Privacy-Preserving Twitter Browsing through Obfuscation

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Microblogging Services

A popular way for information sharing and communication.

Users are able to have timely access to all information available from various providers.

Publish-Subscribe Model

- Information providers (*channels*)
  - ✓politicians
  - ✓news agencies or news reporters
  - ✓hospitals or doctors
  - ✓activists
  - ✓artists
  - ✓religious organizations
  - ✓other communities

- Users subscribe to (or *follow*) channels
  - ➢In this way they receive **interesting** information in a timely manner

Publish-Subscribe Model (example)

channel subscription process

Channel 1

Channel 2

Publish-Subscribe Model (example)

information delivery process

User's following

User's timeline

What about users' privacy?

- The microblogging service knows a user's interests based on the user's channel subscriptions
  - Political preferences (e.g., Barack Obama)
  - Health issues (e.g., cancer)

- Detailed user profiling
  - Privacy-sensitive channels
  - Can be used for many purposes
  - Beyond the control of the users

Threat Model

- An “honest but curious” microblogging service
  - capable of passively gain knowledge about users’ interests by monitoring the channels they follow.
    - knowledge that can be given/sold to third parties e.g. advertisers
- Users that need access to timely information and they are able to follow individual channels.
- A channel can be the account of a physical person, a corporation, a politician’s office, and so on.

HOW CAN WE PROTECT USERS' PRIVACY?

Existing approaches:

1. **No login**
   - limited information available to non-logged in users.
   - Correlation of served content + IP address.
2. **Pseudonym or fake account**
   - IP address, third-party tracking cookies, browser fingerprints can reveal user's identity
3. **Anonymization service (e.g., Tor)**
   - Logging into the service, possibility of Tor nodes blocking
4. **Tor + Fake account**
   - Cookies and fingerprints gathered through anonymous and eponymous browsing sessions
5. **Fake account + Tor + VM per browsing session**
   - Too complex for ordinary users and mobile devices

But…

How can we hide users' interests in a world where it will be practically impossible to hide one's real identity?

Our thesis is:

users' interests can be protected using obfuscation

k-subscription

For each *privacy-sensitive* channel $\mathbf{C_1}$ a user *really* wants to follow with k-subscription, the user will also *randomly* follow **k - 1** additional sensitive channels acting as *noise*:
$\mathbf{C_1}$, $\mathbf{C_2}$, $\mathbf{C_3}$, …, $\mathbf{C_k}$ (where $\mathbf{C_2}$, $\mathbf{C_3}$, …, $\mathbf{C_k}$ are noise channels)

This way:

- The service cannot identify a user's *actual* choices
- Hide the choices of *other* users as well
  - ✓The service cannot identify the users that are actually interested in $\mathbf{C_1}$

Note: All channels $\mathbf{C_1}$, $\mathbf{C_2}$, $\mathbf{C_3}$, …, $\mathbf{C_k}$ belong to the *same* set **S** of privacy-sensitive channels

k-subscription in action

Random noise

Real choices

Following

Catholic Church @catholicEW
Serving the Catholic Bishops of England and Wales. Following/RTs ≠ endorsement.
Following

American Cancer Soc @AmericanCancer
The official American Cancer Society Twitter stream. 100 years ago, we began the fight of a lifetime.Today, you can help us finish the fight. 1-800-227-2345
Following

Everyday Health @HeartDiseases
Follow @HeartDiseases for the latest news and information on living a heart-healthy lifestyle, straight from the editors of @EverydayHealth.
Following

HilaryClinton @HilaryClinton
Following

Barack Obama @BarackObama
This account is run by Organizing for Action staff. Tweets from the President are signed -bo.
Following

Alcohol Problems @AlcoholProbs
Alcohol, the cause and solution to all of life's problems. For questions or promotion contact AlcoholProblems@gmail.com
Following

Obfuscation algorithms

1. **Uniform sampling**
   - Randomly select every channel in **S** as noise with *same* probability
2. **Proportional sampling**
   - Randomly select every channel in **S** as noise with probability *proportional* to its *popularity*

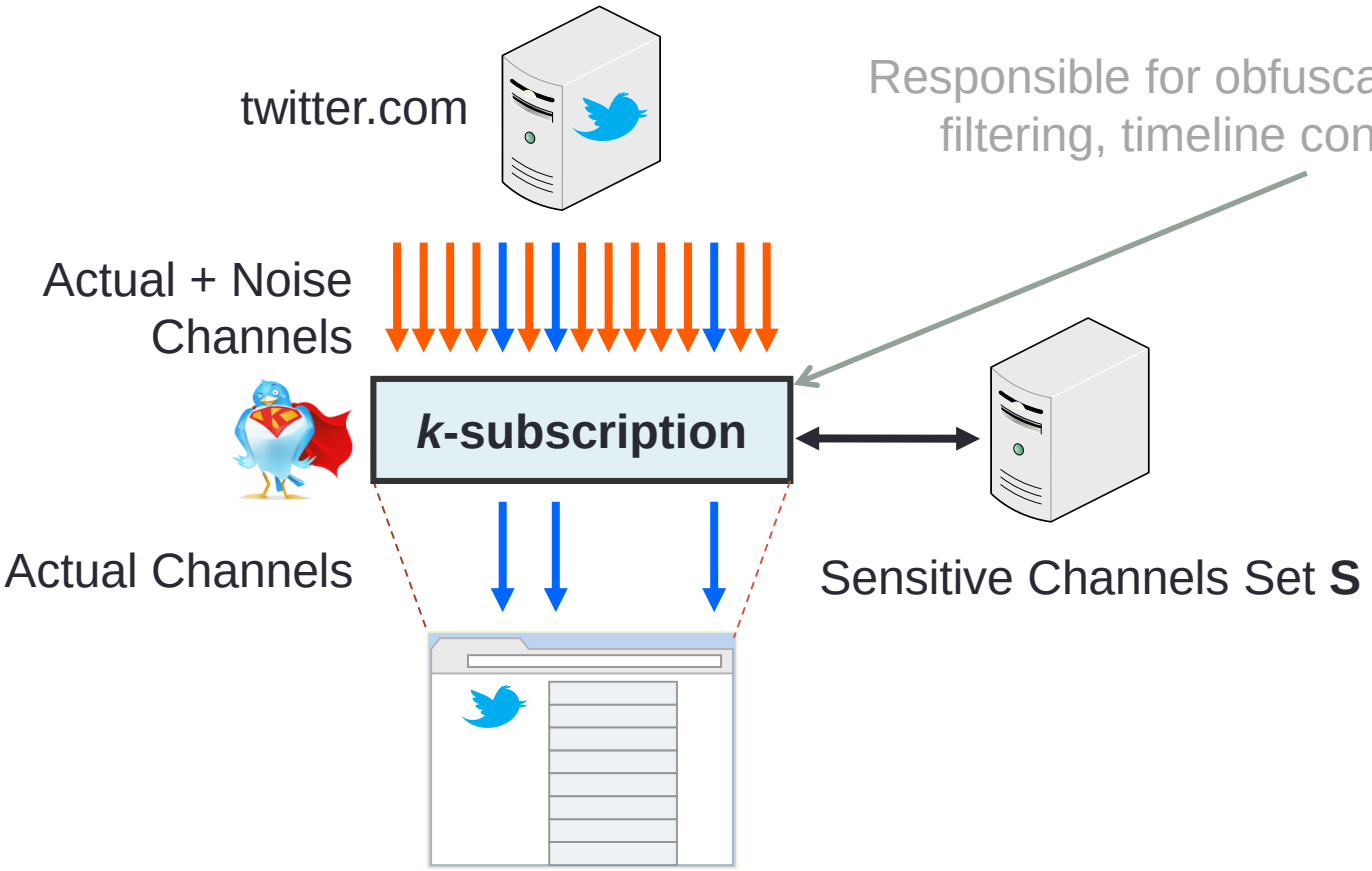
Multiple channels

Following a set of semantically-related channels. Can be easily identified by the service

- Just choose proper **k** so that there are *other* users that select the *same* set as noise

Implementation

- Browser extension for Google Chrome browser
- Using Twitter as case study



Remove the effect of noise (1/2)

What the microblogging service sees:

Real + noise channels

What the user sees:

Only real channels

Remove the effect of noise (2/2)

What the microblogging service sees:

Tweets from real + noise channels

What the user sees:

Tweets only from real channels

Disclosure Probability P_C

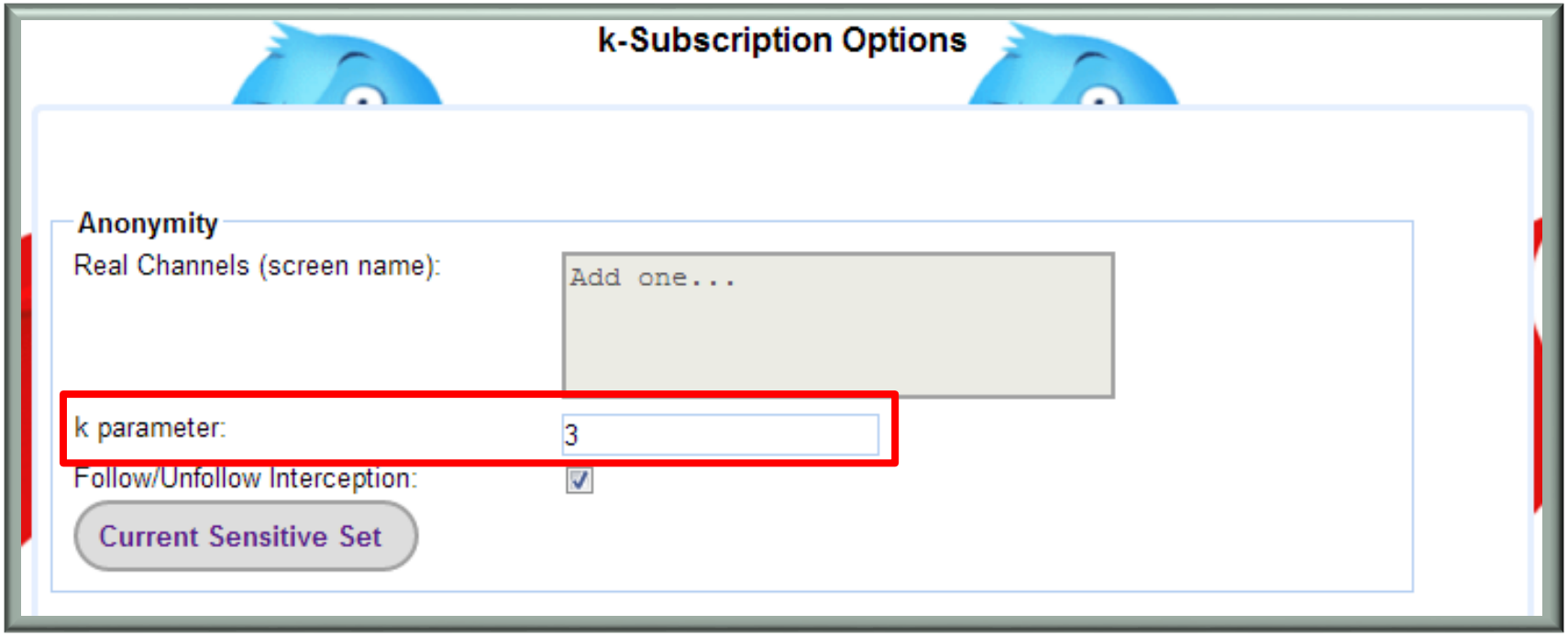
The probability that a user following channel **C** is actually interested in **C**

Depends on

- channel's popularity $\mathbf{p_C}$
  - (e.g number of followers)
- size of set **S** (|**S**|)
  - Publicly released
- obfuscation level **k**
  - Can be inferred => a user follows k channels in short period

The *k* parameter

Fine-tune the **k** parameter to control the preferable *privacy level* and *network overhead*



WHAT IS THE RIGHT K VALUE?

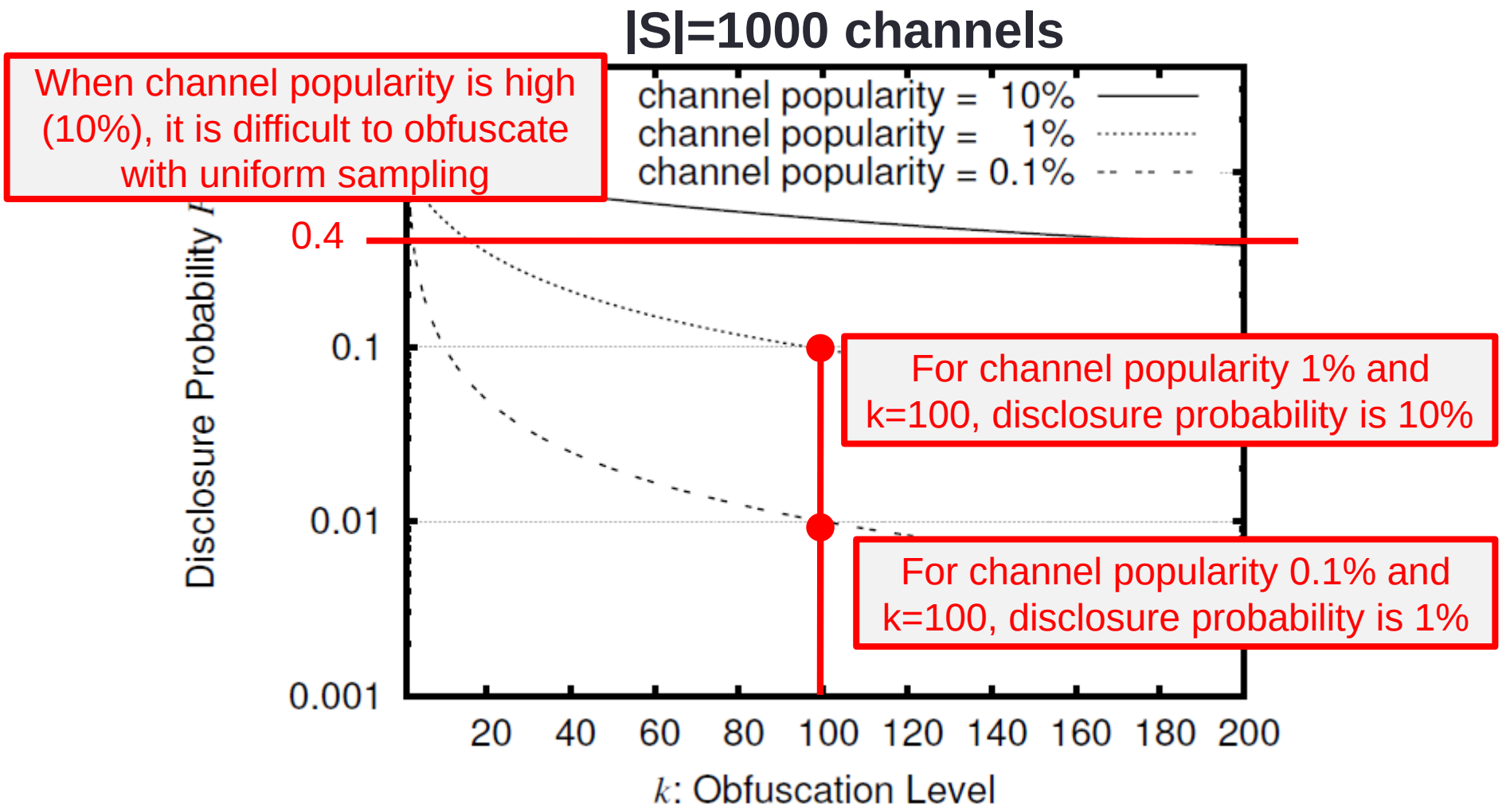
Choosing a value for k

- Analysis and simulation for disclosure probability as a function of **k**

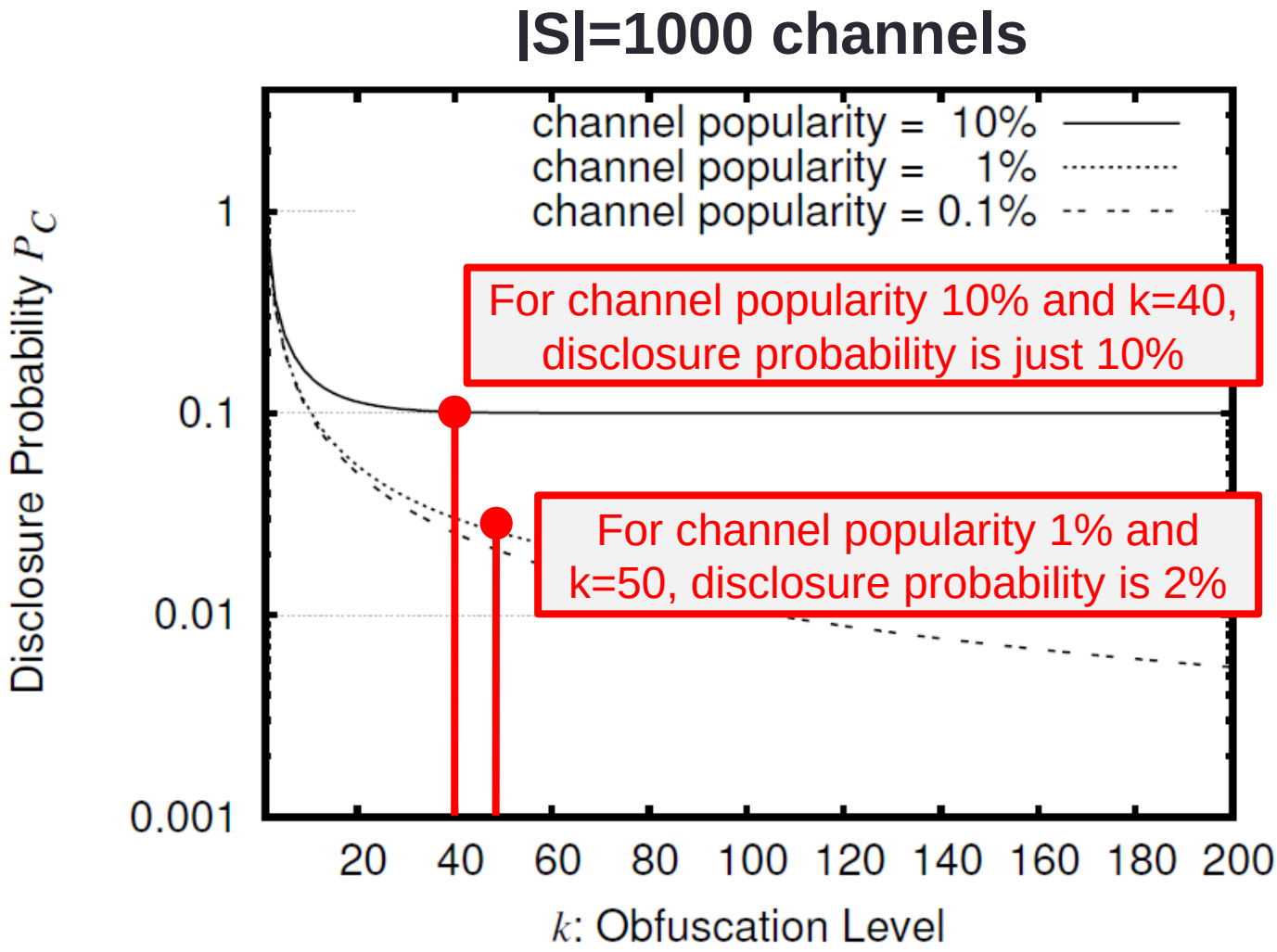
- Experimental evaluation for network overhead as a function of **k**

ANALYTICAL EVALUATION

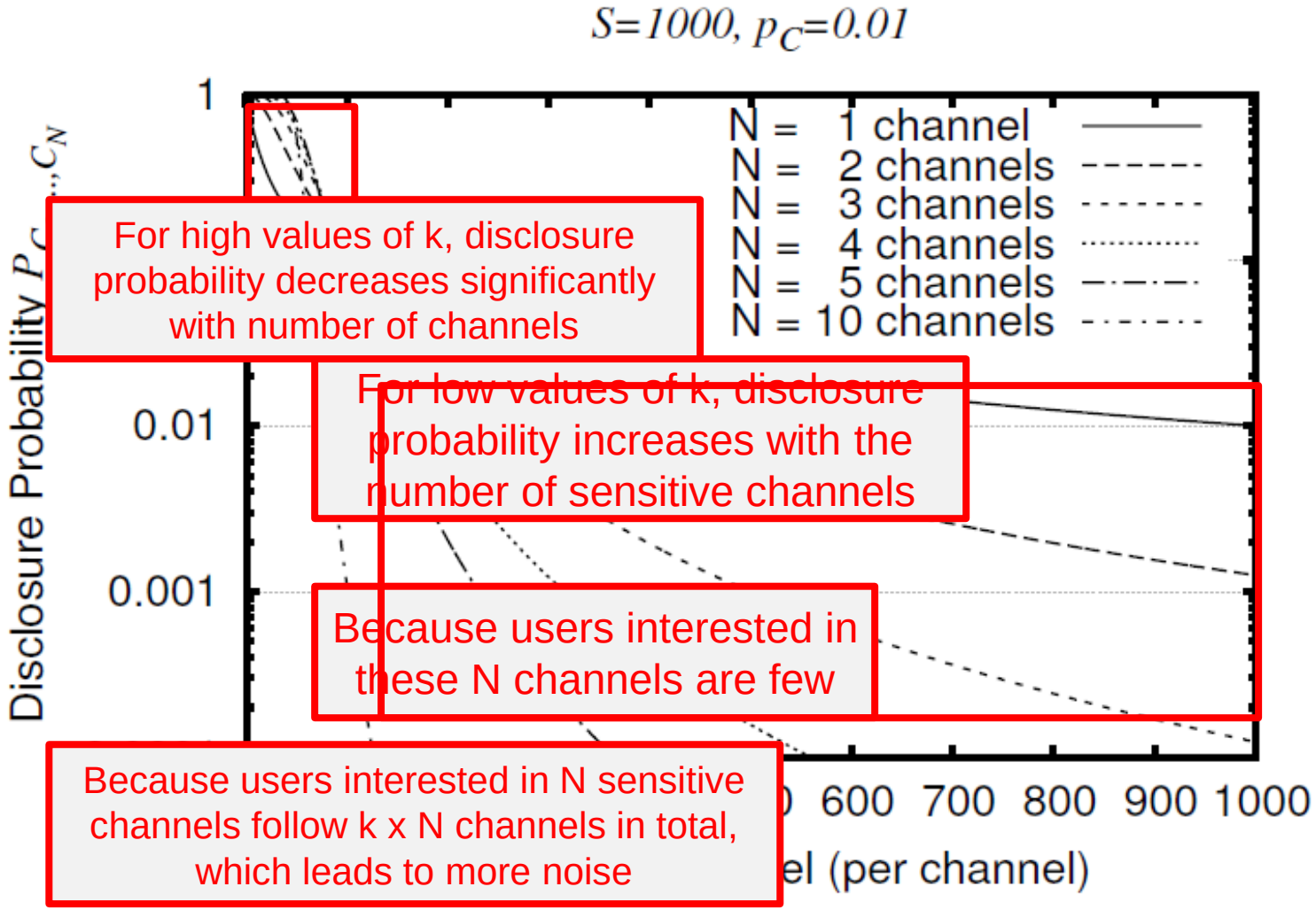
Uniform Sampling



Proportional Sampling



Following Multiple Channels



For high values of k, disclosure probability decreases significantly with number of channels

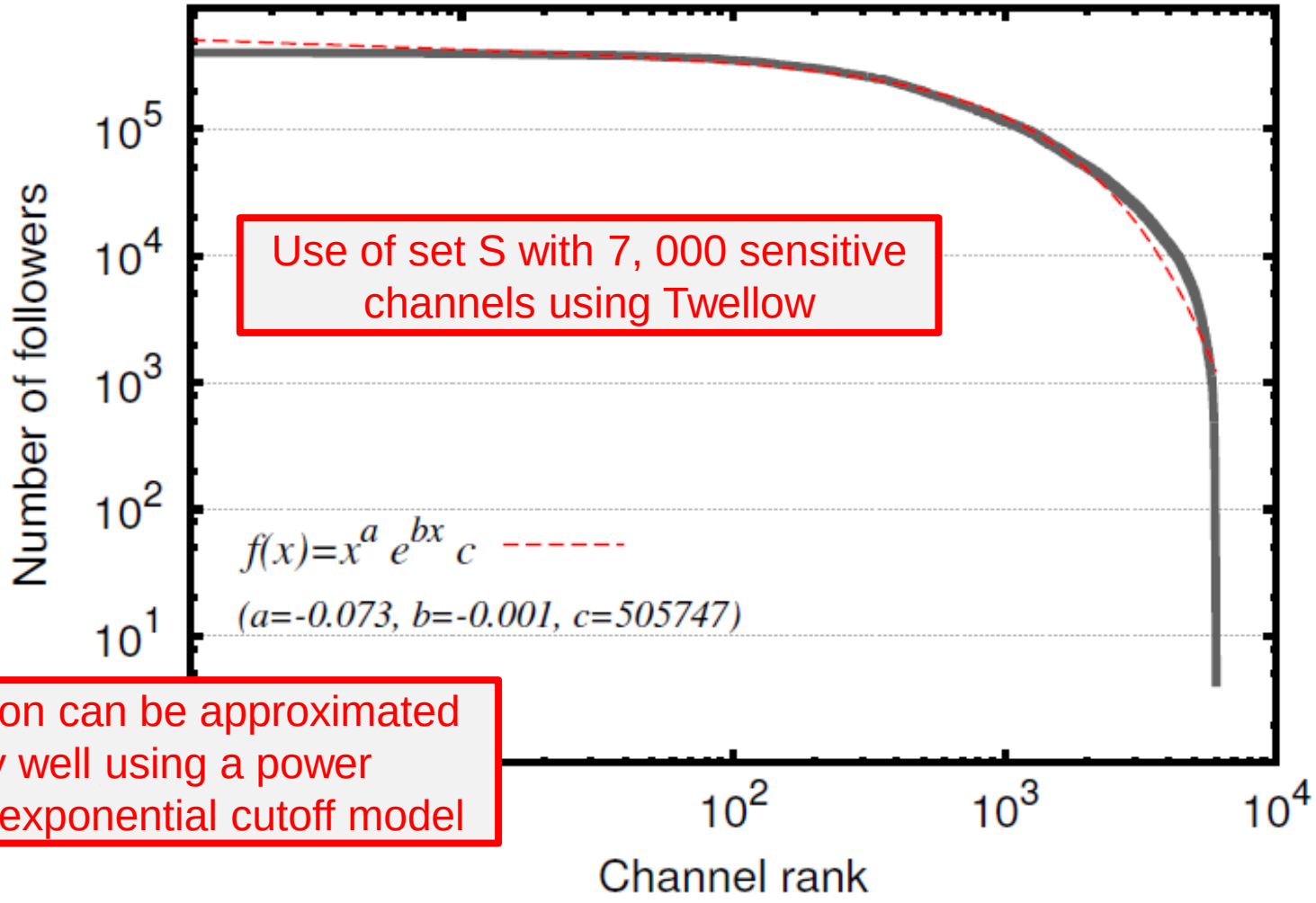
For low values of k, disclosure probability increases with the number of sensitive channels

Because users interested in these N channels are few

Because users interested in N sensitive channels follow k x N channels in total, which leads to more noise

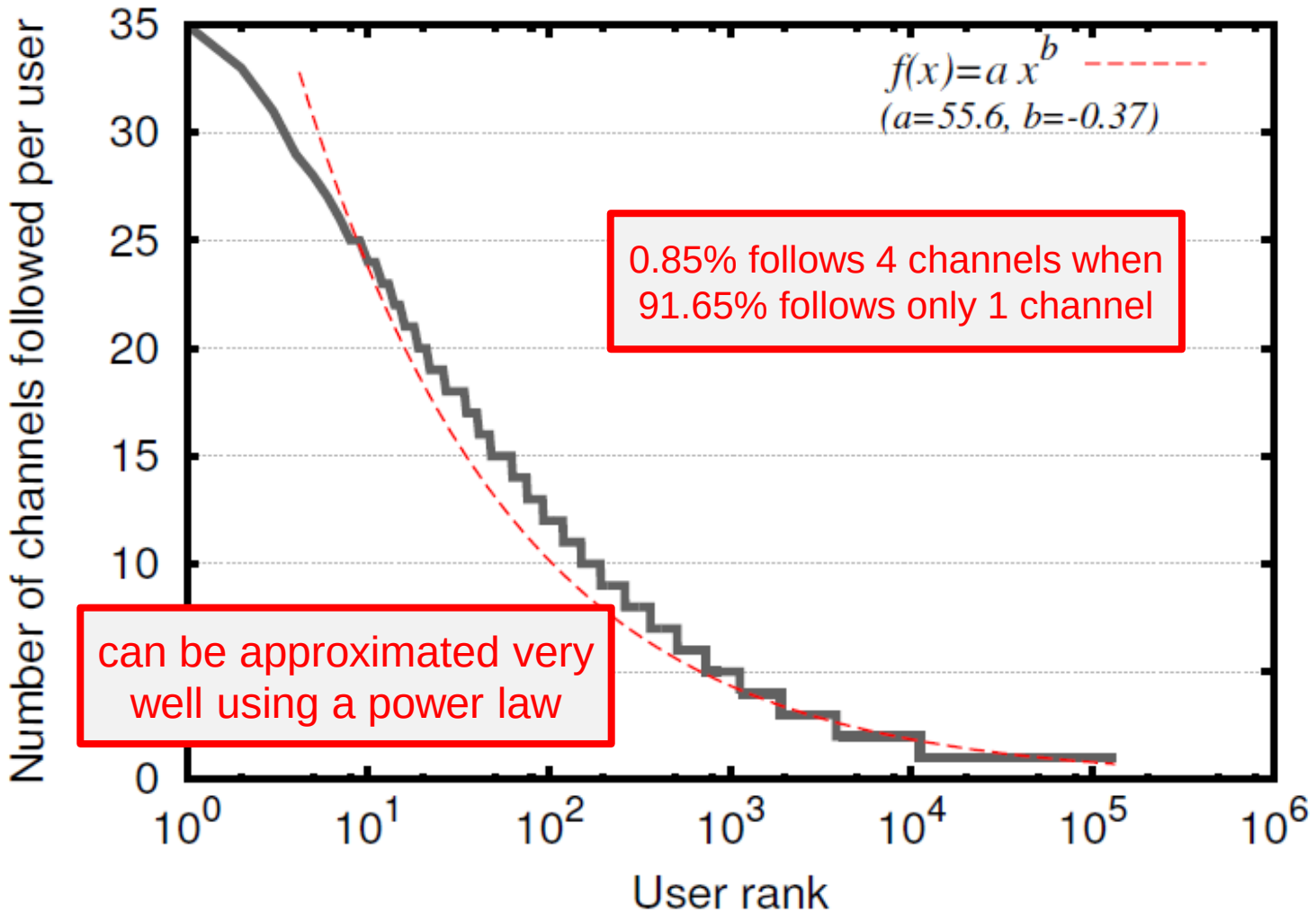
SIMULATION-BASED EVALUATION

Sensitive Channels Popularity Distribution

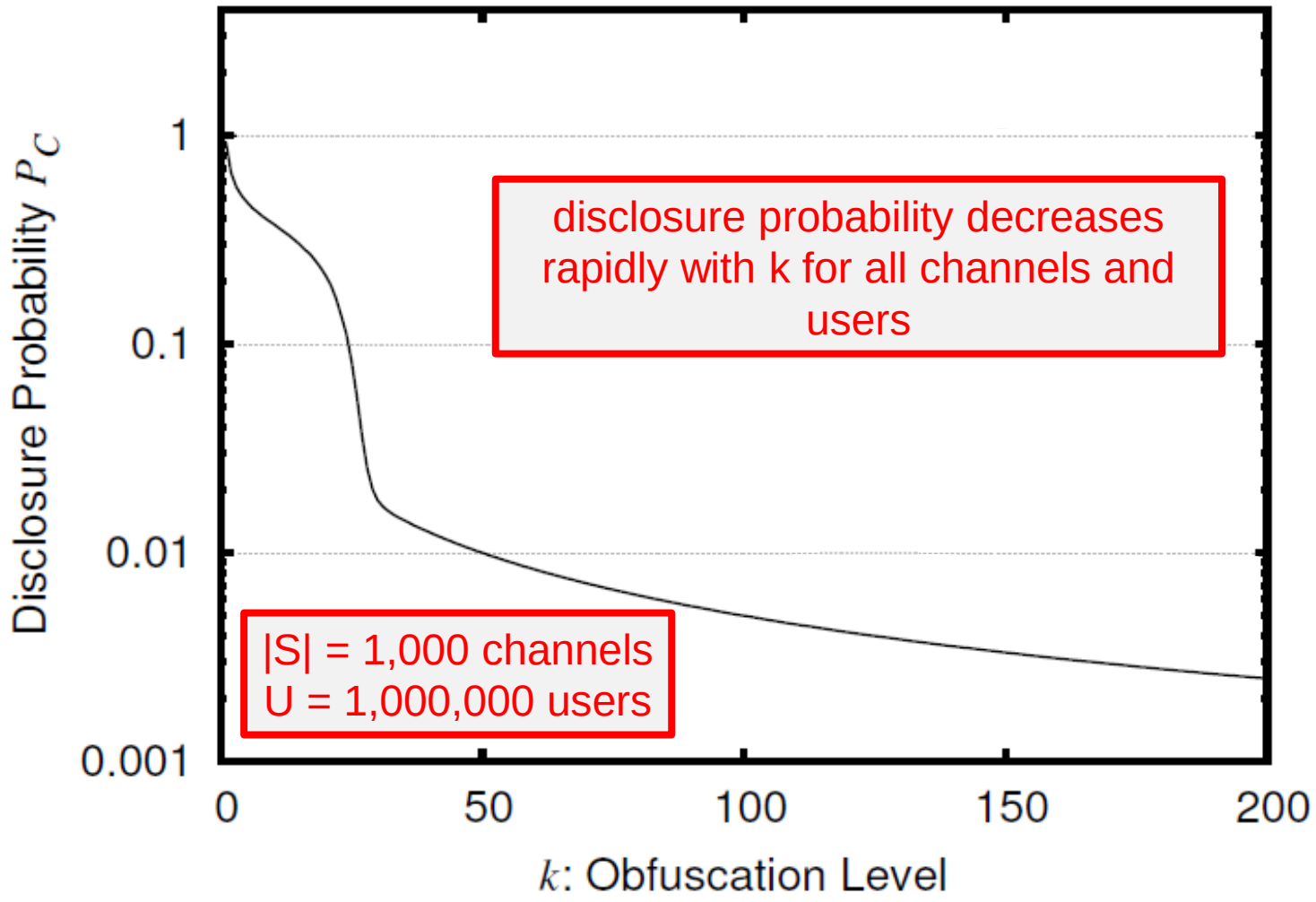


distribution can be approximated very well using a power law with exponential cutoff model

Number of sensitive channels users follow

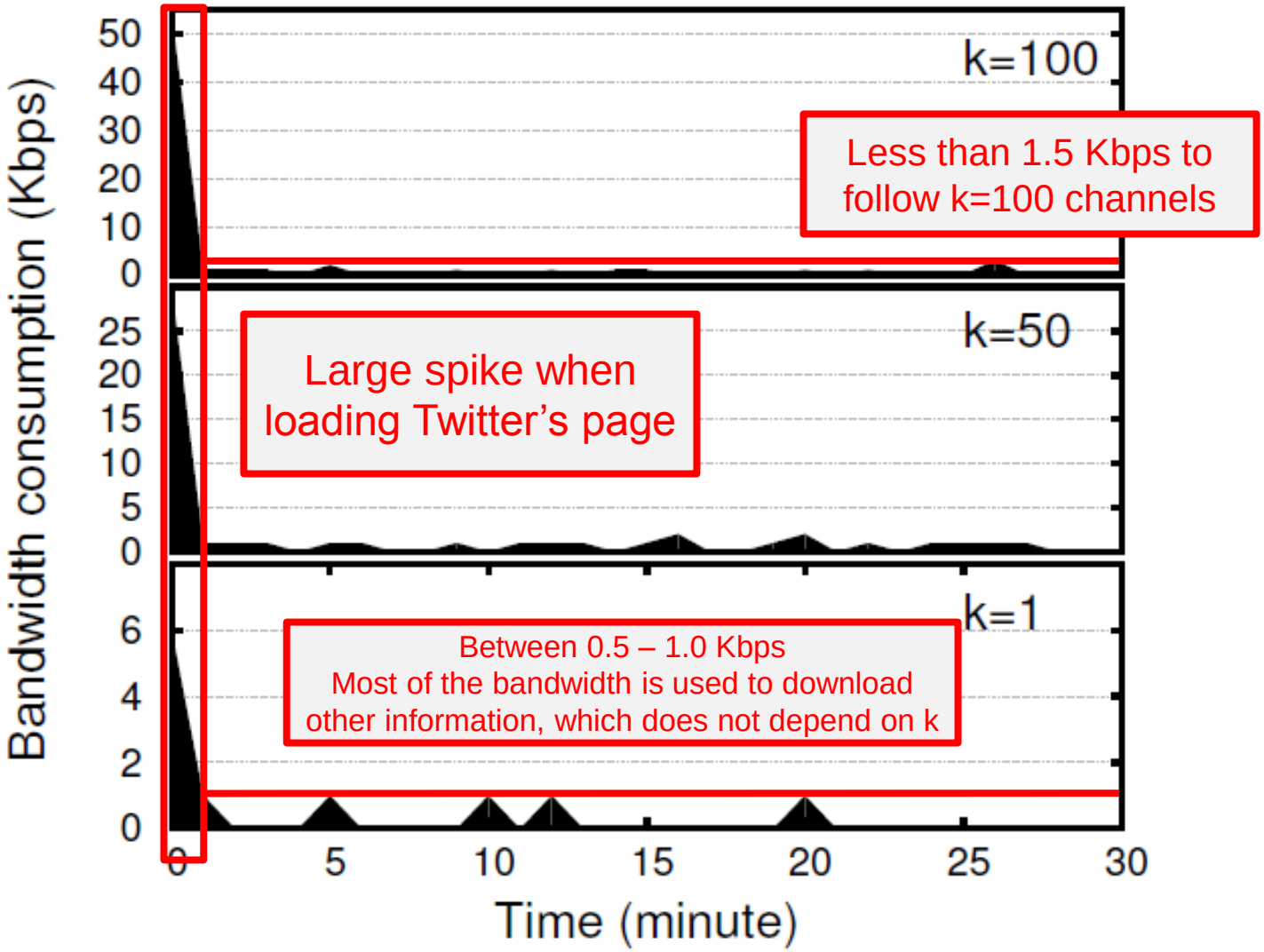


Simulation-Based Study

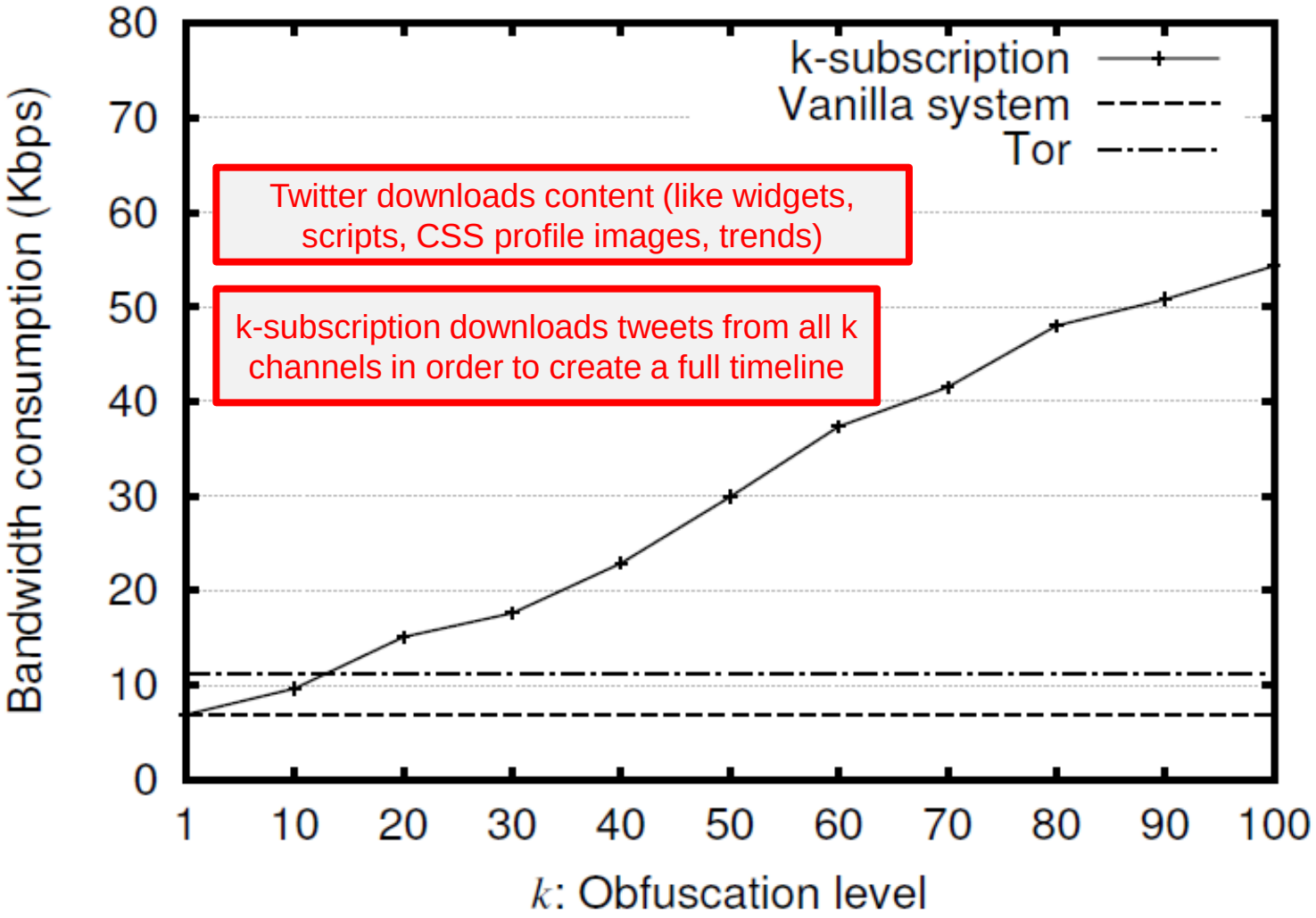


EXPERIMENTAL EVALUATION

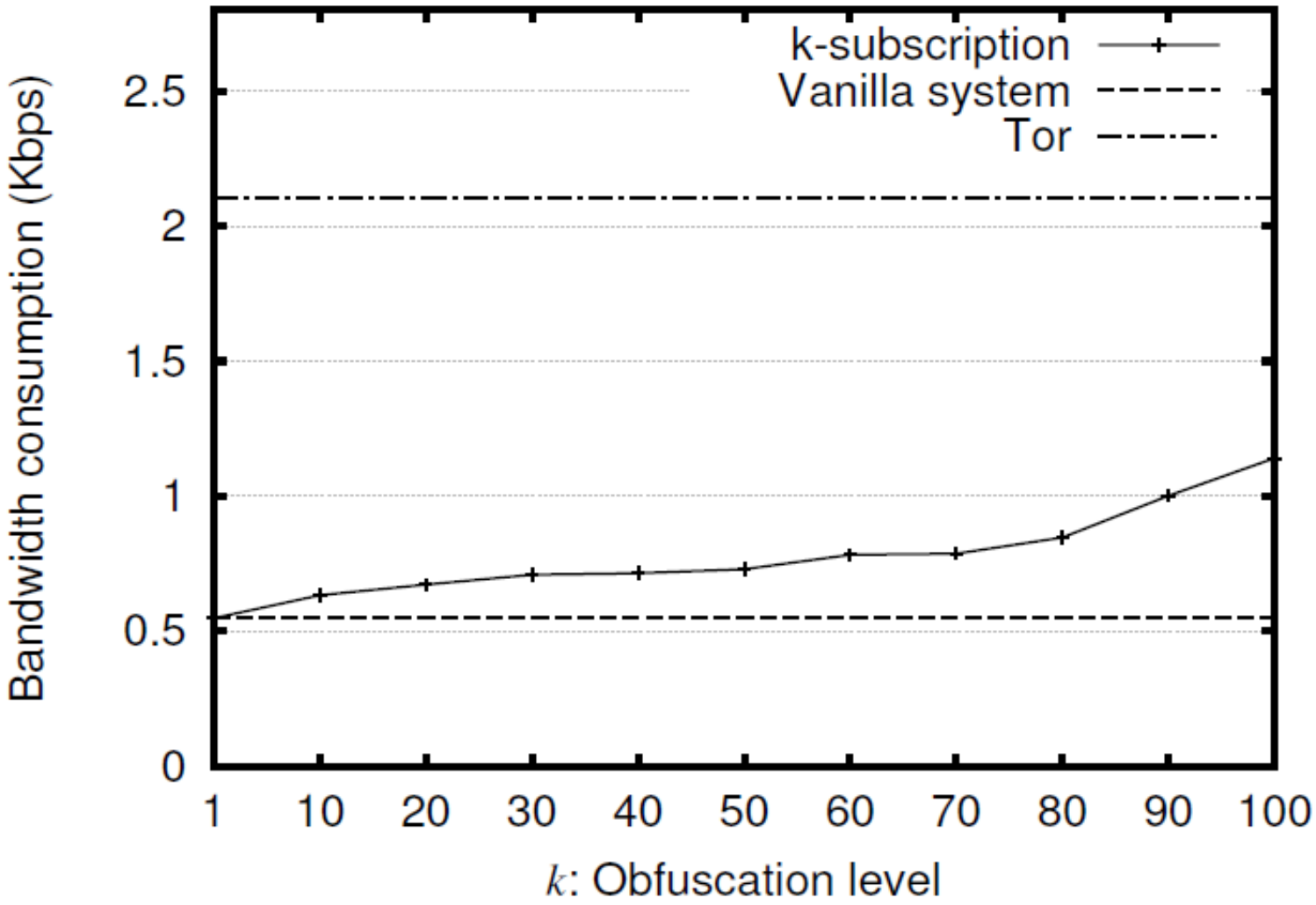
Bandwidth Consumption Over Time



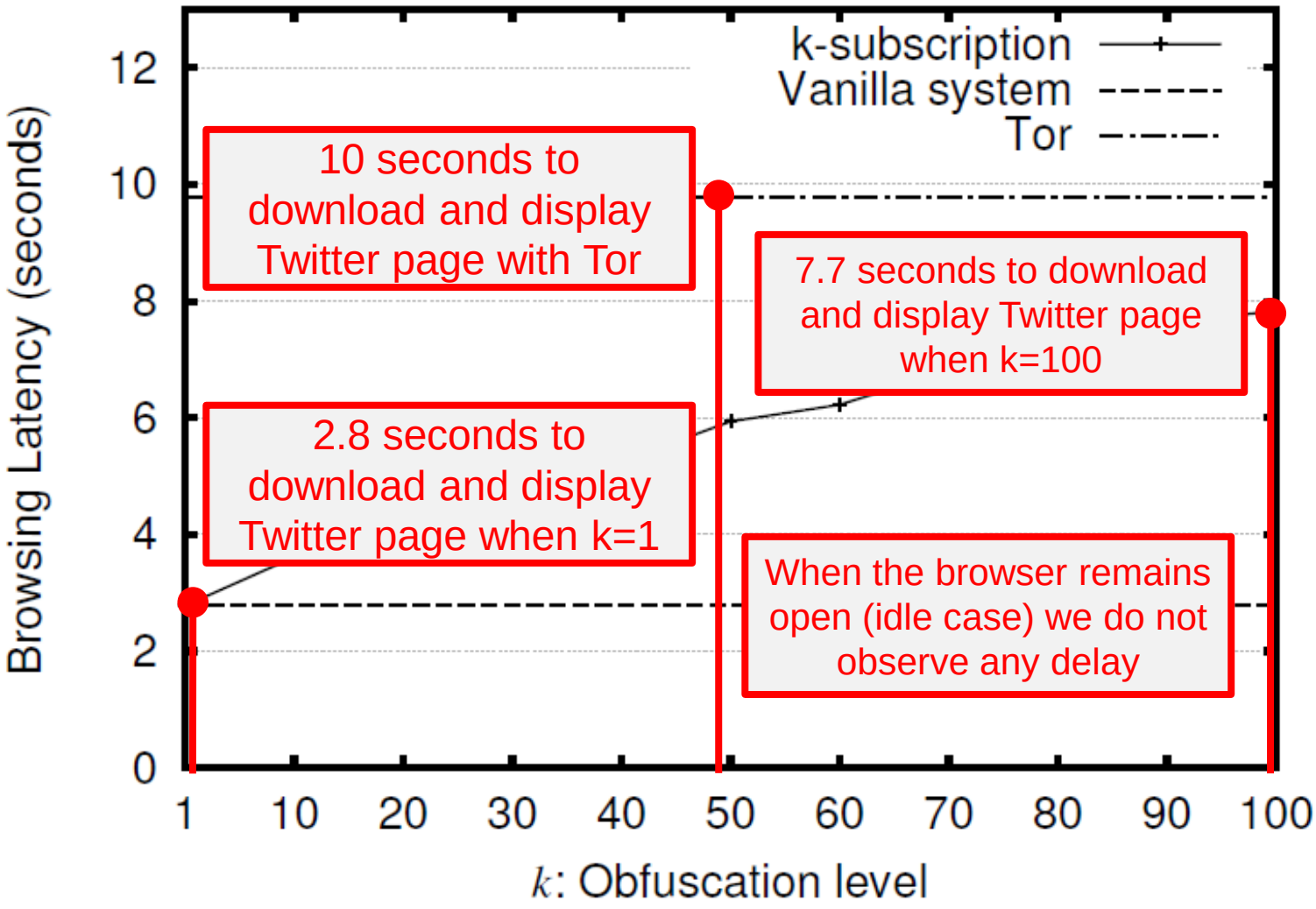
Bandwidth Consumption: Initialization Stage



Bandwidth consumption: Idle stage



Browsing Latency



- Our tool is available as a Google Chrome browser extension
- This work has been published in the 29th Annual Computer Security Applications Conference (ACSAC ‘13) on Dec 2013 at New Orleans, USA

Conclusions

- *k-subscription*: an obfuscation-based approach for privacy-preserving Twitter browsing
  - Hide user's subscriptions within selected noise
  - Hide user's subscriptions within noise of other users
  - Add noise from a common set with sensitive channels

- Fine tuning the k parameter
  - Disclosure probability
  - Network overhead

- In a future where user's identity cannot be hidden privacy could be achieved by:
  - obfuscation and
  - mutual collaboration between users.

BACKUP SLIDES

Posting Messages

k-subscription protects microblogging browsing:

- Does not aim to hide users' interests when users want to post about a sensitive issue
- Does not aim to hide users' interests when users want to retweet a post of a sensitive channel

For protecting user posts there are alternative solutions:

- Hummingbird, #h00t, etc. (*using post encryption*)

Short URLs

Short URL services usually cooperate with microblogging services. So these URL shortening services can be used to infer user's interests based on user clicks on short URLs

- k-subscription, when a user clicks on a short URL, resolves, transparently, on the background all short URLs in tweets from noise and real channels.

Formulas for Disclosure Probability P_C

Uniform Sampling:

$$P_C < \max(1/k, \frac{p_C}{p_C + (1 - p_C) \times (1 - (1 - 1/|S|)^{k-1})})$$

Proportional Sampling:

$$P_C > \max(1/k, \frac{p_C}{p_C + (1 - p_C) \times (1 - (1 - p_C)^{k-1})})$$

Following multiple channels **N**:

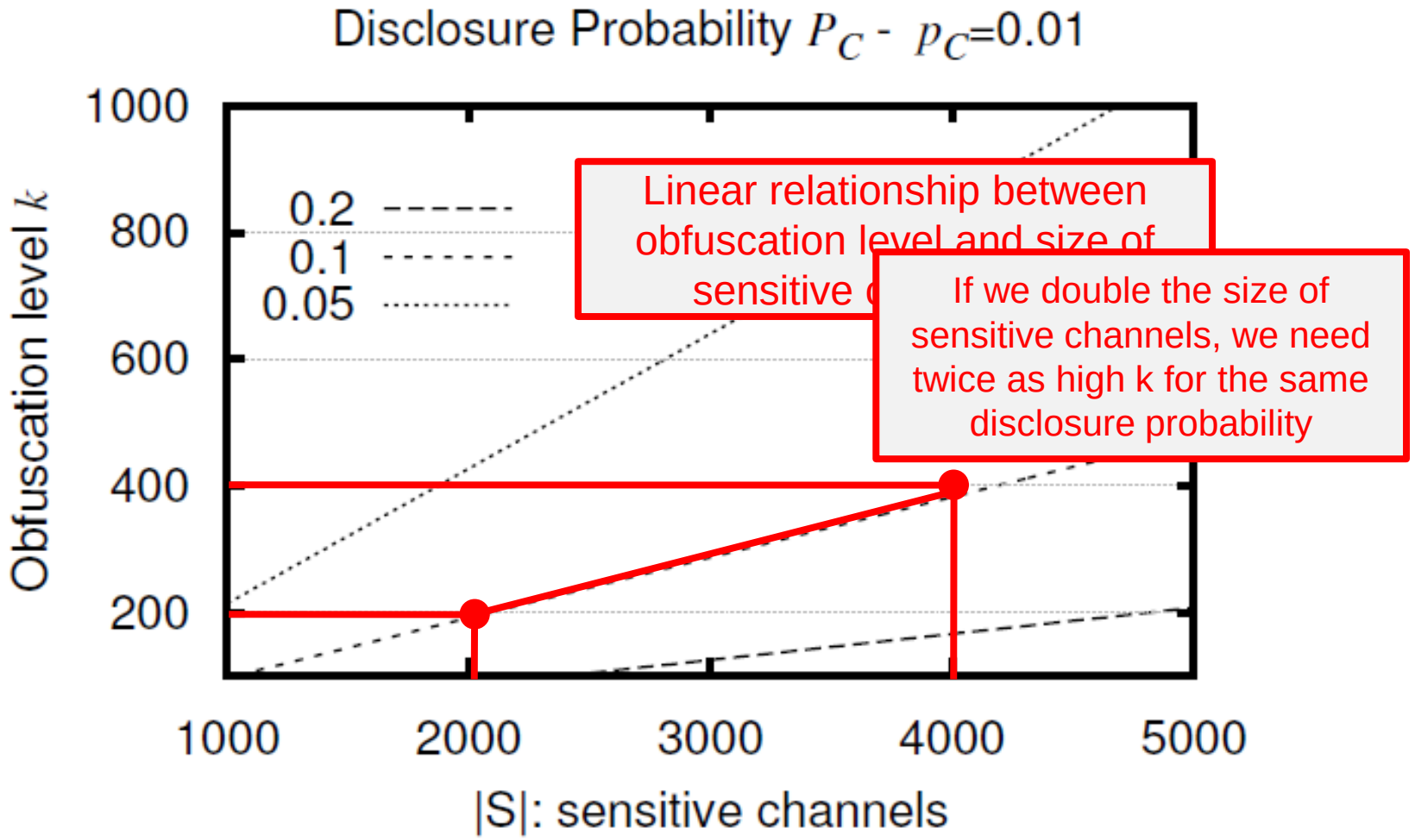
$$P_{C_1,\ldots,C_N} = \frac{p_{C_1,\ldots,C_N}}{p_{C_1,\ldots,C_N} + (1 - p_{C_1,\ldots,C_N}) \times \binom{|S|-N}{(k-1)N-N} / \binom{|S|}{(k-1)N}}$$

Sensitive channels *S*

Maintained by a privacy-related organization

- Users may request, through k-subscription, new sensitive channels to be added in this set
- The set S must be shielded against malicious users that tries to insert a large number of fake channels in order to increase disclosure probability
  - CAPTCHAs to avoid computer bots that inserts batches of fake channels
  - Use of Yahoo Term Extraction API in order to evaluate the channel's sensitivity
  - Channel's activity and channel's audience validation
  - Channel's audience evaluation: amount of followers to the amount of following ratio, number posts coming from API, duplicate or spam posts, posts with unrelated links.

Size of Sensitive Channels Set (1/2)



Channel popularity: 1% Disclosure probabilities: 0.2, 0.1 and 0.05

Size of Sensitive Channels Set (2/2)

- in order to keep the disclosure probability constant:
  - if we double |S| -> we must double k value
- for a constant obfuscation level k:
  - larger |S| -> higher disclosure probability.
- very small |S| would easily give away a user's true interests+limit the users' choice for channels
  - if S contains n members, the microblogging service will be able to conclude with probability at least 1/n that the user is interested in the channel she follows.
- |S| must be enough so $1/|S| < U_C/U$

Why not N-tuples?

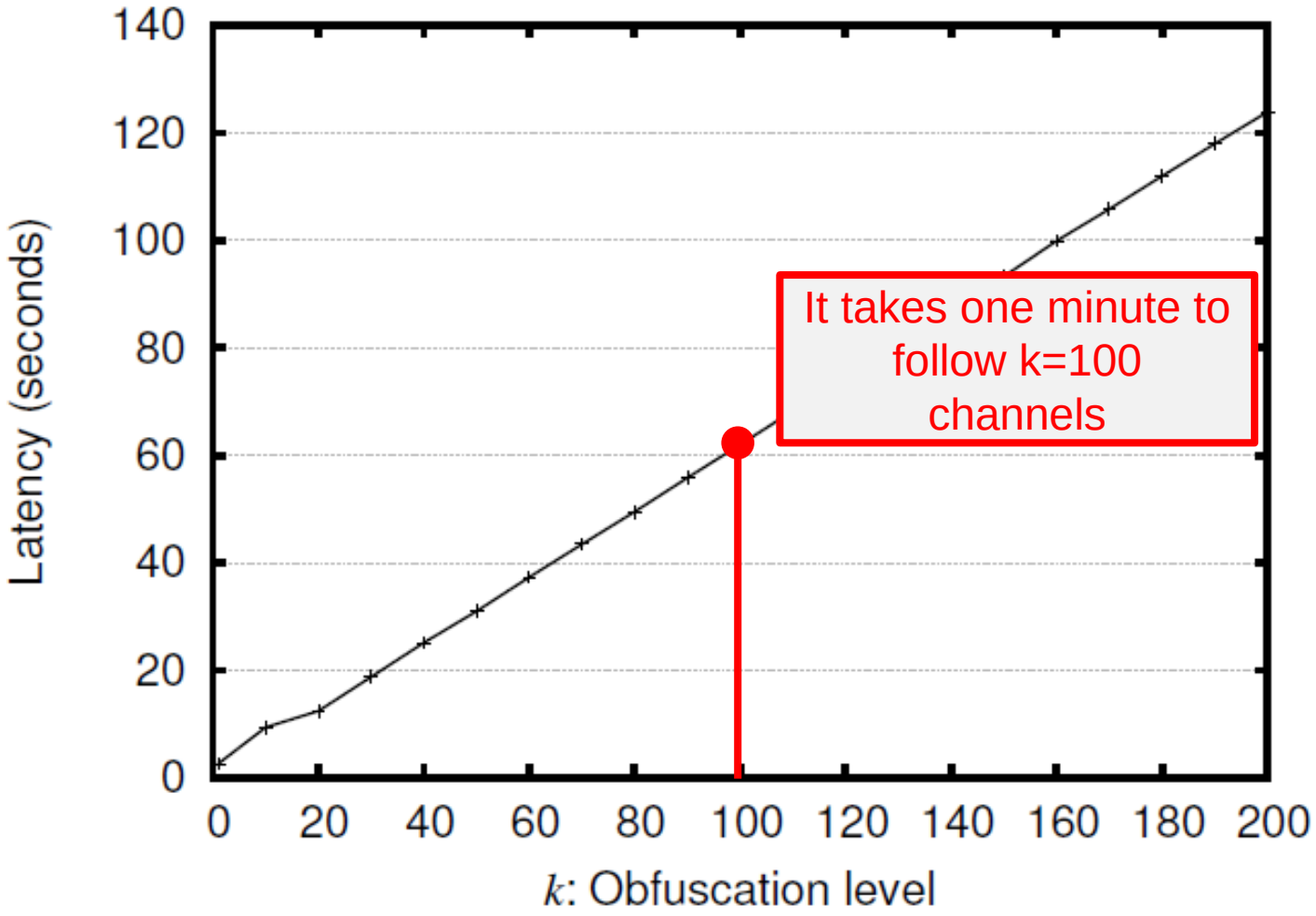
Whenever a user is interested in N related channels:

the $(k - 1) \times N$ noise channels that will follow

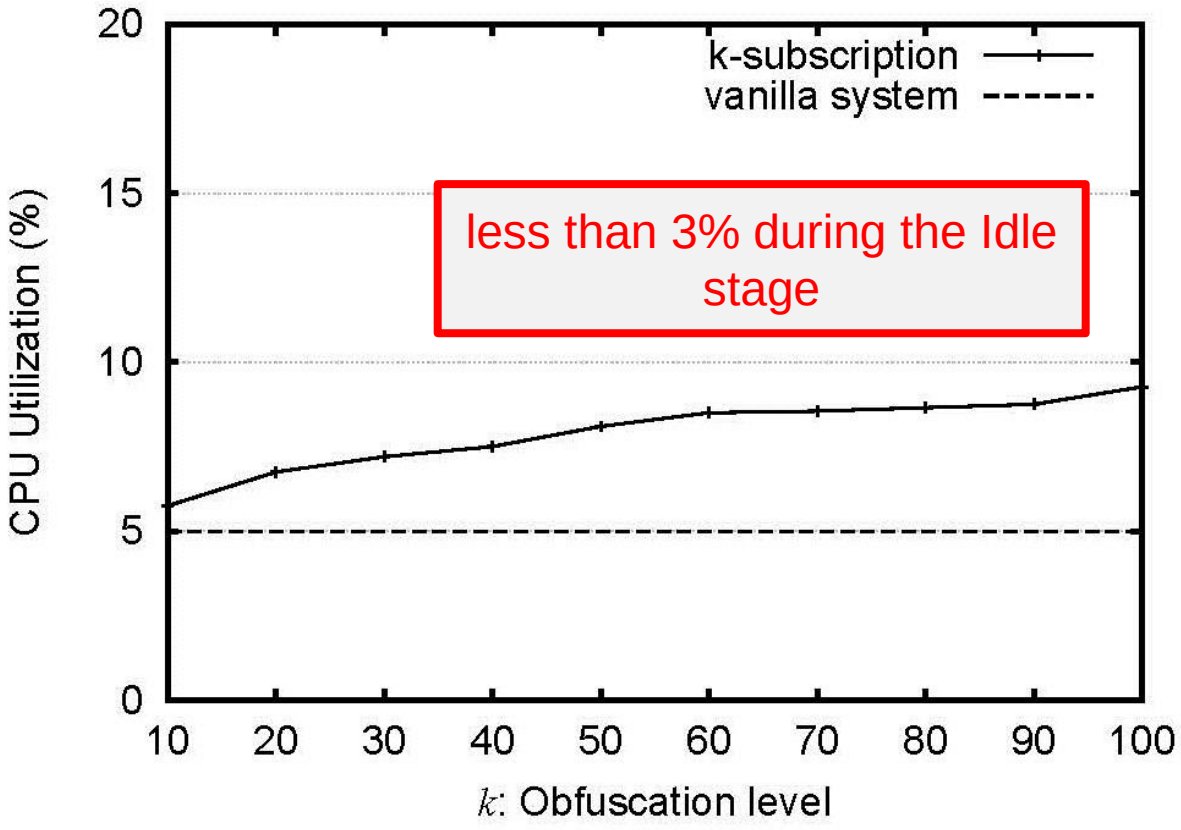
will be selected in N-tuple groups, so that each N-tuple consists of N related noise channels.

<u>However</u>: the microblogging service may use different similarity metrics to identify related channels.

Time to follow a sensitive channel



CPU load ~ Initialization stage



What about giving the wrong impressions?

User following illness-related channels or bankruptcy-related channels => worrying friends + family

- dummy account protects against worrying family
  - (but NOT against microblogging service, that can use IP tracking or cookies)
- followings can be organized in separate private lists (Twitter provides this option).
  - That option also, does not offer protection against Twitter

What about disappearing channels?

People close or delete their accounts:

- If users stop following channel D and it's noise => correlate D's disappearance with the users' change of following patterns => users were interested in channel D.

- If users noise channels start disappearing => service will be in a better position to find the exact channel they are really interested in.
  - add other noise? => NO, the service will figure out the noise channels

✓users interested in D + users who not interested in D but have included D as noise => should do nothing! => the service will not be able to differentiate which users are interested in D and which are not.

k-subscription-UNIF

- when 10% of the users are interested in channel C:
  - it would take a significant percentage of the rest 90% to include channel C among their noise channels,

- when popularity is around 1%:
  - then it is much easier to obfuscate it.
  - for k = 100 the disclosure probability is as low as 0.1