MPC With Delayed Parties Over Star-Like Networks

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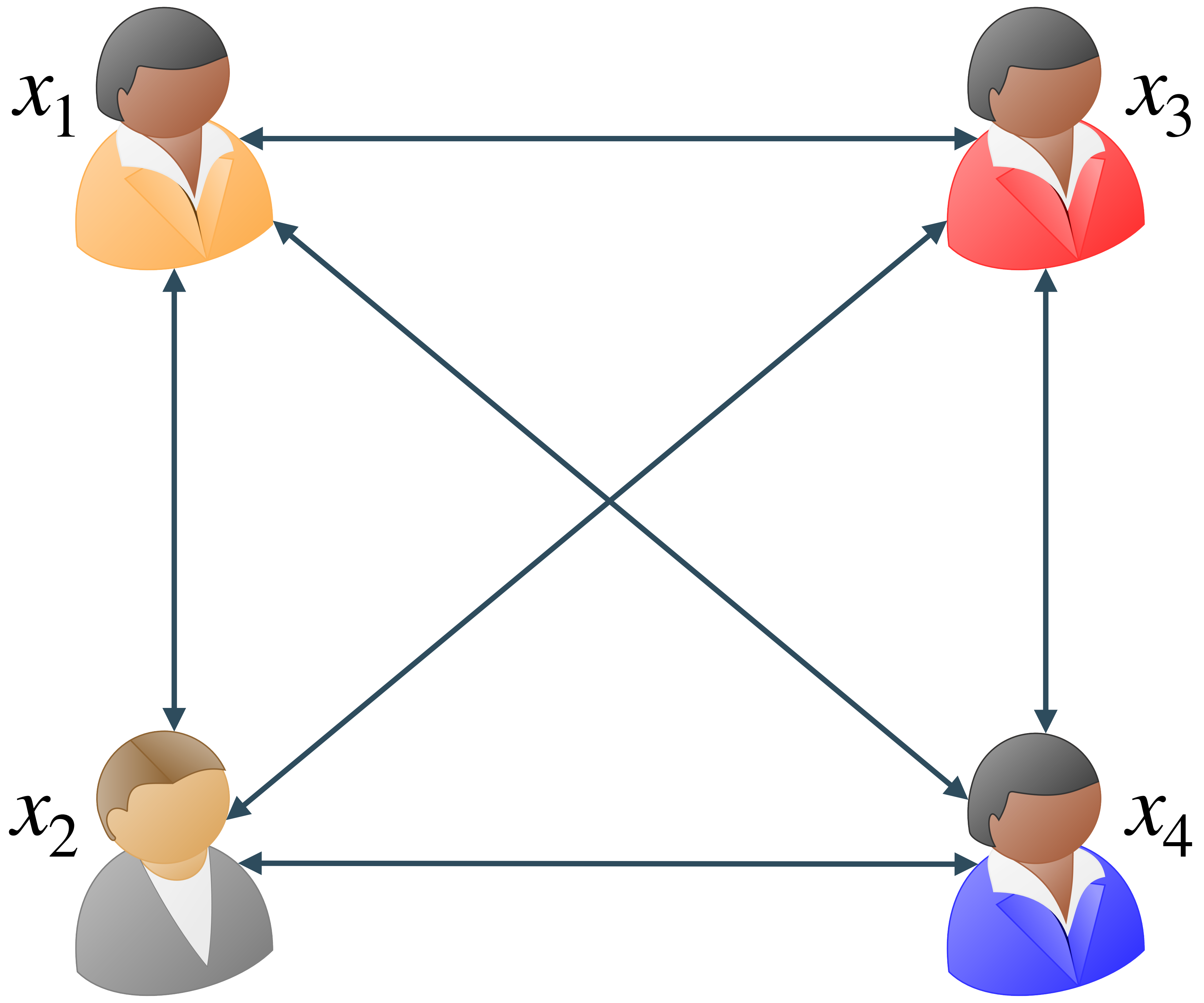
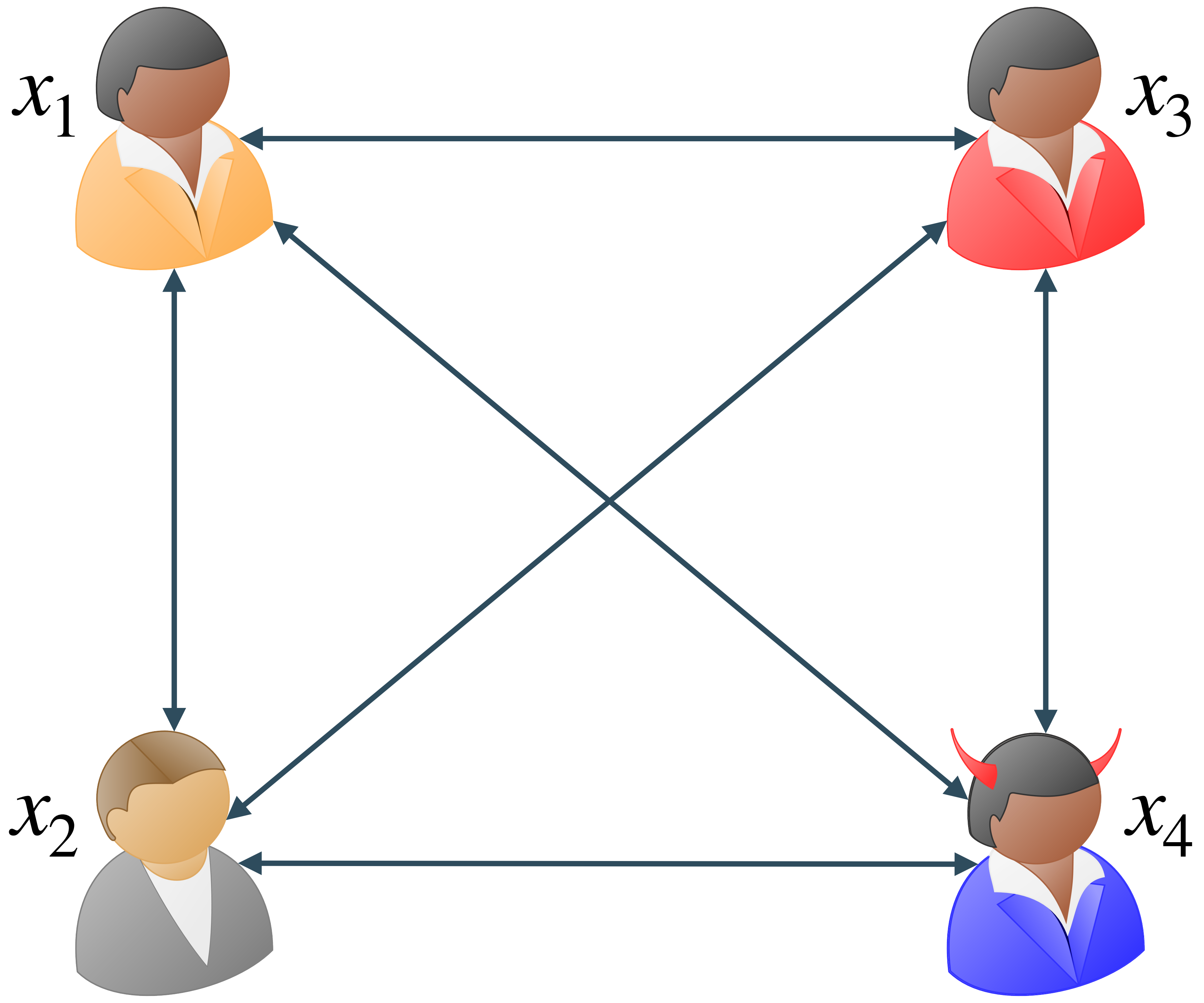
Multiparty Computation



- Technique for computing over encrypted data.
- Achieves privacy by distributing the computation.

Multiparty Computation

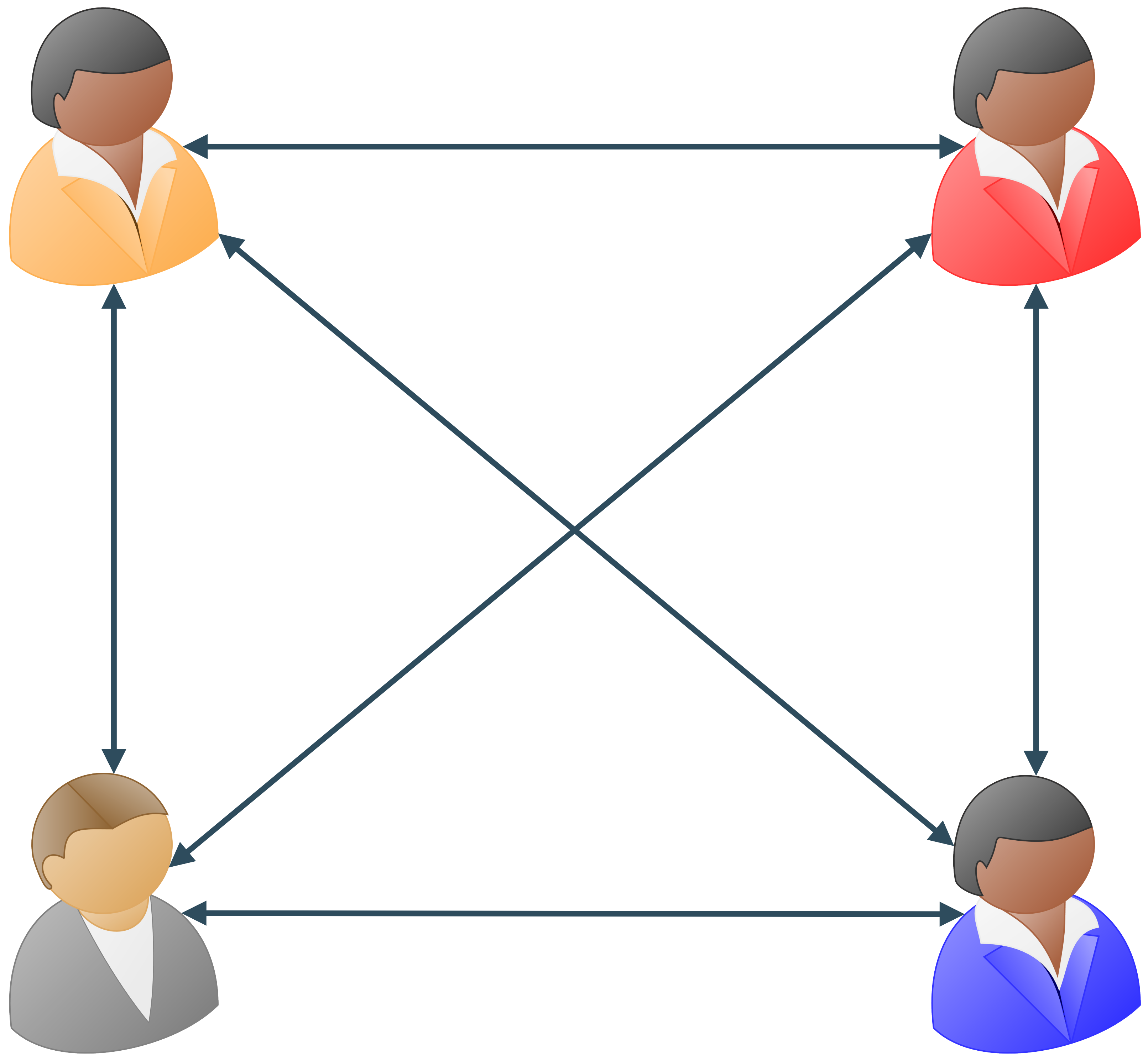


- Technique for computing over encrypted data.
- Achieves privacy by distributing the computation.

Adversary corrupting a percentage of the parties will still learn nothing but the output,

$$y = f(x_1, x_2, x_3, x_4)$$

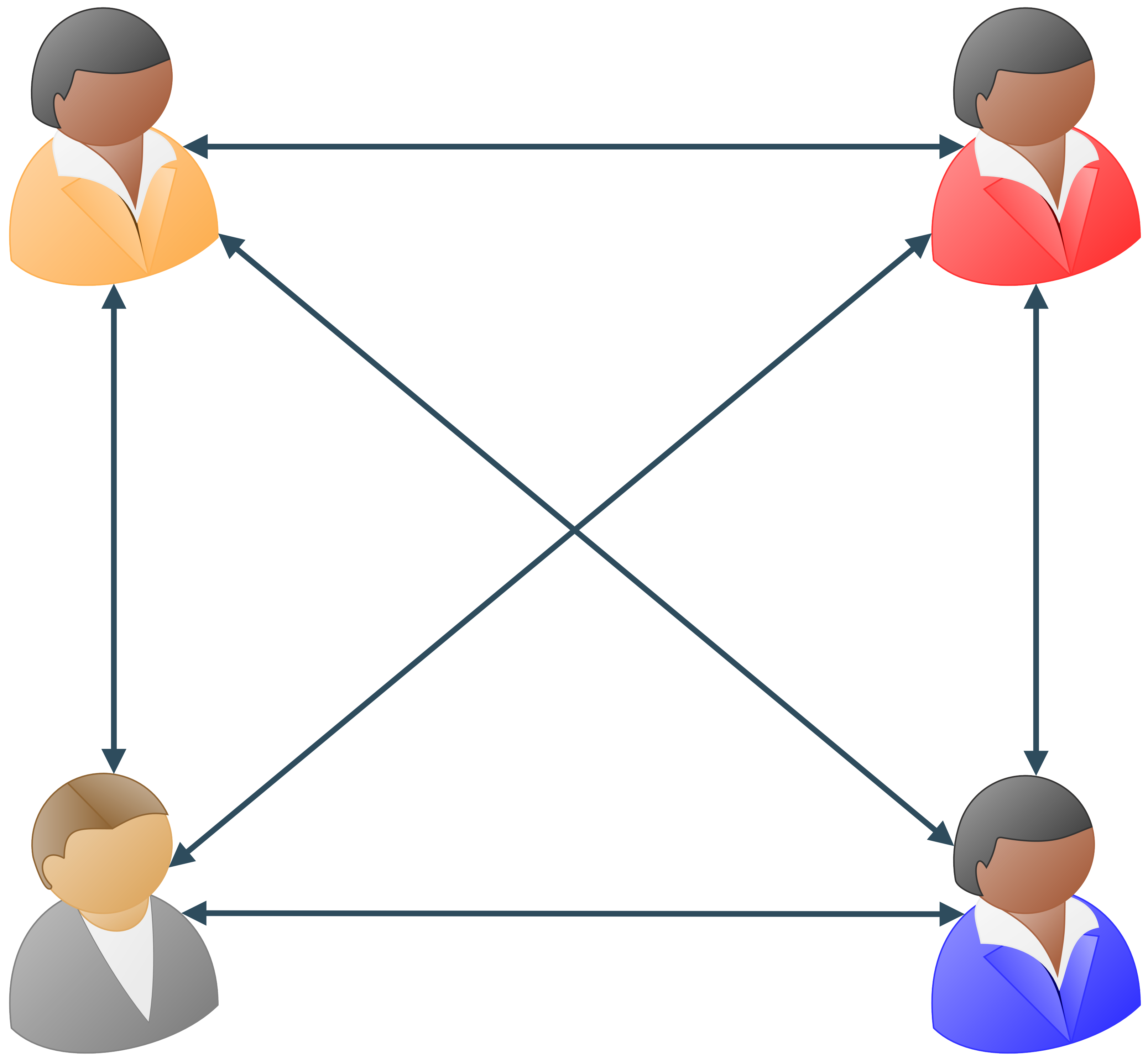
Multiparty Computation



Common assumptions

- Communication channels are direct and fast.

Multiparty Computation



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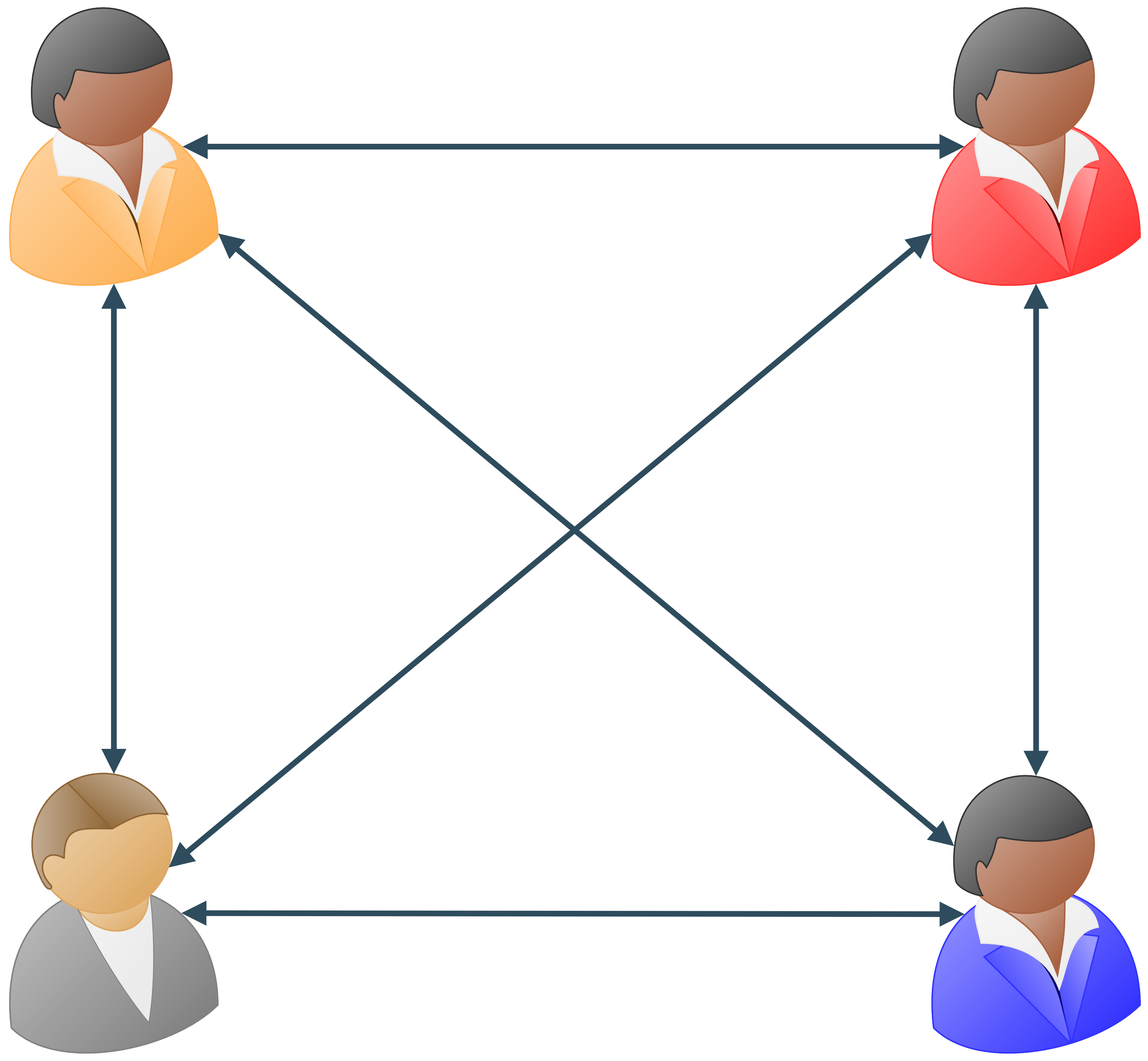
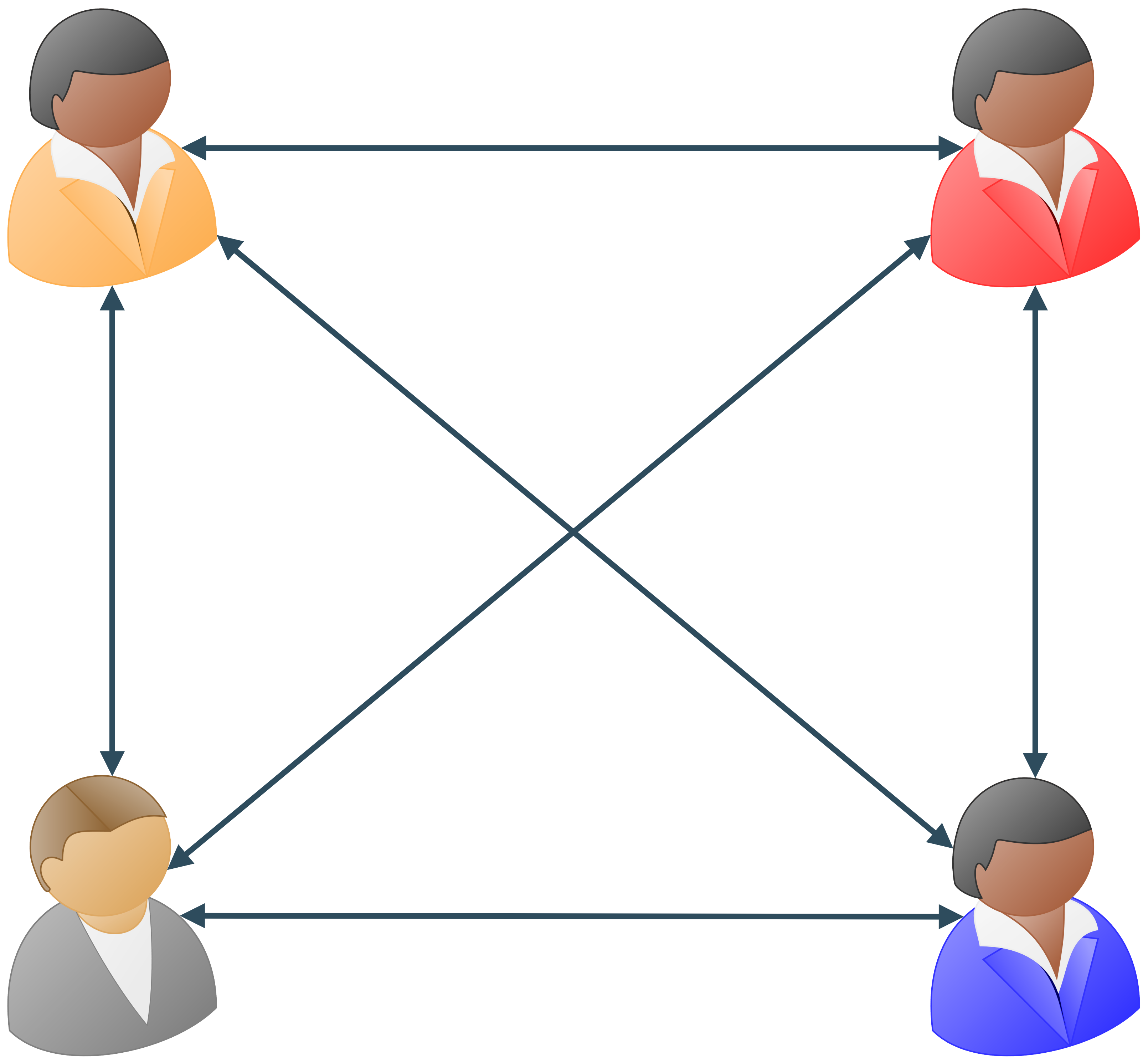


Common assumptions

- Communication channels are direct and fast.
- Parties stay online during the whole computation.

Not the case in currently deployed systems!

This work



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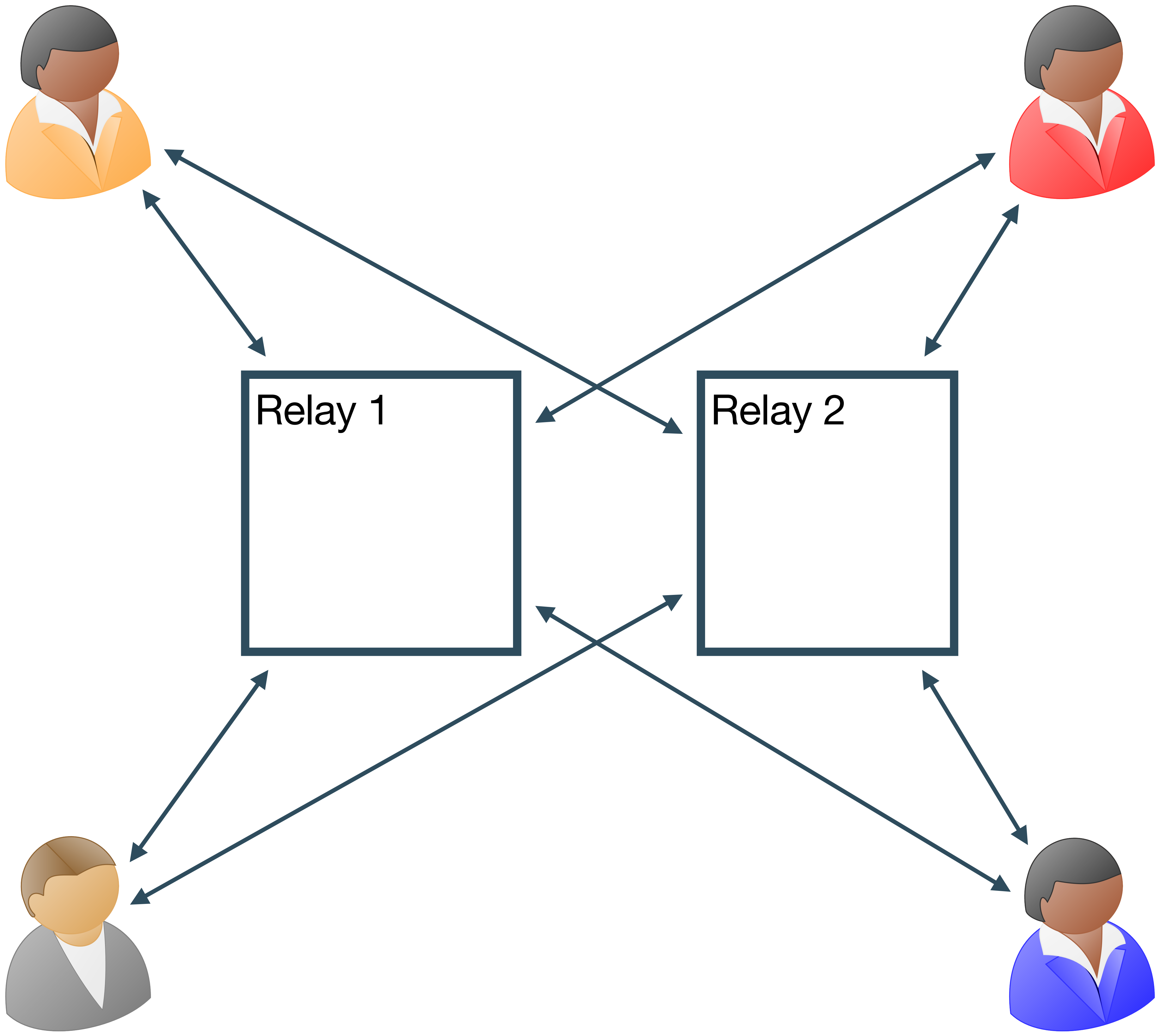

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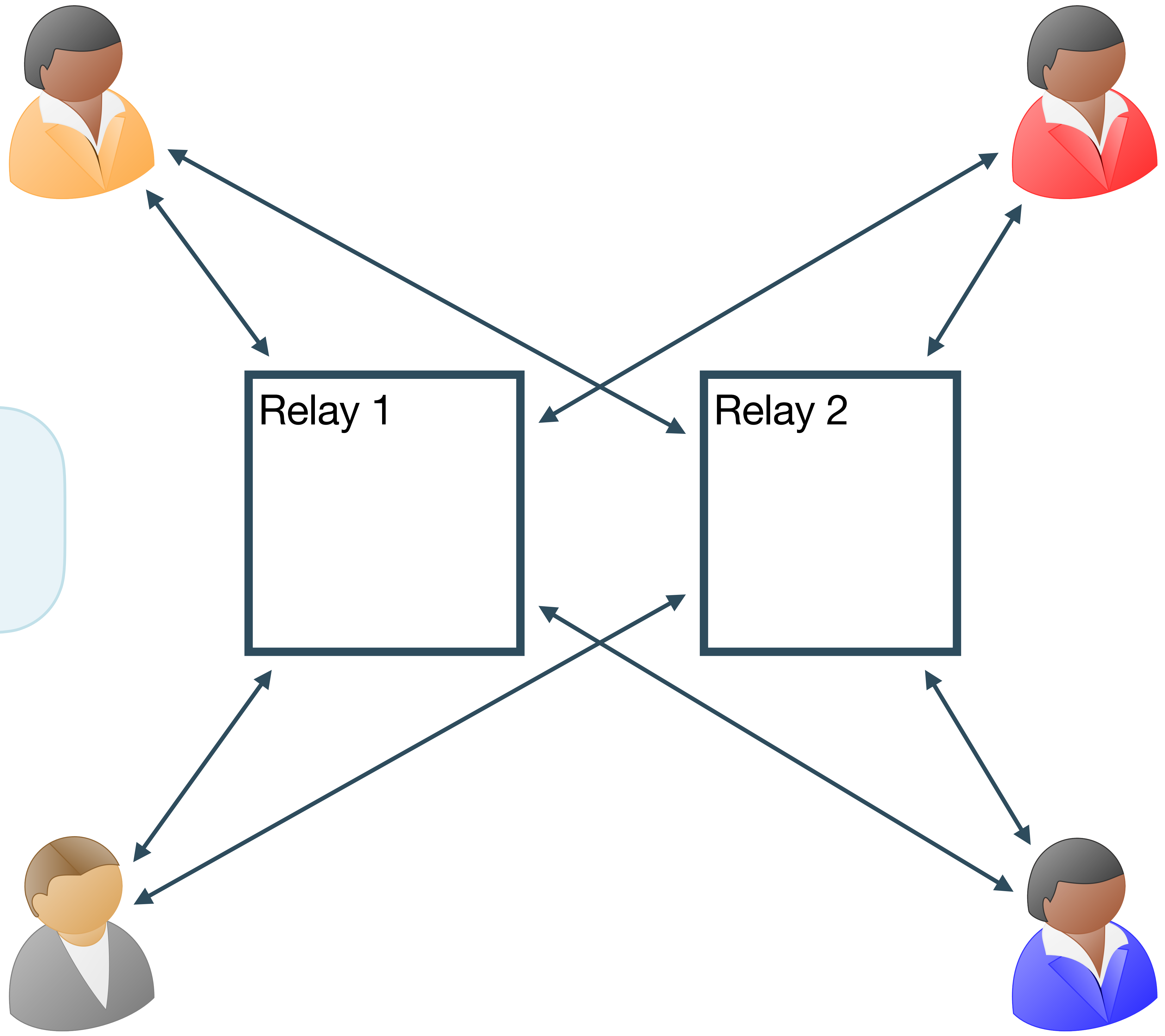
Star-like communication topology with relay nodes



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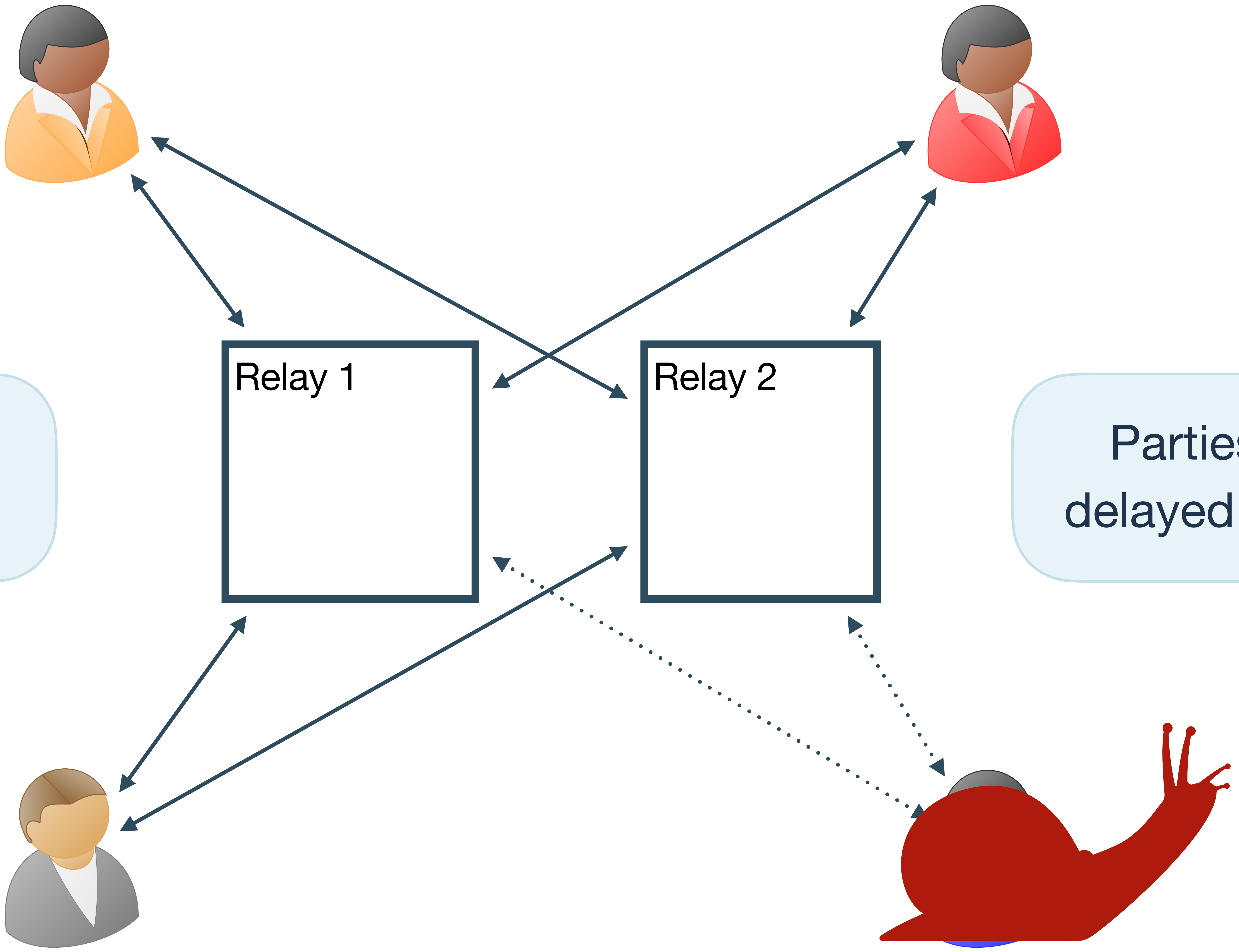

Parties' actions can be delayed for up to δ rounds.

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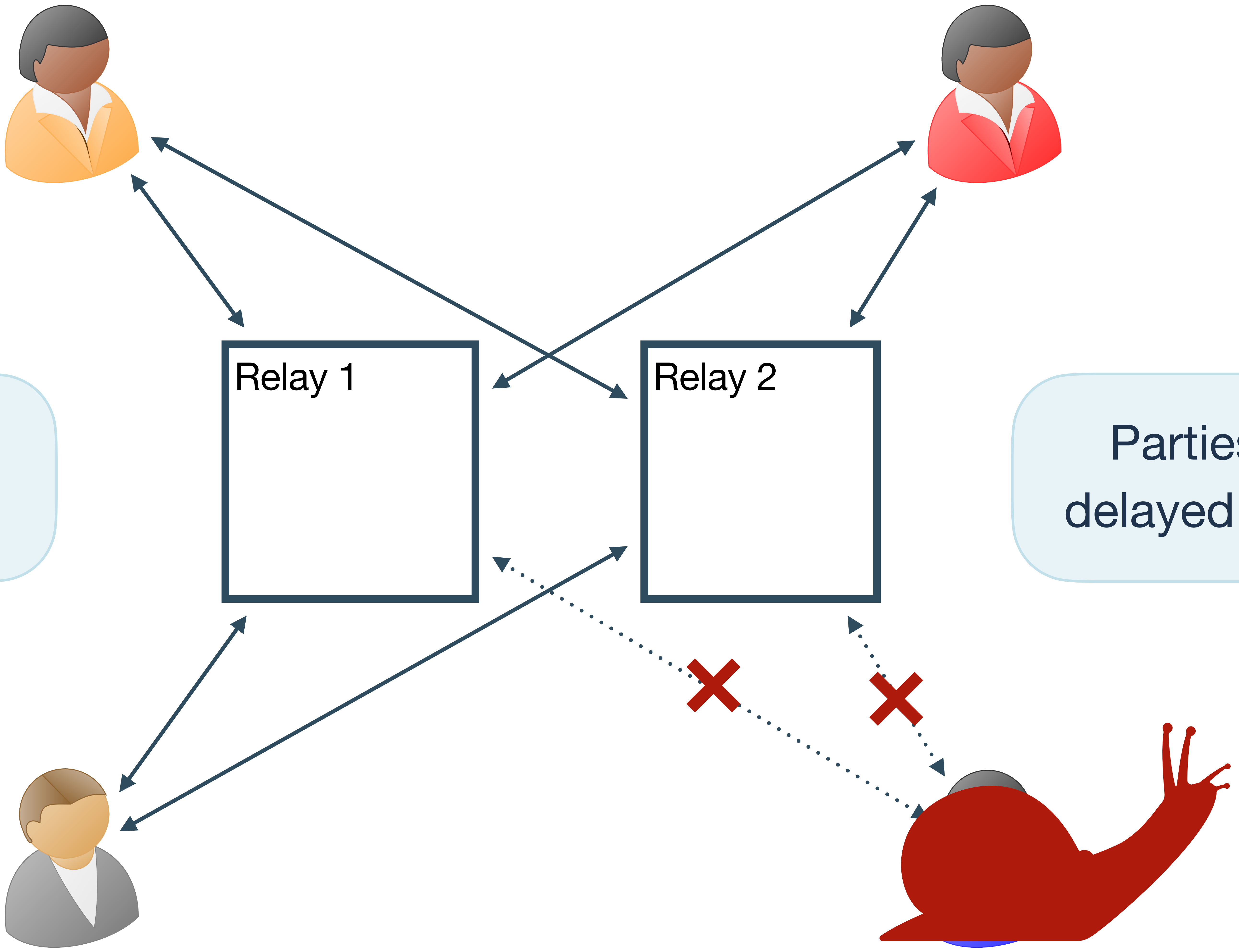

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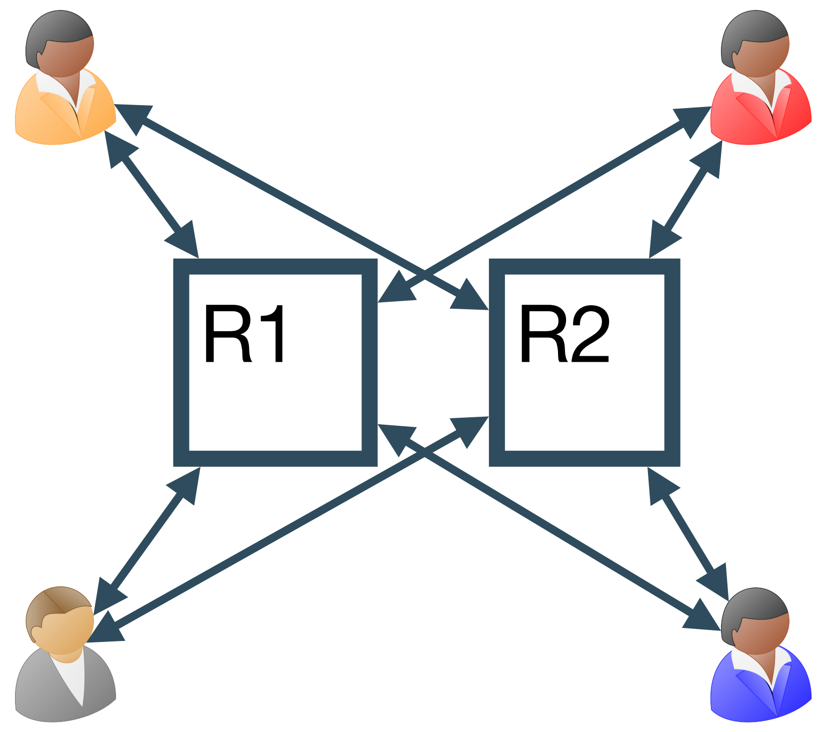
Related work

Related work

Star-like topology

White-City: A framework for massive mpc with partial synchrony and partially authenticated channels
ZenGo technical report, 2020



- Relays maintain consistency via a consensus protocol.
- Designed for threshold ECDSA signing -> no mechanism to limit the number of stored messages.

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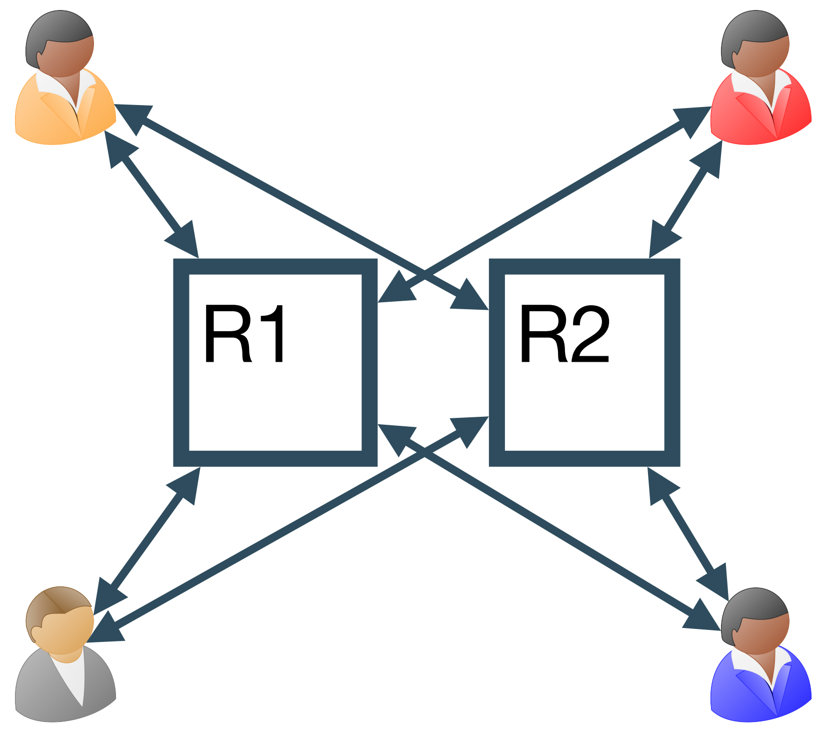

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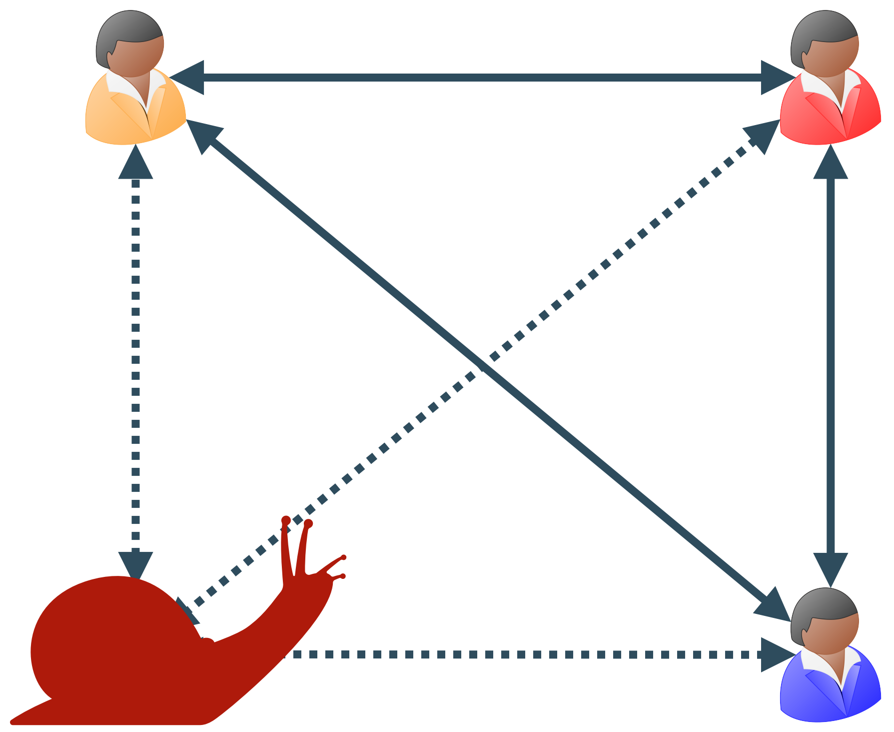
MPC with delays

Generalized pseudorandom secret sharing and efficient straggler-resilient secure computation
Benhamouda et al. [BBG+21]



- Delays are caused by network channels instead of node failures
- Multiplication protocol introduces additional overhead.

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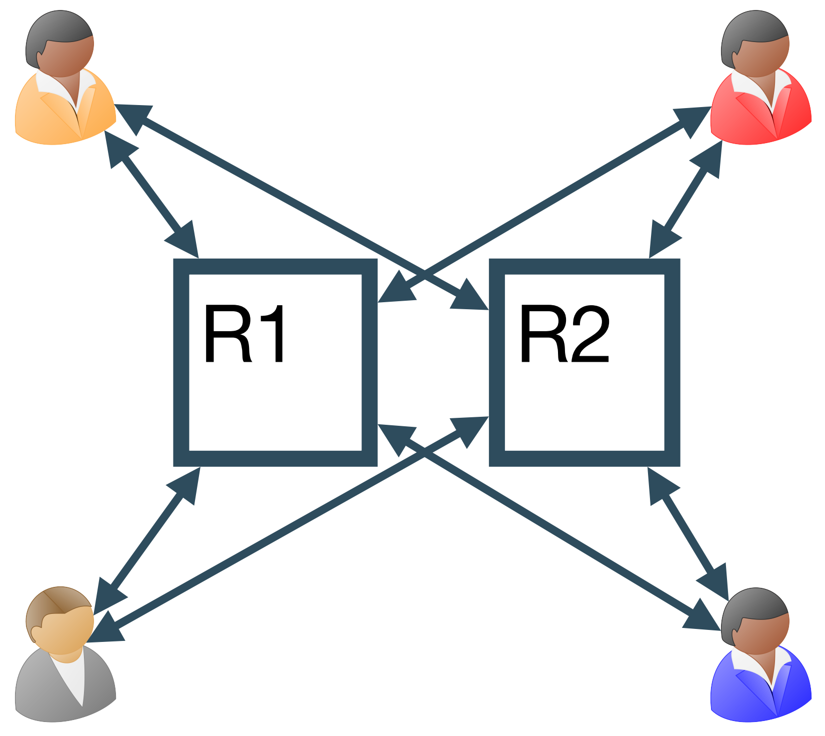

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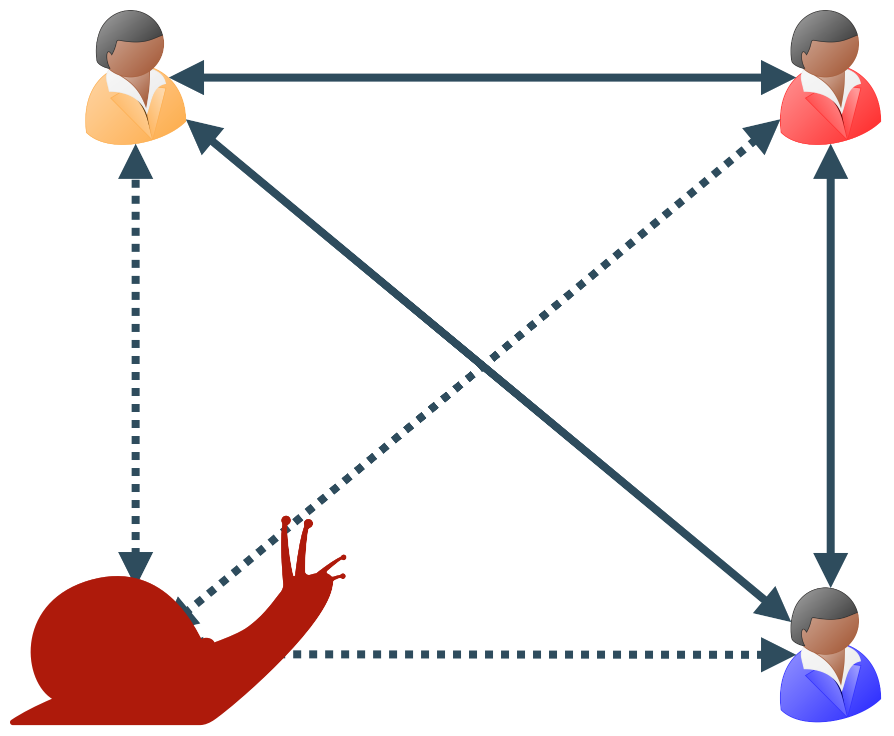

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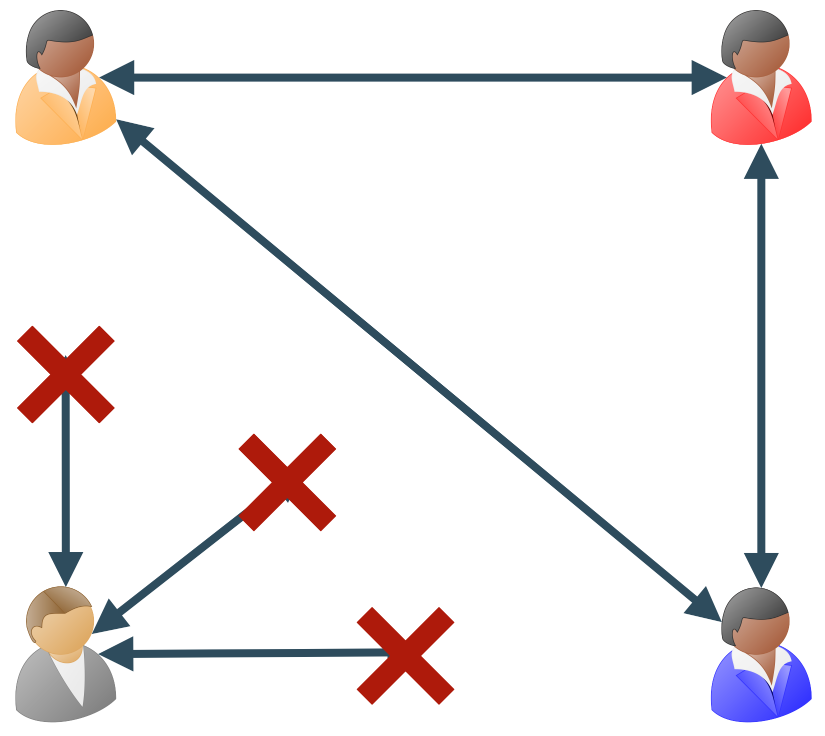
Dynamic participation

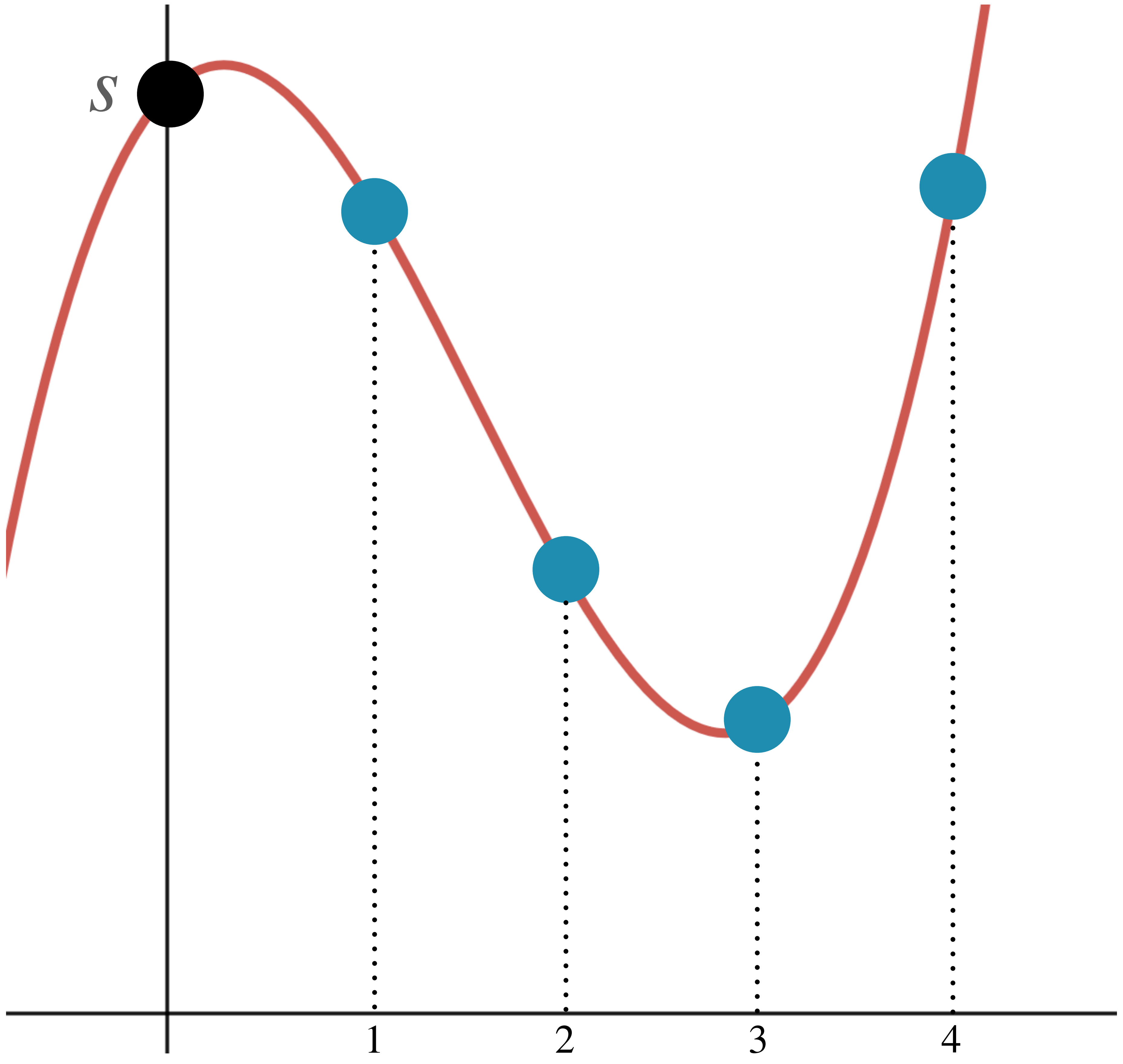
Phoenix: Secure computation in an unstable network with dropouts and comebacks
I. Damgård, D. Escudero, A. Polychroniadou, 2021

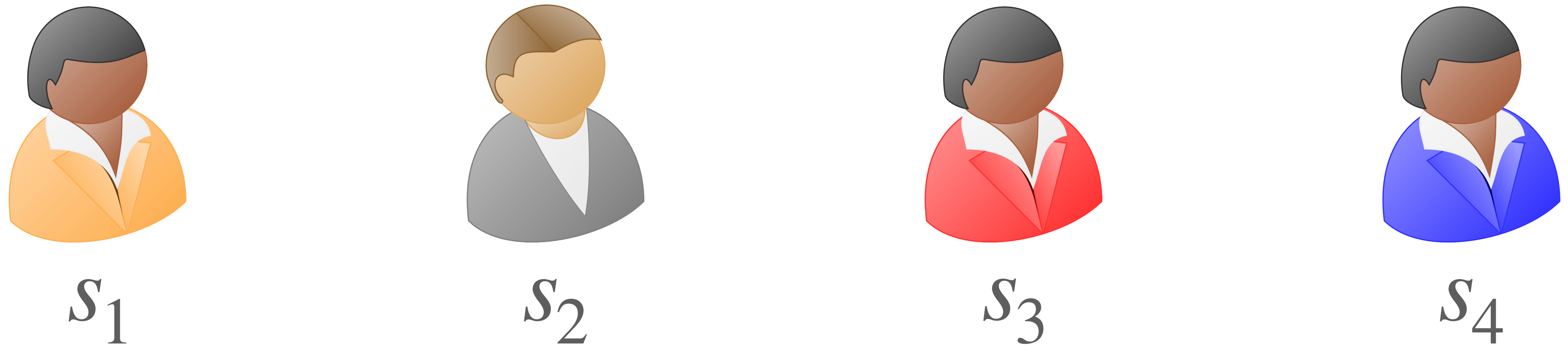


- Parties who dropout are not assumed to receive messages sent while they were offline.
- Requires a certain number of parties to be online from one round to the next one.

Multiparty Computation

Shamir secret sharing





Sharing a secret:

- Sample degree t polynomial such that $p(0) = s$.
- Evaluate $p(x)$ at n public points.
- Give $p(i) = s_i$ to party i.

Reconstructing a secret:

- Parties reveal their shares and reconstruct the polynomial.

Multiparty Computation

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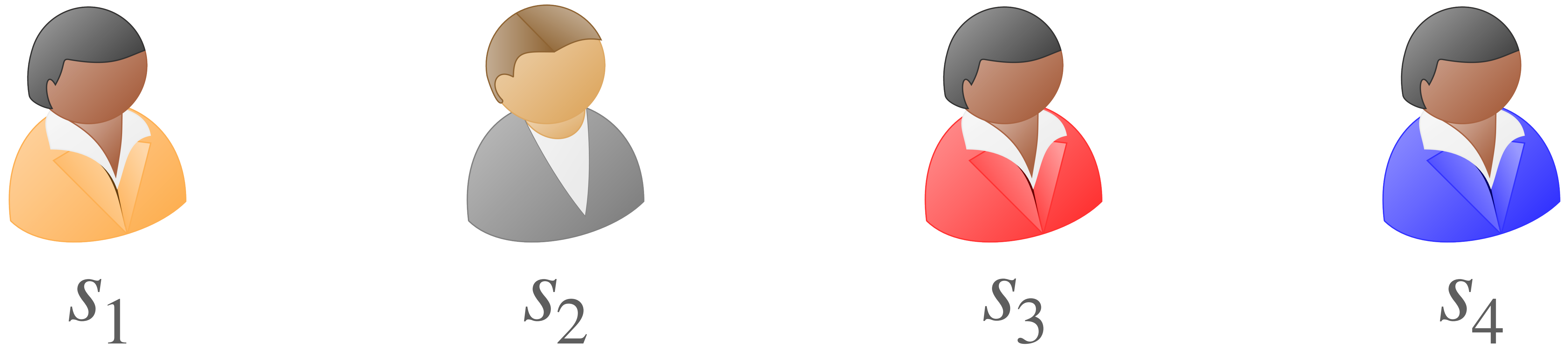
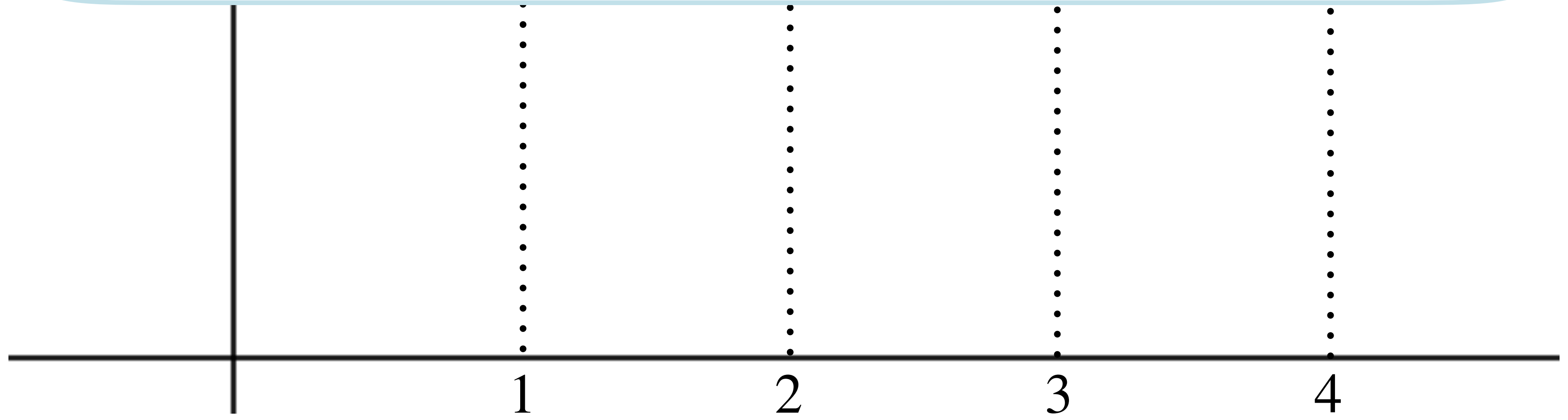


Can have at most t corrupt parties!



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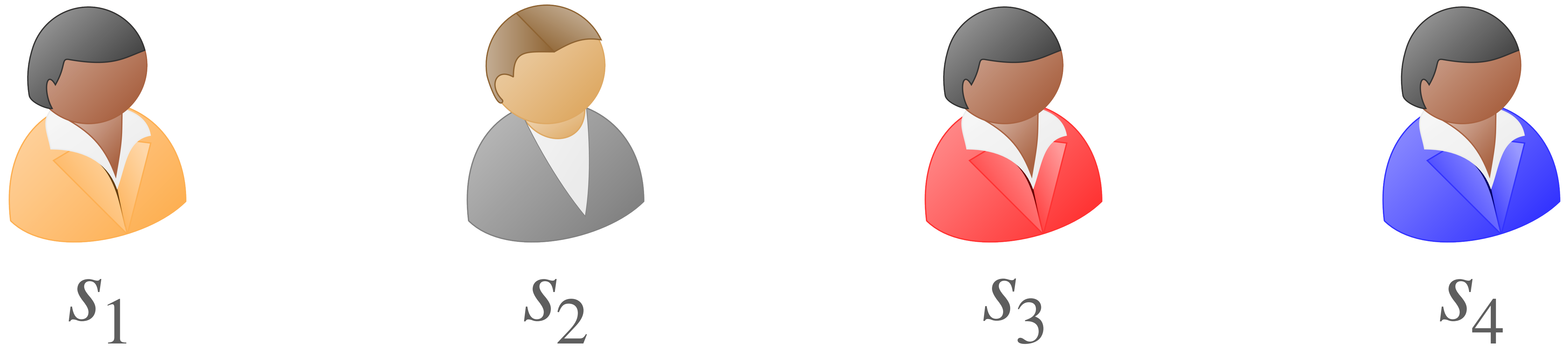

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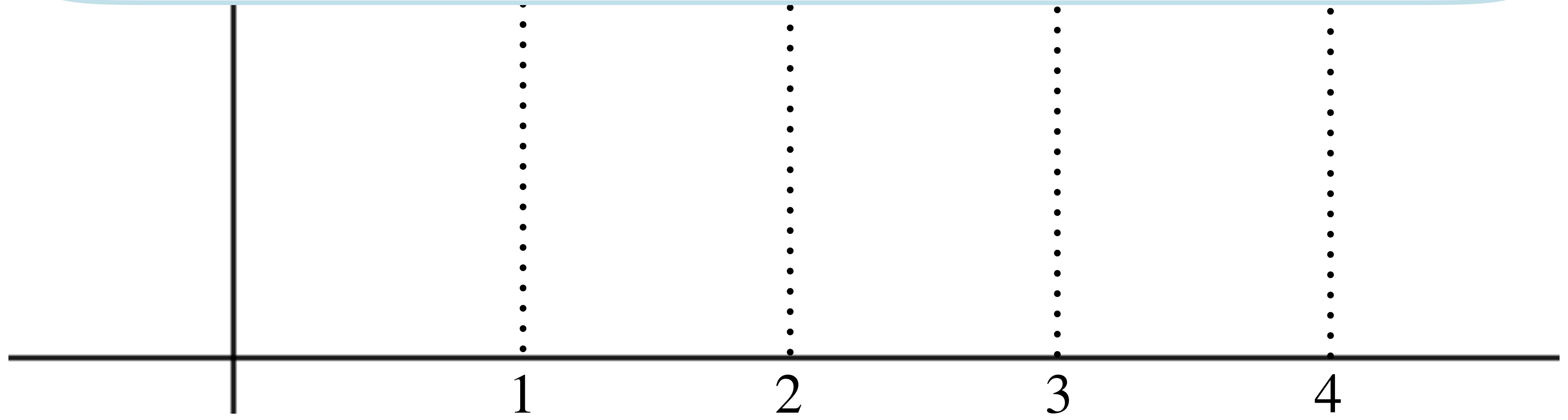
Honest majority: $n \geq 2t + 1$



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Multiparty Computation

Shamir secret sharing

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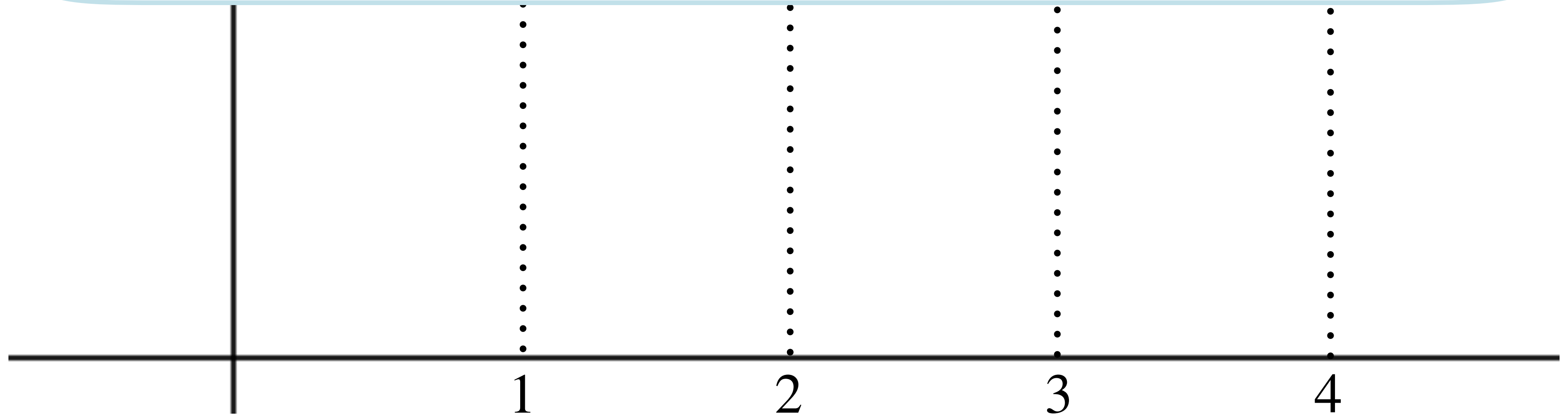
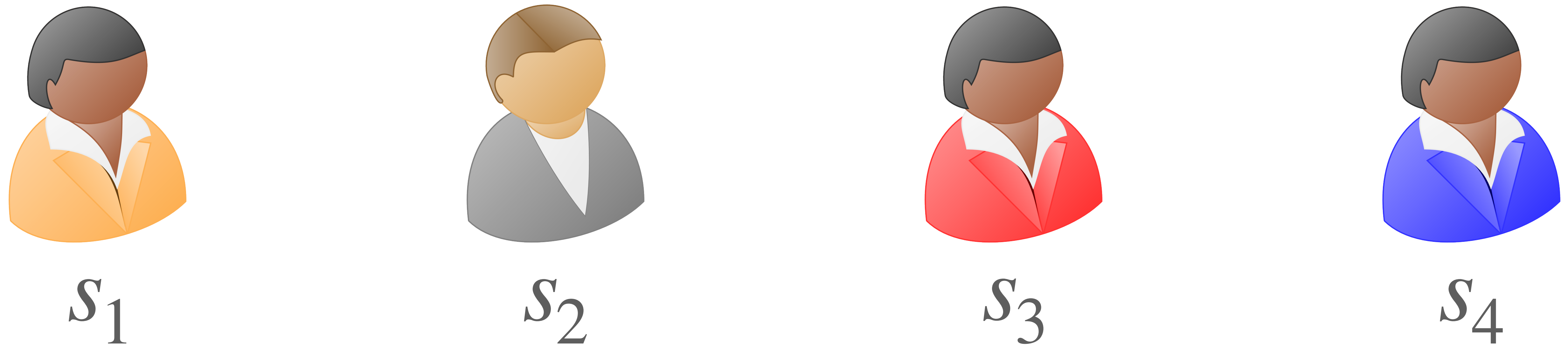
Honest majority: $n \geq 2t + 1$

Strong honest majority: $n > 2t + 1$





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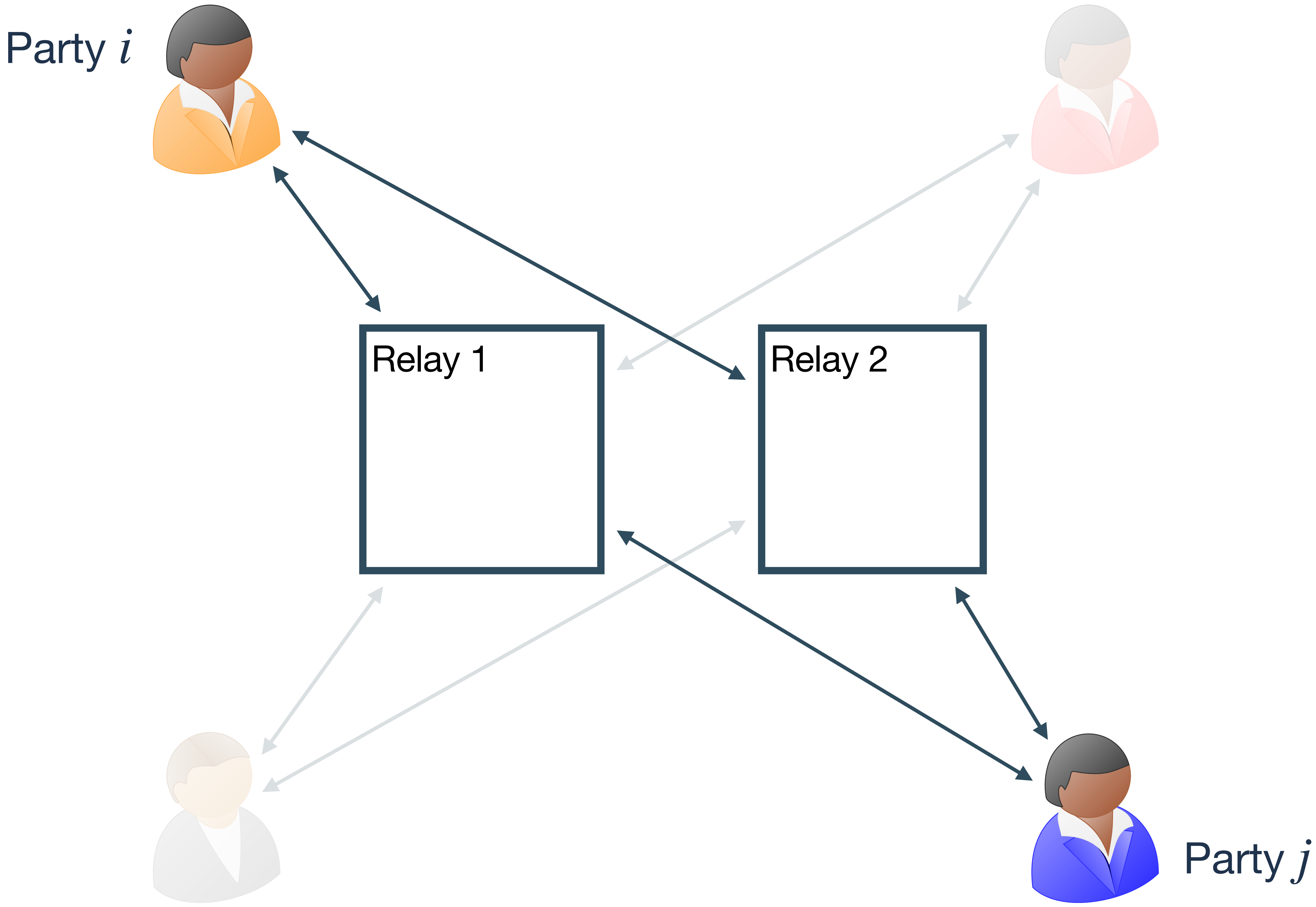
The relays

p2p messages

Broadcast messages

The relays: p2p messages



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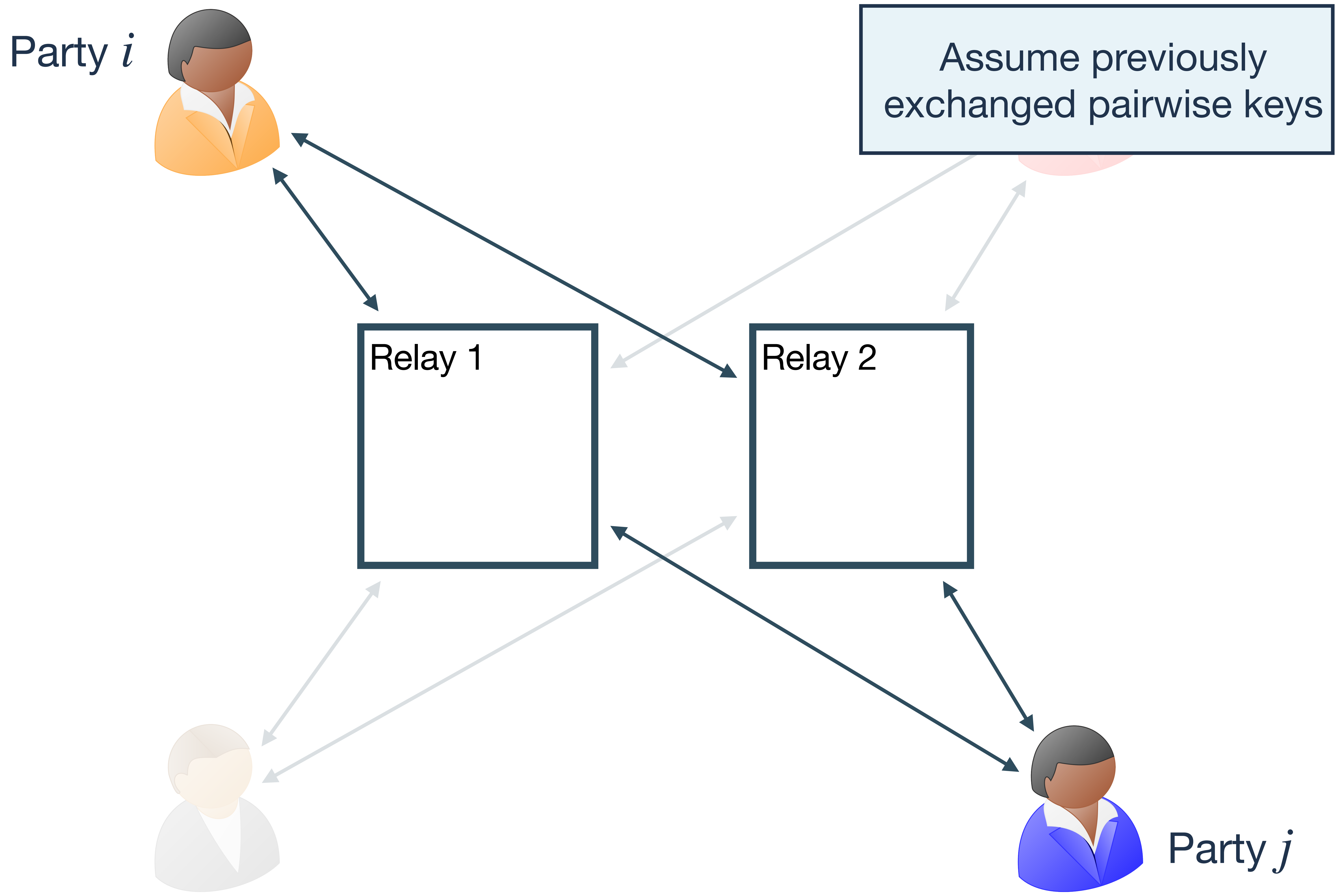

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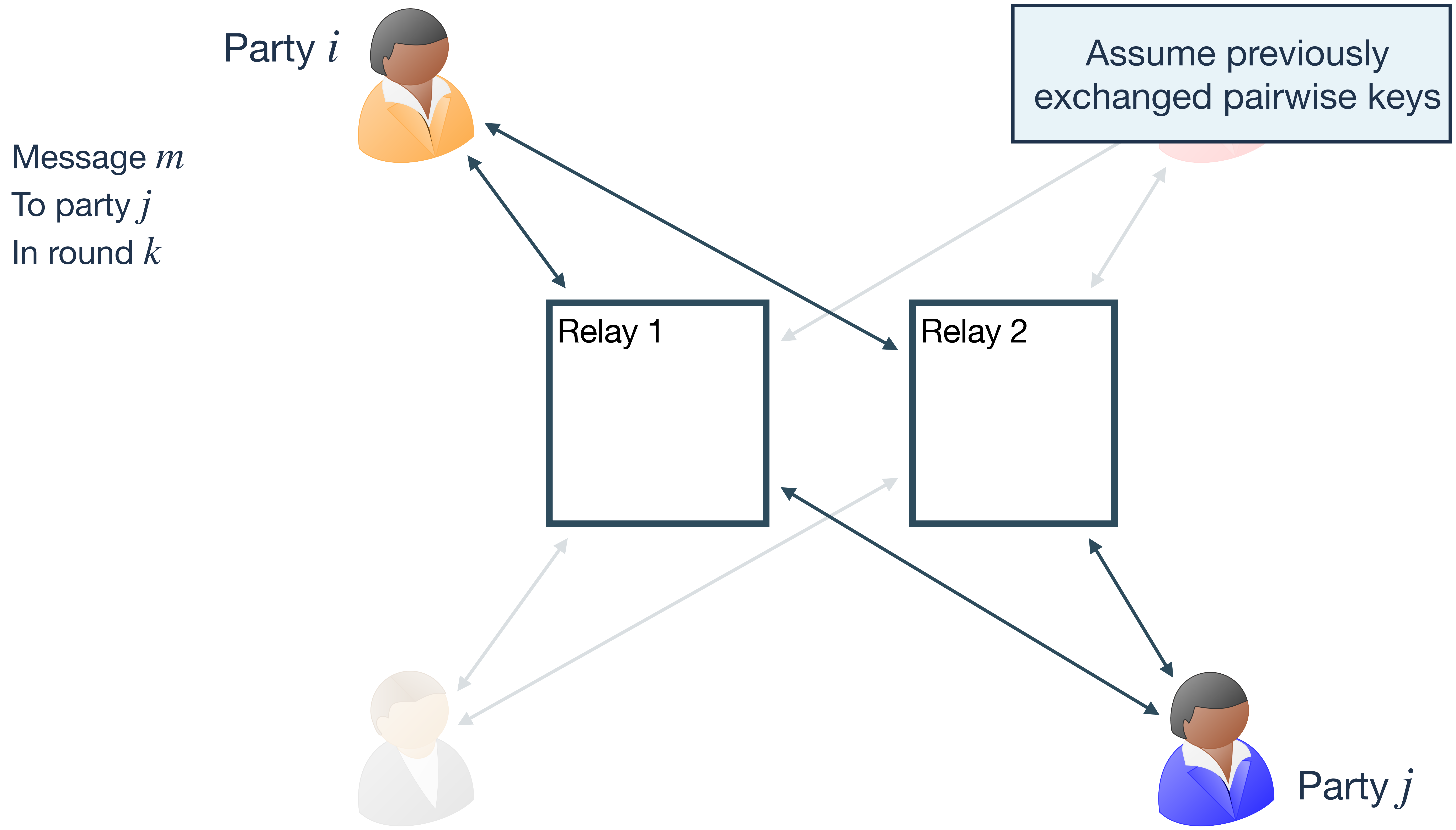
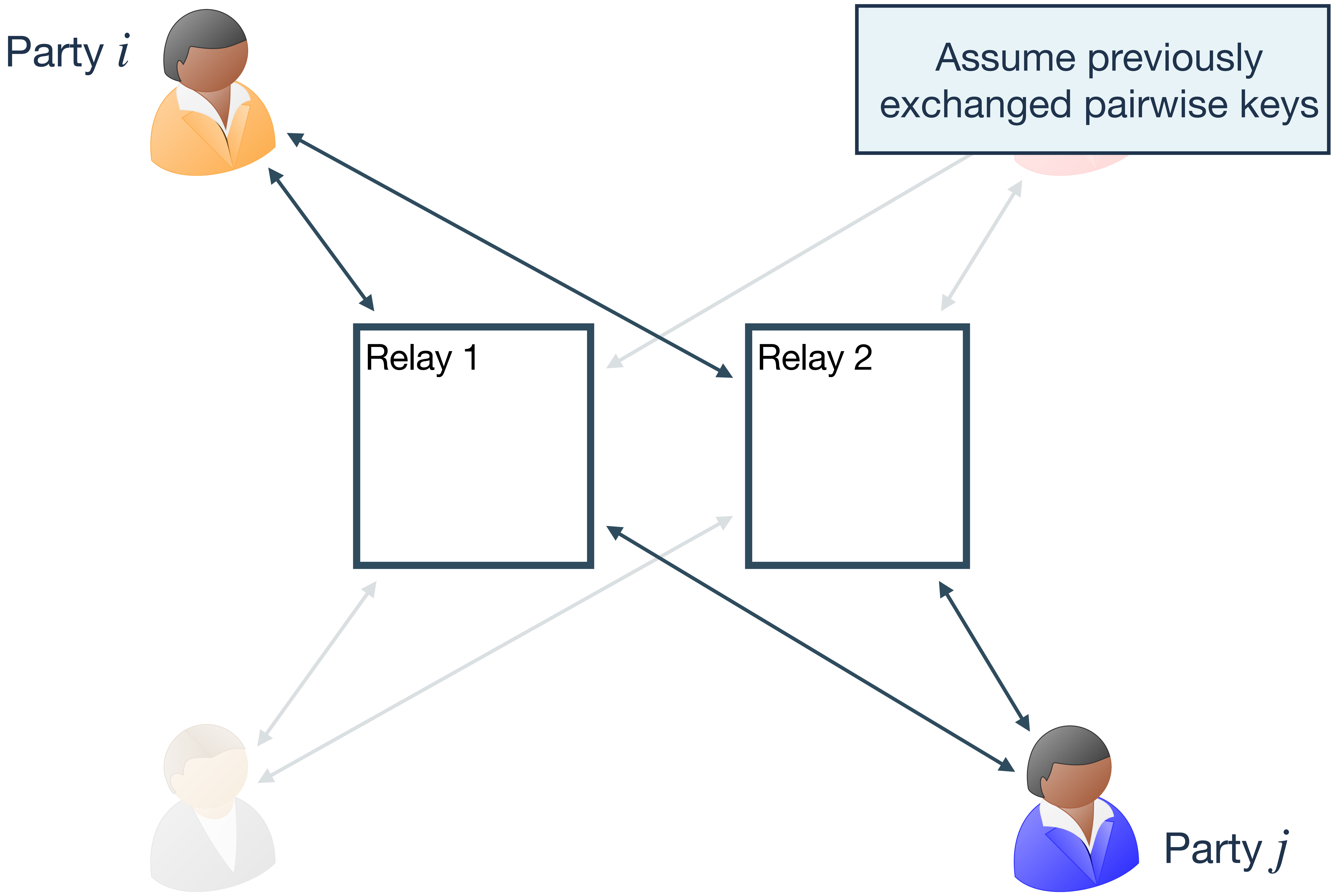


The relays: p2p messages

Message m
To party j
In round k

$c_{i,j,k} = \text{Enc}(m)$



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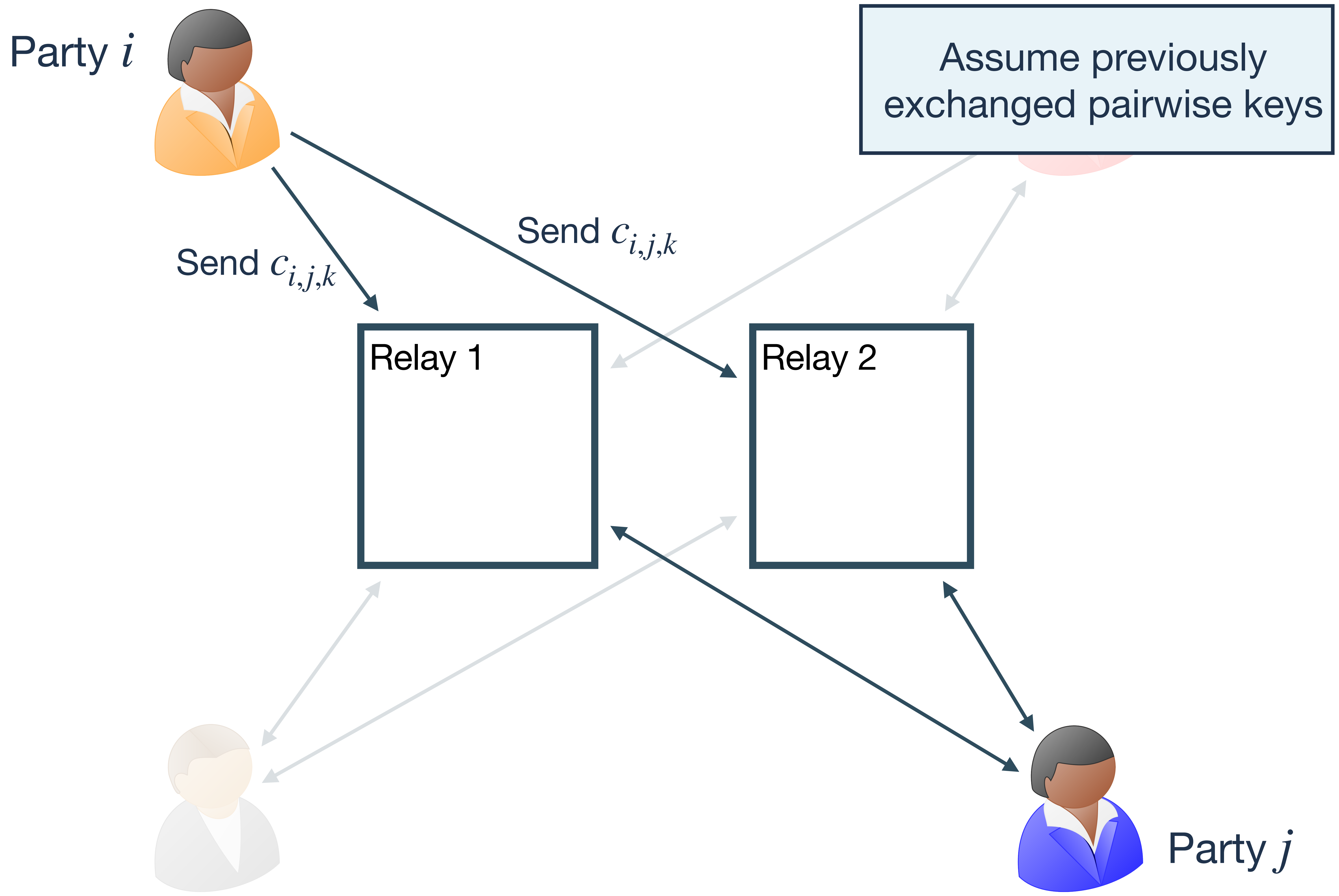

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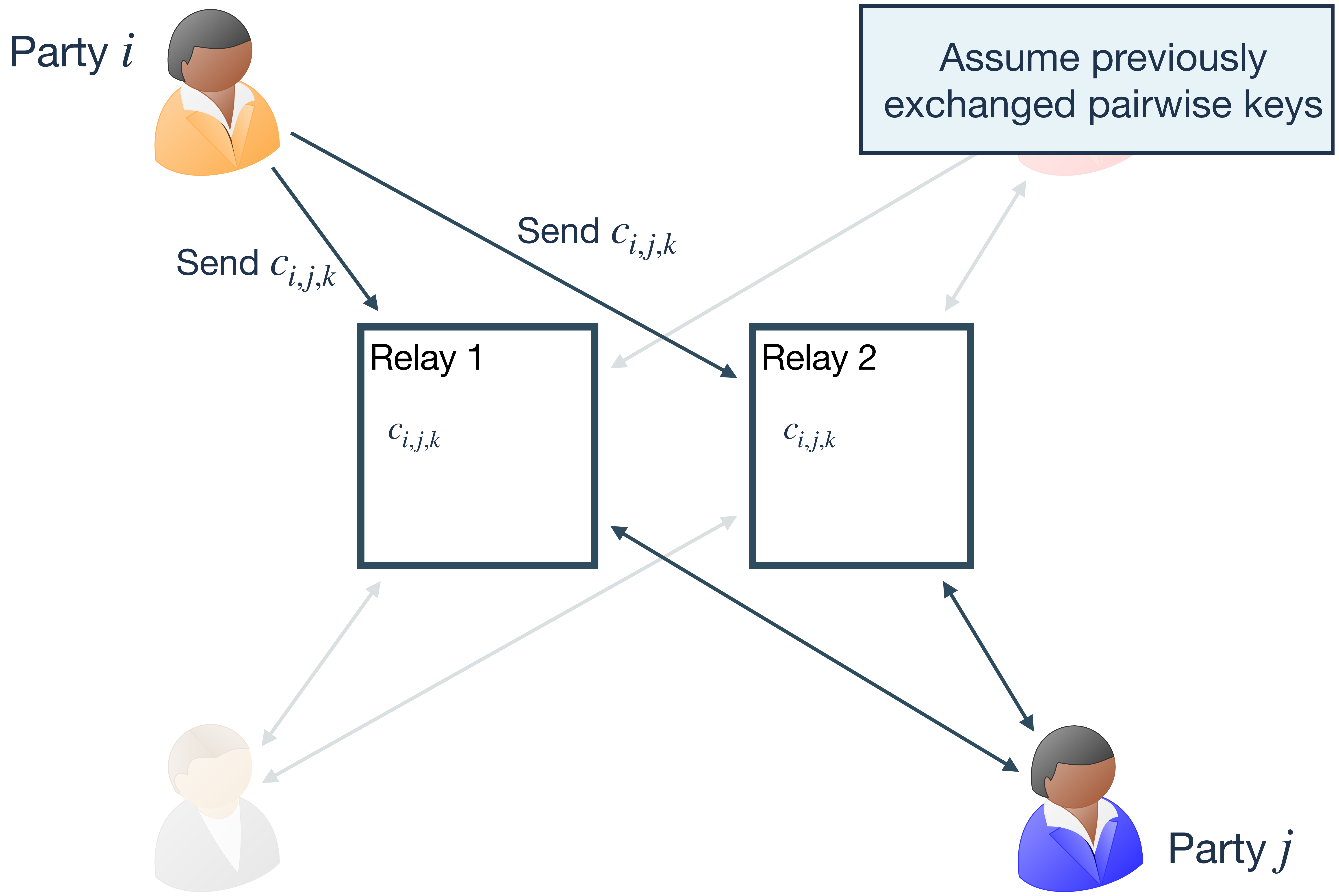

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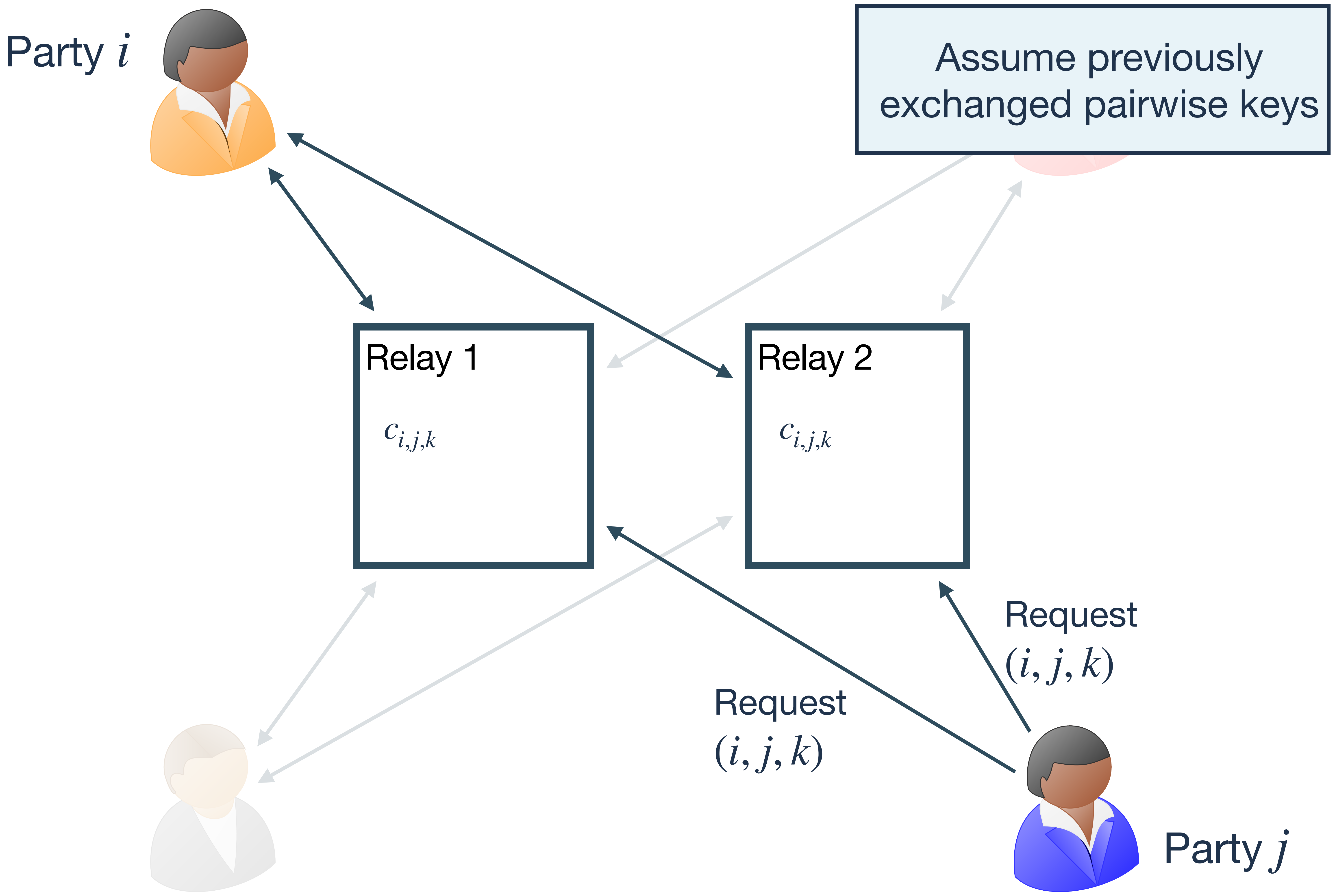

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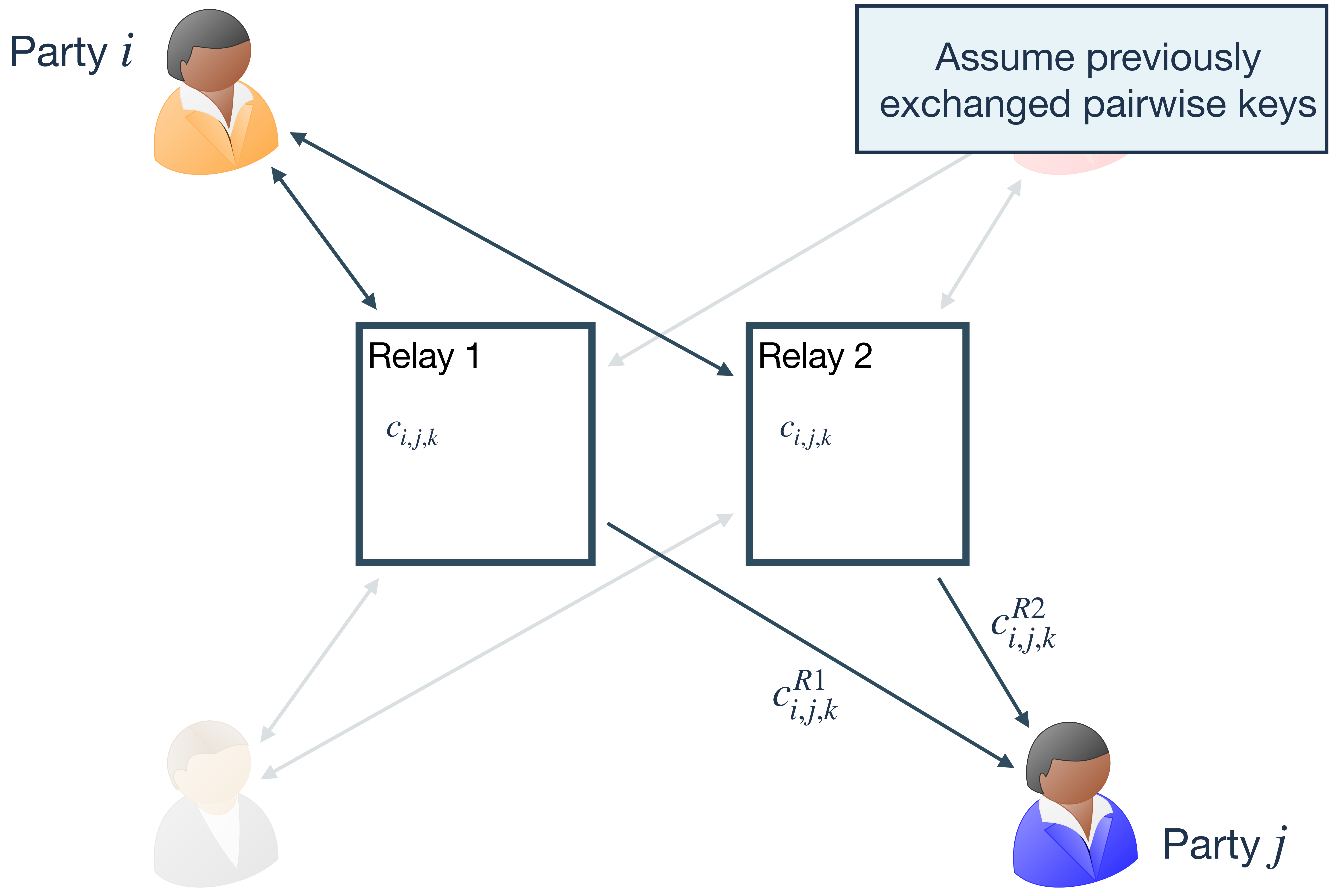

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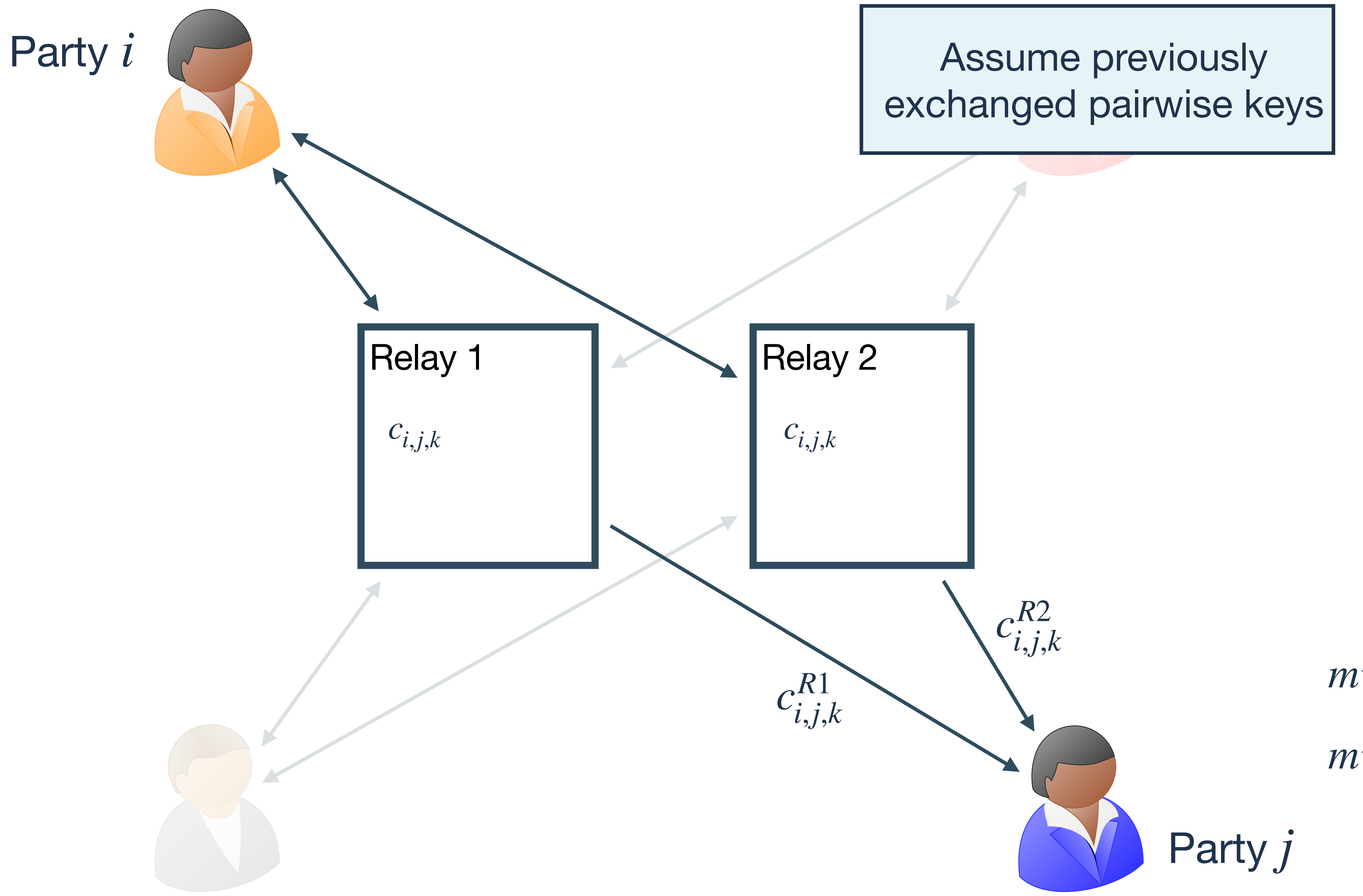


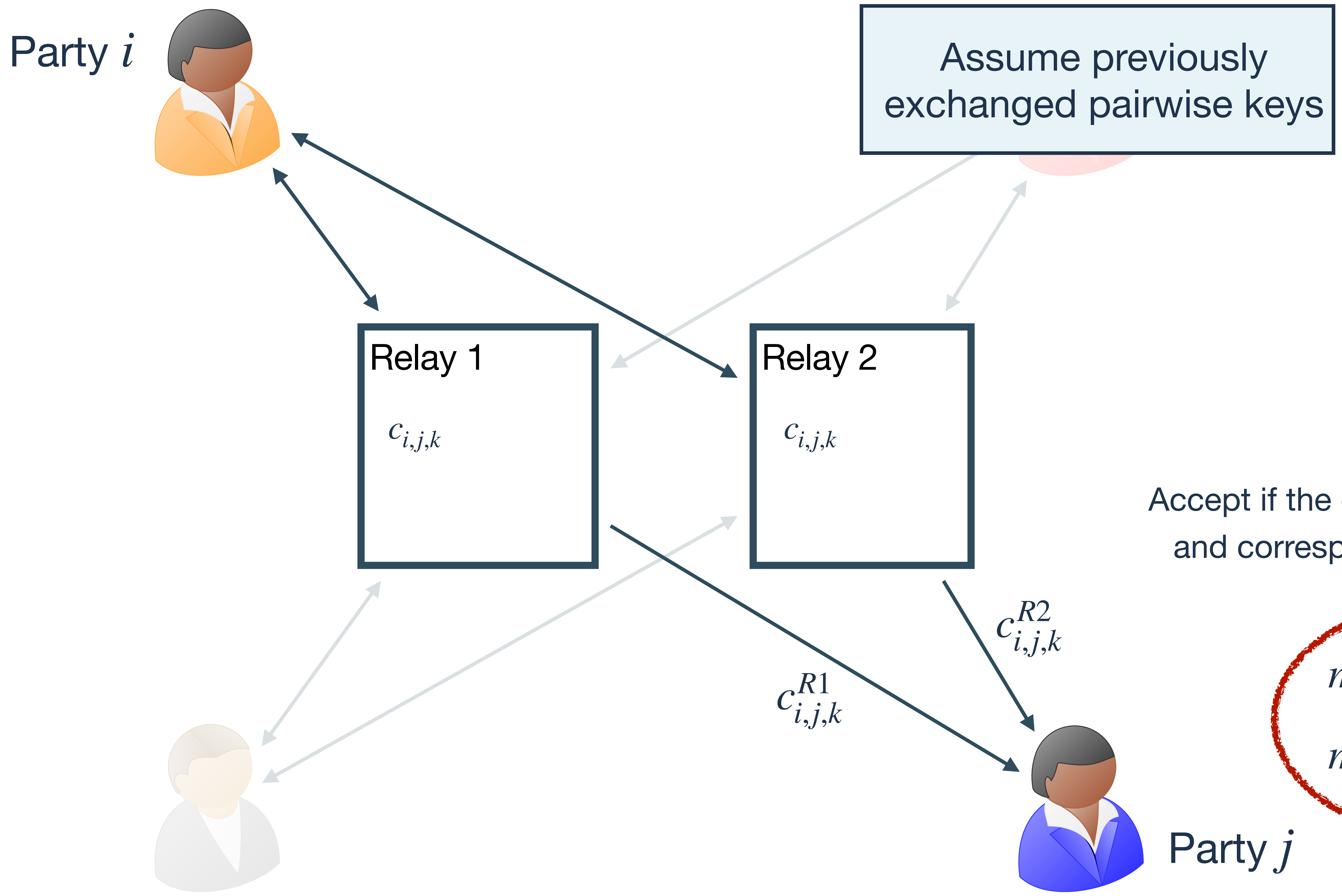
$m^{R1} = \text{Dec}(c^{R1}_{i,j,k})$

$m^{R2} = \text{Dec}(c^{R2}_{i,j,k})$

The relays: p2p messages

Message m
To party j
In round k

$c_{i,j,k} = \text{Enc}(m)$



Accept if the decryption happens correctly and corresponds to the same message

$m^{R1} = \text{Dec}(c^{R1}_{i,j,k})$

$m^{R2} = \text{Dec}(c^{R2}_{i,j,k})$

The relays

p2p messages

From party i to party j.

Commands:

Send: stores encrypted message to party j, round $k_{i,j}$

Request: retrieves message from i to j, round $k_{i,j}$

Erase: erases message from i to j, round $k_{i,j}$

Relay maintains:

- Pairwise message counter $k_{i,j}$
- Pairwise deleting counter $d_{i,j}$

Broadcast messages

The relays

p2p messages

From party i to party j.

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Relay maintains:

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- Pairwise deleting counter $d_{i,j}$

Broadcast messages

From party i to all other parties.

Commands:

SendToAll: stores plaintext message to all parties, round k^{all}

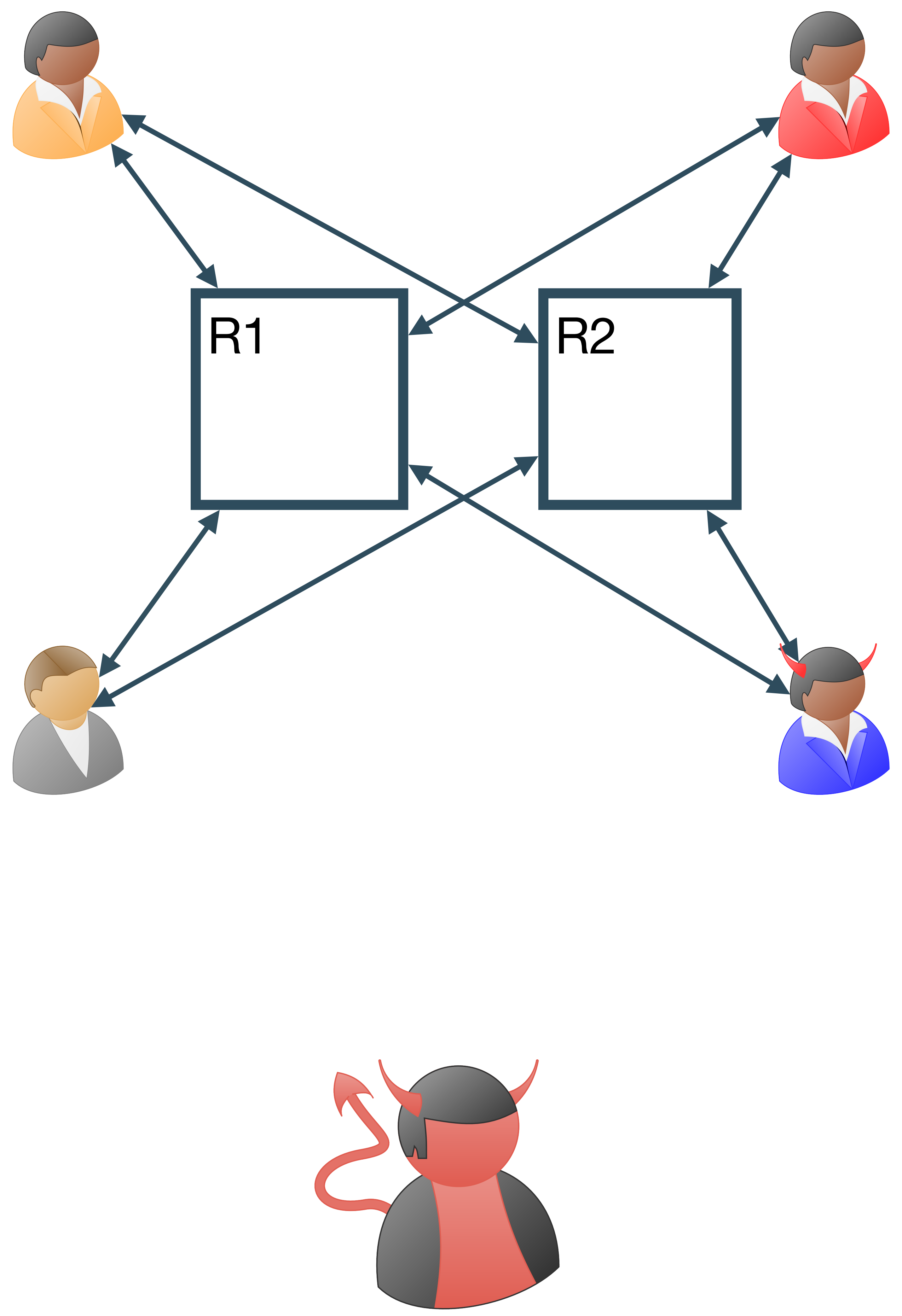
RequestFromAll: retrieves all messages for round k^{all}

EraseAll: erases all messages for round k^{all}

Relay maintains:

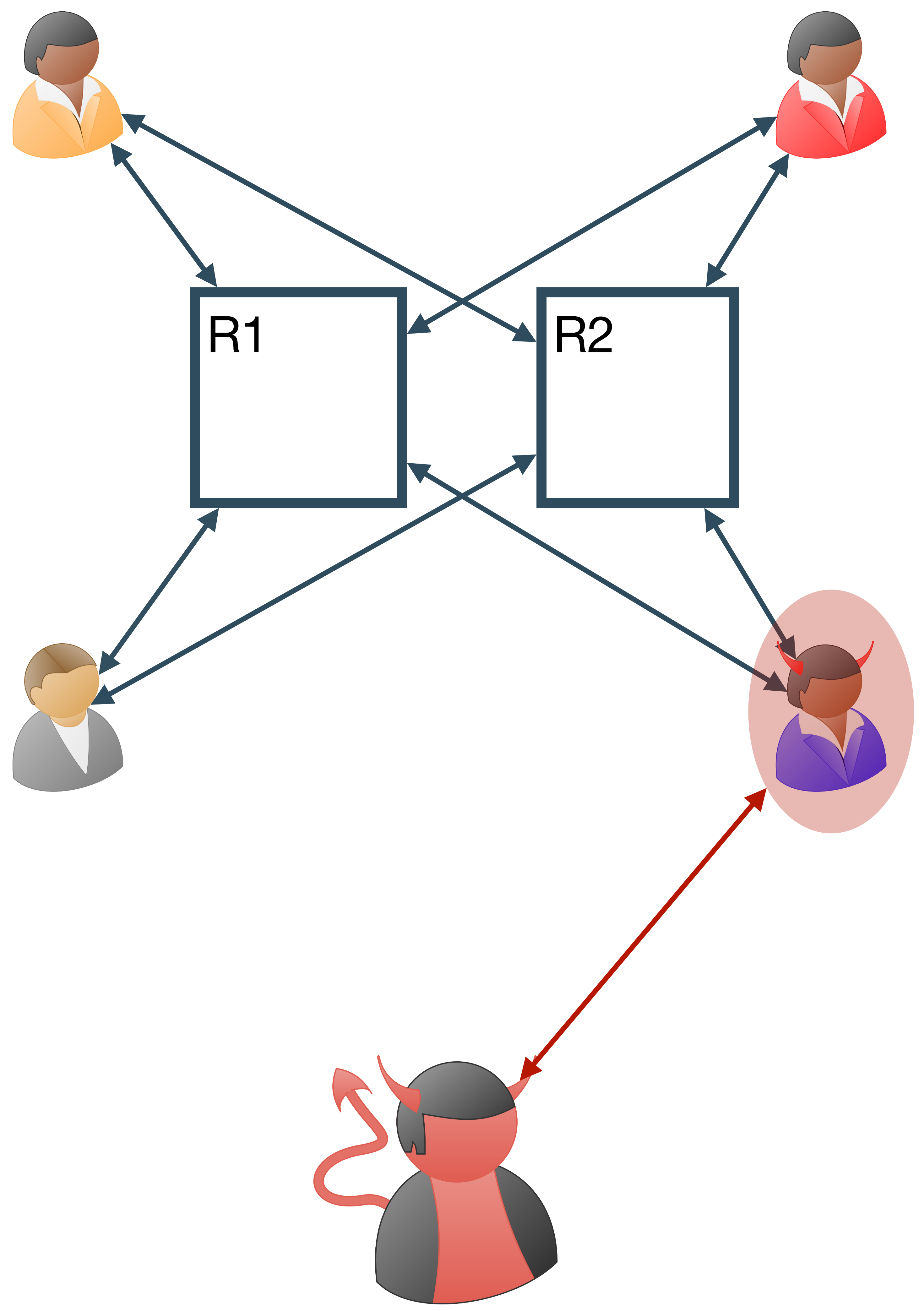
- Global message counter k^{all}
- Global deleting counter d^{all}

The adversary



The adversary

- Can corrupt up to $t < n/2$ parties (static corruption)



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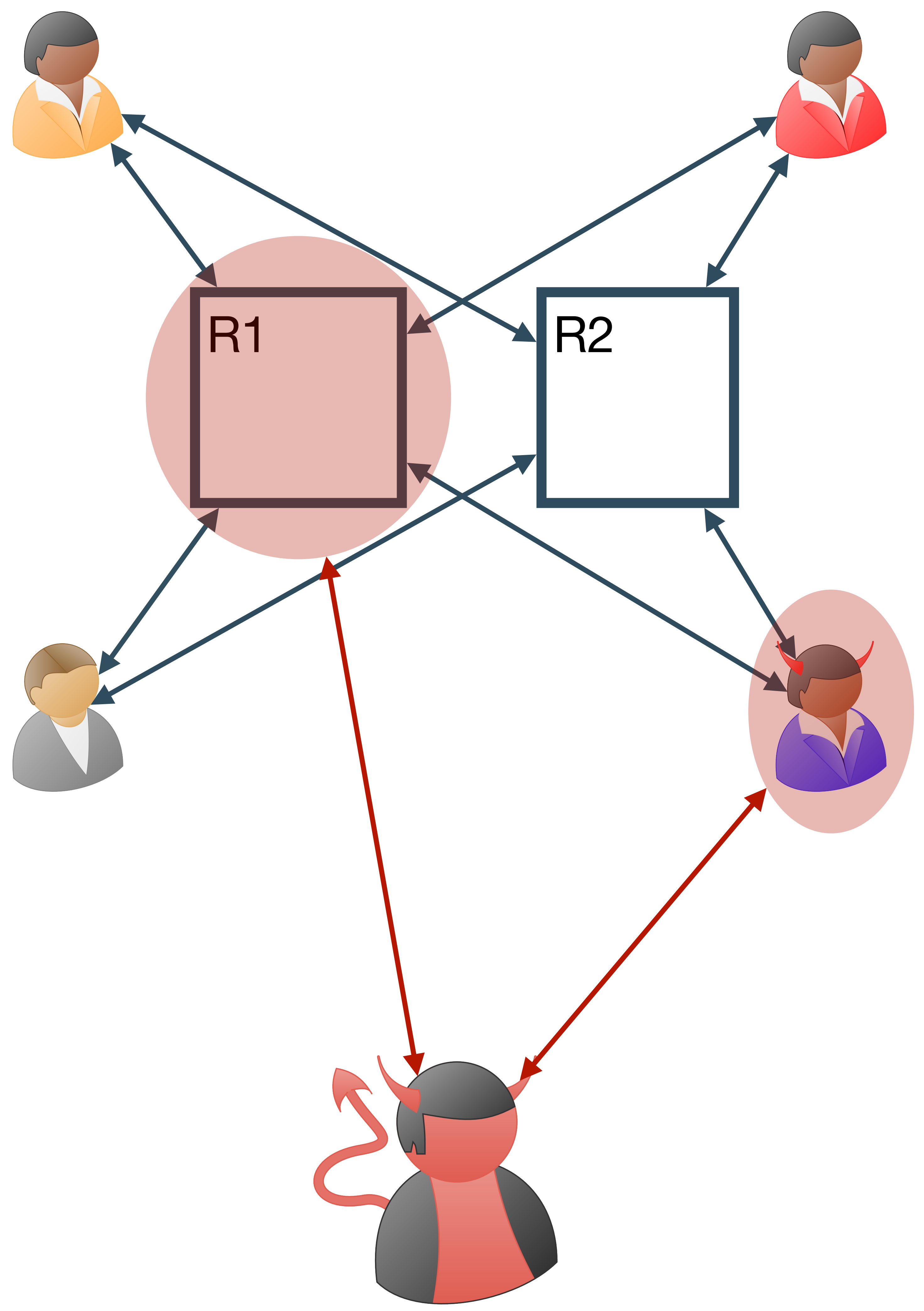

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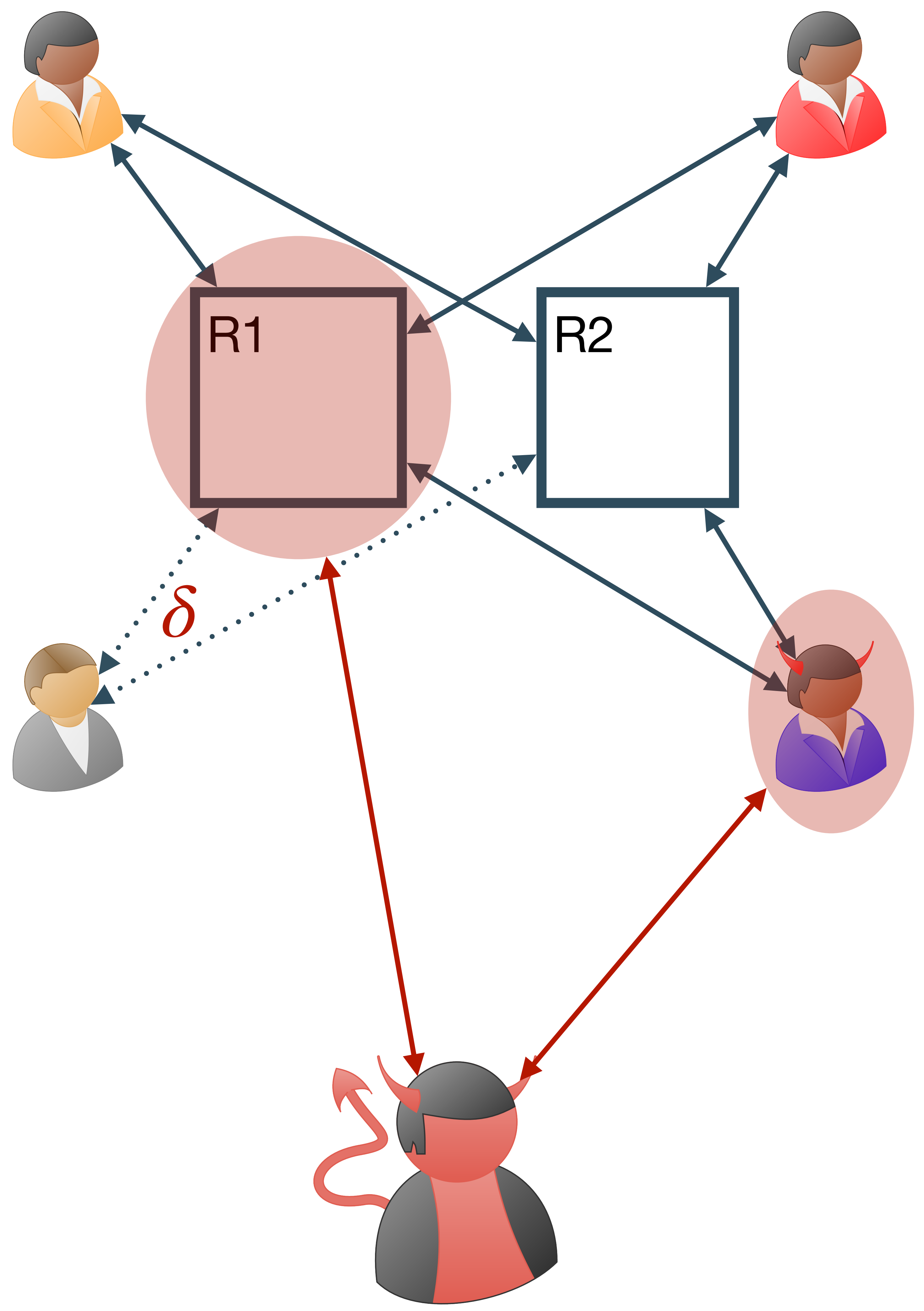
- Can delay an arbitrary number of parties for up to δ rounds



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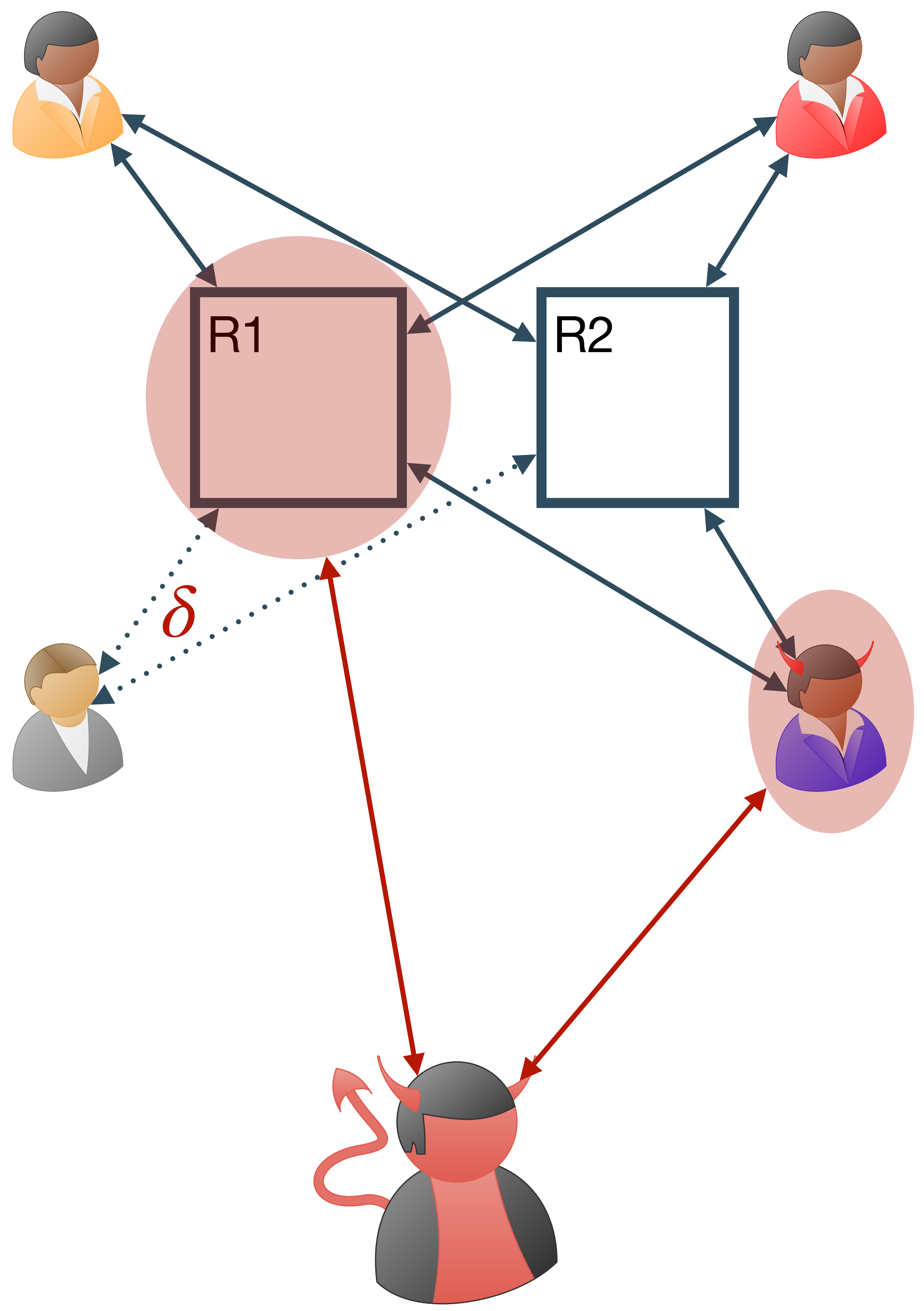


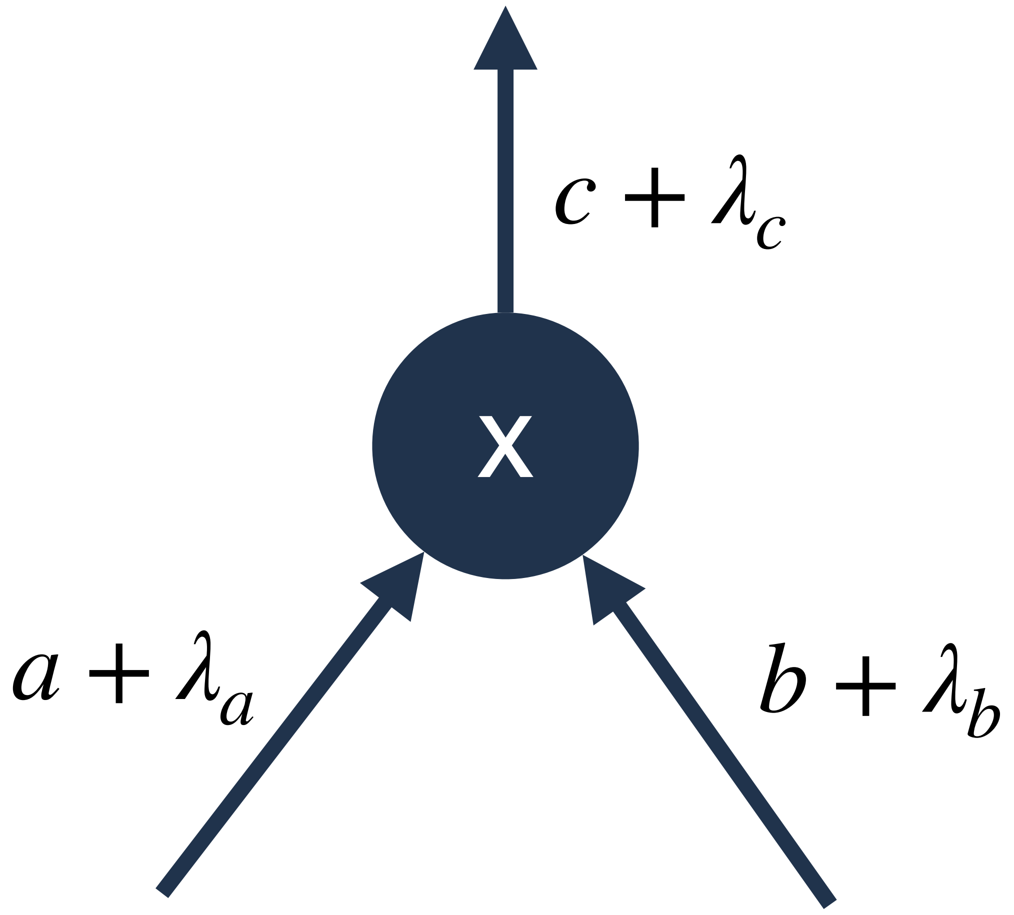
We present an MPC protocol that achieves passive security against this adversary.

Malicious security

Passive security with **additive attacks**

Circuits resilient to additive attacks with applications to secure computation.
Genkin et al. [GIP+14]

Active security with abort



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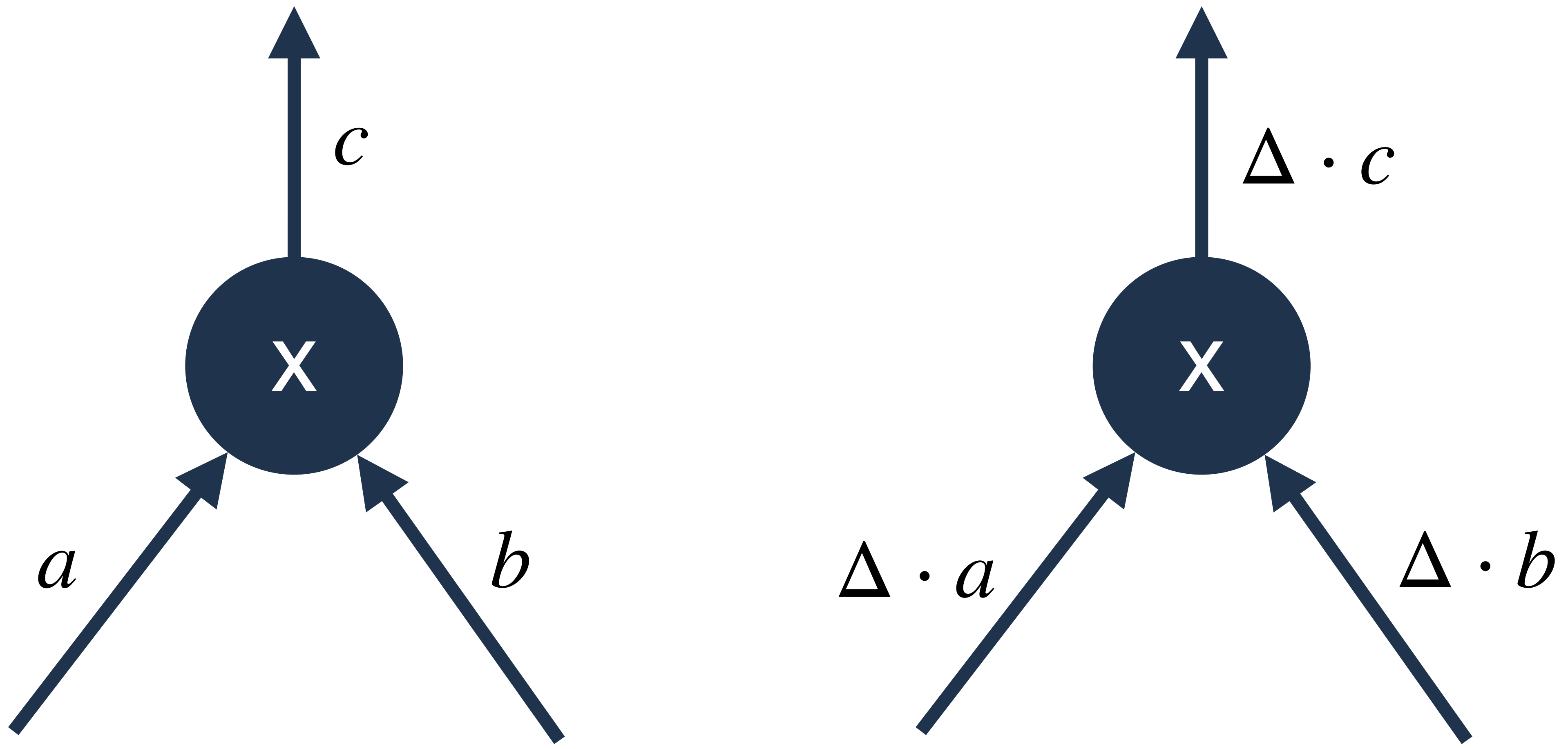

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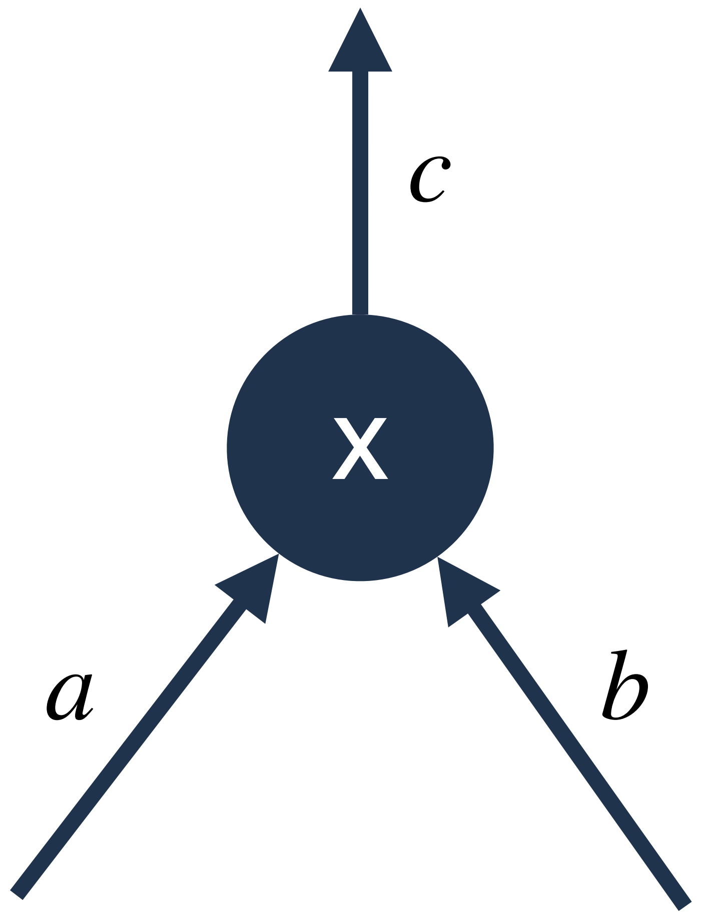

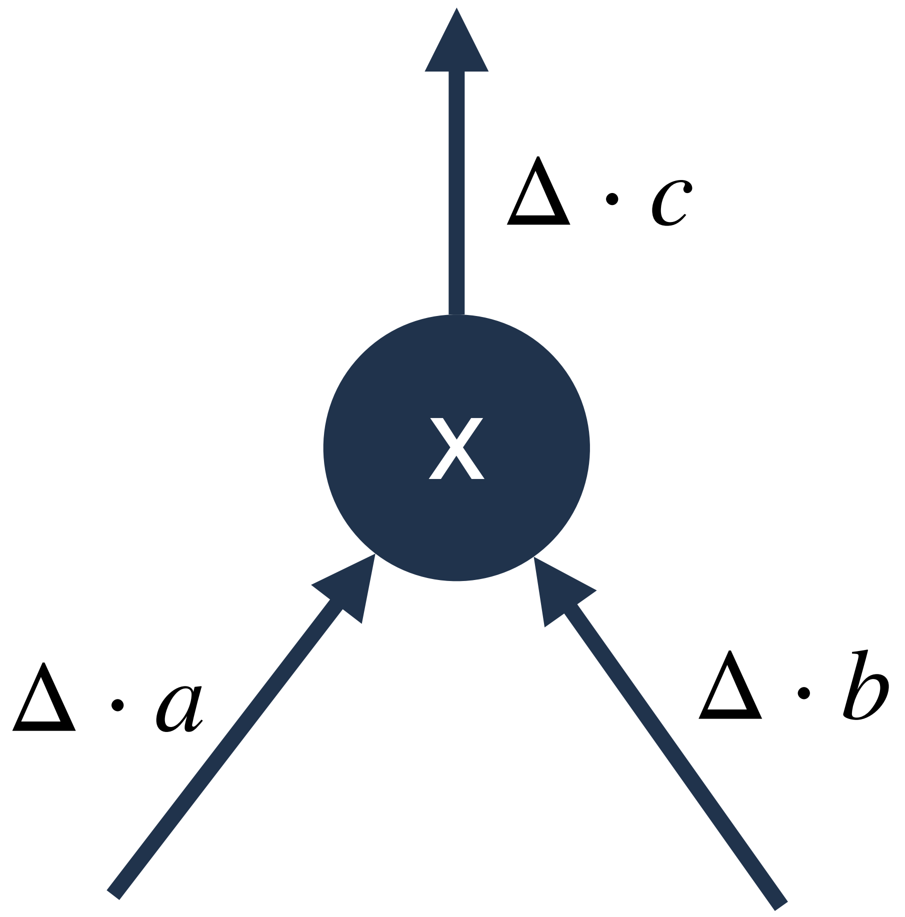

Progressively compute checking equation to avoid having to store large states (similar to FluidMPC [CGG+21])

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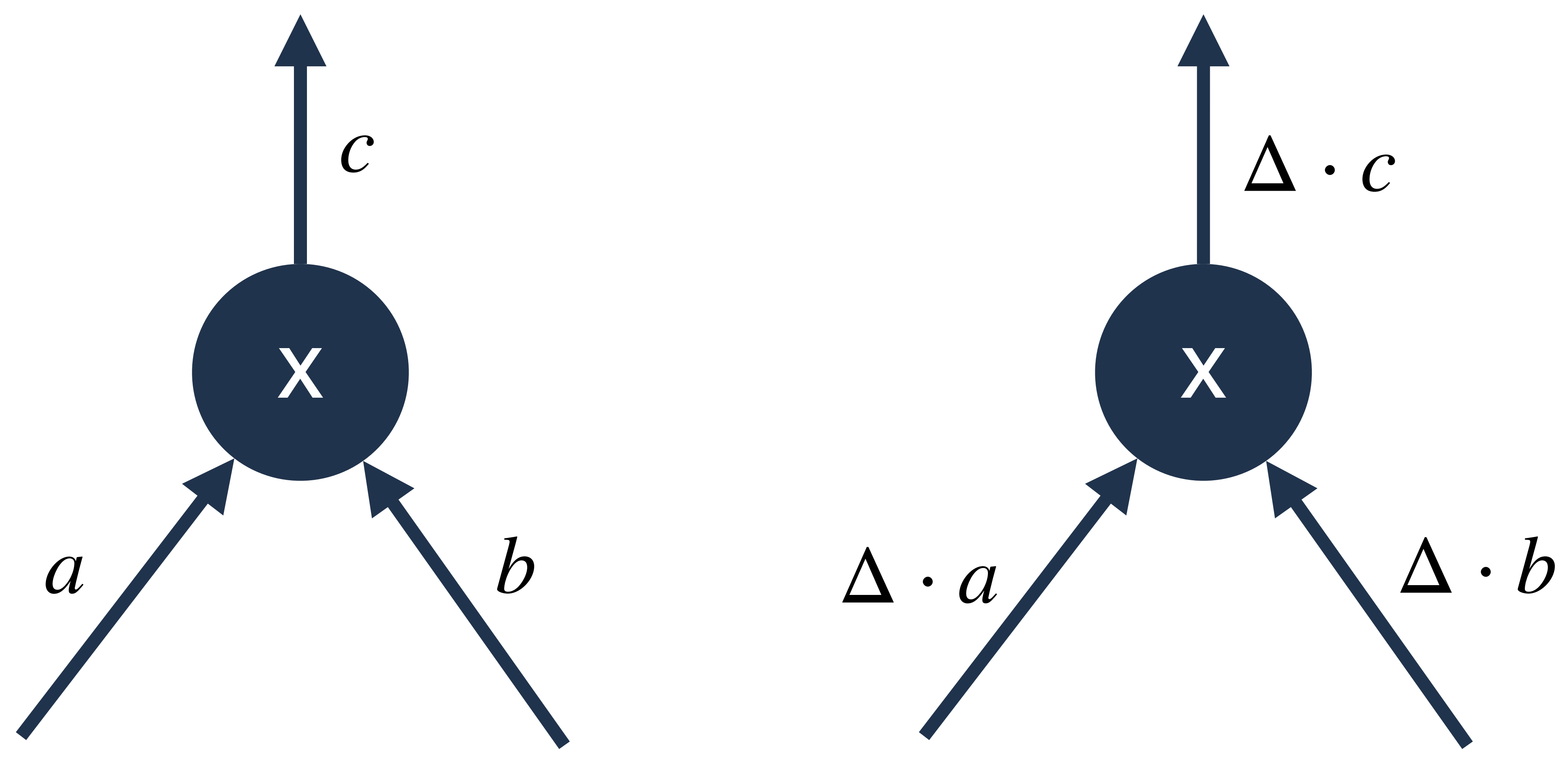


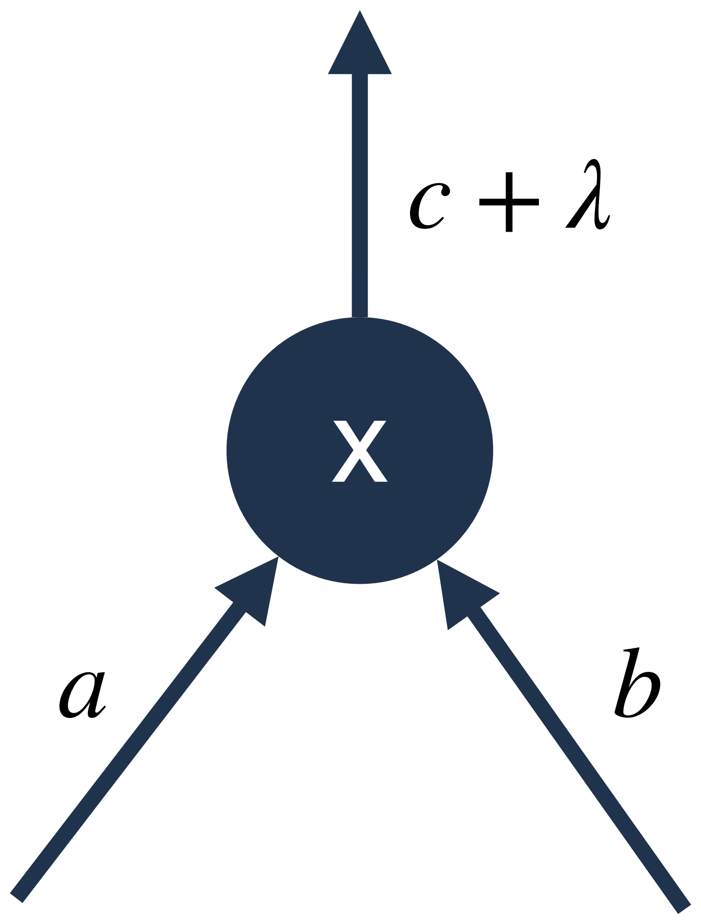
We want to obtain an MPC protocol that is **secure up to additive attacks**

Multiplication protocols

Calculating $[z] = [x] \cdot [y]$

Maurer multiplication

1. Parties locally multiplies their shares to obtain: $[v]_{2t} = [x \cdot y]_{2t} = [x]_t \cdot [y]_t$
2. Each party i distributes a degree t secret sharing $[v_i]_t$ of v_i among the other parties
3. Parties use their shares of the $[v_i]_t$ to calculate $[z]$.



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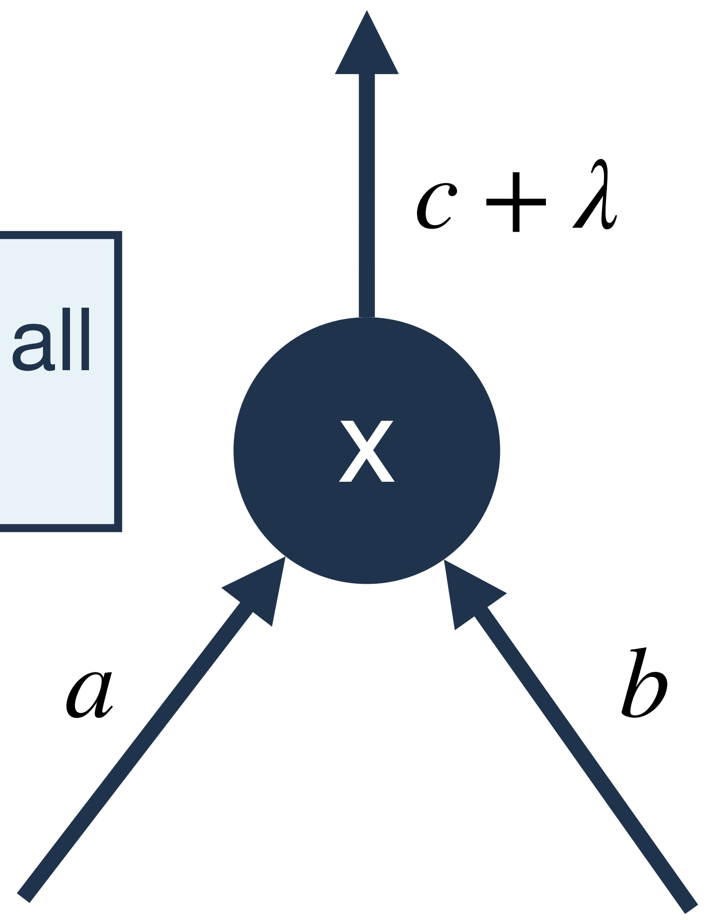
λ is not uniquely determined for all parties



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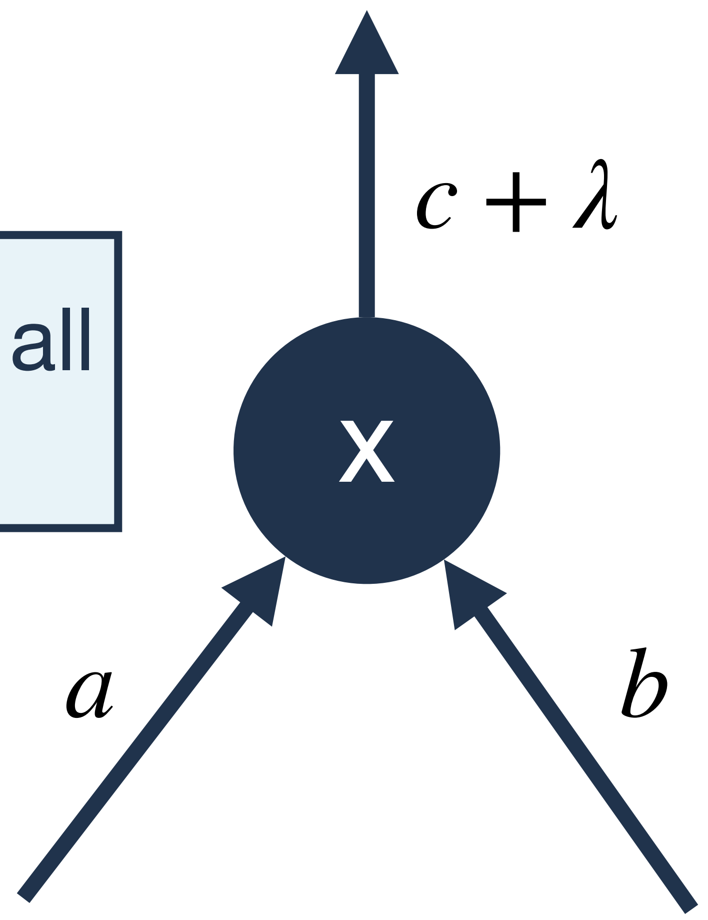

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Damgård-Nielsen multiplication

1. Use a PRSS to generate a degree t and a degree $2t$ sharing of the same random value: $[r]_t, [r]_{2t}$
2. Parties locally calculate: $[v]_{2t} = [x]_t \cdot [y]_t + [r]_{2t}$
3. Each party i sends v_i to party 1. Party 1 reconstructs v and reveals it to all
4. Parties calculate $[z] = v - [r]_t$

Multiplication protocols

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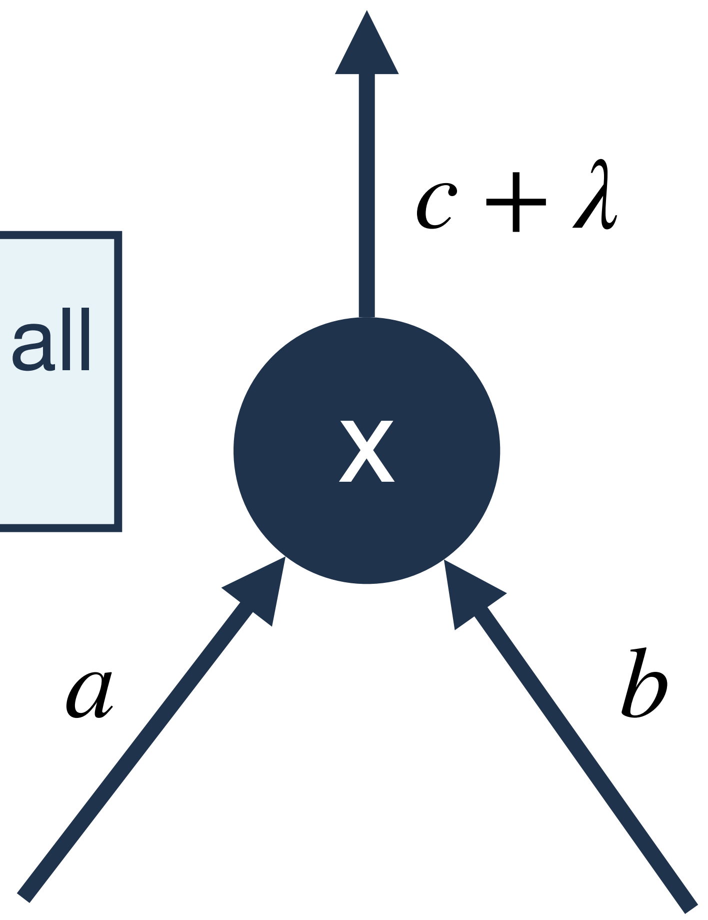

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3. Each party i sends v_i to party 1. Party 1 reconstructs v and reveals it to all
4. Parties calculate $[z] = v - [r]_t$

Double-dipping attack when $n > 2t + 1$

Communication-efficient unconditional MPC with guaranteed output delivery
V. Goyal, Y. Liu, Y. Song, 2019

Multiplication protocols

1-Round Damgård-Nielsen multiplication

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3. Each party i broadcasts v_i . All parties locally reconstruct v.
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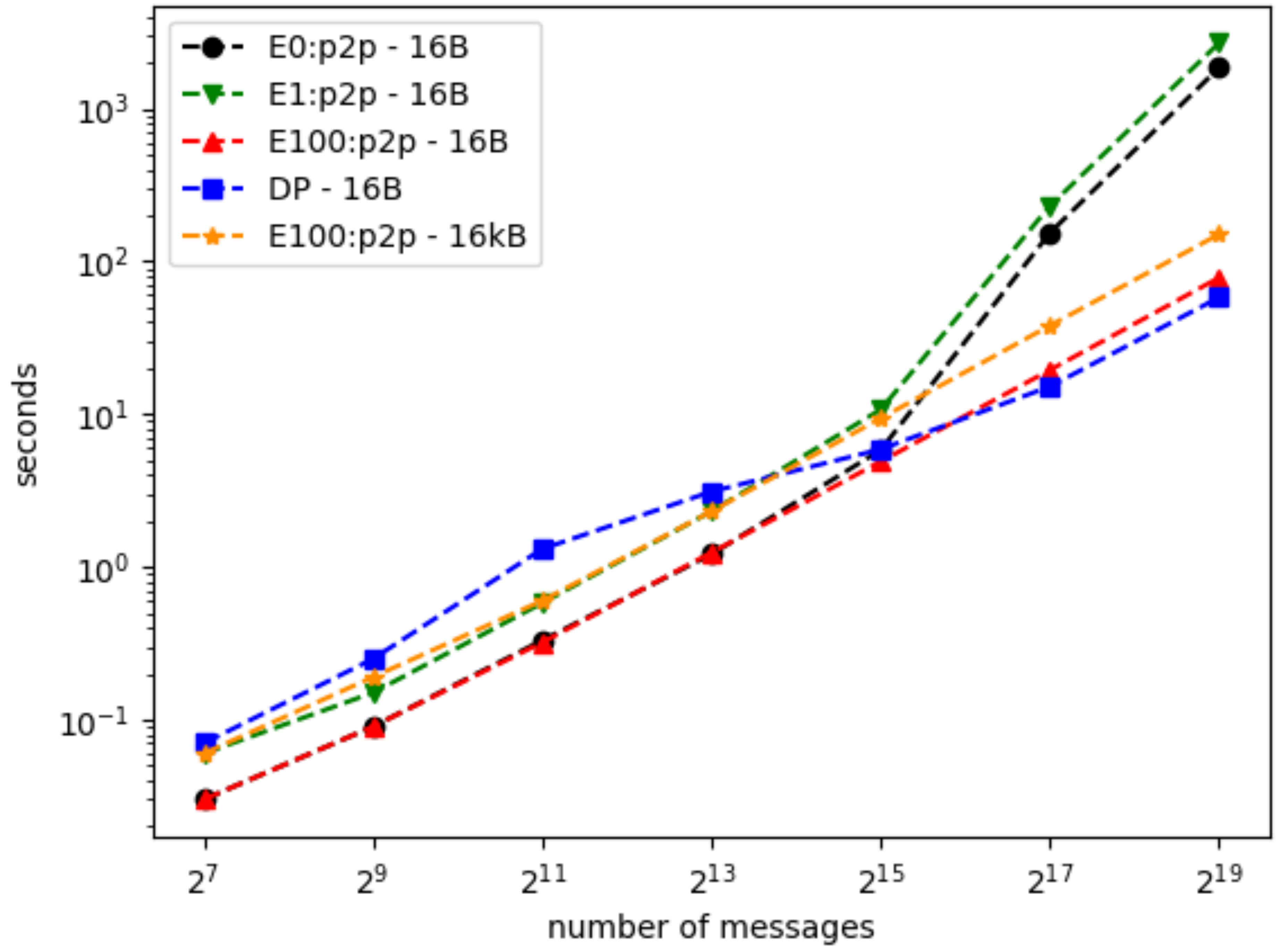
Broadcast in a relay based network is cheap!

Experimental results

Network: relays vs direct connections

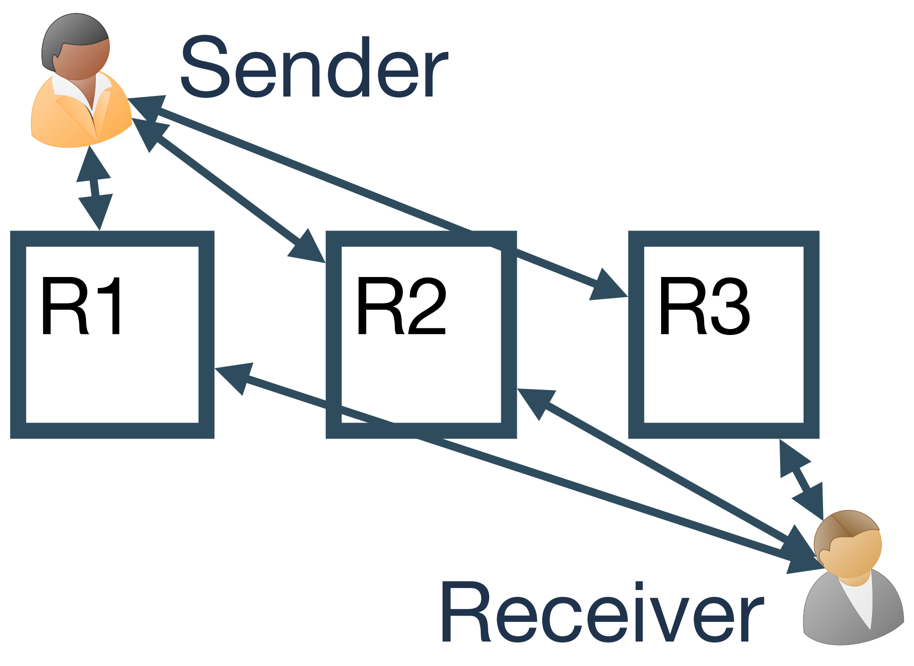
Running time for sending p2p messages.



Experiments:

- **E0**: never erase messages
- **E1**: erase every message after retrieval
- **E100**: erase in batches of 100 messages
- **DP**: communication without relays
- **E100 with large messages**

2 parties
3 relays



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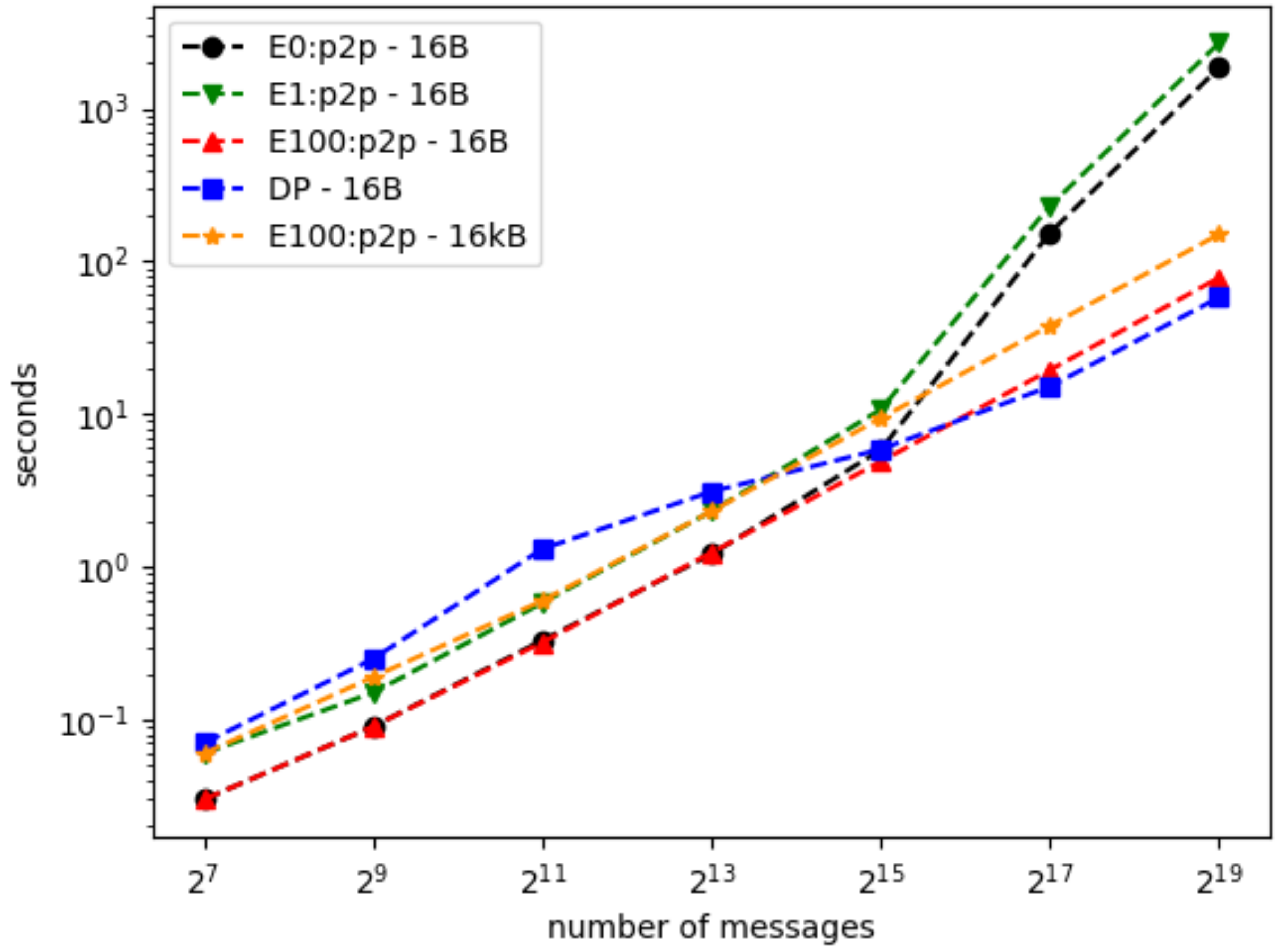

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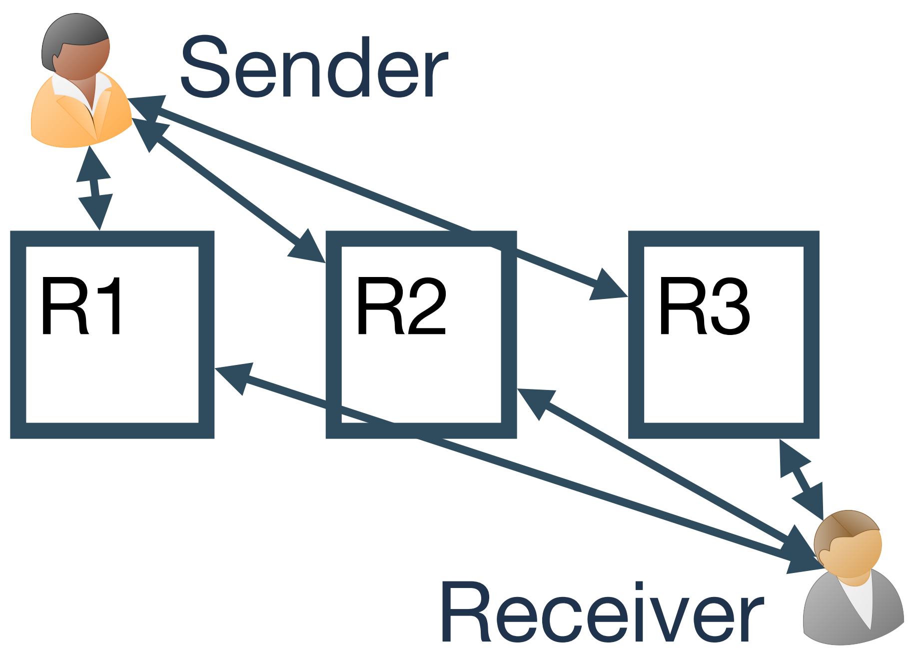

Erasing messages in **batches** ensures small overhead vs direct communication without running out of memory

Experimental results

Network: relays vs direct connections

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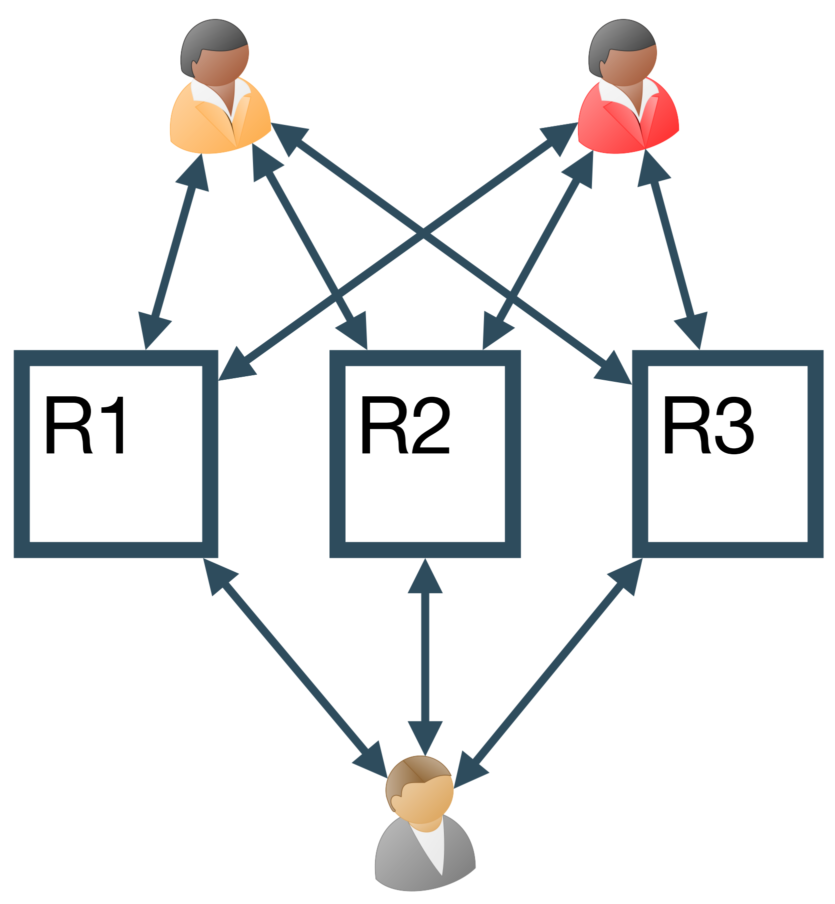
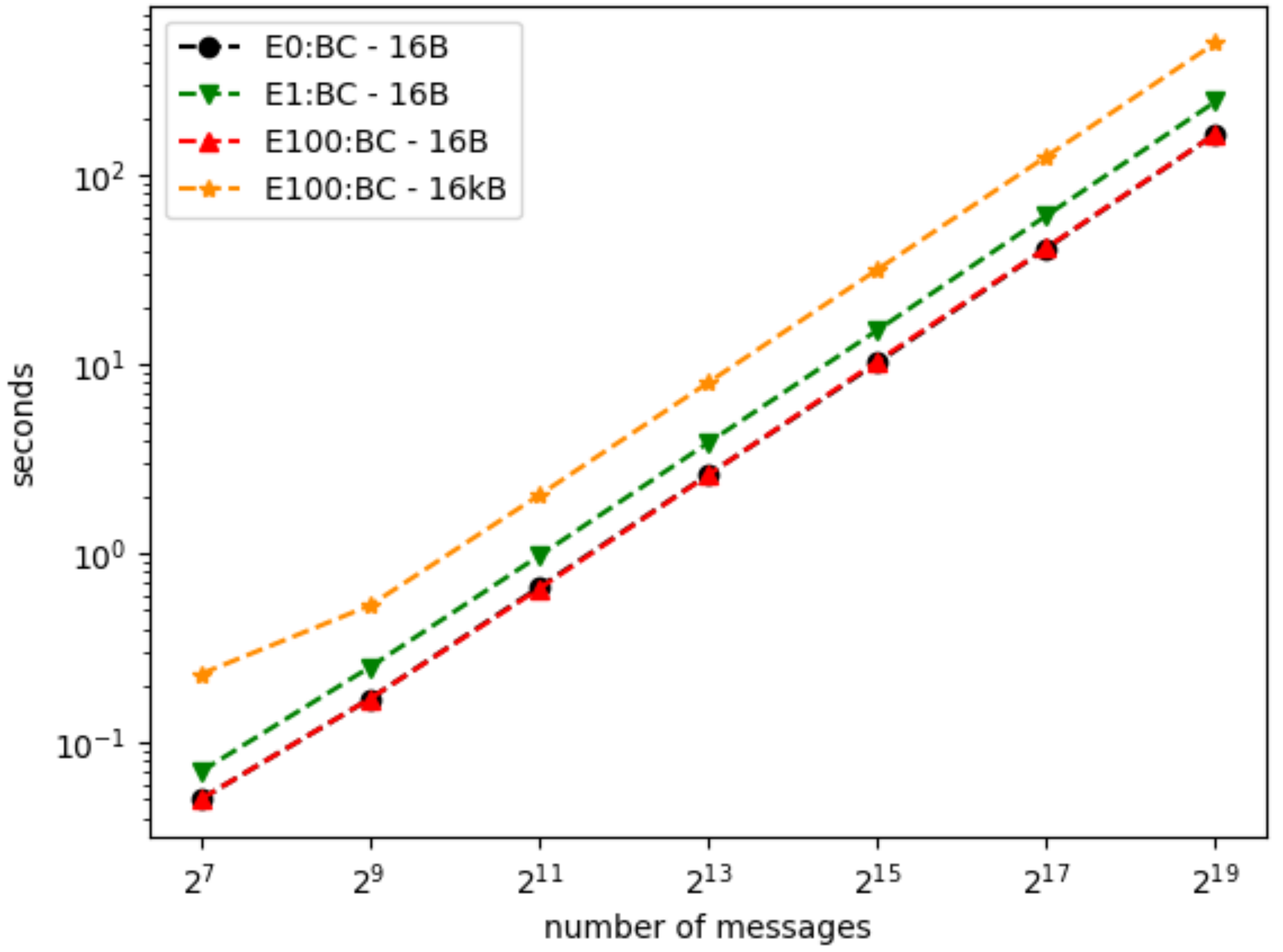


3 parties
3 relays

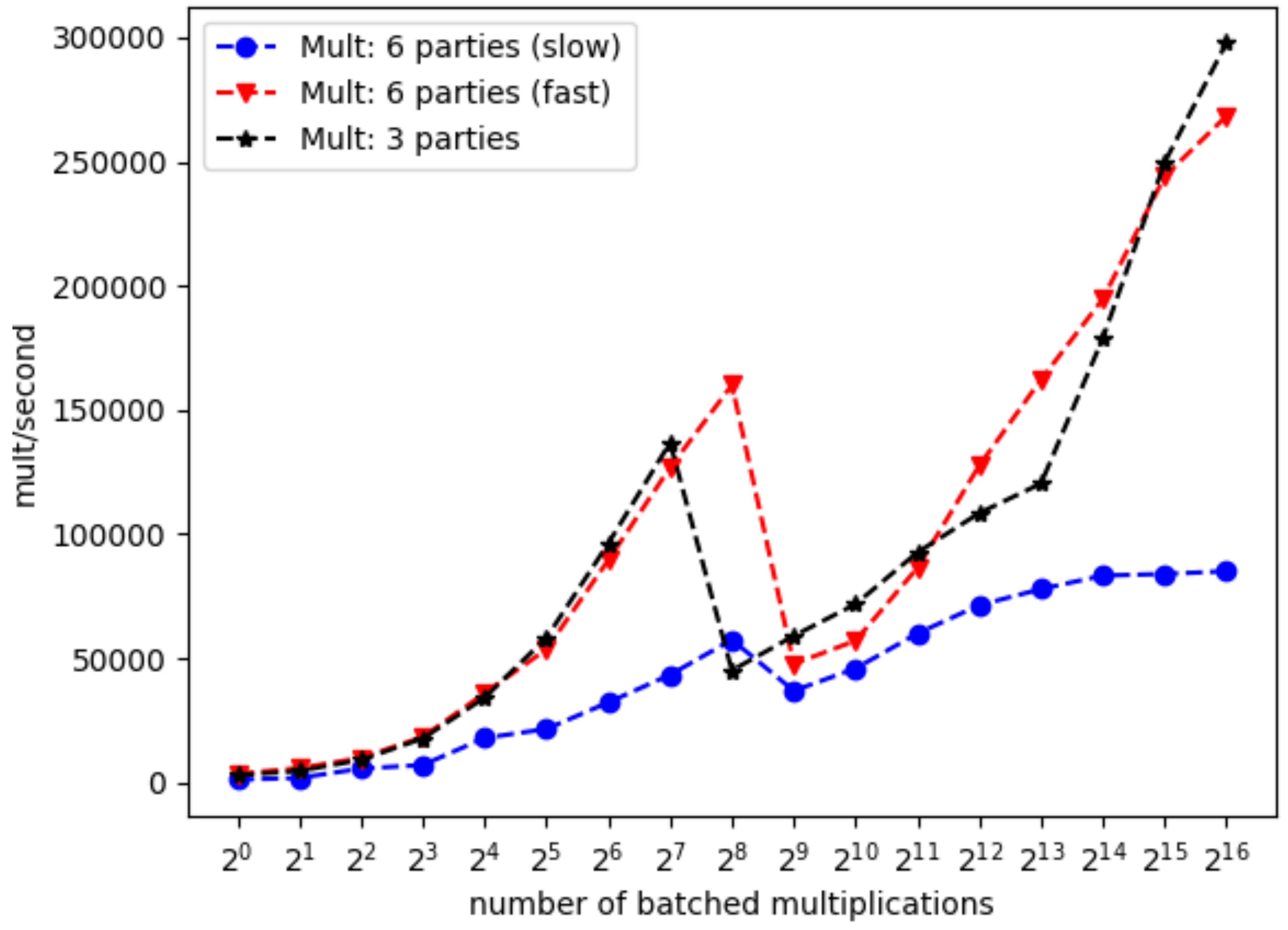
Running time for sending broadcast messages.



Experimental results

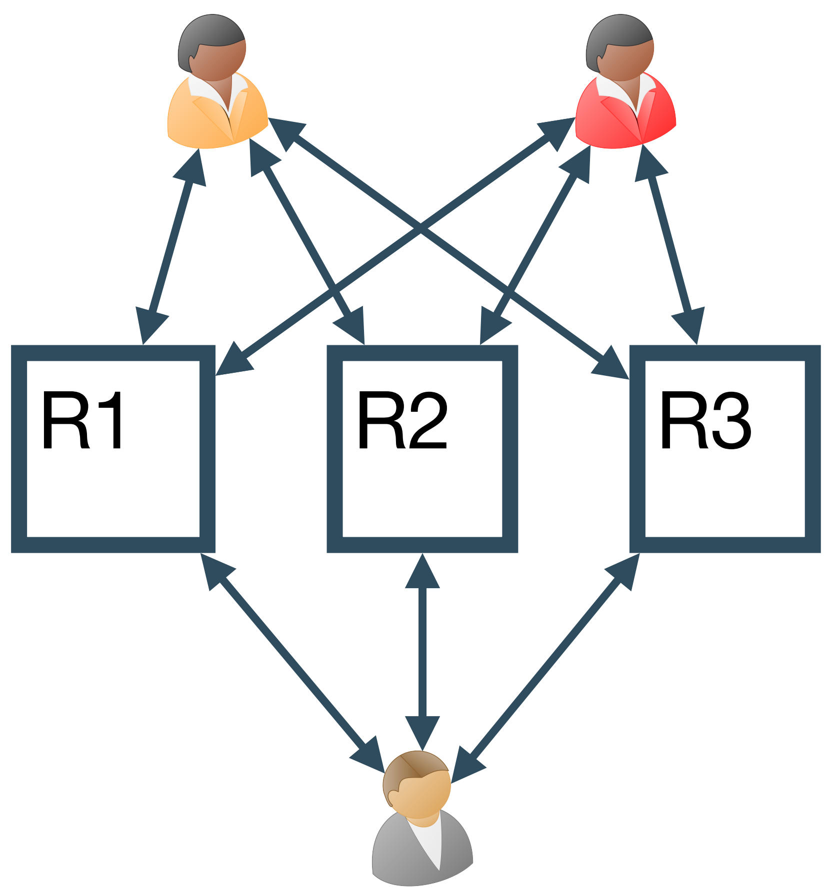
MPC multiplications

Multiplications per second for batched multiplications



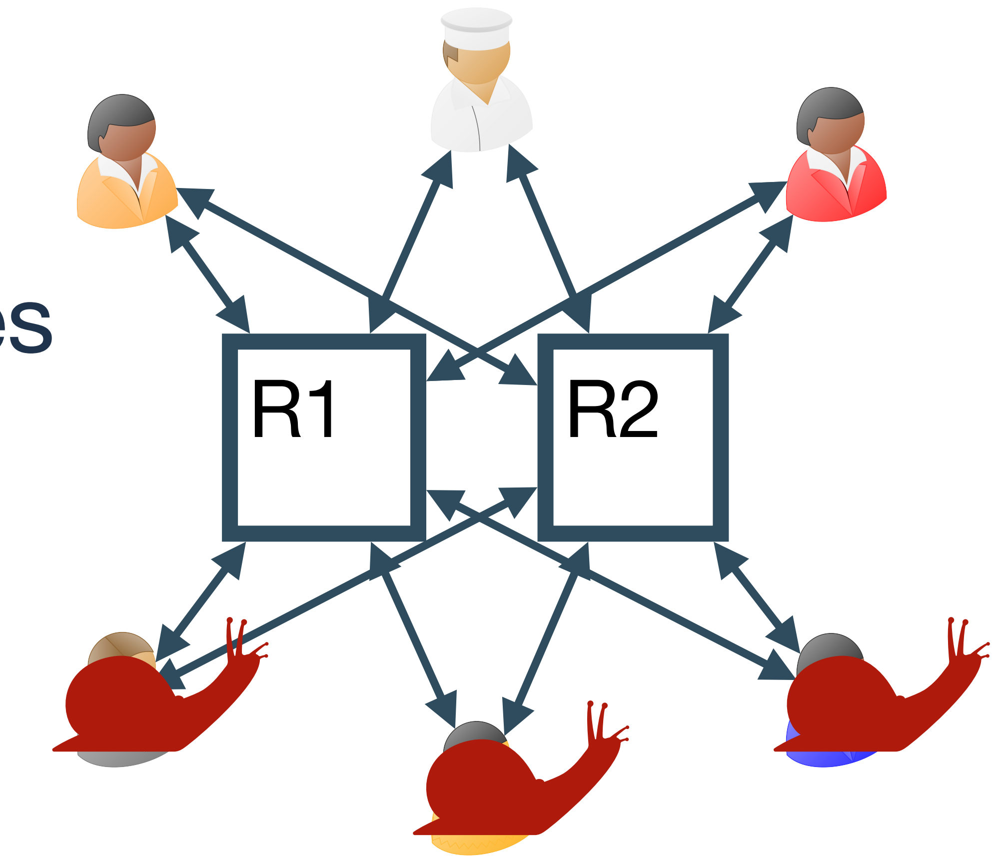
3 parties:

- At most 1 corruption



6 parties:

- At most 1 corruption
- 3 slow parties, 3 fast parties



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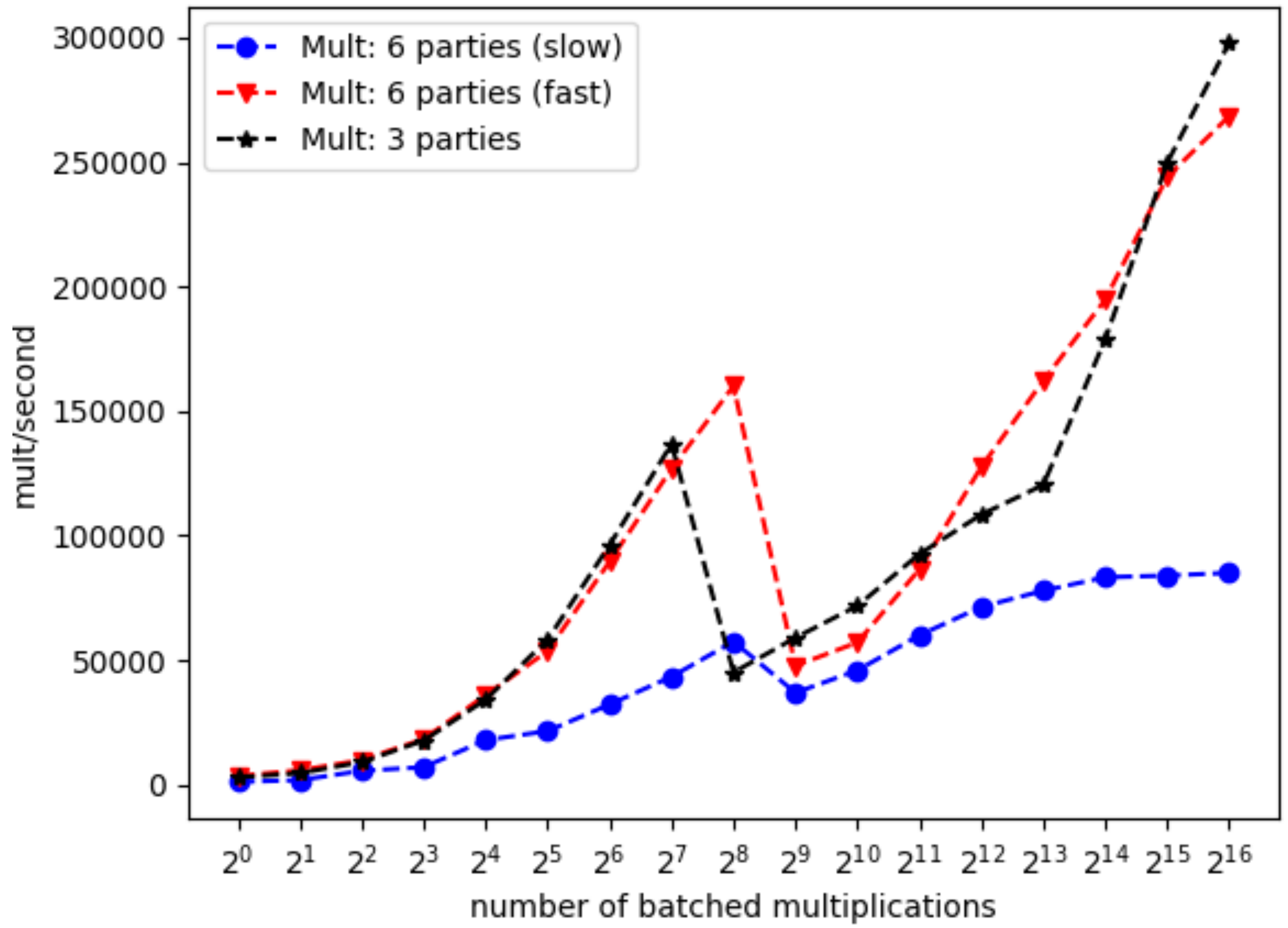

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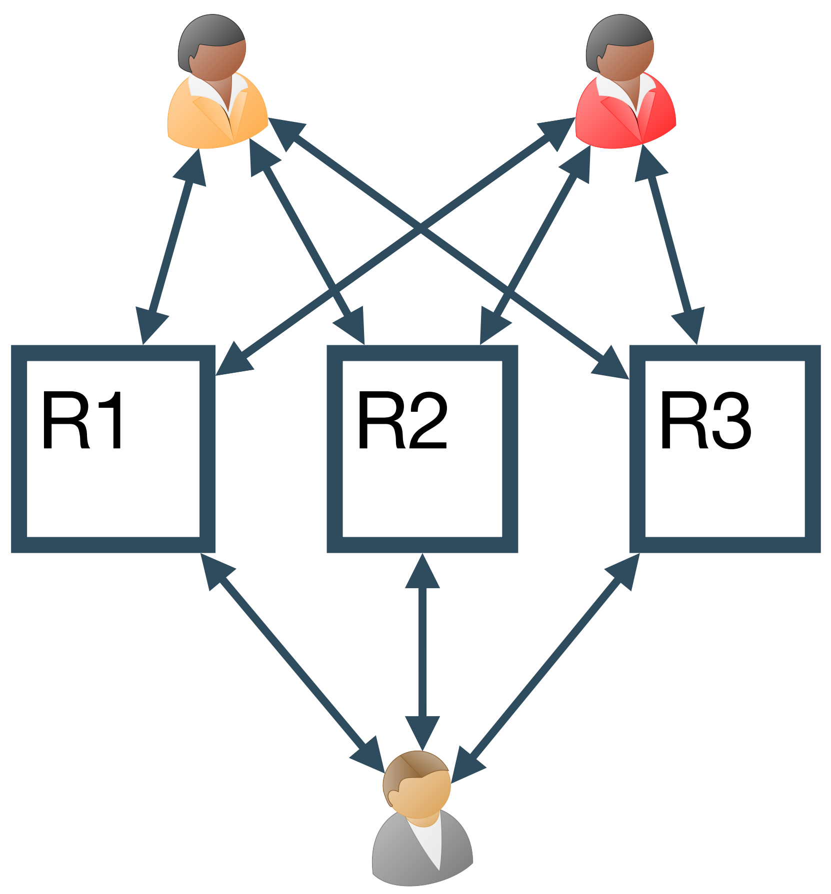

6 parties:

- At most 1 corruption
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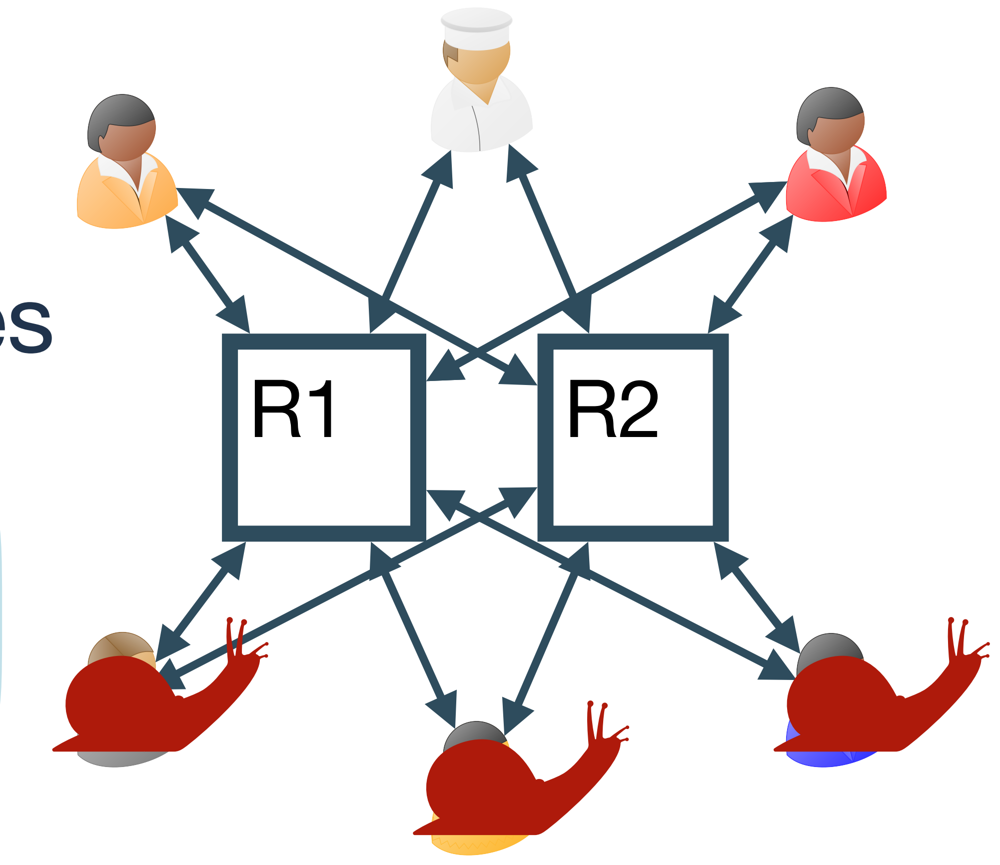
Faster parties:
~ **270k multiplications/s**



Main takeaways

1. New MPC protocol addressing major constraints of deployed systems.
    - Star-like communication topology using relays
    - Secure even in the presence of delayed parties

2. Discussion on multiplication protocols with relays and delays

3. Implementation and experimental evaluation of the effect of relays.

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1. New MPC protocol addressing major constraints of deployed systems.
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Also in the paper:

- Key agreement
- Modelling the state size of relays
- Optimisation ideas for communication and round complexity