Anonymous asynchronous messaging

Various techniques & why they are not common

Steyn Hommes, Nick Marx, Vincent Dankbaar

Agenda & scope

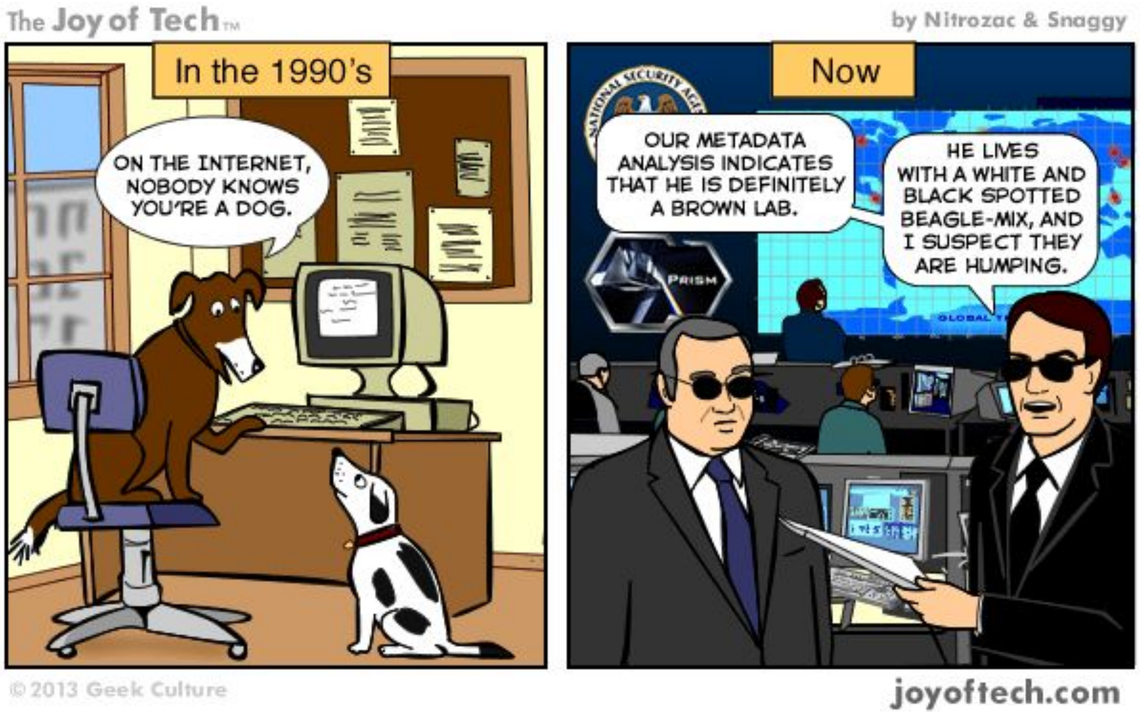
- Motivation
- Background
    - Legal
    - Technical
    - Societal
- Approaches
    - Tor & Mix-nets
    - Private information retrieval (PIR)
- Conclusion

Motivation

We can use End-to-end Encryption to hide the content

But the service provider still knows...

- Sender & receiver
- Sender & receiver location
- Send & receive time
- Message length



Deduce other properties (data mining)

- Social graph
- Work schedule, schedule of other activities
- What type of message

Motivation: Snowden revelations

- In 2013: Revelations about extensive global internet mass surveillance
- AIVD also participated (intelligence and security agency of the Netherlands)
- Both primary data and metadata

“We Kill People Based on Metadata”

General Michael Hayden, former director of the CIA and NSA

https://www.youtube.com/watch?v=kV2HDM86XgI

Usage of Metadata

- Law enforcement: Members of complex criminal networks
- Behavioural studies
- Dictatorship: Friends of people who are against Government
- Prejudices/profiling

Good or Bad: Depends on context

Background

- Legal basis
- General concepts/terminology
- Technical definitions

Legal basis

- Article 8 of the European Convention on Human Rights
  - Right to respect for private and family life
- General Data Protection Regulation (GDPR)
  - Article 4: ‘personal data’ means any information relating to an identified or identifiable natural person
  - Metadata is also protected

Asynchronous messaging apps

Common examples:

- Signal
- Whatsapp
- Messenger
- iMessage
- Line
- WeChat

Signal
'Data Linked To You'

iMessage
'Data Linked To You'

- Contact Info
  - Email Address
  - Phone Number
- Search History
- Identifiers
  - Device ID

WhatsApp
'Data Linked To You'

Analytics

- Purchases: Purchase History
- Location: Coarse Location
- Contact Info: Phone Number
- User Content: Other User Content
- Identifiers: User ID, Device ID
- Usage Data: Product Interaction, Advertising Data
- Diagnostics: Crash Data, Performance Data, Other Diagnostic Data

App Functionality

- Purchases: Purchase History
- Financial Info: Payment Info
- Location: Coarse Location
- Contact Info: Email Address, Phone Number
- Contacts: Contacts
- User Content: Customer Support, Other User Content
- Identifiers: User ID, Device ID
- Usage Data: Product Interaction
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Facebook Messenger
'Data Linked To You'

Third-Party Advertising

- Purchases: Purchase History
- Financial Info: Other Financial Info
- Location: Precise Location, Coarse Location
- Contact Info: Physical Address, Email Address, Name, Phone Number, Other User Contact Info
- Contacts: Contacts
- User Content: Photos or Videos, Gameplay Content, Other User Content
- Search History: Search History
- Browsing History: Browsing History
- Identifiers: User ID, Device ID
- Usage Data: Product Interaction, Advertising Data, Other Usage Data
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- Other Data: Other Data Types

Analytics

- Health & Fitness: Health, Fitness
- Purchases: Purchase History
- Financial Info: Payment Info, Other Financial Info
- Location: Precise Location, Coarse Location
- Contact Info: Physical Address, Email Address, Name, Phone Number, Other User Contact Info
- Contacts: Contacts
- User Content: Photos or Videos, Audio Data, Gameplay Content, Customer Support, Other User Content
- Search History: Search History
- Browsing History: Browsing History
- Identifiers: User ID, Device ID
- Usage Data: Product Interaction, Advertising Data, Other Usage Data
- Sensitive Info: Sensitive Info
- Diagnostics: Crash Data, Performance Data, Other Diagnostic Data
- Other Data: Other Data Types

Product Personalisation

- Purchases: Purchase History
- Financial Info: Other Financial Info
- Location: Precise Location, Coarse Location
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App Functionality

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Other Purposes

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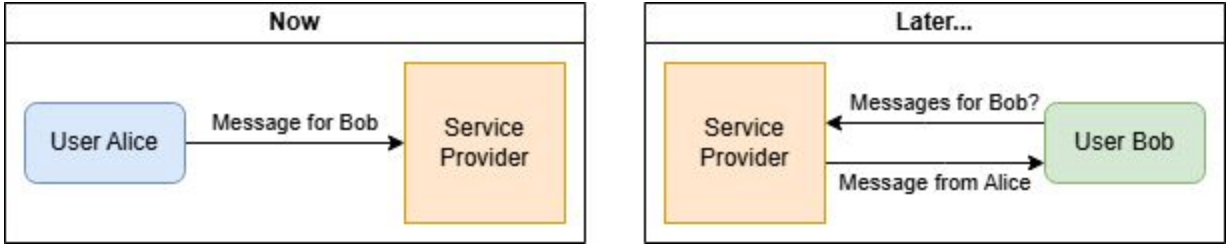
Technical definition: Asynchronous messaging

- Asynchronous?
  - Service provider keeps messages stored
  - Messages can be sent or retrieved when the user wants
- Pro: Users don’t have to coordinate communication
- Cons:
  - Servers need to operate continuously
  - Traditional asynchronous messaging systems ‘require’ metadata
- True asynchronous messaging systems do not use synchronized rounds!



Technical definition: Trust models

No-trust
(Hard PET)

Anytrust
(Soft PET)

Threshold trust
(Soft PET)

General concept: The definition of privacy

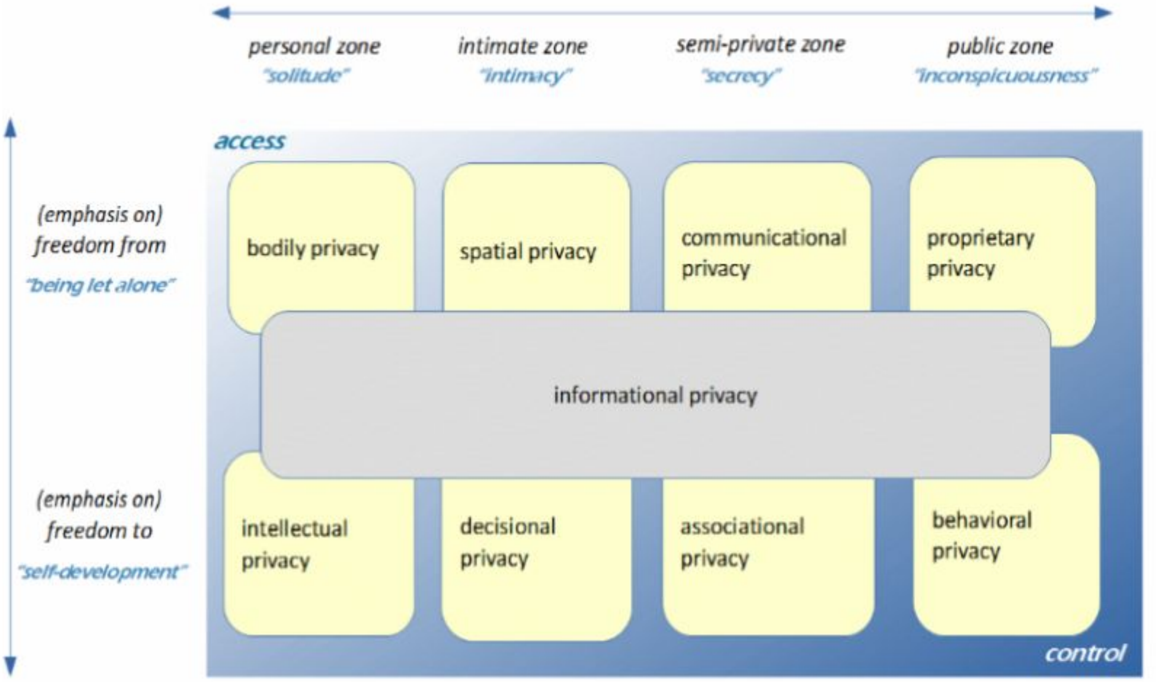
No clear/unanimous definition - we adopt the *Privacy Topology*

Our interest:

- *Communicational* privacy
- *Informational* privacy
- Freedom from “being let alone”

Concretely:
Hide messages from those considered unauthorized to read them

- Is this enough?



Privacy typology by Koops et al. [23]

Technical definition: Anonymity

The anonymity of a subject can be defined[1] as:

‘*A subject is not identifiable* - not uniquely characterized - *within a set of subjects (anonymity set)*’

- **Sender anonymity:** identity of sender is hidden
- **Receiver anonymity:** identity of receiver is hidden
- **Unlinkability of sender/receiver:** sender & receiver communication cannot be identified
- **Sender unobservability:** adversary cannot learn which sender sent a message

1: Pfitzmann et al., 2010

Technical definition: Threat models

Global Passive Adversary (GPA)

- Monitor all incoming/outgoing traffic
- Perform traffic analysis (correlation etc.)
- Does not control nodes

Global Active Adversary (GAA)

- Can monitor and manipulate traffic
- May control/compromise network
- Control traffic

Local Passive Adversary (LPA)

- Monitor incoming/outgoing traffic of a single node
- Does not control node

Local Active Adversary (LAA)

- Can monitor and manipulate traffic of a single node
- May control/compromise node

Approaches

- What we are not talking about
- Tor & Mix-nets
- Private information retrieval (PIR)

What we are not talking about

- Dialing protocols
- DC-Nets
- Multi party computation
- Distributed point functions
- Identity based encryption

How could you hide the receiver of a message?

Broadcast!

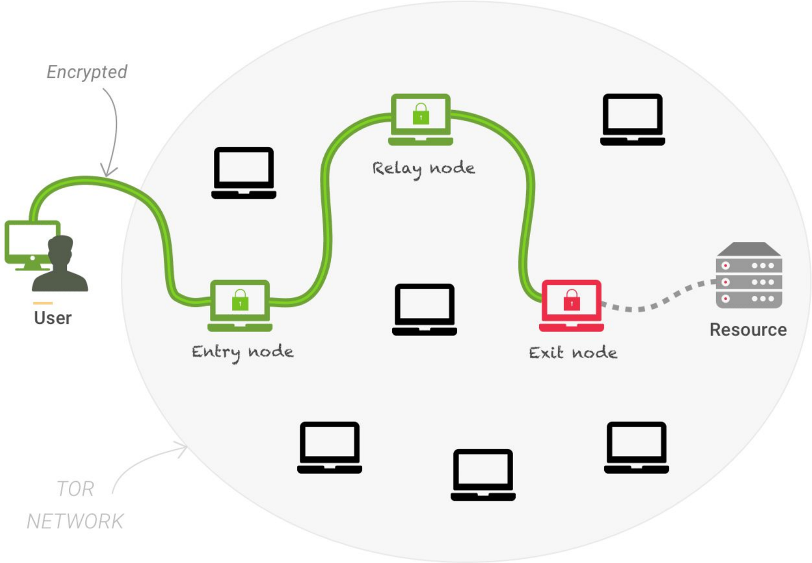
enc(m):

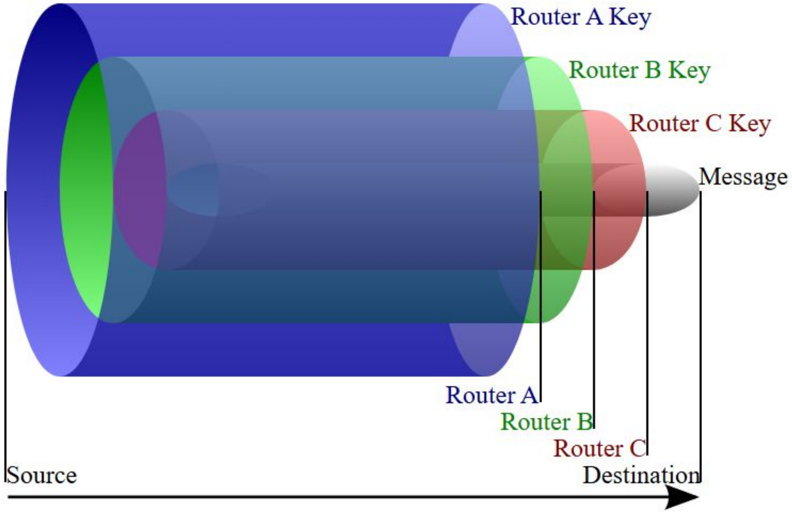
b753b8cc3059717c50288ff822514f8598fc3c606d3b0f02cdb7f778b5a0bbc14908
df2a640f02a8b674640c5b0b57eba0396fcd1642e6744eaf597adee18a447a8fa45e

Inefficient!

Different systems are built on that idea, like P5

Tor

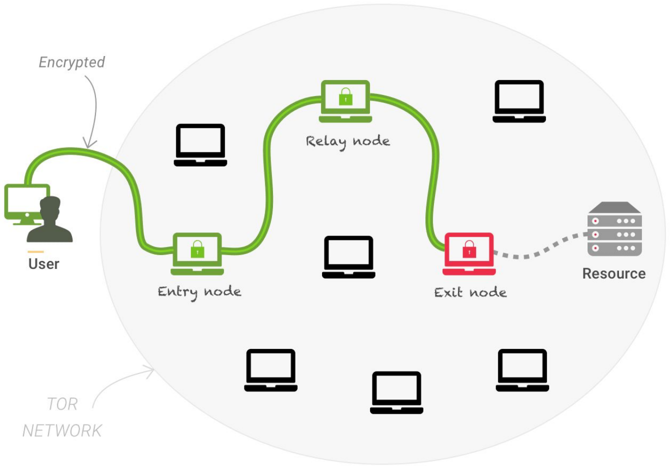




From: https://kinsta.com/wp-content/uploads/2022/06/tor-network.png

From: https://commons.wikimedia.org/wiki/File:Onion_diagram.svg

Pros and cons- Tor



Pros:

- Provides privacy and anonymity by preventing linkability for a single-node observer
- Scalable (horizontally → adding more nodes)
- Low latency
- Congestion control

Cons:

- No protection to traffic tampering (e.g. delay traffic)
- Tradeoff for low latency implies choosing best circuit → increases probability of linkability
- Not resilient against GPA & GAA
    - Recall our assumption; mainstream service provider could acts as GAA

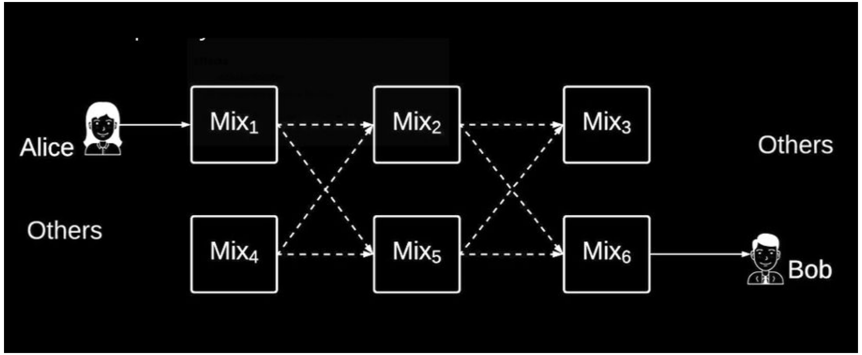
From: https://kinsta.com/wp-content/uploads/2022/06/tor-network.png

Mixnets

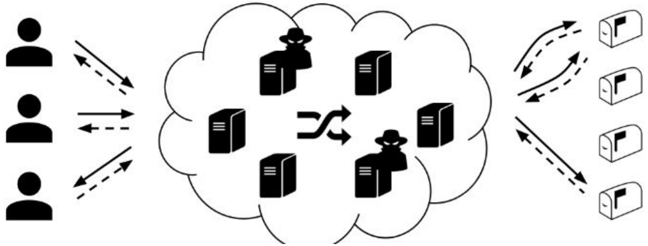
Mixnets

Mixnet characteristics:

- Use *relay* servers for anonymous communication
  - Layered/Onion (TOR-like) encrypted
- Batching & shuffling
  - Break incoming-outgoing traffic link
  - Sending with random delays
  - Shuffle to randomize message order
- Add noise/cover traffic



From: https://constructiveproof.com/posts/2020-02-17-a-simple-introduction-to-mixnets/

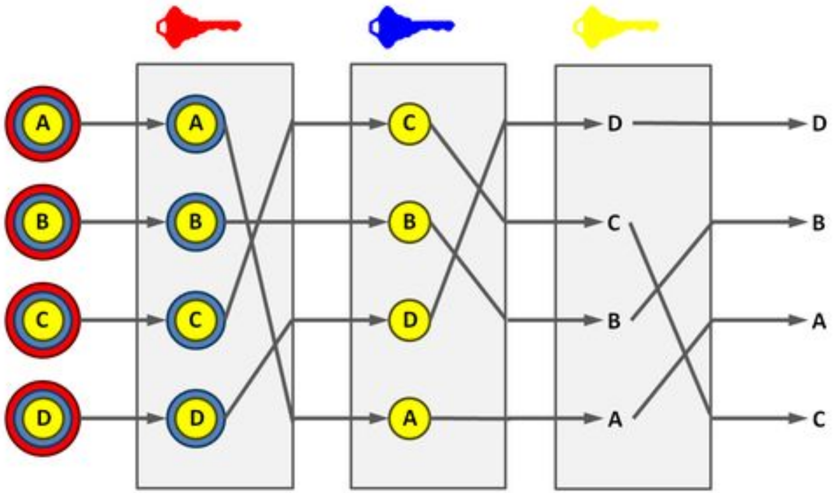


From: Stadium

Layered/Onion encryption

- Recall Tor intuition
- Resist against LPA analysis

Issue?



From: https://en.wikipedia.org/wiki/File:Red_de_mezcla.png

Layered/Onion encryption

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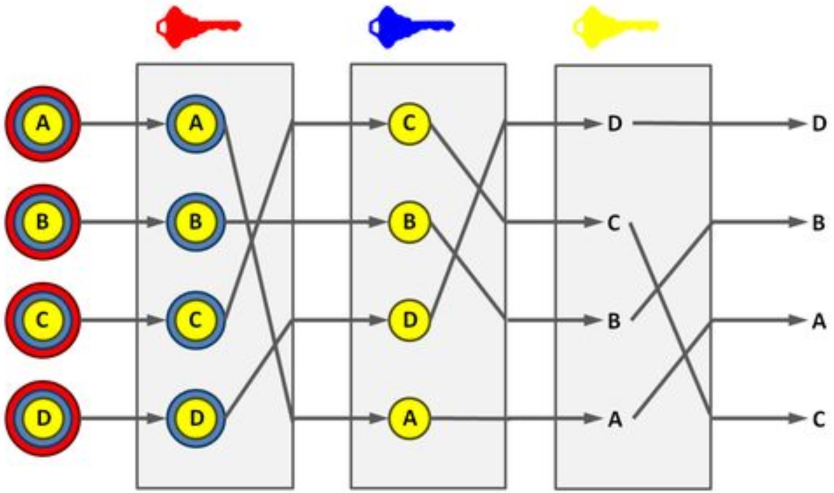
- Latency



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Batching and shuffling

Batching

- Send messages at the same time → resist timing incoming/outgoing traffic
  - Create a larger anonymity set
- Send message batches in rounds

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Shuffling

- Change order of queued/batched messages → mitigate analysis

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Shuffling

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Is this asynchronous? Recall our definition

- Users don’t have to coordinate communication (can be offline)
- System operates continuously
- System does not depend on synchronized rounds for security*

Batching and shuffling

Batching

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Shuffling

- Change order of queued/batched messages → mitigate analysis

Is this asynchronous? Recall our definition

- Users don’t have to coordinate communication (can be offline)
- System operates continuously
- System does not depend on synchronized rounds for security*

- Prior work often operates in synchronized rounds (e.g. Vuvuzela) → offline users cannot receive messages

Solution?

- Have a service provider (SP) take care of clients accessing the network (e.g. Loopix, Groove)

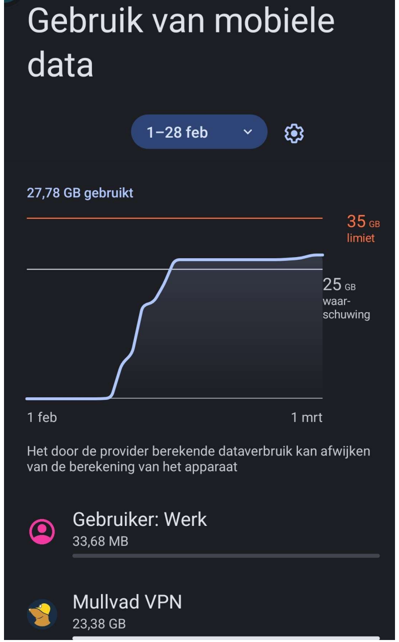
Adding noise/cover traffic

Noise/cover traffic…

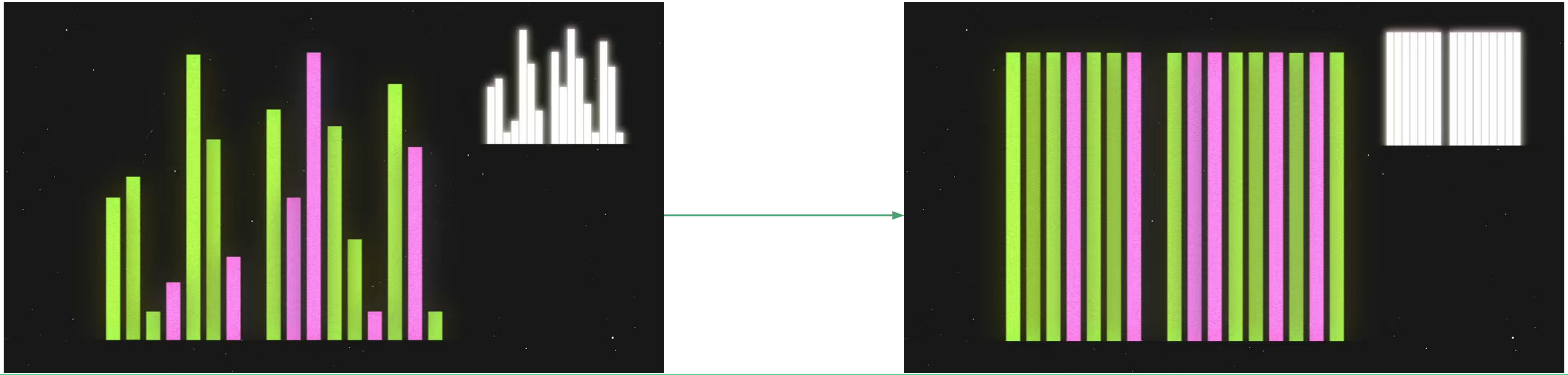
- May improve sender/receiver unlinkability

But also…

- Provides limited protection against GPA over time
- Costs a lot of bandwidth



From: https://mullvad.net/en/vpn/daita



Proposal highlight:

usenix

THE ADVANCED COMPUTING SYSTEMS ASSOCIATION

Groove: Flexible Metadata-Private Messaging

Ludovic Barman, *EPFL;* Moshe Kol, *Hebrew University of Jerusalem;*
David Lazar, *EPFL;* Yossi Gilad, *Hebrew University of Jerusalem;*
Nickolai Zeldovich, *MIT CSAIL*

https://www.usenix.org/conference/osdi22/presentation/barman

Groove characteristics

- Strong threat model - GAA
- Flexible; support multiple devices
    - Portable devices (mobile phones)
- *Oblivious delegation*
- Forward secrecy
    - GAA can’t learn from past communications

Goals:

- Achieve *differential privacy*
- Support millions of users with each, many contacts
- Availability of other service providers remain, if one fails

Groove characteristics

Strong threat model

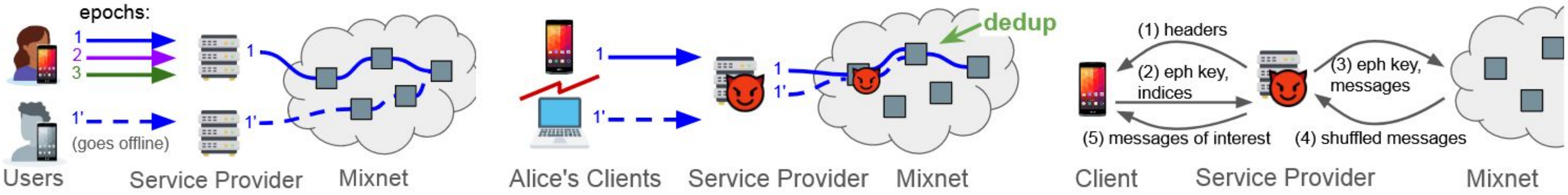
- Global Active Adversary (GAA)
    - Controls all network links
    - Observes when client (dis)connects
    - Can run arbitrary many clients
    - Can observe IP & geographic locations

Groove - design

- Send/receive messages over a *circuit*
  - Fixed route in the mixnet
  - Persists for an epoch
  - In rounds (30s-60s)
- Users exchange messages at *dead drop*
  - “Meeting point” - ephemeral address to deposit messages
- Add 2 types of noise
  - *Doubles*: “simulate” dead drop → mask number of relationships
  - *Singles*: mask when a client does not create a circuit (e.g. being offline)

Groove - basic communication flow

1. Alice and Bob add each other to address book
2. Establish fresh shared secret
   a. Authenticate user, E2EE, agree on dead drop
   b. Sharing this secret is out of scope (see dialing protocol)
3. *Oblivious delegation* to SP
   a. Choose an SP to store messages
   b. Participate on behalf of client
4. SP send message to mixnet periodically
5. Mixnet shuffles and exchanges message at dead drop
6. Mixnet forwards message back to SP
7. User retrieves message from SP (from 1 device)



Groove - highlights

- Trust models:
  - *No trust* for SP
    - Send loopback message to check for malfunctioning (based on Loopix)
  - *Threshold trust* for mixnet
    - Resist f = 20% malicious servers (by default)

- Client may choose schedule interval; good for low power-devices (vs Vuzela recommending being always online)
- Multi device support by: synch user's contact through SP on start
  - Mixnet server removes duplicate messages
- Groove protects against rogue SP
  - Address book is padded to fixed length
  - Onion encrypted messages contain epoch number; honest server drops wrong number
  - Tagging messages in circuits → honest server drops duplicates → no unusual amount of accessing dead drop

Groove - performance comparison

Vuvuzela
- 1 million users, 1 contact, 37s latency

Stadium
- Latency in order of minutes (Zero-knowledge proofs)

Karaoke
- 1 million users, 1 contact, 7s of latency

Yodel*
- 1 million users, 750 ms
    - But connects contacts to dead drop without mixnet

Groove
- 1 million users, 50 contacts, 32s latency

*Yodel focusses on voice calls

Private information retrieval (PIR)

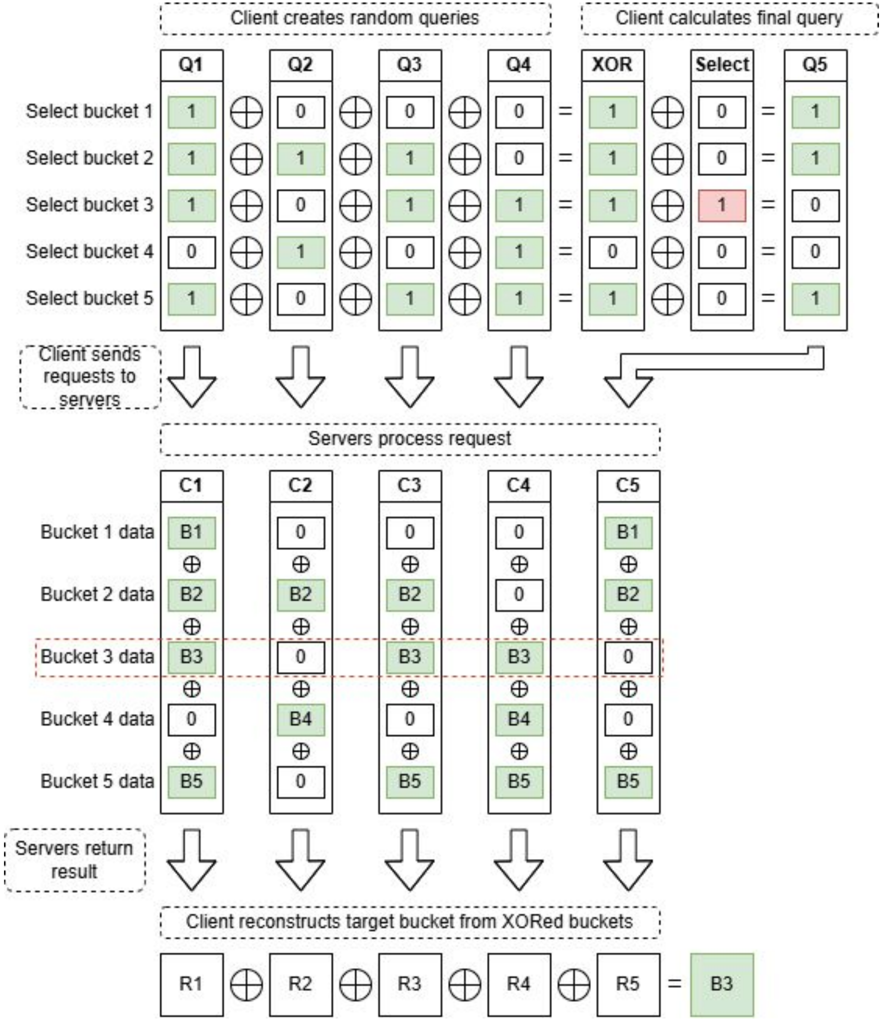
Privacy is expensive

Private information retrieval (PIR)

- Fetching data from a server
- Information theoretic PIR (IT-PIR)
- Computational PIR (C-PIR)
- Receiver anonymity
  - Cannot link data to user
- Generally expensive
- Pseudonymous mailbox architecture

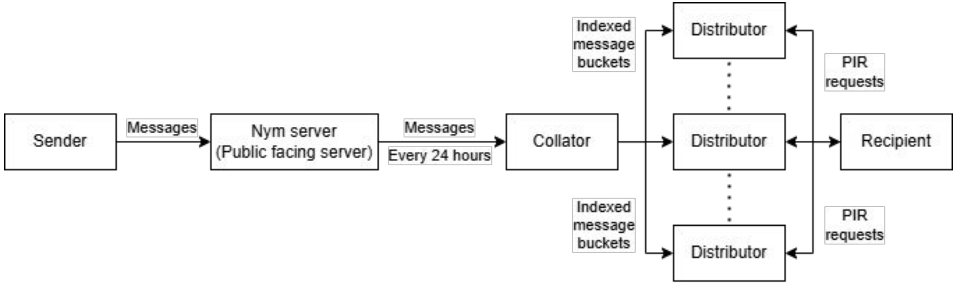
Information Theoretic PIR (IT-PIR)

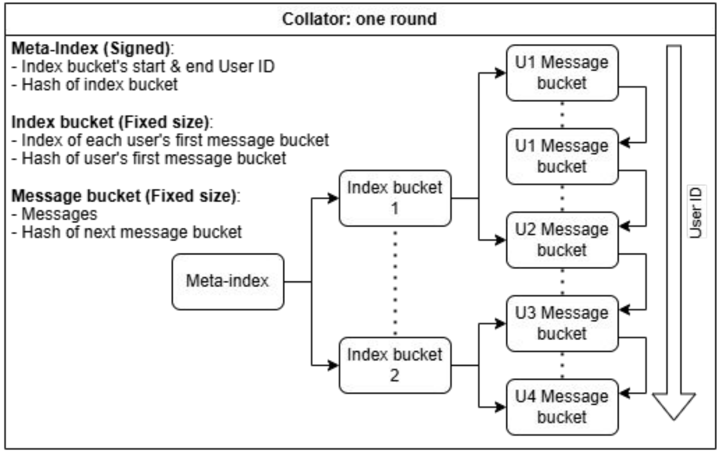
- Anytrust model
- Resists computationally unbounded adversary
- Cheap XOR operations
- Requires multiple servers
- Redundancy weakens trust model


Client creates random queries
Client calculates final query
Q1
Q2
Q3
Q4
XOR
Select
Q5
Select bucket 1
Select bucket 2
Select bucket 3
Select bucket 4
Select bucket 5
Client sends requests to servers
Servers process request
C1
C2
C3
C4
C5
Bucket 1 data
Bucket 2 data
Bucket 3 data
Bucket 4 data
Bucket 5 data
Servers return result
Client reconstructs target bucket from XORed buckets
R1 ⊕ R2 ⊕ R3 ⊕ R4 ⊕ R5 = B3

IT-PIR example: Pynchon gate

- Sender anonymity: Mix net
- Receiver anonymity: IT-PIR
- Mailbox architecture
- Round based
- Not perfectly asynchronous





Computational PIR (C-PIR)

- No-trust model
- Homomorphic encryption
- Only one server needed
- Very expensive

C-PIR example: Pung

- No sender anonymity
- Receiver anonymity: C-PIR
- 1 send & receive request per round
- Optimizations: BST and batch-codes

Actual usage of these technologies

No actual messaging app uses PIR or mix-nets

Biar: Tor

Session: custom onion-network

SimpleX Chat: optional Tor
(using Signal protocol: PFS, post-quantum encryption)

Conclusion

Costs of protecting metadata is quite high - tradeoffs

- Latency
- Potentially no multi-device support

Transport encryption only really took off after people felt the disadvantages

Maybe it will become more relevant in the future

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