Forever Young: Aging Control For Hybrid Networks

Eitan Altman, Rachid El-Azouzi, Daniel Menasché, **Yuedong Xu**

Appeared in MOBIHOC 2019

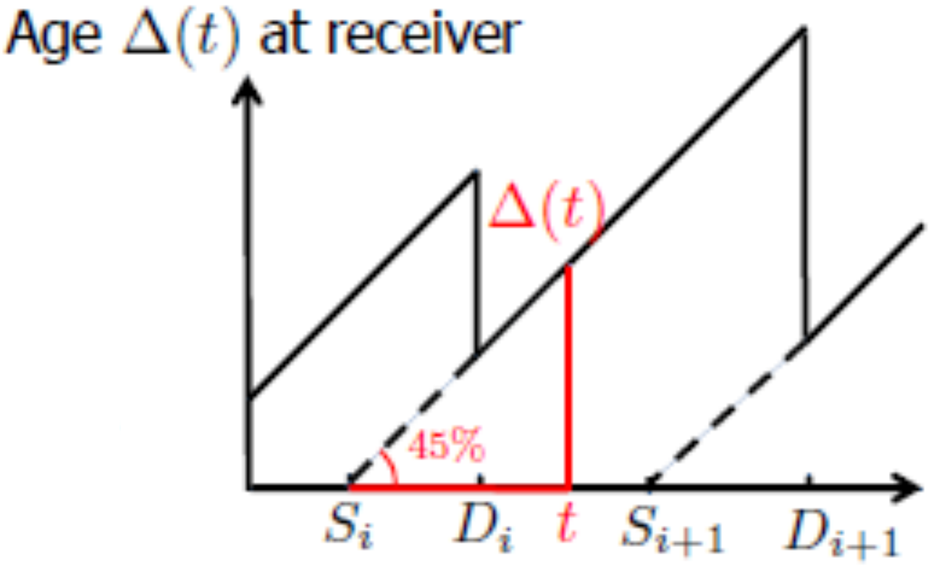
Presented at FCG Workshop’2019@Tsinghua

A History of "Age of Information"

- Real-time monitoring and control [Yin Sun'talk]
  - Internet of things
  - Cyber-physical systems
  - …

- Real-time learning and data analytics
  - Online social networks
  - Distributed machine learning
  - Crowdsourcing and crowdsensing

Data Freshness Metric: Age of Information



generated at time s_i

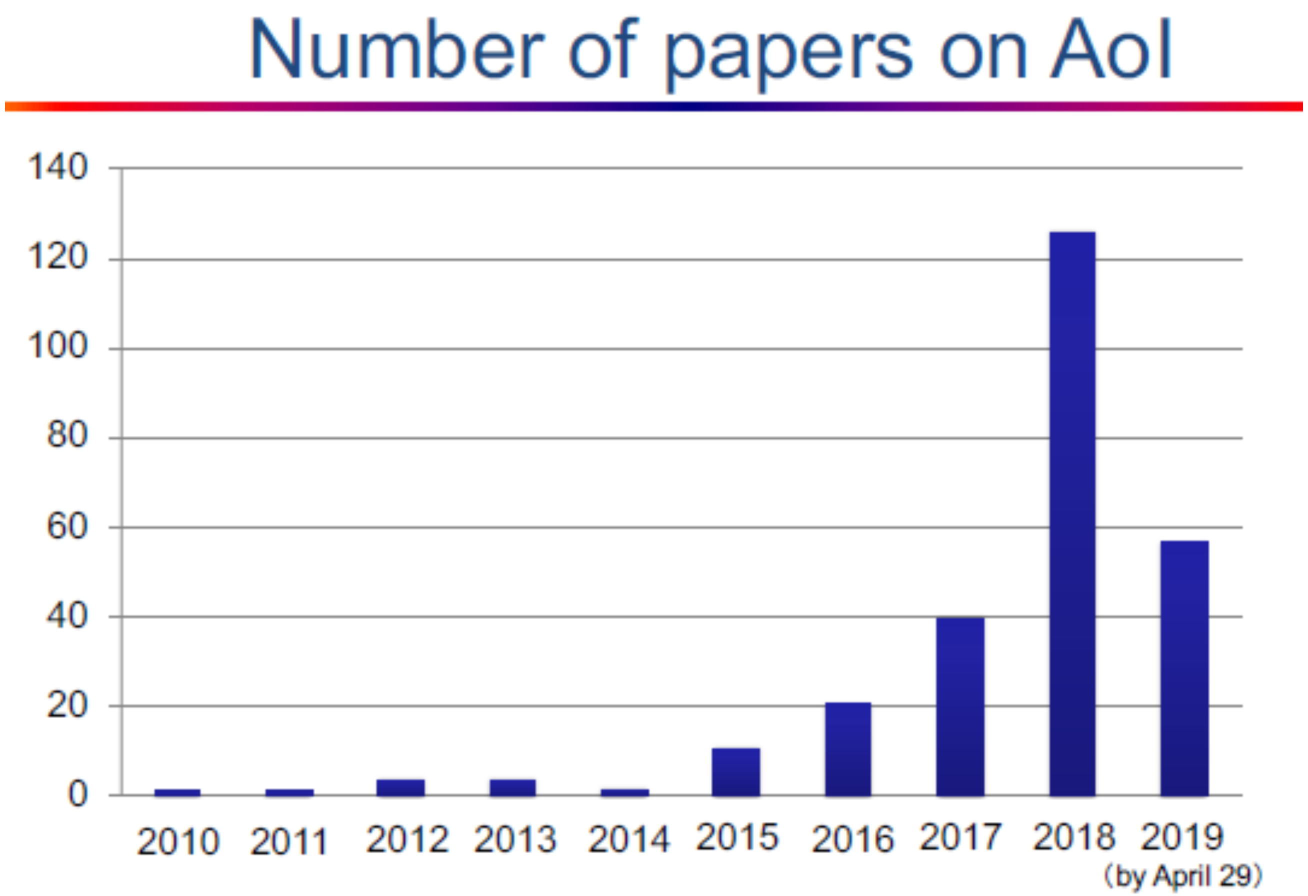
delivered at time d_i

- **Definition:** At time *t*, the **Age of Information** Δ(t) is time difference between the current time *t* and the generation time of the latest received data sample. [Yin Sun’s talk]

Papers on AoI

- Best paper awards on AoI
  - IEEE Infocom 2018
    "Optimizing Age of Information in Wireless Networks with Throughput Constraints"
    Igor Kadota, Abhishek Sinha, Eytan Modiano
  - ACM Mobihoc 2018
    "Optimizing Information Freshness in Wireless Networks under General Interference Constraints"
    Rajat Talak, Sertac Karaman, and Eytan Modiano
  - IEEE ISIT 2018 Jack Keil Wolf award
    "Optimal Lossless Source Codes for Timely Updates"
    Prathamesh Mayekar, Parimal Parag, and Himanshu Tyagi
  - WiOpt 2019, Globecom 2018

Papers on AoI



http://webhome.auburn.edu/~yzs0078/AoI.html

Ten years ago

My first talk on "Forever Young" in September 2010

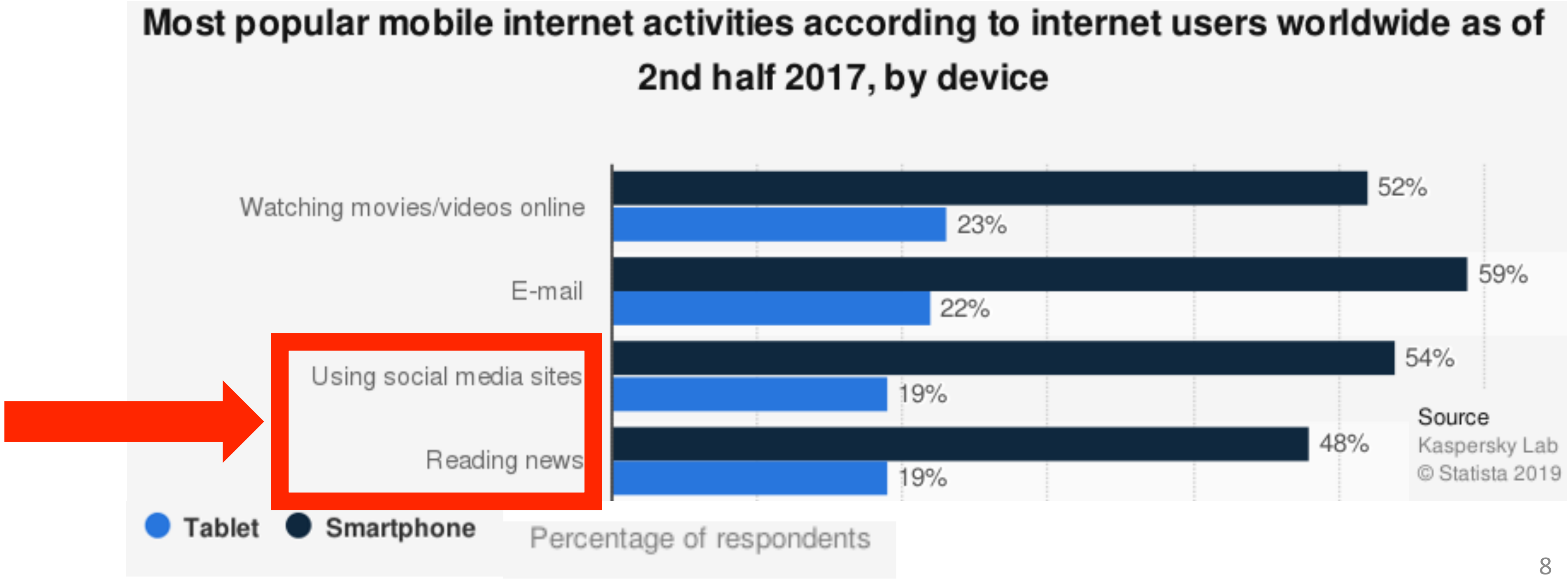
After ten years

- Our paper on Age of Information was finally accepted!
  - https://arxiv.org/abs/1009.4733 (2010)

- 0ur initialization on Age of Information is gradually known to the research community.

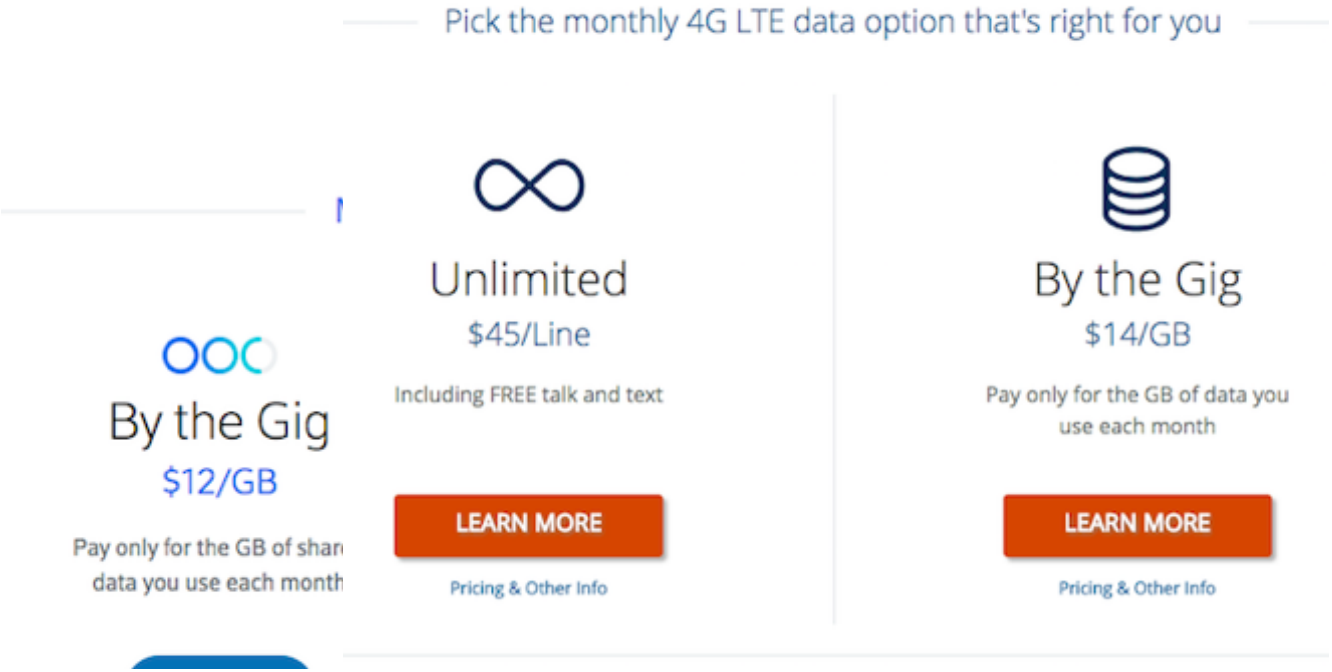
Microblogging applications prevalent

- Microblogging = application involving ***status updates***
  - Twitter, Facebook, Wechat, Tictok, Instagram …
- Very popular among ***mobile users***

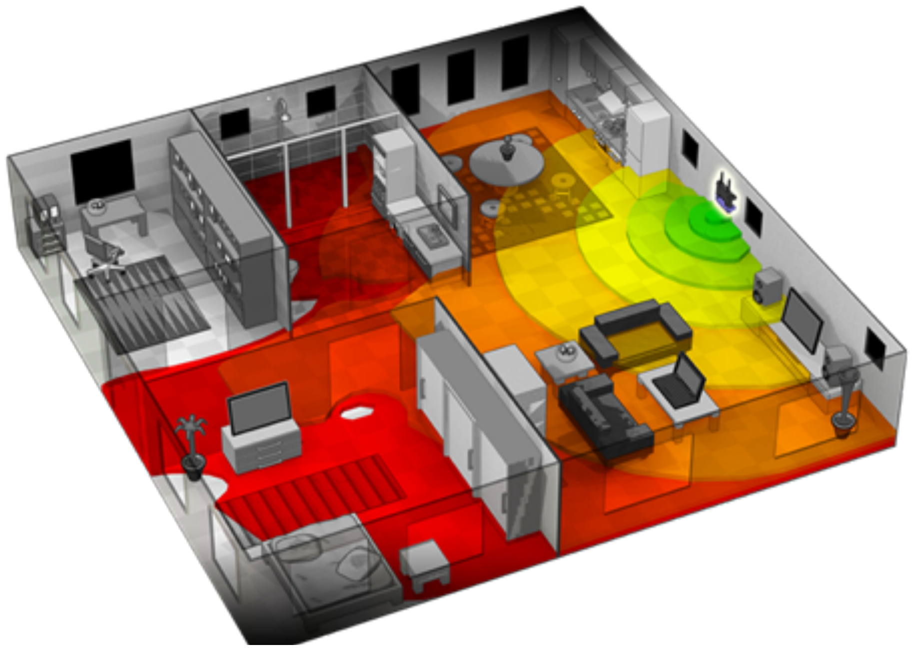


Enabling microblogging for mobile users: challenges

Monetary network access costs



Limited WiFi coverage



How to cope with such challenges?

Age of Information (AoI) plays key role

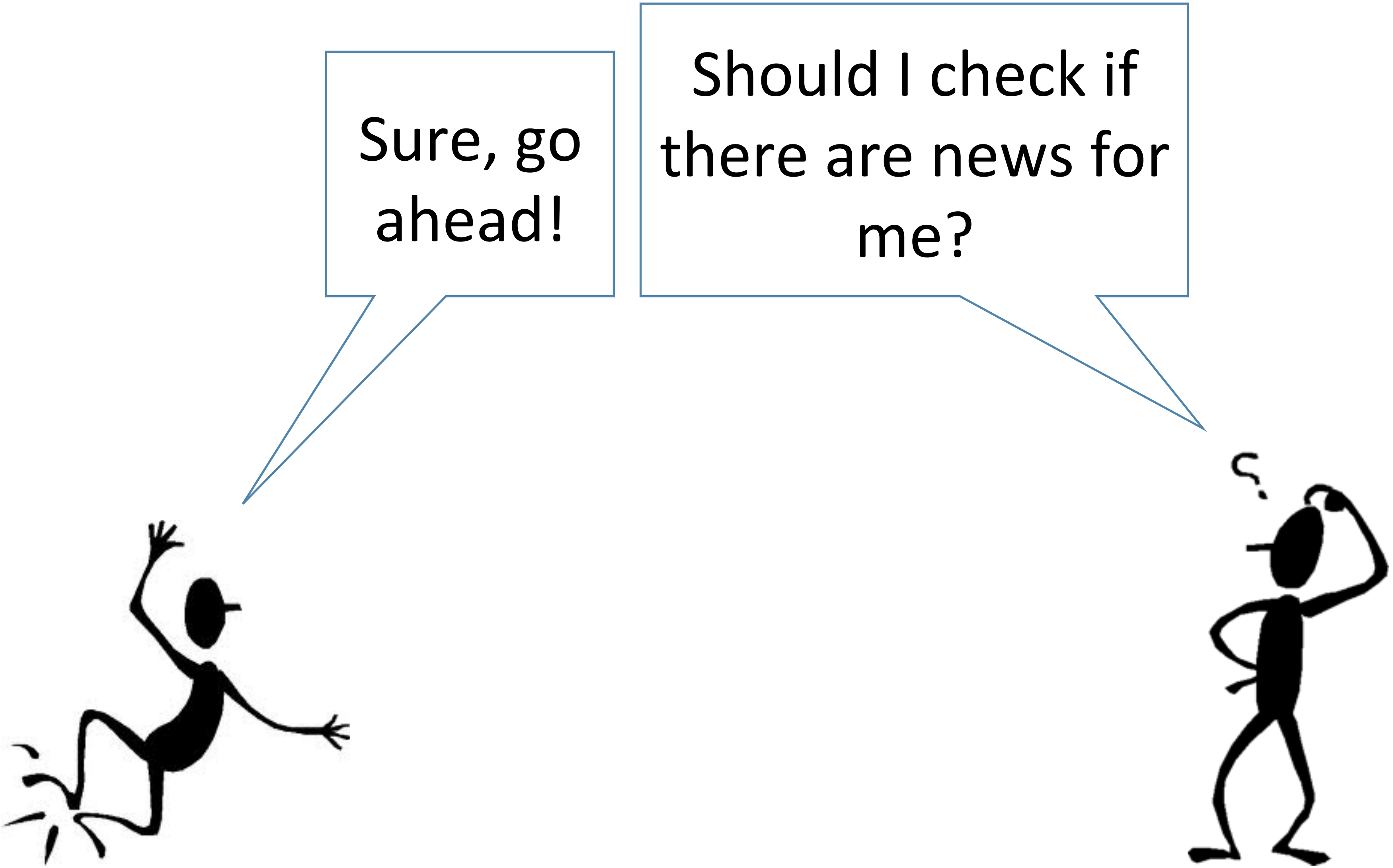
- ❑ As messages age, their utility decreases
- ❑ When to receive status update?
- ❑ How to control the age of information?
- ❑ ***Our goal: devise an aging control policy***

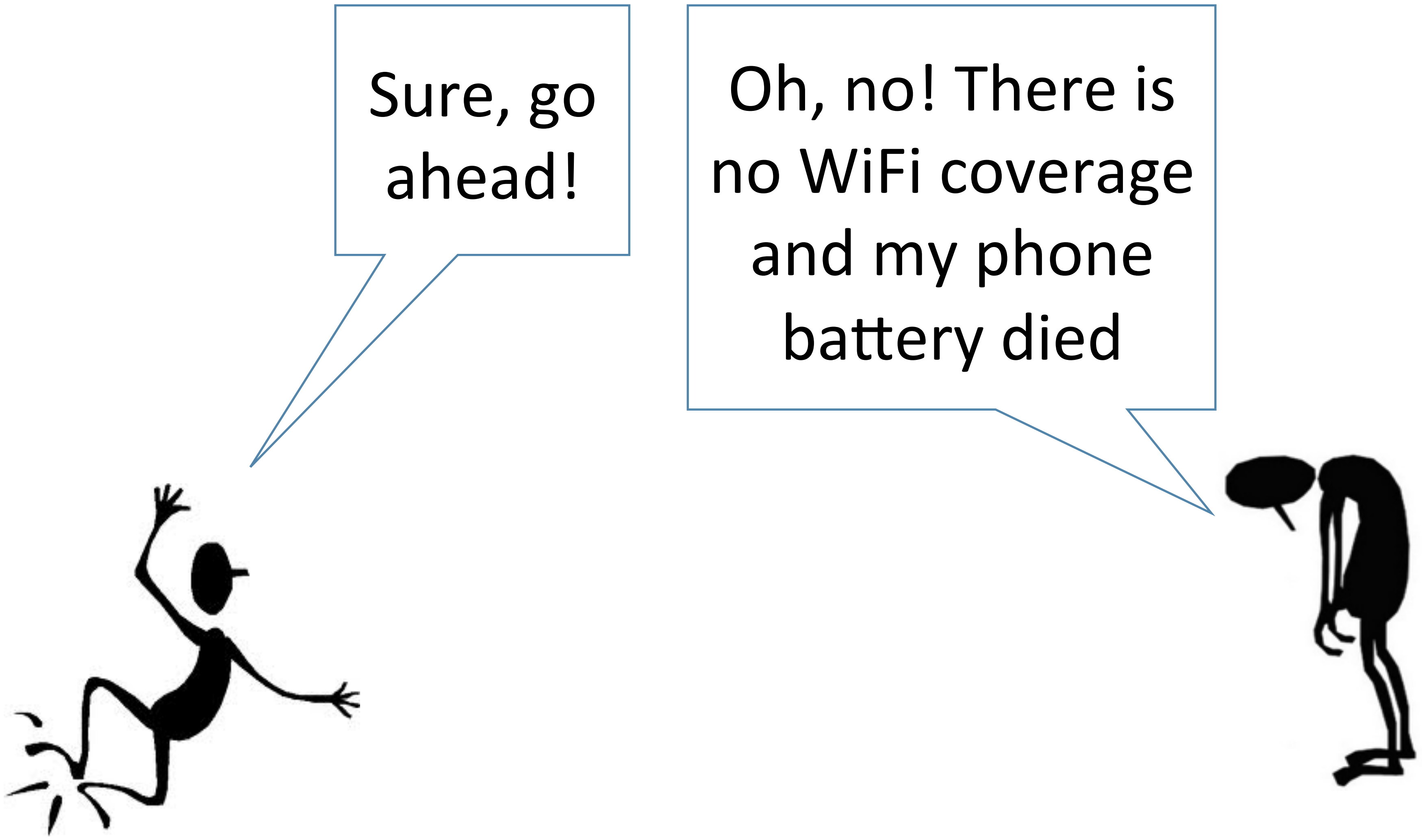
What is the best aging control policy for users?

Outline

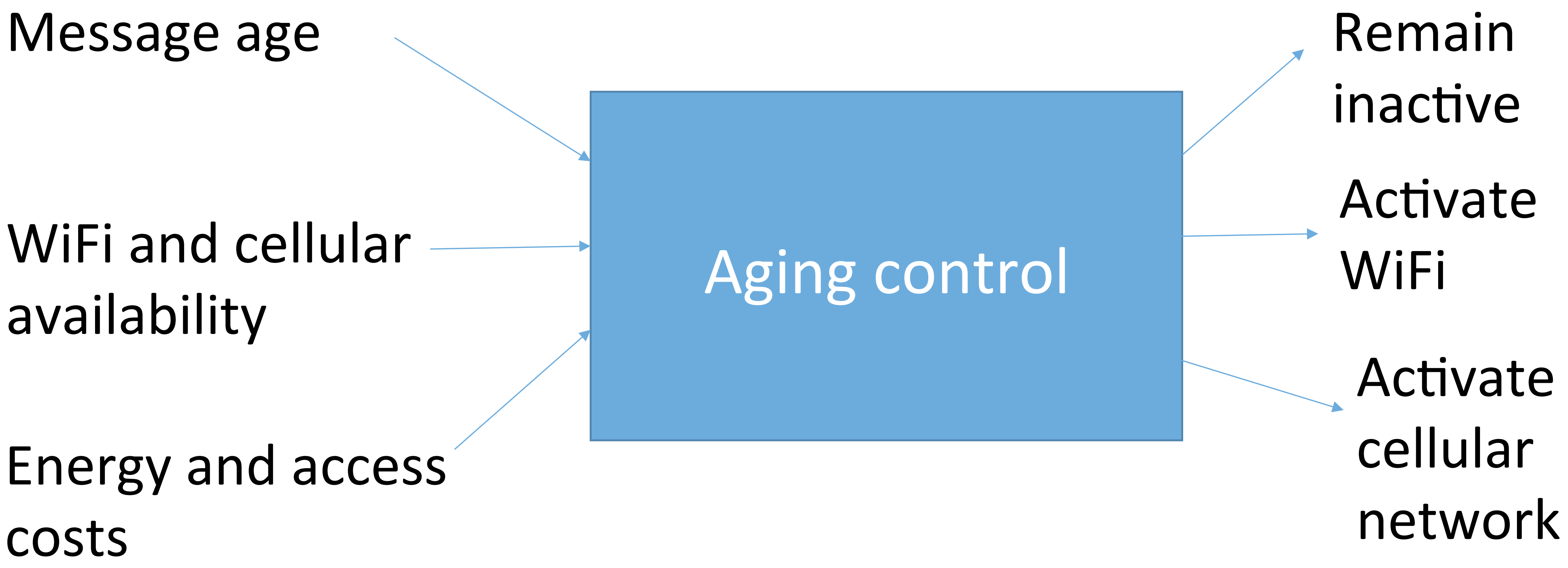
- ❑ **Why aging control?**
- ❑ Model description
- ❑ Model analysis
- ❑ Model evaluation in DieselNet
- ❑Conclusion

Should I check if there are news for me?


Should I check if there are news for me?
Sure, go ahead!


Sure, go ahead!
Oh, no! There is no WiFi coverage and my phone battery died

Aging control in a nutshell



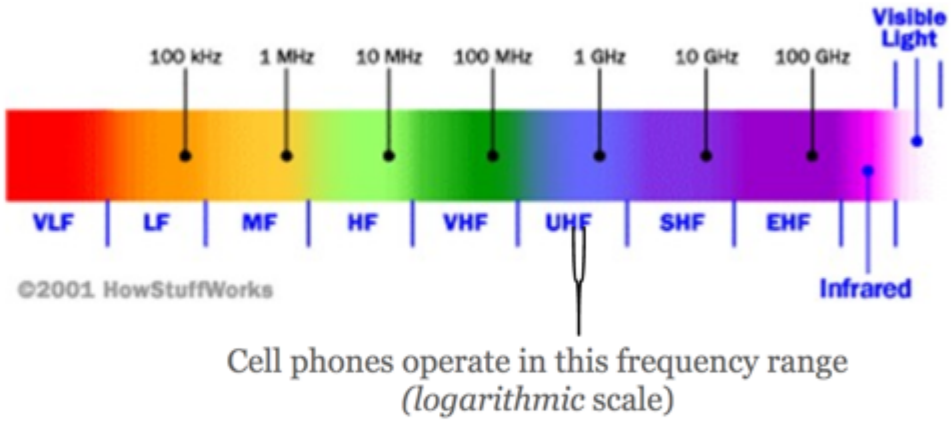
Aging control benefits

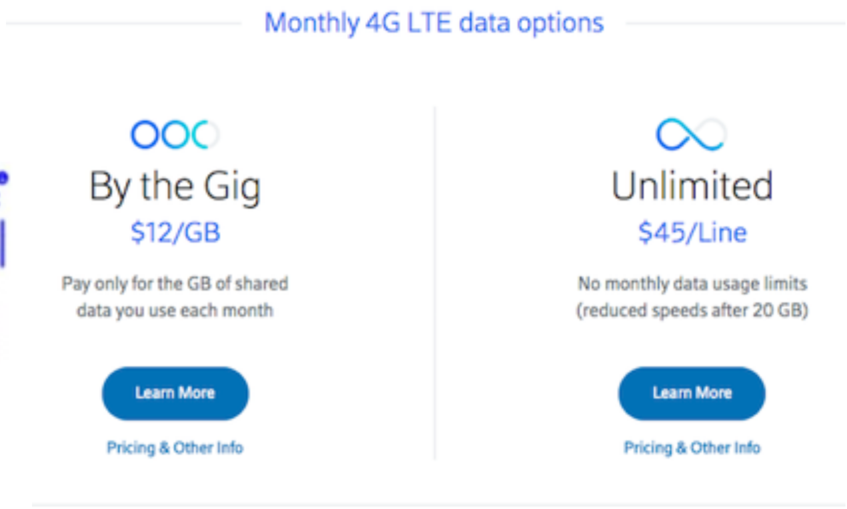
Service provider perspective

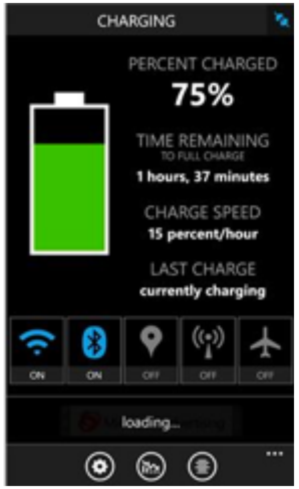
- ❑ Hybrid service provider provides hybrid cellular/WiFi network
- ❑ Off-load limited spectrum cellular network

Subscribers perspective

- ❑ Energy consumption reduction
- ❑ Reduce use of cellular data plan







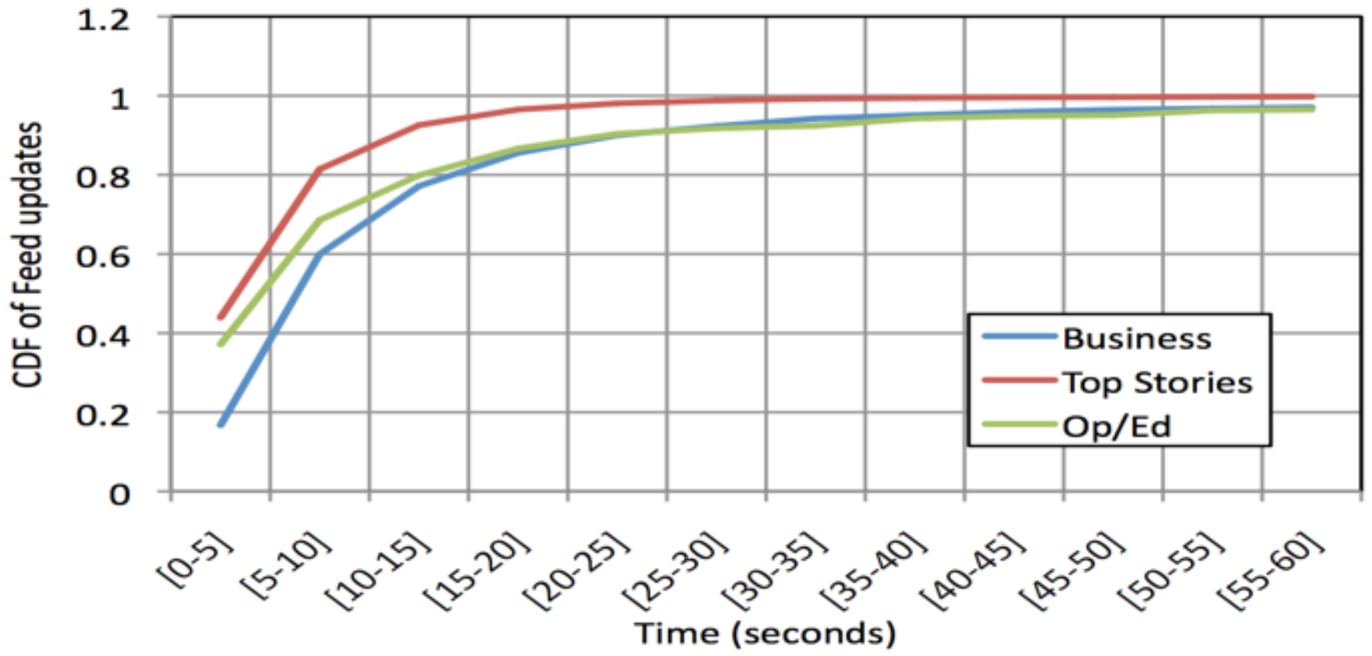
Workload: saturated regime

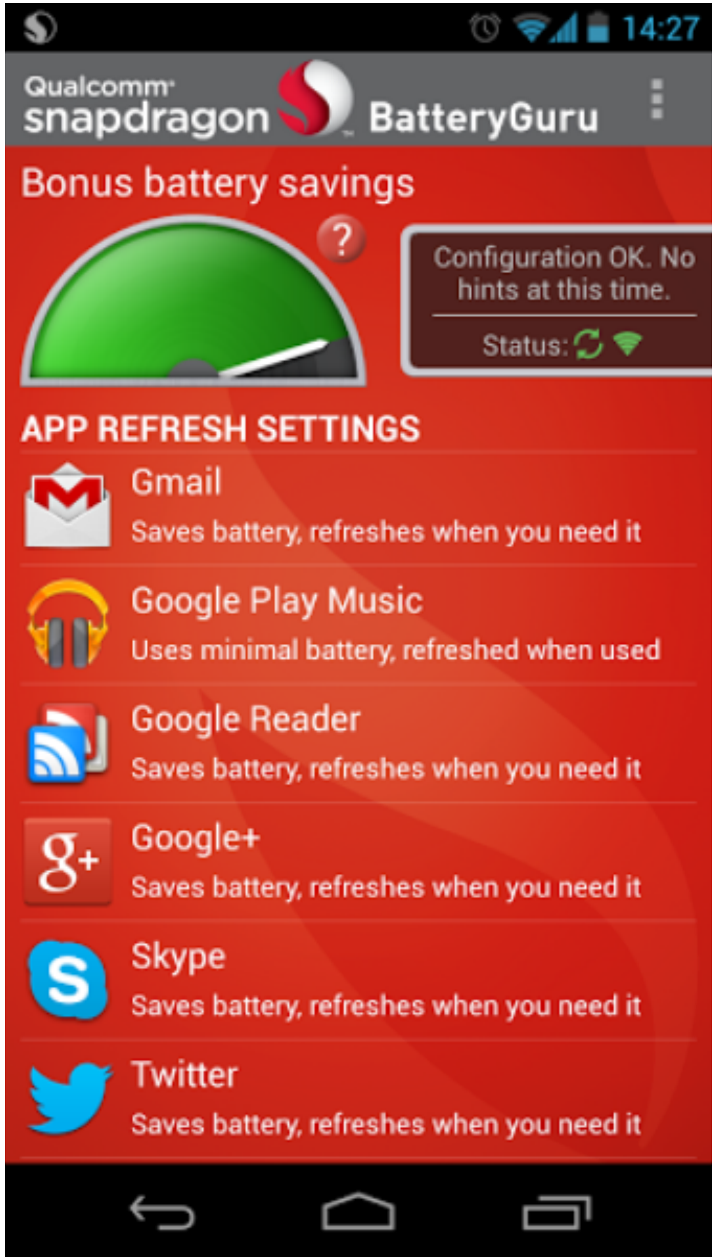
One application

- ❑ e.g., Yahoo! News
- ❑ at least one new item every minute (Niranjan, 2009)

Multiple applications

- ❑ many applications, many updates
- ❑ can be integrated





Adopting aging control

- ❑ How message utility varies as a function of age?
- ❑ Answer: depends on application!
- ❑ Users can tune utility function using applications such as ***Battery Guru***

Outline

- ❑ Why aging control?
- ❑ **Model description**
- ❑ Model analysis
- ❑ Model evaluation in DieselNet
- ❑ Conclusion

Refresh now or procrastinate?

Instantaneous rewards and costs

Future rewards and costs

Markov decision processes are the tool of choice to cope with tradeoff

Goal: when to refresh?

Search for aging control policy

WiFi availability probability p

WiFi scanning cost G

Cellular data plan cost P_C

Message age and message utility x $U(x)$

Aging control: Markov decision process

Remain inactive $a = 0$

Activate WiFi $a = 1$

Activate cellular $a = 2$

Refresh now or procrastinate?

WiFi scanning cost

Unknown by user

Instantaneous reward

Cellular data plan cost

p

$$r(x) = \begin{cases} U(x), & a = \text{none} \\ U(x) - G, & a = \text{WiFi} \\ U(x) - G, & a = \text{cellular}, e = \text{WiFi available} \\ U(x) - G - P_C, & a = \text{cellular}, e = \text{WiFi unavailable} \end{cases}$$

reward = revenue - cost

Refresh now or procrastinate?

Instantaneous reward

$$r(x) = \begin{cases} U(x), & a = \text{none} \\ U(x) - G, & a = \text{WiFi} \\ U(x) - G, & a = \text{cellular}, e = \text{WiFi available} \\ U(x) - G - P_C, & a = \text{cellular}, e = \text{WiFi unavailable} \end{cases}$$

Expected future reward $$R = \lim_{T \to \infty} \frac{\sum_{t=0}^{T} r(x_t)}{T}$$

Markov decision processes are the tool of choice

to maximize expected future reward (dynamic programming solution)

Outline

- ❑ Why aging control?
- ❑ Model description
- ❑ **Model analysis**
- ❑ Model evaluation in DieselNet
- ❑ Conclusion

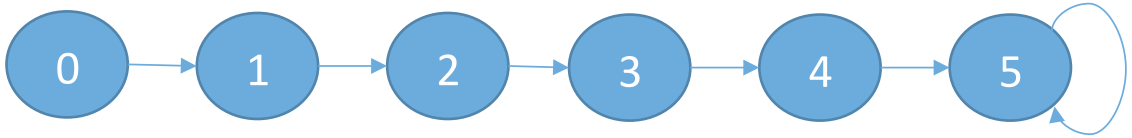
State dynamics for given policy

p = 0.5, $U(x)$ = 5-x
G=0, P_C = 0

Age of Information (AoI) given by Markov chain

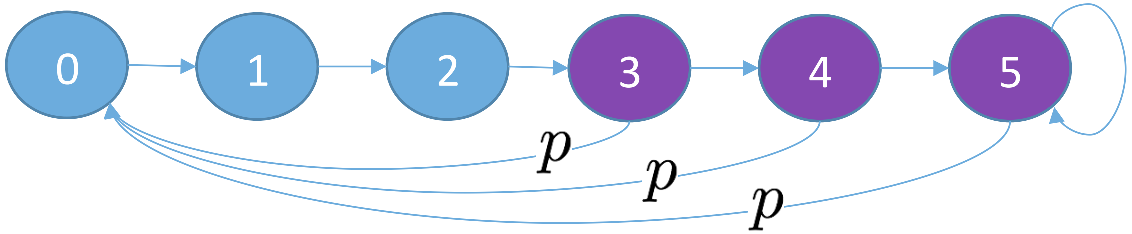
- ❑ *Policy 1*: always inactive

Reward = 0.0



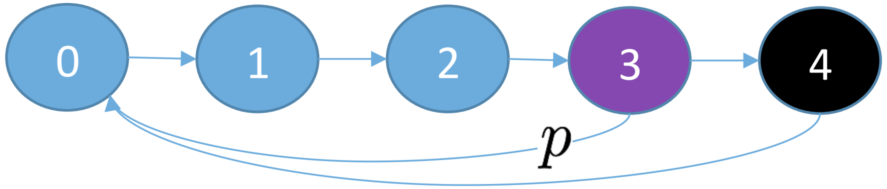
- ❑ *Policy 2*: if age > 2 WiFi
  else inactive

Reward = 2.9

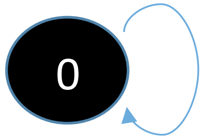


- ❑ *Policy 3*: if age > 3 cellular,
  if age 3 = WiFi, else inactive

Reward = 3.2



always cellular



Reward = 5.0

State dynamics for given policy

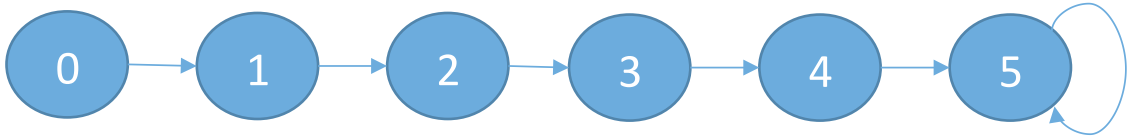
p* = 0.5, *U*(*x*) = 5-*x
***G*=0, P_c = 0**

P_c = 10

Age of Information (AoI) given by Markov chain

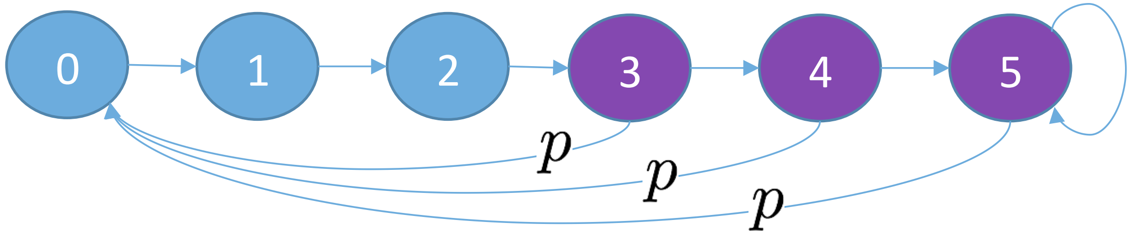
Reward = 0.0

- ❑ *Policy 1*: always inactive



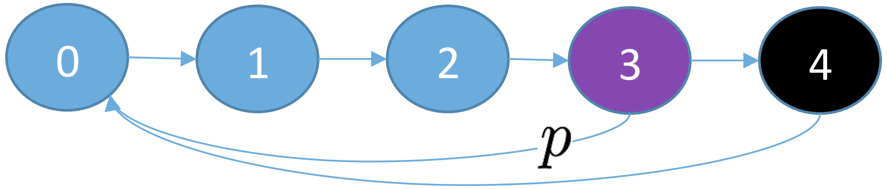
Reward = 2.9

if age > 2 WiFi
else inactive

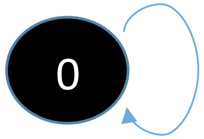


Reward = 2.6

- ❑ *Policy 3*: if age > 3 cellular,
  if age 3 = WiFi, else inactive



- ❑ *Policy 4*: always cellular



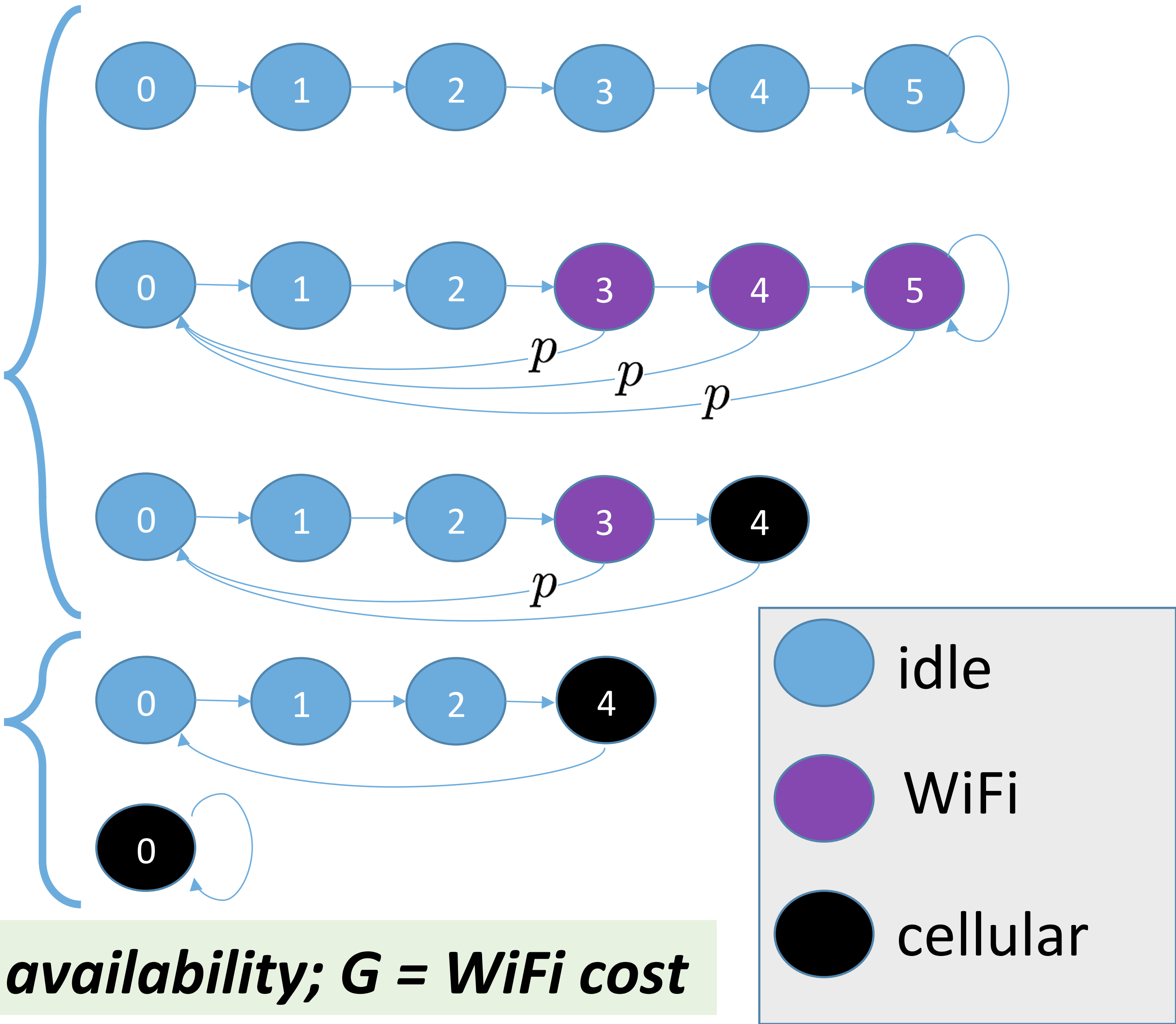
Reward = 5 − 0.5 x 10 = 0.0

Threshold policy

Proposition: aging control problem admits threshold solution

- ❑ *If* $P_c > G/p$ *admits one of those solutions*

- ❑ *If* $P_c < G/p$ *admits one of those solutions*



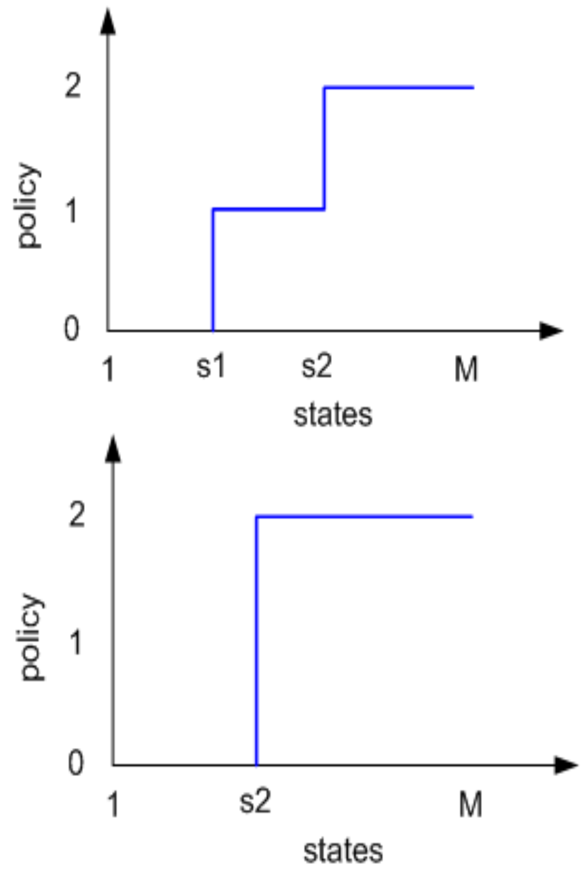
P_c = cellular price; p = WiFi availability; G = WiFi cost

Threshold policy

Proposition: aging control problem admits threshold solution

- *If* $\boldsymbol{P_C > G/p}$ *admits one of those solutions*

- *If* $\boldsymbol{P_C < G/p}$ *admits one of those solutions*

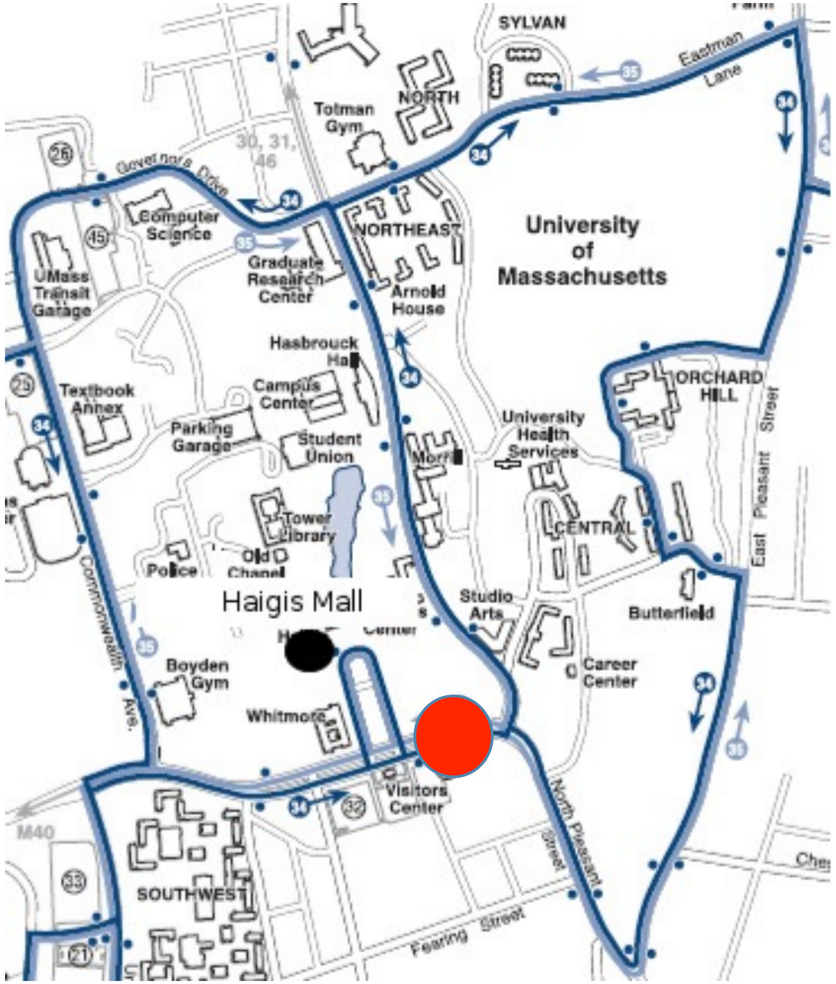


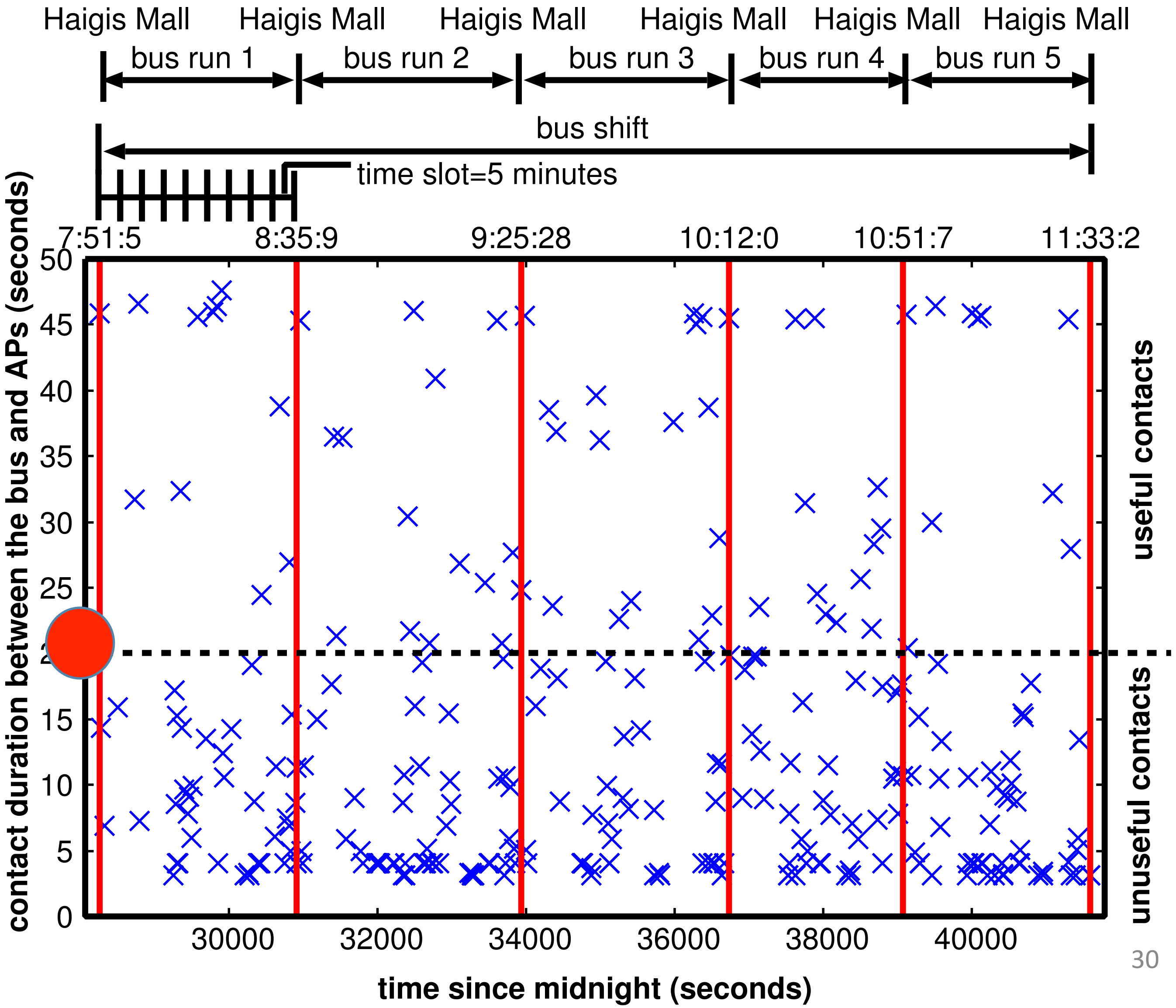
P_C = cellular price; p = WiFi availability; G = WiFi cost

Outline

- ❑ Why aging control?
- ❑ Model description
- ❑ Model analysis
- ❑ **Model evaluation in DieselNet**
- ❑ Conclusion

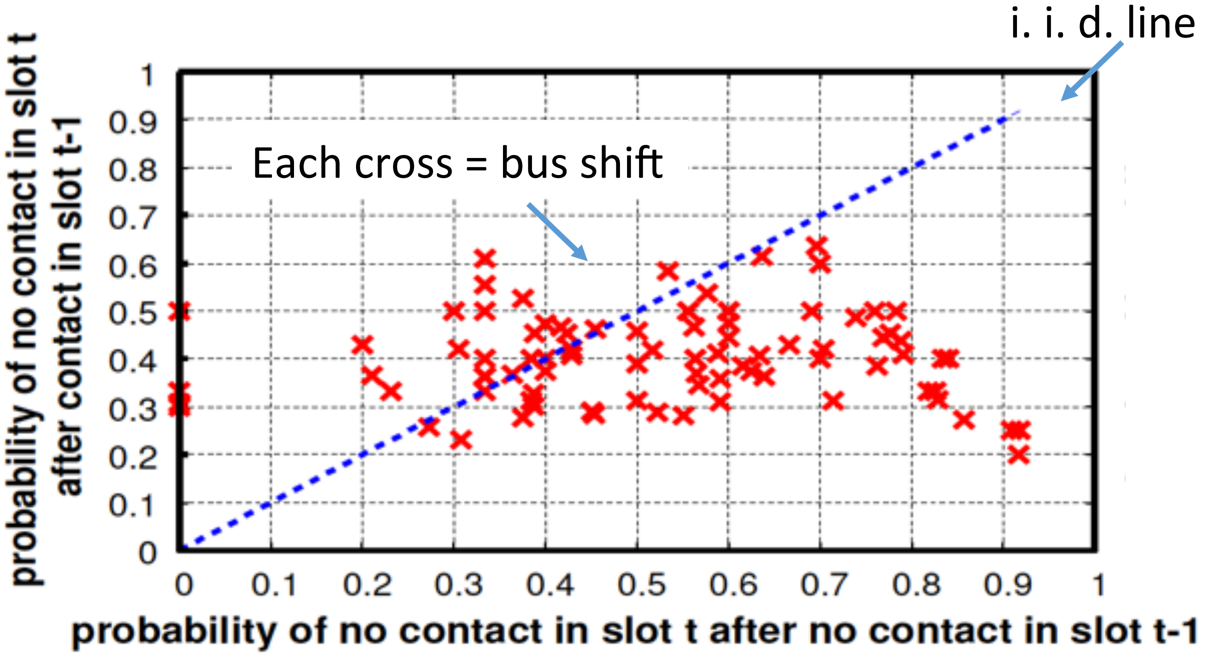
A typical bus-shift at UMass Amherst

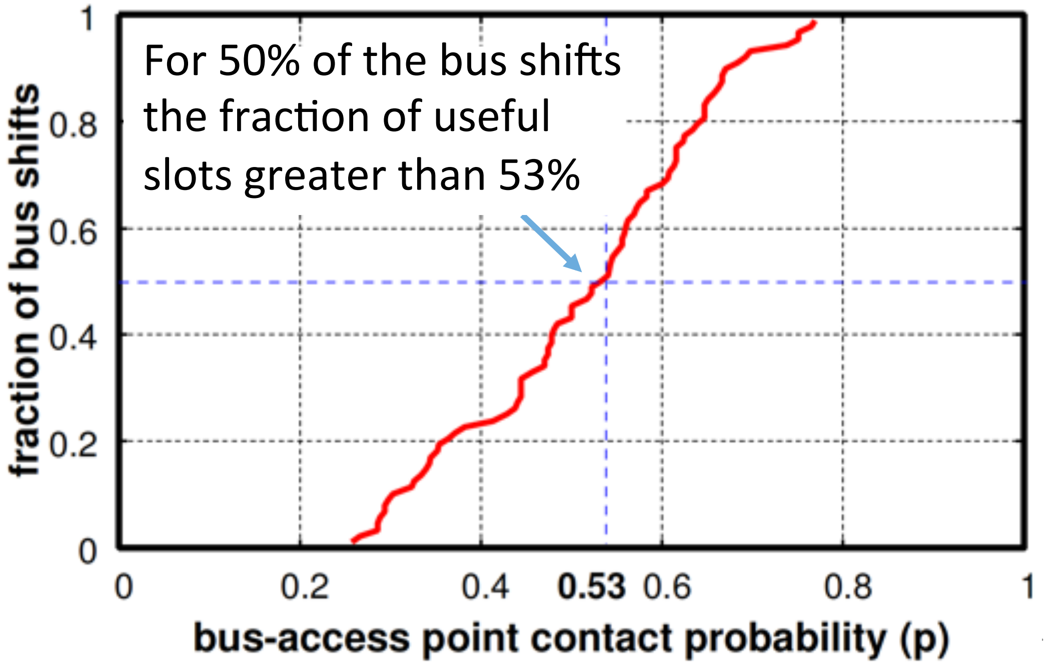




Bus contacts with access points

- Given there was no contact in the previous slot, how likely to have a contact now?
- **Simplest model**: at each slot, probability WiFi available = p
- **From traces**: p = 0.53
- **Extension**: consider Markov chain to track dynamics of p (POMDP)





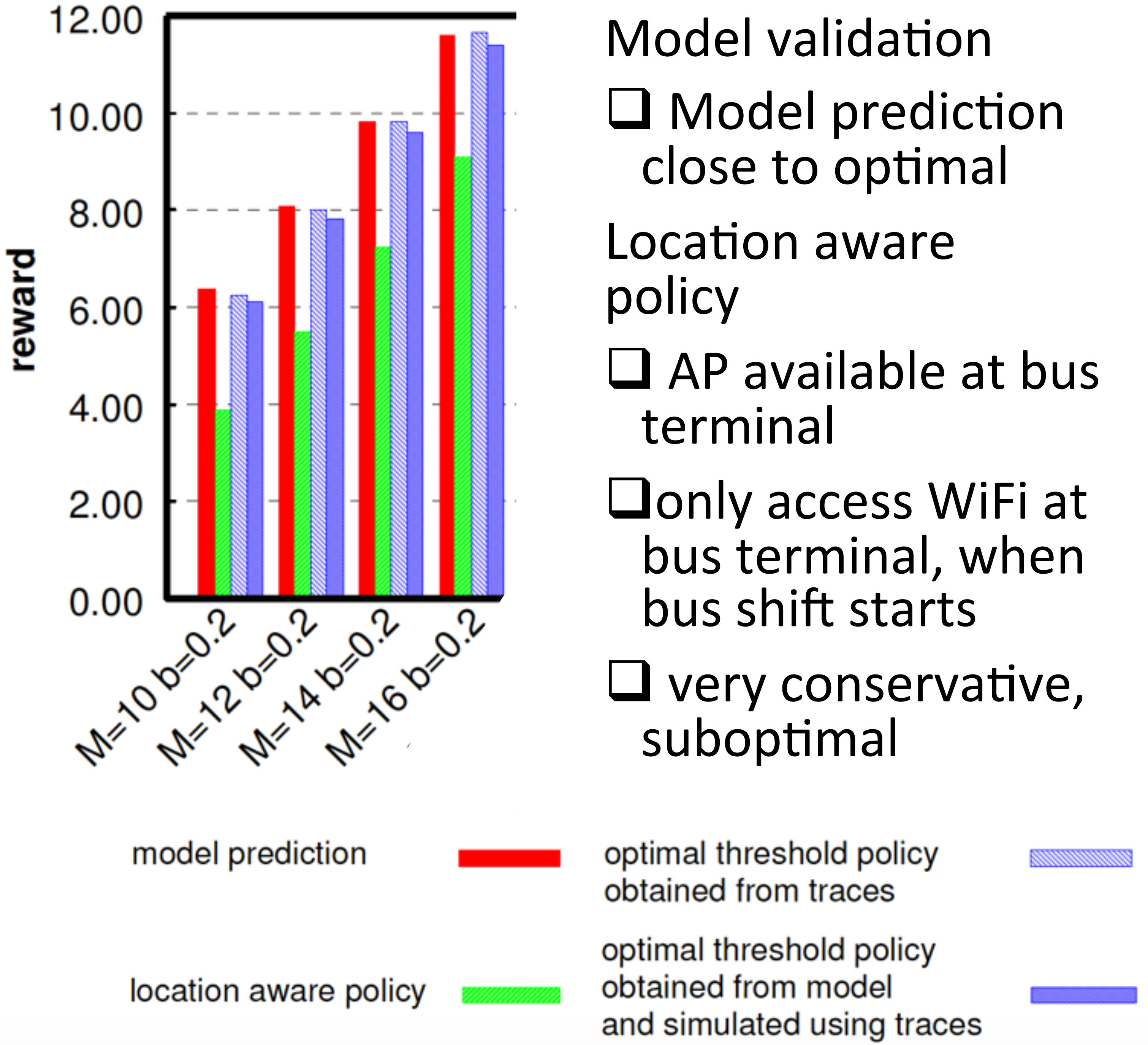
Trace-driven simulation

Assumptions

- WiFi free on campus
- no cellular network

Parameters

- WiFi availability, p = 0.53
- maximum age, M
- message utility, U(x) = max(M − x, 0)
- scaled WiFi energy cost, b = G/(M-1)



Model validation

- Model prediction close to optimal

Location aware policy

- AP available at bus terminal
- only access WiFi at bus terminal, when bus shift starts
- very conservative, suboptimal

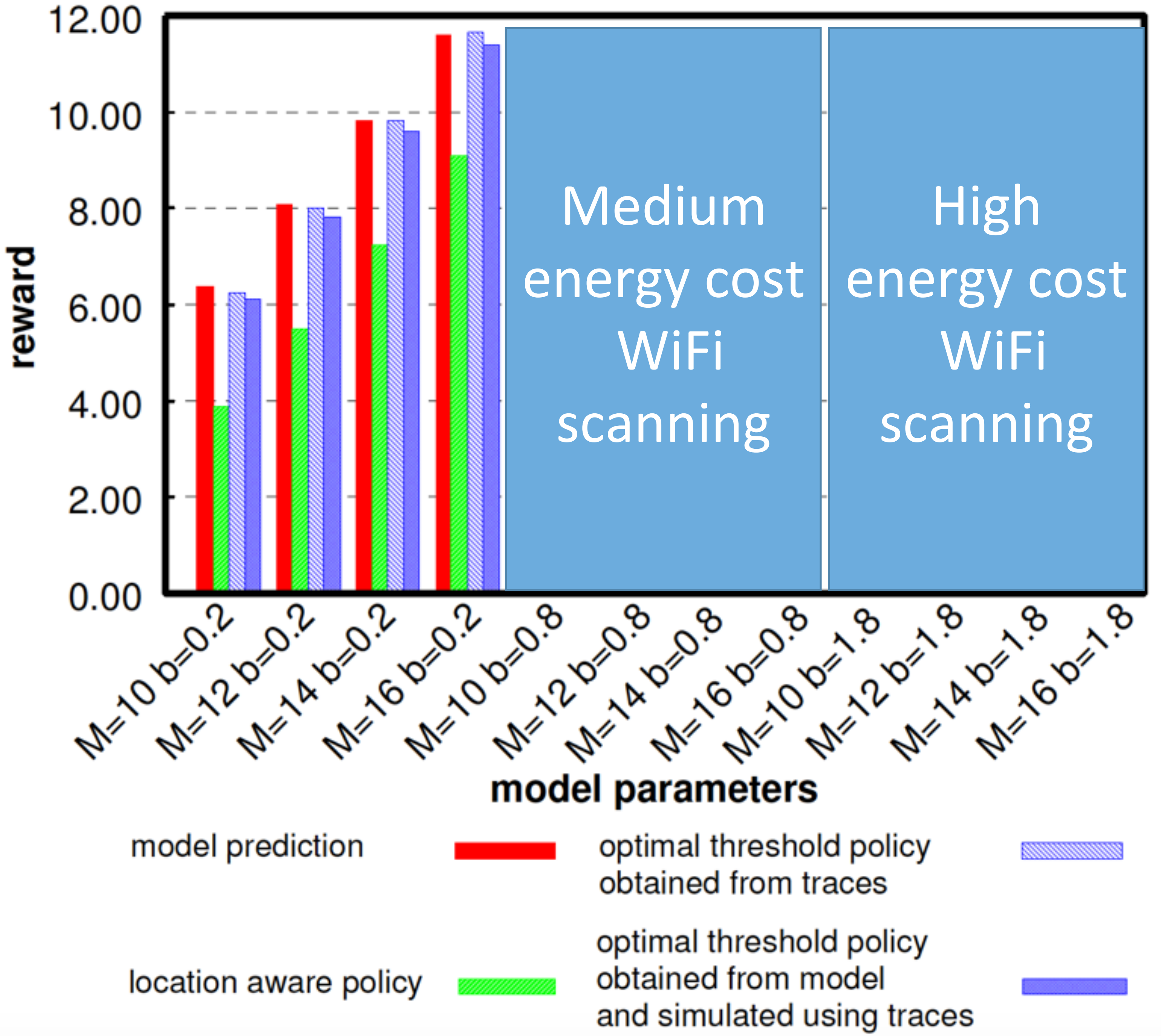
Trace-driven simulation

Assumptions

- ❑ WiFi free on campus
- ❑ no cellular network

Parameters

- ❑ WiFi availability, p = 0.53
- ❑ maximum age, M
- ❑ message utility, U(x) = max(M − x, 0)
- ❑ scaled WiFi energy cost, b = G/(M-1)



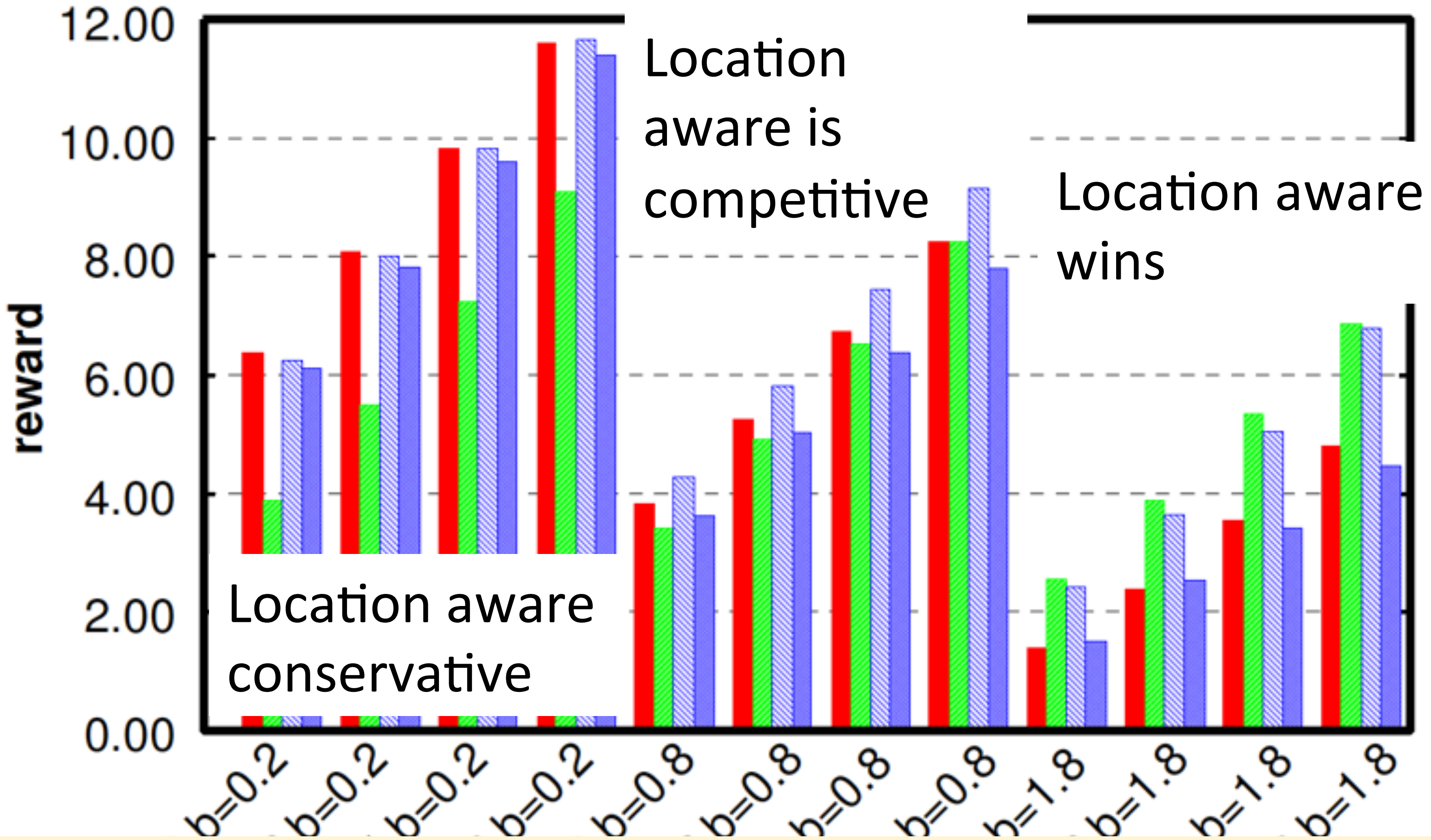
Trace-driven simulation

Assumptions

- WiFi free on campus
- no cellular network

Parameters

- WiFi availability, p = 0.53
- maximum age M
- message utili U(x) = max(M
- scaled WiFi e cost, b = G/(M



If costs are low, helpful to leverage opportunistic encounters with APs. Otherwise, benefit from spatiotemporal correlations

Outline

- ❑ Why aging control?
- ❑ Model description
- ❑ Model analysis
- ❑ Model evaluation in DieselNet
- ❑ **Conclusion**

Conclusion and contributions

- ❑ Proposed novel aging control policy: forever young
- ❑ Showed that exists optimal policy of threshold type
- ❑ Evaluated multiple aging control policies through trace-driven UMass traces
  - ❑ observed that forever young is competitive in practical settings

Future work

- ❑ Historical information about AP availability: account for time and location of previous AP contacts
- ❑ Account for non-saturated sources

Thanks!

Forever Young