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Safely Measuring Tor

"Safely Measuring Tor", Rob Jansen and Aaron Johnson,
In the *Proceedings of the 23rd ACM Conference on Computer and Communication Security* (CCS 2016).

Rob Jansen
U.S. Naval Research Laboratory
Center for High Assurance Computer Systems

Seminar Talk, October 21st, 2016
DC-Area Anonymity, Privacy, and Security Seminar
The George Washington University

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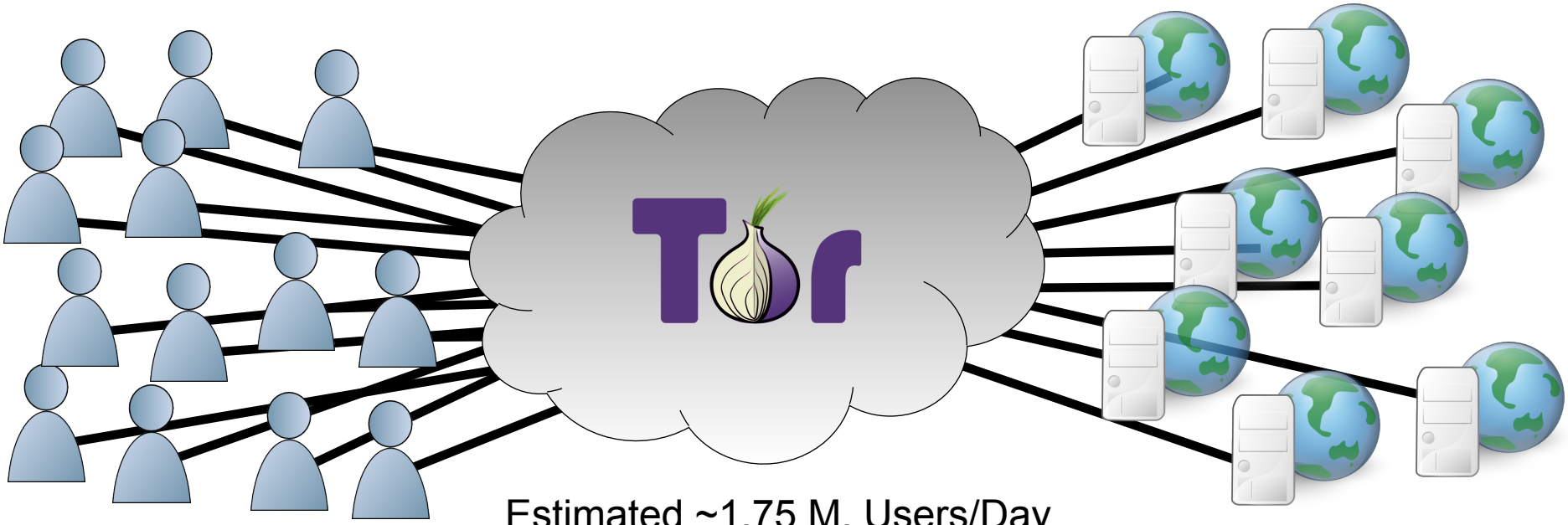
Talk Overview



Estimated ~1.75 M. Users/Day
(metrics.torproject.org)

Tor: an anonymous communication, censorship resistant, privacy-enhancing communication system

- How is Tor being used? being misused? performing?

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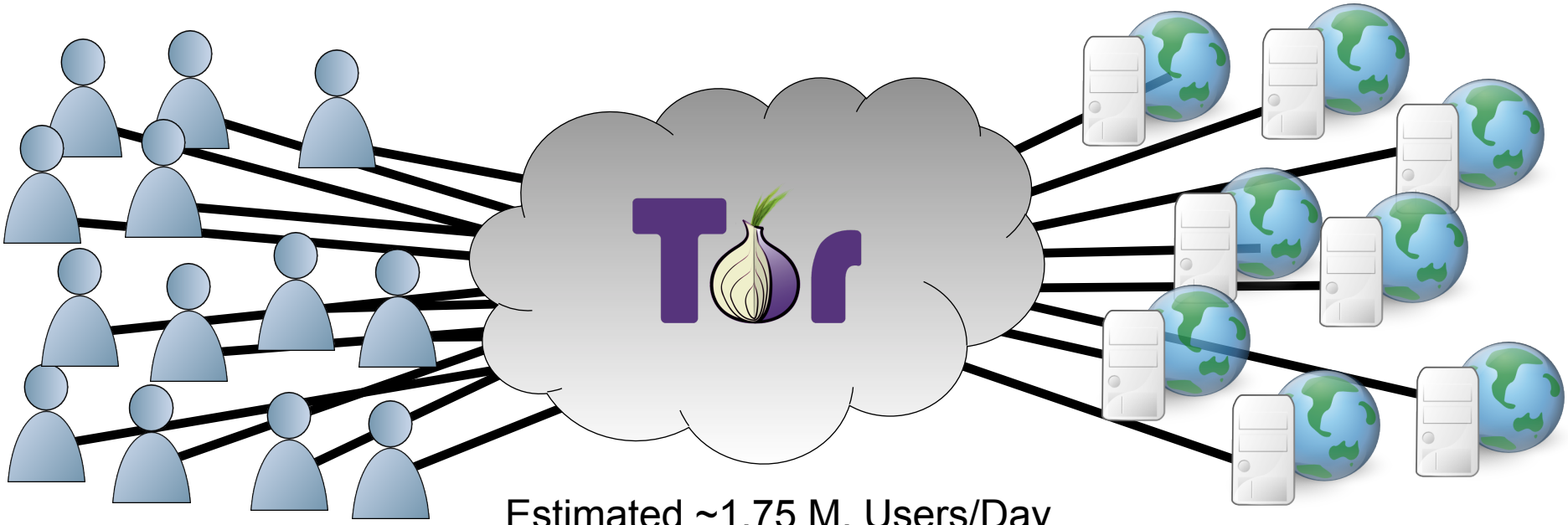

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Tor: an anonymous communication, censorship resistant, privacy-enhancing communication system

- How is Tor being used? being misused? performing?
- Objective: To safely gather Tor network usage statistics
- Approach: Use distributed measurement, secure multiparty computation, and differential privacy

Background and Motivation

- How Tor works
- Why measurements are needed and what to measure
- Measurement challenges

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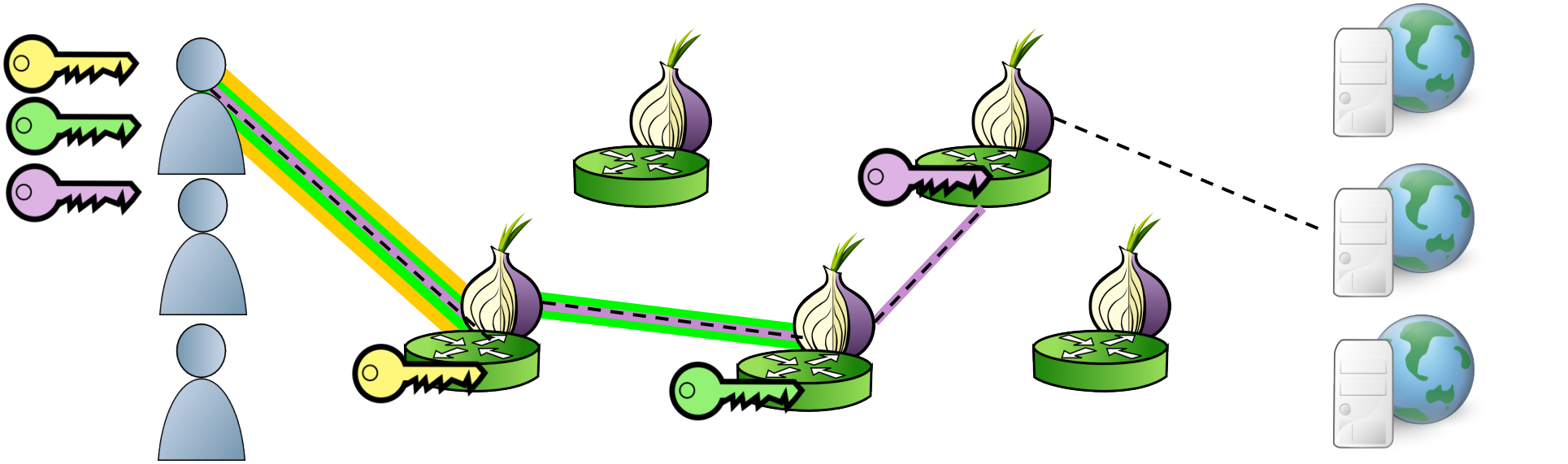
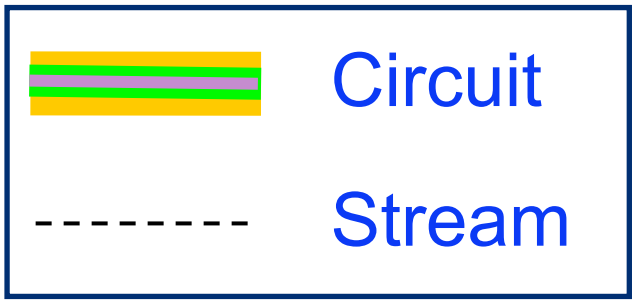
Background: Onion Routing





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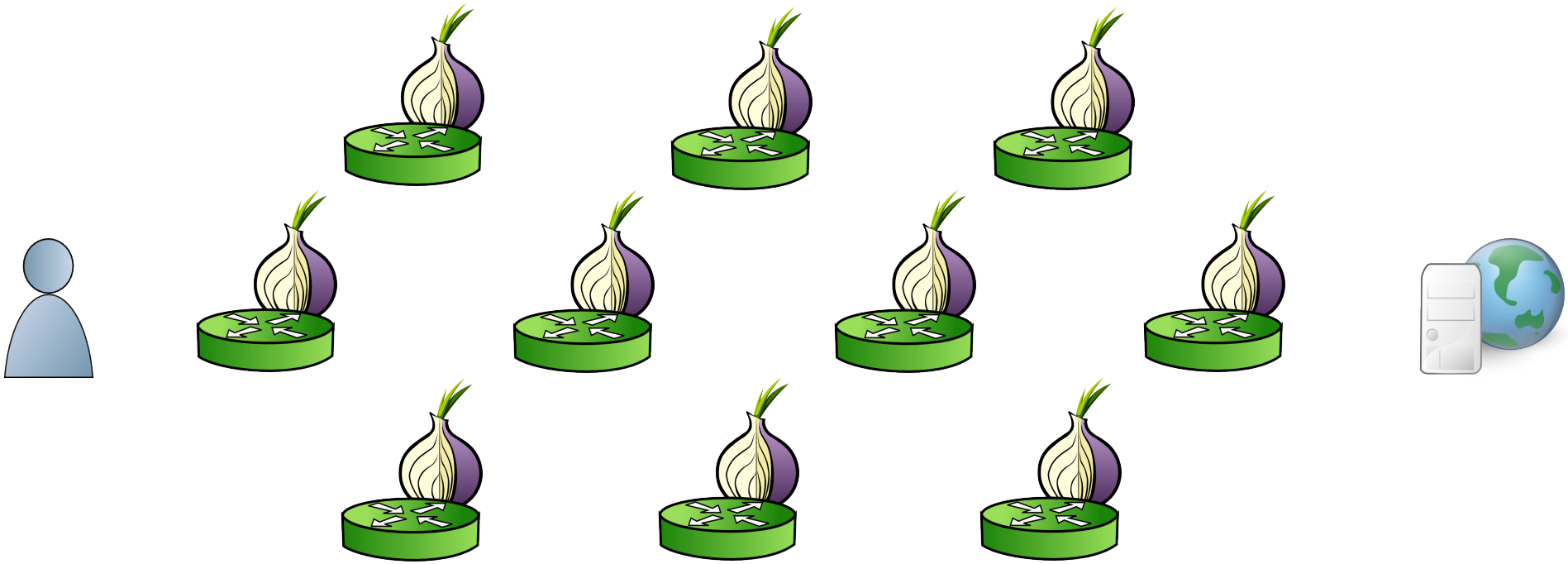
Background: Using Circuits



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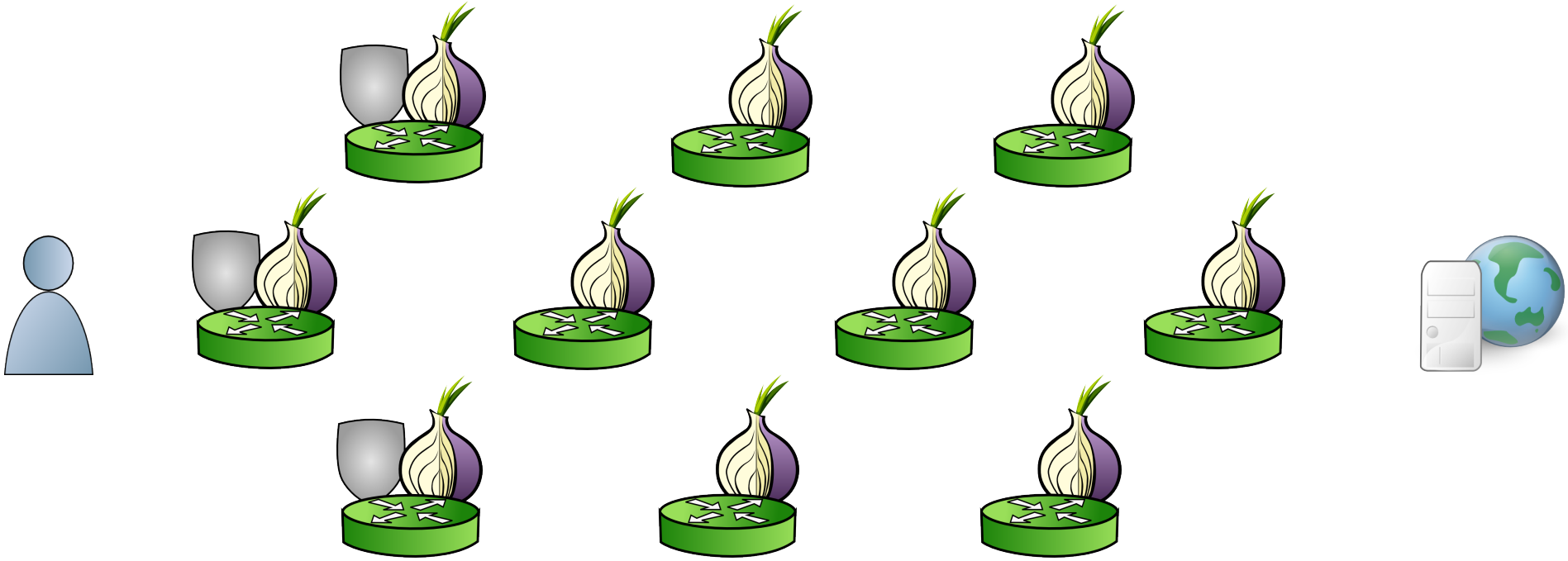

1. Clients begin all circuits with a selected guard

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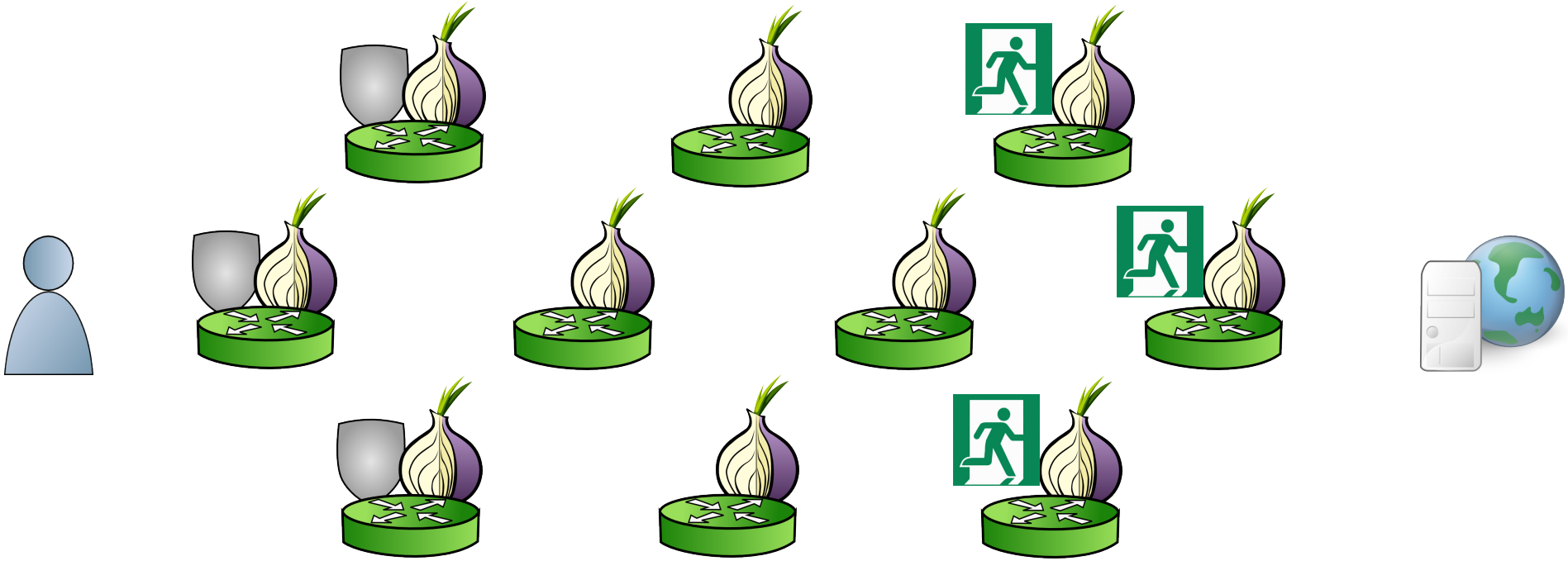

1. Clients begin all circuits with a selected guard
2. Relays define individual exit policies

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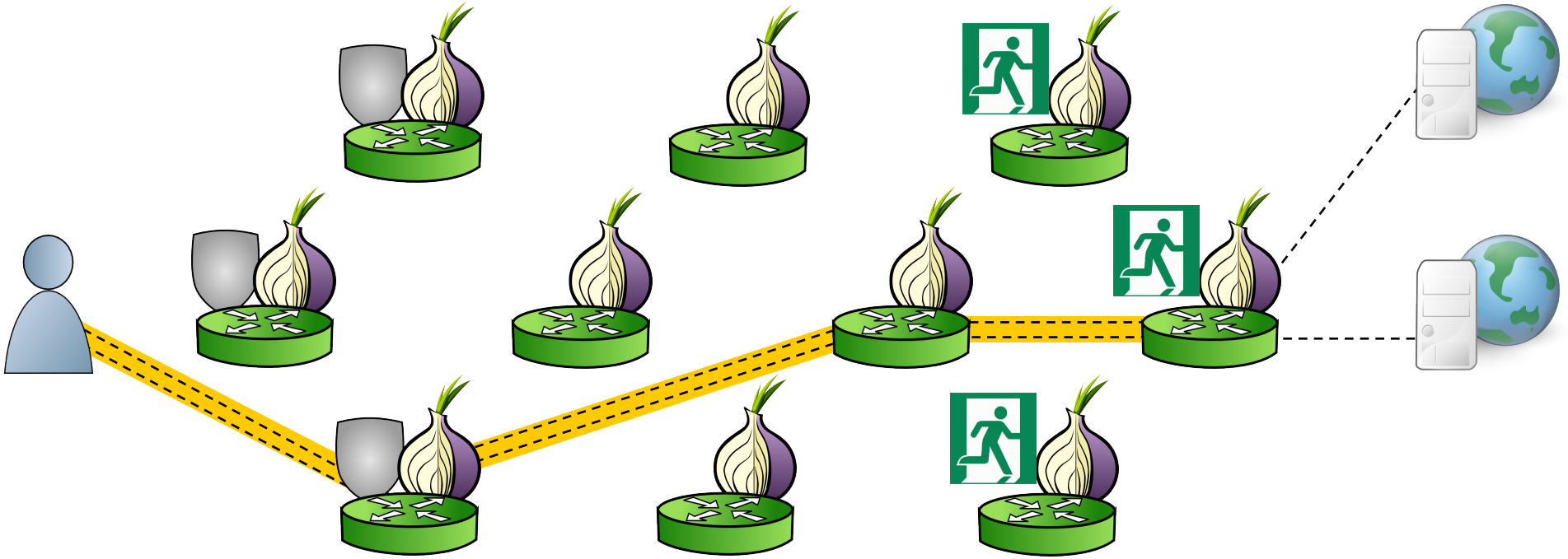
Background: Using Circuits



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3. Clients multiplex streams over a circuit

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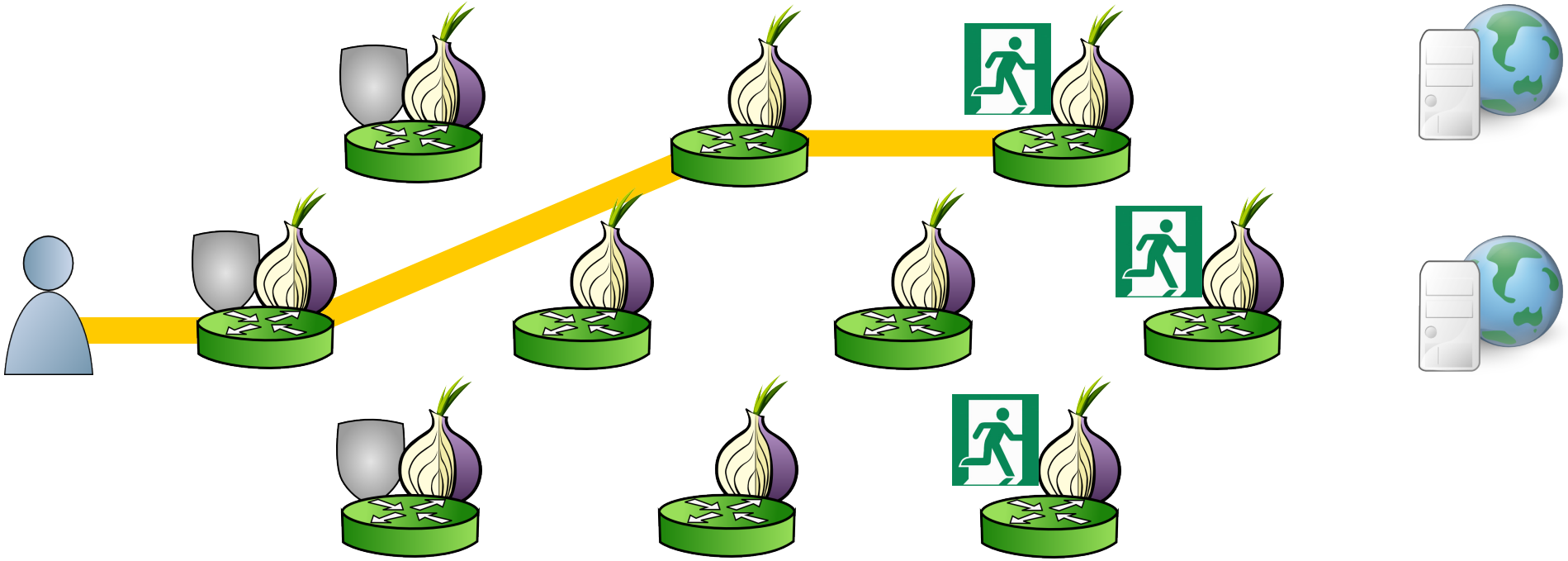

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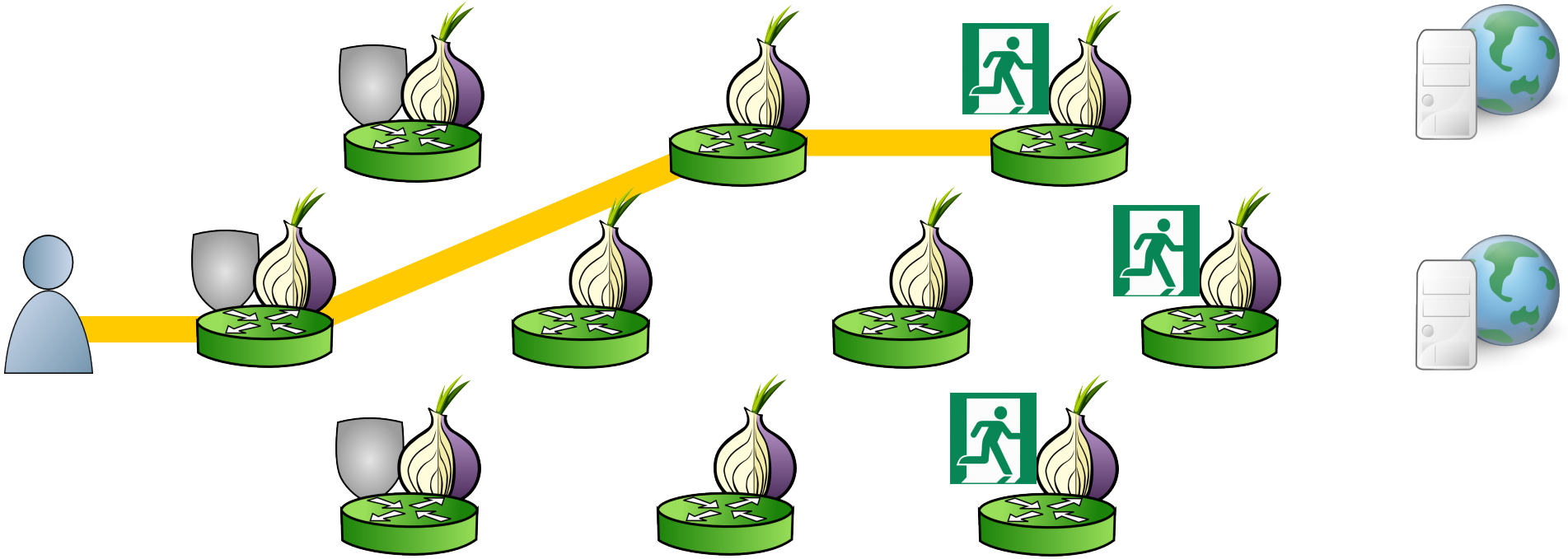

1. Clients begin all circuits with a selected guard
2. Relays define individual exit policies
3. Clients multiplex streams over a circuit
4. New circuits replace existing ones periodically
5. Clients randomly choose relays, weighted by bandwidth

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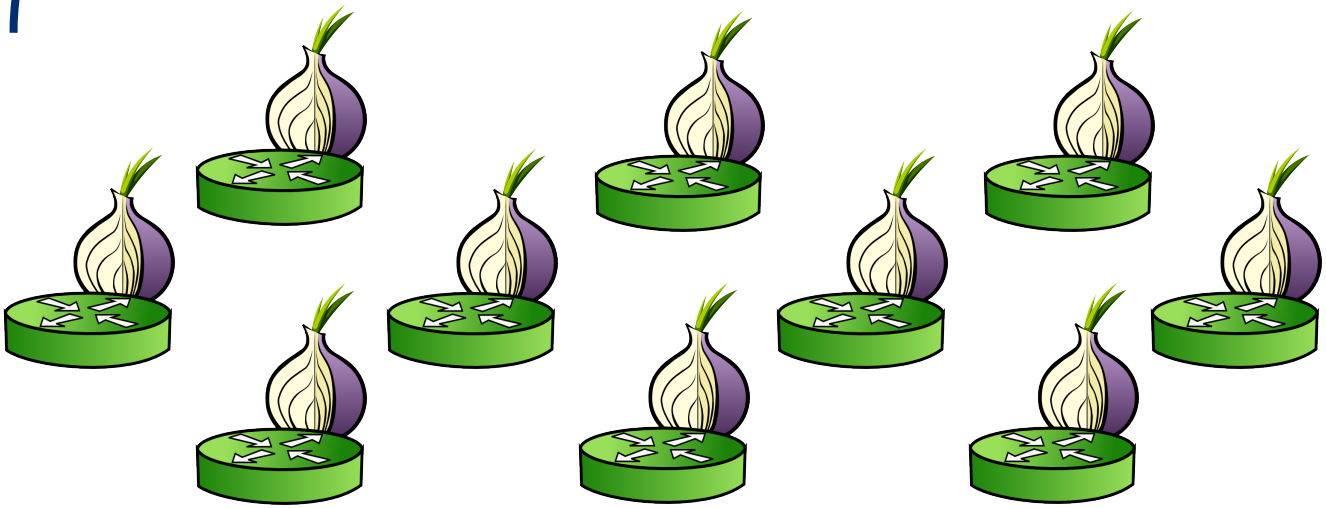
Background: Directory Authorities

Directory Authorities

Hourly network consensus by majority vote

- Relay info (IPs, pub keys, bandwidths, etc.)
- Parameters (performance thresholds, etc.)



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Motivation: Why Measure Tor?

Why are Tor network measurements needed?

- To understand usage behaviors to focus effort and resources
- To understand network protocols and calibrate parameters
- To inform policy discussion

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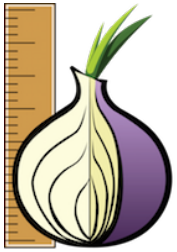
"Tor metrics are the ammunition that lets Tor and other security advocates argue for a more private and secure Internet from a position of data, rather than just dogma or perspective."

– Bruce Schneier (2016-06-01)

Motivation: Measurement Challenges



Tor METRICS

https://metrics.torproject.org

Some Existing Measurements

Data Published	Privacy Techniques	Unsafe	Inaccurate
Relay BW available	Test measurements		✖
Relay BW used	Aggregated ~ 4 hours	✖	
Total # daily users	Inferred (consensus fetches)		✖
# users per country	Aggregated ~ 24 hours, rounded, opt-in	✖	
Exit traffic per port	Aggregated ~ 24 hours, opt-in	✖	

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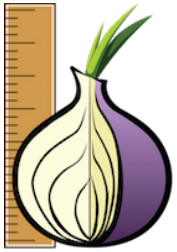
Motivation: Measurement Challenges



Tor METRICS

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Safety concerns:
- Per-relay outputs
- Data stored locally
- No privacy proofs

Some Existing Measurements

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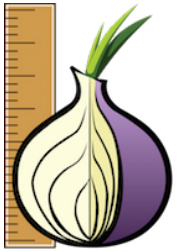

Tor METRICS

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Accuracy concerns:
- Per-relay noise
- Opt-in and inconsistent sampling

Some Existing Measurements

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Motivation: Missing Measurements

Many useful statistics are not collected for safety

Users

- Total number of unique users at any time, how long they stay online, how often they join and leave, usage behavior

Relays

- Total bandwidth capacity, congestion and queuing delays, circuit and other failures, denial of service and other attacks

Destinations

- Popular destinations, popular applications, effects of DNS, properties of traffic (bytes and connections per page, etc.)

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Previous Measurement Studies

Shining Light in Dark Places: Understanding the Tor Network

- McCoy et. al., PETS 2008
- tcpdump of first 150 packet bytes (including 96 payload)
- Collected, stored, manually analyzed sensitive data

Digging into anonymous traffic: A deep analysis of the Tor anonymizing network

- Repeated by Chaabane et. al., NSS 2010
- Also used customized DPI software (OpenDPI)
- Similar ethical issues

Previous Measurement Studies

Shining Light in Dark Places: Understanding the Tor Network

The PrivCount Measurement System

- PrivCount system architecture
- Distributed measurement and aggregation protocol
- Secure computation and private output

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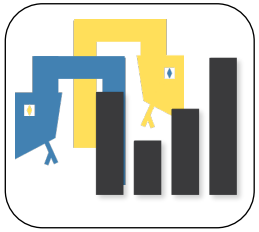
PrivCount: Overview

Distributed measurement system



- "Privacy-preserving counting" system
  - Tracks various types of Tor events, computes statistics from those events
  - Based on PrivEx-S2 by Elahi et al. (CCS 2014)
- Distributes trust using secret sharing across many operators
- Achieves forward privacy during measurement
  - the adversary cannot learn the state of the measurement before time of compromise
- Provides differential privacy of the results
  - prevents confirmation of the actions of a specific user given the output

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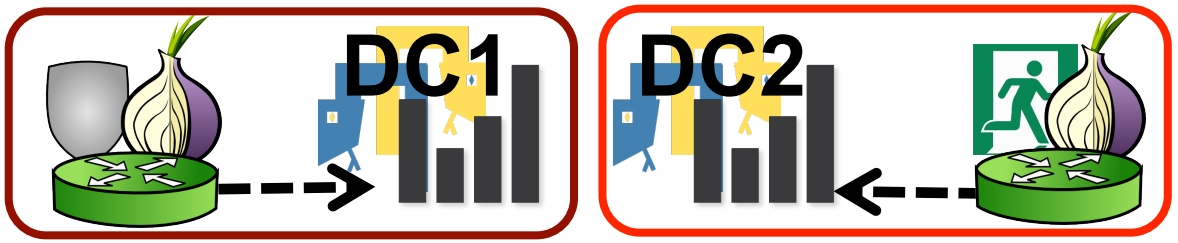
PrivCount: Architecture

Data Collectors (DCs)

- Collect events
- Increment counters



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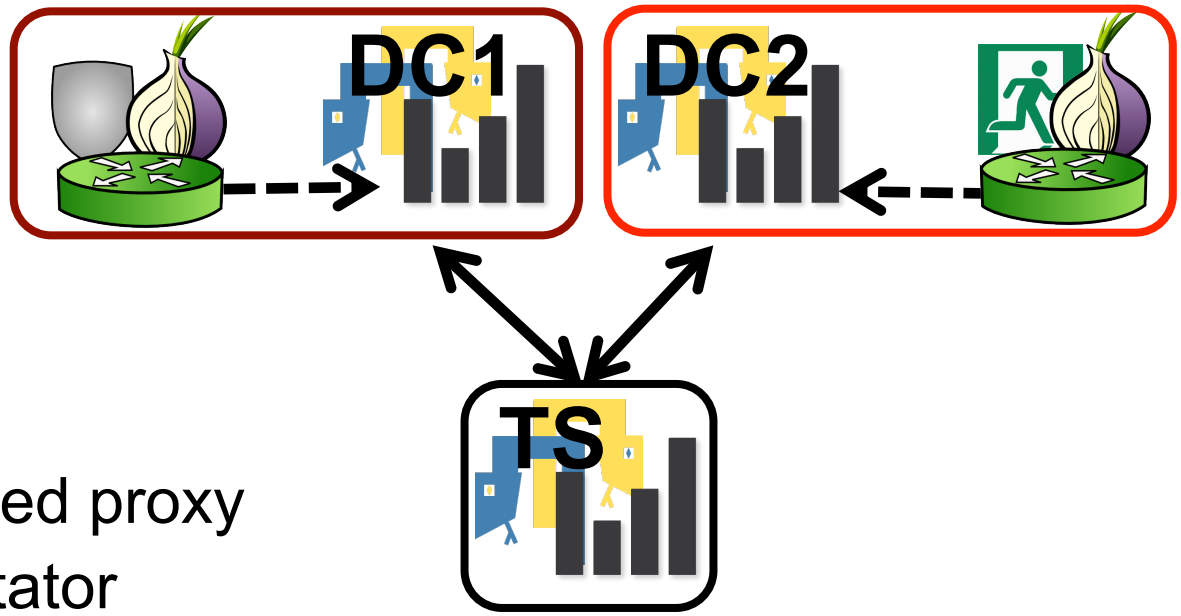

Tally Server (TS)

- Central, untrusted proxy
- Collection facilitator

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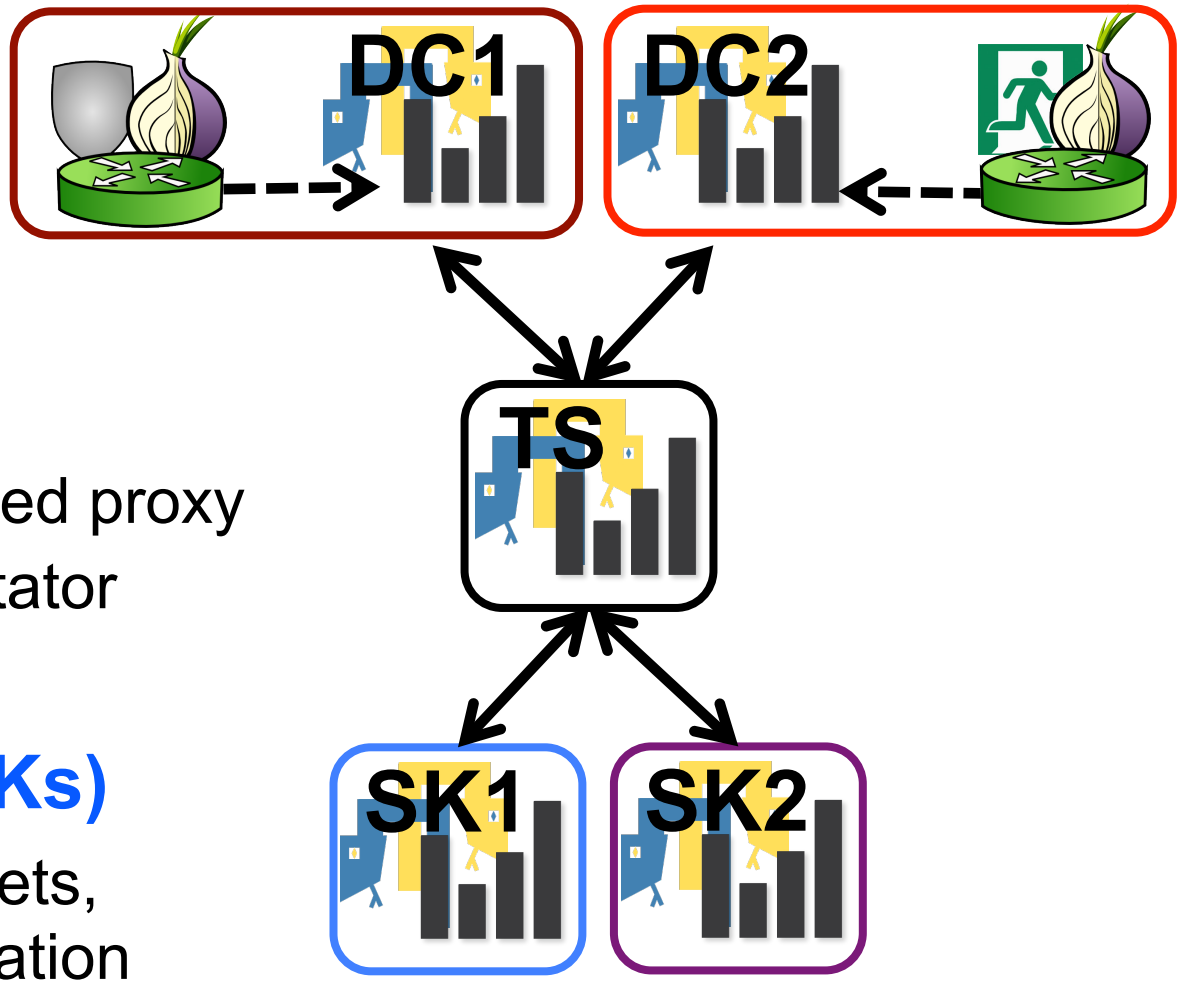

Tally Server (TS)

- Central, untrusted proxy
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Share Keepers (SKs)

- Stores DC secrets, sum for aggregation

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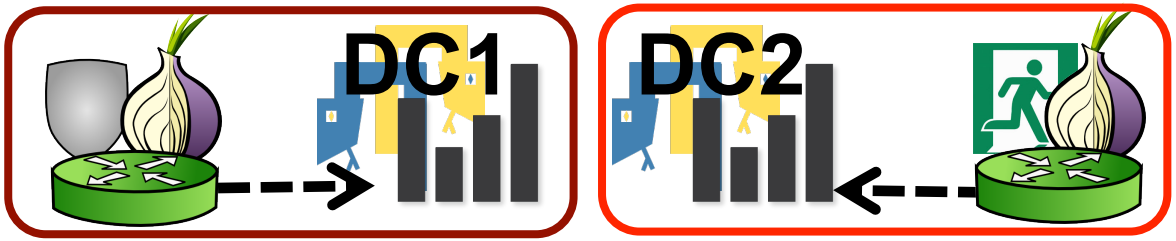
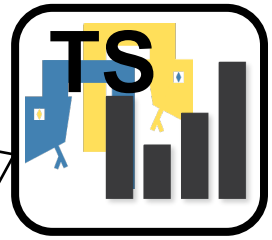
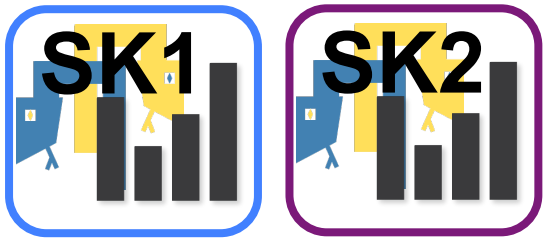
PrivCount: Initialization



Create deployment document

- Privacy parameters ε and δ
- Sensitivity for each statistic
  (max change due to single client)
- Noise weight ω
  (relative noise added by each DC)





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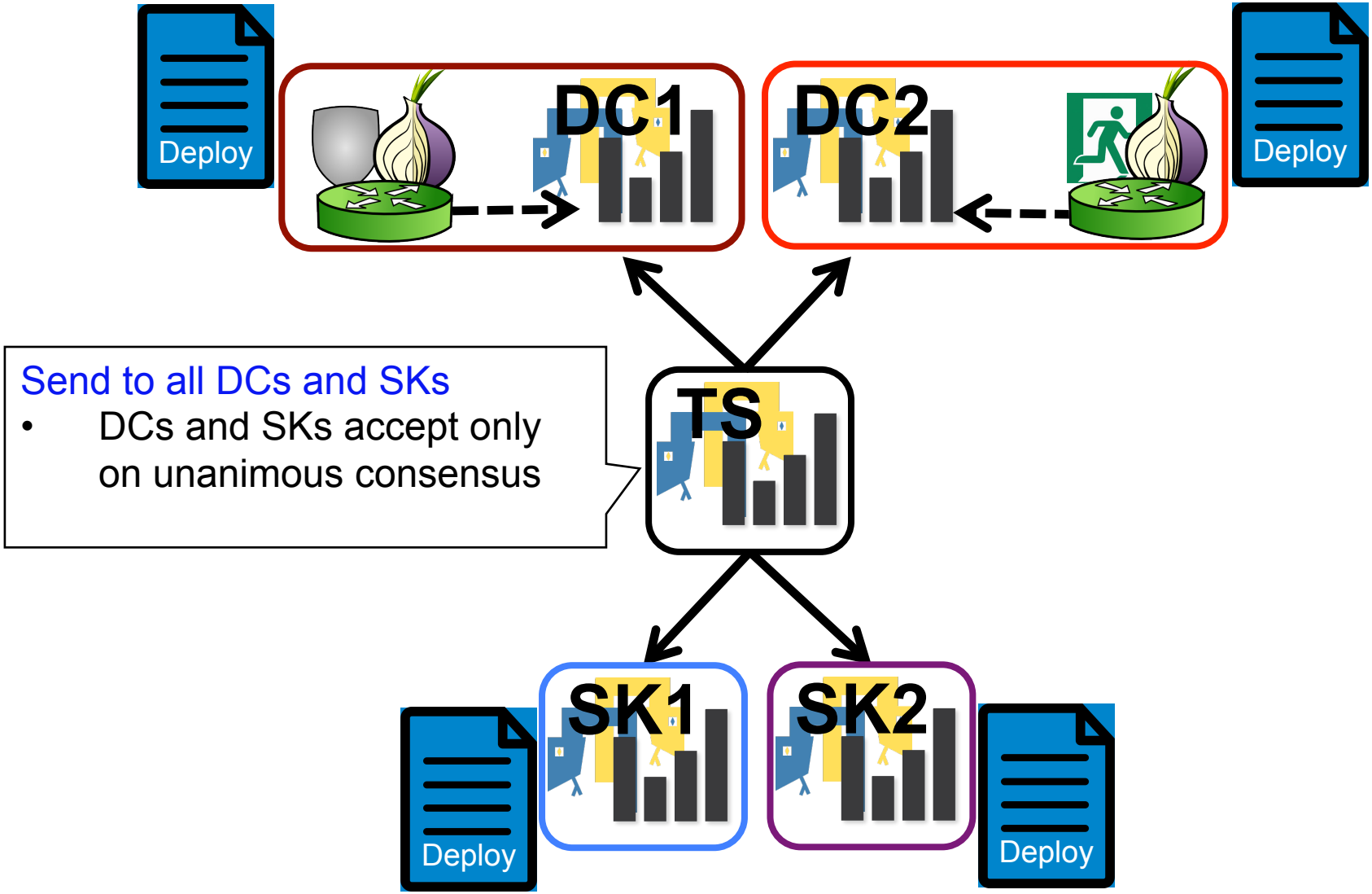

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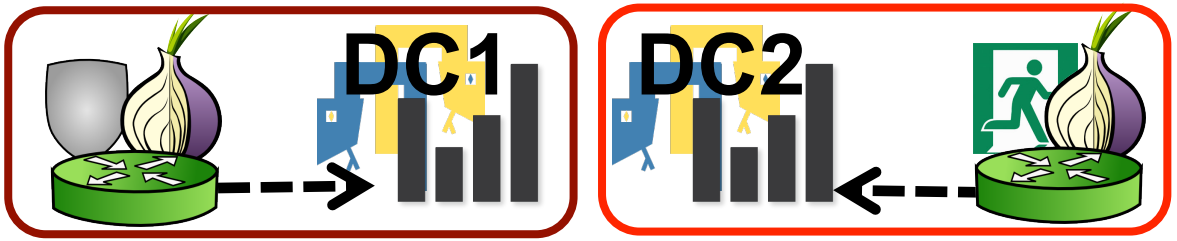
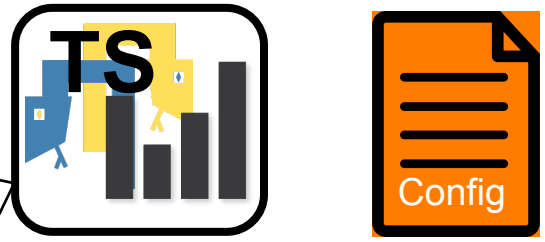
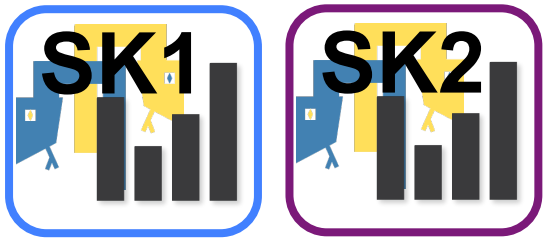
PrivCount: Configuration



Create configuration document

- Collection start and end times
- Statistics to collect
- Estimated value for each statistic (maximize relative per-statistic accuracy while providing (ε, δ)-differential privacy)





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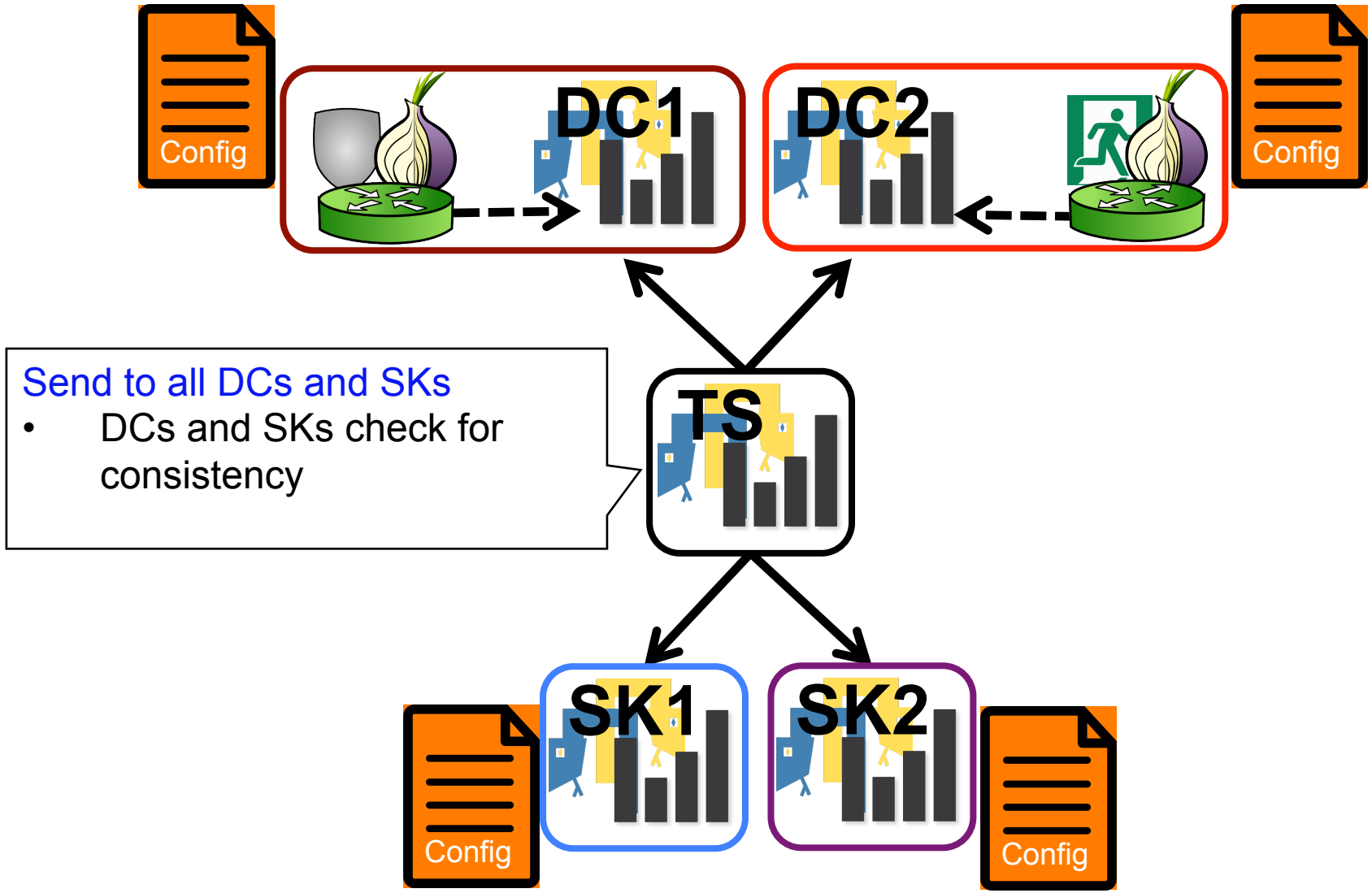

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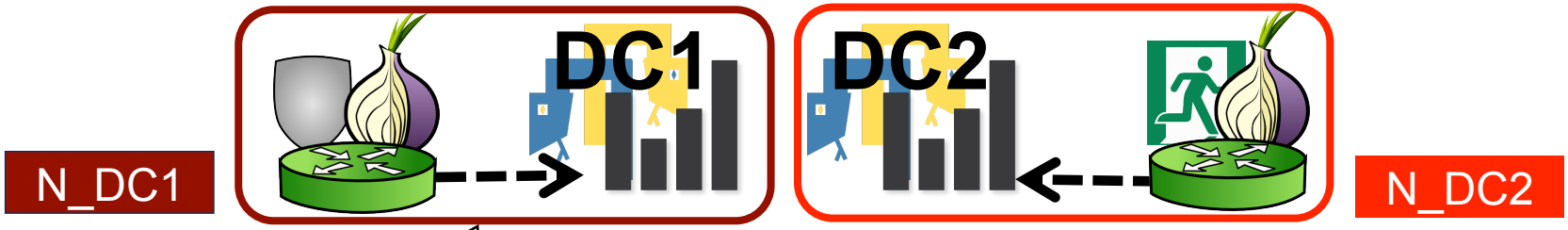
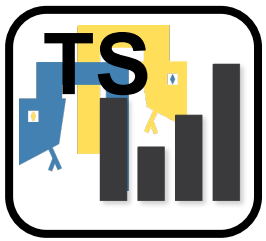
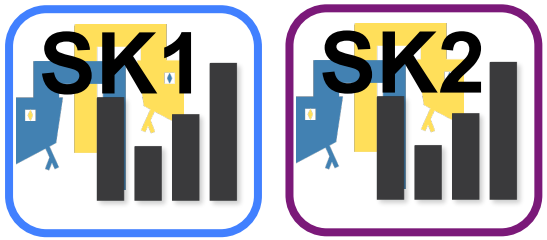
PrivCount: Execution - Setup



Generate noise for each counter

- N ~ Normal(0,ωσ) mod q
- Contributes to differential privacy of the outputs





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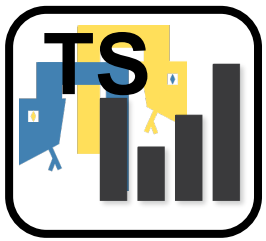
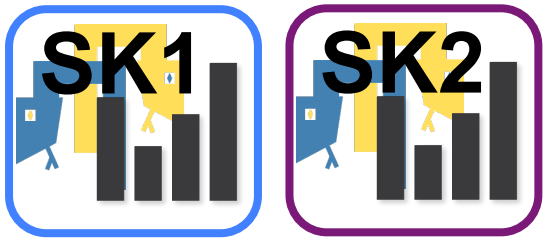
PrivCount: Execution - Setup

Generate random share for each SK

- S ~ Uniform({0, …, q-1})
- "Blinds" the actual counts for forward privacy at the DCs





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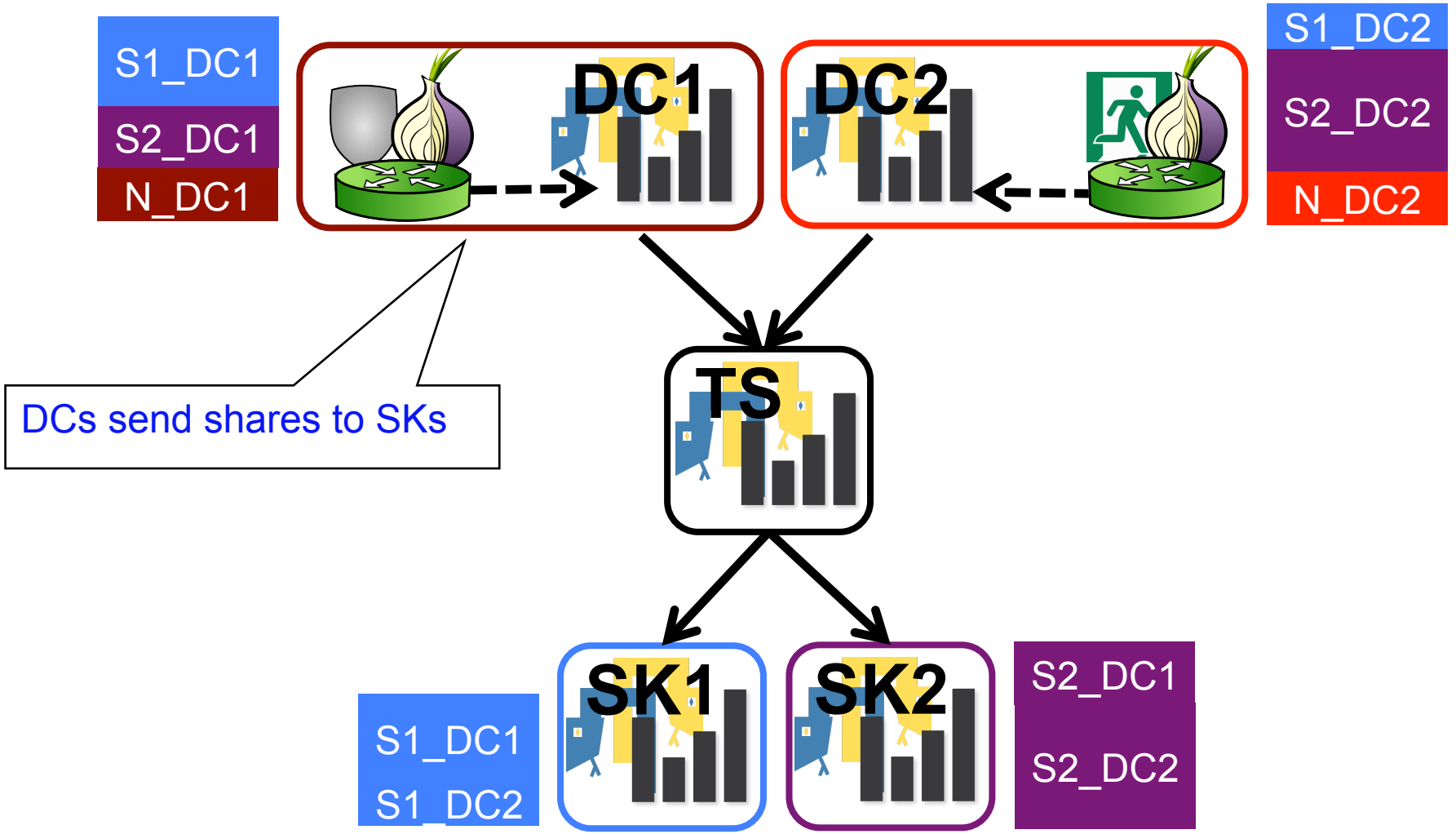

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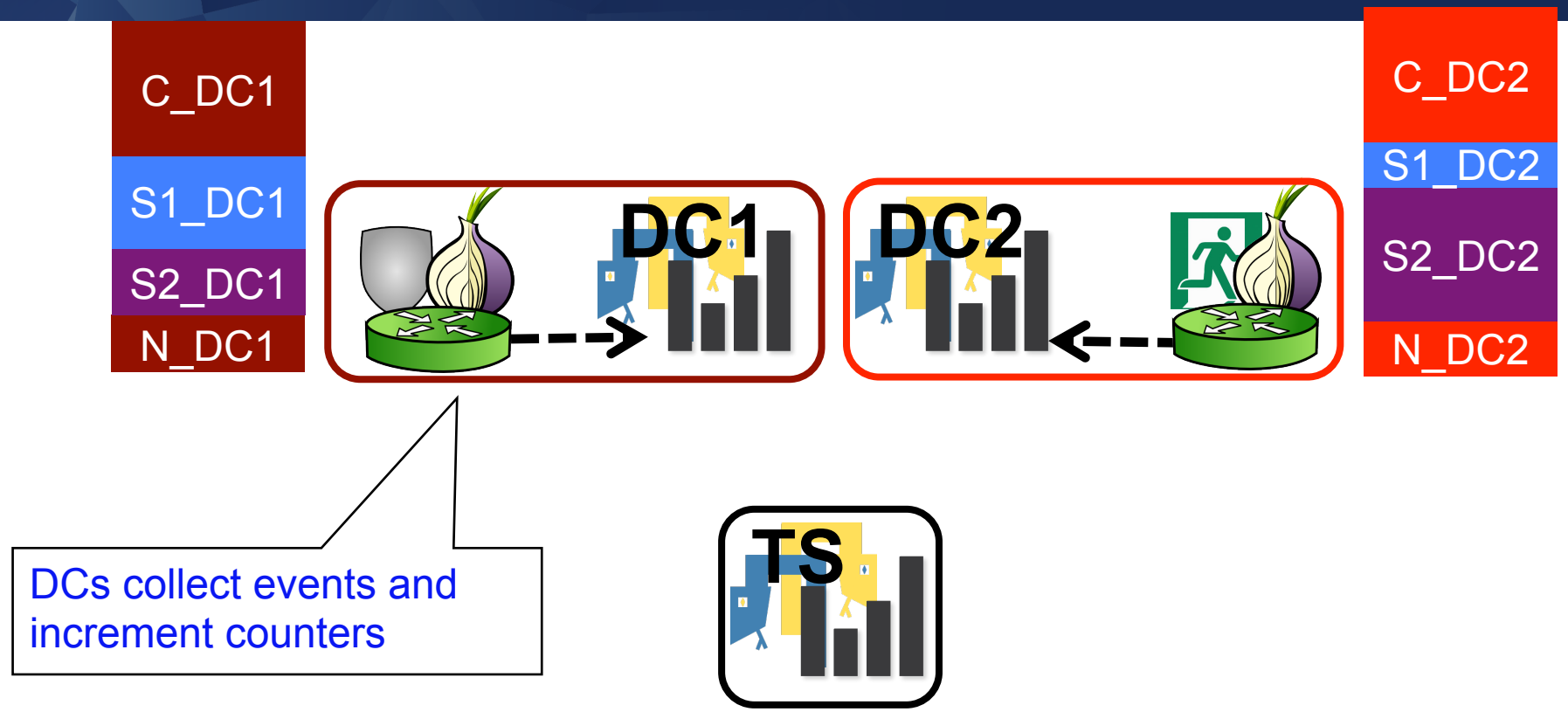
PrivCount: Collection



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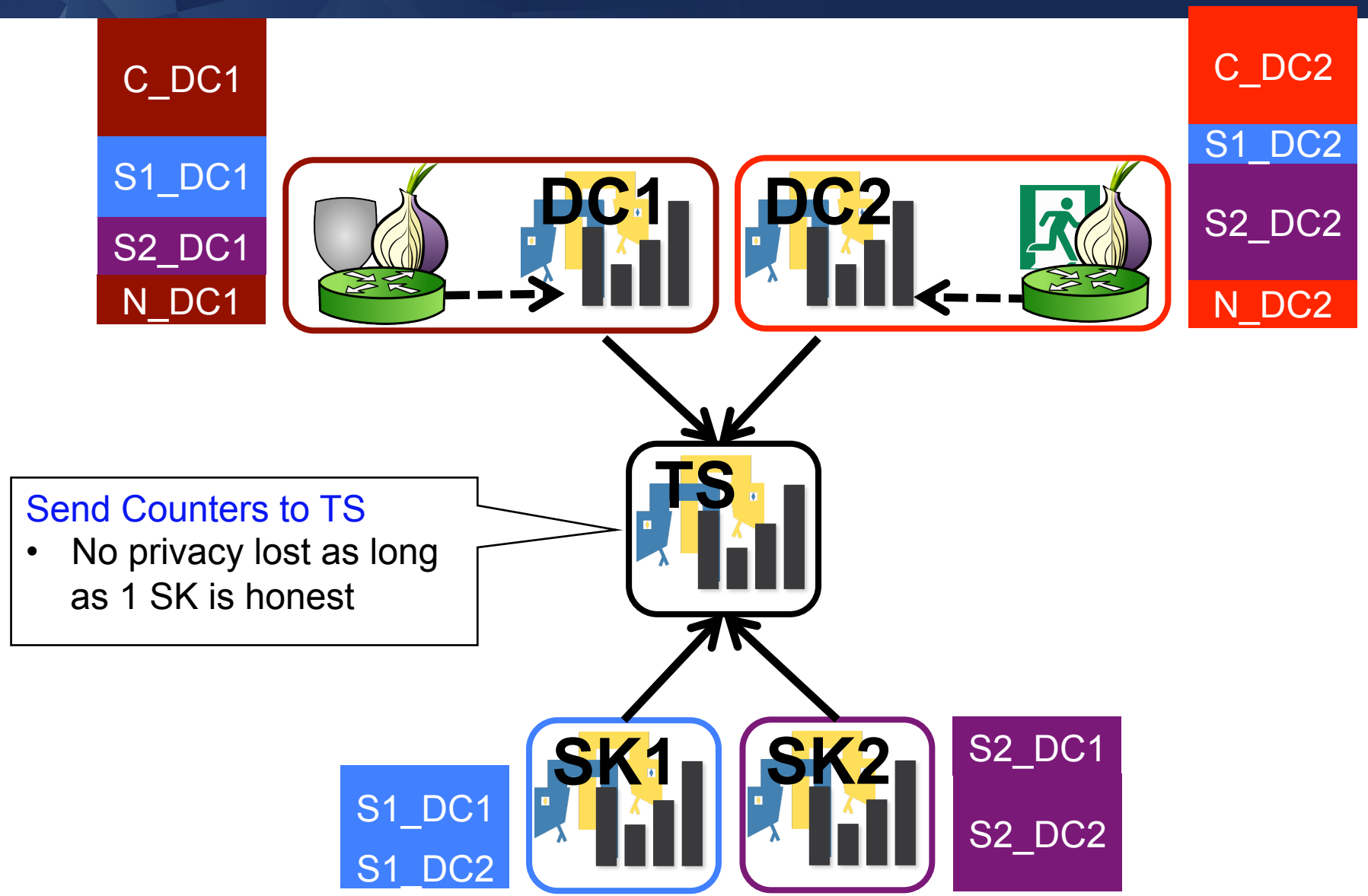

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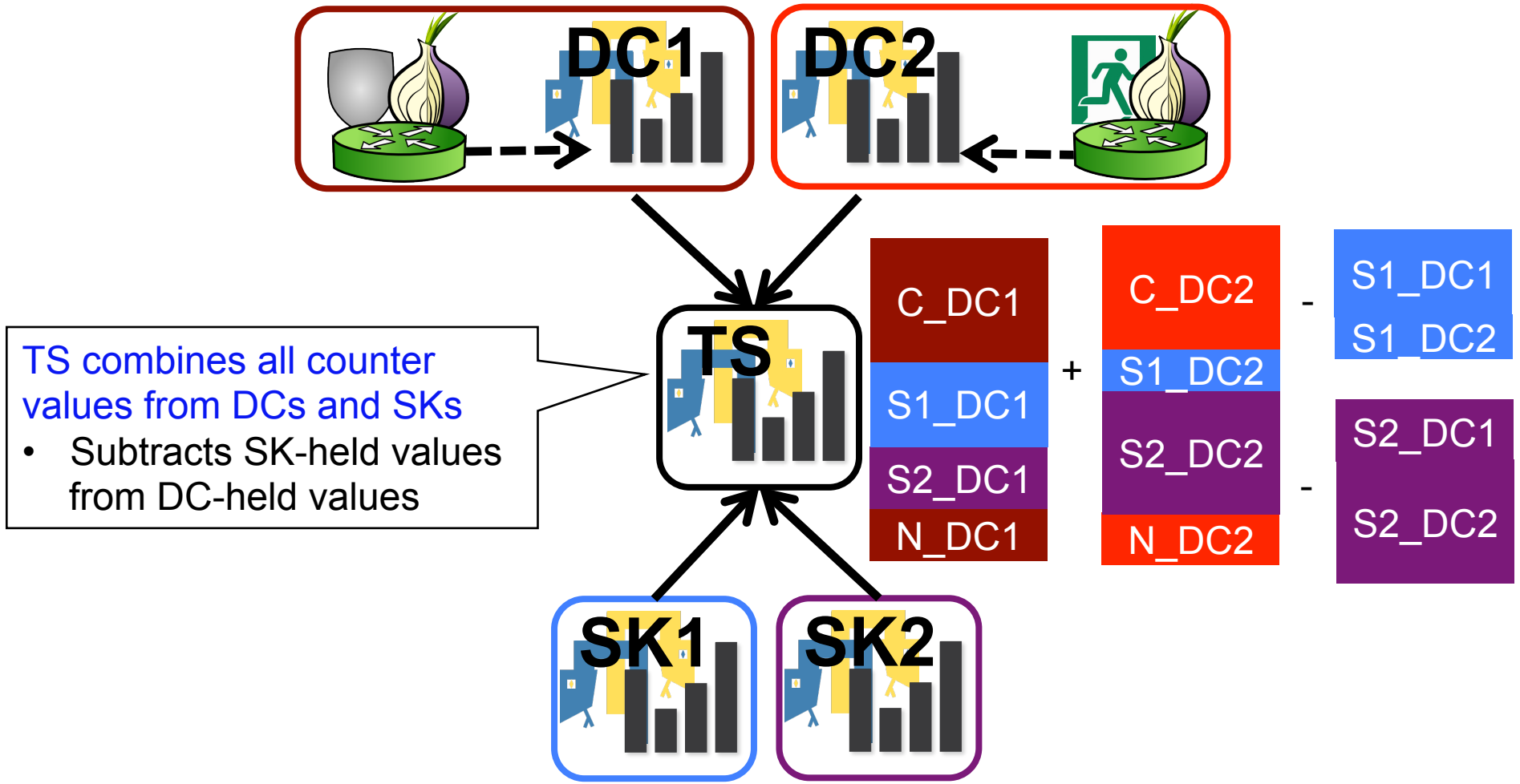
PrivCount: Aggregation



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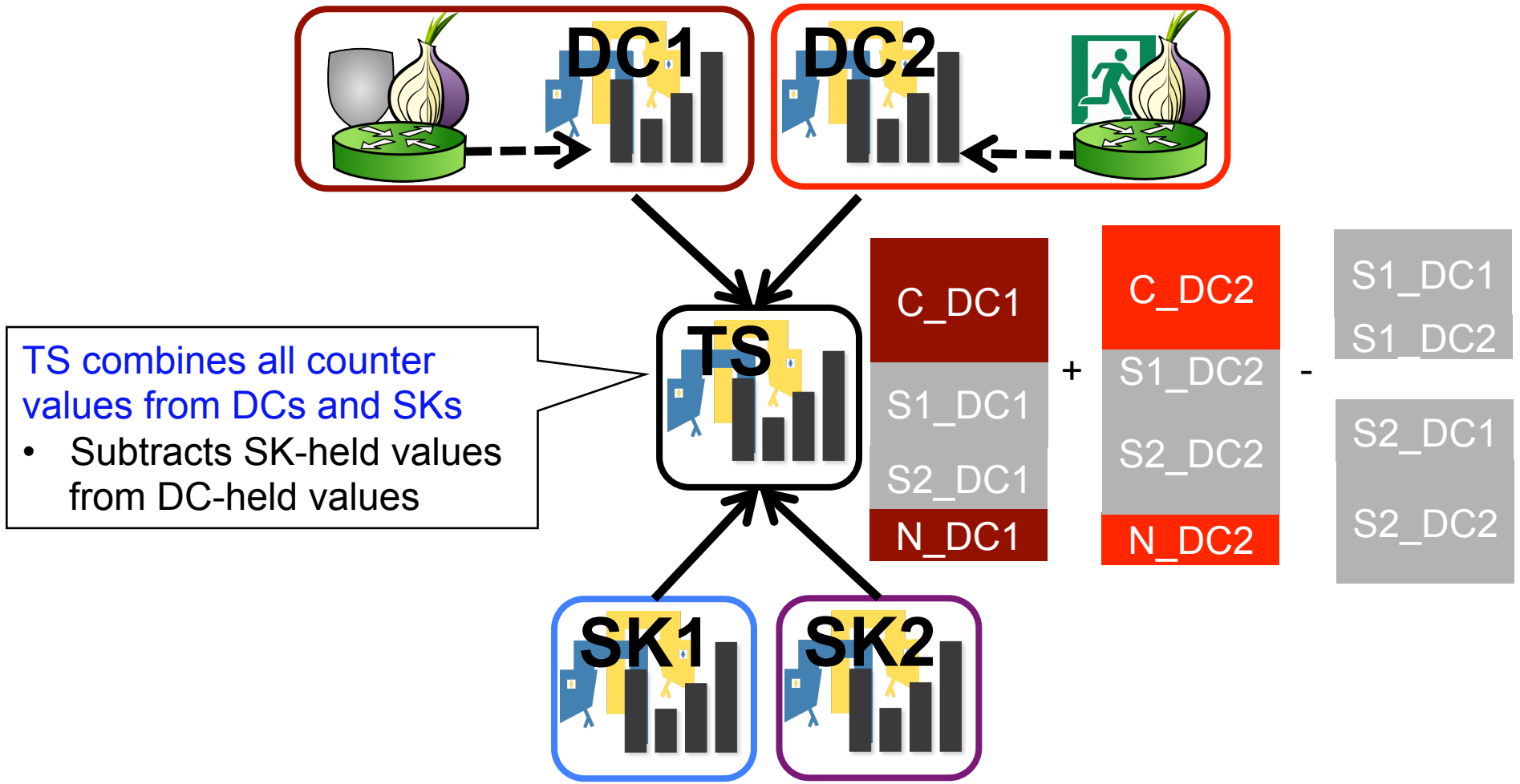

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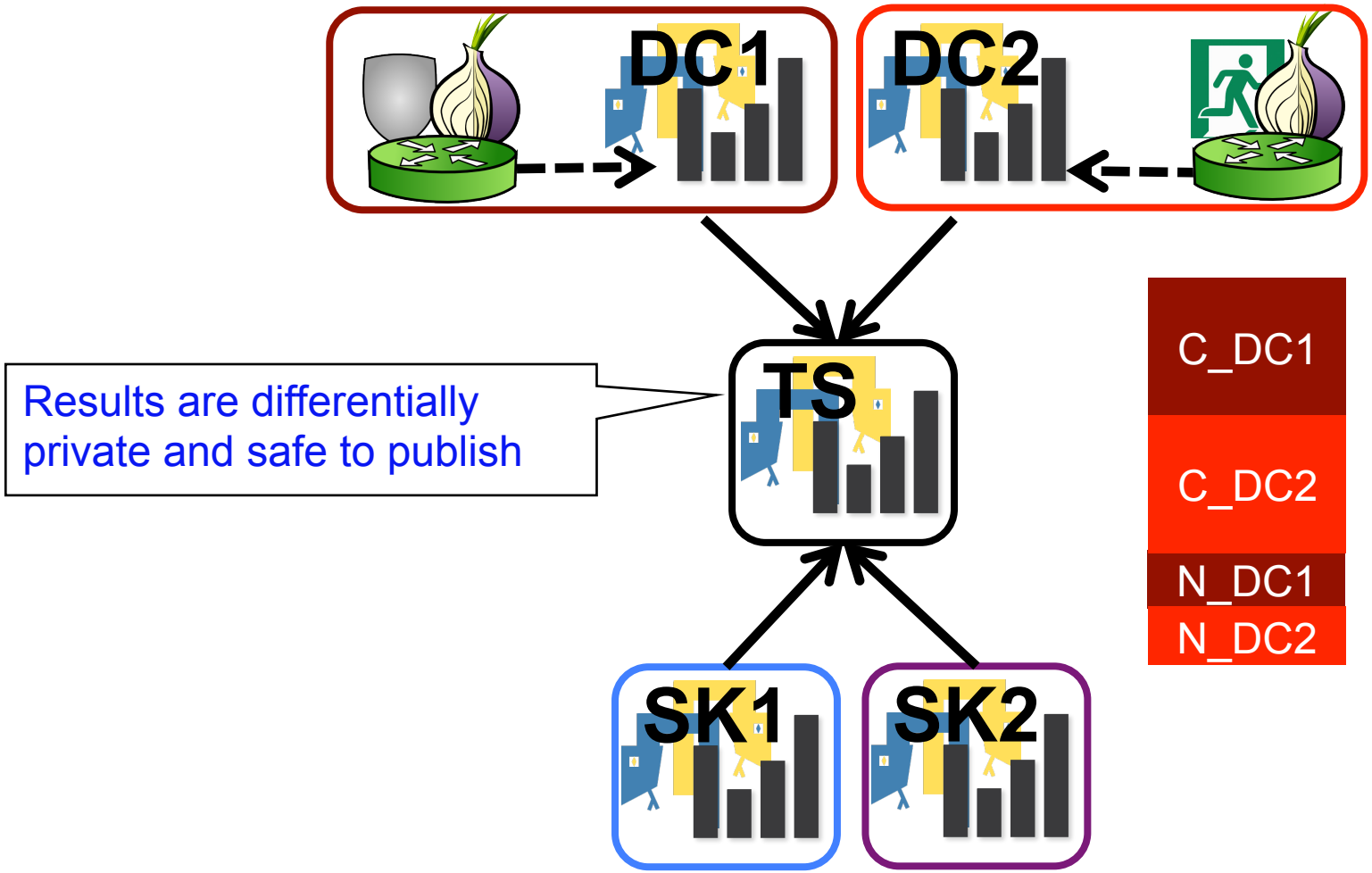

Deployment and Measurement Results

- Configuring and running Tor relays
- “Exploratory” measurements using various exit policies
- “In-depth” measurements of most popular usage
- Network-wide measurement inference

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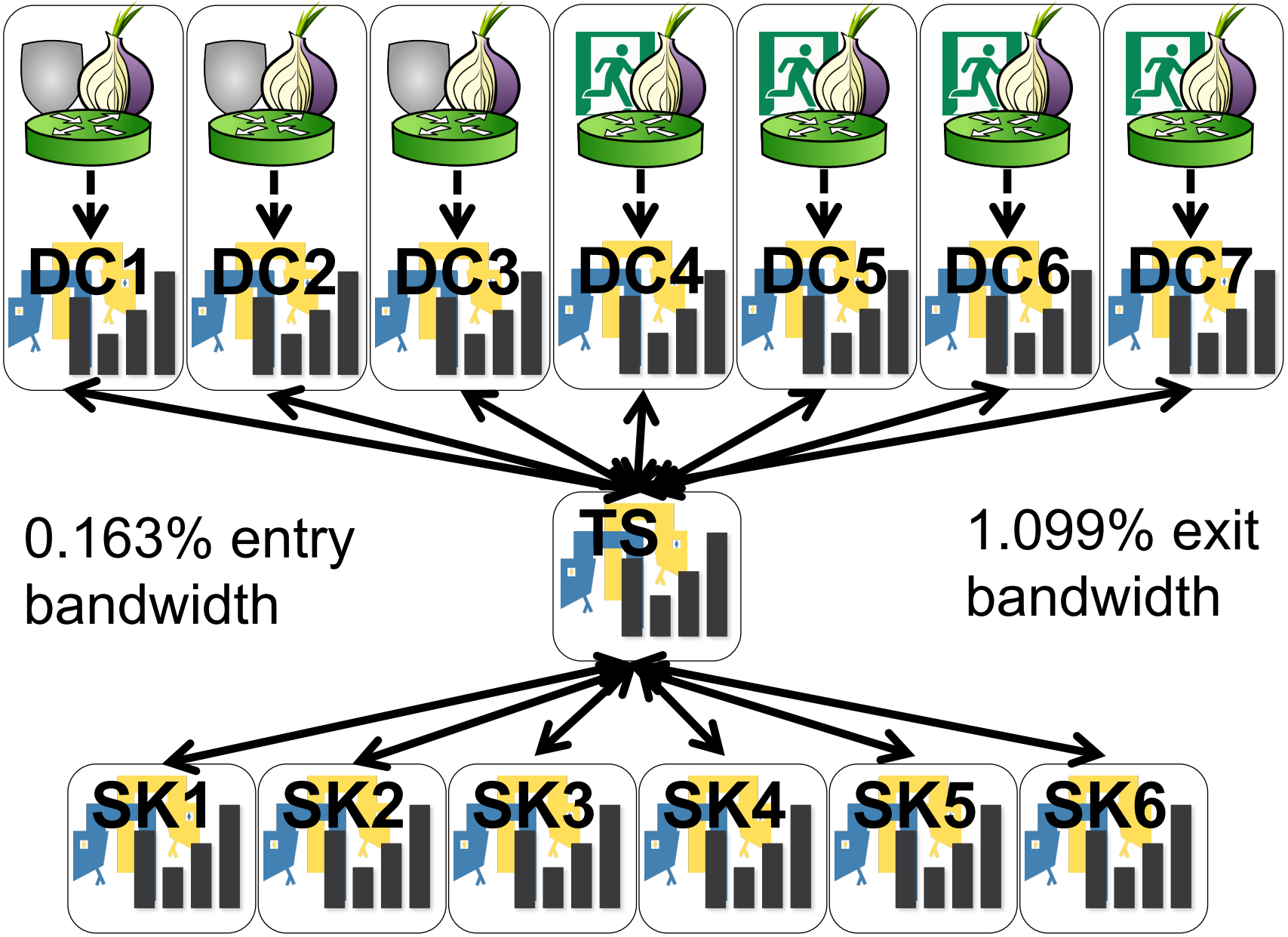
Deploying PrivCount



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Collection Phases

Exploratory phases

- Explore various exit policies (strict, default, open)
- Explore various applications (web, interactive, other)
- Gather only totals (circuits, streams, bytes)
- Use Tor metrics to estimate input parameters
- Run for 1 day, iterate

In-depth phases

- Focus on most popular exit policy and applications
- Gather totals and histograms
- Use exploratory results to estimate input parameters
- Run for 4 days for client stats, 21 days for exit stats

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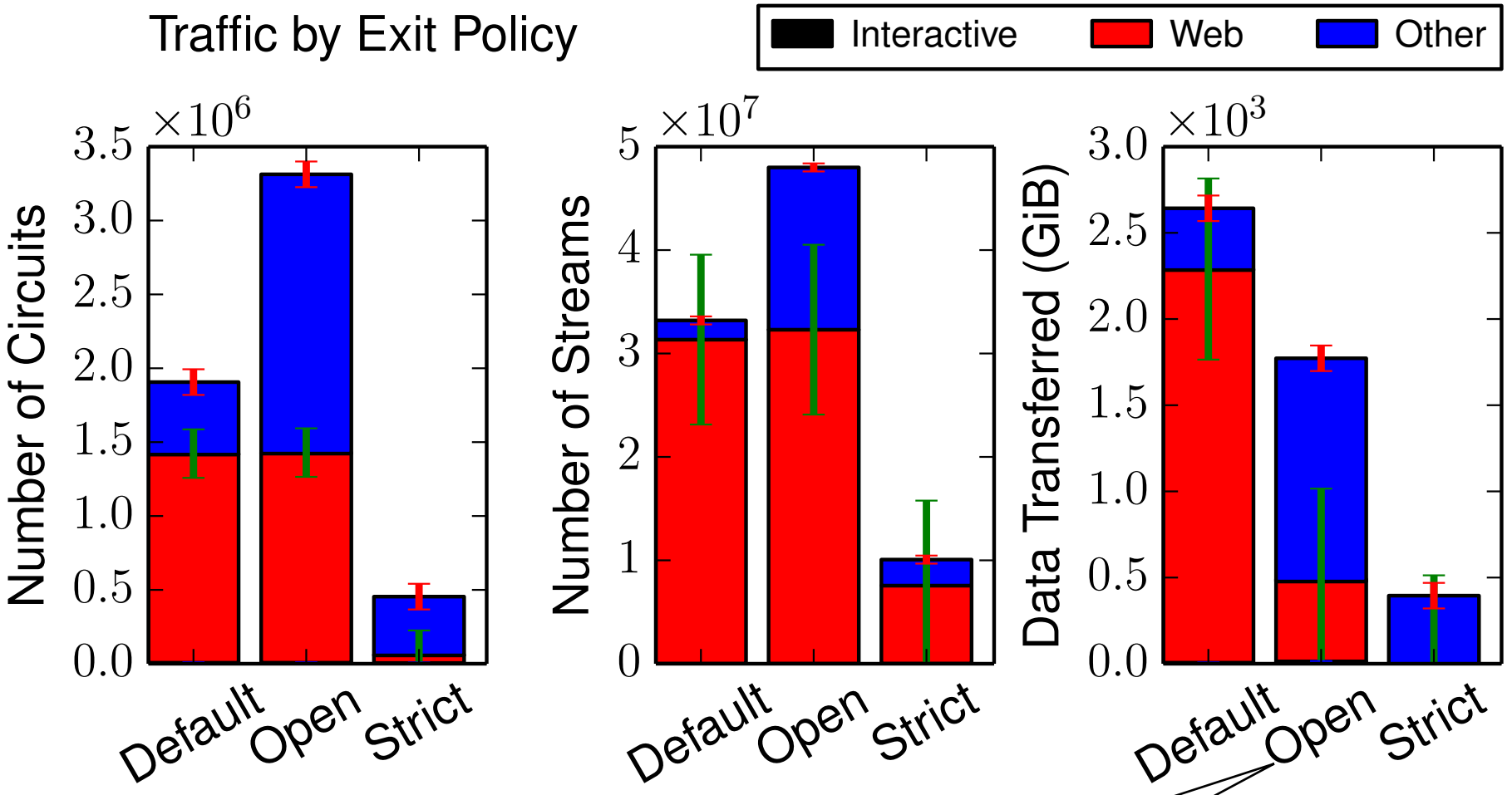
Results: Exit Policies



Open file sharing ports reduce web data transferred

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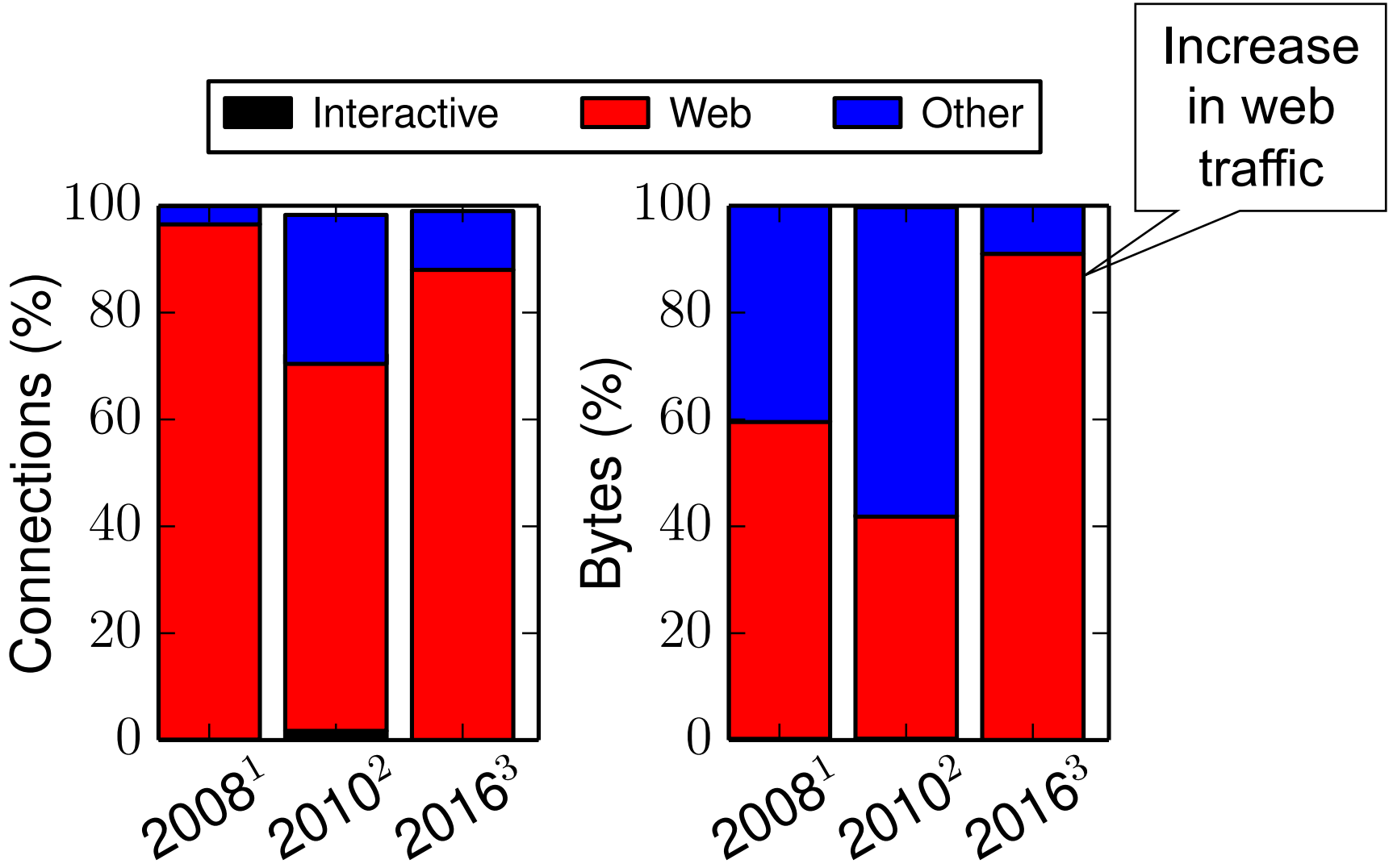
Results: Amount and Types of Traffic



[1] PETS 2008, McCoy... [2] NSS 2010, Chaabane... [3] CCS 2016, Jansen...

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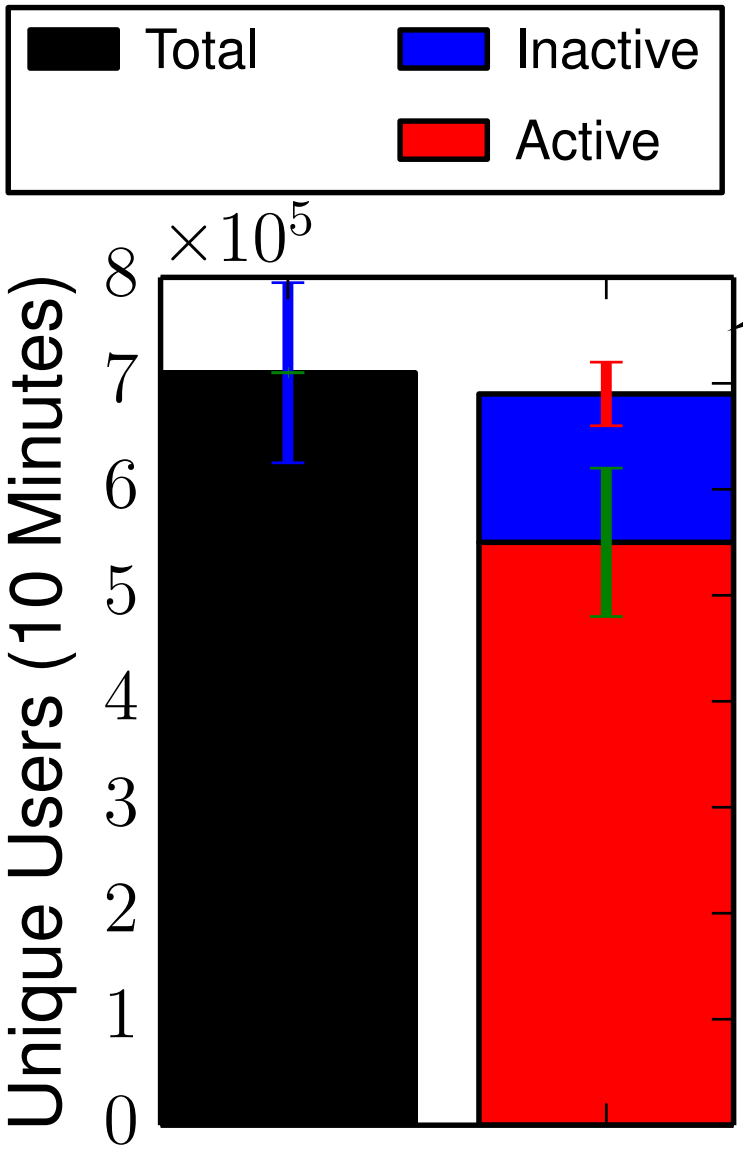
Results: Number of Unique Users



710,000 total users
550,000 active users
In an average 10 mins.

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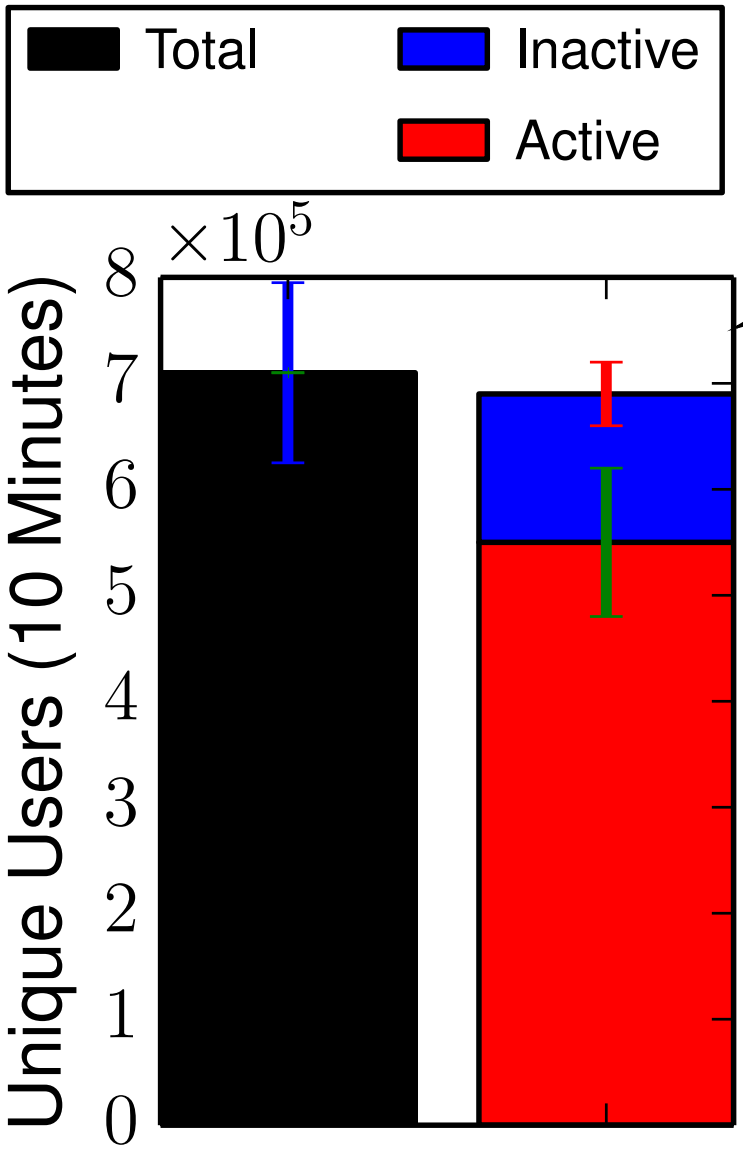
Results: Number of Unique Users



710,000 total users
550,000 active users
In an average 10 mins.

~1,750,000 daily users
(Consensus downloads –
https://metrics.torproject.org)

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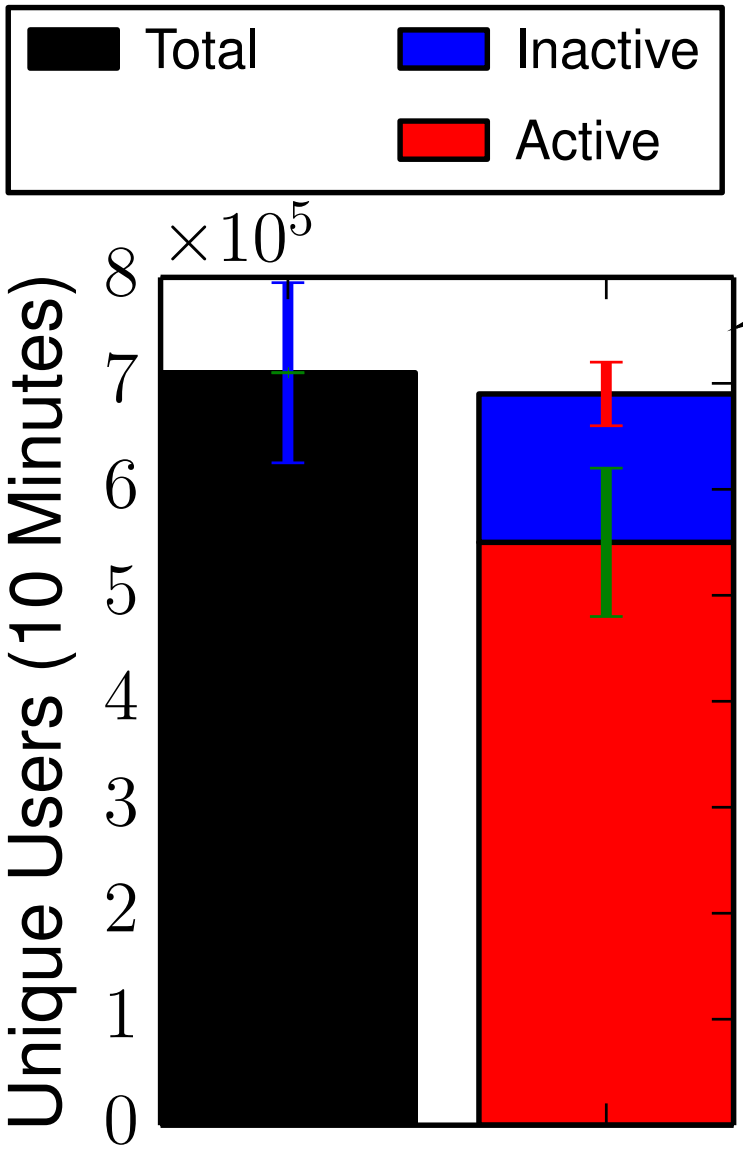
Results: Number of Unique Users



710,000 total users
550,000 active users
In an average 10 mins.

~1,750,000 daily users
(Consensus downloads –
https://metrics.torproject.org)

~800,000 – ~1,600,000
average concurrent users
(Tor Browser update pings -
https://tor-metrics.shinyapps.io/
webstats2/)

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Results: Traffic Modeling Statistics

Table 11: Distributions of Tor network activity from histogram-counter in-depth exit statistics

Statistic		Bin Ranges and Count Distribution (with ± 95% CI)							
Active Circuit Life Time (s)		[1, 480):	57%±44%	[480, 720):	45%±42%	[720, 1200):	0%±33%	[1200, ∞):	0%±35%
Streams Per Circuit	Total	[1, 3):	46%±43%	[3, 7):	38%±41%	[7, 15):	31%±40%	[15, ∞):	9%±37%
	Web	[1, 3):	36%±37%	[3, 7):	22%±33%	[7, 15):	13%±31%	[15, ∞):	3%±28%
	Other	[1, 3):	78%±15%	[3, 7):	10%±9%	[7, 15):	0%±8%	[15, ∞):	2%±8%
Client-bound Bytes Per Stream	Total	[1, 2048):	60%±40%	[2048, 16384):	38%±35%	[16384, 65536):	32%±33%	[65536, ∞):	6%±26%
	Web	[1, 2048):	33%±33%	[2048, 16384):	37%±34%	[16384, 65536):	5%±26%	[65536, ∞):	0%±24%
	Other	[1, 2048):	56%±21%	[2048, 16384):	9%±15%	[16384, 65536):	8%±15%	[65536, ∞):	11%±15%
Server-bound Bytes Per Stream	Total	[1, 512):	57%±39%	[512, 1024):	25%±31%	[1024, 4096):	38%±34%	[4096, ∞):	0%±24%
	Web	[1, 512):	41%±35%	[512, 1024):	36%±34%	[1024, 4096):	23%±30%	[4096, ∞):	2%±25%
	Other	[1, 512):	40%±19%	[512, 1024):	6%±14%	[1024, 4096):	15%±16%	[4096, ∞):	1%±14%
Bytes Per Stream Ratio	Total	(-∞, -1):	80%±45%	[-1, 1):	25%±31%	[1, ∞):	0%±21%		
	Web	(-∞, -1):	70%±42%	[-1, 1):	15%±28%	[1, ∞):	0%±21%		
	Other	(-∞, -1):	45%±20%	[-1, 1):	14%±16%	[1, ∞):	12%±15%		
Inter-stream Creation Time (s)	Total	[0, 1):	87%±47%	[1, 5):	16%±29%	[5, 10):	1%±25%	[10, ∞):	0%±23%
	Web	[0, 1):	68%±41%	[1, 5):	8%±27%	[5, 10):	13%±28%	[10, ∞):	14%±28%
	Other	[0, 1):	16%±16%	[1, 5):	10%±15%	[5, 10):	3%±14%	[10, ∞):	12%±15%

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Conclusion

Distributed measurement for Tor

- Improve accuracy, safety, security
- Allow us to collect more statistics
- Open source: https://github.com/privcount

Future measurement plans

- Network traffic to produce models that can be used to generate realistic traffic
- Onion services to improve reliability and scalability
- Better techniques for cardinality (e.g., # unique users)
- Detecting denial of service attacks and other misbehavior

Contact

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Questions

Privacy

Parameters for (ε, δ)-differential privacy

- ε = 0.3 : same as used by Tor onion service stats
- δ = 10^{-3} : upper bound on prob. of choosing noise value that violates ε-differential privacy
- DCs on 3 machines, add 3x noise

User action bounds

Action	Bound
Simultaneous open entry connections	1
Entry connection open time	24 hours
New entry connections	12
New circuits	146
New streams	30,000
Data sent or received	10 MiB

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PrivCount vs PrivEx

How does PrivCount enhance PrivEx

- Multi-phase iterative measurement
- Expanded privacy notion that simultaneously handles multiple types of measurements
- Optimal allocation of the ε privacy budget across multiple statistics
- Composable security definition and proof
- More capable and reliable tool
- Supports over 30 different types of Tor statistics
- Resilience to node failures and reboots
- Simpler configuration and setup