Proof of Backhaul: Trustfree Measurement of Broadband Bandwidth

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WitnessChain

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Open Networking

- 1990s: Heterogeneous networks linking computers
  - TCP/IP: decentralized routing and congestion control
  - Web 1.0
- 2010: Giant content delivery networks
  - Centralized data centers, cloud computing, caching
  - Web 2.0

Tail Winds of Decentralization: Private 5G

Lightly licensed Airwaves

Commodity Equipment

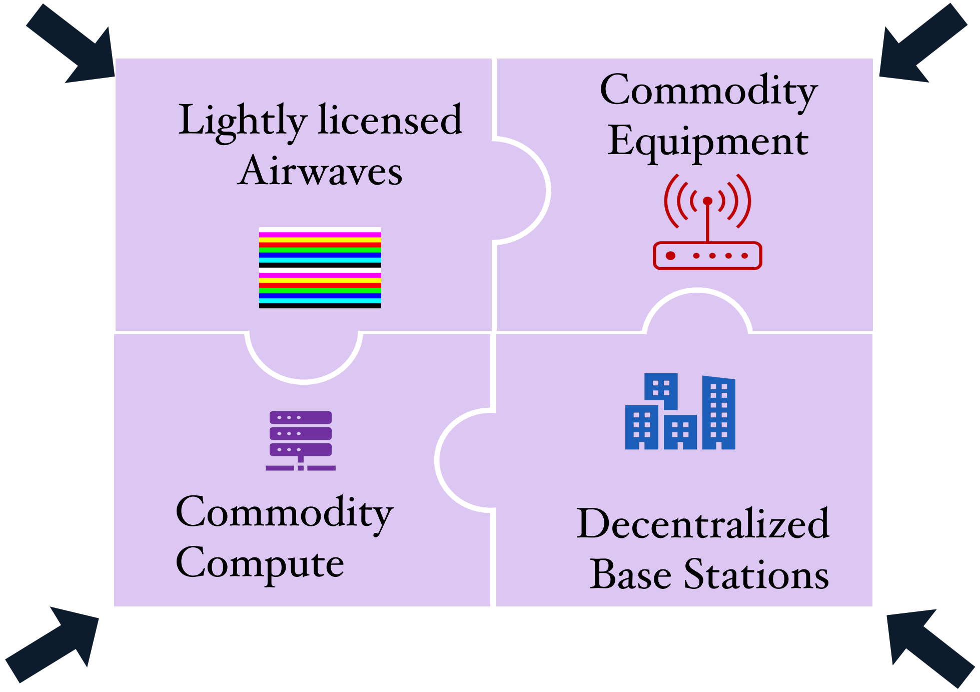
Commodity Compute

Decentralized Base Stations

Components to setup private 5G networks are ready!

Blockchains: Stitching Together

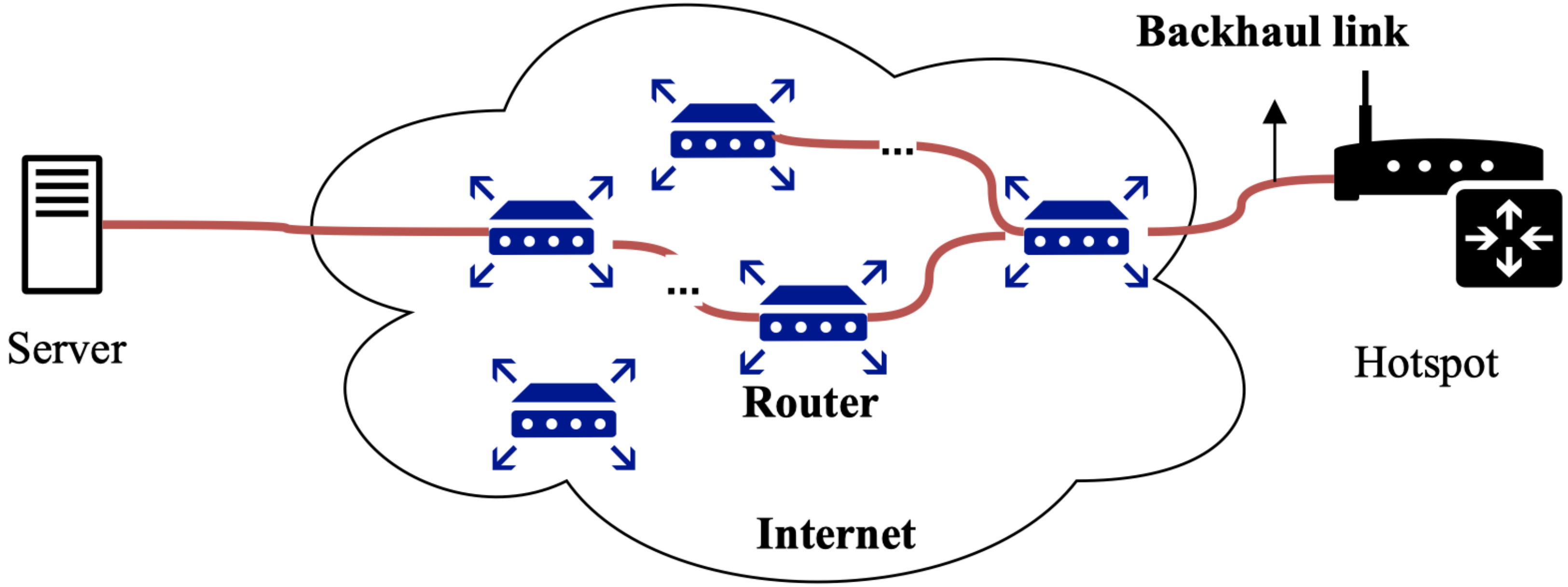
- Low friction way to stitch things together
  - Open and trustless
- Tokenization of incentives



Network Telemetry

- Centralized Telemetry
  - Monitor and optimize network performance
- Decentralized Telemetry
  - Open: no powerful servers (any device)
  - Trustfree: no trusted parties (Byzantine resistance)
  - Network meritocracy: incentive compatibility

Proof of Backhaul

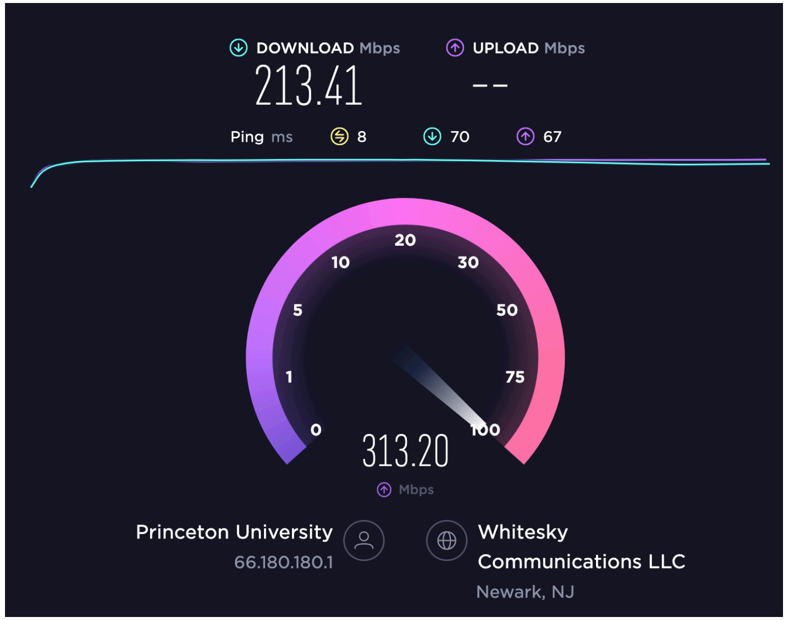


A cryptographic proof system establishing that each party is contributing appropriately towards enabling backhaul bandwidth

Centralized Measurements

Speedtest: speedtest.net

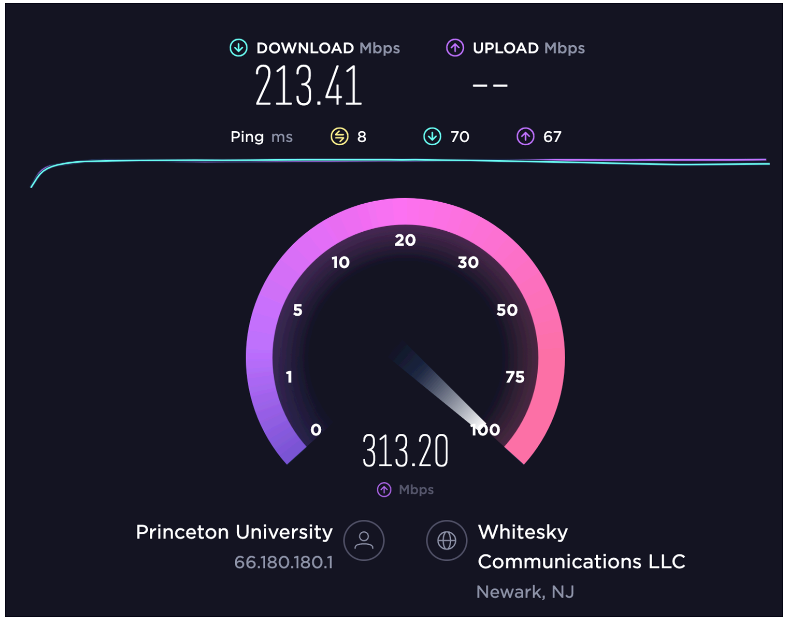
- Nearby powerful servers (high bandwidth, low latency, low packet loss)
- A dedicated foreground service to flood the connection



Centralized Measurements

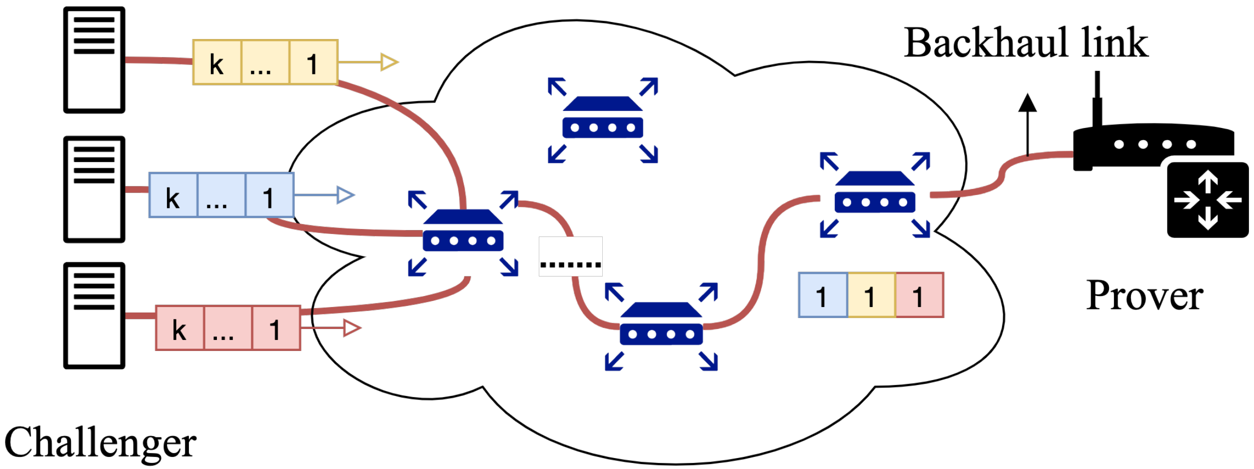
Speedtest: speedtest.net

- Not open: High barrier to entry to be a challenge server
- Not trustfree: Need to trust the challenge server for sending data and the prover for timing measurements



Traffic Aggregation

- Multiple challengers send packets simultaneously
- Packets arrive at the network core around the same time
- Aggregated to an equivalent powerful challenger

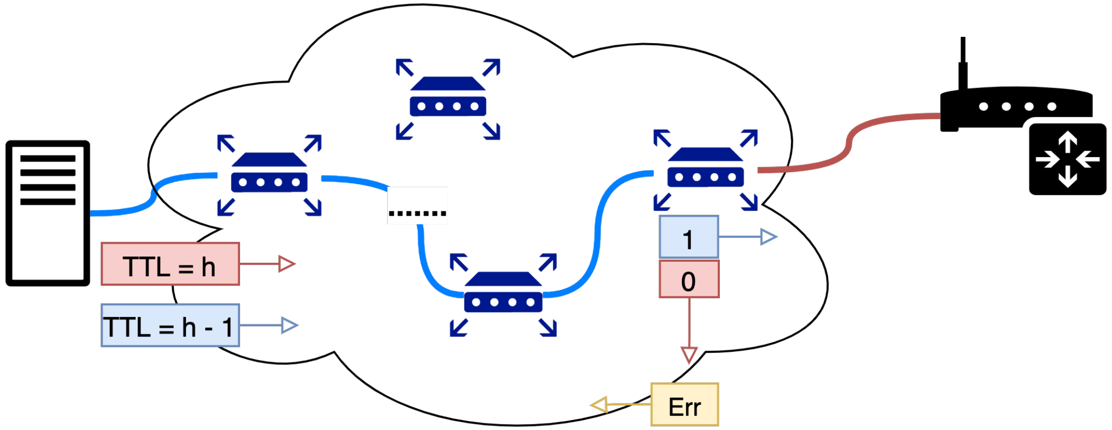


Open but not trustfree

Interactive Measurement

- Pathchar [97']

$$RTT_i = \sum_{k=1}^{i} \frac{B}{\theta_k} + delay \qquad \theta_i = \frac{B}{RTT_i - RTT_{i-1}}$$



Trustfree but not open:
For high-bandwidth provers (>100Mbps), needs a very low jitter path between the challenger and the prover

Combining Aggregation and Interactivity

- Aggregate traffic from multiple challengers

- Prover sends a timing signal upon receiving all the packets

Attacks

- Withholding: corrupted challengers can refuse to send the packets
- Rushing: corrupted prover can collude with a subset of challengers to get packets from an external channel

Trustfree Proof of Backhaul

- Open: Use Traffic Aggregation
- Trustfree: A Byzantine Fault Tolerant (BFT) interactive measurement scheme

Formal Security Properties

- Soundness: no prover can inflate the bandwidth
- Approximate Completeness: if the prover is not corrupted, the protocol will output a bandwidth $\theta'_P \geq \alpha\theta_P$

- Accuracy rate

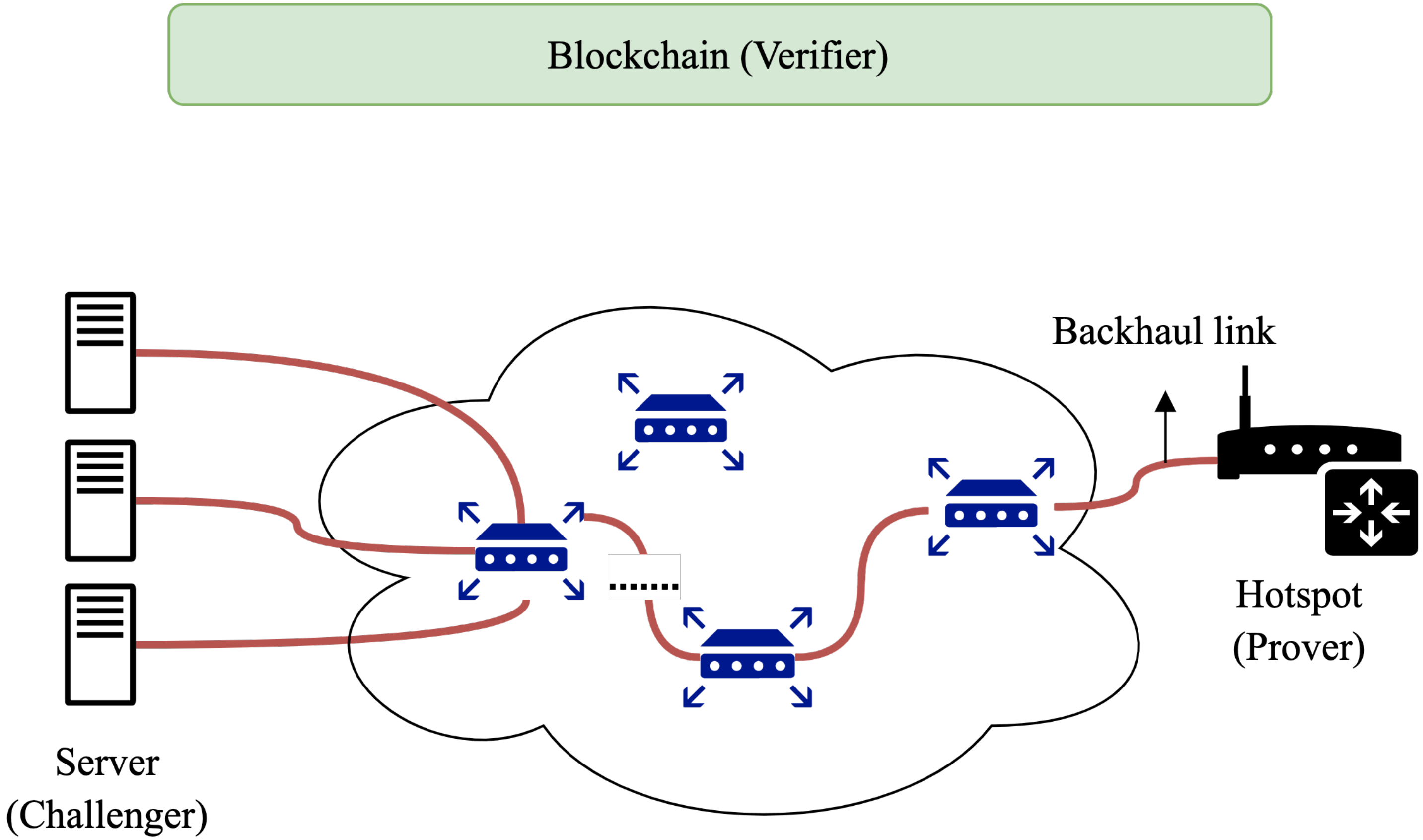
$$\alpha = \frac{n - 2f}{n - f}$$

where n is the number of challengers, f is the number of Byzantine faults

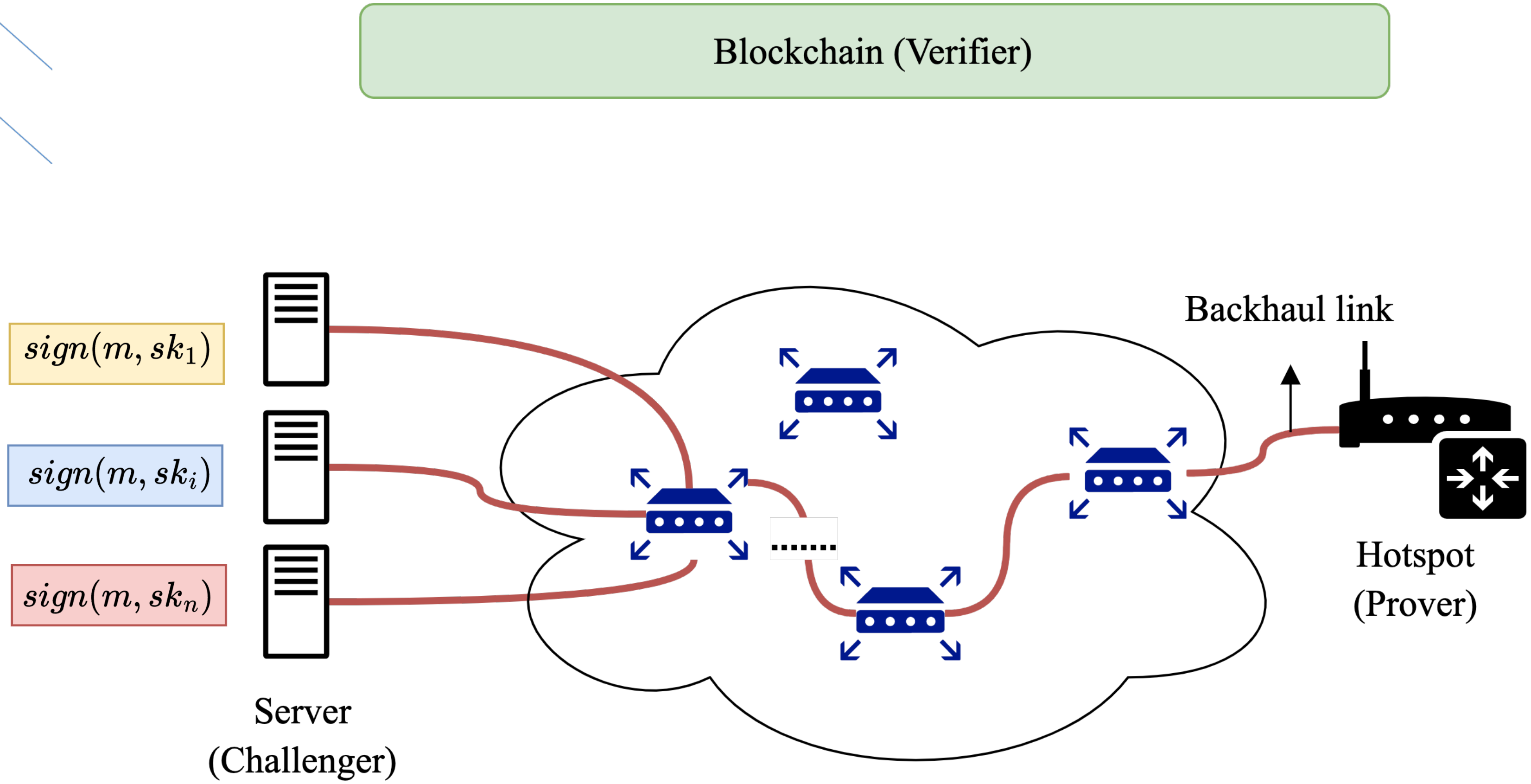
Protocol Primitives

- Unforgeable packets
  - Digital signatures
- Robust timing measurement
  - Median is bounded by honest reports
- Short witness
  - Hash and Merkle tree

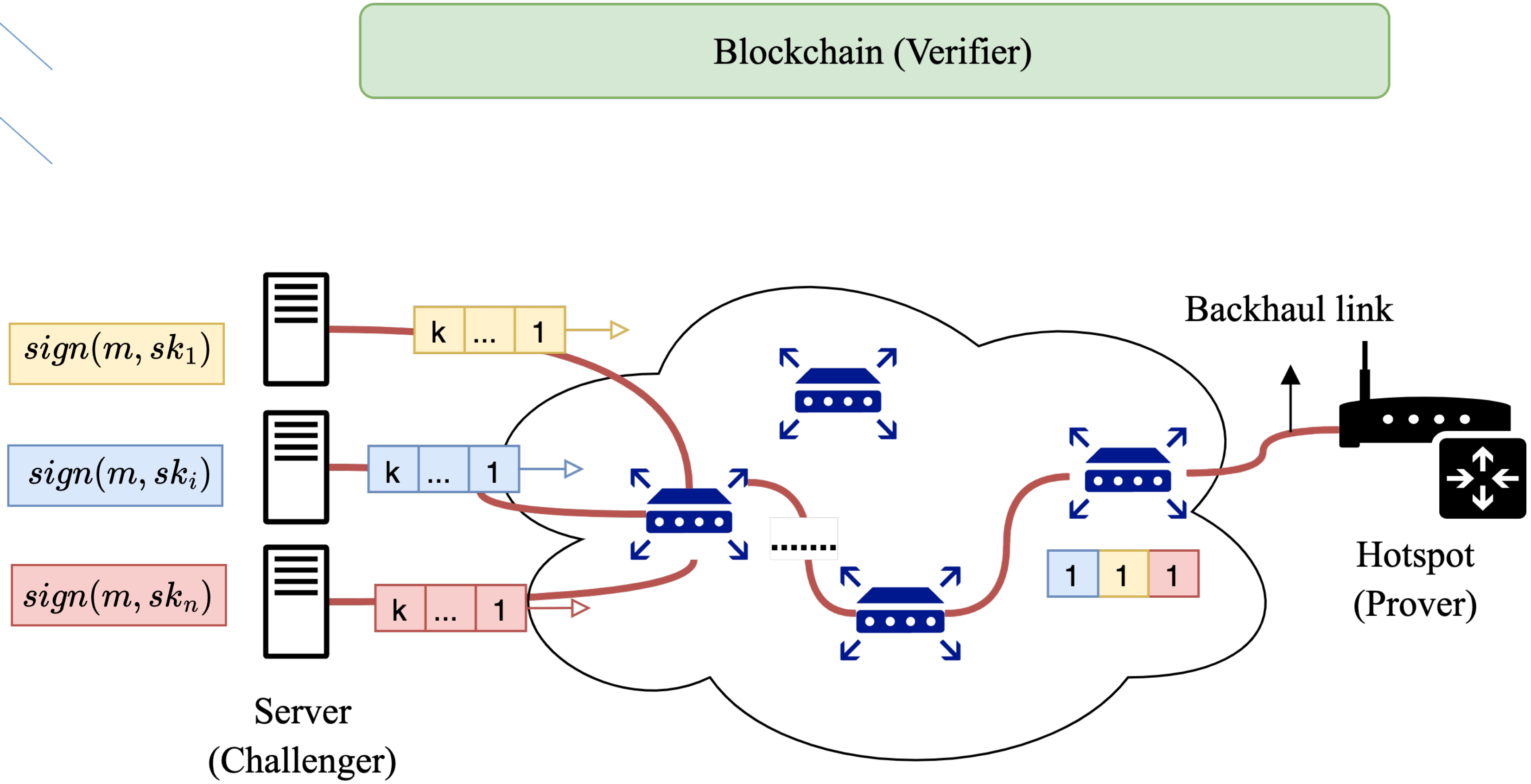
Multichallenger PoB Protocol



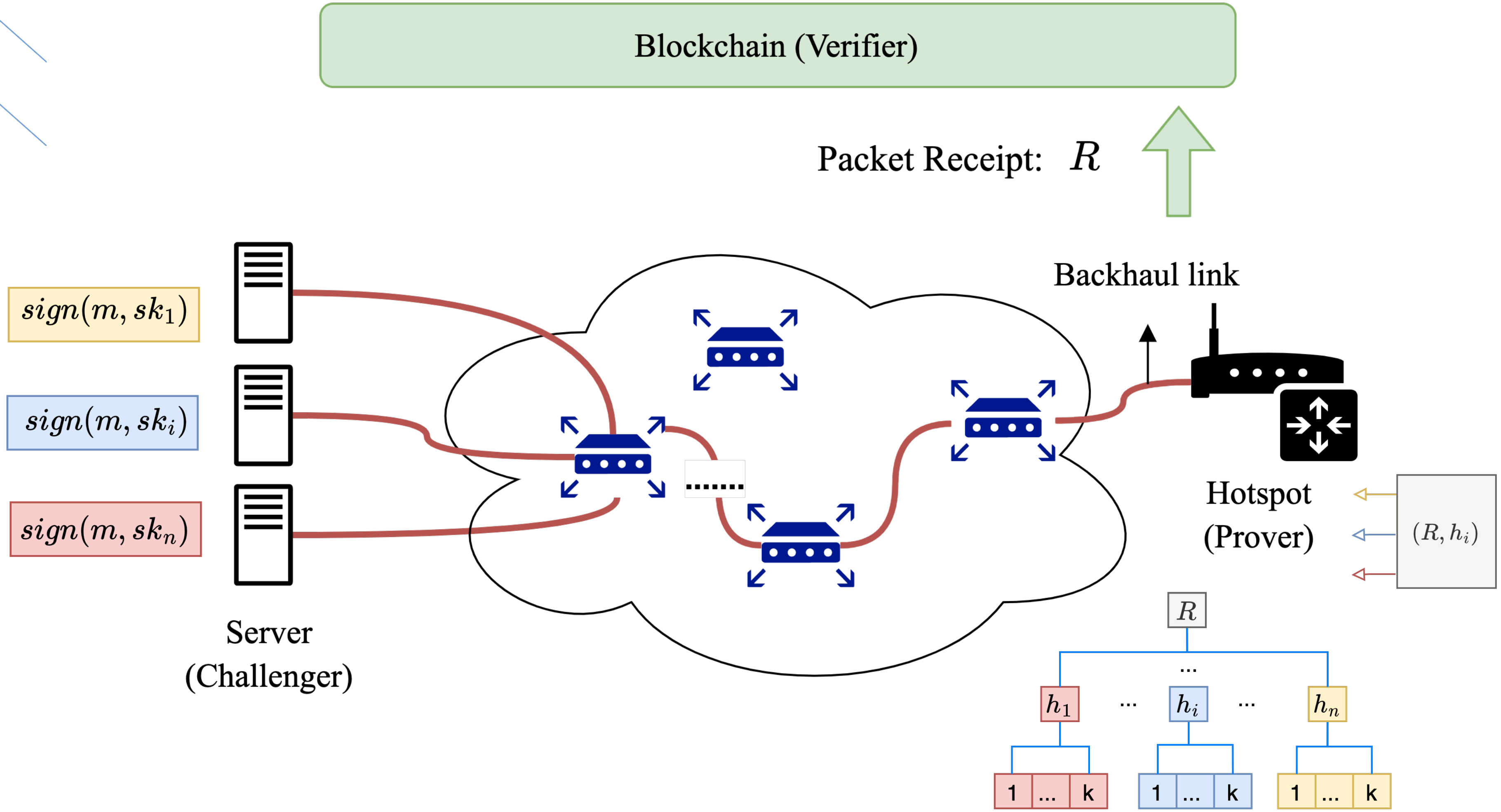
Multichallenger PoB Protocol



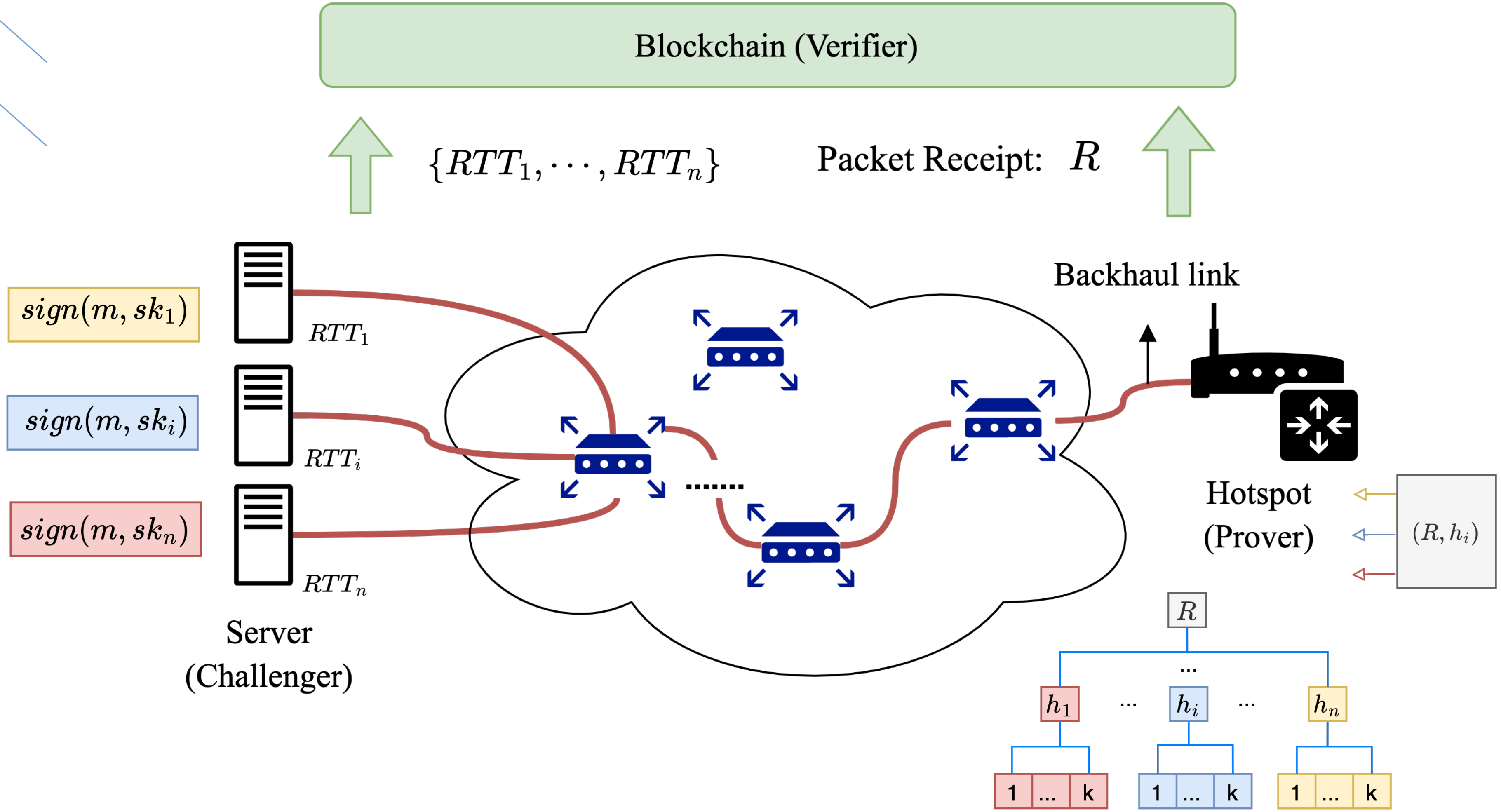
Multichallenger PoB Protocol



Multichallenger PoB Protocol



Multichallenger PoB Protocol



Multichallenger PoB Protocol

1. Verifiable traffic aggregation: Multiple challengers send unforgeable traffic
2. Short packet receipts: Prover commits received packets using Merkle root
3. Local Verification: Challengers verify that their respective challenge traffic was received
4. Robustification: Take median of the RTT measurements

Design Scope Exploration

- Packets: UDP / TCP
- Crypto primitive: with / without signature
- Threat model: with / without access to extra link

TABLE II: Comparison of different protocols in design landscape

	Packets	Crypto primivite	Rushing attack	Accuracy
PoB	UDP	signature	Yes	$(1-2\beta)/(1-\beta)$
PoB-TCP	TCP	signature	Yes	$1-\beta$
PoB-PRG	UDP	pseudorandom generator	Yes	$(1-3\beta)/(1-\beta)$
PoB-shuffle	UDP	signature	No	$1-\frac{(1+\delta_b)\beta^t}{(1-\delta_g)(1-\beta)^t}$ ①

① $0 < \delta_b, \delta_g \leq 1$

System View

- Practical factors: network jitter, synchronization error, computation overhead
- Lightweight: small amount of challenge data
- Open: geographically spread challengers with low bandwidth
- Secure under attacks

Technique	Secure	Challenger BW $<$ Backhaul BW	Accuracy
Pathchar [22], [29], [40]	✗	✓	Low
Packet dispersion based [17], [18], [38], [50]	✗	✗	–
Secure BW estimation [33], [53], [59]	✓	✗	–
Multichallenger PoB	✓	✓	High

(a)

Backhaul BW (Mbps)	Challenger BW (Mbps)	Challenge Data (MB)	Attack	Measured BW (Error %)	Guaranteed BW (Mbps)
250	25	3.44	–	246 (1.6%)	184
500	20	6.86	–	475 (5%)	356
750	75	10.31	–	705 (6%)	529
1000	100	13.75	–	921 (8%)	691
250	32	3.44	Rushing	331 (0.6%)	249
250	32	3.44	Withholding	241 (3.6%)	181

(b)

Thanks!

Full paper: https://arxiv.org/abs/2210.11546

Github: https://github.com/multichallengerpob/proof-of-backhaul

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