conan, Dias de Amorim, Whitbeck, 2009]

Rollernet

- Rollerblade tour in Paris
- 62 nodes
- 3 hours

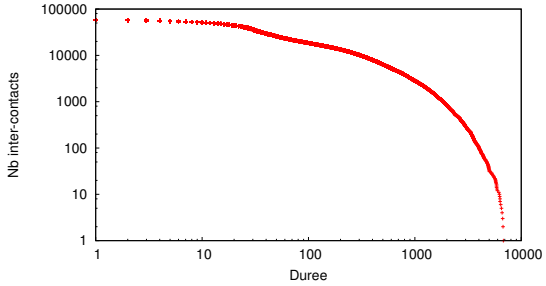
Observations – Contacts duration times

Inverse CDF (cumulative distribution frequency)



Observations – Inter-contacts duration times

Inverse CDF



Discussion

Distributions not homogeneous
(more or less heterogeneous depending on the dataset)

Mobility

Consequences

[Chaintreau, Hui, Crowcroft, Diot, Gass, Scott, 2006]
Inter-contacts duraction times following a powerlaw
$\Longrightarrow$

Discussion

Distributions not homogeneous
(more or less heterogeneous depending on the dataset)

Mobility

Observations incompatible with hypothesis made in the previous article:
It is not reallistic to model a regular and uniform mobility

Consequences

[Chaintreau, Hui, Crowcroft, Diot, Gass, Scott, 2006]
Inter-contacts duraction times following a powerlaw
$\Longrightarrow$ no efficient communications possible

Random Walk

Principe

- Mobile node with random speed, random destination
- one connects two nodes depending on their distance

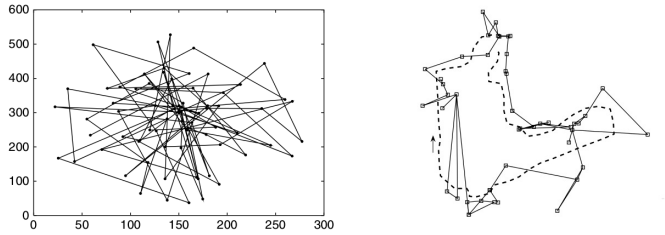
Very standard/classical, numereous different names

Variants depending on:

- boundaries for the speed: $[v_{min}; v_{max}]$
- destination chosen by position or orientation
- handling extreme cases

Random Walk

Typical mobility patterns in 2D: *RW* vs real traces



Not reallistic for MANET

Towards more reallistic models: *Random Waypoint*

no break $\Rightarrow$ little time to find good paths

Integrating breaks: *Random Waypoint model (RWP)*

- *RW* destination by position (2D space), $v \in [0; v_{max}]$
- addition of breaks before any modification of orientation

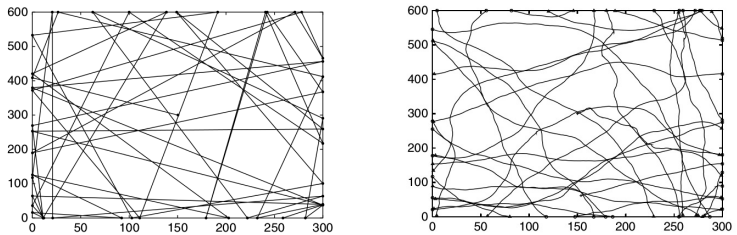
standard in the years 2000

Towards more reallistic models: *Random Waypoint*

Focus on the center: **density not uniformly distributed**

Possible solutions

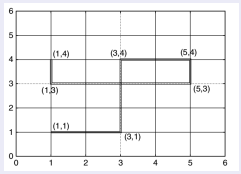
1. random orientation + bounce on the borders
2. no borders



Towards more reallistic models

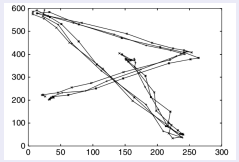
Mobility in urban networks

Impose constraints on the mobility



Correlation among agent's mobility

- mobility based on center of gravity
- agents distributed around the center



Are those models more reallistic?

Studied article

Otiy: Locators Tracking Nodes
Mathias Boc, Anne Fladenmuller, Marcelo Dias de Amorim
ACM Conext, 2007

Dataset

Wifi connexions to access points in a campus

- $\sim$ 5 500 students
- 188 buildings, 566 access points
- 3 years of measure

Motivations: wifi communications on a meshed network

Proposition of the article

To send a message to one node

Need to know its access point
Locator of one node : device which memorise this access point
(This device is also an AP)

Proposition

Compute a timetable for each node:
one locator dedicated in advance for each time slot,
Goal: locator close to the node

Approach

Timetable

- Duration: one week
- splitted in time slots of 1 hour

Creating the timetable

For each time slot s :
the node memorise the access point A_s to which it has been connected most.

At the end of the week:
A_s is the locator for slot s for next week.

Validation

Principe:

Study if a node is close to its locator

Difficulties

- Localisation of access points unknown
- Matching location $\leftrightarrow$ access point fluctuates
  (ping-pong effect, ...)

Solution

Creation of *groups* of access points.

For each node,
$\longrightarrow$ graph between access points

Weight of a link (i, j): number of transition $i \leftrightarrow j$

Goal :

Regroup access points according to this graph

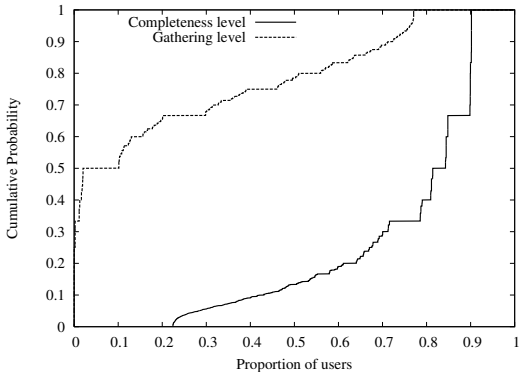
Group of access points

Algorithm (parameter $0 \leq k \leq 1$)

1. Initialisation : each AP alone in its group
2. Sort links according to the weight (decreasing order)
3. For each link (i, j) :
   c_i, c_j : groups of i and j
   If $w(i, j) > k \max(\textit{weight in } c_i, \textit{weight in } c_j)$:
   merge c_i and c_j

Result on the gathering

- Gathering : nb of groupes / nb of AP seen
- Completeness : nb of links between clusters / nb of possible links

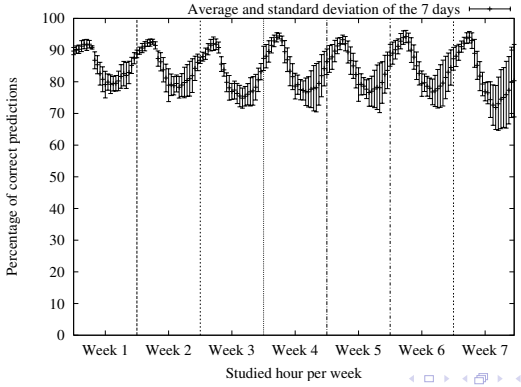


Cyclic behaviour

For each hour:

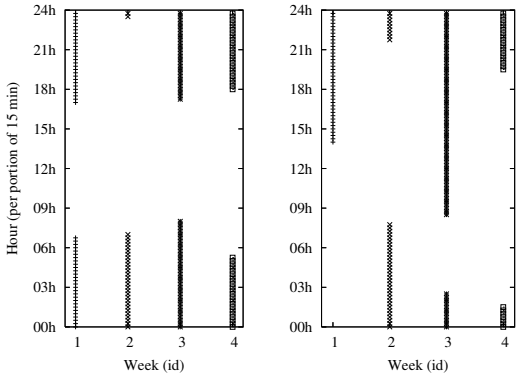
Fraction of nodes which return to the same place than previous week

Average + standard deviation over the 7 days of the week



Evolution of the activity

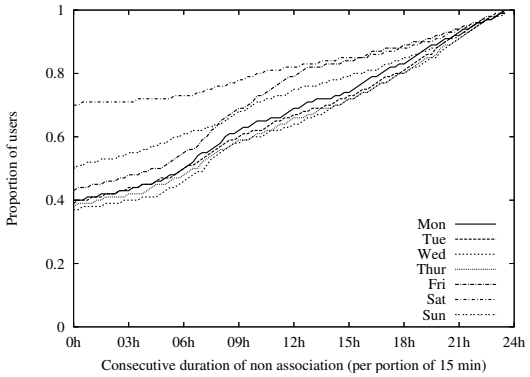
Periods of activity of two nodes over 4 different weeks



Depends of the node

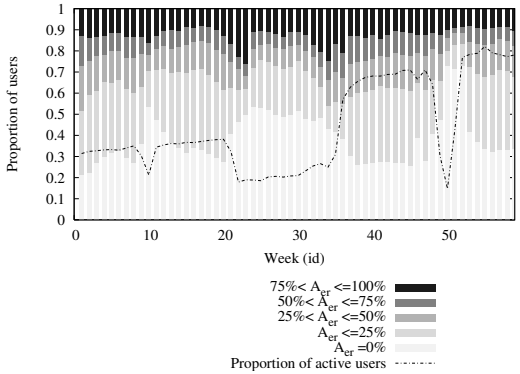
Activity according to the day of the week

Duration of maximal non association for each day, over each week



Depends of the day

Results



Conclusion of the article

Important cyclic behaviour for the nodes

Interesting to rely on a timetable

Outline

Conclusions

We have seen:

- For static nodes, the capacity decreases while number of nodes increases
- For mobile nodes, it can be better

$\longrightarrow$ Important to study mobility

- Mobility depends of the node
- Cyclic behaviour

$\longrightarrow$ Impact on the communications?
$\longrightarrow$ Protocols relying on properties of the expected mobility?