Aging Rules: What Does the Past Tell About the Future in MANET?

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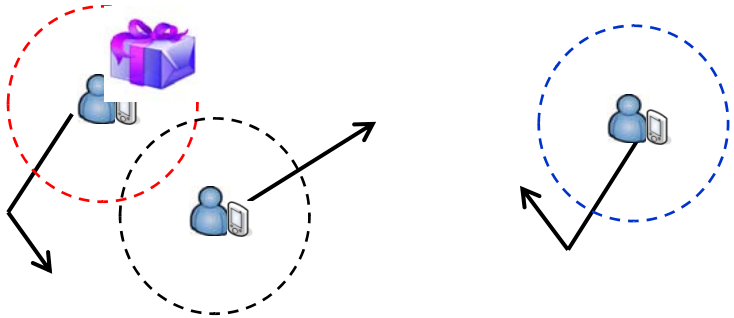
May 19, 2009

Mobile Ad-hoc Network (1)



- Intermittently connected mobile ad-hoc network: packet transmission through exploring the node mobility

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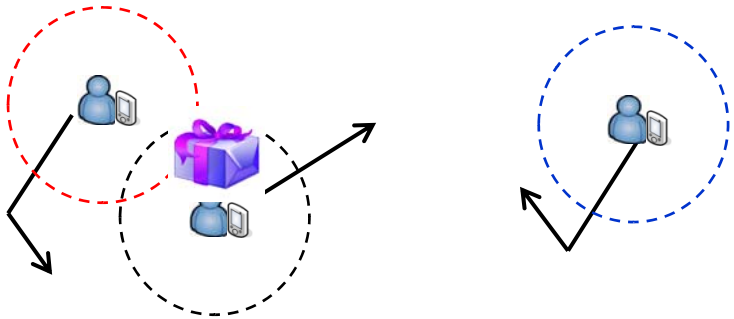

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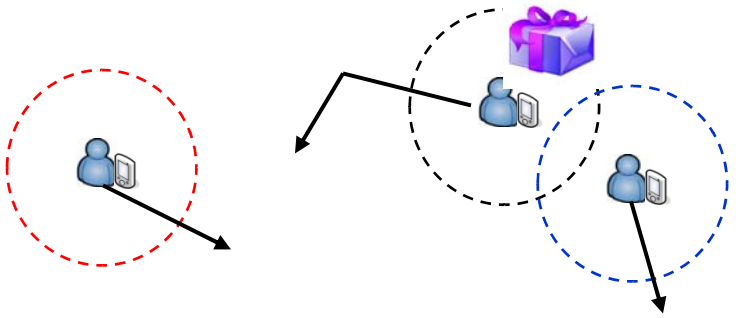

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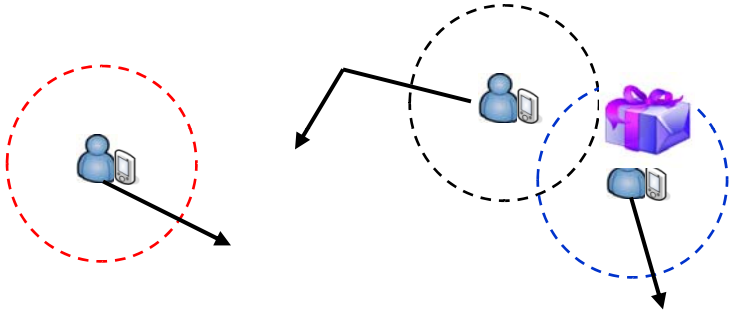
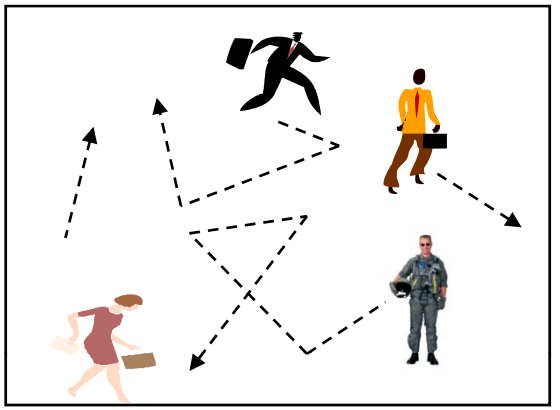


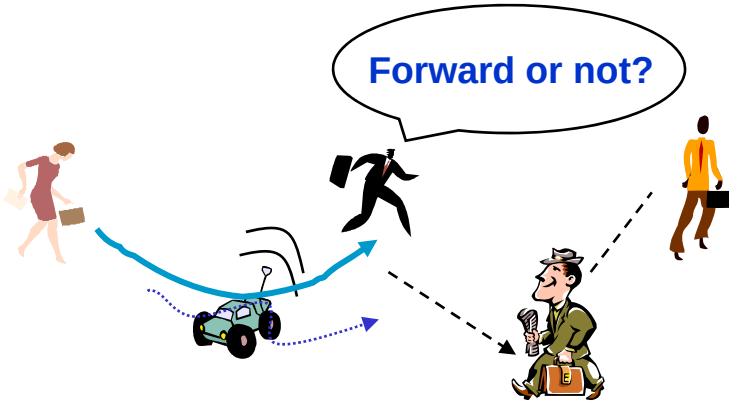
- Intermittently connected mobile ad-hoc network: packet transmission through exploring the node mobility

Mobile Ad-hoc Network (2)

- Performance decided by:
  - Underlying mobility patterns
    - Real traces: realistic for any specific scenario
    - Synthetic mobility models: tractable analysis and design over different mobility settings in a controlled and repeatable manner
  - Forwarding/routing strategies

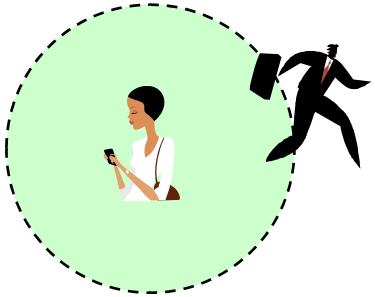


Random Mobility Pattern



Forwarding Strategy

Inter-meeting Time



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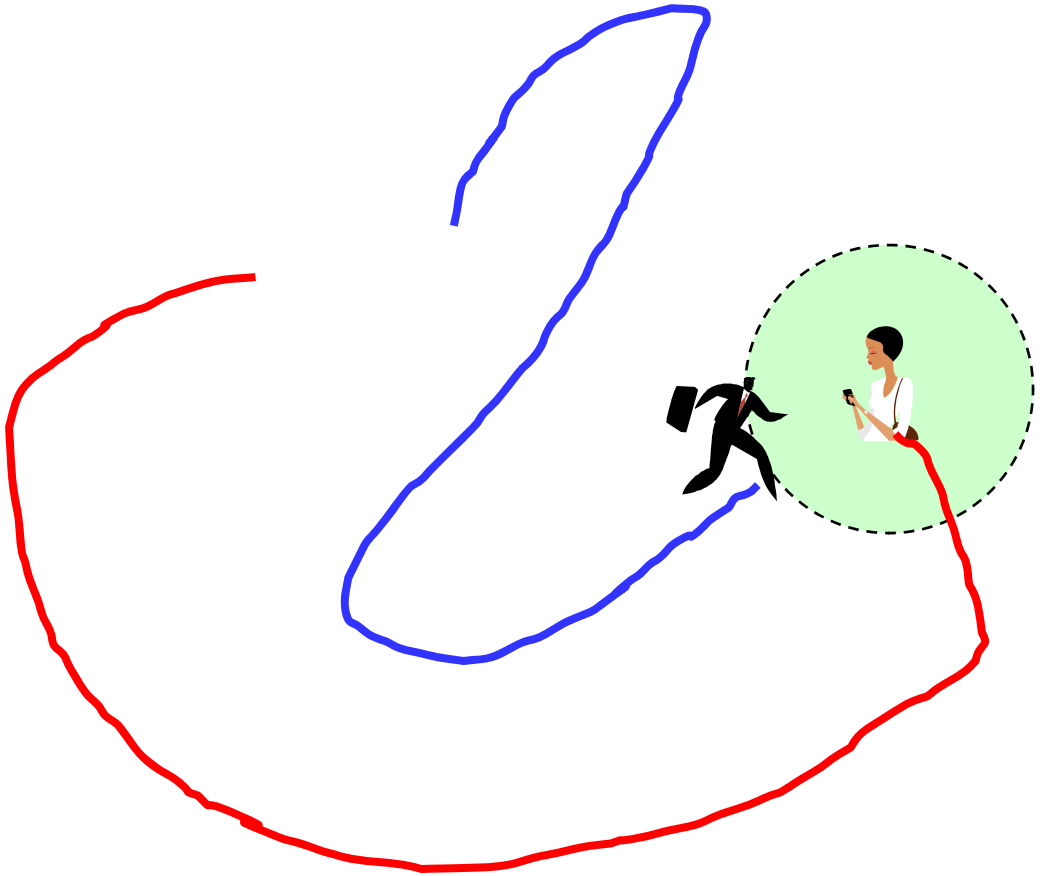

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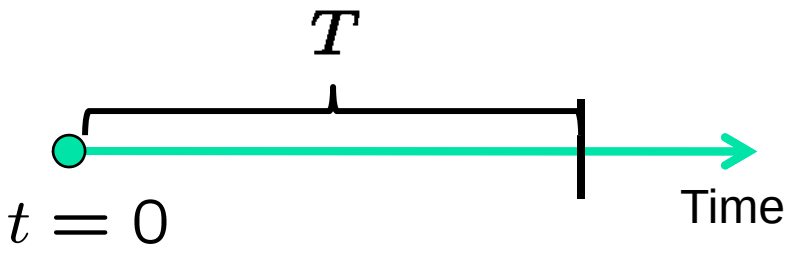

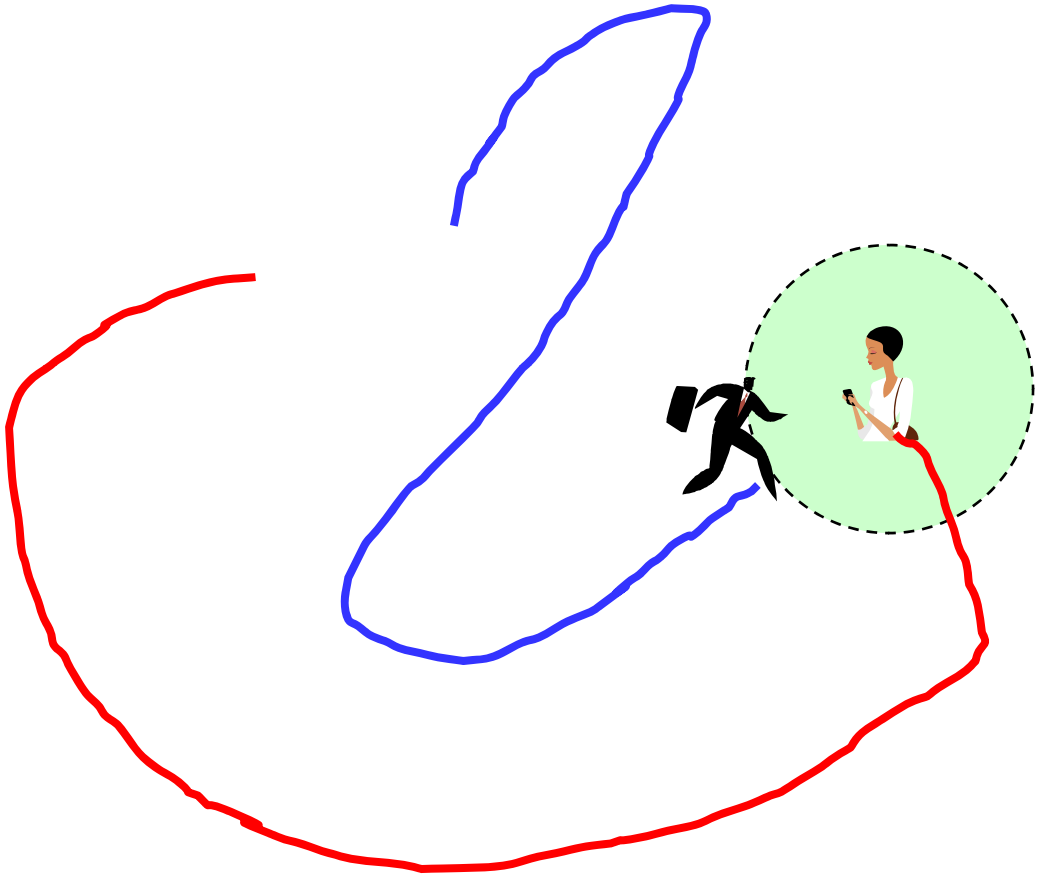

- **Inter-meeting time:** how long a random pair of mobile nodes need to wait to see each other again

Two Separate Approaches

Two Separate Approaches

Examples of analysis based on exponential inter-meeting time assumption

M. Grossglauser and D. N. C. Tse. *Infocom,* 2001.

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Aging Property: background (1)

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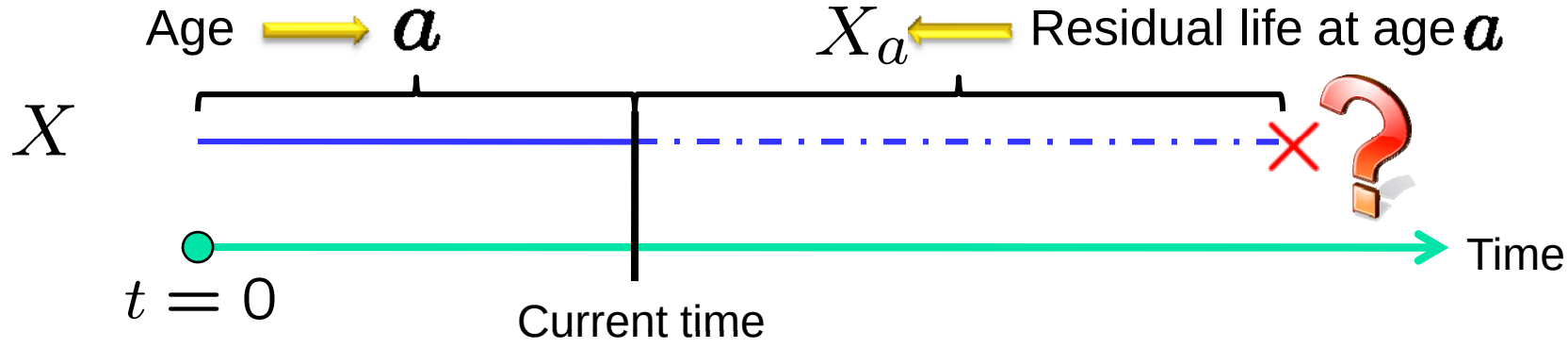

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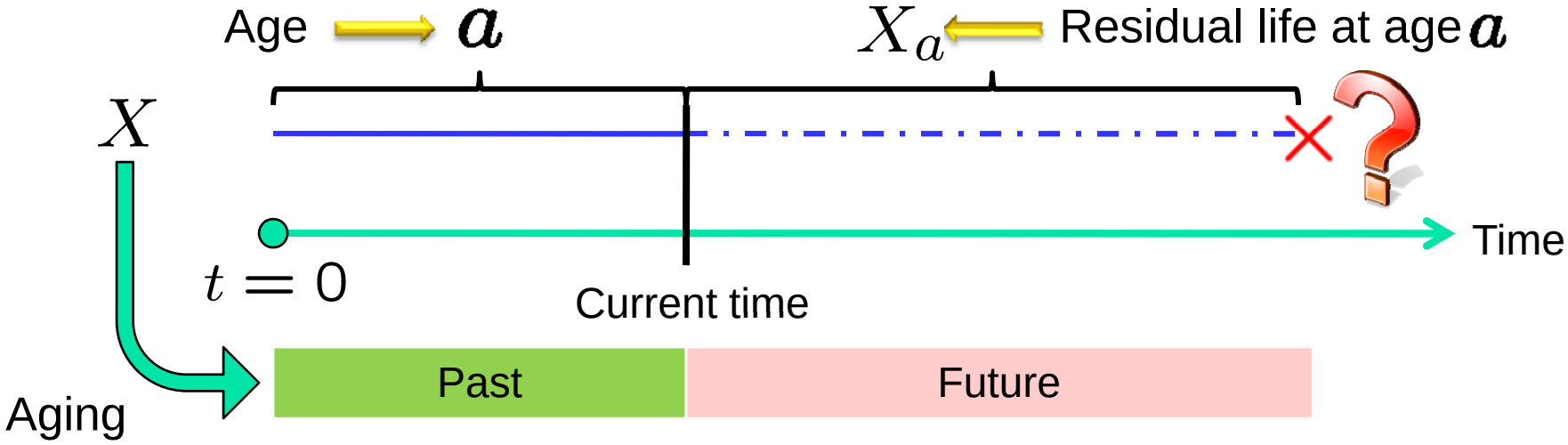

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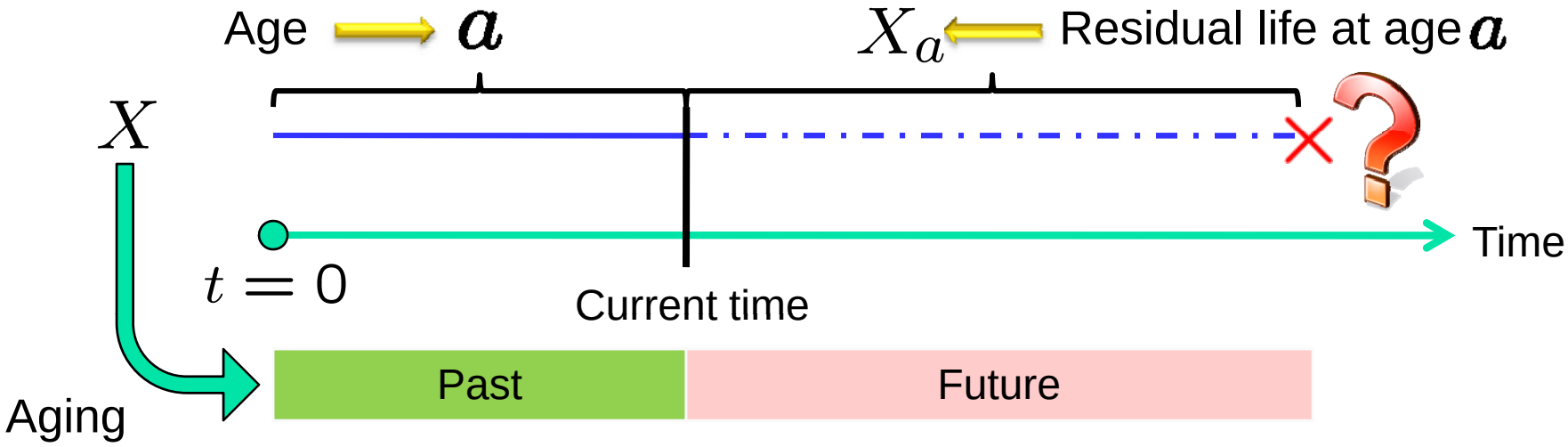

Life time T

	Zero aging	**Positive aging**	**Negative aging**
T_{child}	T_{child}	T_{child}	T_{child}
	$\equiv_s$	$\mathrel{\rotatebox{90}{$\vee$}}_s$	$\mathrel{\rotatebox{90}{$\wedge$}}_s$
T_{adult}	T_{adult}	T_{adult}	T_{adult}

Background: Positive aging

- X_a decreases in a in the sense of stochastic ordering

$$\mathbb{P}\{X_{a1} \geq x\} \leq \mathbb{P}\{X_{a2} \geq x\}, \text{ i.e., } X_{a1} \leq_{st} X_{a2}, \forall\, a1 \geq a2$$

  - In previous example: the child lives longer than the adult
  - Necessary and sufficient condition for such ordering: Increasing Failure Rate (IFR)

$$r(x) = \mathbb{P}\{X = x\}/\mathbb{P}\{X \geq x\}$$

Probability of life ends at x when it has survived up to x

  - Other variants exists

- Positive aging in weaker sense than IFR
  - New Better then Used (NBU): $X_a \leq_{st} X_0$

Background: Negative aging

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  - In previous example: the child lives longer than the adult
  - Necessary and sufficient condition for such ordering: Decreasing Failure Rate (DFR)

$$r(x) = \mathbb{P}\{X = x\}/\mathbb{P}\{X \geq x\}$$

Probability of life ends at x when it has survived up to x

  - Other variants exists

- Negative aging in weaker sense than DFR
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Our Work

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Zero aging

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[illegible] MobiHoc, 2009

Positive aging

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Han Cai [illegible]. *MobiCom*, 2007; MobiHoc, 2008

Negative aging

Questions to be Answered

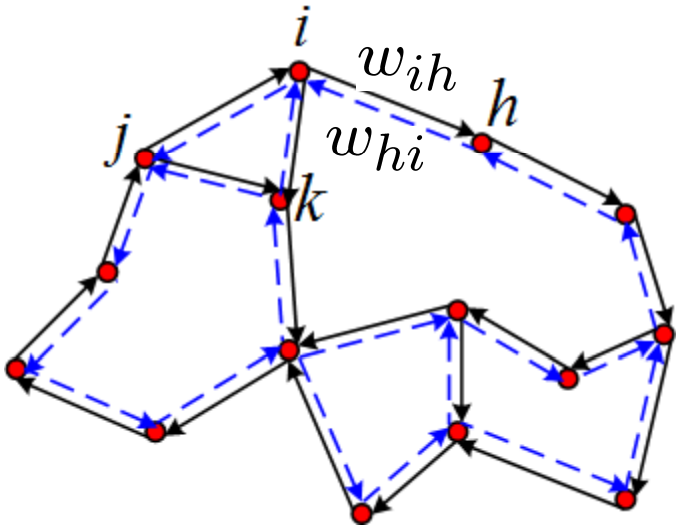
What sacrifice have we made for simplicity?

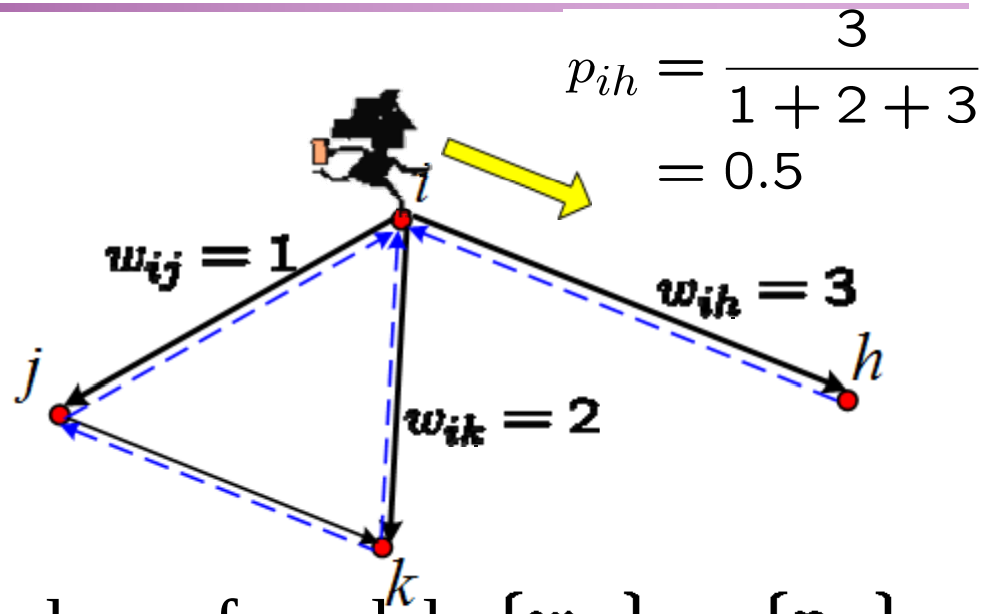
Is non-exponential inter-meeting time purely a disaster for MANET performance analysis and design?

Content

- **Mobility Patterns with Zero/Negative/Positive Aging Inter-meeting Time**
  - **Zero/Negative/Positive aging (CFR/DFR/IFR&NBU)**
  - Negative/positive aging: under synthetic mobility models
- **Performance Comparison: Non-exponential Inter-meeting time vs. Exponential Counterpart**
- **Aging in Forwarding/Routing**

Random Walk on Directed Graph





- Our definition of each class of models: $\{w_{ij}\}$, or $\{p_{ij}\}$
  - Focus: mobility features giving rise to unique aging property
  - Assumptions:
    - Connection: weakly connected, connected, 2-connected
    - Non-bipartite

Difficulty of Aging Property Study

- Existing analysis on non-exponential inter-meeting time: current status
  - Head/tail behavior: the behavior of inter-meeting time distribution at **small/large** t [1, 2, 3, 4]
  - First-order behavior: **average** inter-meeting time [4]

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  $r(t) = \mathbb{P}\{T = t\}/\mathbb{P}\{T \geq t\}$ increases (decreases) in ***all*** t?

  $\mathbb{P}\{T \geq t + \tau\} \leq (\geq)\mathbb{P}\{T \geq t\}\mathbb{P}\{T \geq \tau\}$ holds for ***all*** t and τ ?

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- Our analysis on the aging property
  - Characteristics of relative mobility vs. aging: Inter-meeting of a random walker to a static reference site (home site)

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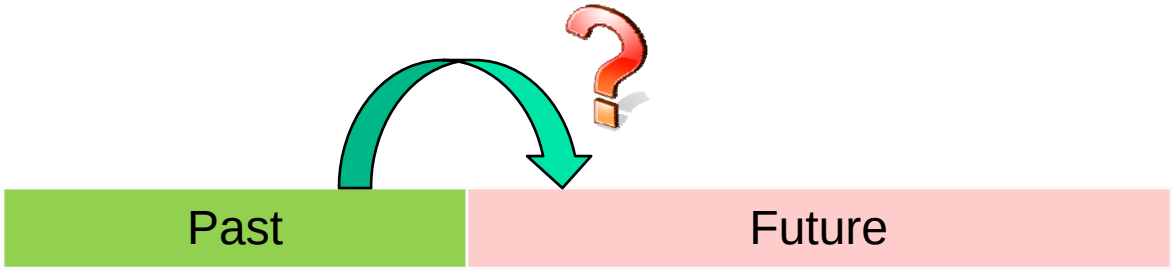
Aging: the Power to Predict **Future** From the **Past** Information

- The past and the future are tied with each other.



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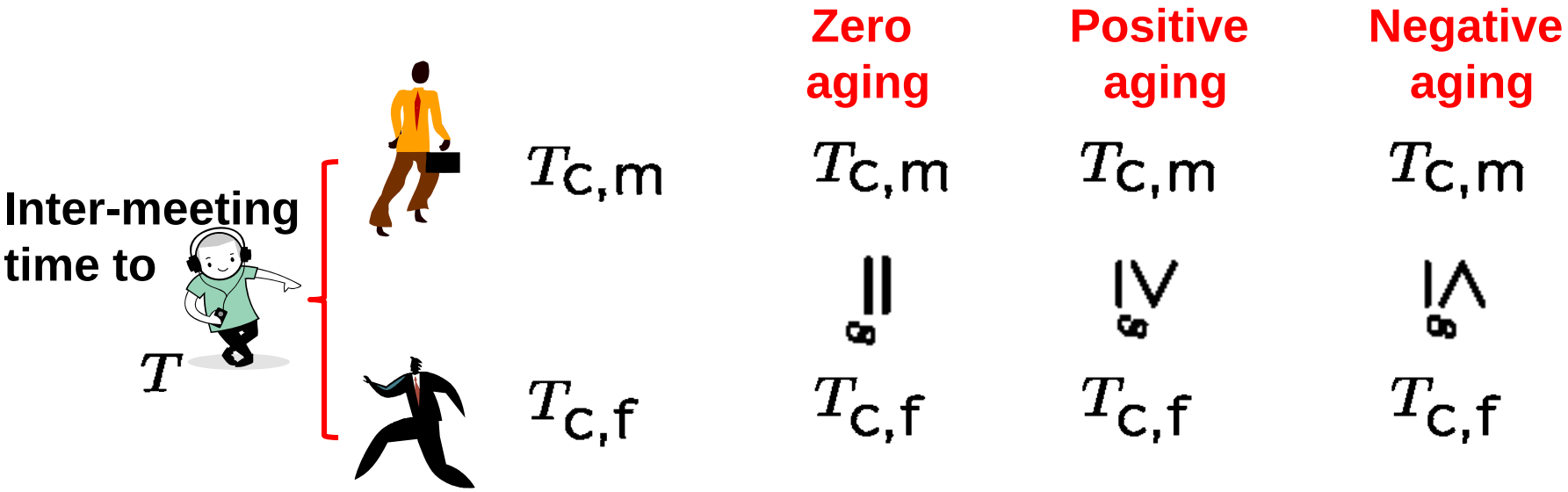
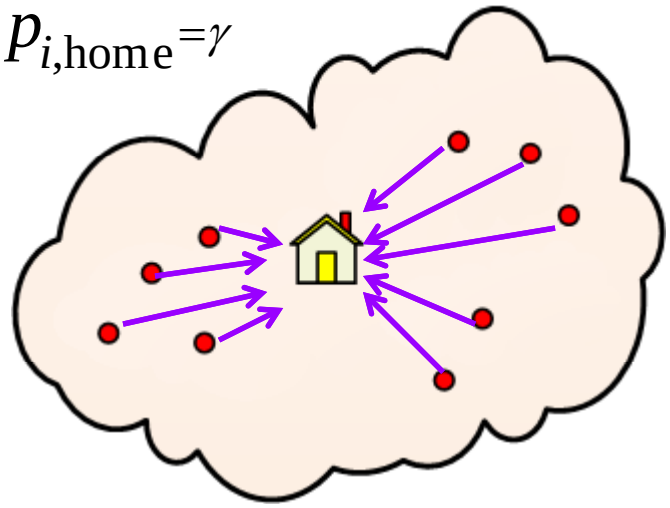


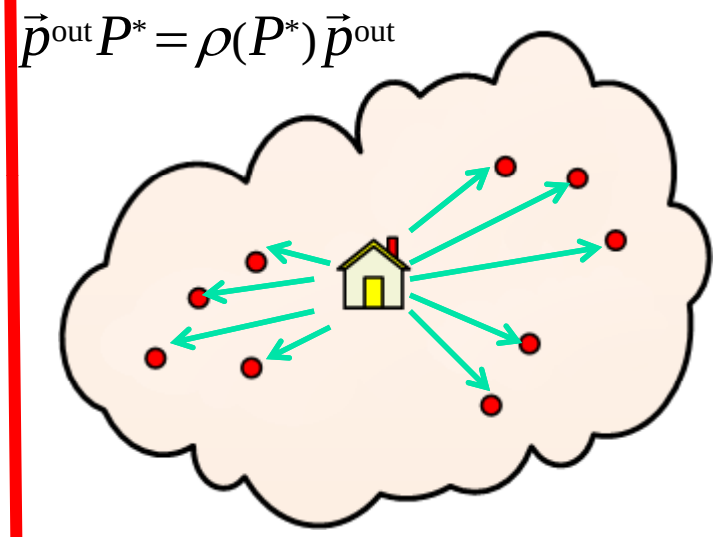
Relationship between the past and the future?
What sacrifice have we made when ignoring the tie between the past and the future for simplicity?

-- Our analysis will tell

Zero-aging: Mobility Model Class 1

- Key feature: ***small world*** around the home site

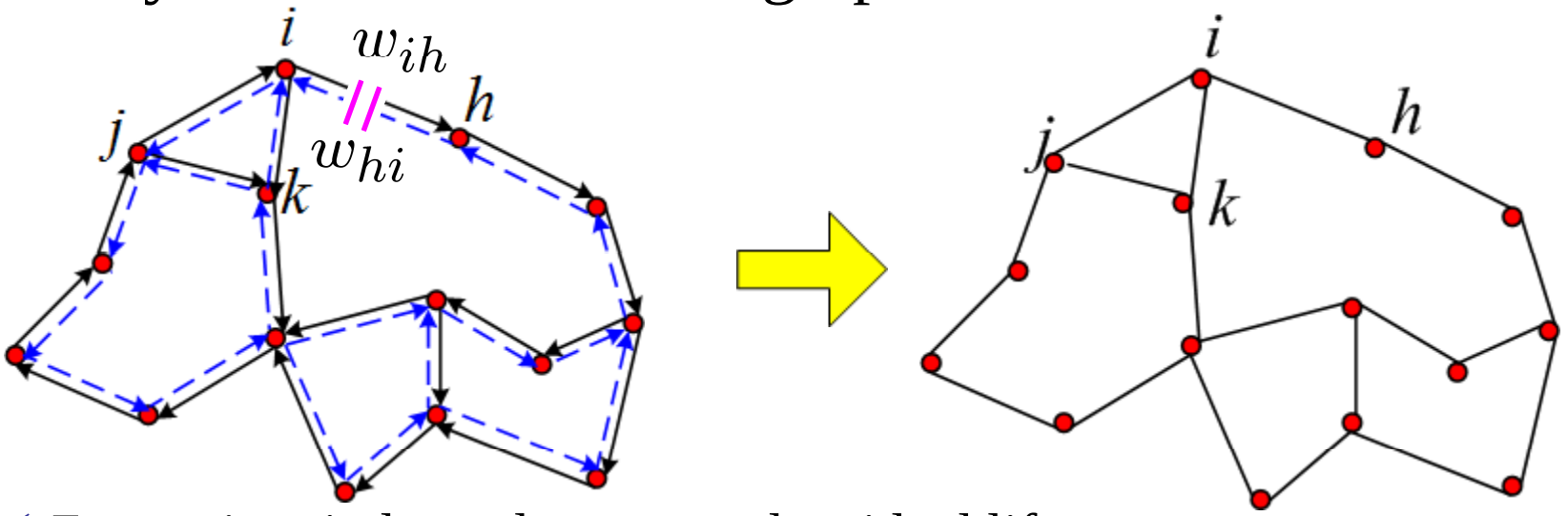




- Subclass 1: homogeneous in-home condition
  - Special case: i.i.d. model
- Subclass 2: out-home condition

Negative-aging: Mobility Model Class 2

- Any random walk on undirected graph
  - Time reversible Markov Chain $\pi_i p_{ij} = \pi_j p_{ji}$
- Key feature: ***undirected*** graph



✓ Zero aging: independent age and residual life

✓ Negative aging: larger age → larger residual life. Dependence brings opportunity to design (***predict the future***)

Negative-aging: examples

- Examples of negative-aging class of mobility models:
  - 1-D, 2-D random walk on grid
- In real traces and synthetic mobility models:
  - Power-law or mixture (power-law + exponential) behavior : suggests negative aging property [1, 2, 3]
  - [4] compared non-exponential inter-meeting times, which actually all have negative aging

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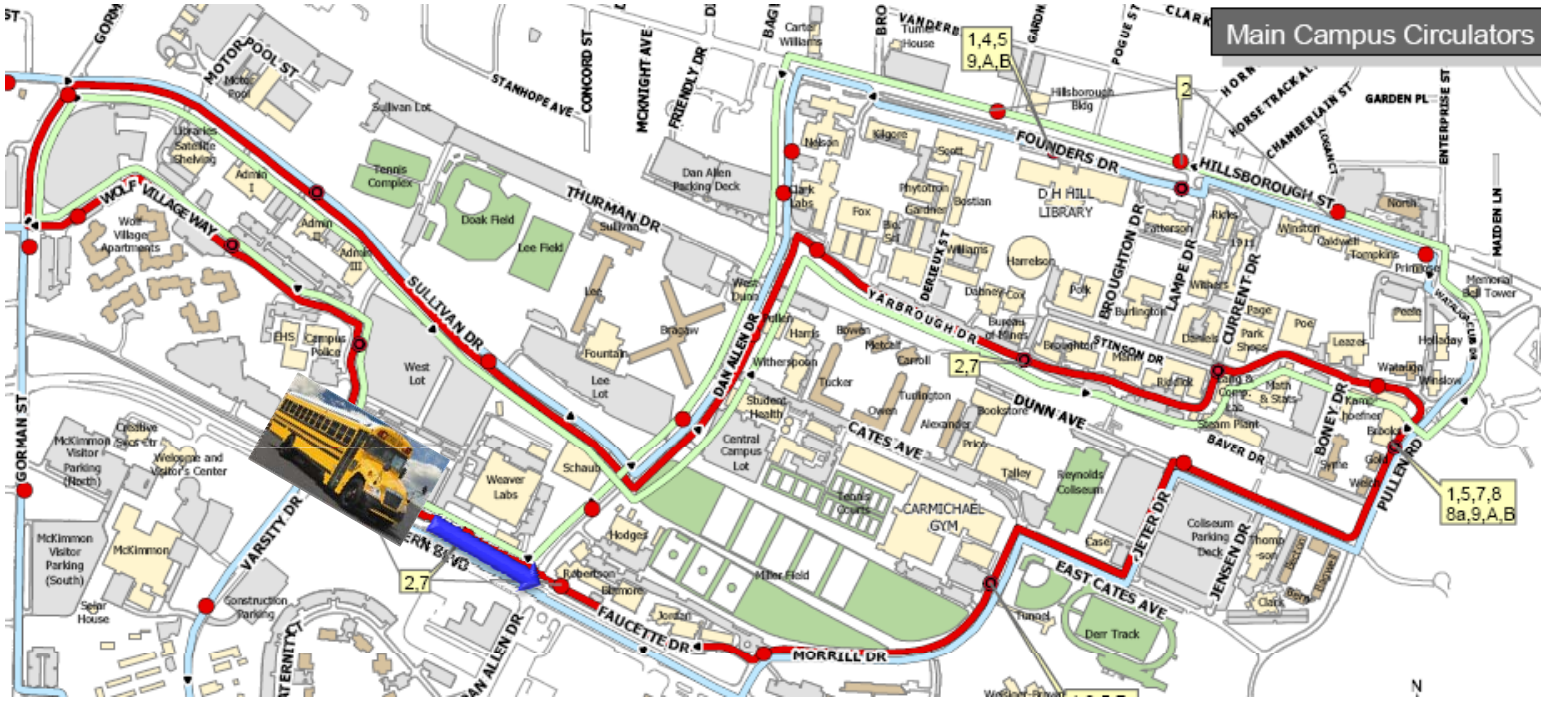
- Bus routes (http://www2.acs.ncsu.edu/trans/transportation/wolfline/)



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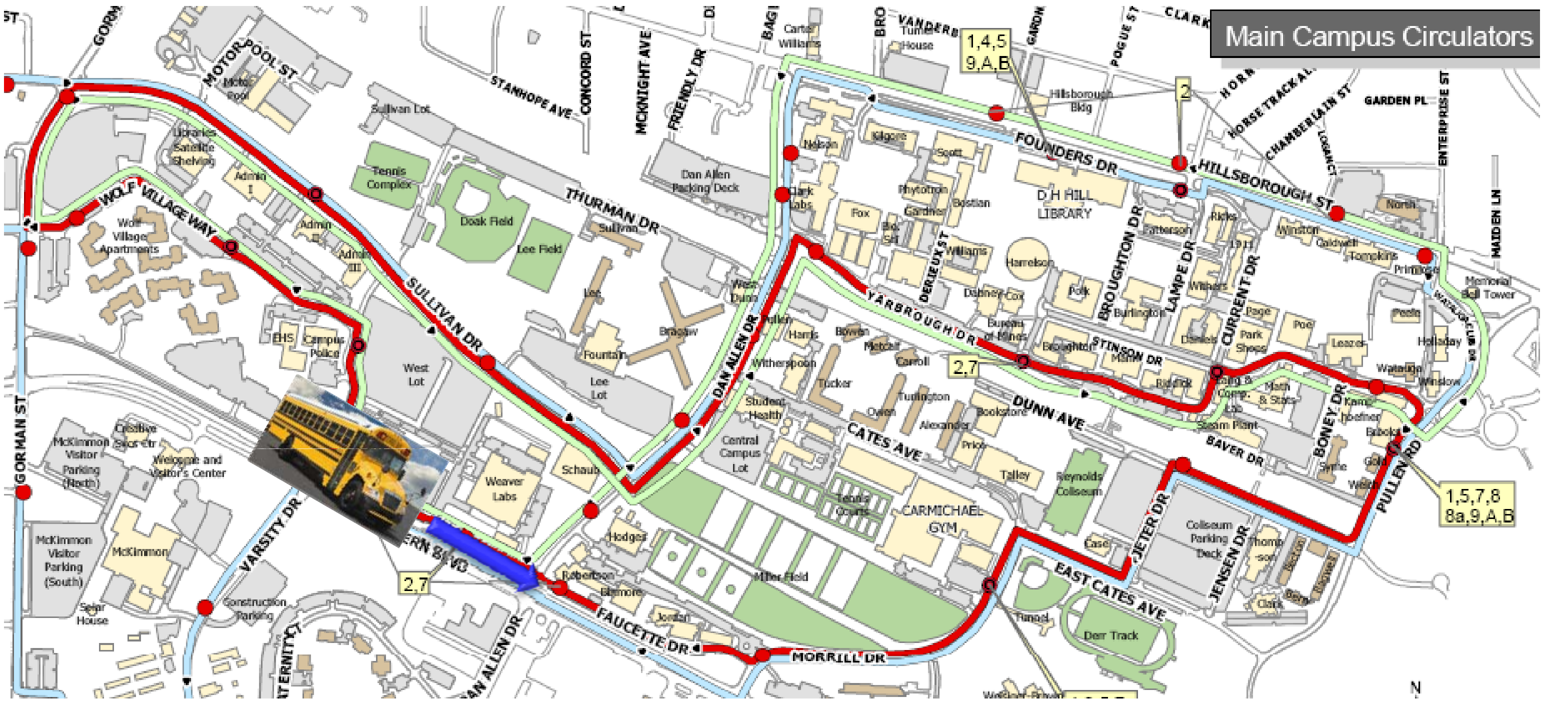

Small World?

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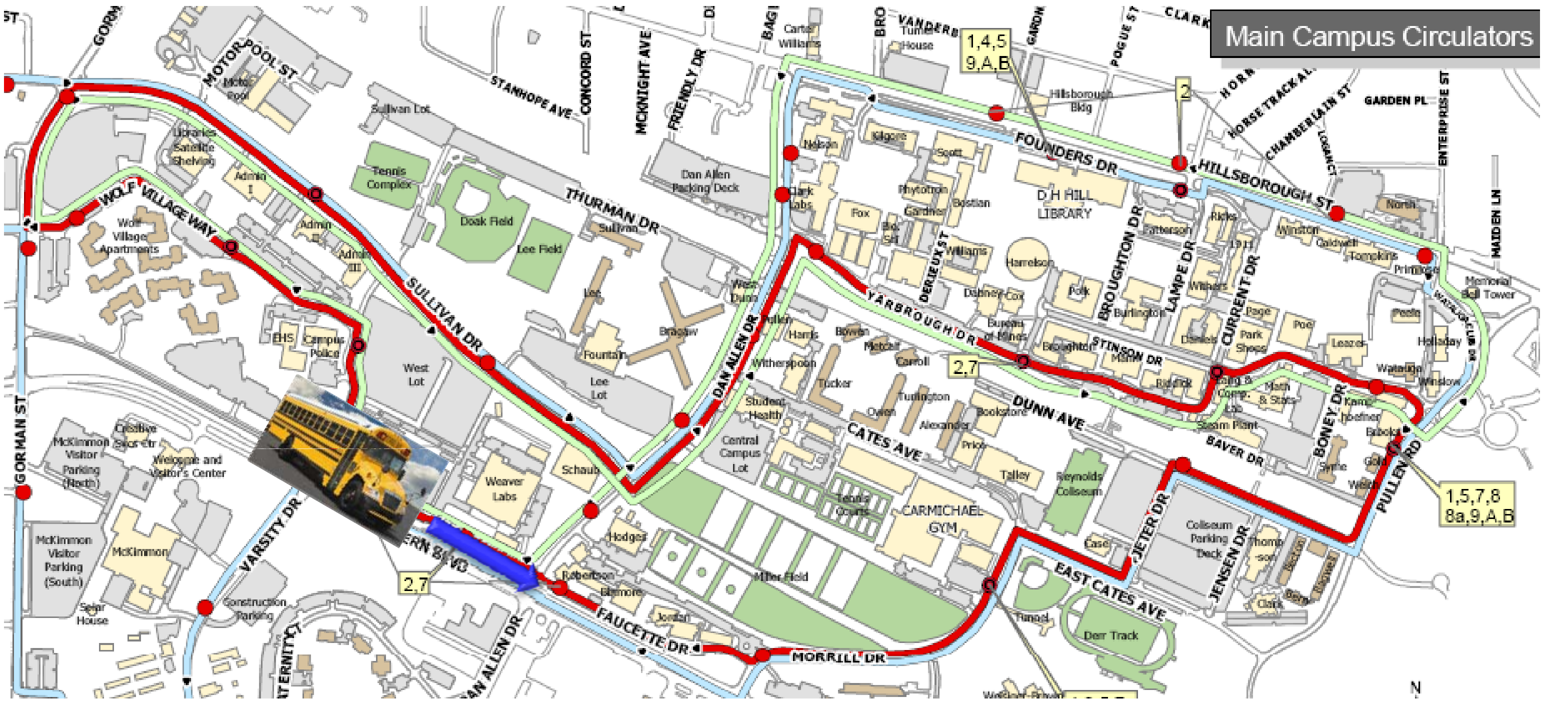

Sma  orld?

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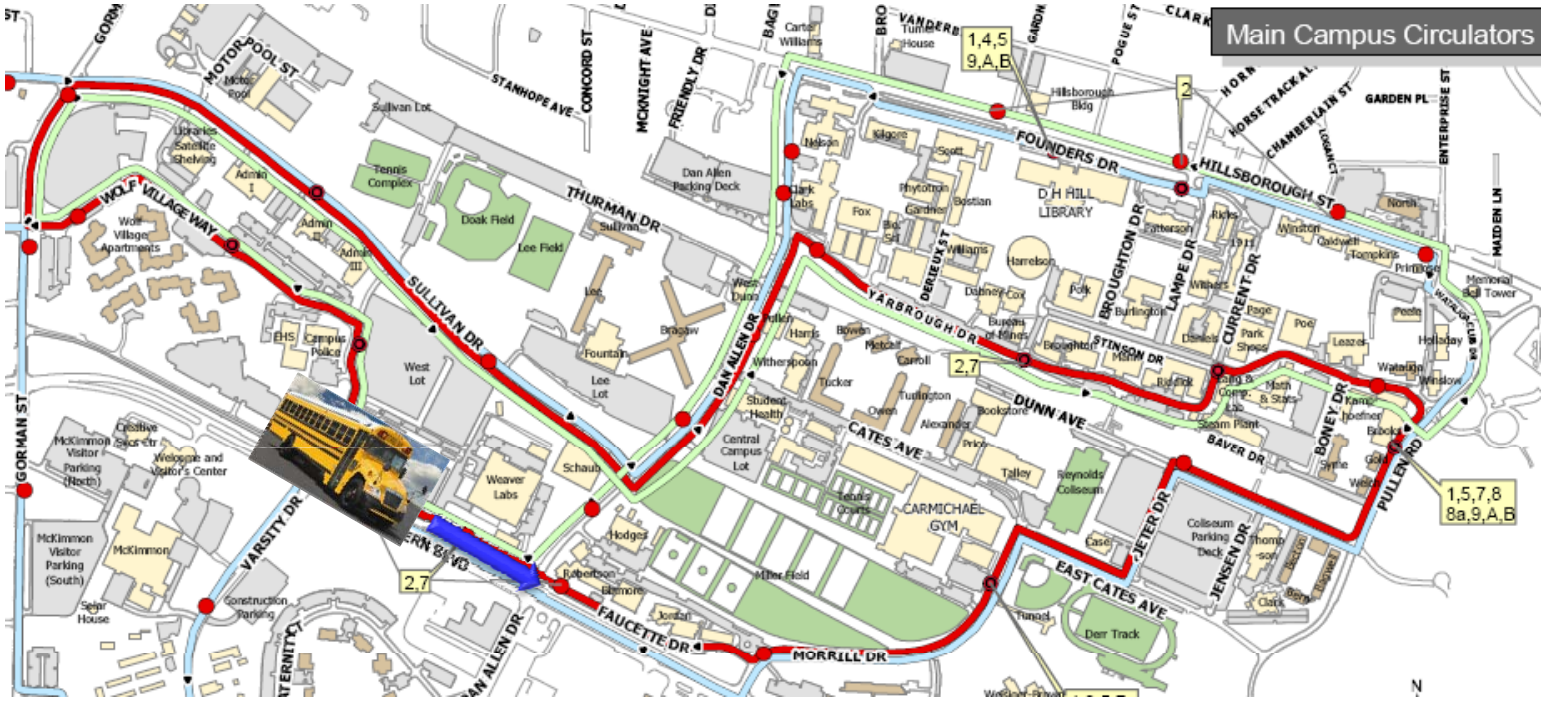

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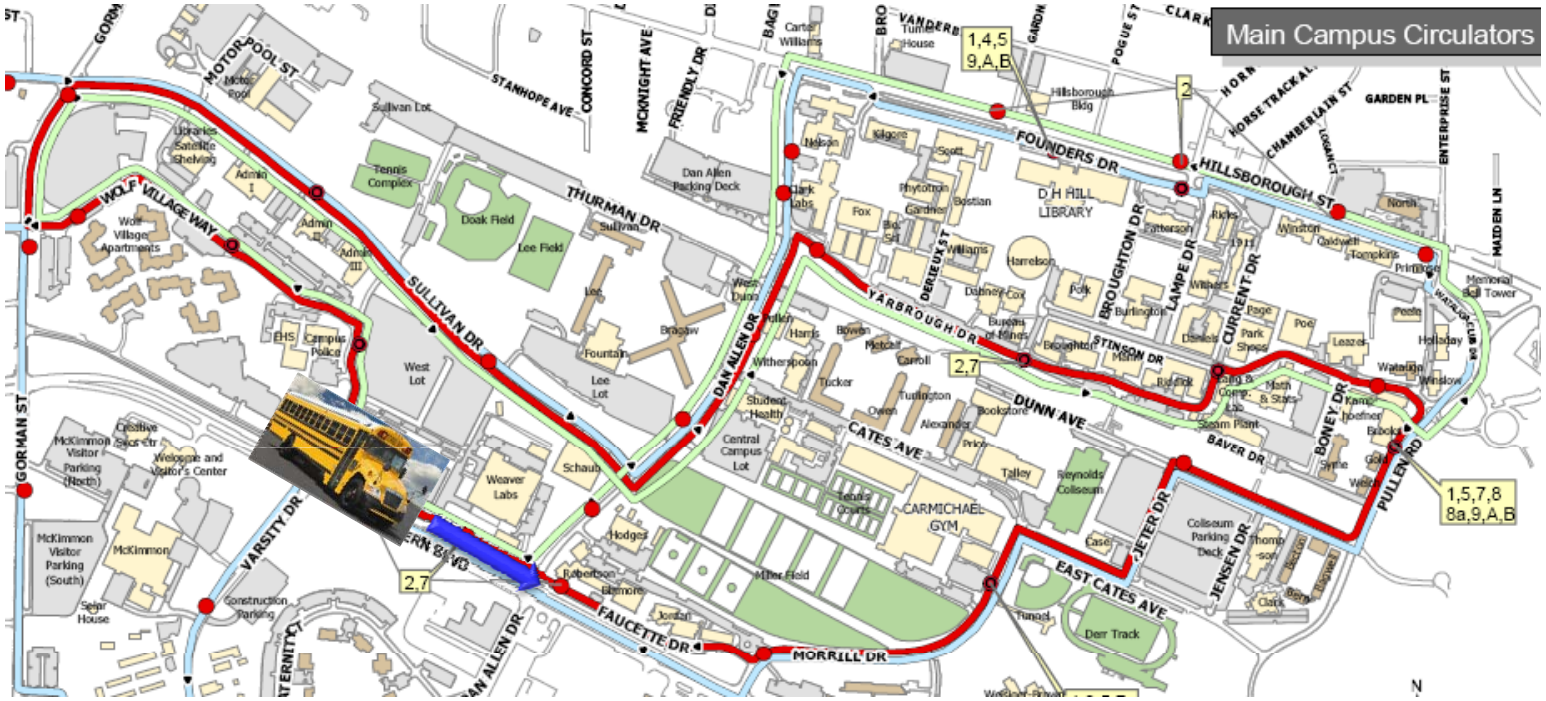

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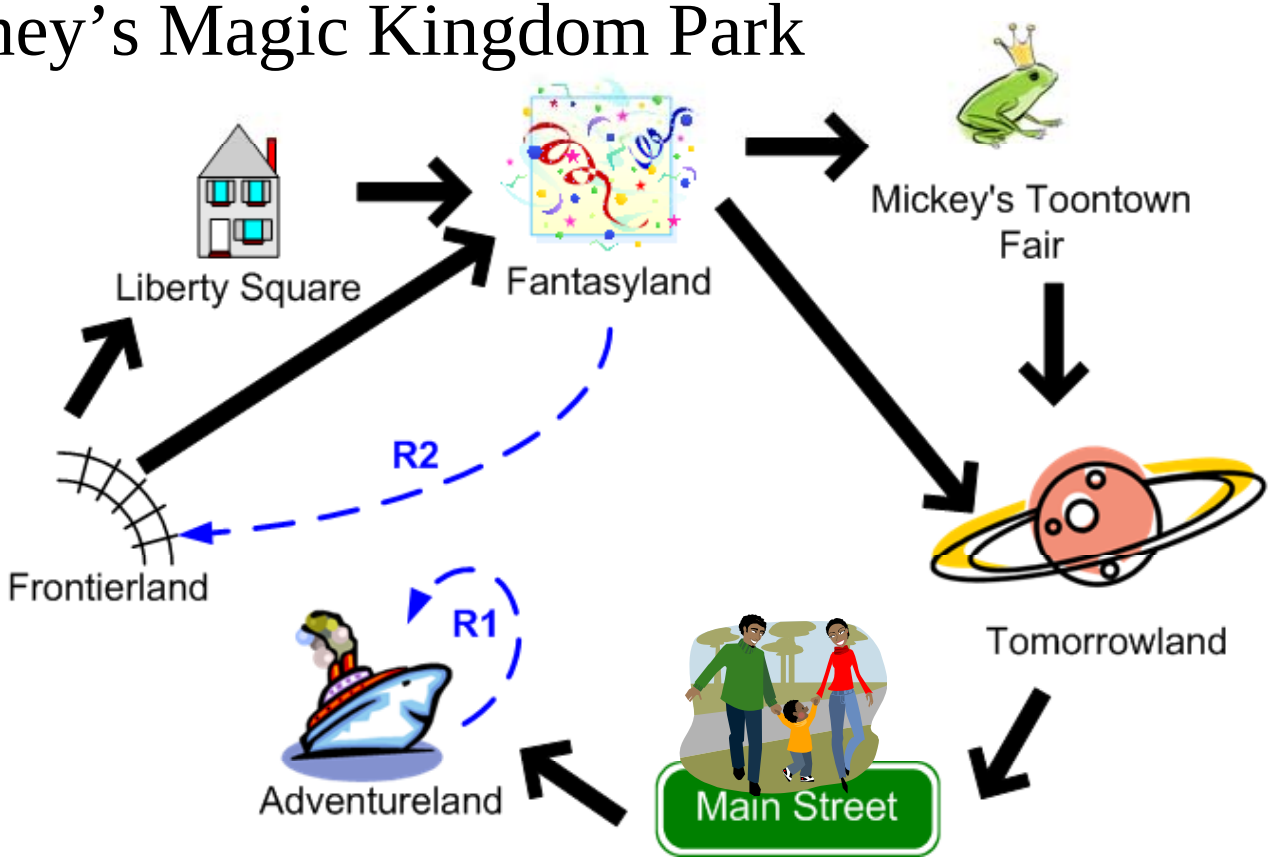
Motivation of **Positive-aging** Model Class: 2

- Disney's Magic Kingdom Park



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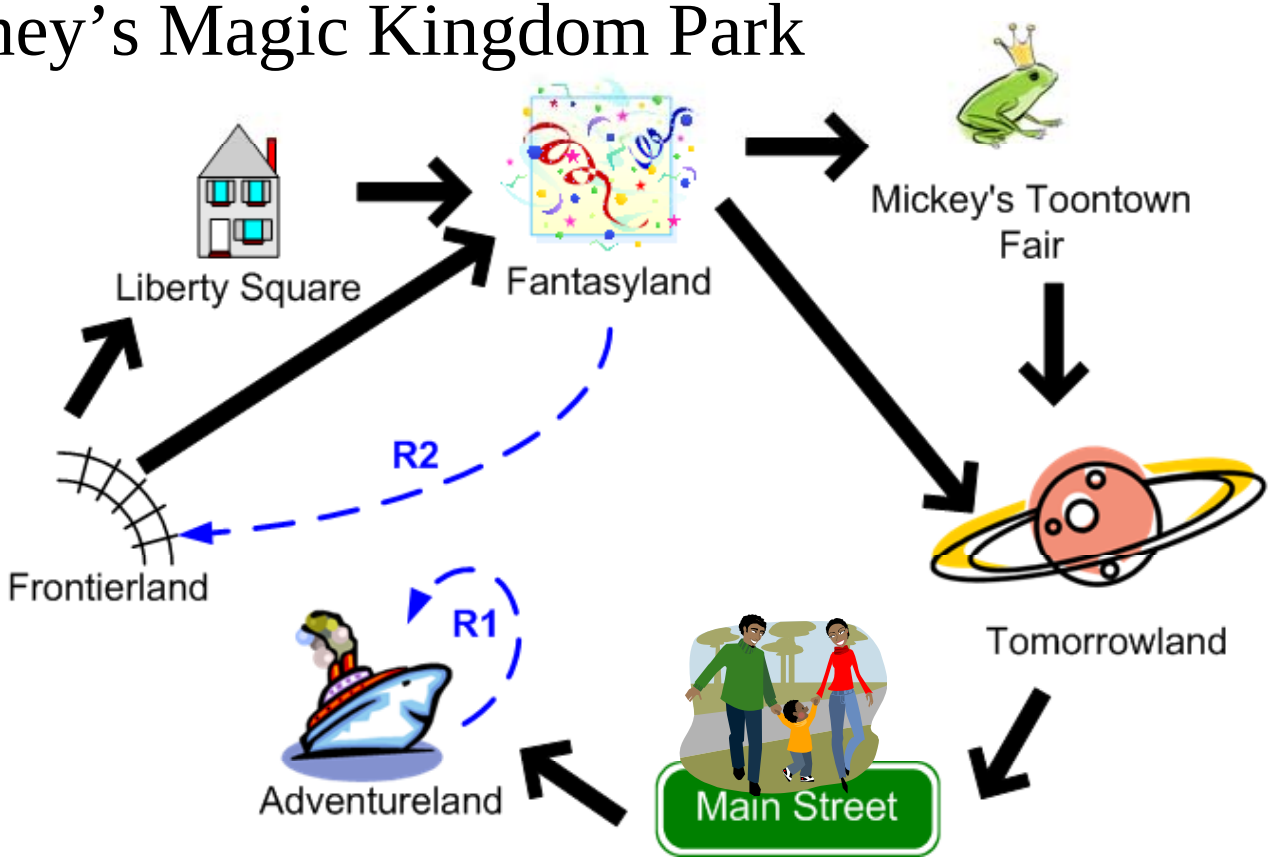

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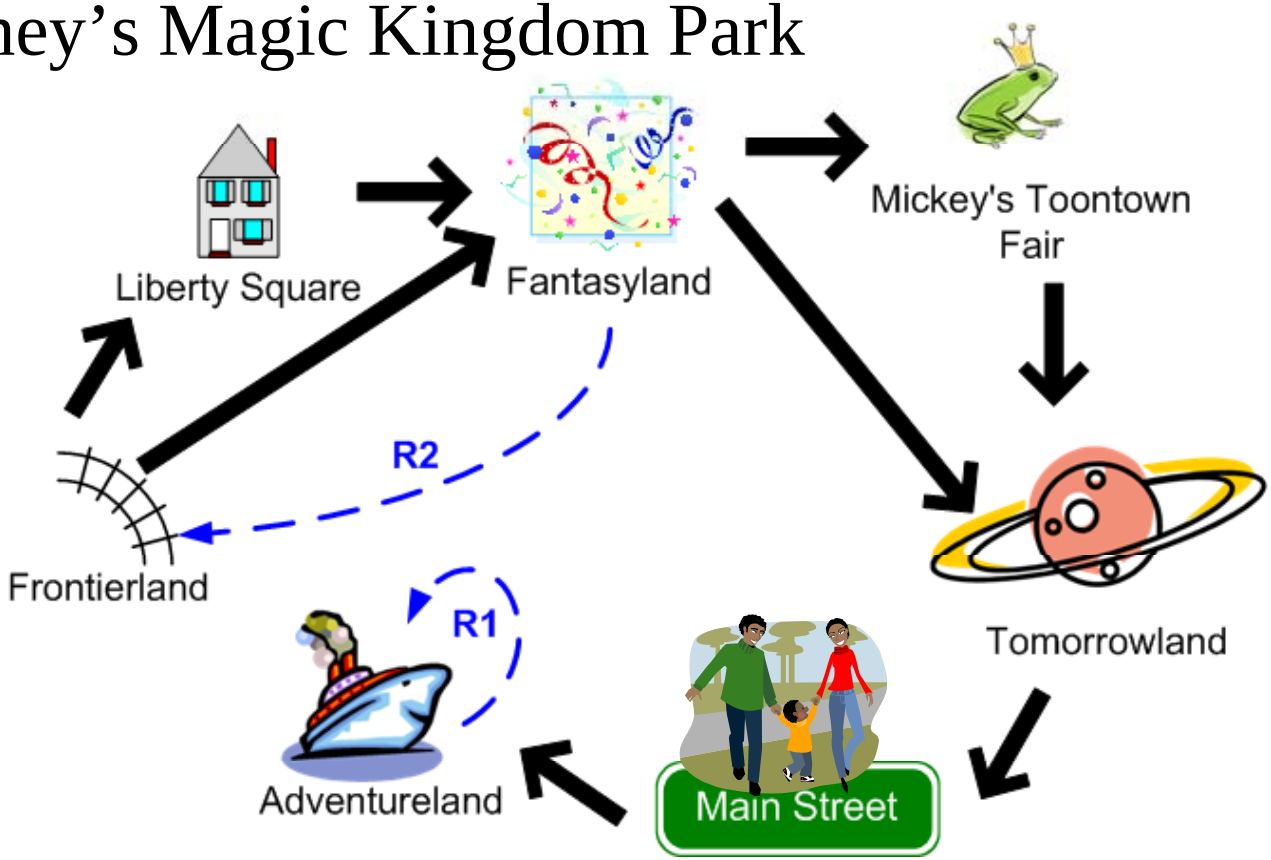

Sma orld?

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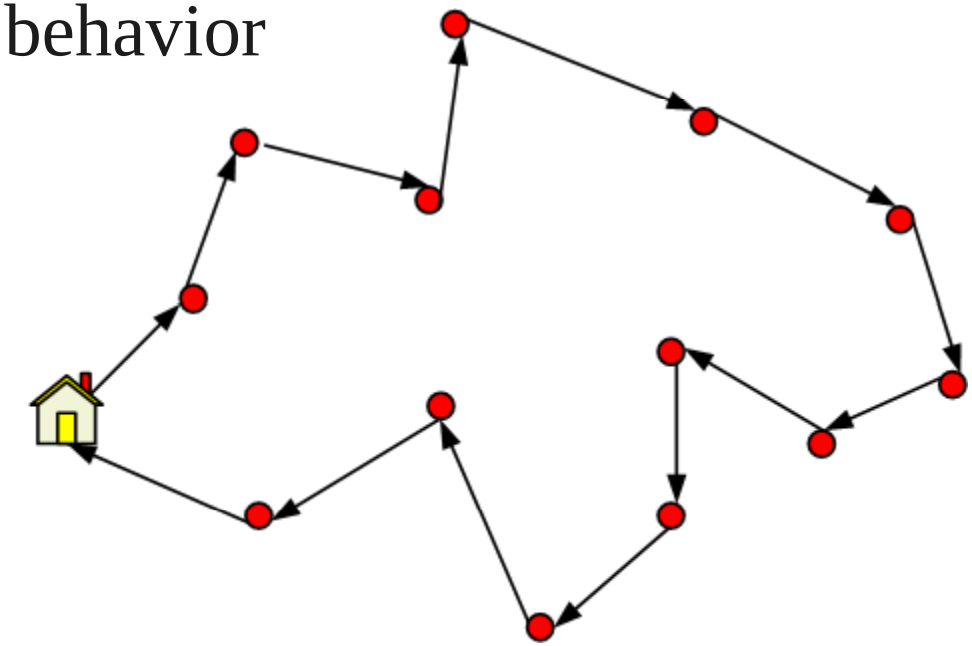
Positive-aging: Mobility Model Class 3 & 4

- Key feature: ***tour-like*** behavior
- Main tour



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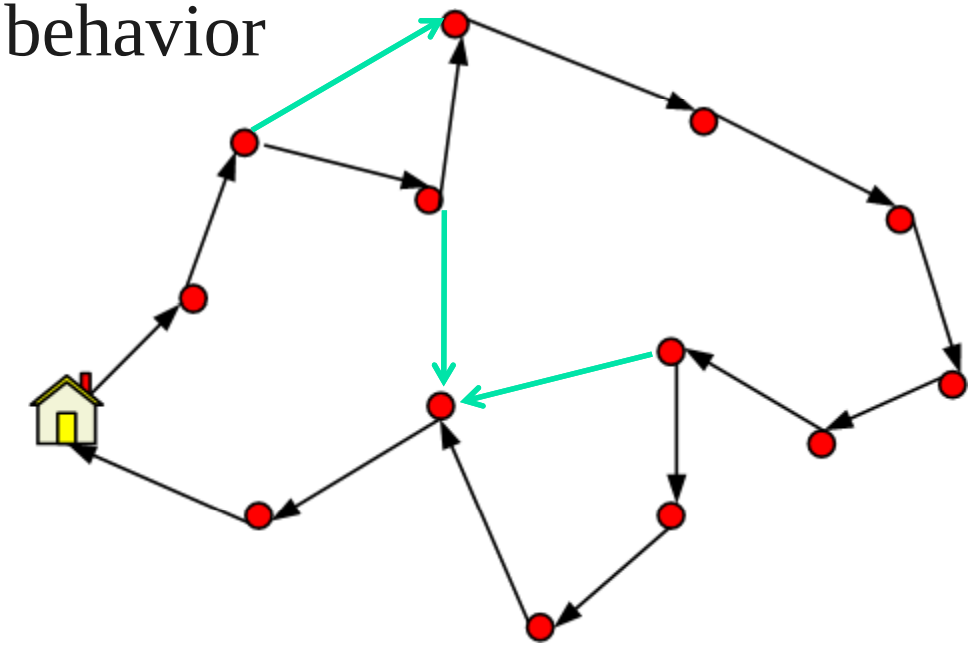

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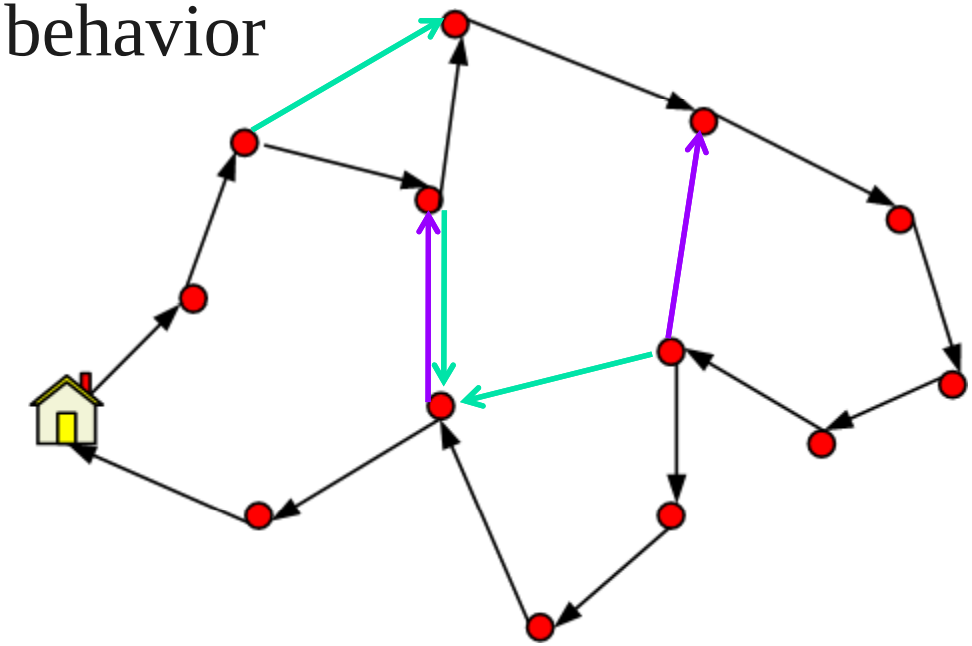

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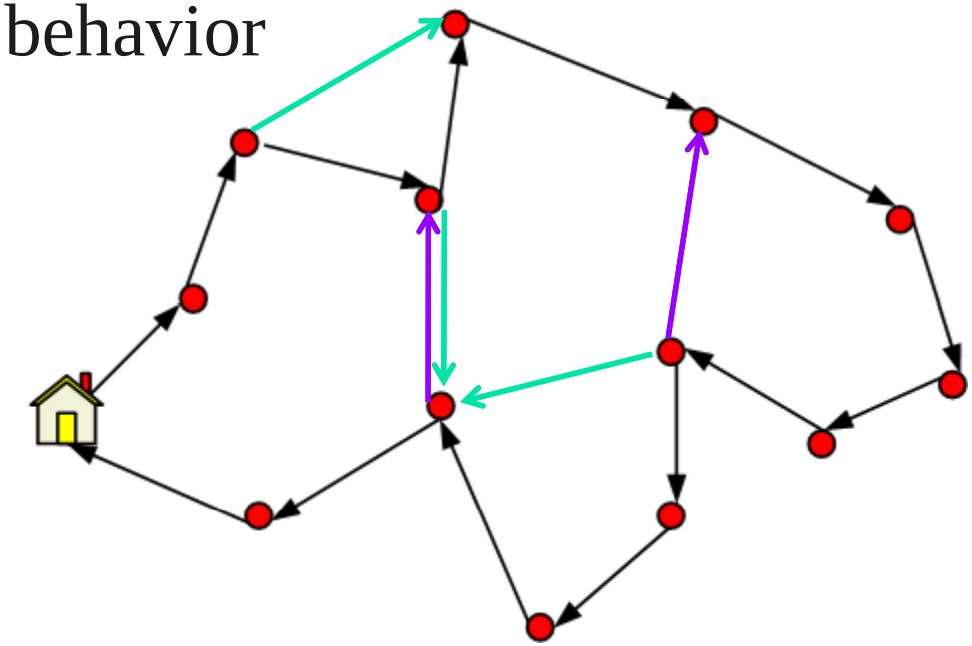

Progressive-route condition

$$p_{ij}=\begin{cases}(1-(N-i+1)s_i)/i, & i>j\\ s_i, & i\le j\end{cases}$$

$$Ns_1\le(N-1)s_2\cdots\le s_N$$

Stochastic monotone condition

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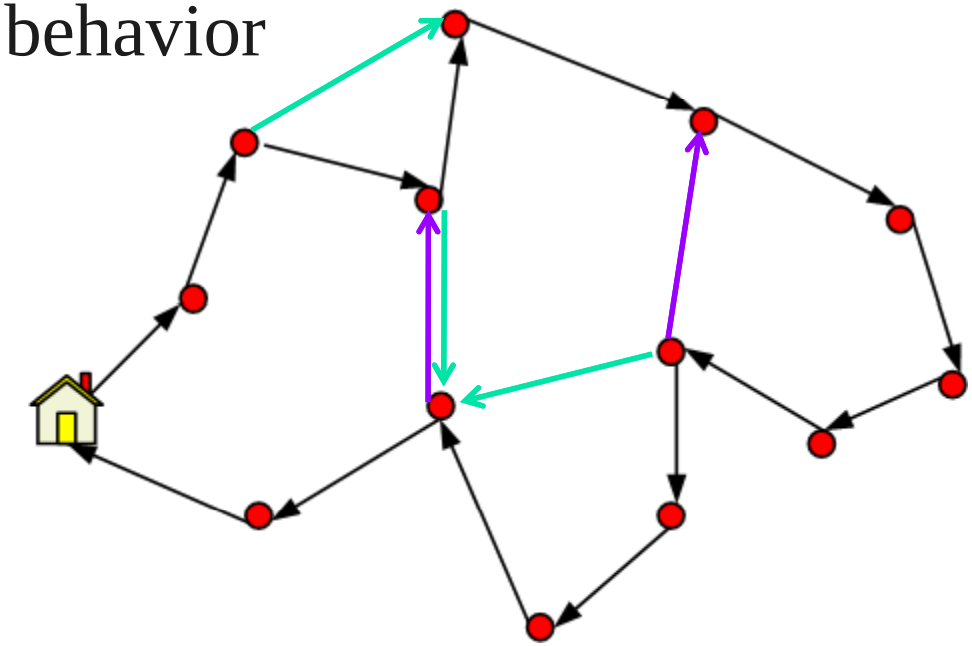
  - Bypass
  - Go backward



Intuition behind complicated technical conditions: tendency of going ***forwards/backwards*** becomes ***stronger/weaker*** as time goes on

Summary on mobility model classes

- Zero-aging class: **small world**
- Negative-aging class: **undirected (time reversibility)**
- Positive-aging class: **tour-like**

Content

- **Mobility Patterns with Zero/Negative/Positive Aging Inter-contact Time**
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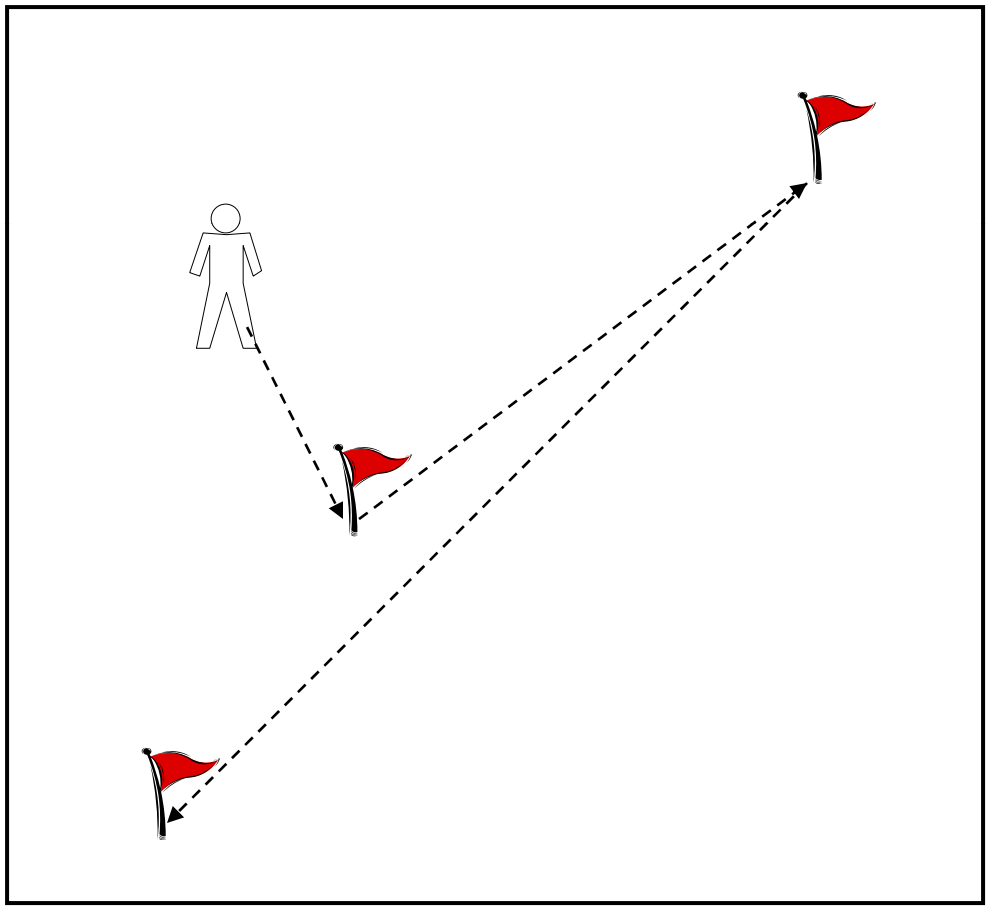
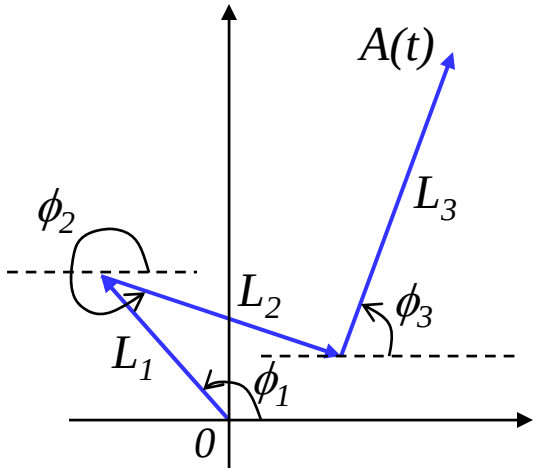
RWP and RW Mobility Models

RWP: Random Waypoint

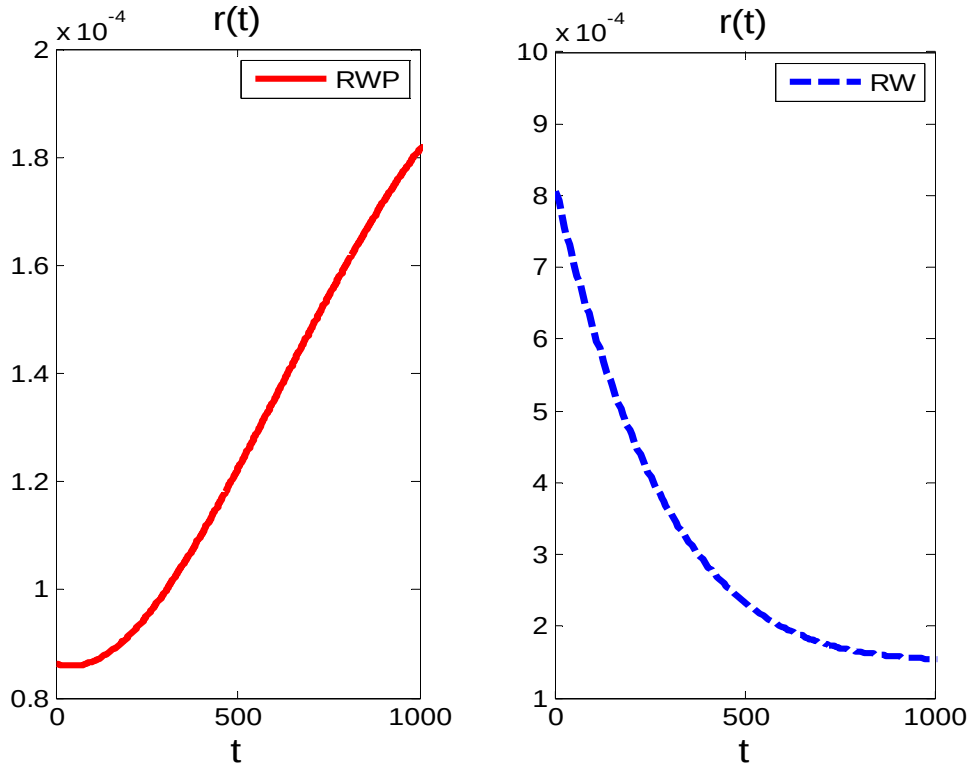


RW: Random Walk



Aging Property: RWP and RW

- Characteristics of relative mobility under RWP and RW
  - RWP: biased node position/direction → ***tour-like***
  - RW: uniform node position/direction → ***time reversibility***



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Compare Two Approaches

Examples of analysis based on exponential inter-meeting time assumption

M. Grossglauser and D. N. C. Tse. Mobility increases the capacity of Ad Hoc wireless networks. *ToN*, 2002.

R. Groen[illegible], and G. Koole. *SIGMETRICS* , 2004.

Zero aging

G. Sharma, R. Mazumdar, and N. B. Shroff . *Infocom 2006.*

T. Spyropoulos, K. Psounis, and C. Raghavendra. *ToN* 2008.

Examples of analysis based on non-exponential inter-meeting time

Positive aging

[illegible] MobiHoc, 2009

A. Chaintreau, P. Hui, J. Crowcroft, C. Diot, R. Gass, and J. Scott. *Infocom*, 2006.

T. [illegible] and M. Vojnovic. *Mobicom*, 2007.

Negative aging

Han Cai [illegible]. *MobiCom*, 2007; MobiHoc, 2008

Compare Two Approaches

Examples of analysis based on exponential inter-meeting time assumption

Examples of analysis based on non-exponential inter-meeting time

What sacrifice have we made for simplicity?

Compare Two Approaches

The approach based on exponential inter-meeting time assumption *always under-estimate* the actual network performance, under inter-meeting time with *positive aging*.

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Convex Ordering of Inter-meeting Time

- Inter-meeting time T vs. its exponential counterpart T_e satisfying

$$T \rightarrow \mathbb{E}\{T\} \rightarrow \mathbf{P}\{T_e \geq t\} = e^{-\frac{t}{\mathbf{E}\{T\}}}$$

  - Model class 2: $T \geq_{cv} T_e$

$$\mathbb{E}\{\phi(T)\} \geq \mathbb{E}\{\phi(T_e)\}$$

for any convex function $\phi(\cdot)$

$$\mathbb{P}\{D > t\} = \frac{\mathbb{E}\{[T-t]^+\}}{\mathbb{E}\{T\}} \geq \frac{\mathbb{E}\{[T_e-t]^+\}}{\mathbb{E}\{T_e\}} = \mathbb{P}\{D_e > t\}$$

Actual delay of one-hop forwarding strategy

Delay estimated under exp. based approach

Convex Ordering of Inter-meeting Time

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Exp. approach gives stochastically smaller delay than the actual one

  - Model class 3 & 4: $T \leq_{cv} T_e$

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Exploit the Aging Property

Is non-exponential inter-meeting time purely a disaster for MANET performance analysis and design?

Exploit the Aging Property

Exploit the aging property can be ***beneficial*** to forwarding/routing, but ***incorrect*** use of such information is ***more harmful than doing nothing***.

Age-based Forwarding: NOT Aging-based

- Intuition behind age-based forwarding [1,2]
  - Essentially the same as age in mobile wireless sensor network [3,4]: smaller age → shorter distance

[1] H. Dubois-Ferriere, M. Grossglauser, and M. Vetterli. Age matters: efficient route discovery in mobile ad hoc networks using encounter ages. In *ACM MobiHoc,* Annapolis, MD, June 2003.
[2] T. Spyropoulos, K. Psounis, and C. S. Raghavendra. Spray and Focus: Efficient Mobility-Assisted Routing for Heterogeneous and Correlated Mobility. In *PerCom Workshops '07, White Plains, NY, 2007.*
[3] Matthias Grossglauser and Martin Vetterli. Locating nodes with ease: last encounter routing in ad hoc networks through mobility diffusion. In *IEEE Infocom,* San Francisco, March 2003.
[4] Stratis Ioannidis and Peter Marbach. A brownian motion model for last encounter routing. In *IEEE Infocom, Barcelona, Spain, April 2006.*

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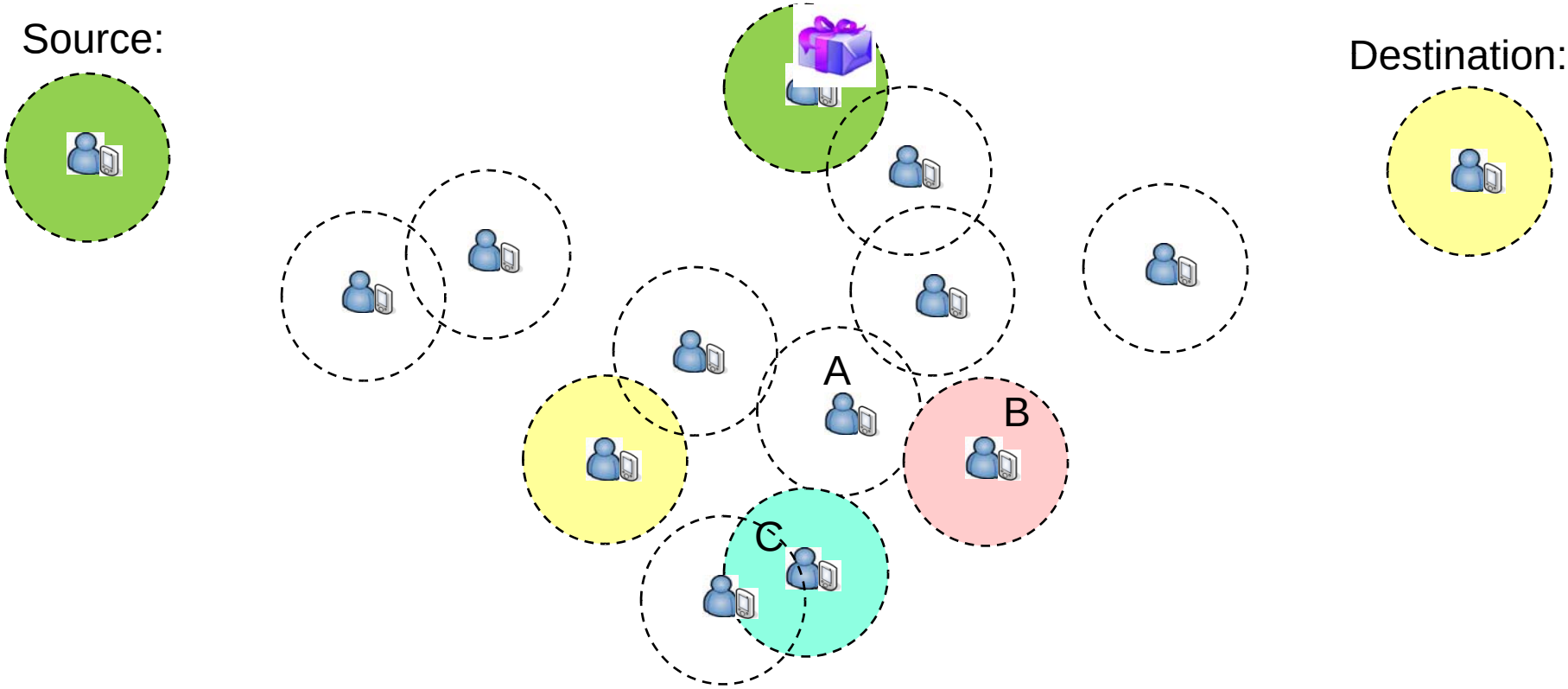

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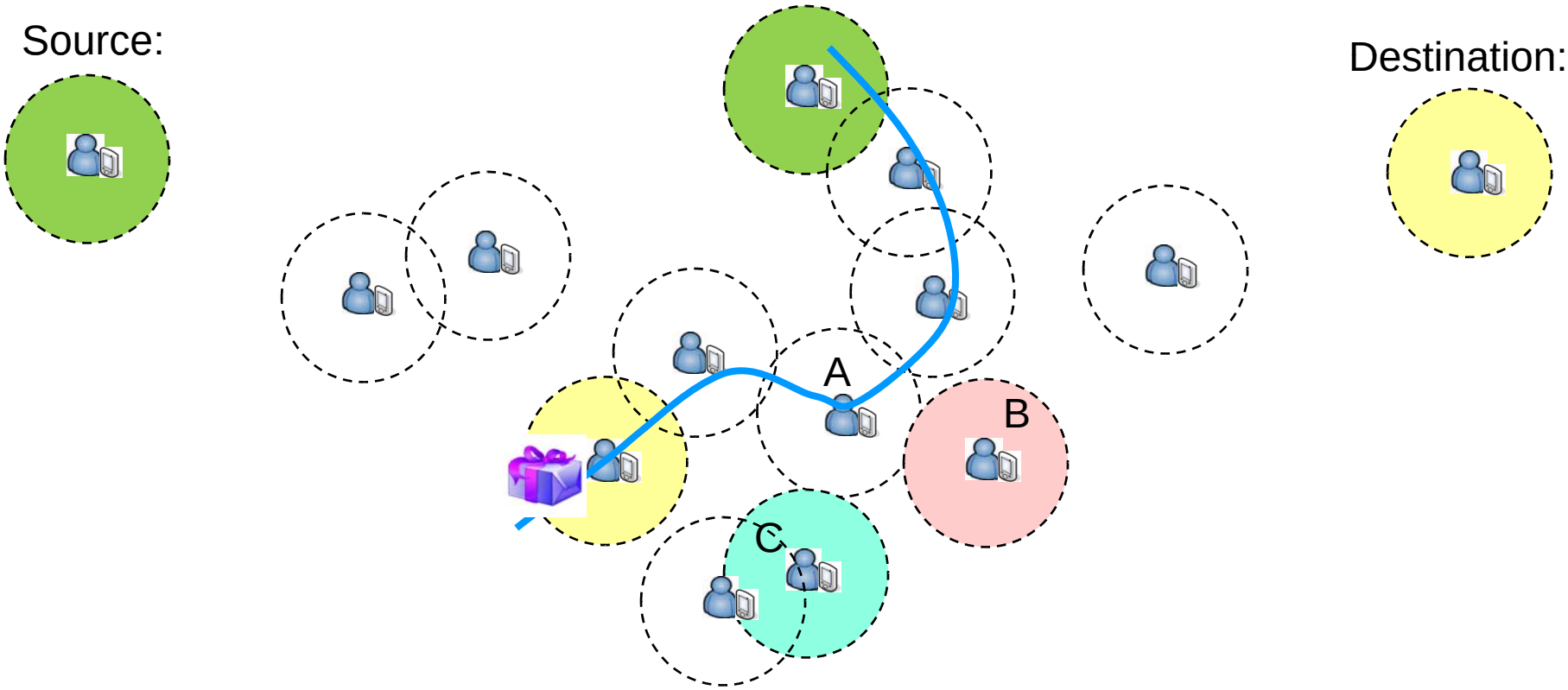

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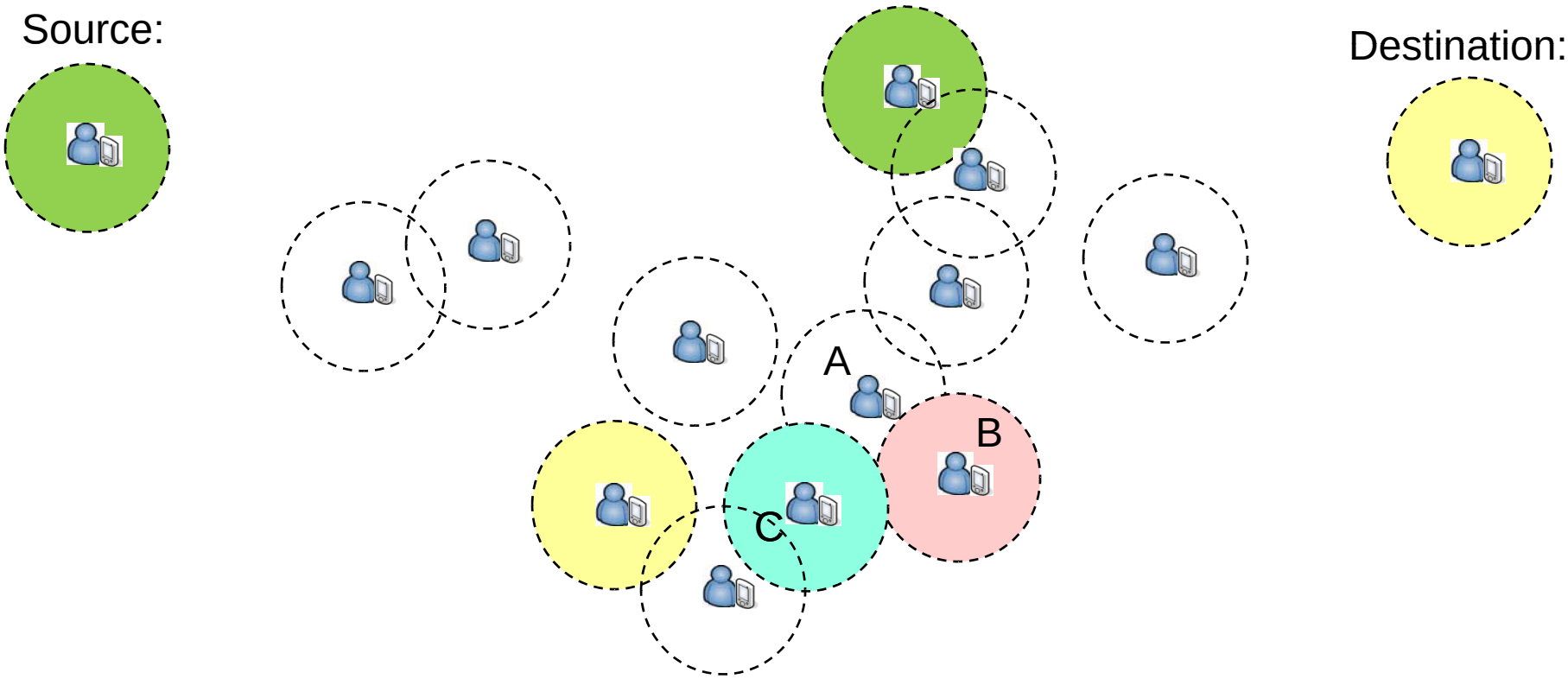

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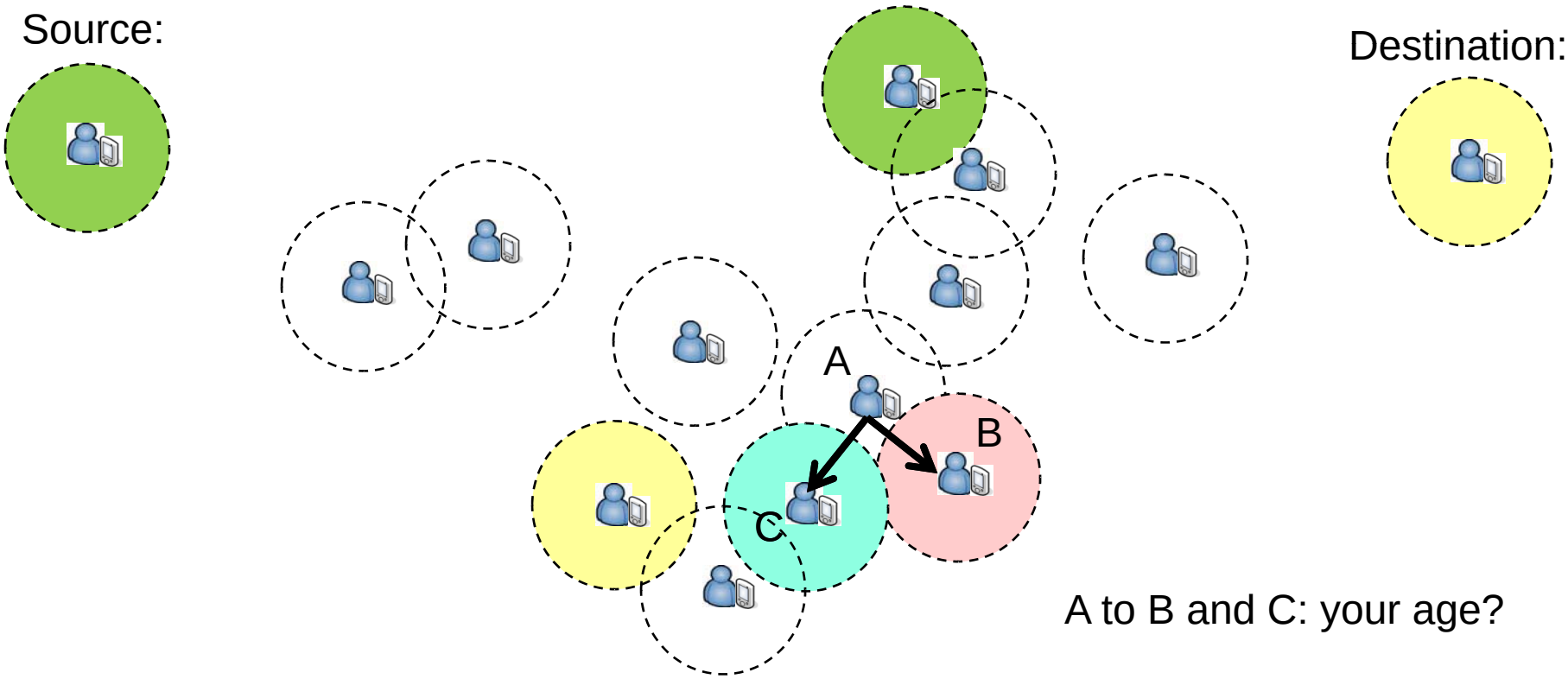

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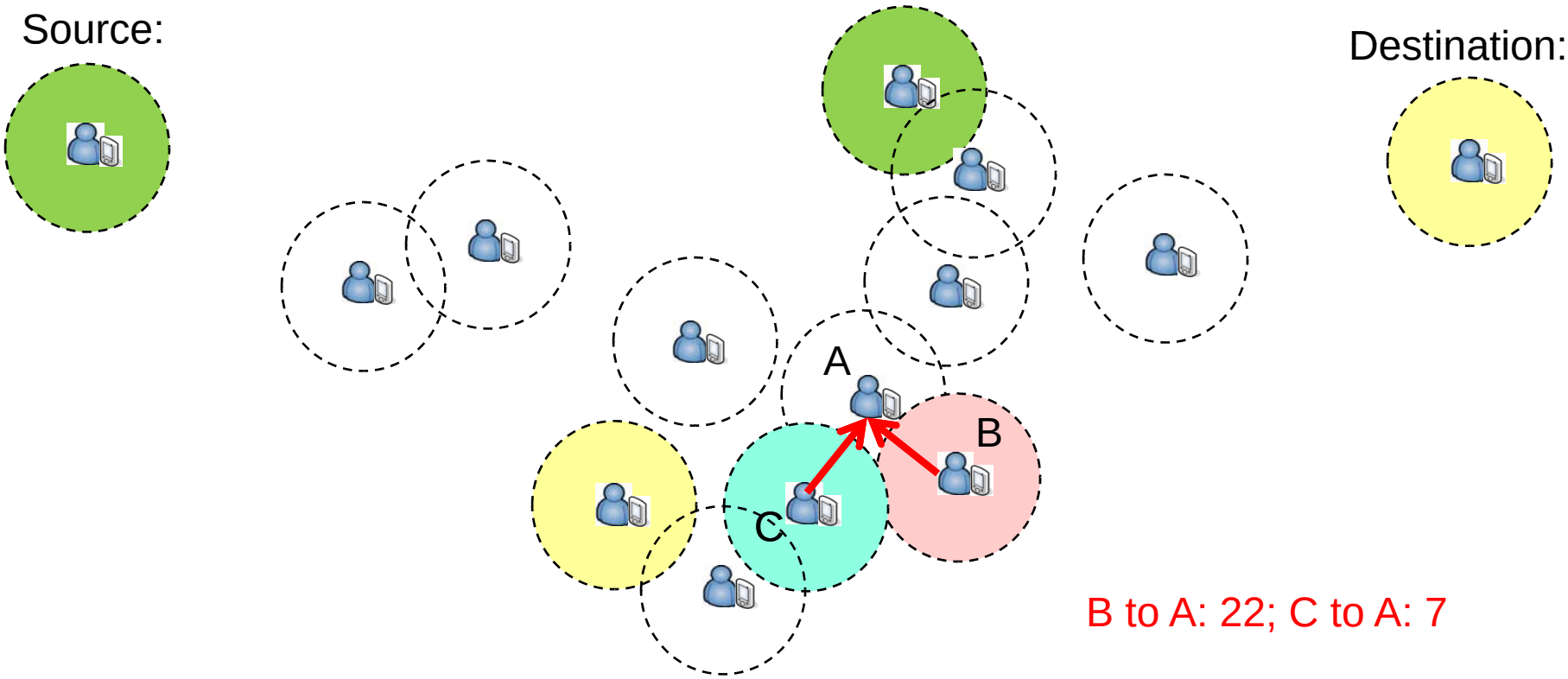

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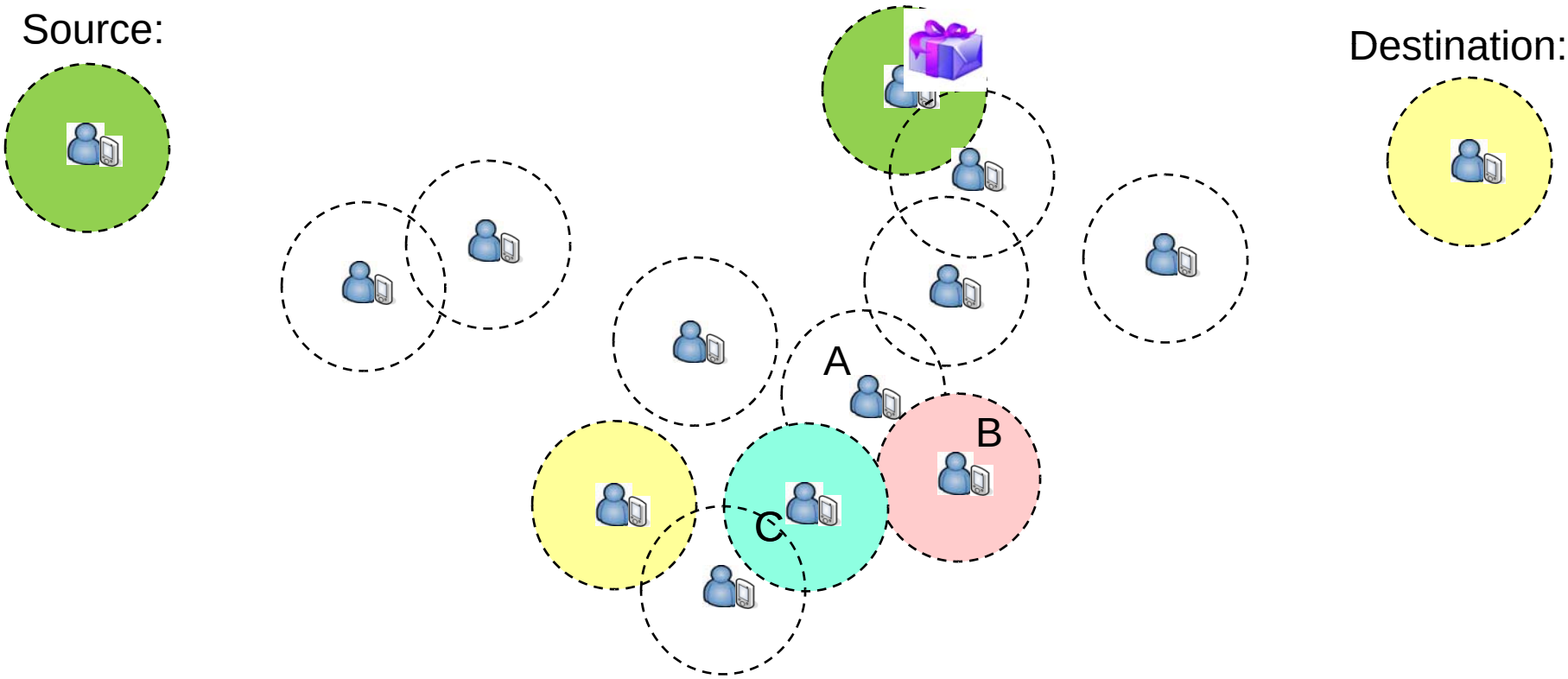

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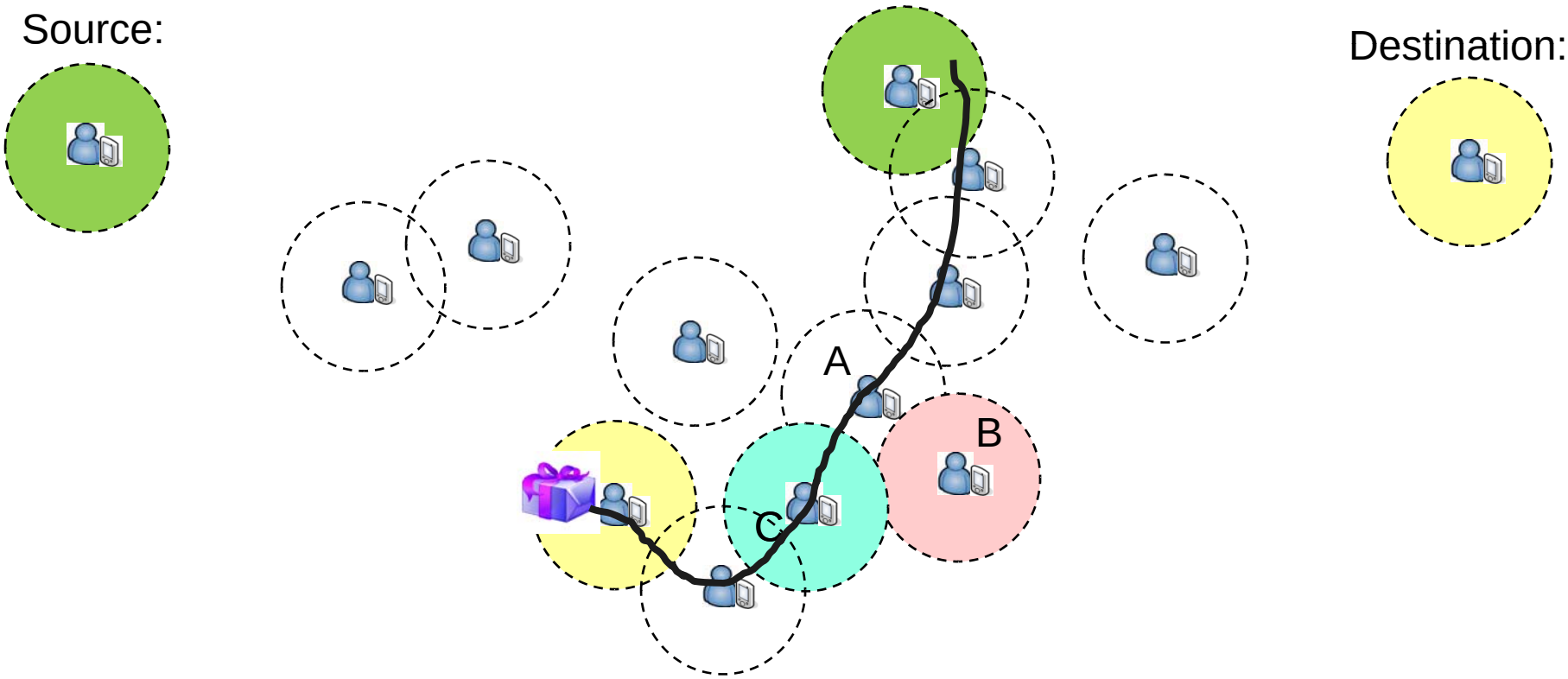


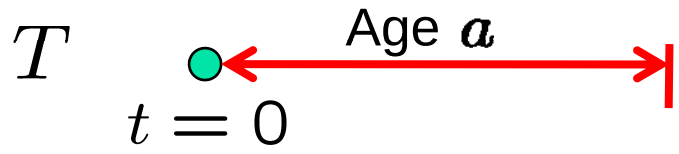
Intuition

Intuition: A pair of mobile nodes in *shorter distance* will meet each other in *shorter time*. Hence, mobile node with *smaller age* will meet the destination in *shorter time*.

Intuition

Past

Re-routing **Distance**



Use the past information (age) to estimate what has happened (distance) in the past

Intuition

Past

Re-routing **Distance**

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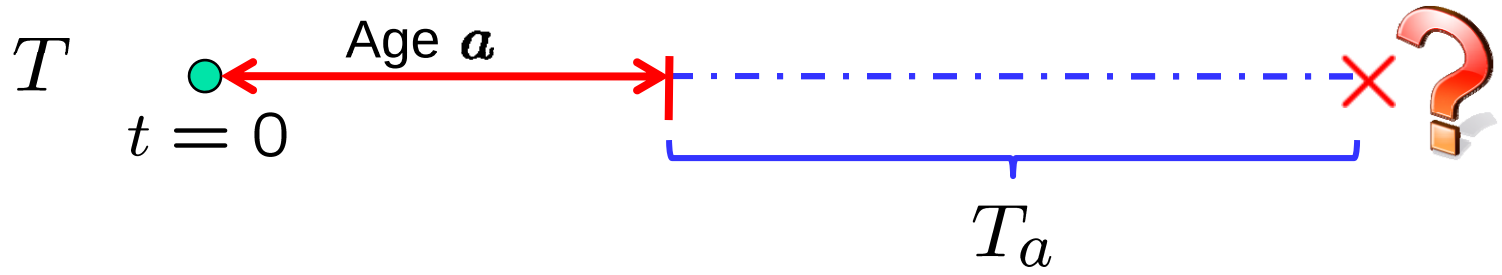


Forwarding **Residual life**

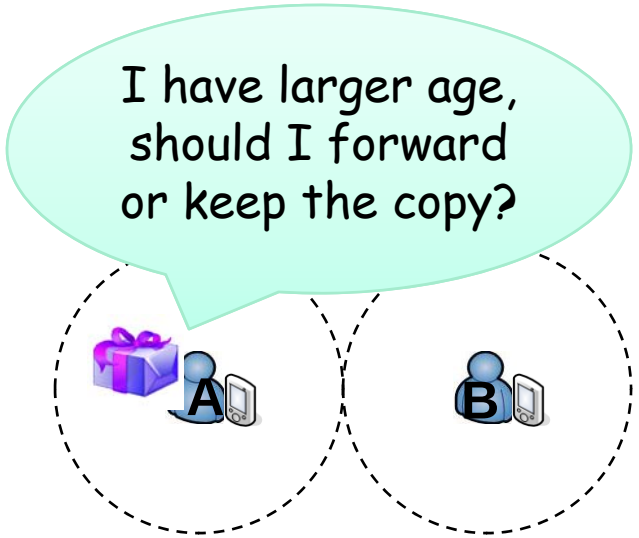
Future

Use the past information (age) to estimate what will happen (residual life) in the future

Intuition

Intuition: A pair of mobile nodes in *shorter distance* will meet each other in *shorter time*. Hence, mobile node with *smaller age* will meet the destination in *shorter time*.

Exploit the aging property



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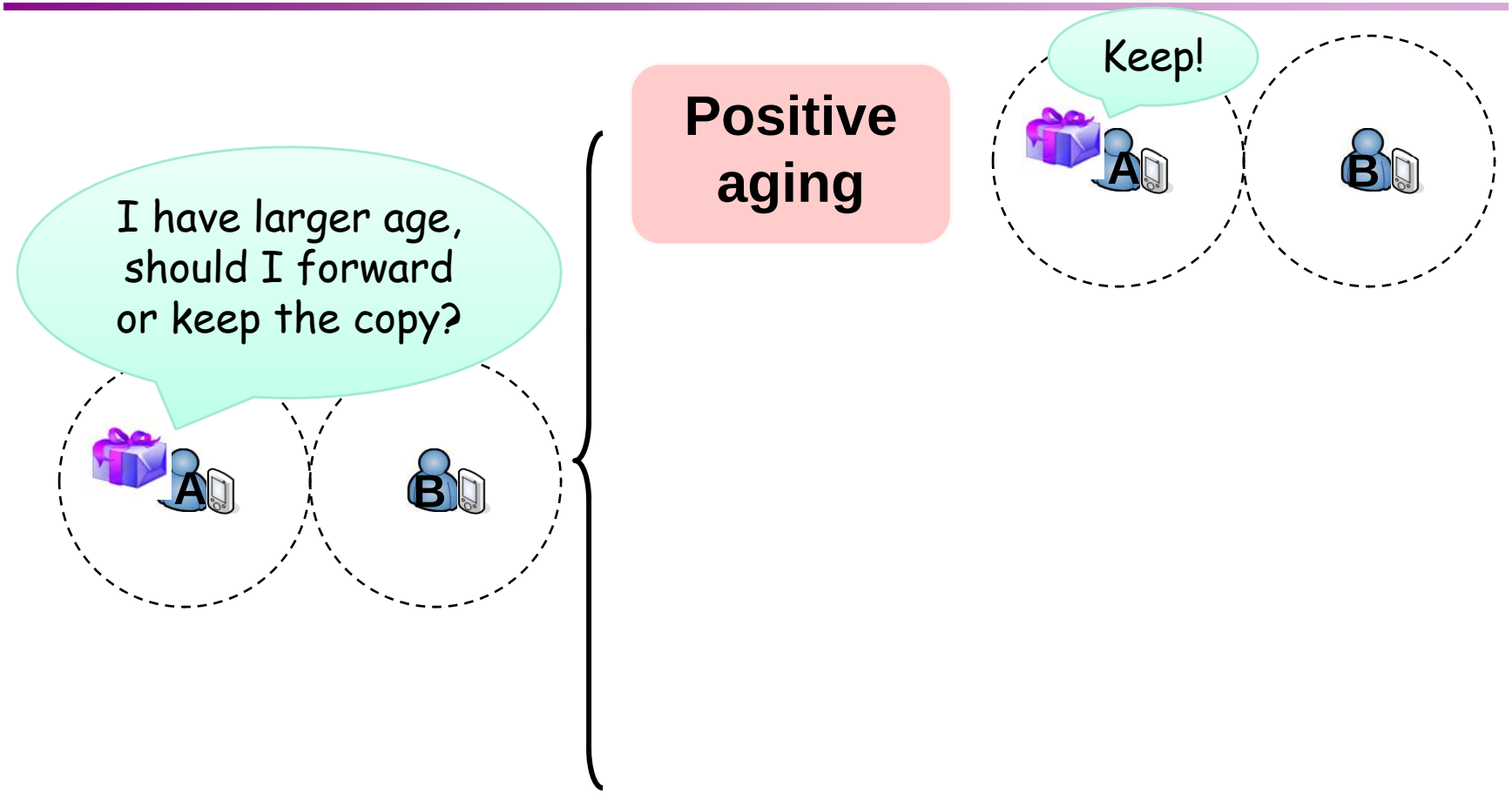

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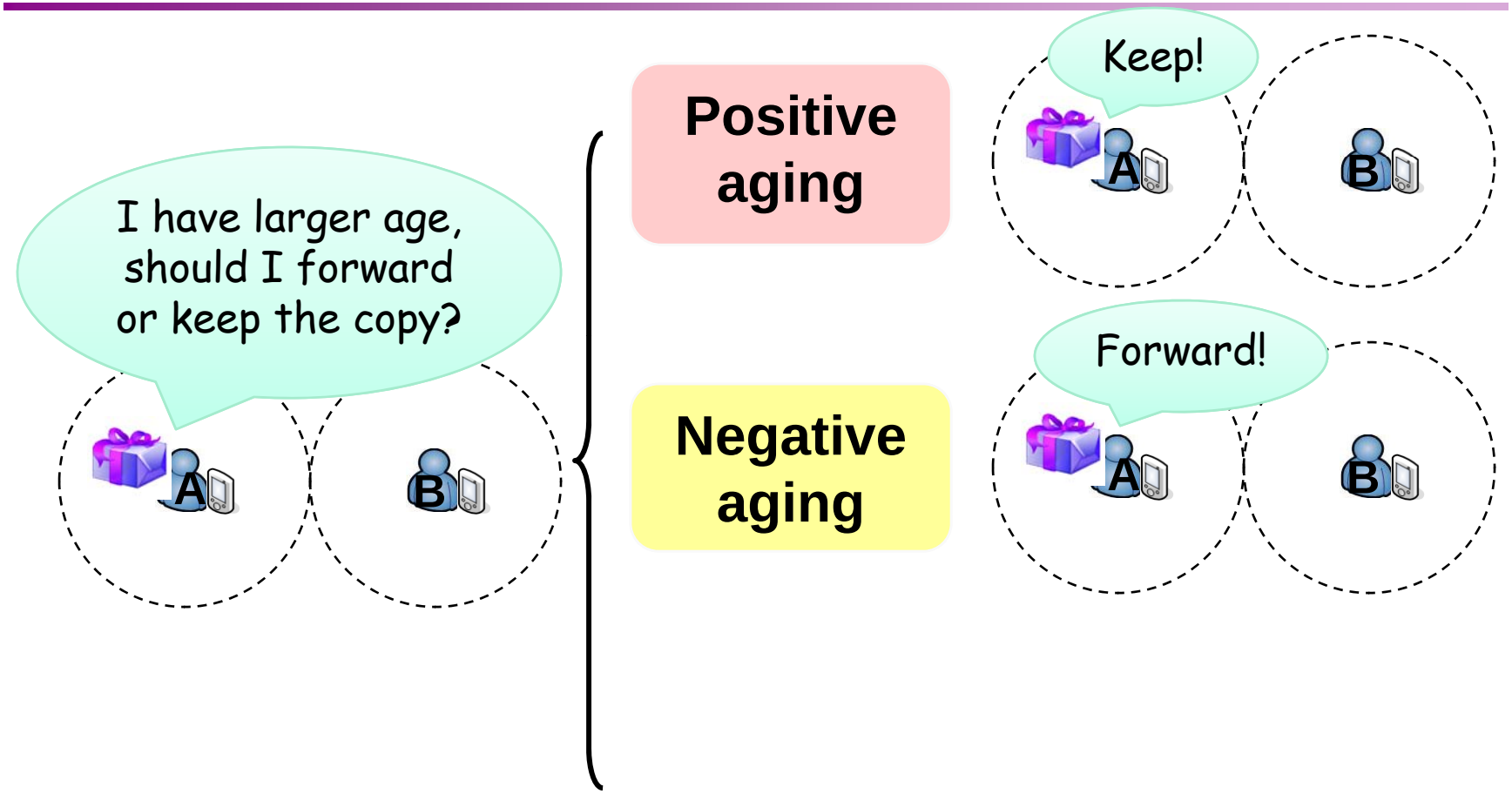

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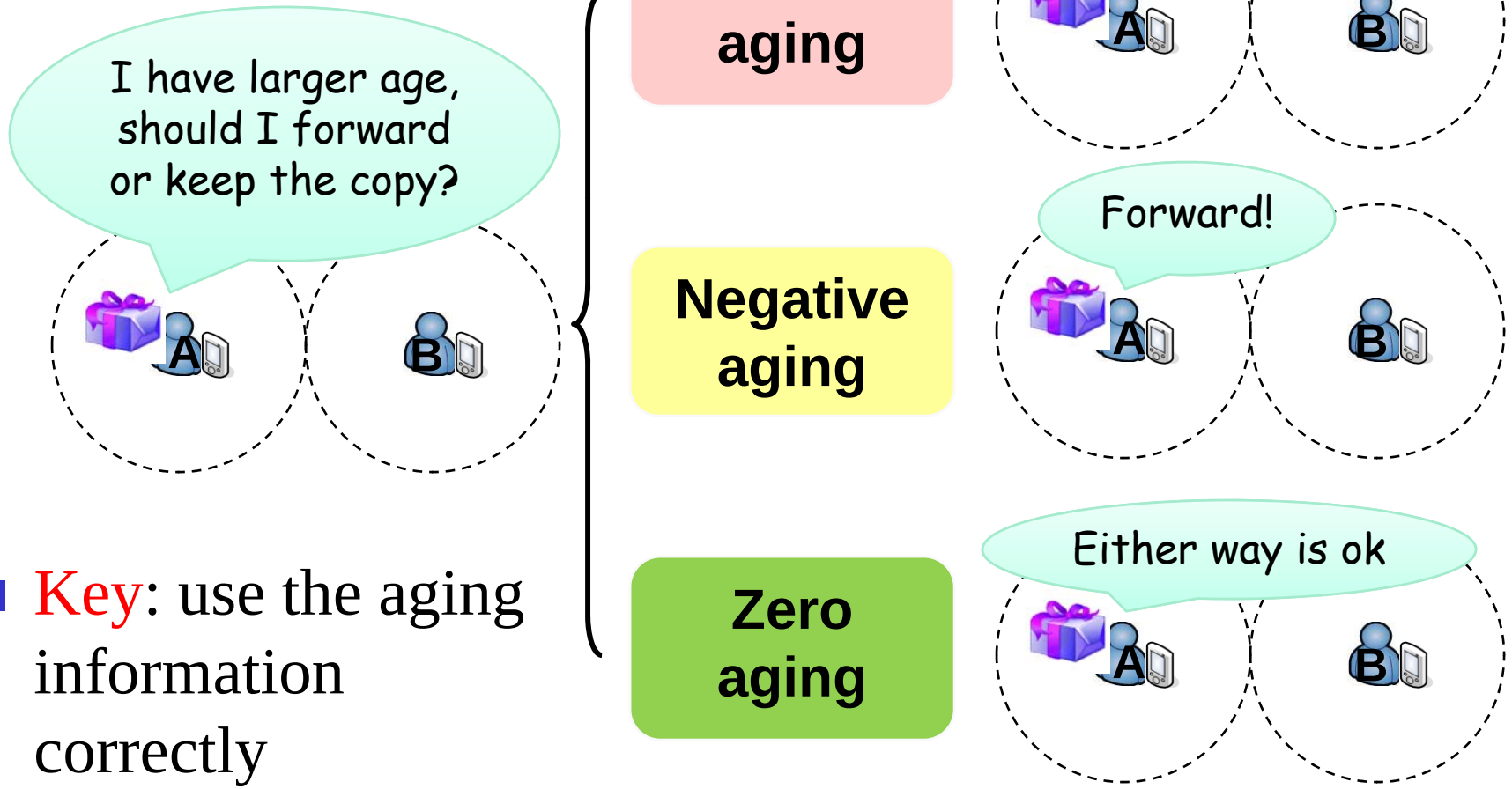

- Key: use the aging information correctly

Conclusion

- Analysis: zero/negative/positive-aging models
- Aging does rule:
  - **The exp. assumption based approach *always under-estimate* the actual network performance, under inter-meeting time with *positive aging*.**
  - **The exp. assumption based approach *always over-estimate* the actual network performance, under inter-meeting time with *negative aging*.**
  - **Exploit the aging property can be *beneficial* to forwarding/routing, but *incorrect* use of such information is *more harmful than doing nothing*.**

Thank You!

Questions ?