DUO-Onions and Hydra-Onions

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Why do we need anonymity ?

- business to business communication
- consumer protection
- privacy protection
- economic and political security of a country

Possible dangers

- anonymity can be used for good and evil purposes

Applications of Protocols Providing Anonymity

- anonymous communication
- anonymous access to databases
- anonymous browsing
- anonymous file sharing

Target

- messages can be kept secret (easy)
- keep secret who is communicating with whom
  how to hide that two parties are communicating?

Techniques that Provide Anonymity

- MIXes - David Chaum ’81
- DC-networks -David Chuam ’85
- Onions - Rackoff and Simon ’91

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- core of practical systems:
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  - ONION ROUTING,
  - TOR
- scalable, fully distributed, no a priori infrastructure

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- scalable, fully distributed, no a priori infrastructure
- sometimes the same idea is used for evil purposes: hiding a source of an attack

Onions

If A wants send a message m to server B

- A chooses at random λ intermediate nodes $J_1, \ldots, J_\lambda$;
- A creates an onion:

  $O :=$

$$\mathrm{Enc}_B(m)$$

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- ...

Route of an Onion

single onion

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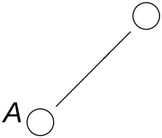

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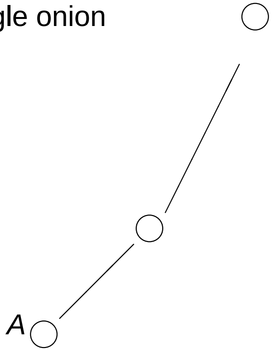

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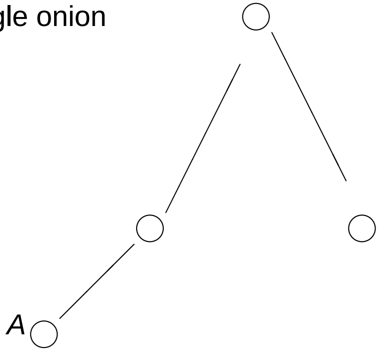

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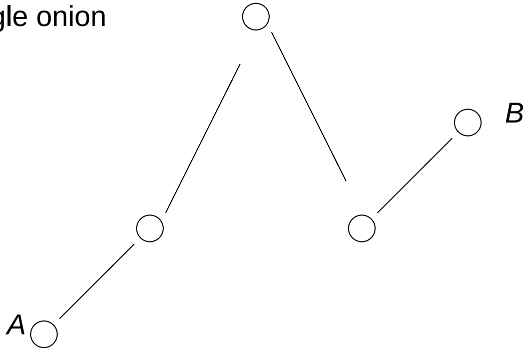
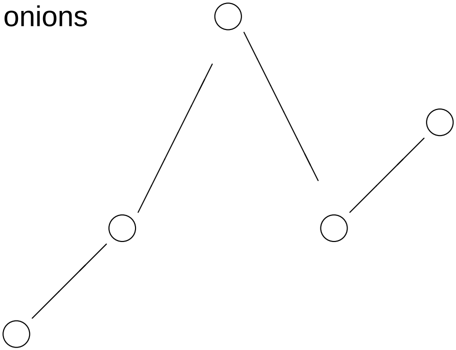


Onions at Work

many onions



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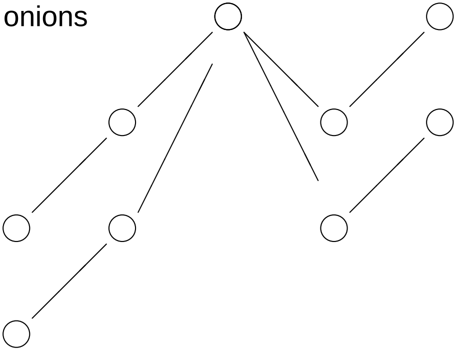

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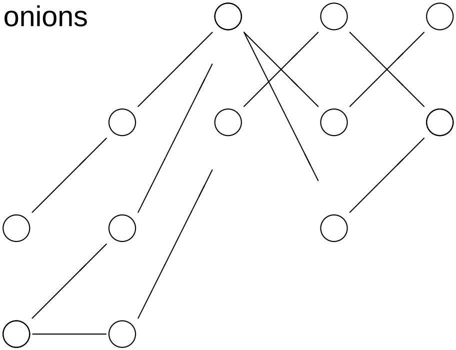

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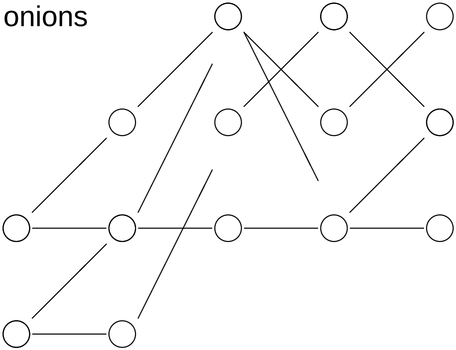

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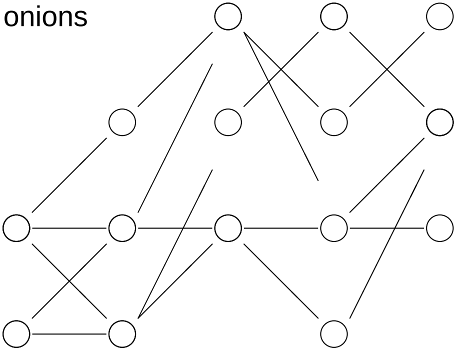

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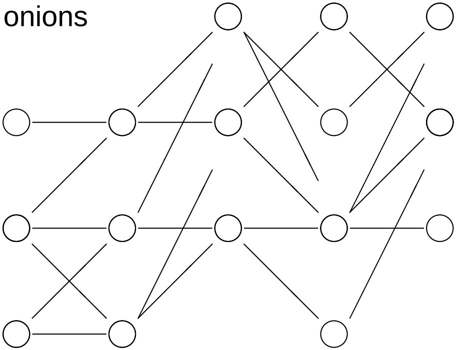

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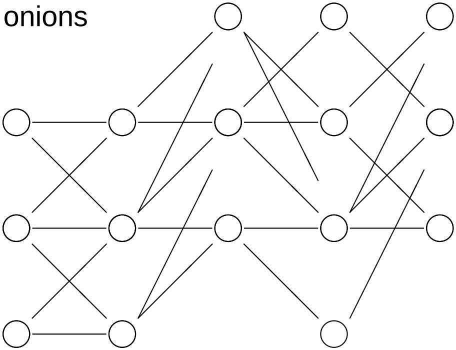

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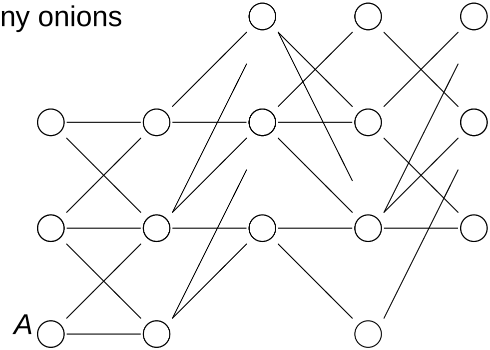

destination of the message starting at *A*?

Viewpoint of an External Observer

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- no relationship can be derived between messages entering a node and leaving a node at the same time
  (probabilistic encryption, padding, ... have to be used)
- but: transmitting a message from a node to another node can be detected

Security of Onions - Problem Areas

1. breaking anonymity by eavsdropping and traffic analysis

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- problems 1,2 - some results and techniques are known
- **not concerned so far, this paper**

Adversaries

Adversary wants to **determine any <u>nontrivial</u> relation between the senders and receivers** and/or **break the traffic**
Different models of an adversary:

passive adversary :

- an adversary can monitor the whole traffic, or
- only a fraction of connections may be traced at each moment

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Different models of an adversary:

passive adversary :

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active adversary : may influence the traffic

- non-adaptive (an attack cannot be adapted to the traffic observed), or
- adaptive

Adversary Model is Important!

Required path length in different models. Let n be a number of messages.

An adversary can monitor the whole traffic:

- no security proof for the original protocol
- modified version of the protocol (routing in growing groups)
  Rackoff, Simon, FOCS'91, for $\lambda \approx \log^{11} n$,
  Czumaj, Kutyłowski, SODA'98, for $\lambda = O(\log^2 n)$

Only a fraction of connections may be traced

- Berman, Fiat, Ta-Shma, FC'2004, for $\lambda = O(\log^4 n)$
- Gomułkiewicz, Klonowski, Kutyłowski, ISC'2004, for $\lambda = \Theta(\log n)$

Server Failures

- a long path makes failure of delivery more probable,
- no detours can be applied to avoid failure nodes — at least for the original onions

$\Rightarrow$ anonymity at a price of service quality

How to Cope with Servers Failures ?

problem case: If $n/\log n$ out of n servers are down and the length of the paths is $\lambda = \log n$, then each packet gets lost with a constant probability.

a simple solution: Send the same message many times via independant paths.
disadvantage: communication overhead

DUO-Onions Protocol

Situation: An adversary destroys some number of servers (of his choice) to break communication with onions.

Countermeasure:

- at each step two servers can be used as the next hop server on the path,
  but each server sends a message **to exactly one of them**,
- encoding of an onion is modified.

Result: (Exponentially) better probability of delivery than through sending the same message through many paths.

DUO-Onions -Construction Details

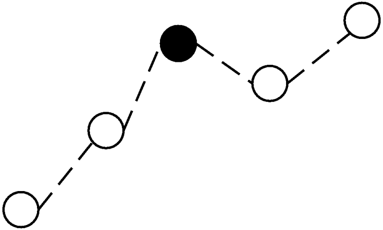
- For each step i two servers $J_{i,1} \neq J_{i,2}$ are chosen.
- encoding:

$$\begin{aligned}
\mathcal{DO}_\lambda = &\ \left(\mathsf{Enc}_B(k_{\lambda+1}), \mathsf{SEn}_{k_{\lambda+1}}(m, r_{\lambda+1})\right)\ , \\
\mathcal{DO}_i = &\ \left(\mathsf{Enc}_{J_{i,1}}(k_{i+1}, 1), \mathsf{Enc}_{J_{i,2}}(k_{i+1}, 2), \right. \\
&\qquad \left. \mathsf{SEn}_{k_{i+1}}(J_{i+1,1}, J_{i+1,2}, \mathcal{DO}_{i+1}, r_{i+1})\right) \quad \text{for } i < \lambda\ , \\
\mathcal{DO} = &\ \mathcal{DO}_1\ .
\end{aligned}$$

where SEn - symetric encryption scheme.

Instead of 2 servers we can choose K alternative servers at each step.

DUO-Onions at Work



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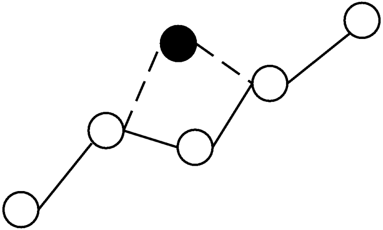

DUO-Onions versus Regular Onions Sent Many Times

advantages
- much higher probability of delivery,
- faster reaction to faults, faster delivery,

disadvantages size of an onion increases

HYDRA-Onions

- Adaptive adversary wants to block delivering a particular message. The adversary controls a constant fraction of servers and links between them at each moment.
- LET the countermeasures be also dynamic!

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- We send a stream of k paths with messages encoding the same m.

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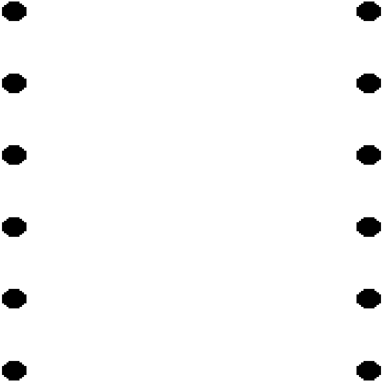
- At each moment we should have k subonions encoding m.
- If an adversary kills some of the subonions, a mechanism of HYDRA-Onions enables the stream to regenerate quickly:

each intermediate server sends the message to the next server on its path
and
to another server on a randomly chosen path of the same stream

HYDRA-Onions - Idea



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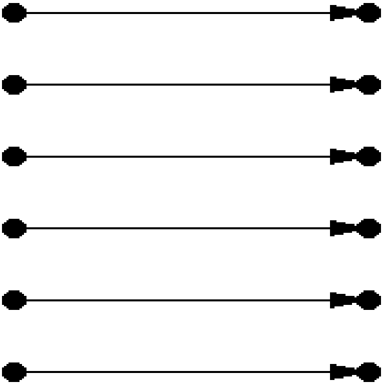

basic links

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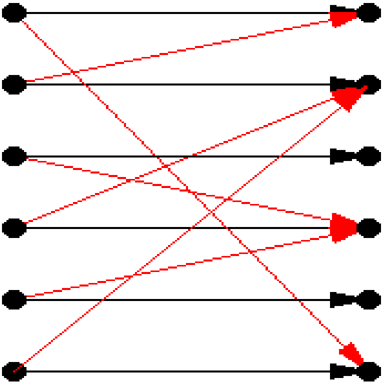

additional links

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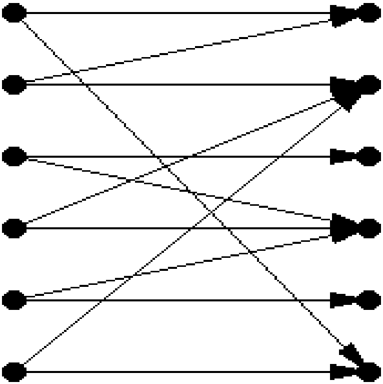

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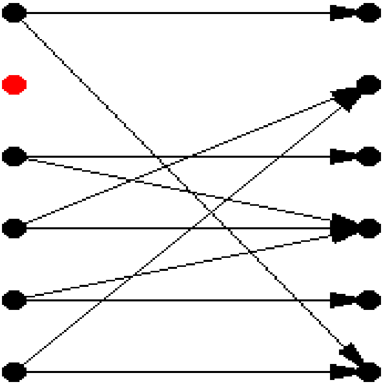

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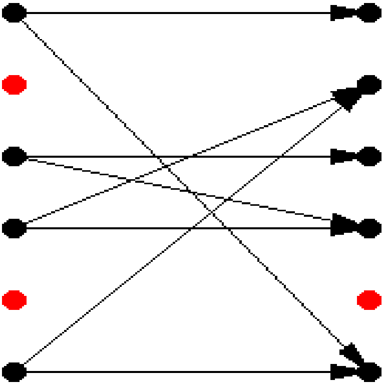

two servers are blocked

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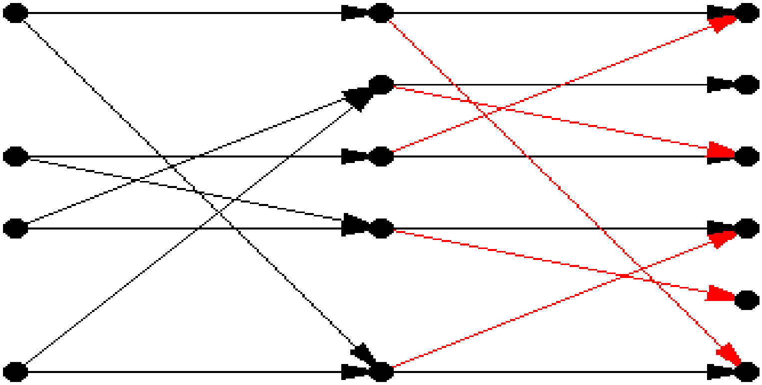

stream regeneration during two steps

HYDRA-Onions -Idea

- an adversary has to “catch” all k streams simultaneously
- otherwise the strem regenerates fast and again k paths exist

reason: random graphs are expanders with high probability

HYDRA-Onions -Construction for $k = 3$

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- streams of messages encoding *m*:
  may the additional links betray the structure of a path and **reveal where to attack**??
- certainly – the number of additional links should be kept as small as possible (less links, less information for an adversary)
  well, 1 additional link is enough for expansion features

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- **can an adversary design a clever strategy to improve his chances?**
- **a strategy can be focused not only on killing a stream but also on detecting it and killing at the next move**

Noga Alon's Lemma [2001]

there are limitations on clever strategies

Lemma

For every fixed $\varepsilon > 0$*, and every fixed integer* $t > 0$*, and for any graph* G *with* n *vertices and at least* εn^2 *edges, the number of subgraphs of* G *isomorphic to* $K_{t,t}$ *(bipartite complete graph with* t *vertices on each side) is at least:*

$$\frac{1}{2}\binom{n}{t}\binom{n}{t}(2\varepsilon)^{t^2}$$

Consequences of Alon's Lemma

For every fixed $\varepsilon > 0$, and every fixed integer $t > 0$, and for any graph G with n vertices and at least εn^2 edges, the number of subgraphs of G isomorphic to $K_{t,t}$ (bipartite complete graph with t vertices on each side) is at least:

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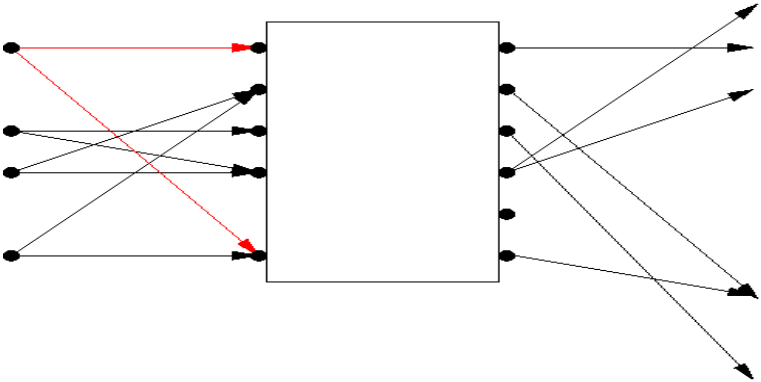
- graph G – links not monitored by an adversary
- $K_{t,t}$ in G – a subset of nodes within which an adversary has NO information – so called **crossover structure**
- the lemma says: no matter how clever is the adversary in determining G, a large number of crossover structures emerge

Why a Crossover is Bad for an Adversary?



which link to disrupt?

Consequences

- for the servers $J_{t,1}, J_{t,2}, J_{t,3}$ holding m at step t and servers $J_{t+1,1}, J_{t+2,2}, J_{t+3,3}$ holding m at step $t+1$:

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- for $K > 3$ the chances that the links seen by the adversary to see a disconnected graph from links belonging to the same stream grow substantially

Future work

- a deeper analysis of graph-theoretic aspects,
- security proofs regarding traffic analysis.

Thanks for your attention!