Anonymous communication with on-line and off-line onion encoding

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Privacy in Communication Systems

- messages can be kept secret
- reliable authentication
- how to hide that two parties are communicating??

Need of Anonymity in Communication

- a health insurance company discovers that an applicant has sought information on specific heart diseases – his application get rejected!
- buying a product – the seller knows where I have checked the prices.
  – the game becomes unfair!

Design Goals

- provable security

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- provable security
- scalability
- layered approach consistent with communication systems architecture
- adaptiveness to network load
- the end-user machine has limited knowledge of the network
- resistance against dynamic attacks (not only observing the network but also inserting/deleting messages)

Naive or Local Network Solutions

- **all-to-all**: send the encrypted message to all participants, communication overhead!

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- **token ring**: encoded messages go around the ring communication delay!

Onion Encoding

$$m$$

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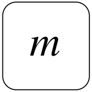

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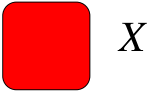

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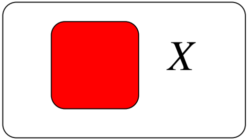

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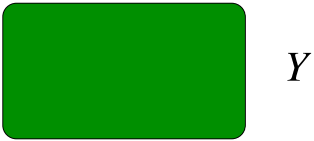

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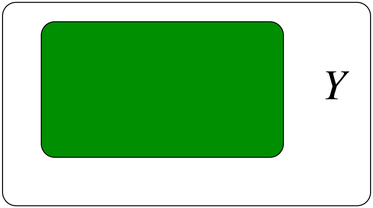

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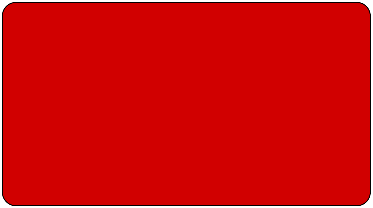

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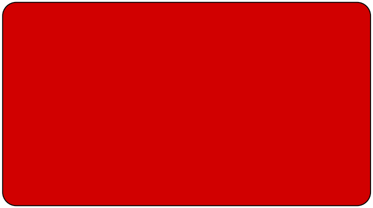

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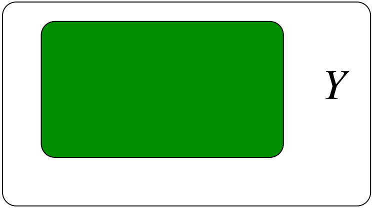

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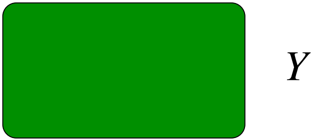

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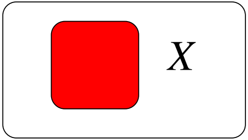

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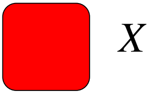

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Route of an Onion

single onion

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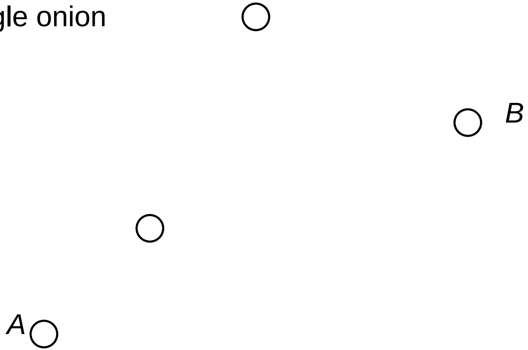

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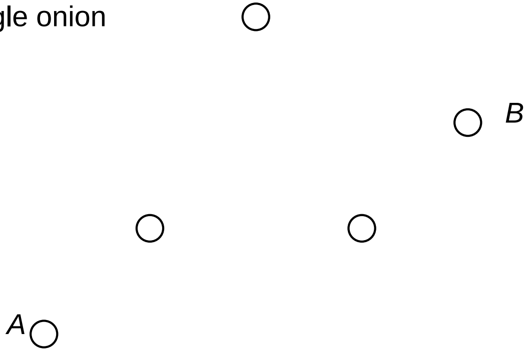

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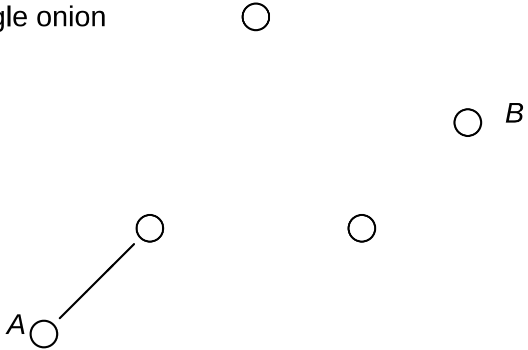

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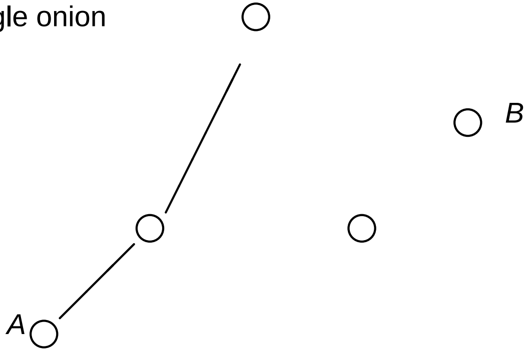

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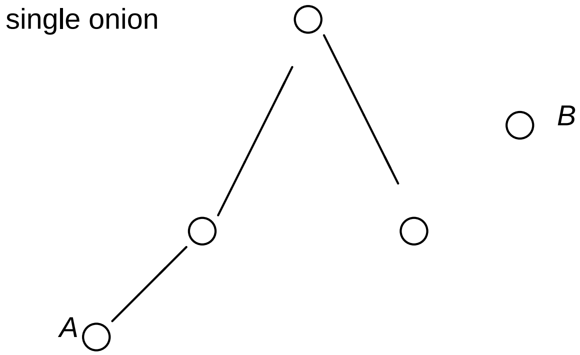

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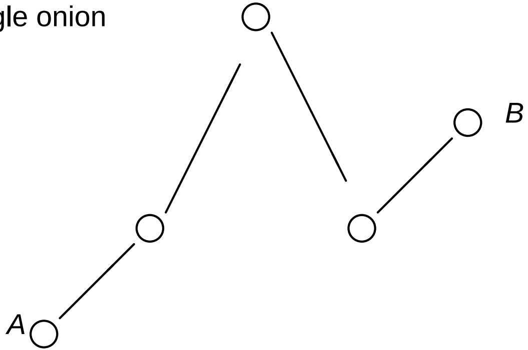

Classical Onions

If *A* wants send a message *m* to server *B*

- *A* chooses at random λ intermediate nodes $J_1, \ldots, J_\lambda$;

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$$O := \mathrm{Enc}_{J_1}(\ldots(\mathrm{Enc}_{J_{\lambda-1}}(\mathrm{Enc}_{J_\lambda}(\mathrm{Enc}_B(m), B), J_\lambda), J_{\lambda-1})\ldots, J_2)\ .$$

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If A wants send a message m encrypted as O to server B

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- J_2 decrypts ..
- J_2 sends .. to J_3

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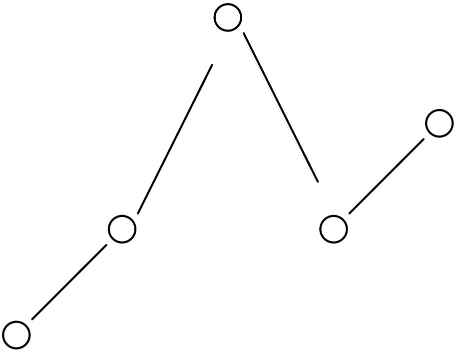
- ...

Onions at Work



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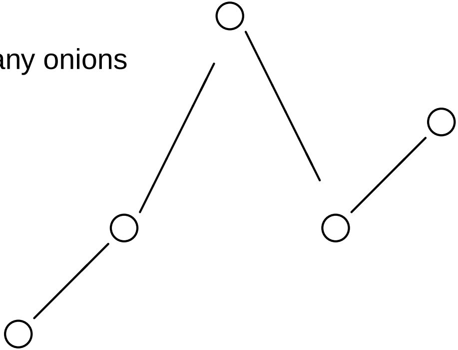
many onions



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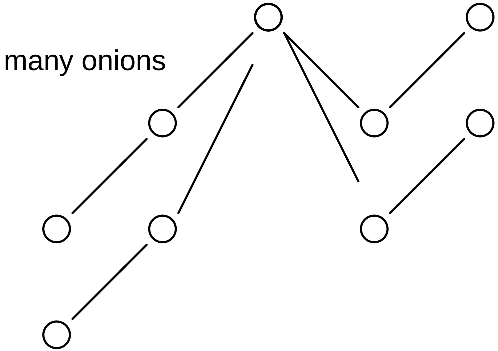

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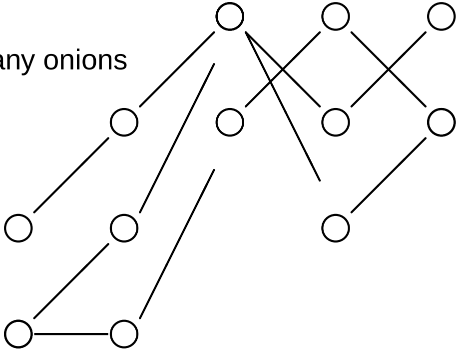

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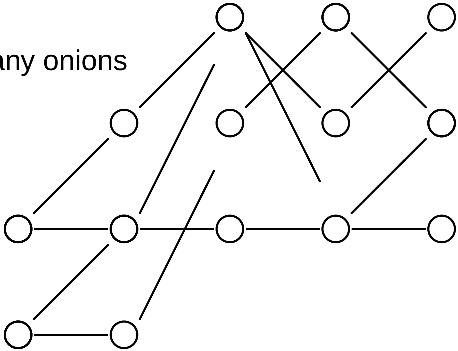

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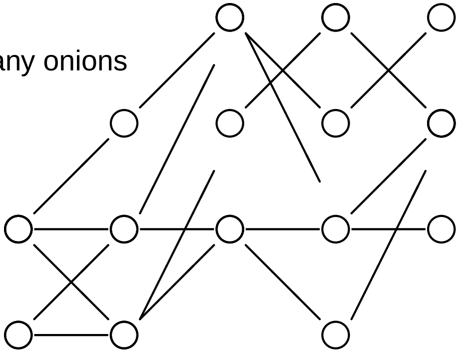

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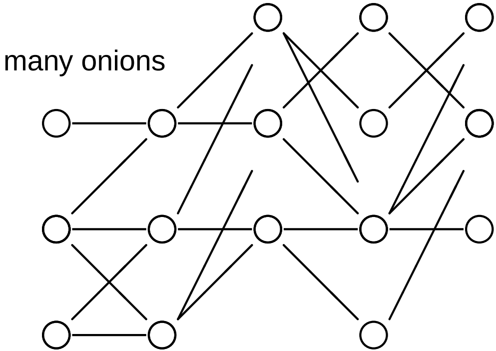

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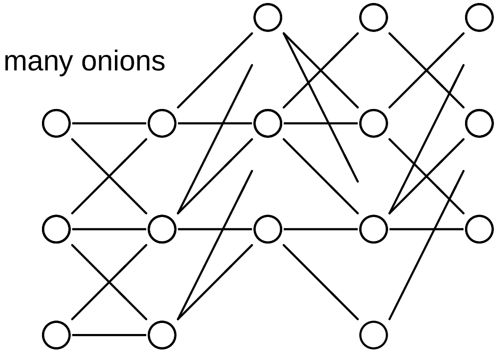

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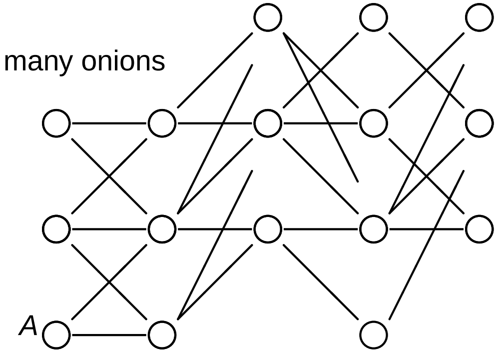
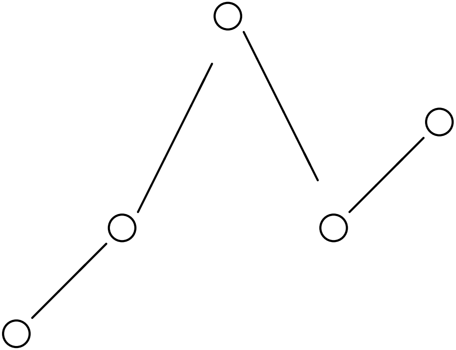


destination of the message starting at A?

Disadvantages – Repetitive Attack

an adversary re-sends the same onion



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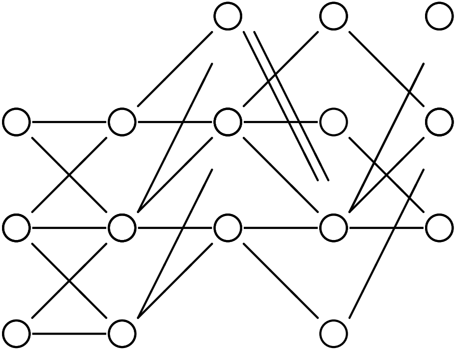

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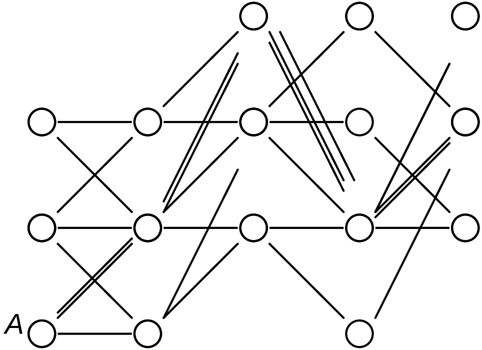

Problem Solution: Universal Re-Encryption

technique due to P. Golle, M. Jakobsson, A. Juels, P. Syverson

- ciphertext obtained with a public key of recipient Alice but everybody can re-code it without knowing the public key of Alice or her identity
- any connection between a ciphertext before and after re-coding undetectable by a third party
- perfect tool for an anonymous re-mailer, ...

URE setup

- q - prime, G - a group of rank q with hard discrete logarithm problem
- g - generator of G,
- $x < q$ - private key of Alice
- $y = g^x$ - public key of Alice

URE Ciphertexts

Encryption:

k_0, k_1 - random

A ciphertext of m:

$$(\alpha_0, \beta_0; \alpha_1, \beta_1) := \left(m \cdot y^{k_0}, g^{k_0}; y^{k_1}, g^{k_1}\right)$$

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Re-encryption:

k_0', k_1' - random
The message after re-encryption:

$$\left(\alpha_0 \cdot \alpha_1^{k_0'}, \beta_0 \cdot \beta_1^{k_0'}; \alpha_1^{k_1'}, \beta_1^{k_1'}\right)$$
$$= \left(m \cdot y^{k_0 + k_1 \cdot k_0'}, g^{k_0 + k_1 \cdot k_0'}; y^{k_1 \cdot k_1'}, g^{k_1 \cdot k_1'}\right)$$

Decryption

$(\alpha_0, \beta_0; \alpha_1, \beta_1)$

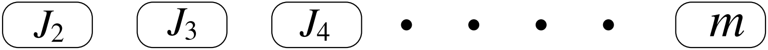
Like for ElGamal:

$$m := \frac{\alpha_0}{\beta_0^x}$$

$$m' := \frac{\alpha_1}{\beta_1^x}$$

A message m is accepted $\Leftrightarrow m' = 1$

URE-Onions



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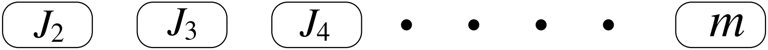

- an URE-onion consists of λ blocks
- a block = URE ciphertext
- encoded plaintexts:
  $J_2, J_3, \ldots, J_\lambda, m$

- advantage: each block can be re-encrypted while processing at a server
  repetitions get undetected!

URE-Onions - Partial Decryption

Goal: enforce processing along the path

- $y_1, \ldots, y_\lambda$ = public keys of $J_1, \ldots, J_\lambda$
- ciphertext of J_i encoded with the public key $y_1 \cdot y_2 \cdot \ldots \cdot y_{i-1}$:

$$(J_i \cdot (y_1 \cdot y_2 \cdot \ldots \cdot y_{i-1})^k, g^k, (y_1 \cdot y_2 \cdot \ldots \cdot y_{i-1})^{k'}, g^{k'})$$

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- partial decryption of (a, b, c, d) by J_1:

$$a := a/b^{x_1}, \quad c := c/d^{x_1}$$

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Result:

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- partial decryption of all blocks
  $\Rightarrow$ the next hop address J_i or m is retrieved

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  $\Rightarrow$ the next hop address J_i or m is retrieved
- re-encryption of all blocks
- random permutation of all blocks
- delivery to J_i or to the final destination

Further Possibilities: Inserting a Ciphertext

Empty container :

$$(a, b, c, d) = \left(1 \cdot y^{k_0}, g^{k_0}; y^{k_1}, g^{k_1}\right)$$

Inserting m :

$$a := a \cdot m$$

Result :

$$(a, b, c, d) = \left(m \cdot y^{k_0}, g^{k_0}; y^{k_1}, g^{k_1}\right)$$

Navigators

Navigators $\equiv$ „empty onions"

- $Nav[J_1, \ldots, J_\lambda] = O_{y_1,\ldots,y_\lambda}(-)$

Online Merge Onions

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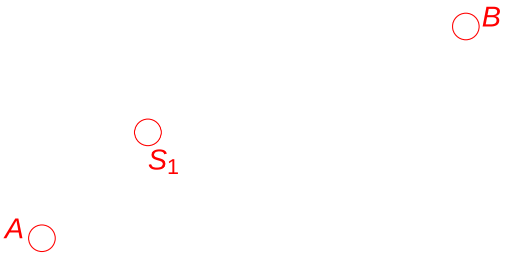

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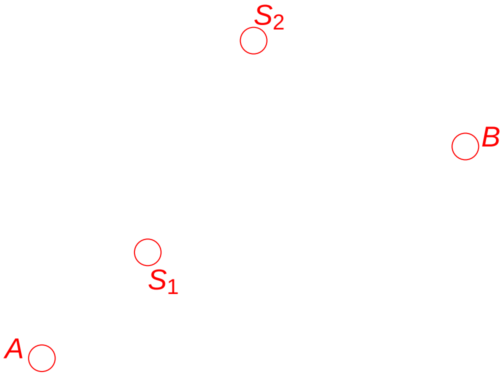

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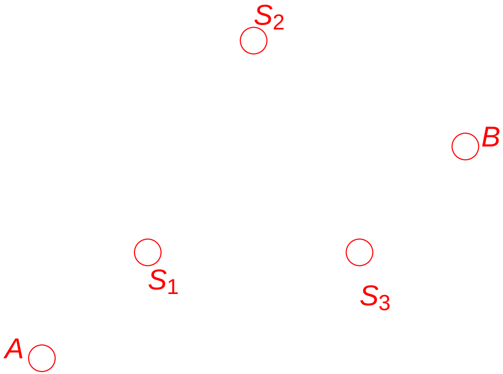

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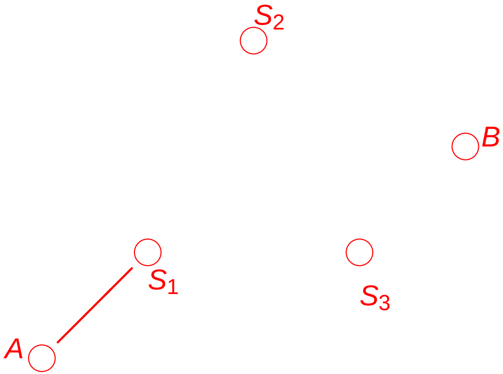

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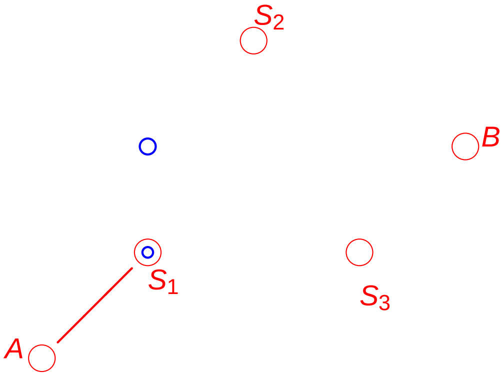

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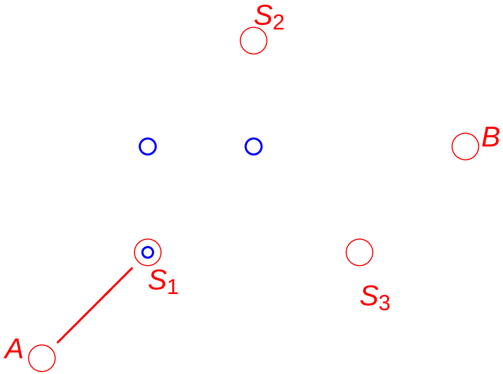

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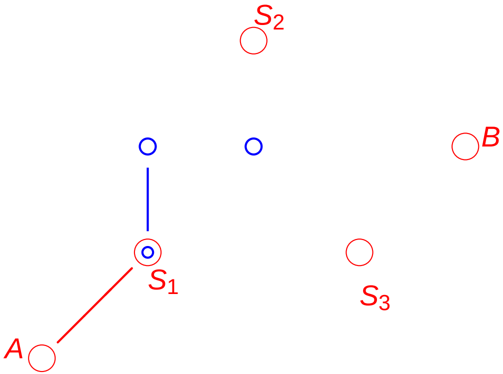

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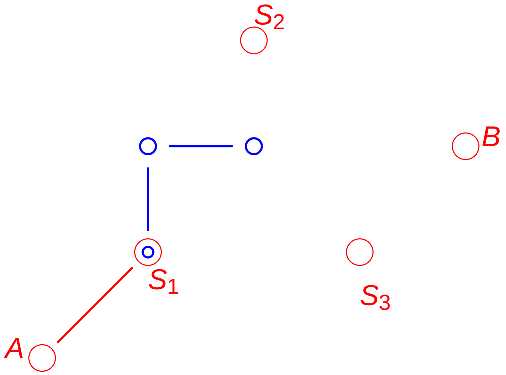

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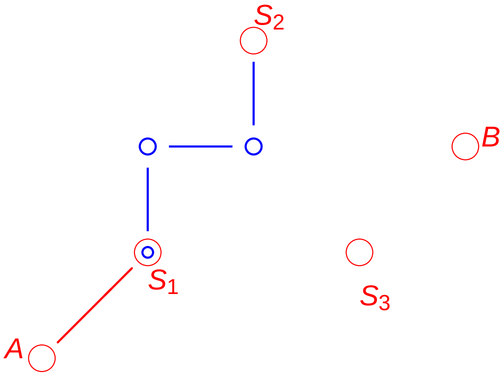

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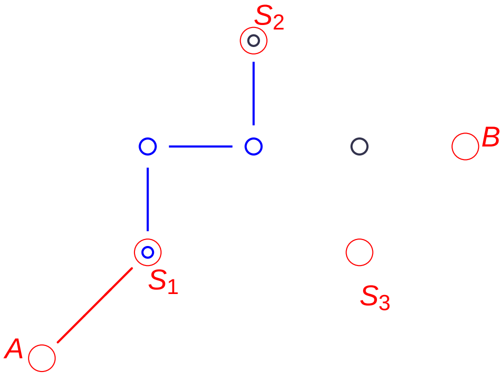

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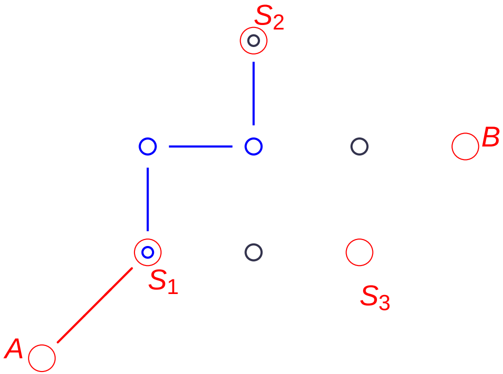

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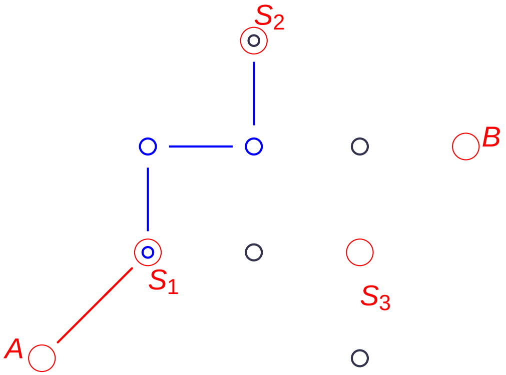

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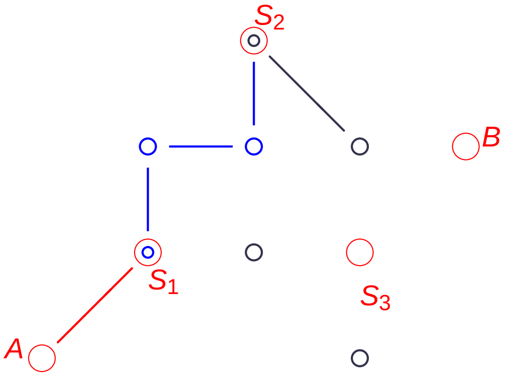

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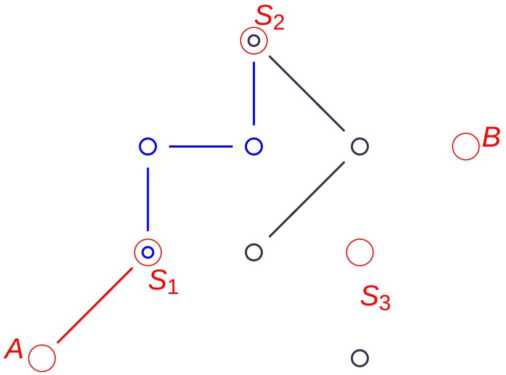

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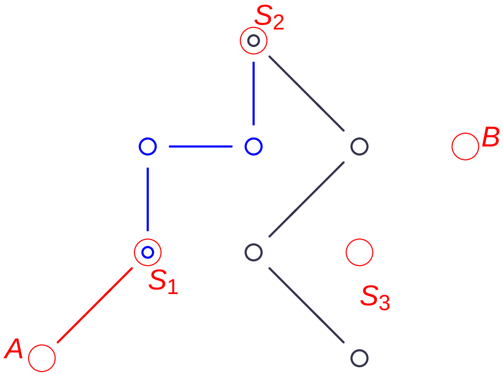

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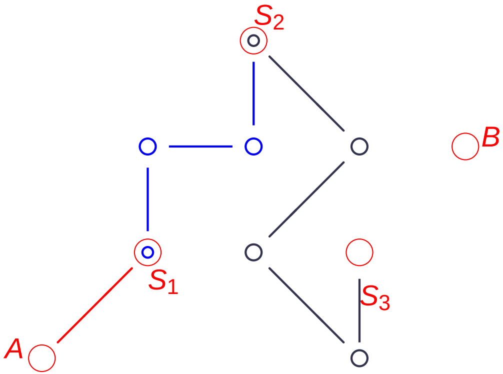

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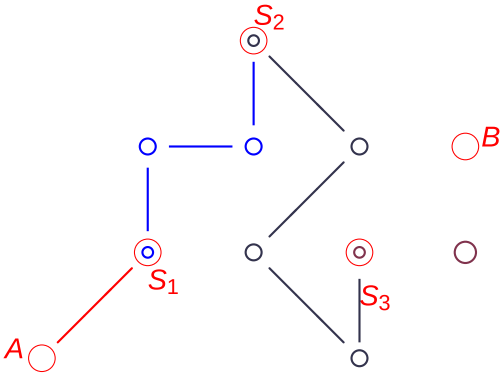

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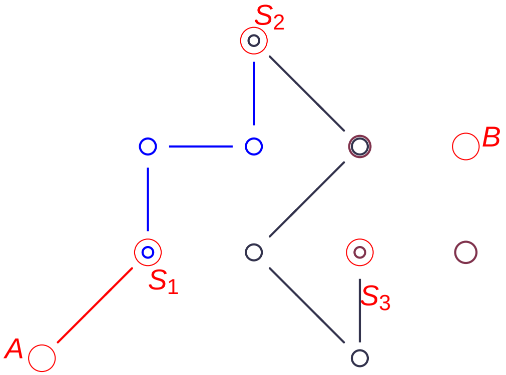

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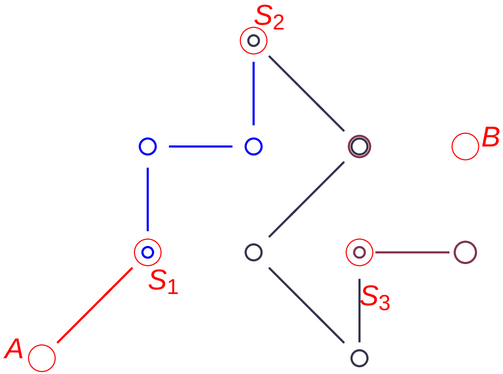

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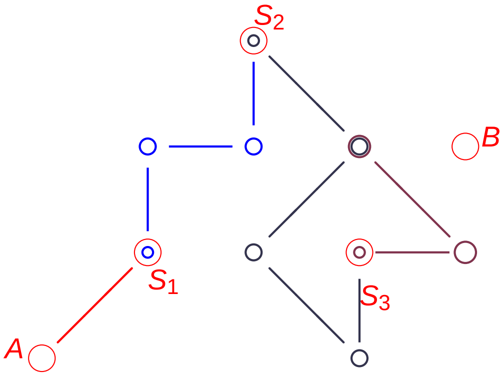

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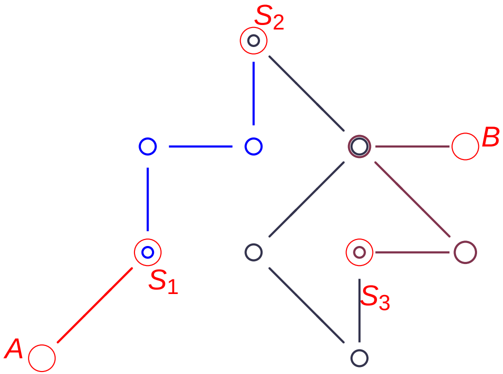

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A has a message *m* for *B*. Then *A*:

- chooses at random *k* servers S_1, ..., S_k

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$$Nav[S_1, S_k](to\ B)\ , \quad URE_{y_B}(m)$$

Online Merge Onions – processing

A message obtained by a server on a path of m consists of:

- $Nav[J_i, J_m](toS_j)$ – “local navigator” chosen online
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- partial decryption of navigators
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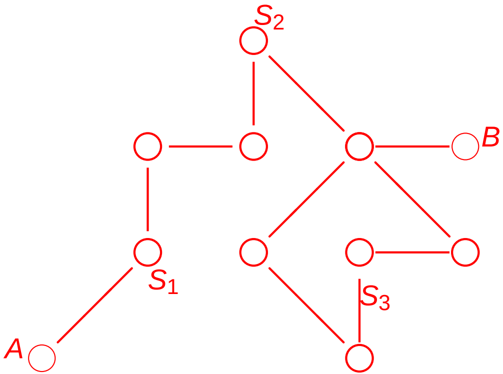
the ith server from the list $S_1, \ldots, S_k$ proceeds:

- retrieves $Nav[S_{i+1}, S_k])$ with its private key
- chooses a local navigator $M[J_1, \ldots, J_l]$ and inserts the message "to S_{i+1}"
- URE-encrypts $Nav[S_{i+1}, S_k])$ for this path
- sends to J_1

Online Merge Onions - repetitive attack



repetitive attack?

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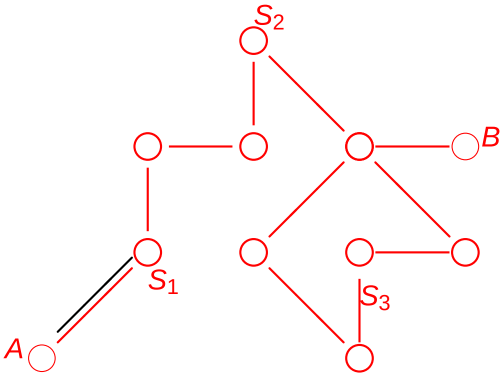

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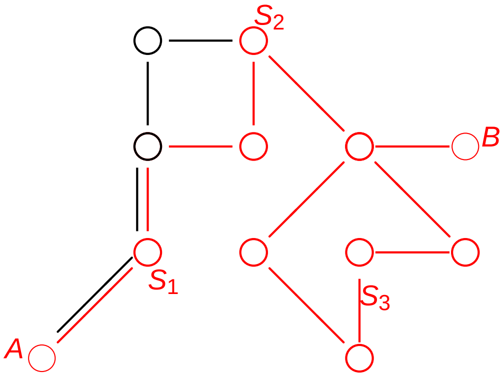

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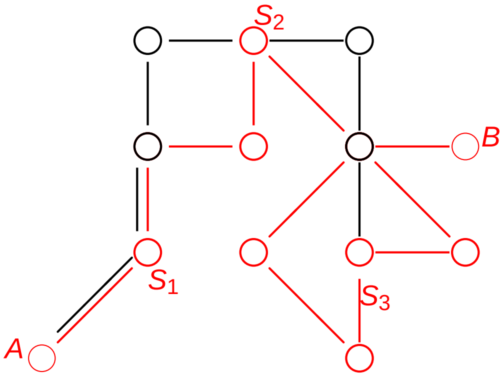

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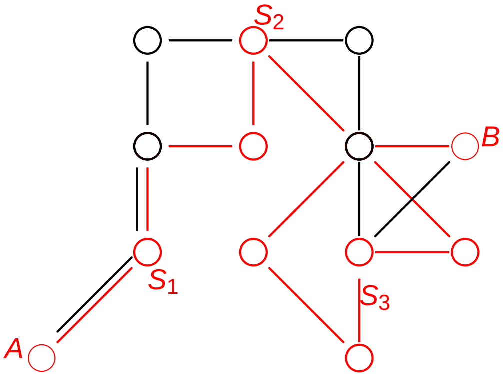

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- layered architecture
- onions can be prepared in advance

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Thank you for attention!