More Efficient Oblivious Transfer Extensions with Security for Malicious Adversaries

Gilad Asharov — **Hebrew University**
Yehuda Lindell — Bar-Ilan University
Thomas Schneider — Darmstadt
Michael Zohner — Darmstadt

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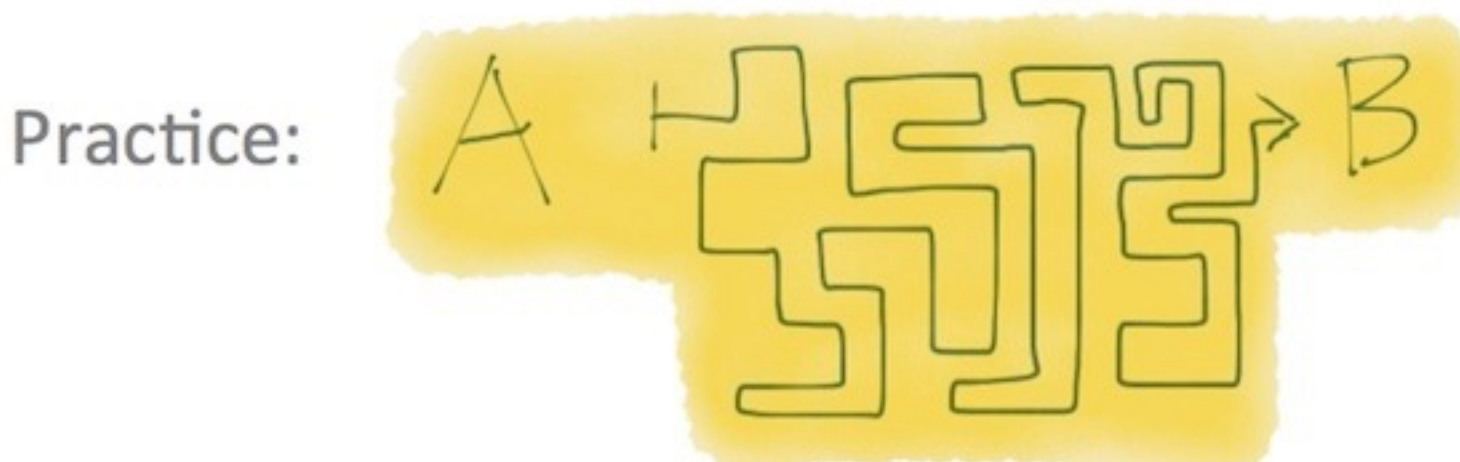
From Theory to Practice

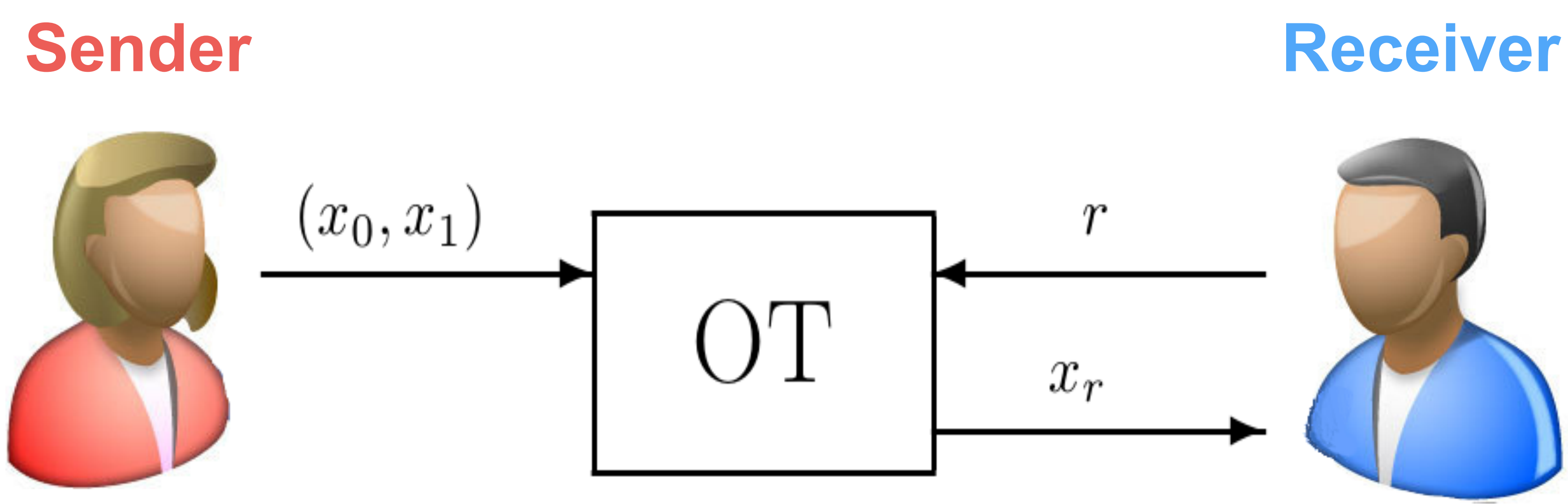
[Yao82,Yao86,GMW87,BGW88,CCD88,RB89,…]



Secure computation becomes practical!

[MNPS04,LP07,LPS08,PSSW09,KSS12,FN13,SS13,LR14,HKK+14, FJN14,NNOB12,LOS14,DZ13,DLT14,DCW13,JKO13]

1-out-of-2 Oblivious Transfer



- **INPUT: Sender** holds two strings (x_0,x_1), **Receiver** holds r
- **OUTPUT: Sender** learns nothing, **Receiver** learns x_r,

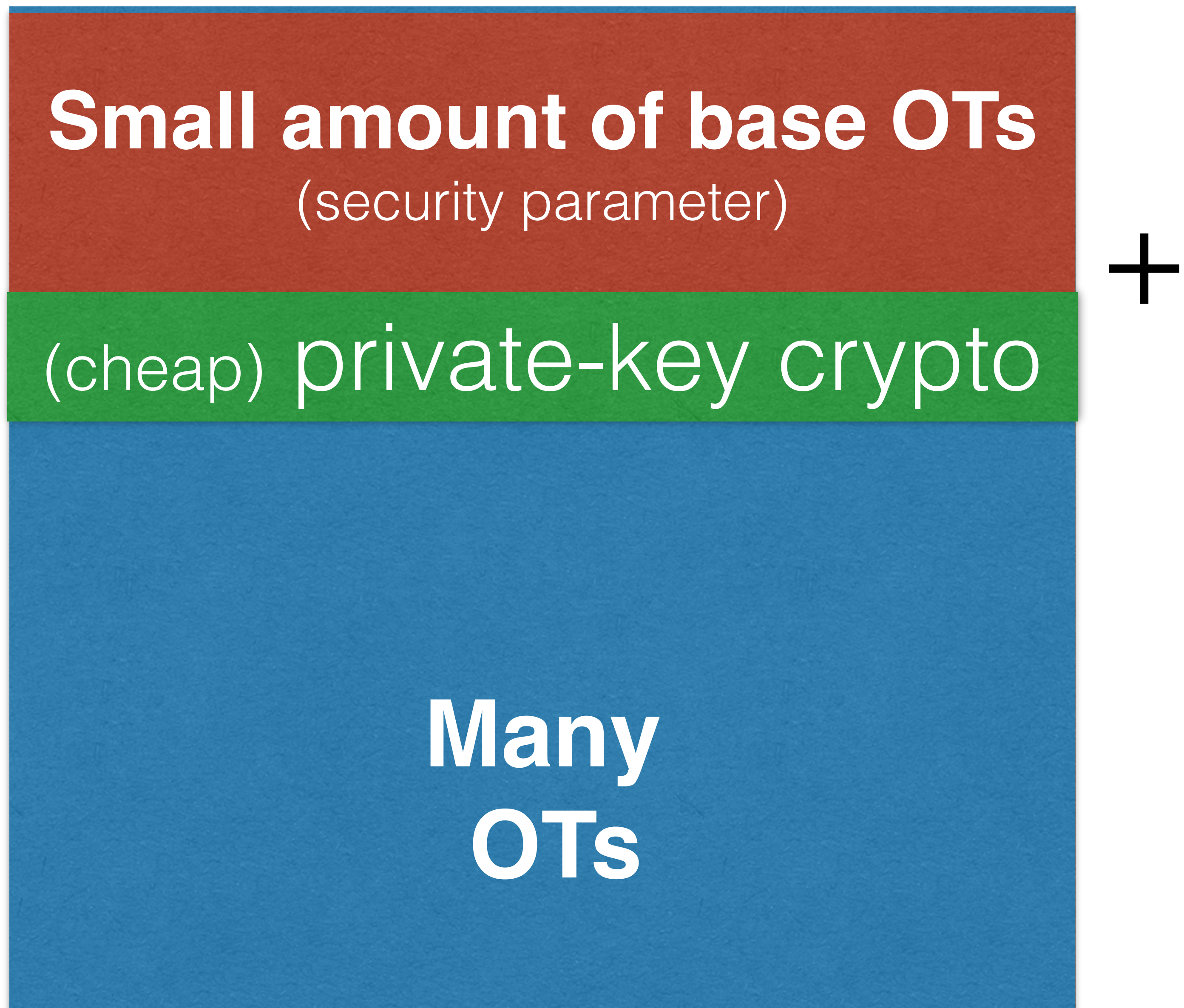
Oblivious Transfer and Secure Computation

- OT is a basic ingredient in (almost) all protocols for secure computation
- **Protocols based on Garbled Circuits (Yao):**
  1 OT per ***input***
  [LP07,LPS08,PSSW09,KSS12,FN13,SS13,LR14,HKK+14,FJN14]
- **Protocols based on GMW:**
  1+ OT per ***AND-gate***
  TinyOT [NNOB12,LOS14] MiniMac protocols [DZ13,DLT14]

How Many OT's?

- **The AES circuit:** Uses 2^{19} OTs
  (when evaluated with TinyOT)
- **The PSI circuit:** (for $b=32, n=2^{16}$) Uses 2^{30} OTs
  (when evaluated with TinyOT)
- Using [P_{eikert}V_{aikuntanathan}W_{aters}08]: 350 OTs per second
  - 1M (2^{20}) OTs > 45 minutes(!)
  - 1G (2^{30}) OTs > 45000 minutes > 1 month…
- [C_{hou}O_{rlandi}15] - 10000 OTs per second (?)

OT Extensions



OT Extension and Related Work

- Introduced in [Beaver96]
- Ishai, Kilian, Nissim, Petrank [IKNP03]
  “Extending Oblivious Transfer Efficiently”
- Optimizations semi-honest: [KK13, ALSZ13]
- Optimizations malicious:
  [Lar14,NNOB12,HIKN08,Nie07]

This Work

- Efficient protocol for OT extension, malicious adversary, based on IKNP
- It outperforms all previous constructions
- Optimizations, implementation

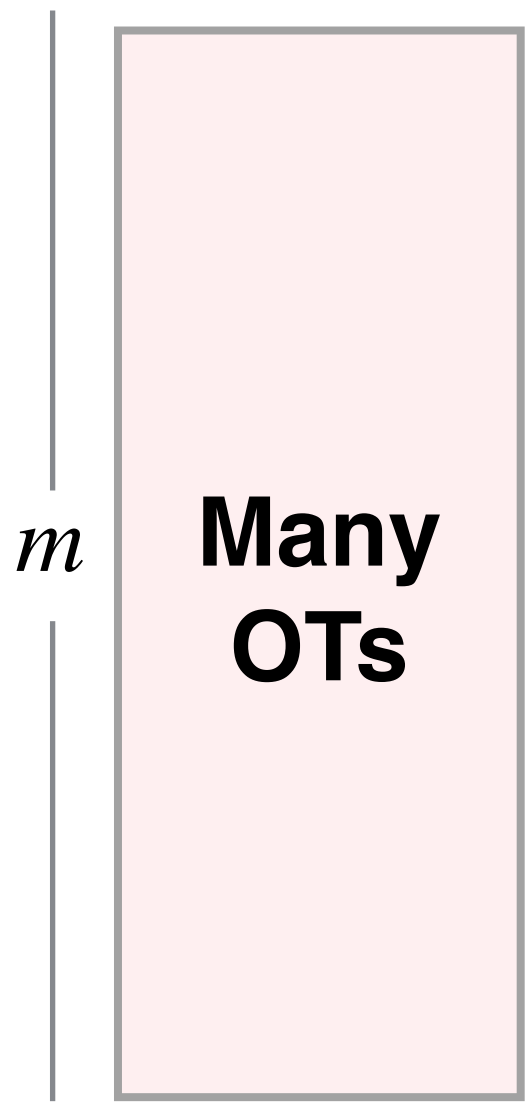
- This Talk:
  - IKNP protocol
  - Our protocol, its security
  - (Implementation) and performance

Extending OT Efficiently[1]

[IKNP03]

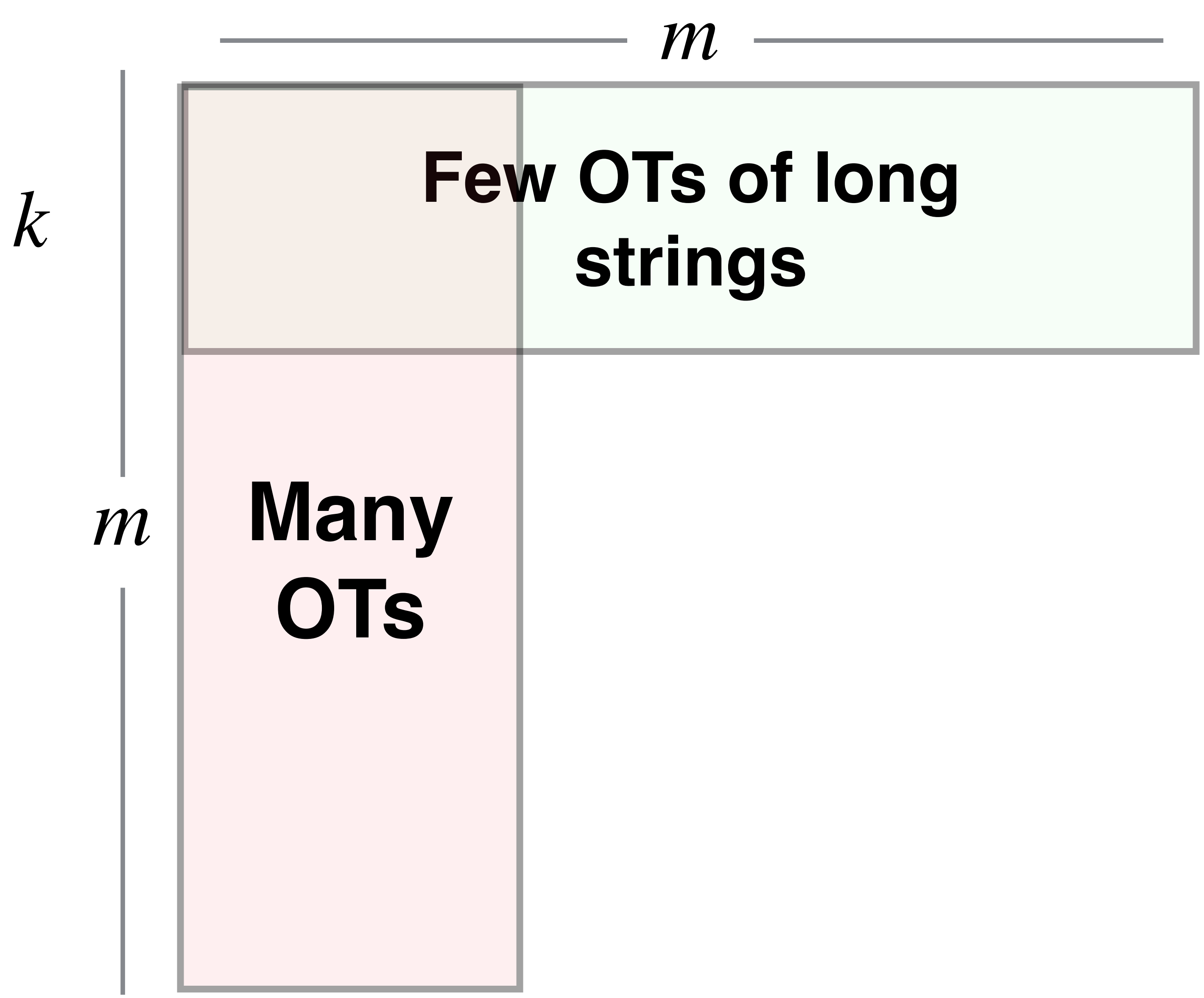
[1]Semi-honest

IKNP - Idea

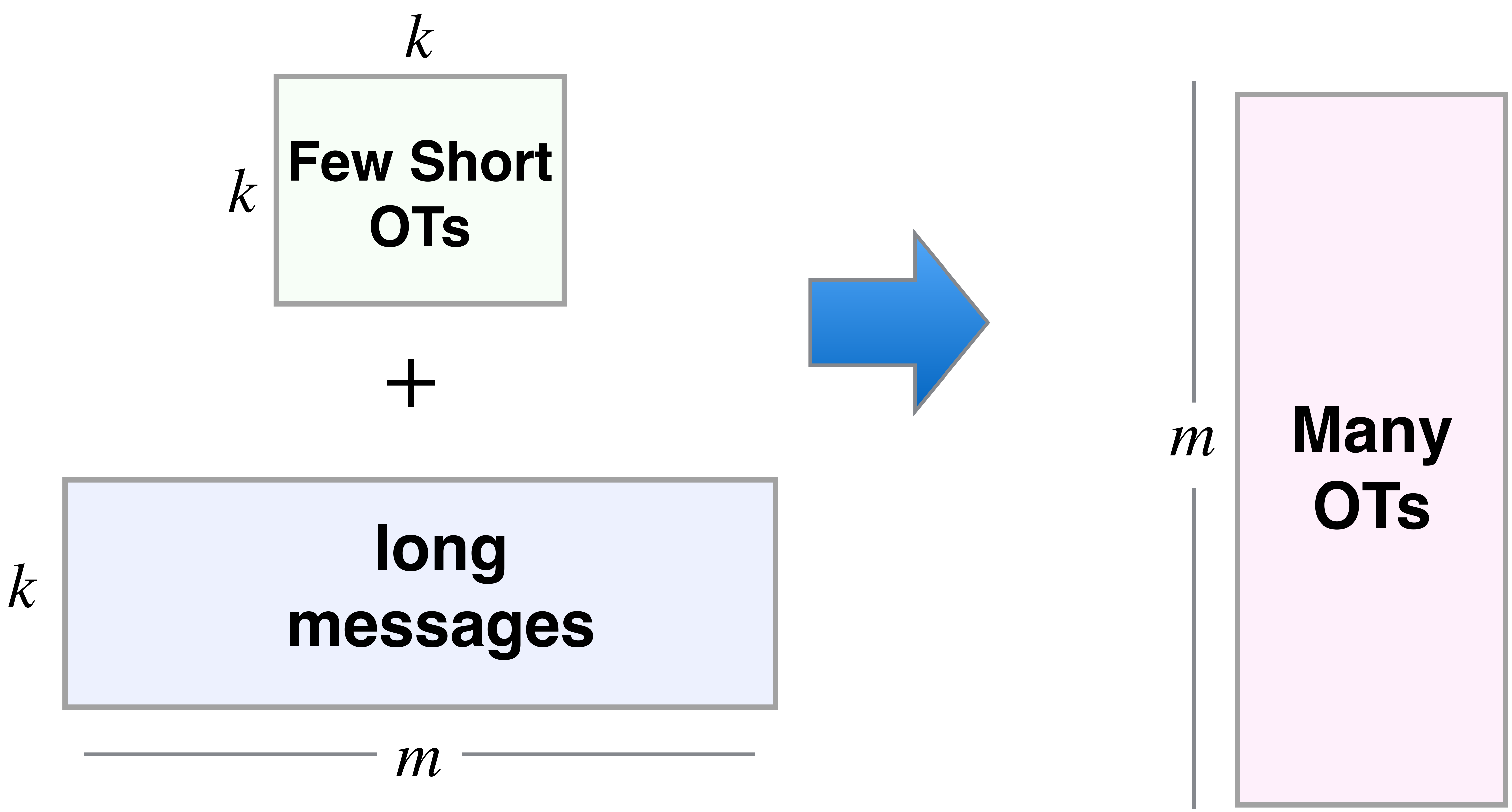


expensive

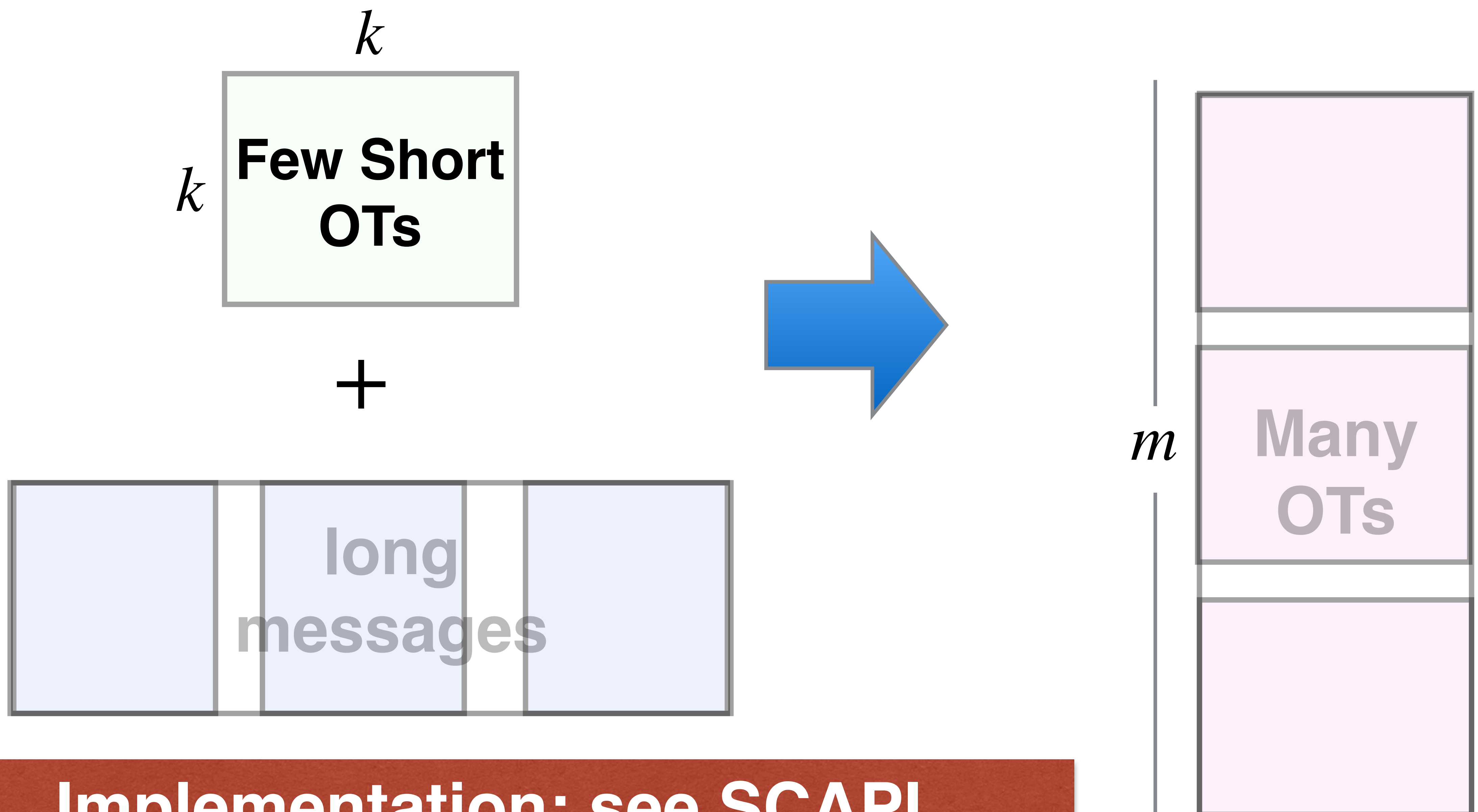
IKNP - Idea



IKNP - Implementation



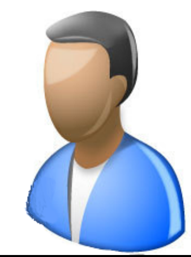
In Practice [ALSZ,CCS13]



Implementation: see SCAPI
https://github.com/cryptobiu/scapi

IKNP

$\{x_j^0, x_j^1\}_{j=1}^{m}$ 

 $\mathbf{r} = (r_1,\ldots,r_m)$

$\mathbf{s} = (s_1,\ldots,s_\ell)$

$\mathbf{k}_1^{s_1},\ldots,\mathbf{k}_\ell^{s_\ell}$

Base OTs

$\{\mathbf{k}_i^0, \mathbf{k}_i^1\}_{i=1}^{\ell}$

$\xleftarrow{\mathbf{u}^1,\ldots,\mathbf{u}^\ell}$

$\mathbf{u}^i = G(\mathbf{k}_i^0) \oplus G(\mathbf{k}_i^1) \oplus \mathbf{r}$

$\mathbf{Q}$

$\mathbf{T}$

*

*

$y_j^0 = x_j^0 \oplus H(\mathbf{q}_j)$

$y_j^1 = x_j^1 \oplus H(\mathbf{q}_j \oplus \mathbf{s})$

$\xrightarrow{y_j^0, y_j^1}$

When Moving to Malicious

- The protocol is already secure with respect to malicious **Sender**
- The **Receiver** sends many messages of the same form

$$\xleftarrow{\mathbf{u}^1,\ldots,\mathbf{u}^\ell} \qquad \mathbf{u}^i = G(\mathbf{k}_i^0) \oplus G(\mathbf{k}_i^1) \oplus \mathbf{r}$$

- Security against malicious **Receiver**: we must guarantee that it uses the **same** value **r** in these messages

The Protocol

$\{x_j^0, x_j^1\}_{j=1}^{m}$

$\mathbf{r} = (r_1, \ldots, r_m)$

Base OTs

$\mathbf{u}^i = G(\mathbf{k}_i^0) \oplus G(\mathbf{k}_i^1) \oplus \mathbf{r}$

$\xleftarrow{\mathbf{u}^1, \ldots, \mathbf{u}^\ell}$

$\mathbf{Q}$ $\mathbf{T}$

Consistency Check of $\mathbf{r}$

$y_j^0 = x_j^0 \oplus H(\mathbf{q}_j)$

$y_j^1 = x_j^1 \oplus H(\mathbf{q}_j \oplus \mathbf{s})$

$\xrightarrow{y_j^0, y_j^1}$

The Consistency Checks

Consistency Check

$$\mathbf{u}^{i} = G(\mathbf{k}_{i}^{0}) \oplus G(\mathbf{k}_{i}^{1}) \oplus \mathbf{r}$$

$$\mathbf{u}^{j} = G(\mathbf{k}_{j}^{0}) \oplus G(\mathbf{k}_{j}^{1}) \oplus \mathbf{r}$$

Consistency Check

$$\mathbf{u}^i = G(\mathbf{k}_i^0) \oplus G(\mathbf{k}_i^1) \oplus \mathbf{r}$$
$$\mathbf{u}^j = G(\mathbf{k}_j^0) \oplus G(\mathbf{k}_j^1) \oplus \mathbf{r}$$

$$\oplus \begin{array}{l} \mathbf{u}^i = \mathbf{t}_i^0 \oplus \mathbf{t}_i^1 \oplus \mathbf{r} \\ \mathbf{u}^j = \mathbf{t}_j^0 \oplus \mathbf{t}_j^1 \oplus \mathbf{r} \end{array}$$

$$\mathbf{u}^i \oplus \mathbf{u}^j = \mathbf{t}_i^0 \oplus \mathbf{t}_i^1 \oplus \mathbf{t}_j^0 \oplus \mathbf{t}_j^1$$

$$\boxed{\mathbf{u}^i \oplus \mathbf{u}^j \oplus \mathbf{t}_i^{s_i} \oplus \mathbf{t}_j^{s_j}} \; ?= \; \boxed{\mathbf{t}_i^{1-s_i} \oplus \mathbf{t}_j^{1-s_j}}$$

$$\mathrm{H}(\mathbf{u}^i \oplus \mathbf{u}^j \oplus \mathbf{t}_i^{s_i} \oplus \mathbf{t}_j^{s_j}) \; ?= \; \mathrm{H}(\mathbf{t}_i^{1-s_i} \oplus \mathbf{t}_j^{1-s_j})$$

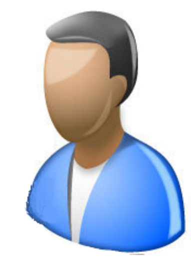
Consistency Check

$$h_{i,j}^{0,0} = H(\mathbf{t}_i^0 \oplus \mathbf{t}_j^0)$$

$$h_{i,j}^{0,1} = H(\mathbf{t}_i^0 \oplus \mathbf{t}_j^1)$$

$$h_{i,j}^{1,0} = H(\mathbf{t}_i^1 \oplus \mathbf{t}_j^0)$$

$$h_{i,j}^{1,1} = H(\mathbf{t}_i^1 \oplus \mathbf{t}_j^1)$$



For every pair (i,j)

$$\xleftarrow{\hspace{10em}}$$

$$\mathbf{u}^1,\ldots,\mathbf{u}^\ell \quad \{h_{i,j}^{0,0}, h_{i,j}^{0,1}, h_{i,j}^{1,0}, h_{i,j}^{1,1}\}_{i,j}$$

Alice checks that every pair *(i,j)*:

$$h_{i,j}^{1-s_i,1-s_j} \;?\!= H(\mathbf{u}^i \oplus \mathbf{u}^j \oplus \mathbf{t}_i^{s_i} \oplus \mathbf{t}_j^{s_j})$$

$$h_{i,j}^{s_i,s_j} \;?\!= H(\mathbf{t}_i^{s_i} \oplus \mathbf{t}_j^{s_j})$$

Does it work?

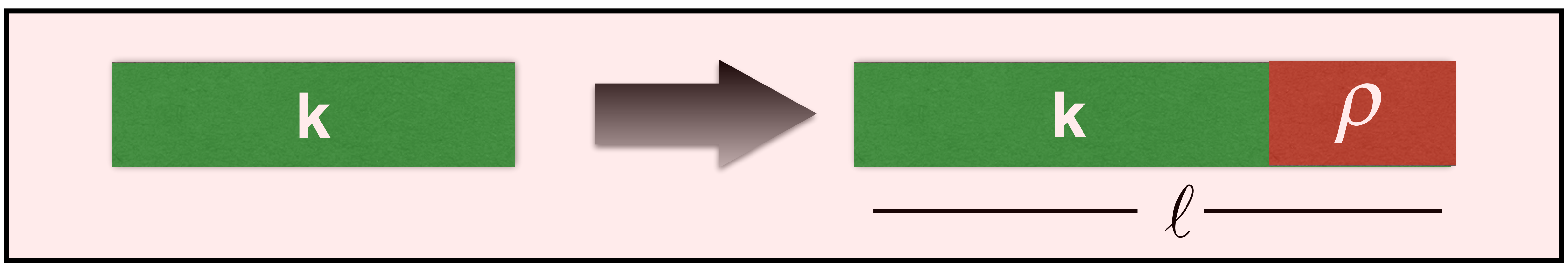
- **Our check is not sound:**
  - The adversary can still send $\mathbf{u}^i$, $\mathbf{u}^j$, with $\mathbf{r}^i \neq \mathbf{r}^j$
  - But, it takes a risk…
  - Effectively, in order to pass the verification of (i,j) it has to guess either $\mathbf{s}_i$ or $\mathbf{s}_j$

- Our check guarantees the following:

If the adversary tries to cheat with u^i, u^j it gets caught with probability 1/2!

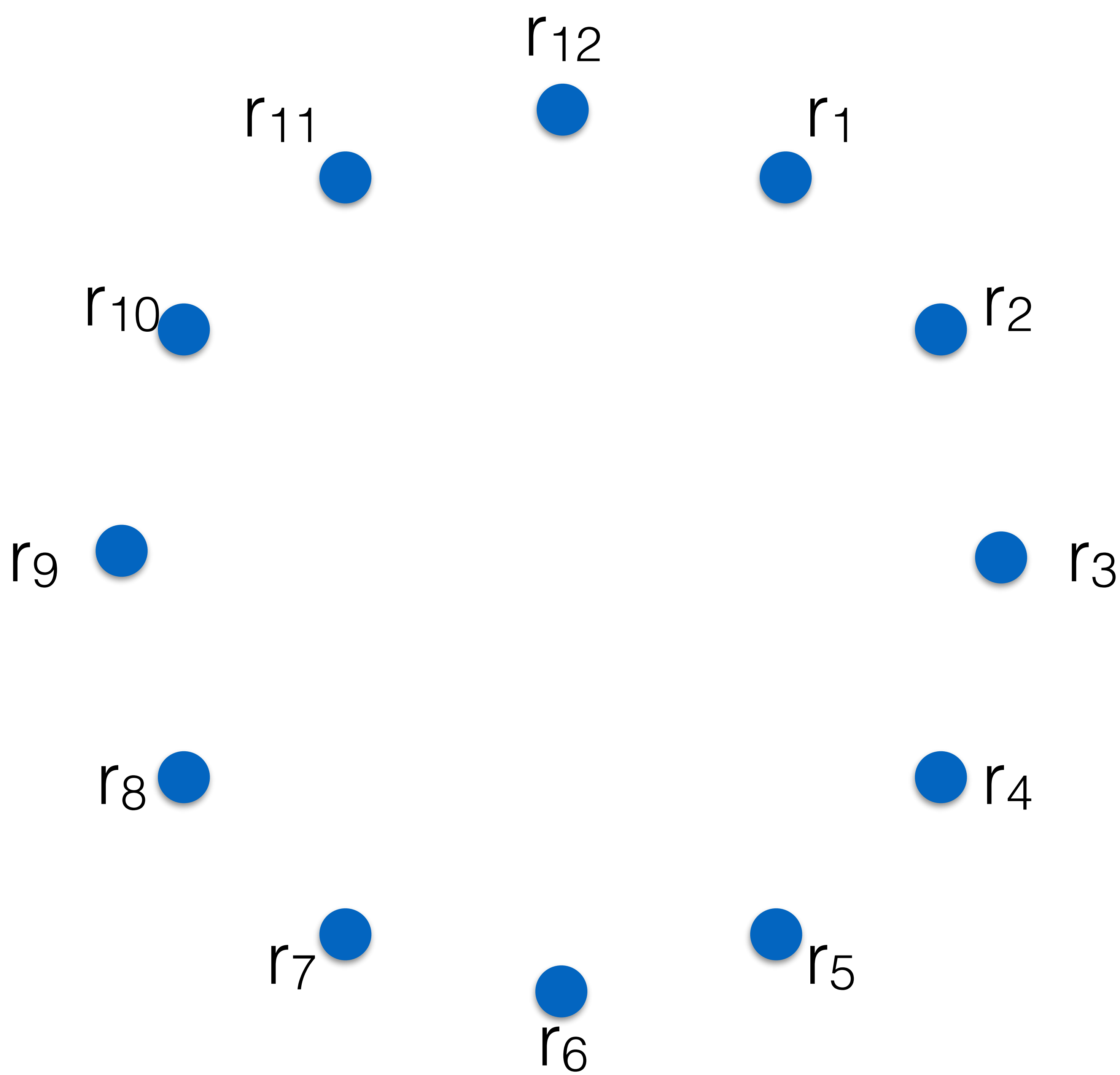
Consistency Check

- **Receiver** cannot cheat in many messages
  - with each cheat - one bit of **s** is leaked
  - **s** is the "secret key" of the sender
- **Solution** - increase the size of **s**



- But wait… you have ℓ^2 amount of checks
  Do we really need this huge amount of checks?

How many checks do we really need?



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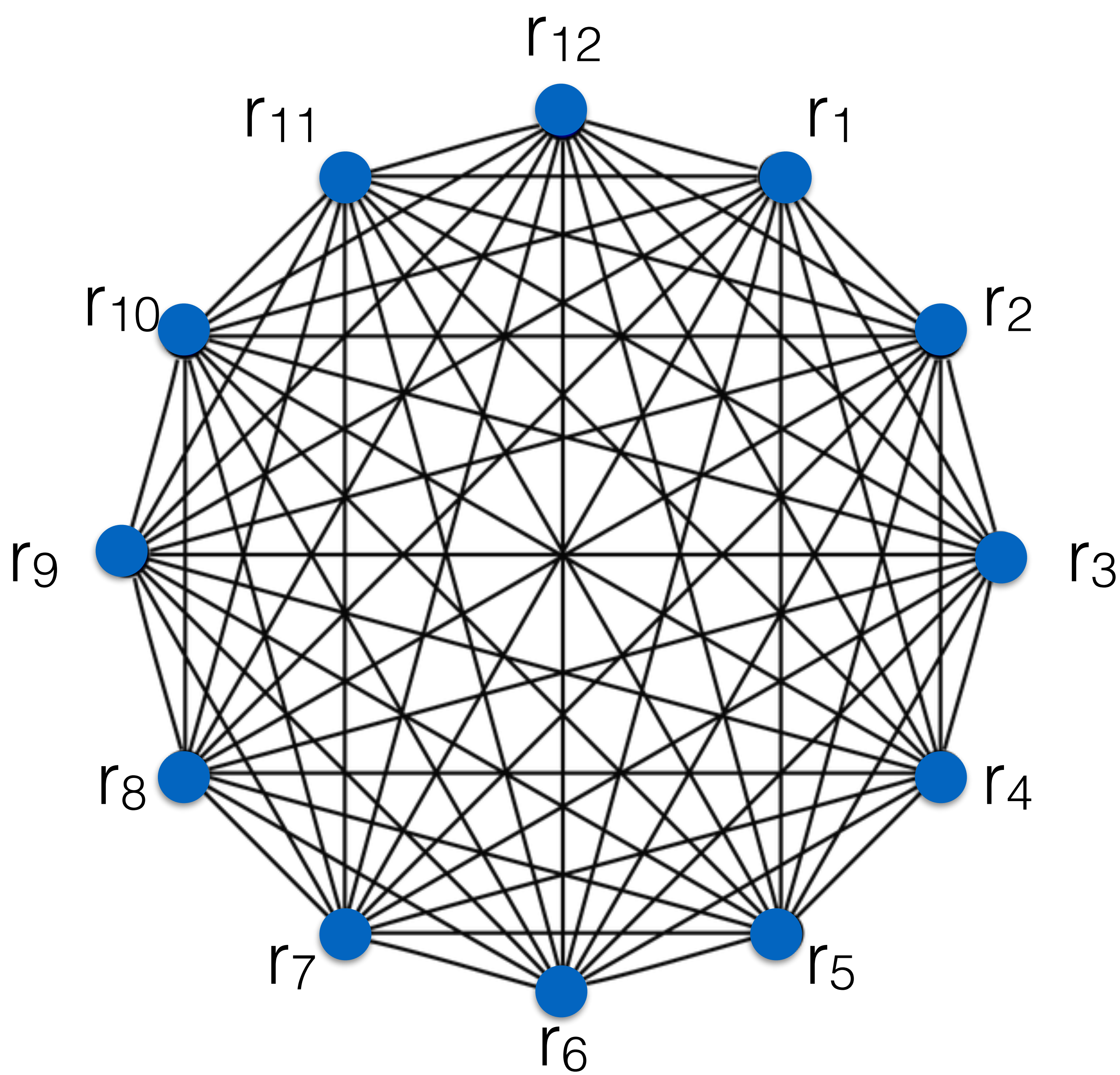

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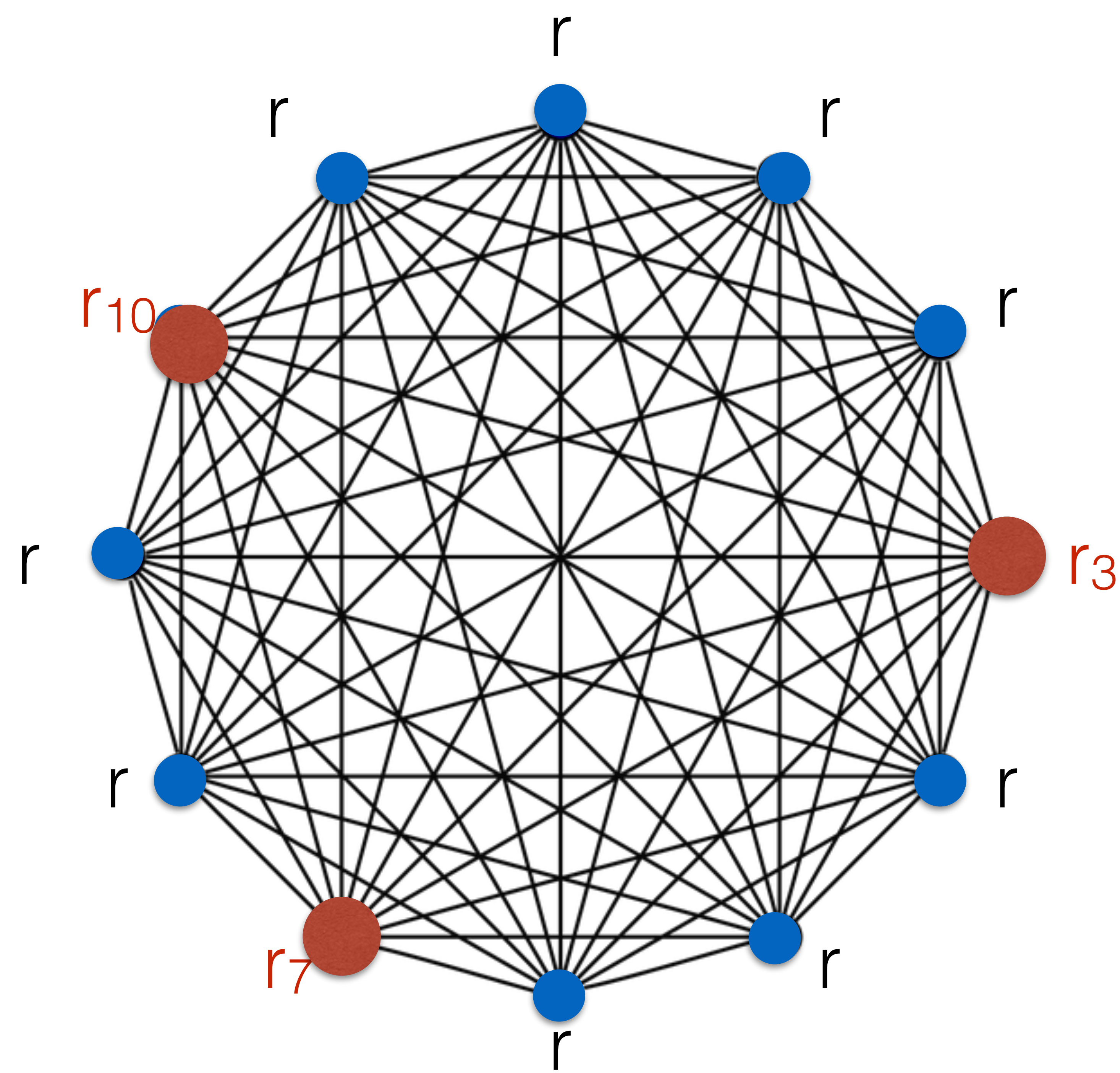

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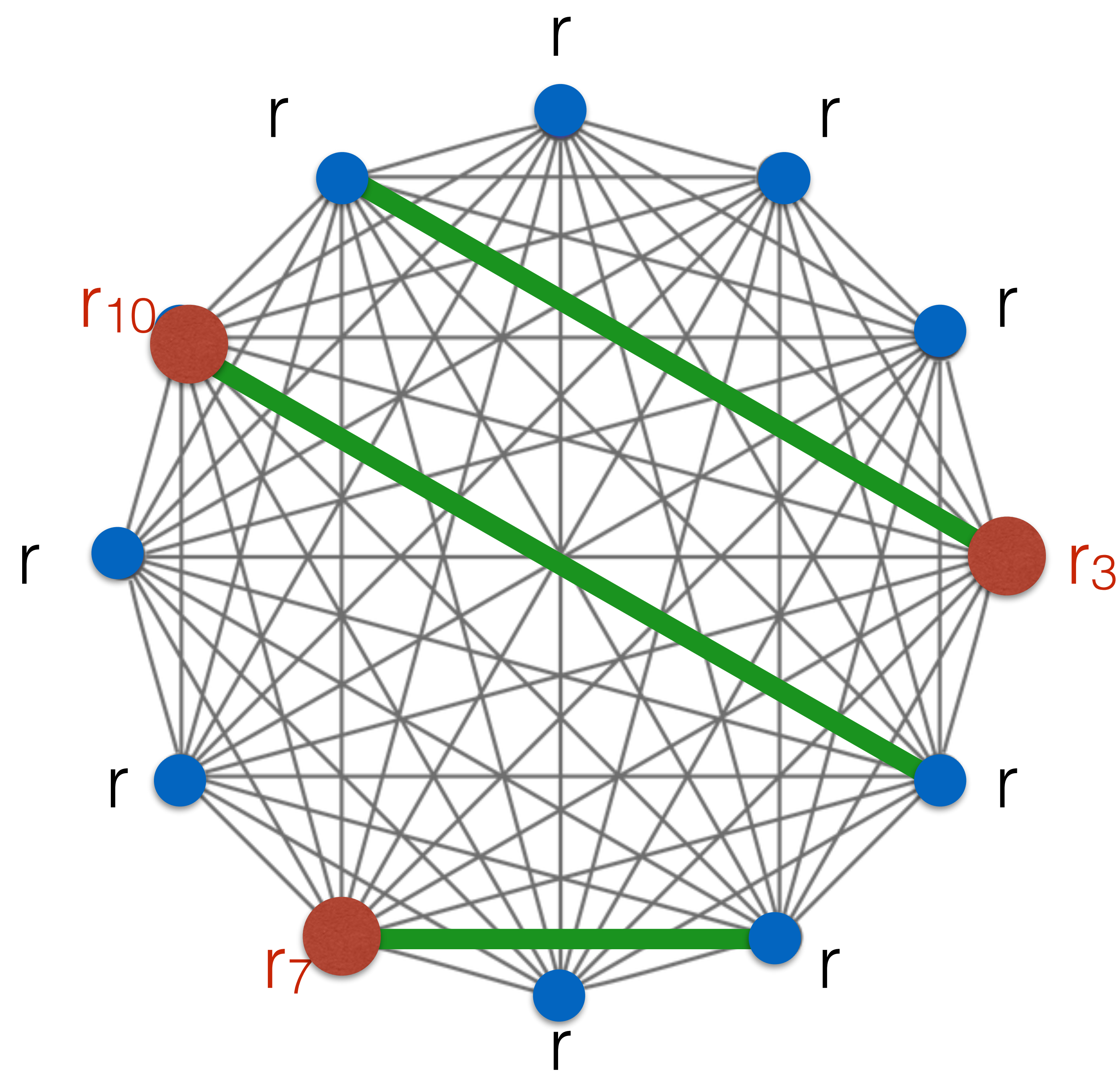
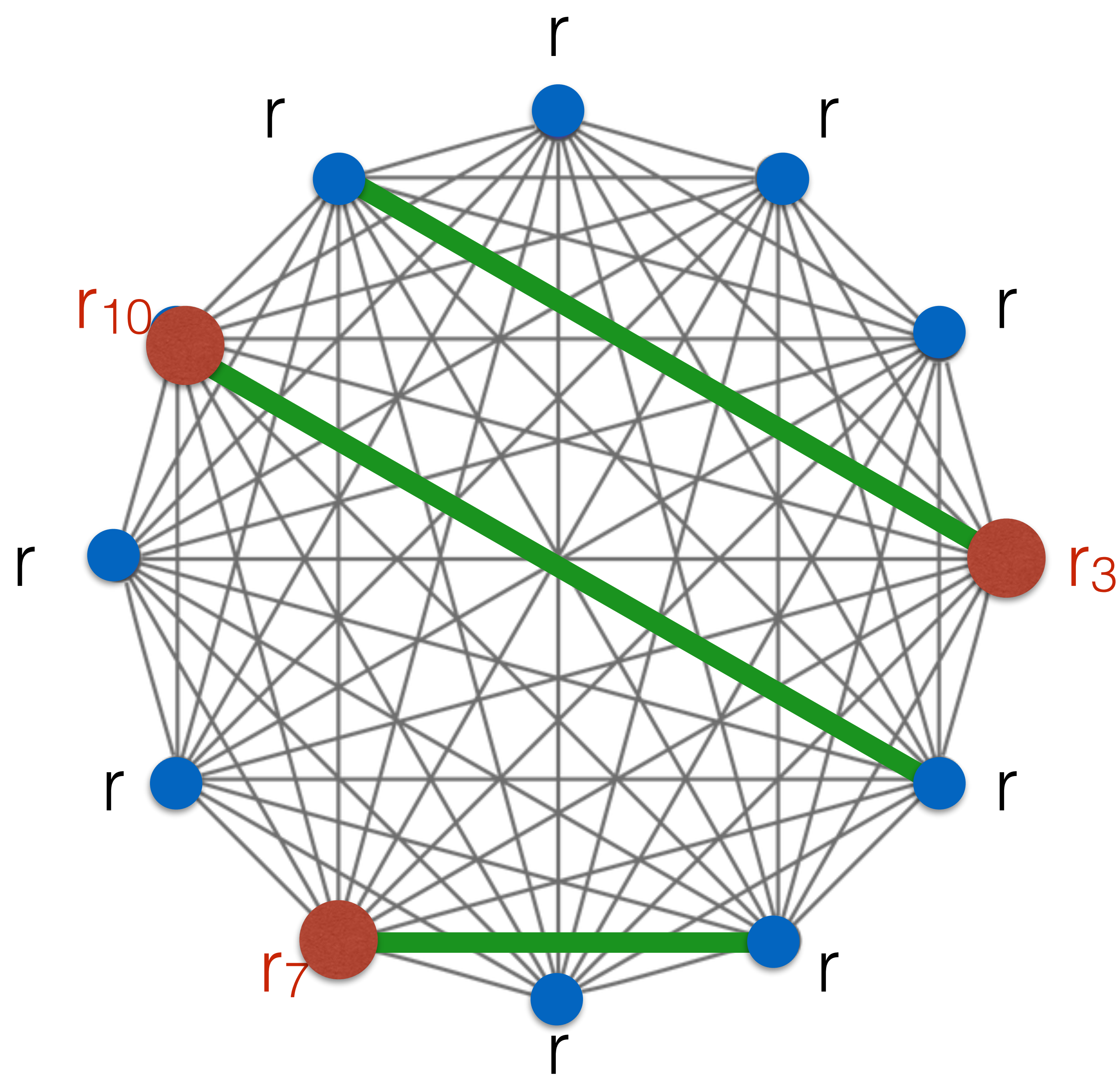


The needed property:
For any “large enough" set of **bad** vertices
(> p=40), **there exists** p-matching with the **good** vertices



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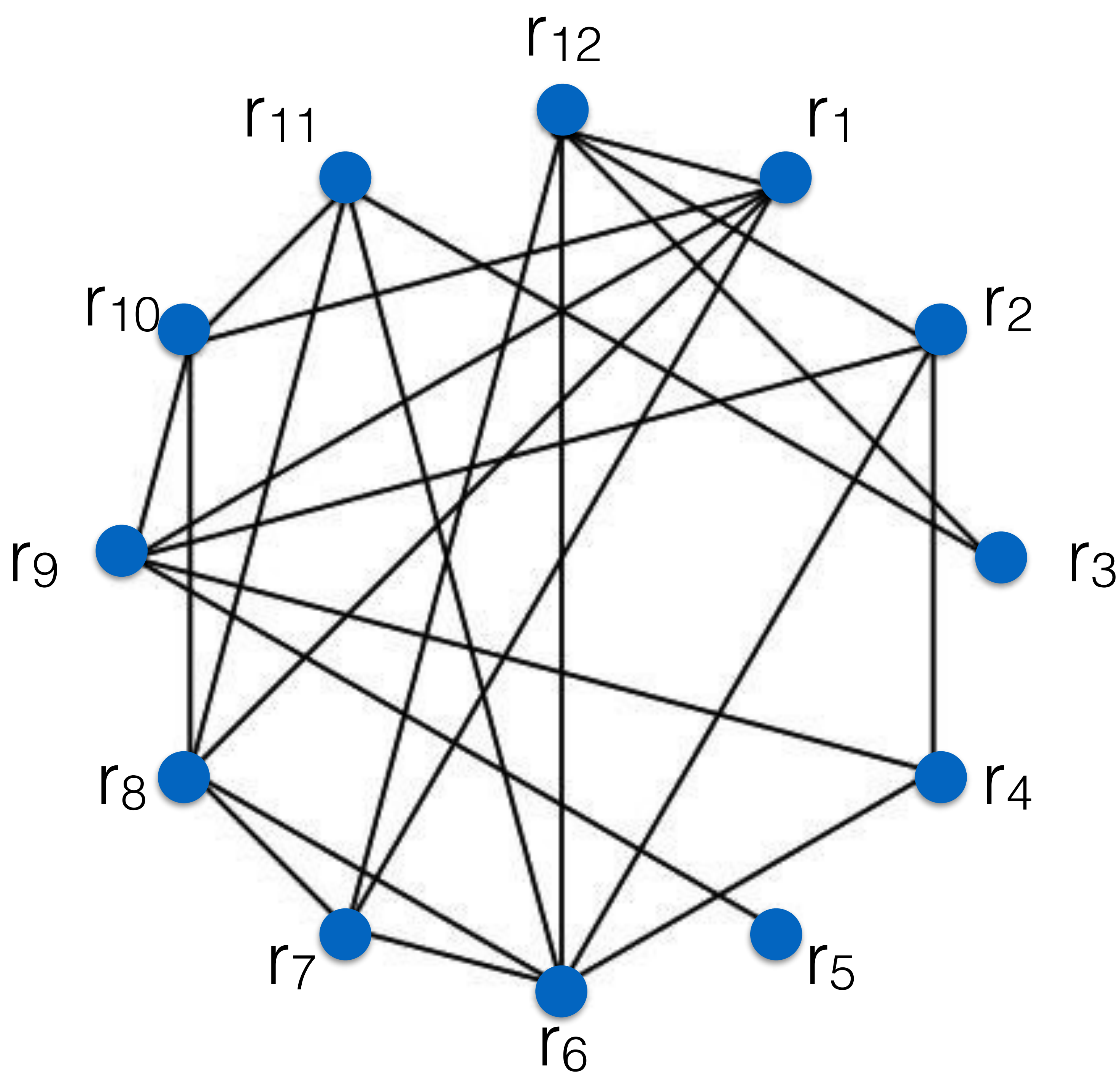

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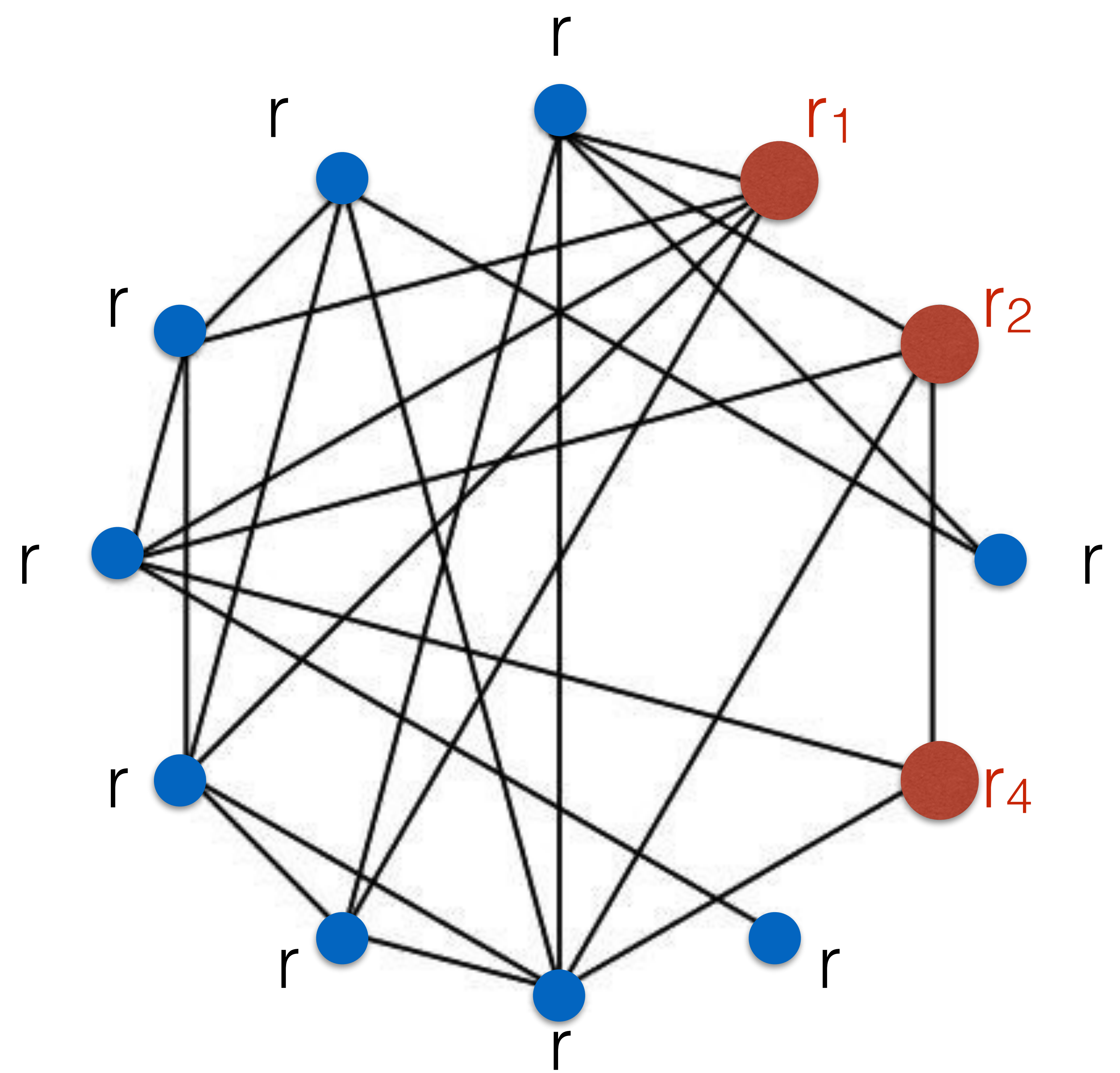

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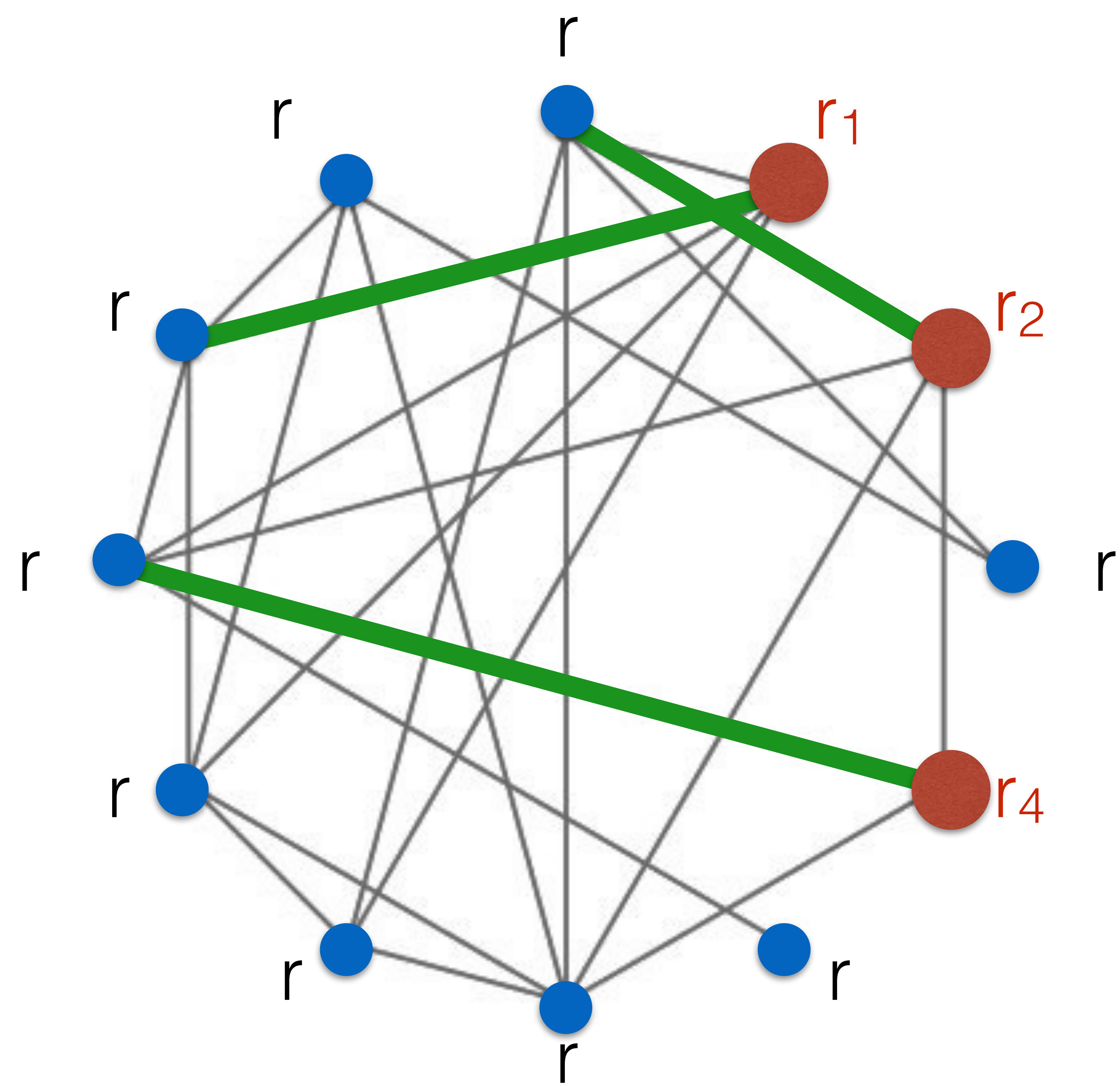


How Many Checks?

The needed property:
For any "large enough" set of **bad** vertices (> *p*=40), **there exists** *p*-matching with the **good** vertices

- We show that random **d-regular graph** satisfies the above (for appropriate set of parameters)
  - For k=128, p=40
    - 168 base OTs, complete graph: 14028
    - 190 base OTs, d=2, checks: 380
    - 177 base OTs, d=3, checks: 531

- **Covert**: (168 base OTs) probability 1/2, just random 7 checks!

Instantiation of **H**

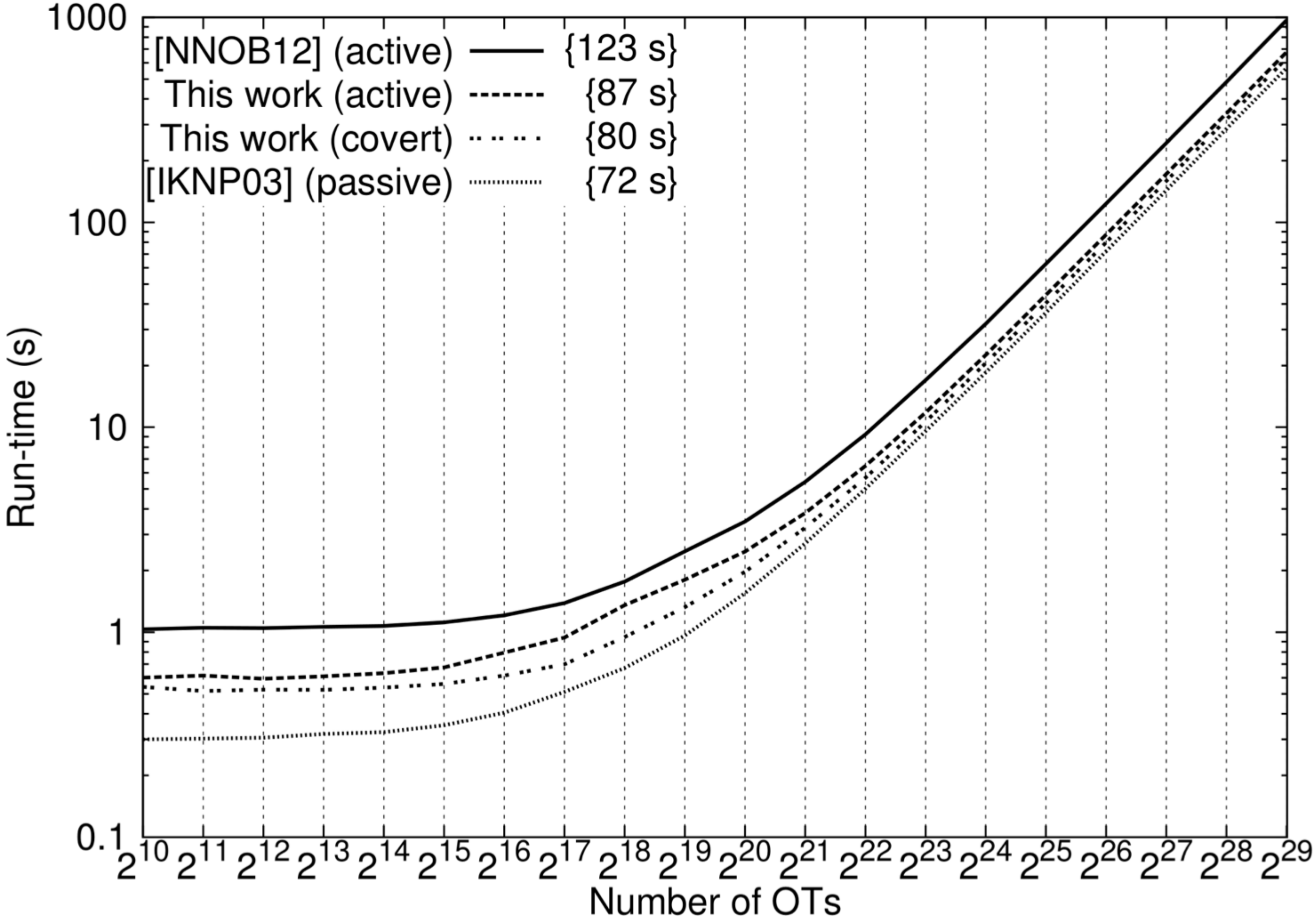
- [IKNP] assumes that **H** is **Correlation-Robust**
- Sometimes, in order to gain more efficiency, protocols need some stronger properties of **H**, and so it is assumed to be a **Random-Oracle**
- **Correlation-robustness** is much more plausible assumption than **random-oracle**
- We have some leakage of **s**, and so **H** is assumed to be **Min-Entropy Correlation Robustness**

Performance

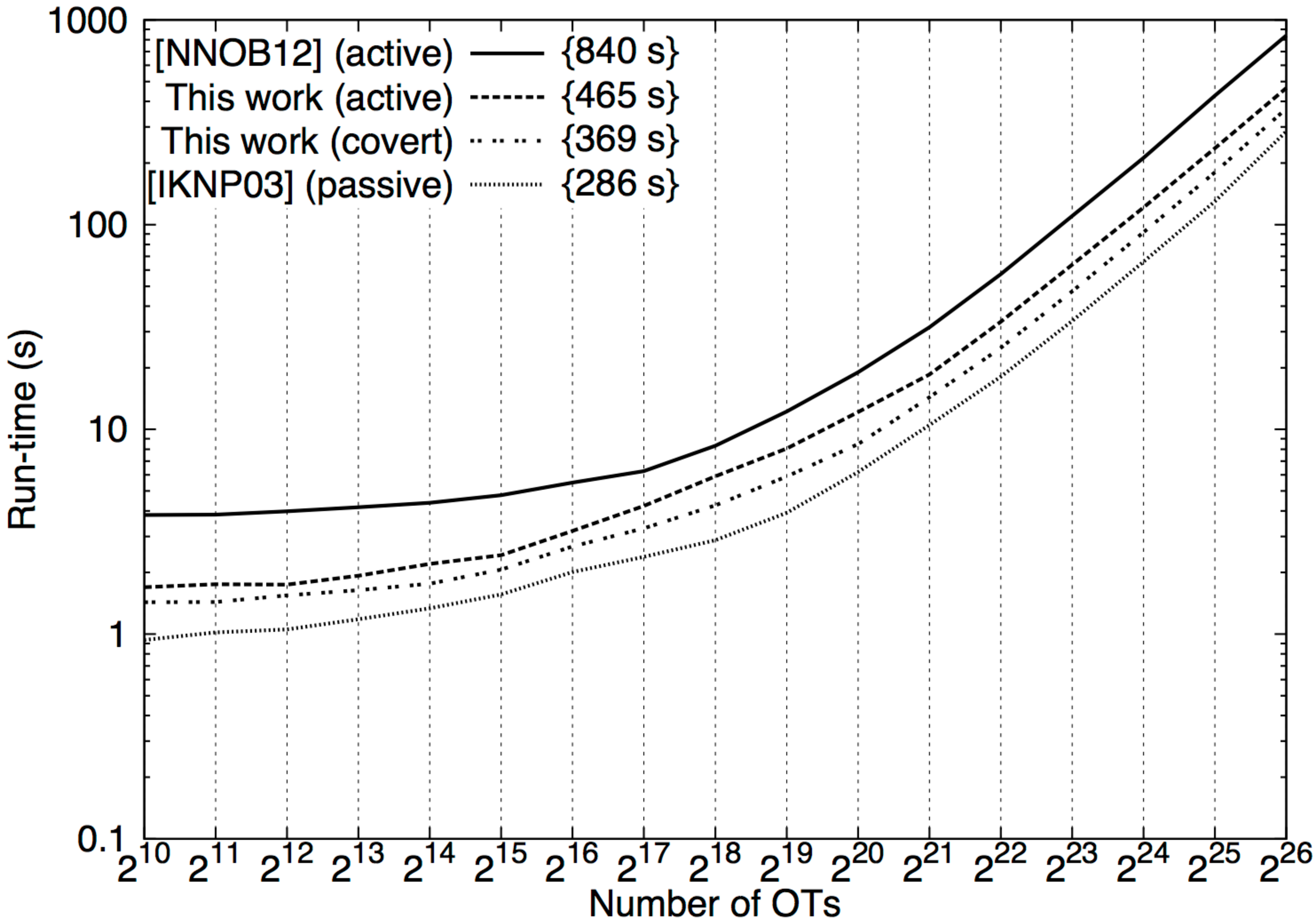
Empirical Evaluation

- Benchmark: 2^{23}=8M OTs
- **Local scenario (LAN):**
  Two servers in the same room
  (network with low latency and high bandwidth)
  12 sec (190 base OTs, 380 checks)
- **Cloud scenario (WAN):**
  Two servers in different continents
  (network with high latency and low bandwidth)
  64 sec (174 base OTs, 696 checks)

Comparison - LAN Setting



Comparison - WAN setting



Conclusions

- More efficient OT extension - more efficient protocols for MPC
- Optimized OT extension protocol, malicious adversary
- Combination of theory and practice

Thank You!