



Distributing Content Updates Over a Mobile Social Network

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Opportunistic Communication



- Bluetooth and/or WiFi enabled devices
- Communication opportunities whenever people meet

Application: Distributing Content Updates



- A wireless service provider distributes content that changes dynamically.

Application: Distributing Content Updates

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UK EDITION SWITCH TO GLOBAL EDITION HEADLINES: Animal experiments could end in a generation

Latest: Hutton quits as Brown reshuffles Cabinet

Defence Secretary follows James Purnell out of Cabinet, upsetting reshuffle, but publicly backs Gordon Brown

LIVE: The reshuffle as it happens

COMMENT: A stronger Brown survives - for now

IN DEPTH: Cabinet watch - resigned, loyal or gone quiet?

BLOG: 5 signs of weakness

Labour suffers heavy losses in elections

Departure ignites warfare on the airwaves

Purnell resignation shocks Gordon Brown

Prime Minister dealt devastating blow as Work and Pensions Secretary quits Cabinet and tells him to stand down

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Militants Show New Boldness in Cities of Iraq

By ALISSA J. RUBIN

BAGHDAD — Security officials say that jihadi and Baath militants are regrouping as a smaller but still lethal insurgency, threatening the relative calm in most of Iraq.

Obama, in Europe, Faces Big Challenges to Agenda

By DAVID E. SANGER

3:34 AM ET

LONDON — Amid signs of a rebuke of American economic leadership, the president arrived for a meeting of the Group of 20.

Inmates at Guantánamo Pose a Dilemma

By WILLIAM GLABERSON and MARGOT WILLIAMS

WASHINGTON — The Obama administration must decide what to do with 17 Uighur Muslims held in Cuba. Ishaq Hassan, above, has offered to take one of them in.

Room for Debate: Where Can the Uighurs Go? | Comments

Obama to Seek Arms Control

GLOBAL SPOTLIGHT

OPINION - Zoom: Whose Father Was He? (Part Three)

Errol Morris searches for the story behind a photo found on a fallen soldier.

MARKETS

Data delayed at least 15 minutes

U.S.	AMERICAS	EUROPE	ASIA	CO
BRITAIN	GERMANY			
FTSE 100	DAX			
3,898.21	4,039.99			
-27.93	-0.71%	-44.77	-1.10%	

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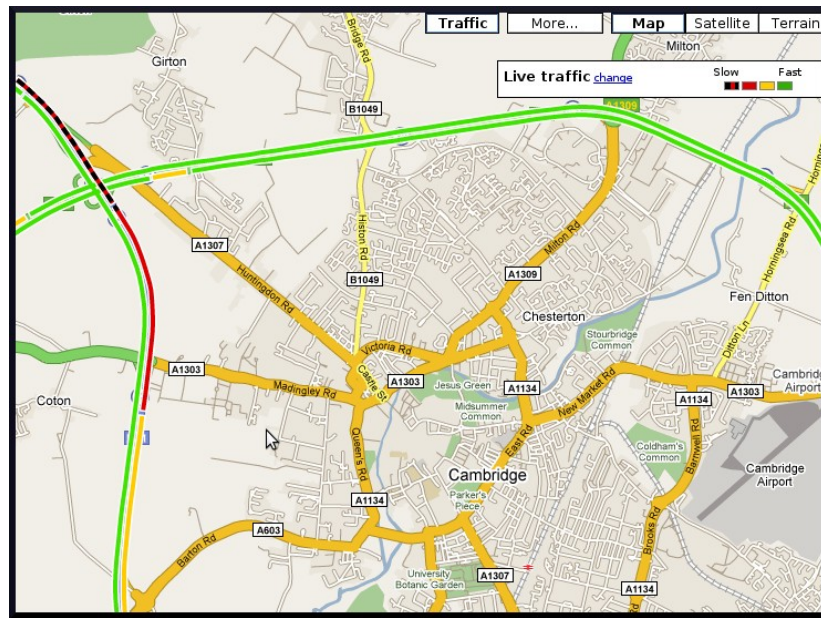
Stock, ETFs, Funds Go



▪ News



Application: Distributing Content Updates

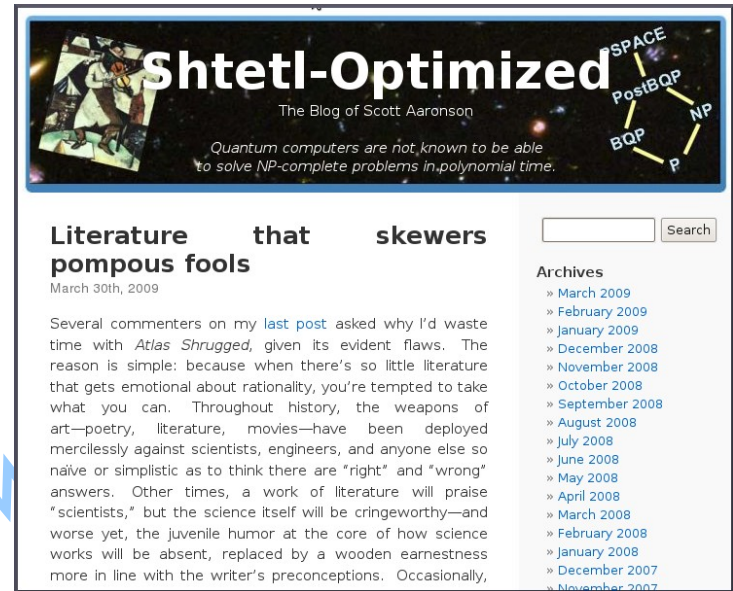
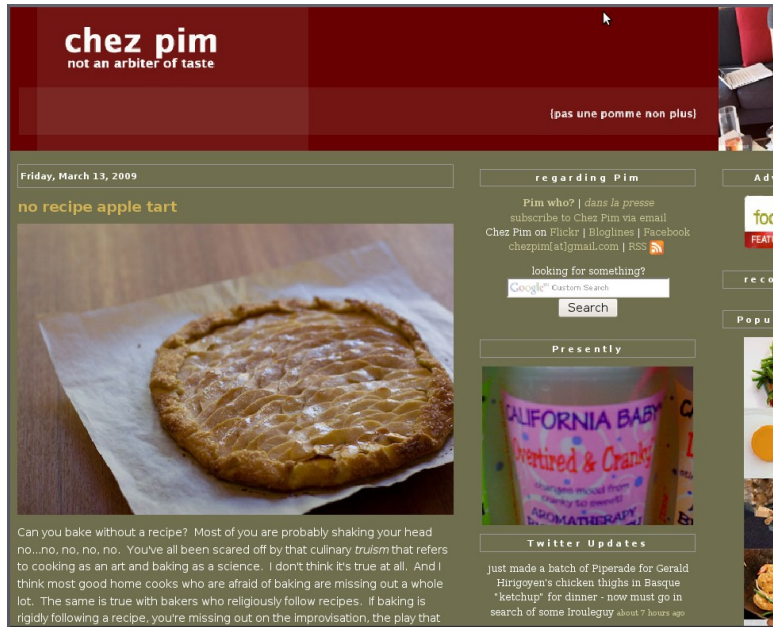


The screenshot shows the Bloomberg.com mobile interface. At the top, it displays the site name and navigation options like 'HOME', 'NEWS', 'MARKET DATA', 'PERSONAL FINANCE', and 'TV and RADIO'. A main news headline reads 'Obama Believes Bankruptcy Best Option for GM'. Below this, there's a section for 'EUROPE' with a line chart for 'DJ STOXX 50' showing a value of 1,800.32 and a change of -15.67. A table of 'EQUITY INDEXES' is also visible, listing values and changes for DJStoxx 600, FTSE 100, DAX 30, CAC 40, and S&P/MIB. A 'LIVE TV' section is at the bottom right.

INDEX	VALUE	CHANGE	% CHANGE
DJStoxx 600	176.04	-0.42	-0.24
FTSE 100	3,910.84	-15.30	-0.39
DAX 30	4,058.01	-26.75	-0.65
CAC 40	2,784.07	-23.27	-0.83
S&P/MIB	15,599.00	-276.00	-1.74

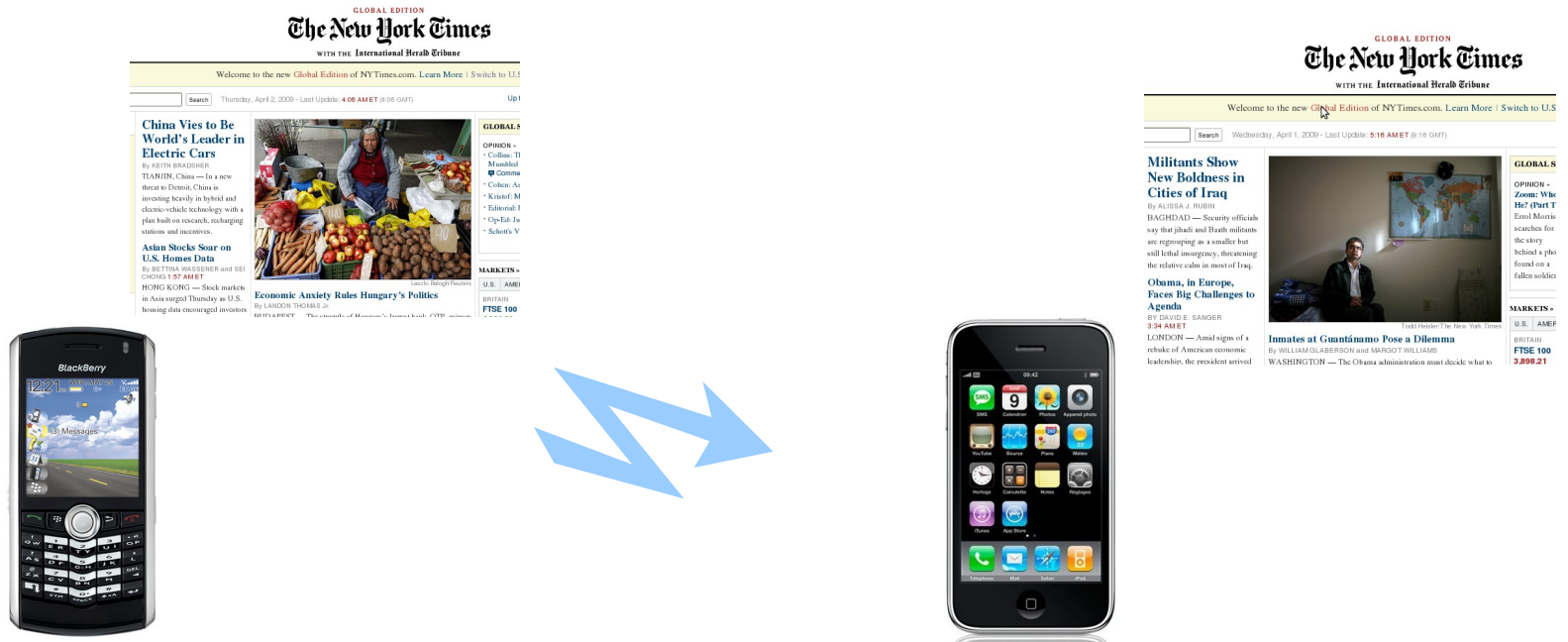
- News
- Traffic information, stock prices

Application: Distributing Content Updates



- News
- Traffic information, stock prices
- Blogs, etc.

Users Can Share Updates



- User with most recent content pushes it to the one whose content is outdated

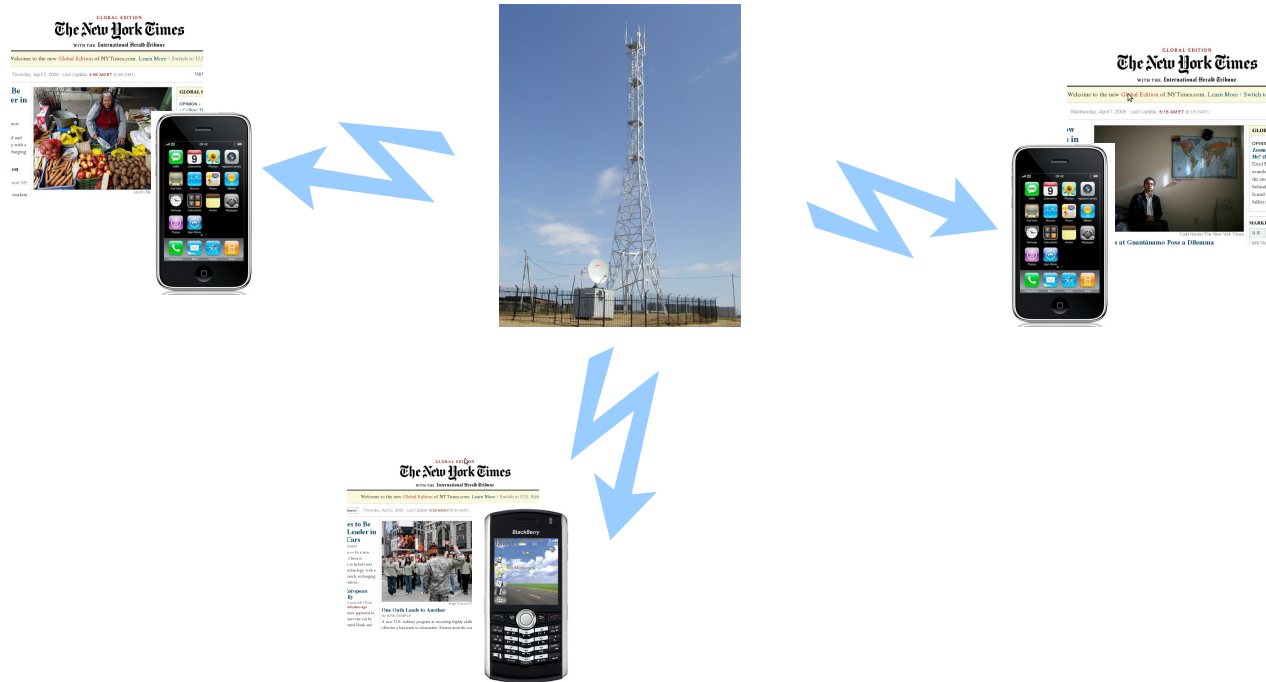
Questions

Goal:

- Make content at users as “fresh” as possible



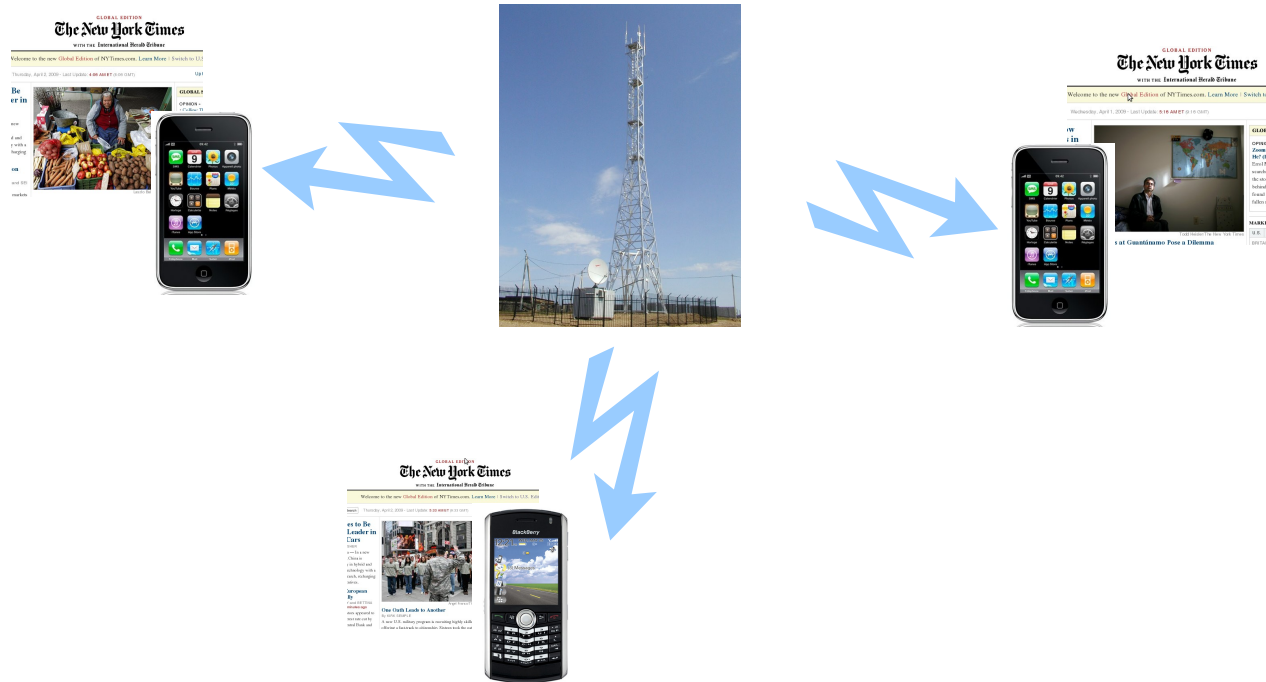
Questions



Optimality: Allocation of downlink rate

- *E.g.*, push updates to “social” users more frequently?

Questions



Scalability: How does age grow with user population n ?

- *E.g., $O(n)$? $O(\log n)$?*

Our Results

Optimality

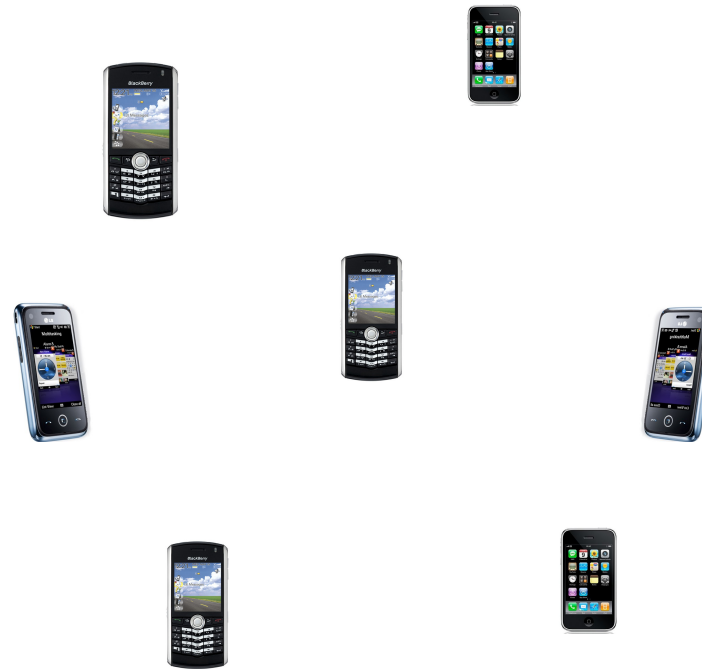
- The service provider can compute an optimal allocation of its downlink rate.

Scalability:

- The age of content at users will grow slowly (as $\log n$) if the social network is an *expander*.



Model: Update Distribution Process



n users

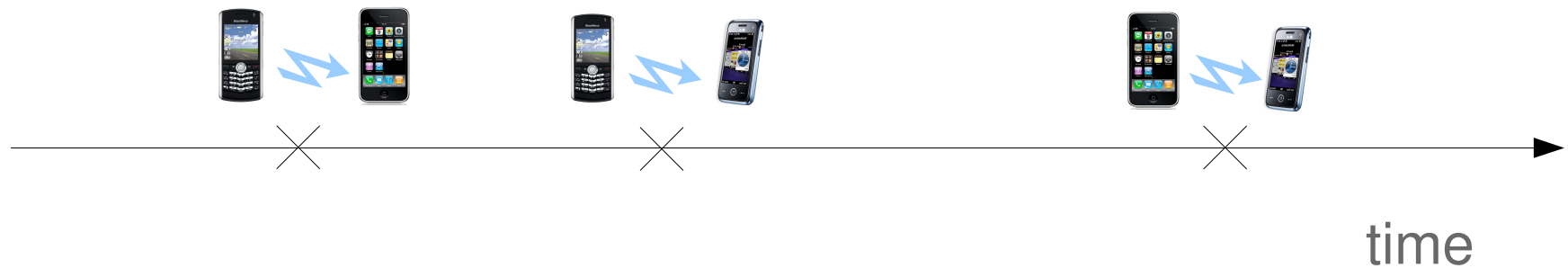
Model: Update Distribution Process



Each user i receives updates according to Poisson process with rate x_i , where

$$\sum_{i=1}^n x_i \leq \mu$$

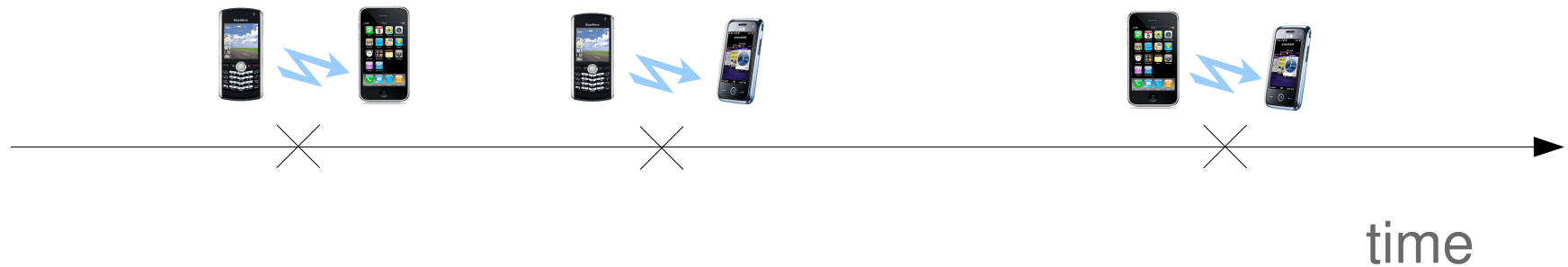
Model: Contact Process



E.g.:

- Independent inter-contact times (but not necessarily identically distributed)
- Random trip mobility [Le Boudec and Vojnovic '06]
- Group mobility [Hong et al.'99, Musolesi and Mascolo '07]
- Markov chain mobility [e.g., Nicholson and Noble '08]

Model: Contact Process



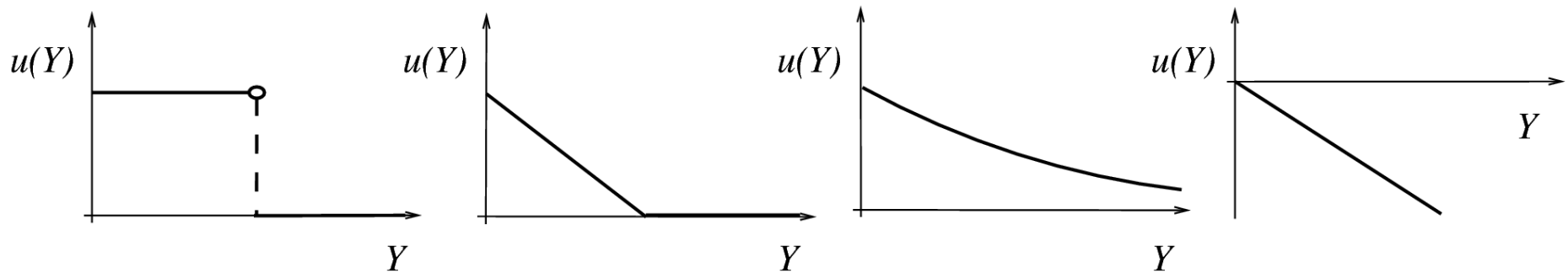
E.g.:

- Independent inter-contact times (but not necessarily identically distributed)
- Random trip mobility [Le Boudec and Vojnovic '06]
- Group mobility [Hong et al.'99, Musolesi and Mascolo '07]
- Markov chain mobility [e.g., Nicholson and Noble '08]

General model: joint contact process is *stationary ergodic*.

Model: User Utilities

$u_i(Y)$: Utility of user i when the age of its content is Y .



Fresher content is better.



SOCIAL WELFARE MAXIMIZATION

$$\begin{aligned} \text{Maximize:} \quad & f(\vec{x}) = \sum_{i=1}^n \mathbb{E}_{\vec{x}}[u_i(Y_i)] \\ \text{subject to:} \quad & \sum_{i=1}^n x_i \leq \mu, \\ & x_i \geq 0, 1 \leq i \leq n, \end{aligned}$$

where

Y_i : the age of content at i (in steady state),

$u_i(Y_i)$: the utility at i ,

x_i : the injection rate at i ,

μ : the downlink capacity.



Main Result

Theorem: SOCIAL WELFARE MAXIMIZATION is a convex optimization problem.



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Hence, it can be solved by gradient descent.



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Hence, it can be solved by gradient descent.

Algorithms for estimating the gradient

- **Centralized:** The service provider knows all user utilities and collects user contact logs
- **Distributed:** The gradient is estimated by the users in a decentralized manner



Decentralized Estimation of the Gradient

- Objective function:
$$f(\vec{x}) = \sum_{i=1}^n \mathbb{E}_{\vec{x}}[u_i(Y_i)]$$



Decentralized Estimation of the Gradient

■ Objective function: $f(\vec{x}) = \sum_{i=1}^n \mathbb{E}_{\vec{x}}[u_i(Y_i)]$

■ Each user i estimates $\frac{\partial \mathbb{E}_{\vec{x}}[u_i(Y_i)]}{\partial x_j}$, for all j , in a distributed manner.



Decentralized Estimation of the Gradient

- Objective function:
$$f(\vec{x}) = \sum_{i=1}^n \mathbb{E}_{\vec{x}}[u_i(Y_i)]$$

- Each user i estimates $\frac{\partial \mathbb{E}_{\vec{x}}[u_i(Y_i)]}{\partial x_j}$, for all j , in a distributed manner.

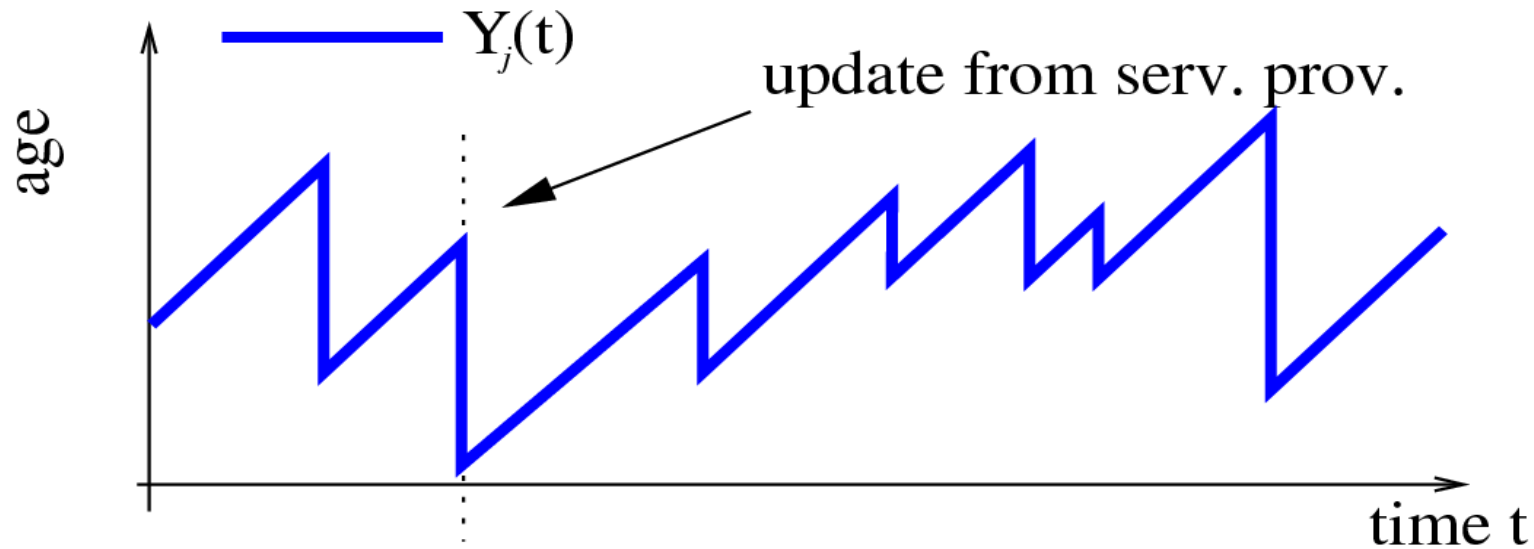
- These estimates are reported to the service provider, who then computes

$$\frac{\partial f(\vec{x})}{\partial x_j} = \sum_{i=1}^n \frac{\partial \mathbb{E}_{\vec{x}}[u_i(Y_i)]}{\partial x_j}, \quad \text{for all } j.$$



An Unbiased Estimator of

$$\frac{\partial E_{\bar{x}}[u_i(Y_i)]}{\partial x_j}$$

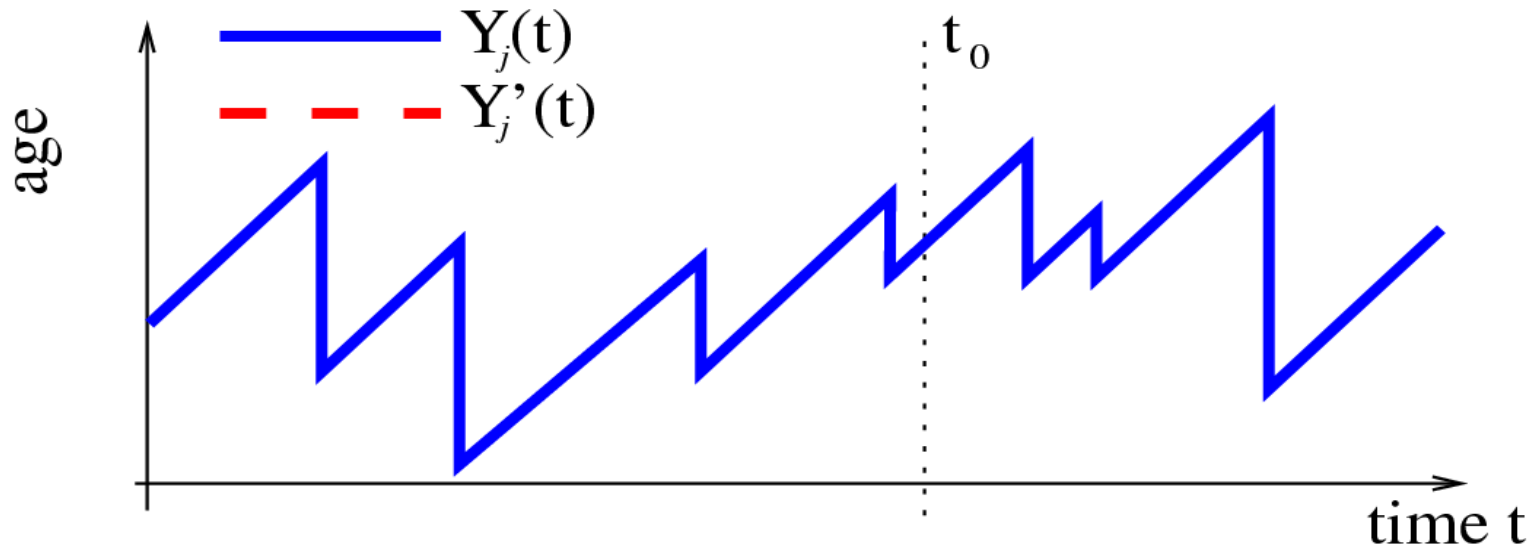


The age $Y_j(t)$ increases between encounters, and becomes zero when a new update is received from the service provider.

An Unbiased Estimator of

$$\frac{\partial E_{\bar{x}}[u_i(Y_i)]}{\partial x_j}$$

User j :



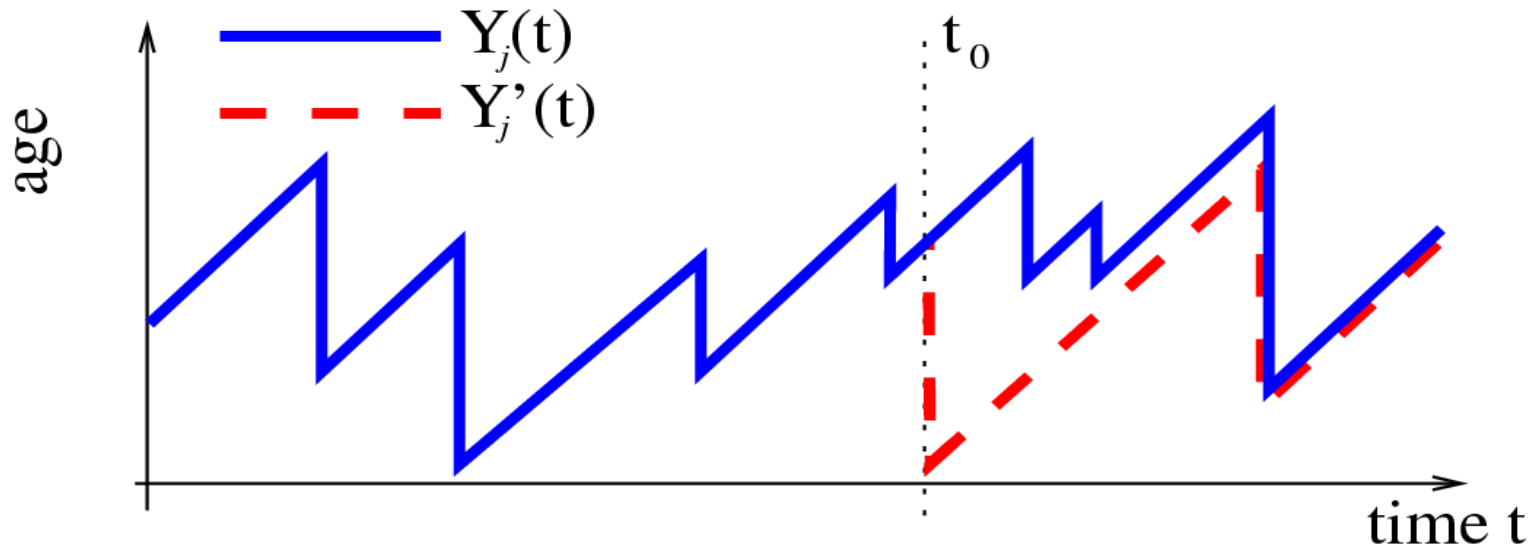
At some time t_0 , user j pretends it receives an update from the service provider.



An Unbiased Estimator of

$$\frac{\partial E_{\bar{x}}[u_i(Y_i)]}{\partial x_j}$$

User j :



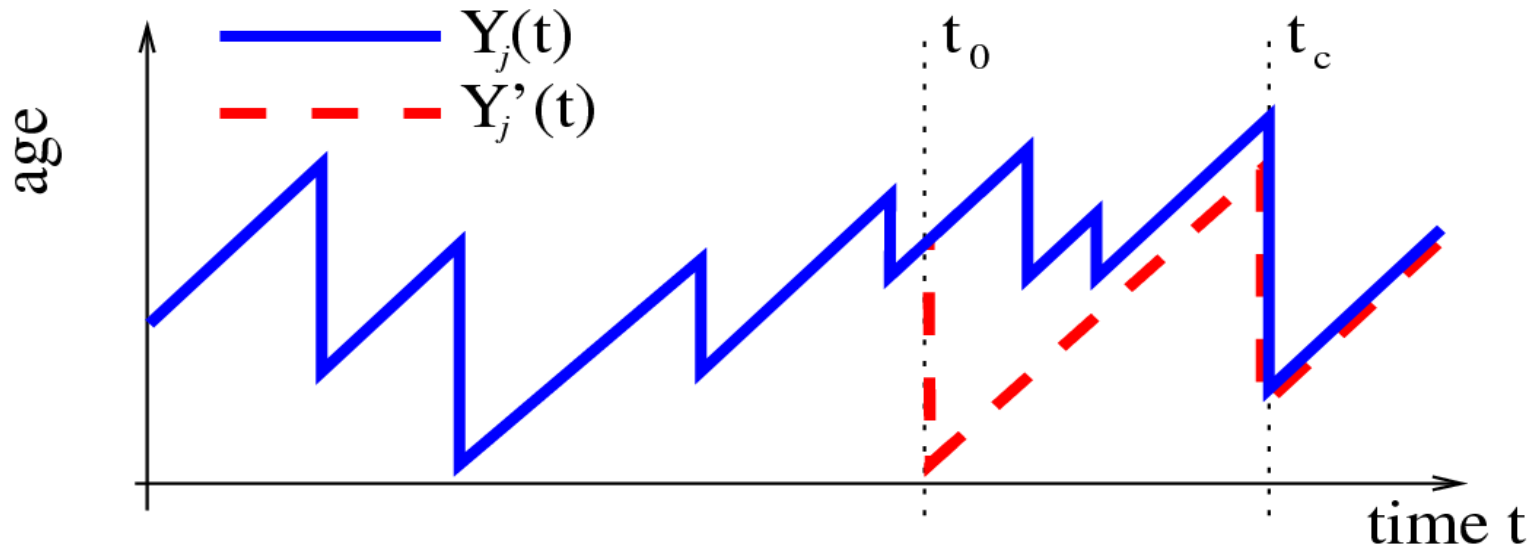
From that point on, j maintains a “**dummy**” age process $Y'_j(t)$, along with its actual age process $Y_j(t)$.



An Unbiased Estimator of

$$\frac{\partial E_{\bar{x}}[u_i(Y_i)]}{\partial x_j}$$

User j :



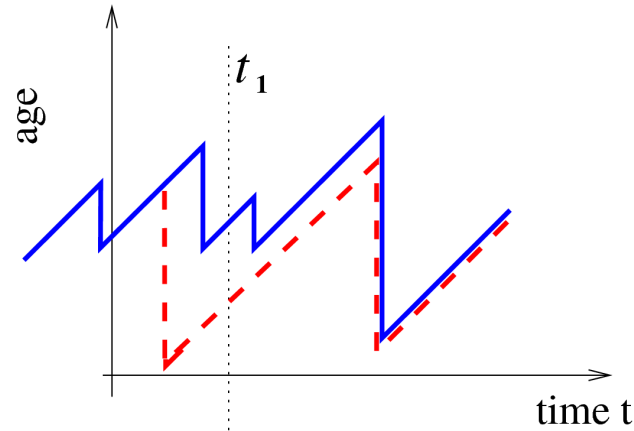
Eventually, $Y'_j(t)$ and $Y_j(t)$ coincide.



An Unbiased Estimator of

$$\frac{\partial E_{\bar{x}}[u_i(Y_i)]}{\partial x_j}$$

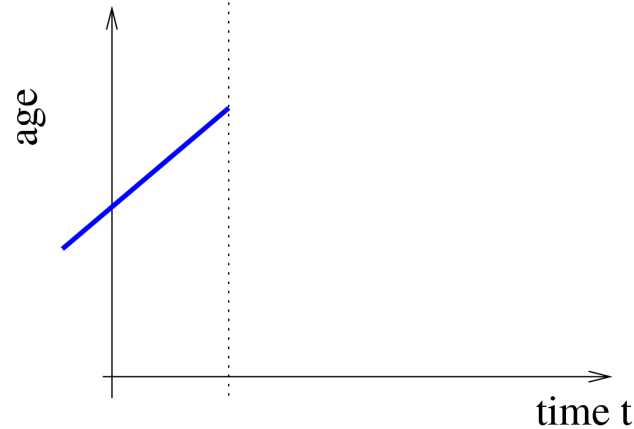
User j :



— $Y_j(t)$

- - - $Y'_j(t)$

User i :



— $Y_i(t)$

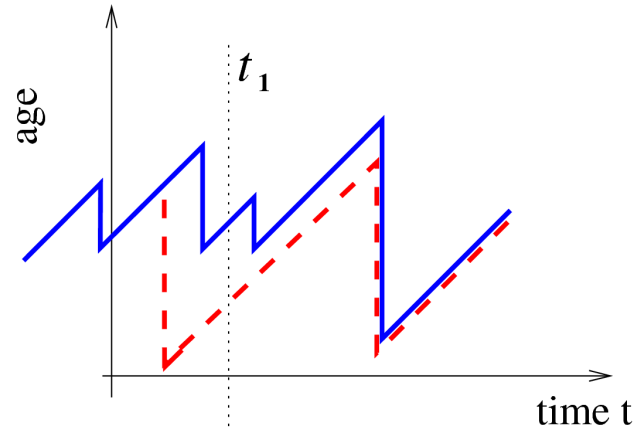
User i meets j at time t_1 , while j is maintaining a “dummy” age process.



An Unbiased Estimator of

$$\frac{\partial E_{\bar{x}}[u_i(Y_i)]}{\partial x_j}$$

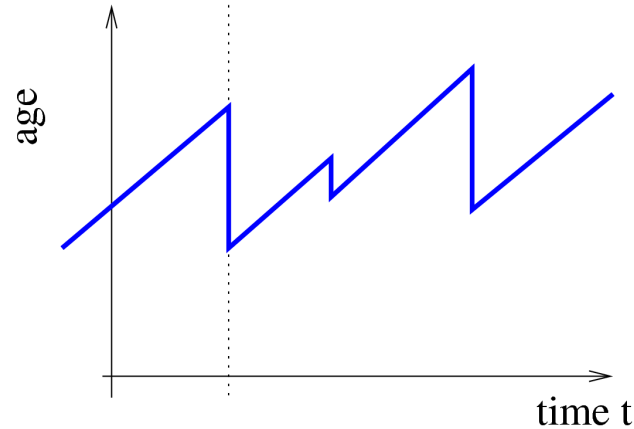
User j :



— $Y_j(t)$

- - - $Y'_j(t)$

User i :



— $Y_i(t)$

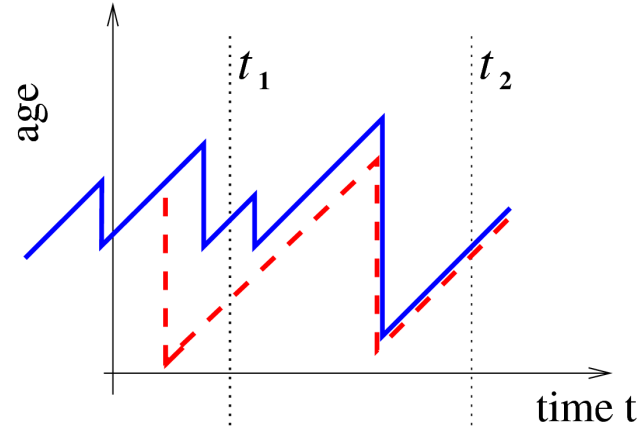
User i receives content from j , changing its actual age $Y_i(t)$.



An Unbiased Estimator of

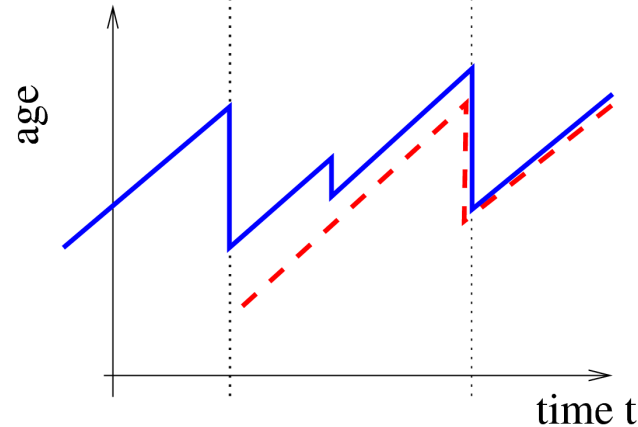
$$\frac{\partial E_{\bar{x}}[u_i(Y_i)]}{\partial x_j}$$

User j :



— $Y_j(t)$
- - $Y'_j(t)$

User i :



— $Y_i(t)$
- - $Y'_i(t)$

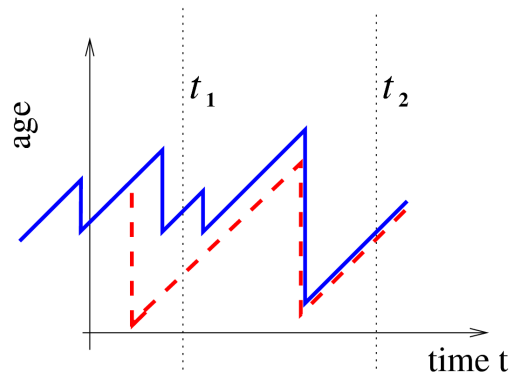
User i also starts a “dummy” age process $Y'_i(t)$. Again, $Y'_i(t)$ and $Y_i(t)$ will eventually coincide.



An Unbiased Estimator of

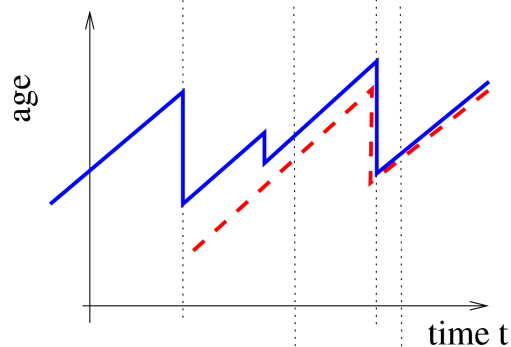
$$\frac{\partial E_{\bar{x}}[u_i(Y_i)]}{\partial x_j}$$

User j :



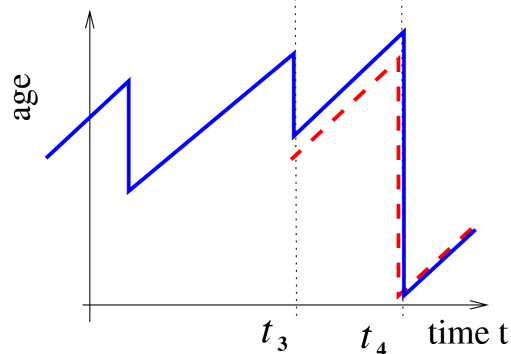
— $Y_j(t)$
- - $Y'_j(t)$

User i :



— $Y_i(t)$
- - $Y'_i(t)$

User k :



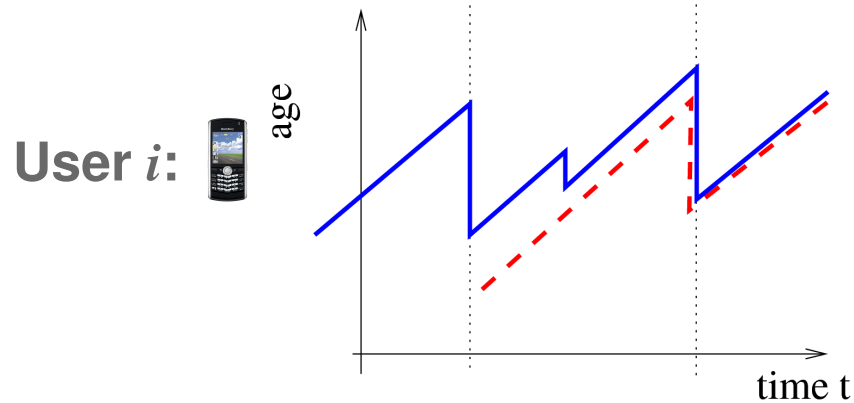
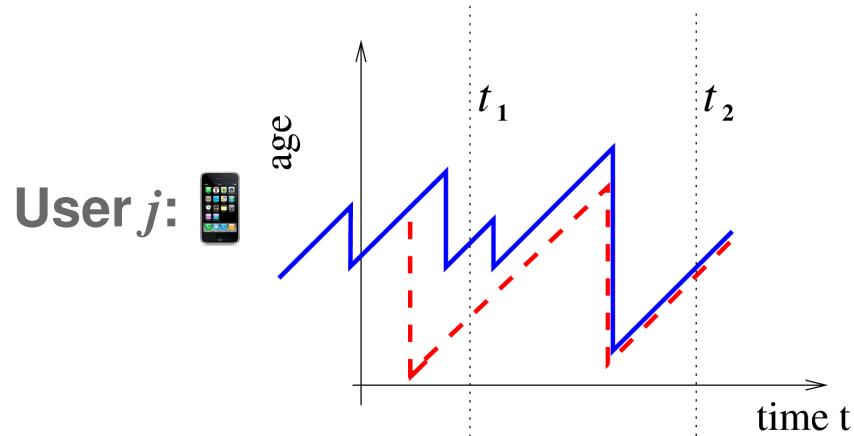
— $Y_k(t)$
- - $Y'_k(t)$

If i meets a third user k , while maintaining a “dummy” age process, k also creates a dummy age process $Y'_i(t)$.



An Unbiased Estimator of

$$\frac{\partial E_{\bar{x}}[u_i(Y_i)]}{\partial x_j}$$



$$\Delta_{i,j} = \int_{t_1}^{t_2} u_i(Y_i(s)) - u_i(Y'_i(s)) ds$$

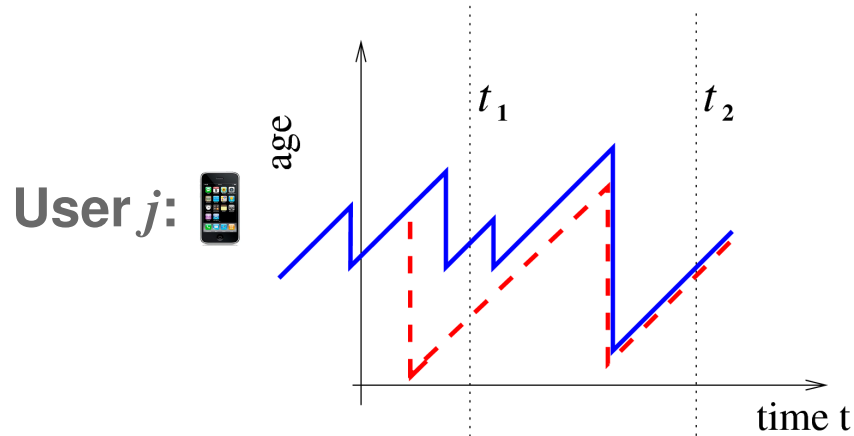
[Bremaud, Vasquez-Abad 92]:

The quantity $\Delta_{i,j}$ is an unbiased estimator of $\frac{\partial E_{\bar{x}}[u_i(Y_i)]}{\partial x_j}$.

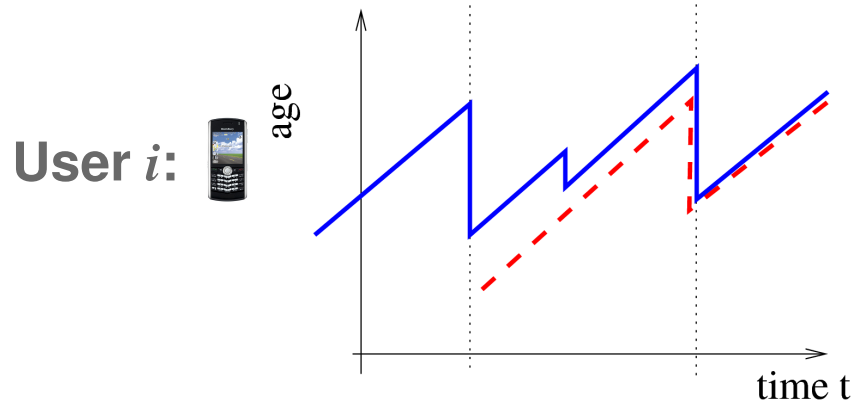


An Unbiased Estimator of

$$\frac{\partial E_{\bar{x}}[u_i(Y_i)]}{\partial x_j}$$



$$\Delta_{i,j} = \int_{t_1}^{t_2} u_i(Y_i(s)) - u_i(Y'_i(s)) ds$$



$\Delta_{i,j}$ is similar to the *sample path shadow price* of a packet in a congested network [Gibbens and Kelly, 99].

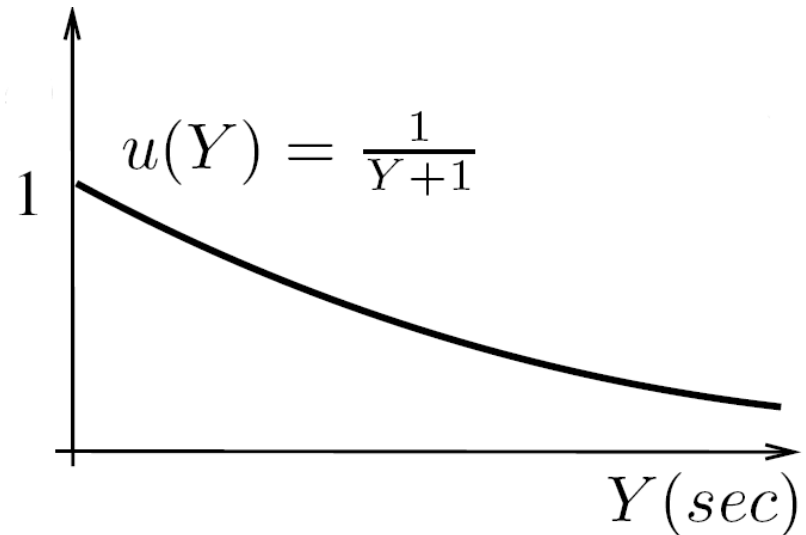
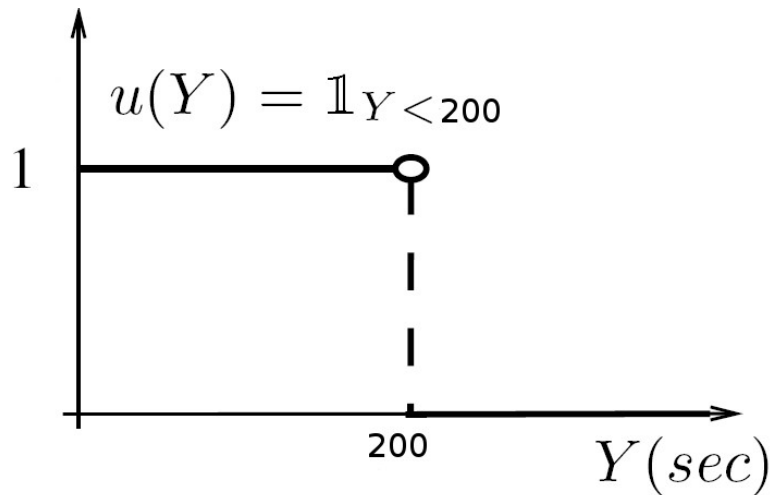


Empirical Study

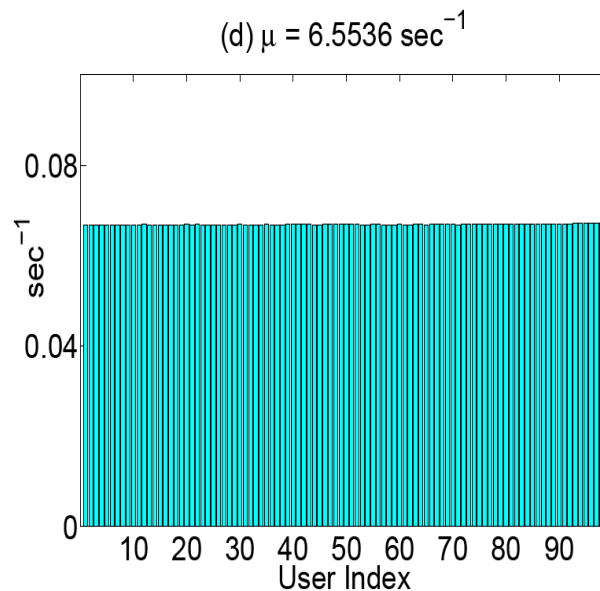
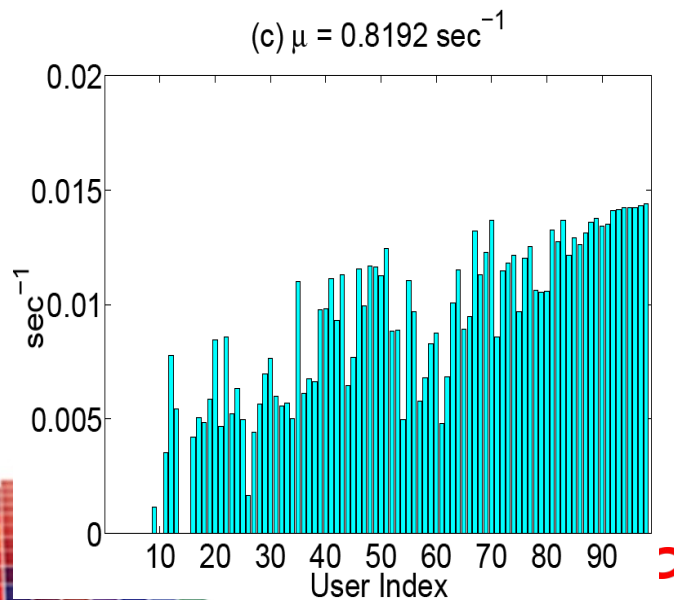
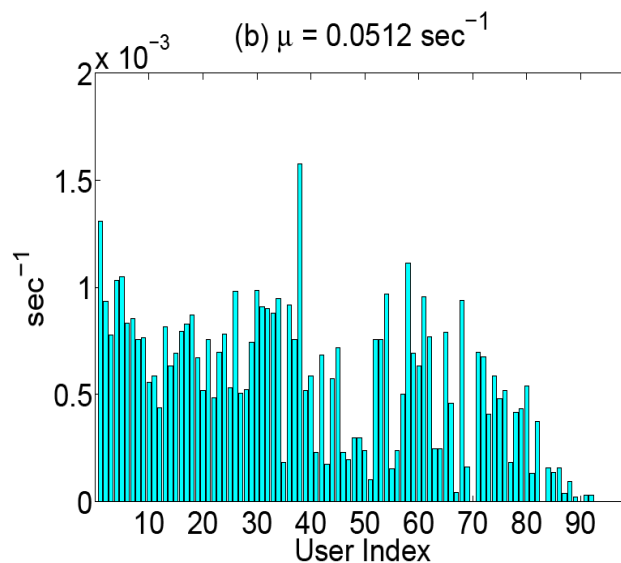
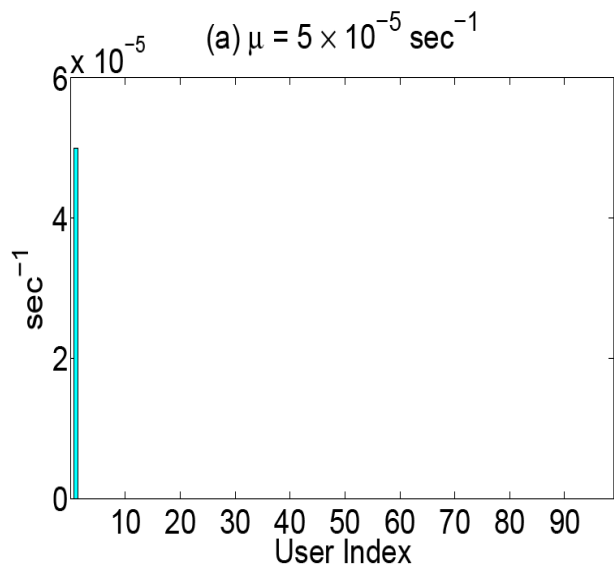
Infocom 06: 10 hours, 98 users

MIT: 80 days, 95 users

User utilities:



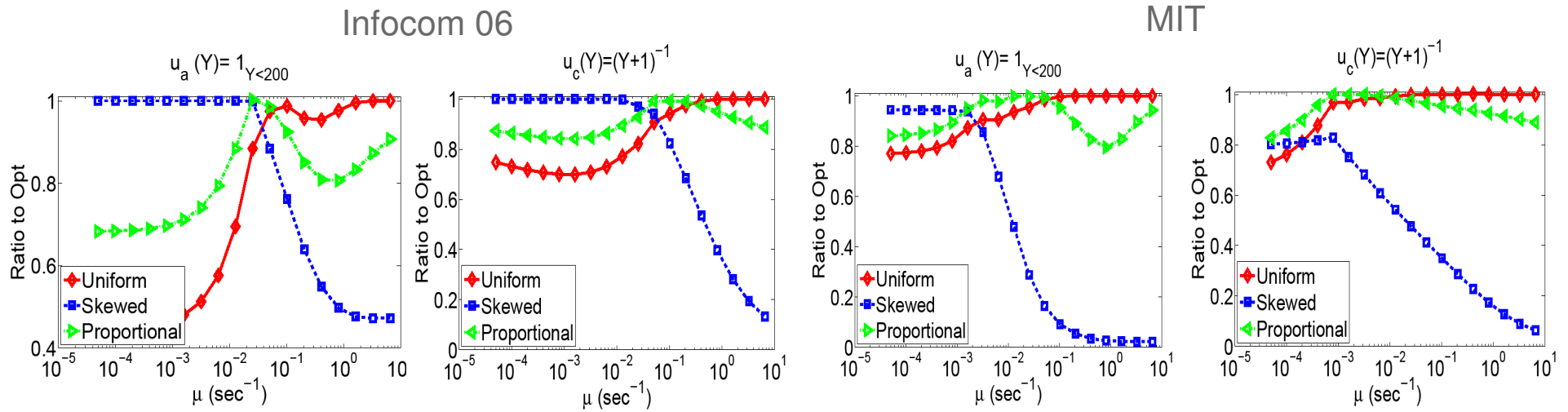
Optimal Allocations (Infocom '06)



Optimal rate allocations for step-function utilities.

Users are indexed from most to least social.

Comparison to Heuristic Allocations



Ratio of social welfare of heuristic rate allocations to the optimal.

μ (sec ⁻¹)	No-sharing	Skewed	Proportional	Uniform	Optimal
0.0128	2.5%	34%	24%	30%	34%
0.0256	5.1%	42%	42%	37%	42%
0.1024	19%	46%	56%	60%	60%

Fraction of users with age below 200sec (Infocom 06).



Conclusions & Future Work

Conclusions

- Service provider can distribute updates in optimal way.
- No need to know utilities and/or contact statistics!
- Optimal allocation can be non-trivial.

Future work

- Incentives to share
- Pricing
- Full decentralization-no service provider



Thank you!

S. Ioannidis, A. Chaintreau, and L. Massoulié: *Optimal and Scalable Distribution of Content Updates in a Mobile Social Network*. In INFOCOM 2009.

S. Ioannidis, and A. Chaintreau: *On the Strength of Weak Ties in Mobile Social Networks*. In SNS 2009.

A. Chaintreau, J.Y-Le Boudec, and N. Ristanovic: *The age of gossip: Spatial mean-field regime*. In SIGMETRICS 2009.



Scalability

Restricted Model:

- Users meet according to independent Poisson processes with rates $q_{ij} \geq 0$.
- Weighted graph $G(V,E)$ where
 - V = the set of users,
 - $E = \{(i,j), i,j \in V\}$,
 - The weight of edge (i,j) is $q_{ij} \geq 0$.

Weighted Edge Expansion:

$$h_G = \min_{A \subseteq V, |A| \leq |V|/2} \frac{\sum_{i \in A, j \in A^c} q_{ij}}{|A|}$$



Main Result

Theorem: If $x_i = \mu/n$, for all $i \in V$, (*i.e.*, the rate allocation is uniform) the expected age seen by any user $i \in V$ in steady state satisfies

$$\mathbb{E}_{\bar{x}}[Y_i] \leq \frac{2}{\mu} (2e^{-1/2} + \log(n)) + h_G^{-1} \log(n)$$

where h_G the edge expansion G .

- If G is an expander, the expected age is $O(\log n)$.
- Considerable improvement compared to no-sharing ($O(n)$).

