Dumbo-MPC: Efficient Fully Asynchronous MPC with Optimal Resilience

Yuan Su[1], Yuan Lu[2], Jiliang Li[1], Yuyi Wang[3], Chengyi Dong[1], Qiang Tang[4]

[1]Xi'an Jiaotong University

[2]Institute of Software Chinese Academy of Sciences

[3]CRRC Zhuzhou Institute

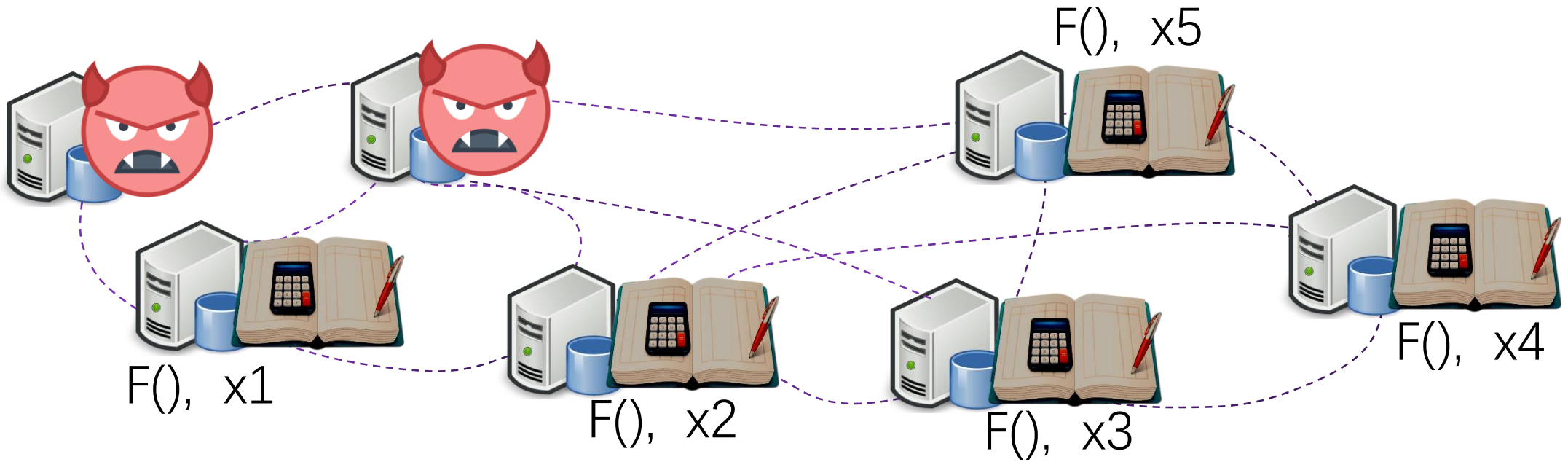
[4]The University of Sydney

contents

1 In Need of Practical Asynchronous MPC

Secure Multi-Party Computation

Collectively compute: **Y=F(x1, x2, x3, x4, x5)**



- Jointly and privately compute function
  - **Correctness (integrity):** correct evaluation result
  - **Privacy：** leaking nothing except the result

MPC-as-a-Service (MPCaaS)

MPCaaS with offline-online paradigm

Offline phase

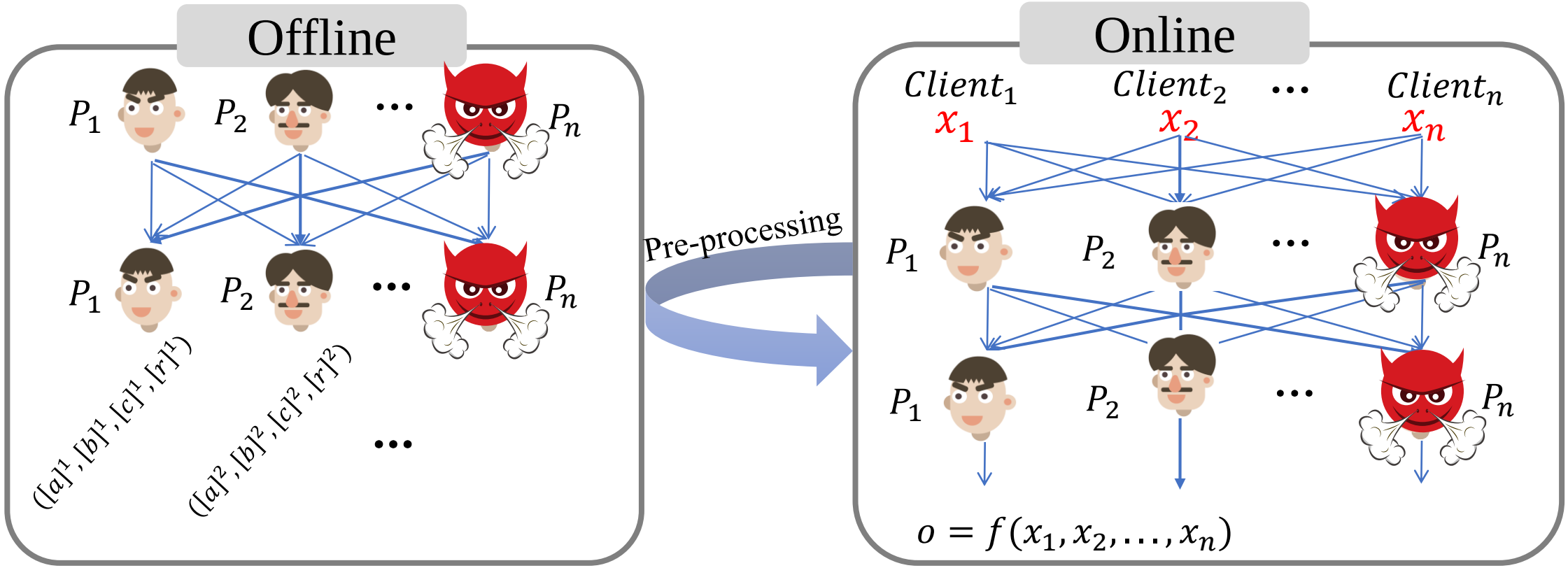
Beaver triples $([a], [b], [c])$ where $c = ab$

Random shares $[r]$

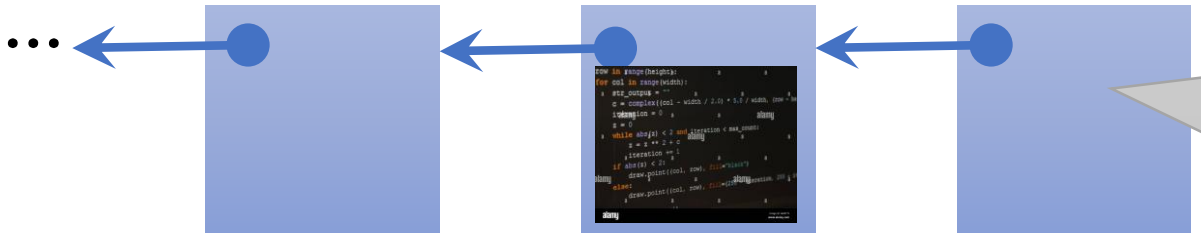
Online phase

Handle private inputs

Privately evaluate function f



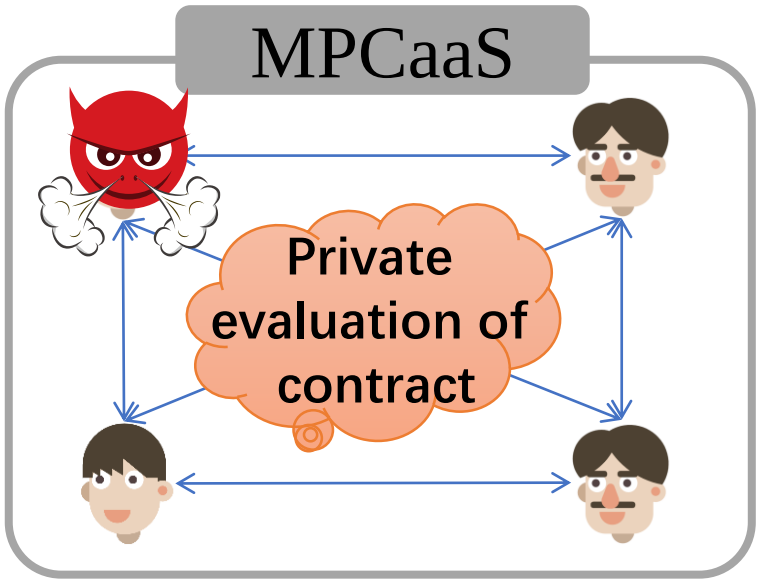
Call for Robustness (G.O.D.)



Transaction's cipher

TX Execution Result

In the application of
private smart contract,
we expect **G.O.D. !!!**
Otherwise, censorship !!!



Private Smart Contract

Enigma Project

6.5K Followers

Follow

Home About

Enigma Project in Enigma

Introducing Secret Network

Our mainnet blockchain is now known as Secret Network, thanks t...

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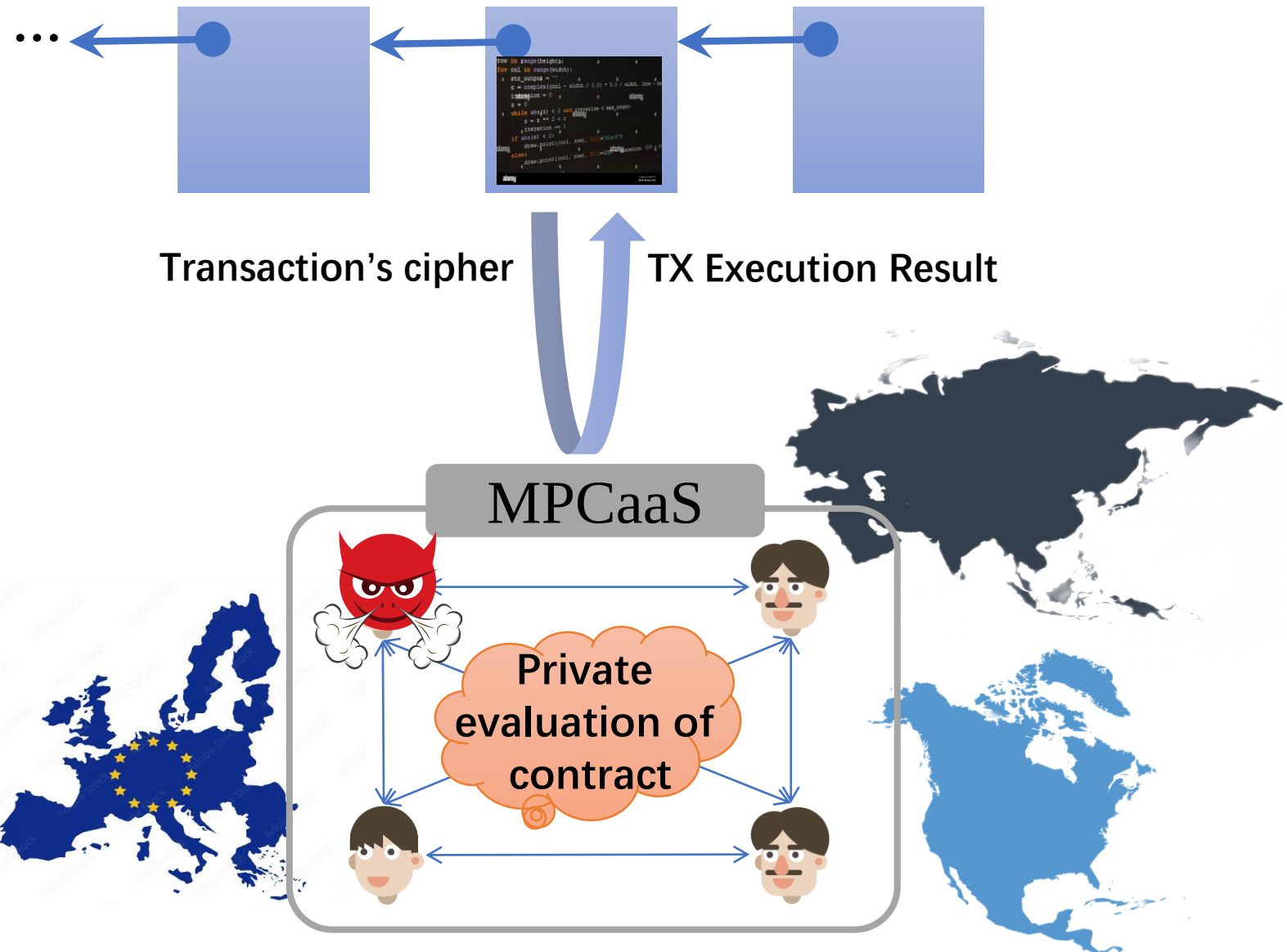
Call for Robustness (G.O.D.) in Asynchrony



Most Earlier MPCaaS:

In-house deployment in **Local Area Network** !!!

New Demand:

Global deployment over unreliable **Internet** !!!

- **Transmission interruption**
- **Fluctuating bandwidth**
- **Internet attacks**
- **Network misconfiguration**

Call for Robustness (G.O.D.) in Asynchrony

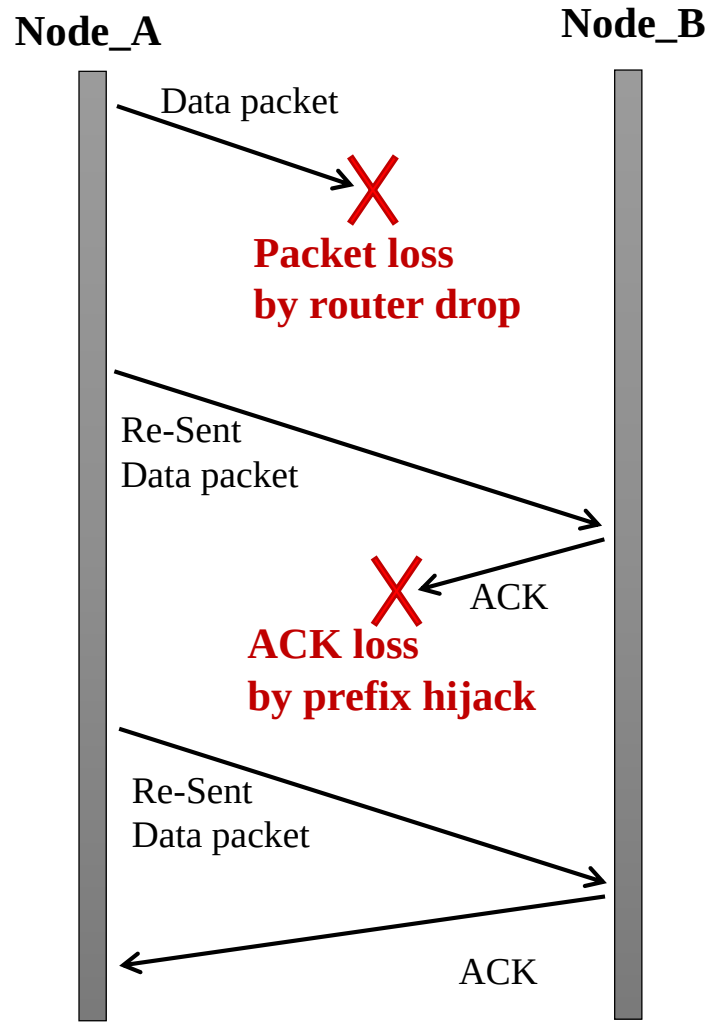
- We seperate the network conditions as:
  - **Synchronous** Network:

    Exist **known** upper bound of network delay

  - **Asynchronous** Network:

    Network delay is not only **unknown** but also **unfixed;**
    Nevertheless, messages can be **eventually** delivered;
    Make ***minimal*** assumptions about the network condition.

Network	Computationally-Secure Robust MPC
Sync.	t<n/2
Async.	t<n/3



TCP (enhanced by TLS)
is Asynchronous !!!

Vulnerabilities of Sync. MPC in Asynchrony

Most (practical) MPCaaS is synchronous !!

- **G.O.D. Violation in Async.**
  - **Excluding those inherent impossible: $t < n$**
  - **Many expected robust MPC:**
    - ✓ **Not *robust* at all in async.**

Protocols	Thld. ($t <$)	IT online	asyn. securities	
			Privacy	GOD
HN06 [56]	$n/2$	✗	✗	✗
GLZ20 [51]	$n/2$	✓	✗	✗
GLS19 [49]	$n/3$	✓	✗	✗
DN07 [41]	$n/3$	✓	✗	✗
BH08 [13]	$n/3$	✓	✗	✗
VIFF [37]	$n/3$	✓	✓	✗
HyperMPC [9]	$n/3$	✓	✓	✗
SPDZ [40, 42]	n	✓	✓	✗
EMP [78]	n	✗	✓	✗

Why cannot wait messages forever to restore robustness ?

Taking BGW as example:

Have to gather all honest parties' shares to correct malicious shares, which is impossible !

That's the challenge of asynchrony !!!

Vulnerabilities of Sync. MPC in Asynchrony

Most (practical) MPCaaS is synchronous !!

- **Privacy Breach in Async.**
  - **Many expected robust MPC:**
    - ✓ ***not private*** **in async.**

Protocols	Thld. ($t <$)	IT online	asyn. securities	
			Privacy	GOD
HN06 [56]	$n/2$	✗	✗	✗
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DN07 [41]	$n/3$	✓	✗	✗
BH08 [13]	$n/3$	✓	✗	✗
VIFF [37]	$n/3$	✓	✓	✗
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SPDZ [40, 42]	n	✓	✓	✗
EMP [78]	n	✗	✓	✗

Many sync. robust MPC “eject” unresponsive parties !

In asynchrony, honest parties can be eventually all “ejected” !

Design Objective

■ Threat model:

- **Full Asynchrony:**
  - ✓ adversary can arbitrarily delay messages
- **Optimal Resilience:**
  - ✓ against t<n/3 malicious corruptions (servers)

■ Security goal:

- **Private** and **G.O.D.**

■ Efficiency requirement:

- almost **I.T. online** phase
- concretely and asymptotically efficient

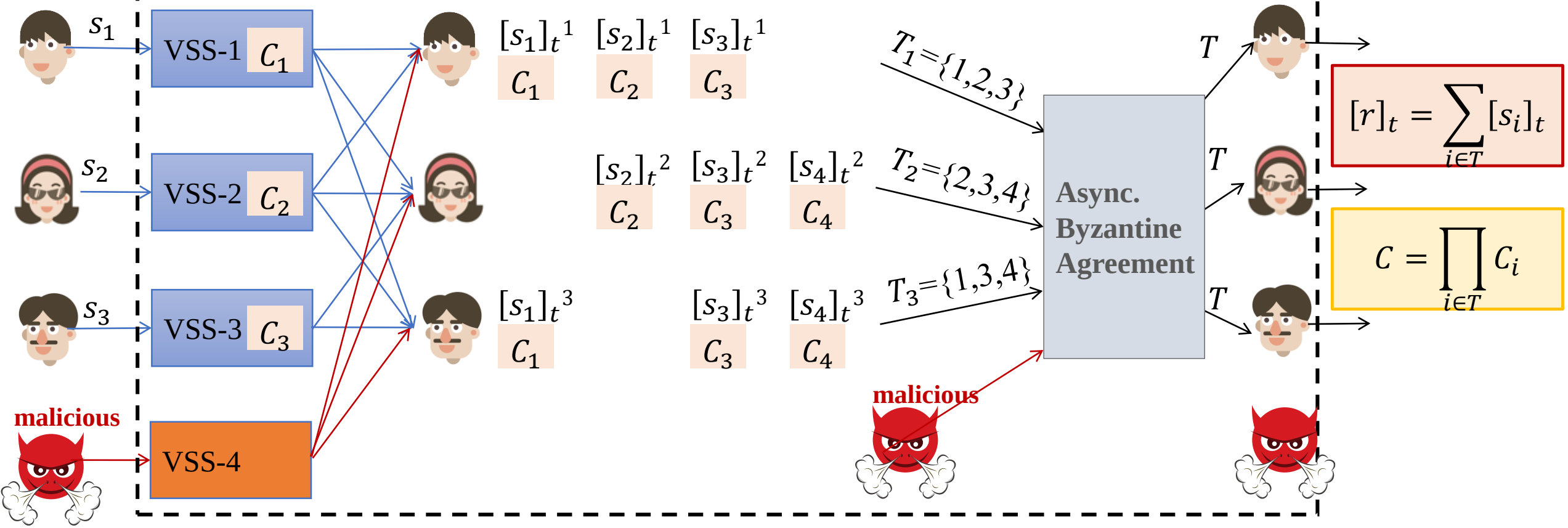
Protocols	Thld. ($t <$)	I.T. online	asyn. G.O.D.	comm. / gate		# secrets to be shared per triple
				Good	Bad	
CHP13 [30]	$n/4$	✓	✓	$O(n)$	$O(n)$	48
CP17 [32]	$n/4$	✓	✓	$O(n)$	$O(n)$	48
DXKR23 [41]‡	$n/3$	✓	✗	$O(n^3)$	–	$2n$
	$n/4$	✓	✓	$O(n^3)$	$O(n^3)$	$2n$
hbMPC [66]	$n/3$	✓	✗	$O(n)$	–	12
HNP08 [60]	$n/3$	✗	✓	$O(n^2)$	$O(n^2)$	-
CP15 [31] †	$n/3$	✗	✓	$O(n)$	$O(n)$	-
CHL21 [28]	$n/3$	✗	✓	$O(n^2)$	$O(n^2)$	-
PCR08 [60]	$n/3$	✓	✓	$O(n^5)$	$O(n^5)$	$9n+6$
CP23 [33]	$n/3$	✓	✓	$O(n^4)$	$O(n^4)$	$6n$
SS23 [77]	$n/3$	✓	✓	$O(n^2)$	$O(n^3)$	$6n$
GS23 [54]	$n/3$	✓	✓	$O(n^2)$	$O(n^3)$	$3n$
GLS24[52]	$n/3$	✓	✓	$O(n)$	$O(n)$	$\sim 230K$
Dumbo-MPC	$n/3$	✓	✓	$O(n)$	$O(n^2)$	$n+6$

Prior Art & Remaining Challenges

GRR98/GS23

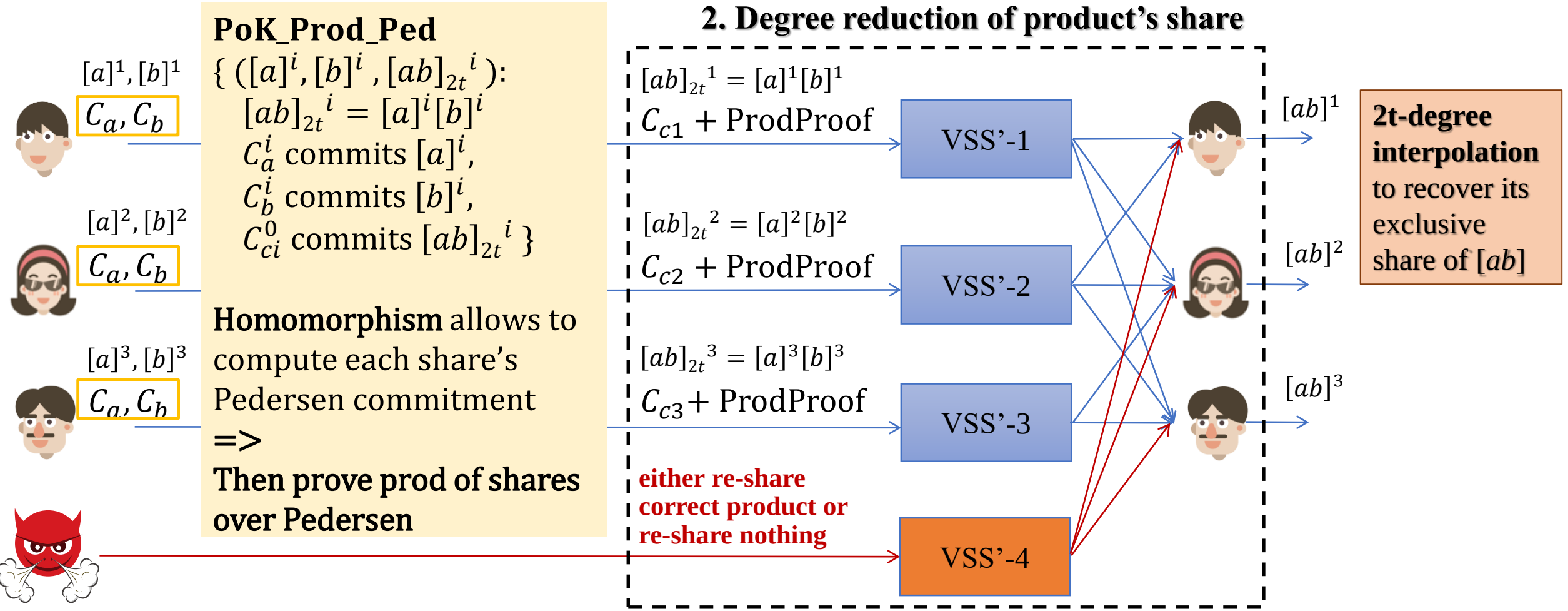
- **Random sharing + degree reduction + Pedersen polynomial commitment + proof-of-product over Pedersen**

1. Generation of random sharing



GRR98/GS23

- **Random sharing + degree reduction + Pedersen polynomial commitment + proof-of-product over Pedersen**



GRR98/GS23

- **Random sharing + degree reduction**
  + Pedersen polynomial commitment + proof-of-product over Pedersen

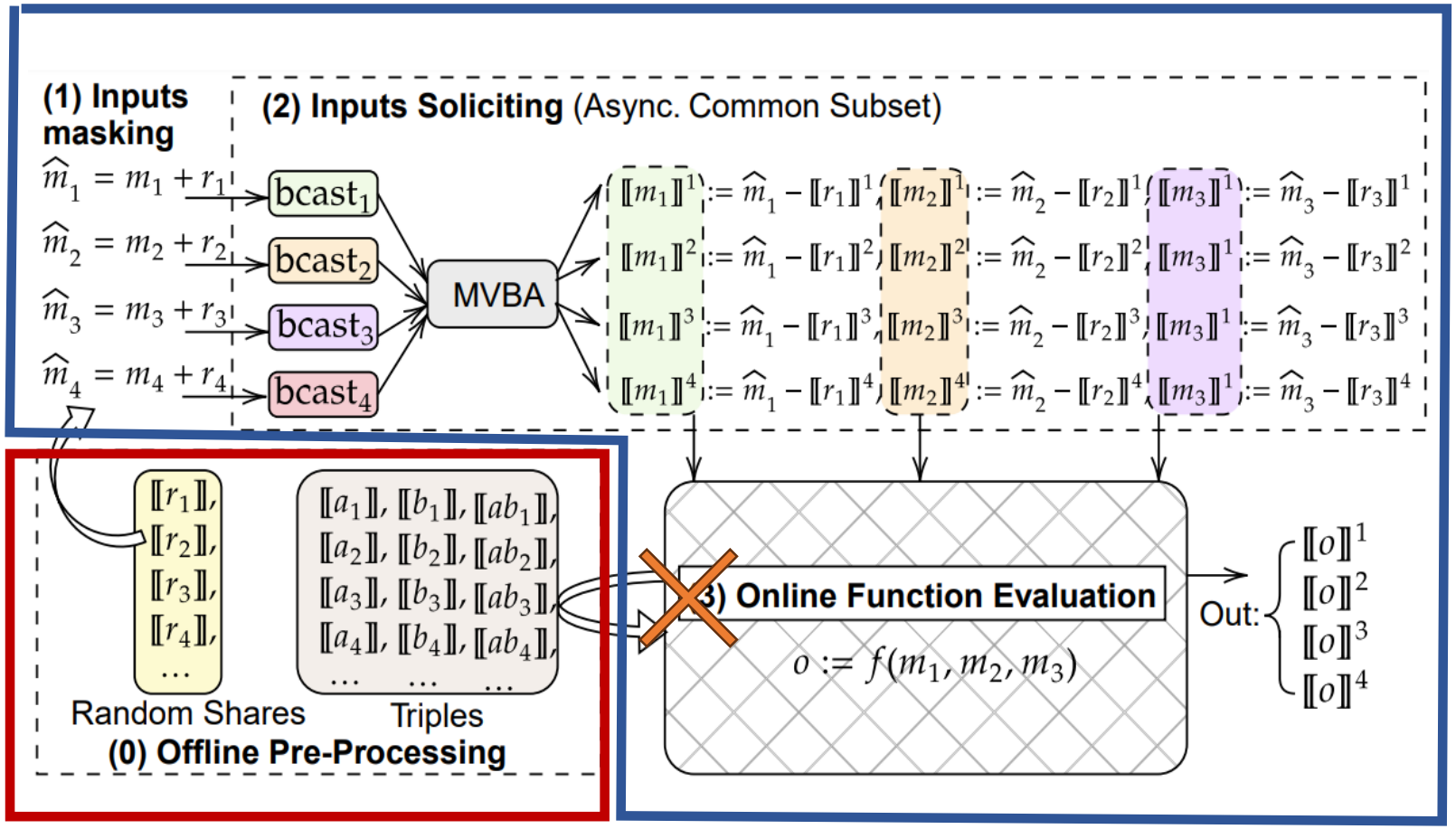
- **Remaining efficiency issues:**
  - Worst-case ***cubic*** communication complexity per triple
    (due to large size of Pedersen commitment)
  - Require ***3n*** secrets to be shared per triple
    (due to inefficient generation of random sharing)

HoneyBadgerMPC: sacrifice offline robustness

- **Robust online phase + non-robust offline phase** (requiring all parties honest)

  => **no G.O.D.,** but can generate triples much faster than GS23 in very good case

Non-robust offline eventually means non-robust online



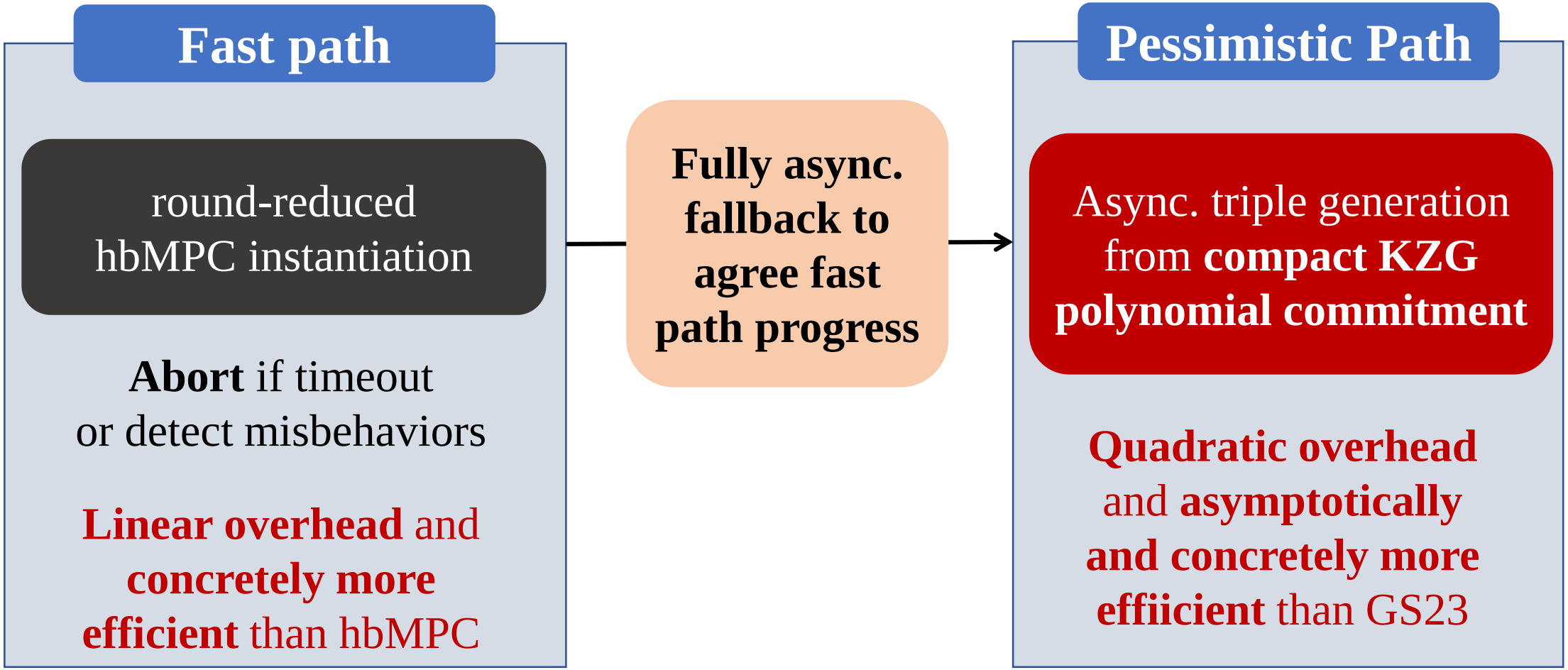
Recap the state-of-the-art

- **GS23:** all-phase **robust**, but very **inefficient**
- **hbMPC:** offline **non-robust**, but **more efficient in good case**

- **Question: Can we have the best-of-both ?**
  - **Bad case:** both asymptotically and concretely better than GS23
  - **Good case:** at least as high performant as hbMPC and
    can securely fallback when optimistic condition fails

Our Solution: Dumbo-MPC

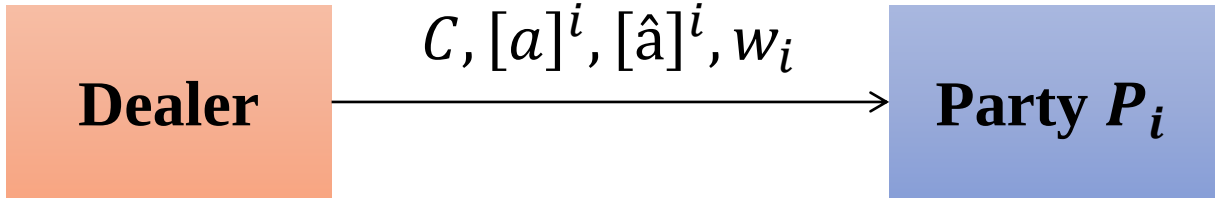
High-level overview



Proof of secrets' product over KZG

■ Devise proof-of-product relation over KZG commitment

- why Pedersen convenient => interpolate in exponent to derive any evaluation's commitment
- Augment KZG commitment by introducing **hidden evaluation interface**



New interface computes:

$$T_i = g^{[a]^i} h^{[\hat{a}]^i}$$

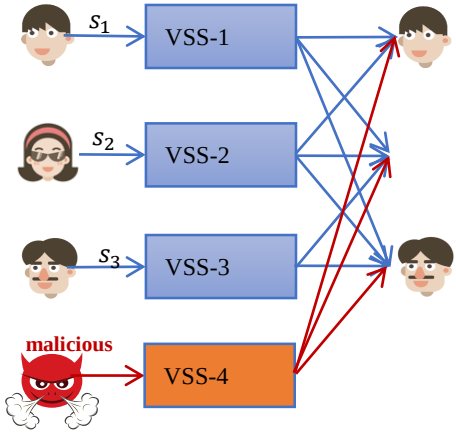
-and-

ω_i binds T_i to C

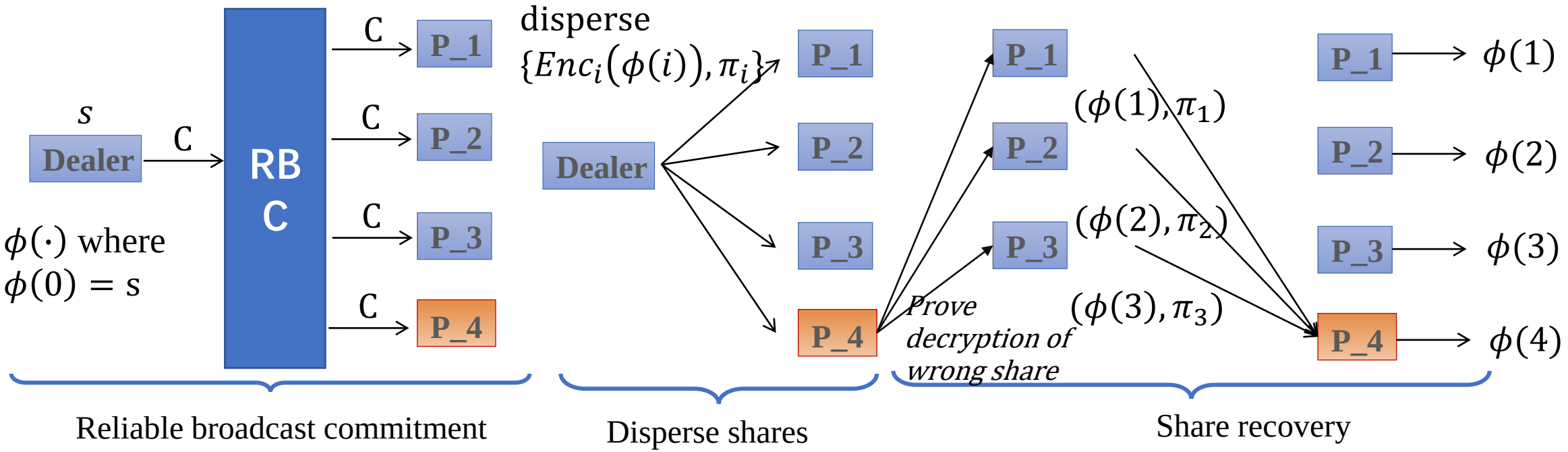
- Hidden evaluations are:
  - ✓ **Binding** => cannot open as secrets not binding to C
  - ✓ **Hiding** => all $\{T_i\}$ and all $\{\omega_i\}$ do not leak extra information

- Then, can prove correct multiplication by zk-PoK of product relation over Pedersen

Efficient AVSS instantiation w/ concurrent composability

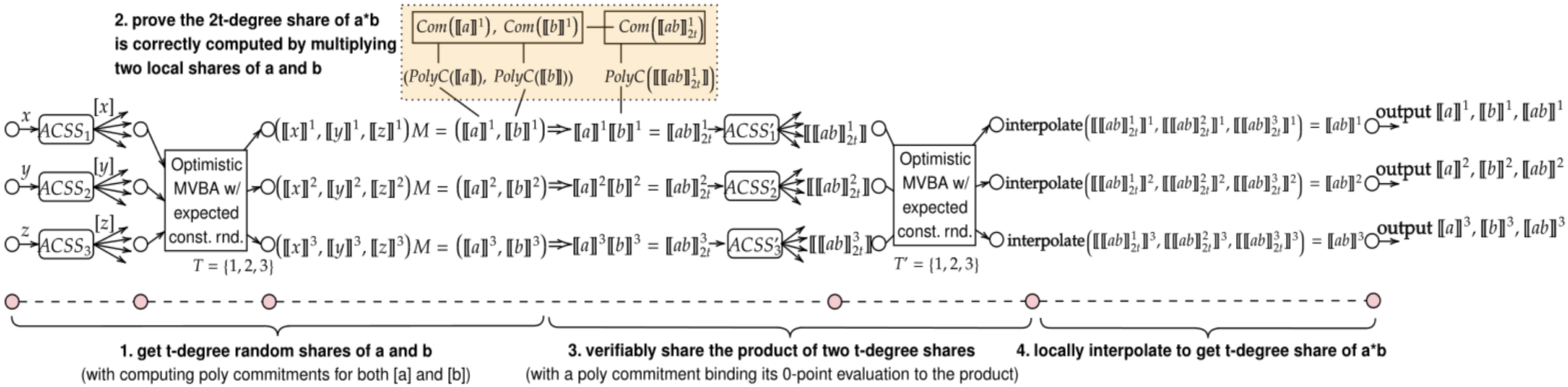


- Using KZG to instantiate the state-of-the-art **batch AVSS** (hbACSS)
- **Remaining non-triviality: lacking concurrent composability in hbACSS**
  - drop-in IND-CCA PKE + using different keys in different dealer's instances



More efficient triple generation protocol

- **Efficient triple instantiation from compact KZG commitment:**
  - **Asymptotically more efficient AVSS** for secret sharing (as succictness of KZG)
  - Good-case **round-reduced** async. Byzantine agreement (**good-case terminate in 5 rounds**)
  - Extract random sharing via super-invertible matrix (as homomorphism of KZG) => **reducing # of secrets to share from *3n* to *n*+O(1)**

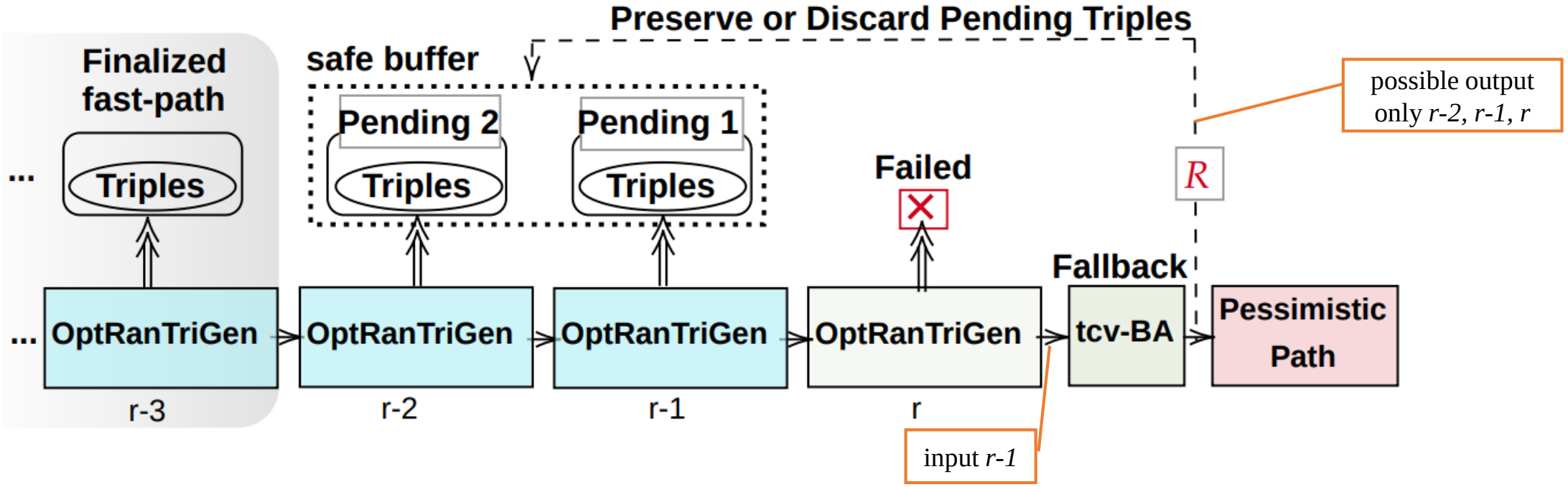


Dual-mode triple generation framework

■ Fast Path and Fallback:

- **Fast-path features:** when abort in round *r*, all honest parties must finish round *r-2*
  => all triples before round *r-2* can be finalized

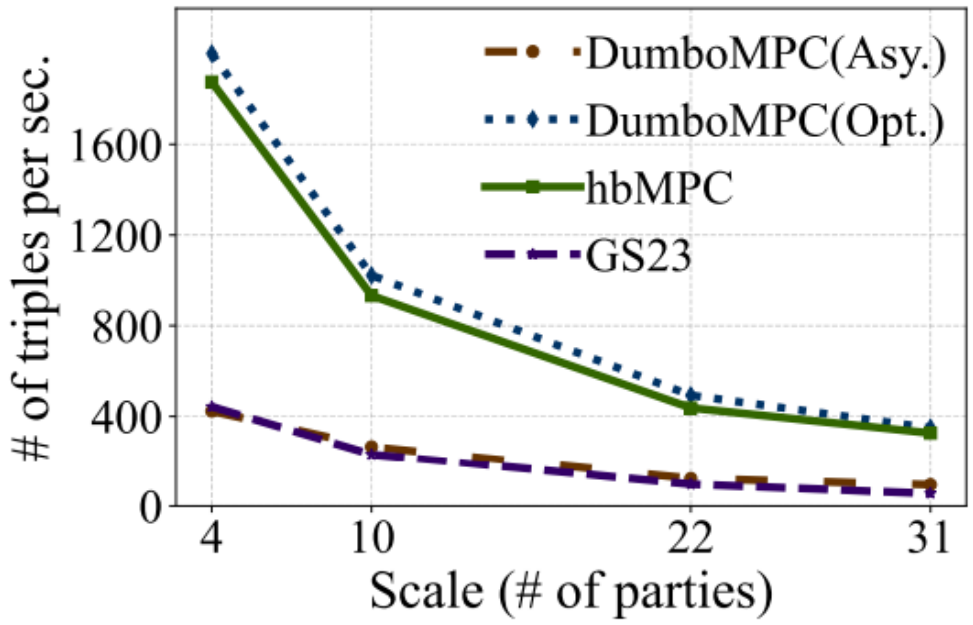
- **Fallback implementation:** two-consective-value Byzantine agreement
  => conceptually minimal BA (choose one out of two integers)



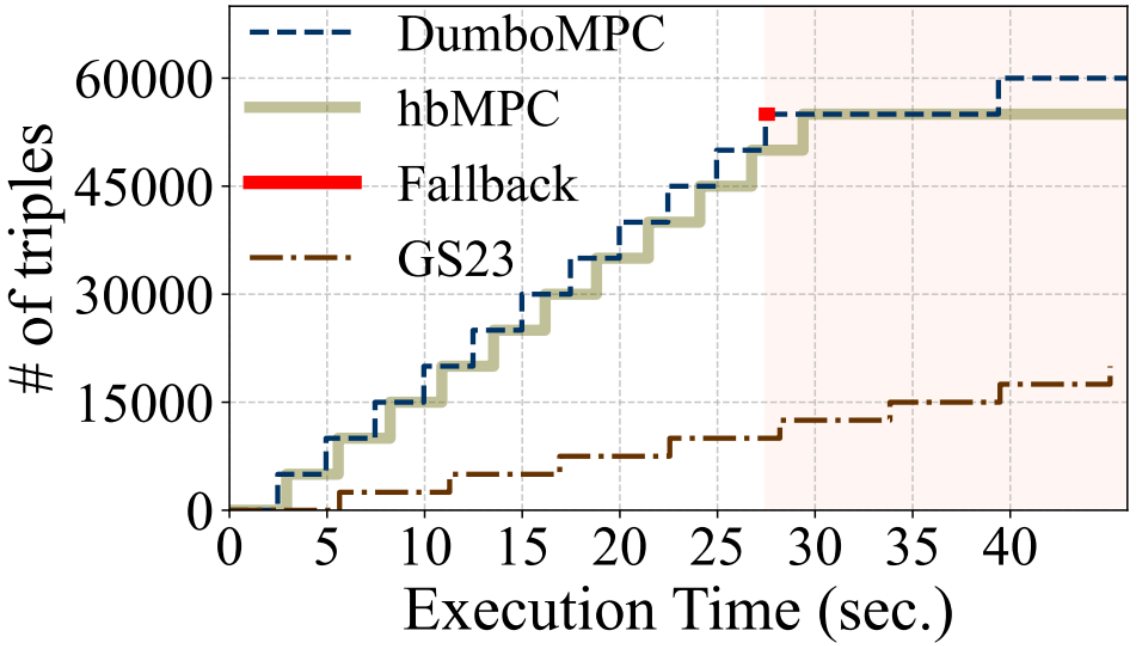
Evaluations

- **Bad case faster than GS23**
- **Good case faster than hbMPC + secure fallback**

triple throughput for varying *n*



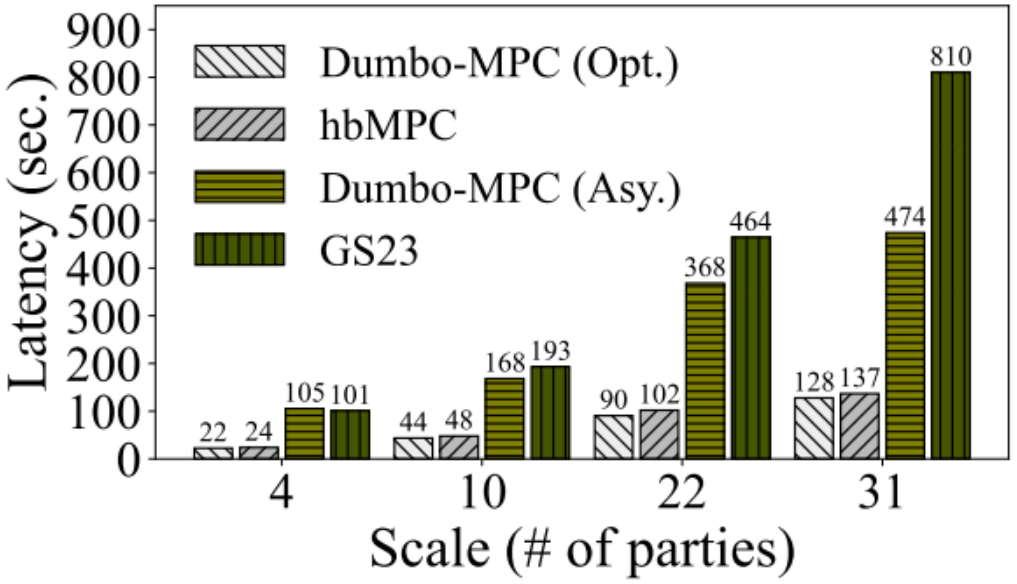
***n=4* in face of a dynamic crash**



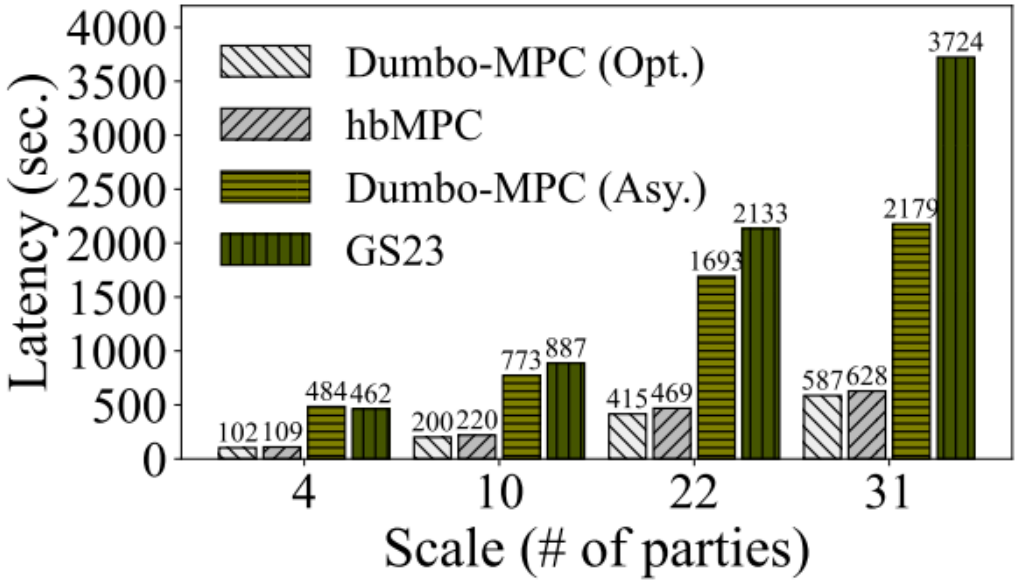
Evaluations

- **Bad case faster than GS23**
- **Good case faster than hbMPC + secure fallback**

Latency of pre-processing triples for (a) Vickery auction and (b) mixing net



(a) Vickery auction



(b) Switching network

Summary

Async. MPC-as-a-Service framework Dumbo-MPC (BGW paradigm from SS)**:**

- **More efficient async. triple generation**
  - ✓ efficient instantiation as proof-of-product over KZG
  - ✓ asymptotically and concretely better than GS23
- **Good-case fast path + secure async. fallback**
  - ✓ slightly faster than hbMPC by reducing redundant rounds
  - ✓ Secure async. fallback

Thanks !