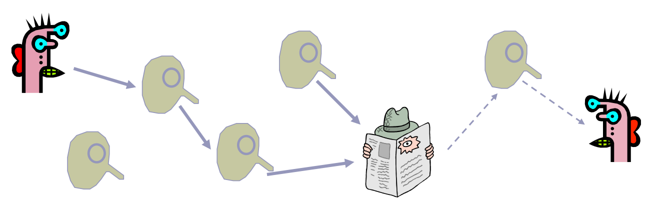
15-744: Computer Networking

L-23 Privacy

Overview

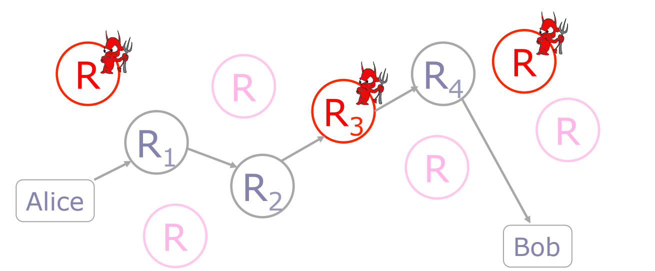
- Routing privacy
- Web Privacy
- Wireless Privacy

Randomized Routing



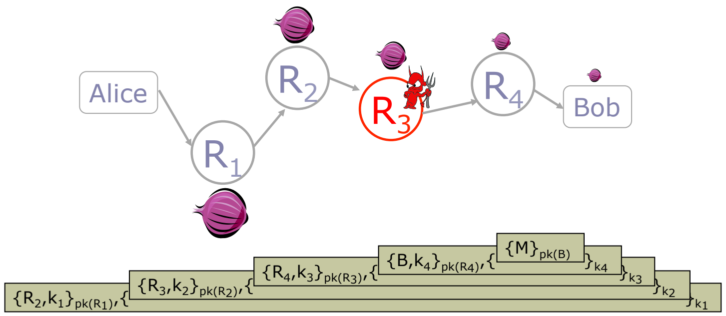
- Hide message source by routing it randomly
  - Popular technique: Crowds, Freenet, Onion routing
- Routers don't know for sure if the apparent source of a message is the true sender or another router

Onion Routing



- Sender chooses a random sequence of routers
  - Some routers are honest, some controlled by attacker
  - Sender controls the length of the path

Route Establishment

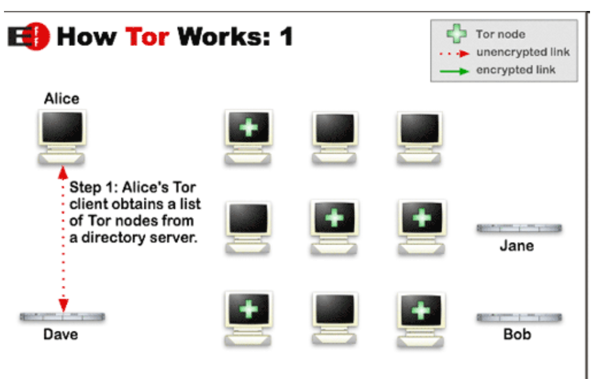


Routing info for each link encrypted with router's public key
Each router learns only the identity of the next router

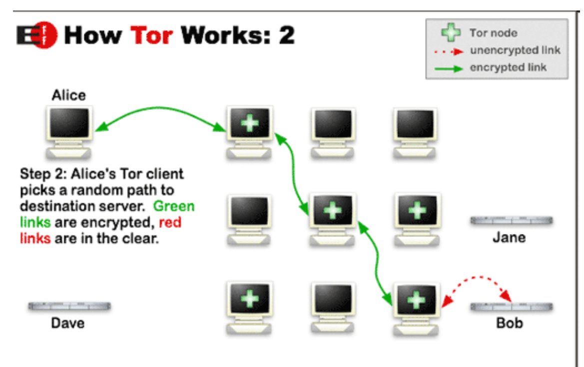
Tor

- Second-generation onion routing network
  - http://tor.eff.org
  - Developed by Roger Dingledine, Nick Mathewson and Paul Syverson
  - Specifically designed for low-latency anonymous Internet communications
- Running since October 2003
- 100s nodes on four continents, thousands of users
- "Easy-to-use" client proxy
  - Freely available, can use it for anonymous browsing

How does Tor work?

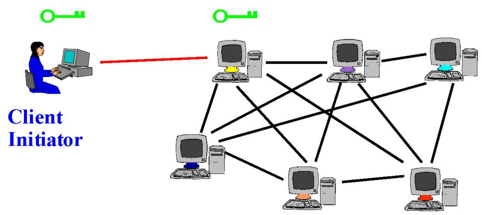


How does Tor work?



Tor Circuit Setup (1)

- Client proxy establish a symmetric session key and circuit with Onion Router #1



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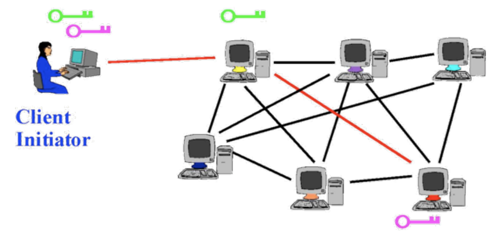
Tor Circuit Setup (2)

- Client proxy extends the circuit by establishing a symmetric session key with Onion Router #2
  - Tunnel through Onion Router #1 (don't need)



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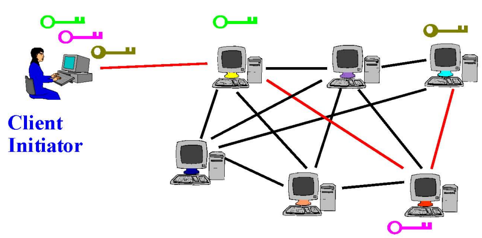
Tor Circuit Setup (3)

- Client proxy extends the circuit by establishing a symmetric session key with Onion Router #3
  - Tunnel through Onion Routers #1 and #2



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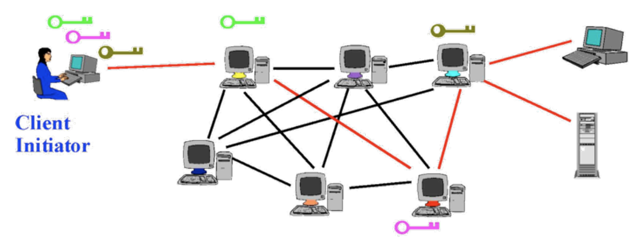
Using a Tor Circuit

- Client applications connect and communicate over the established Tor circuit
  - Datagrams are decrypted and re-encrypted at each link



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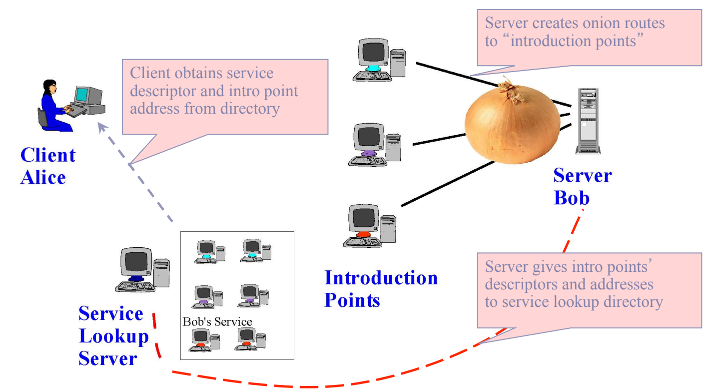
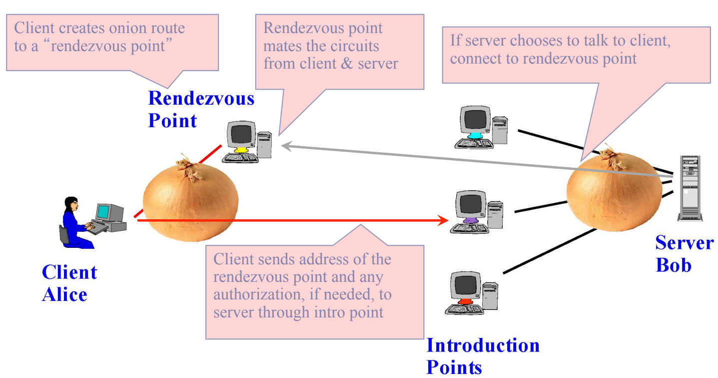
Location Hidden Servers

- Goal: deploy a server on the Internet that anyone can connect to without knowing where it is or who runs it
- Accessible from anywhere
- Resistant to censorship
- Can survive full-blown DoS attack
- Resistant to physical attack
  - Can’t find the physical server!

Creating a Location Hidden Server



Using a Location Hidden Server



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An “Old” Problem

- Many governments/companies trying to limit their citizens’ access to information
  - Censorship (prevent access)
  - Punishment (deter access)
  - China, Saudi Arabia, HP
- How can we defeat such attempts?
  - Circumvent censorship
  - Undetectably

17

Proxy-Based Web Censorship

- Government manages national web firewall
  - Not optional---catches ALL web traffic
- Block certain requests
  - Possibly based on content
  - More commonly on IP address/publisher
  - China: Western news sites, Taiwan material
- Log requests to detect troublemakers
  - Even without blocking, may just watch traffic
- But they don’t turn off the whole net
  - Creates a crack in their barrier

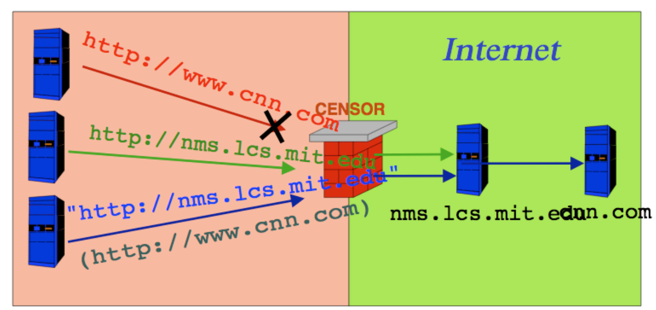
18

Goal

- Circumvent censor via innocent web activity
  - Normal web server and client cooperate to create covert channel
- Without consequence for client
- And without consequence for server
  - Broad participation increases system robustness
  - Ensure offering service doesn’t lead to trouble
  - e.g., loss of business through being blocked
  - Also, “law knows no boundaries”

19

The Big Picture



20

Requirements

- Client deniability
  - Detection could be embarrassing or worse
- Client statistical deniability
  - Even suspicion could be a problem
- Server covertness/statistical deniability
  - If server detected, can be blocked
- Communication robustness
  - Even without detecting, censor could scramble covert channel
- Performance (bandwidth, latency)

21

(Un)related Work

- SSL
  - Encrypted connection---can't tell content
  - Suspicious!
  - Doesn't help reach blocked servers
  - Govt. can require revealing SSL keys
- Anonymizing Proxies
  - Prevent servers from knowing identity of client
  - But proxy inside censor can't reach content
  - And proxy outside censor can be blocked
  - And use of proxy is suspicious

22

Safeweb/Triangle boy

- Operation
  - Client contacts triangle-boy "reflector"
  - Reflector forwards requests to blocked server
  - Server returns content to client (IP spoof)
- Circumvents censorship
- But still easily detected
  - "Local monitoring of the user only reveals an encrypted conversation between User and Triangle Boy machine." (Safeweb manual)

23

Summary

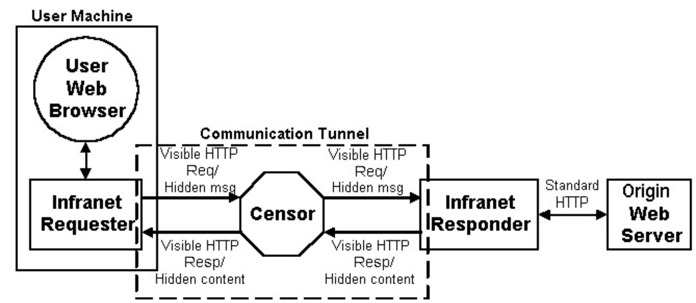
- Easy to hide what you are getting
  - Just use SSL
- And easy to circumvent censors
  - Safeweb
- But hard to hide that you are doing it

24

Circumventing Censors

- Censors allow certain traffic
- Use to construct a covert channel
  - Talk to normal servers
  - Embed requests for censored content in normal-seeming requests
  - Receive censored content hidden in normal-seeming responses
- Requester: client asking for hidden content
- Responder: server covertly providing it

System Architecture



Receiving Content is Easier Half

- Responder is a normal web server, serving images (among other things)
- Encrypt data using requestor key
- Embed in “unimportant, random” bits of images
  - E.g., high order color bits
  - Watermarking
- Encrypted data looks random---only requestor can tell it isn’t (and decrypt)

Example

- One image has embedded content
- You can’t tell which (shows it’s working)

Goals Analysis

- Client looks innocent (receives images)
  - Infranet users & nonusers indistinguishable
- Server less so
  - Any one image seems innocent
  - But same image with different "random bits" in each copy is suspicious
  - Evasion: never use same image-URL twice
    - Justify: per-individual customized web site
    - Human inspection might detect odd URL usage
  - Evasion: use time-varying image (webcam)
- Performance: 1/3 of image bits

29

Upstream (Requests) is Harder

- No "random content bits" that can be fiddled to send messages to responder
- Solution: let browsing pattern itself be the message
- Suppose web page has k links.
  - GET on i^{th} link signifies symbol "i" to requestor
  - Result: $\log_2(k)$ message bits from link click
- Can be automated
- To prevent censor from seeing message, encrypt with responder key

30

Goals Analysis

- Deniability: requestor generates standard http GETs to allowed web sites
  - Fact of GETs isn't itself proof of wrongdoing
  - Known rule for translating GETs to message, but message is encrypted, so not evidence
- Statistical deniability
  - Encrypting message produces "random" string
  - Sent via series of "random" GETs
  - Problem: normal user browsing not random
    - Some links rare
    - Conditional dependence of browsing on past browsing

31

Performance vs. Deniability

- Middling deniability, poor performance
  - Request URL may be (say) 50 characters
  - 16 Links/Page (say) means 4 bits
  - So need 100 GETs to request one URL!
  - And still poor statistical deniability
- Can we enhance deniability?
  - Yes, by decreasing performance further
- Can we enhance performance?
  - Yes, and enhance deniability at same time

32

Paranoid Alternative

- Settle for one message bit per GET
  - Odd/even links on page
  - Or generalize to “mod k” for some small k
- User has many link choices for each bit
  - Can choose one that is reasonable
  - Incorporate error correcting code in case no reasonable next link sends correct bit
- Drawback: user must be directly involved in sending each message bit
  - Very low bandwidth vs time spent

Higher Performance

- Idea: arithmetic coding of requests
  - If request i has probability p_i, then entropy of request distribution is $-\Sigma\, p_i \log p_i$
  - Arithmetic coding encodes request i using $\log p_i$ bits
  - Result: expected request size equals entropy
  - Optimal
- Problem: requestor doesn’t know probability distribution of requests
  - Doesn’t have info needed for encoding

Solution: Range Mapping

- Adler-Maggs
- Exploit asymmetric bandwidth
- Responder sends probability distribution to requester using easy, downstream path
- Requestor uses this “dictionary” to build arithmetic code, send encoded result
- Variation for non-binary
  - Our messages aren’t bits, they are clicks
  - And server knows different clicks should have different probabilities

Toy Example

- Suppose possible requests fewer than links on page
- Responder sends dictionary:
  - “link 1 means http://mit.edu”
  - “link 2 means http://stanford.edu”
  - Assigns common requests to common GETs
- Requestor GETs link matching intended request
- One GET sends full (possibly huge) request
- Problem: in general, ∞ possible requests
  - Can’t send a dictionary for all

Overview

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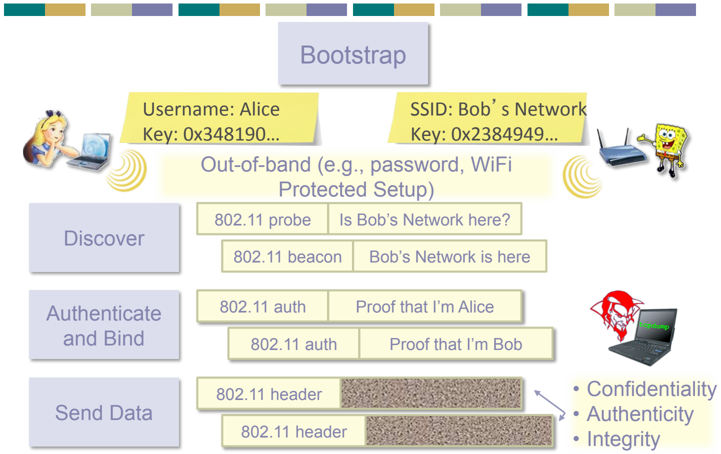
37

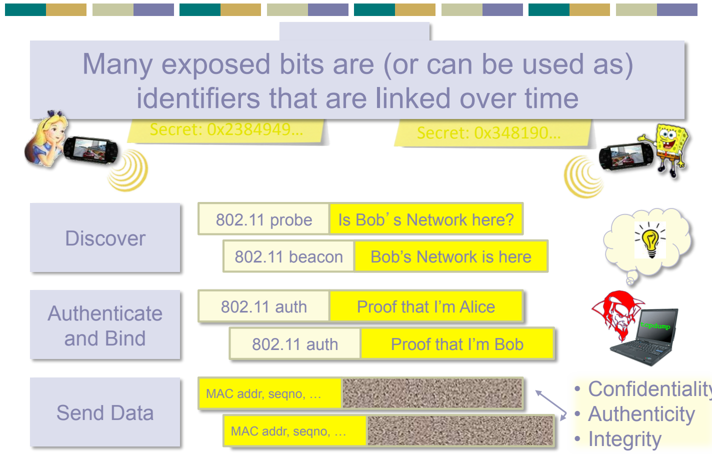
Our Wireless World

Best Security Practices



39

Privacy Problems Remain



40

Problem: Long-Term Linking

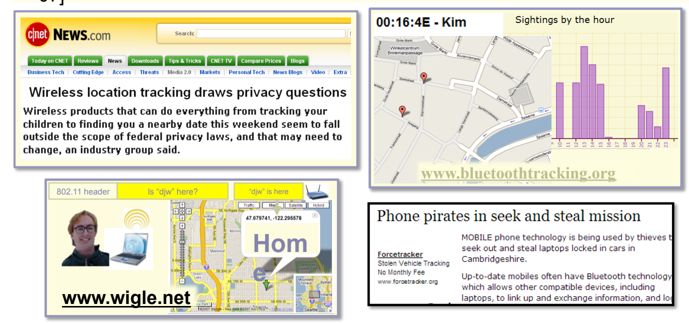
Easy to identify and relate devices over time

41

Problem: Long-Term Linking

Linking enables location tracking, user profiling, inventorying, relationship profiling, …

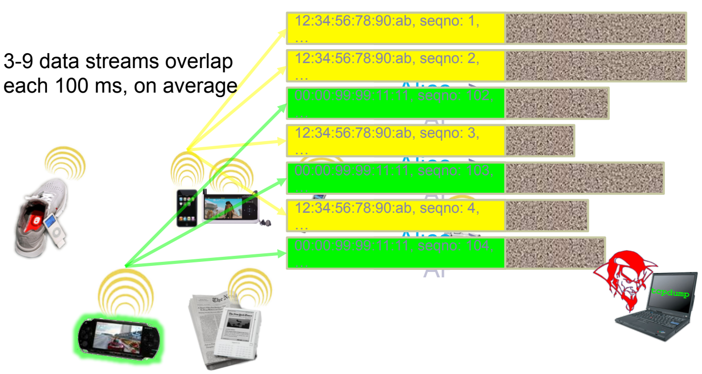
[Greenstein, *HotOS* '07; Jiang, *MobiSys* '07; Pang, *MobiCom* '07, *HotNets* '07]



42

Problem: Short-Term Linking

3-9 data streams overlap each 100 ms, on average



Easy to isolate distinct packet streams

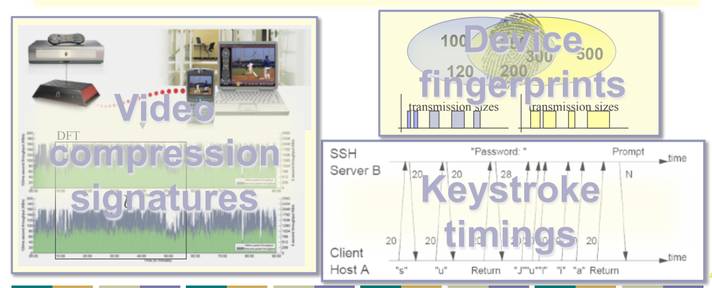
43

Problem: Short-Term Linking

Isolated data streams are more susceptible to side-channel analysis on packet sizes and timing

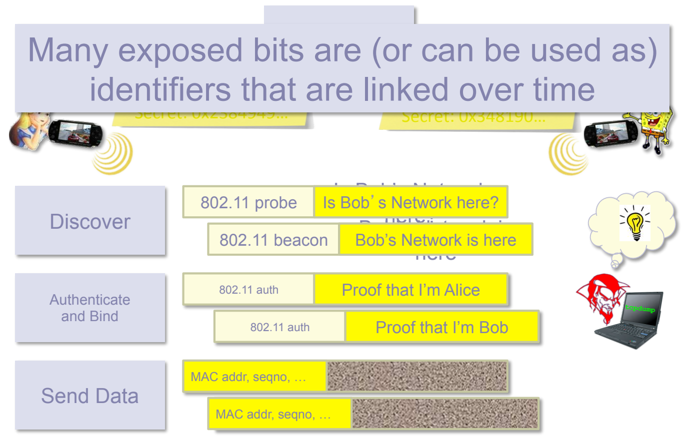
– Exposes keystrokes, VoIP calls, webpages, movies, …

[Liberatore, *CCS* '06; Pang, *MobiCom* '07; Saponas, *Usenix Security* '07; Song, *Usenix Security* '01; Wright, *IEEE S&P '08*; Wright, *Usenix Security* '07]



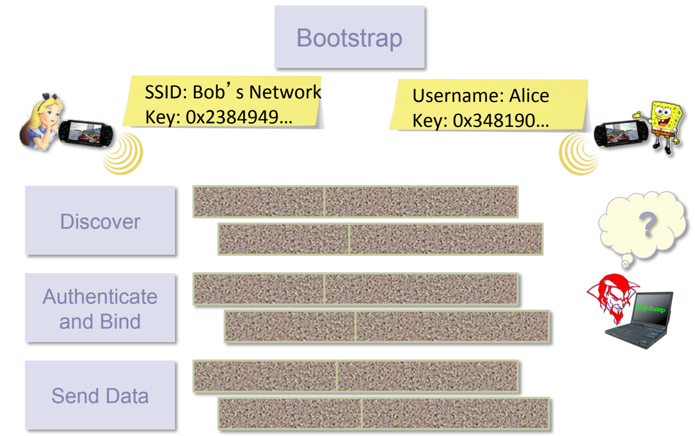
44

Fundamental Problem



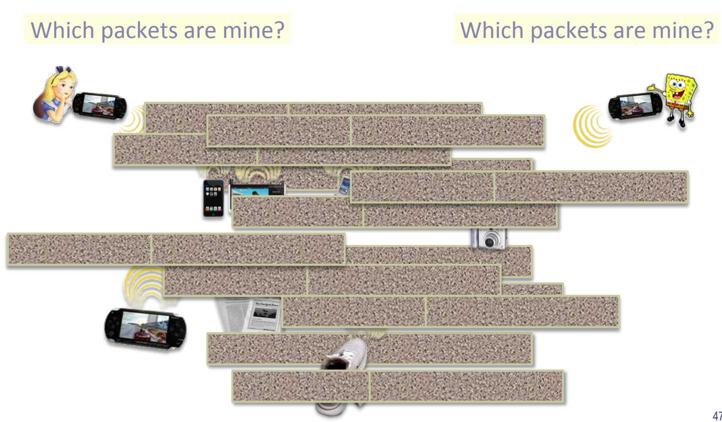
45

Goal: Make All Bits Appear Random



46

Challenge: Filtering without Identifiers

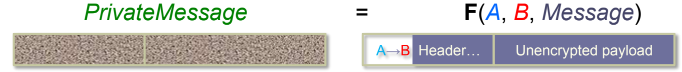


47

Design Requirements

- When *A* generates *Message* to *B*, she sends:

PrivateMessage = **F**(*A*, *B*, *Message*)



where **F** has these properties:

- **Confidentiality**: Only *A* and *B* can determine *Message*.
- **Authenticity**: *B* can verify *A* created *PrivateMessage*.
- **Integrity**: *B* can verify *Message* not modified.
- **Unlinkability**: Only *A* and *B* can link *PrivateMessages* to same sender or receiver.
- **Efficiency**: *B* can process *PrivateMessages* as fast as he can receive them.

48

Solution Summary

	Confidentiality	Authenticity	Integrity	Unlinkability	Efficiency
802.11 WPA	Only Data Payload	Only Data Payload	Only Data Payload	🚫	✓
MAC Pseudonyms					
Public Key Symmetric Key					
SlyFi: Discovery/Binding					
SlyFi: Data packets					

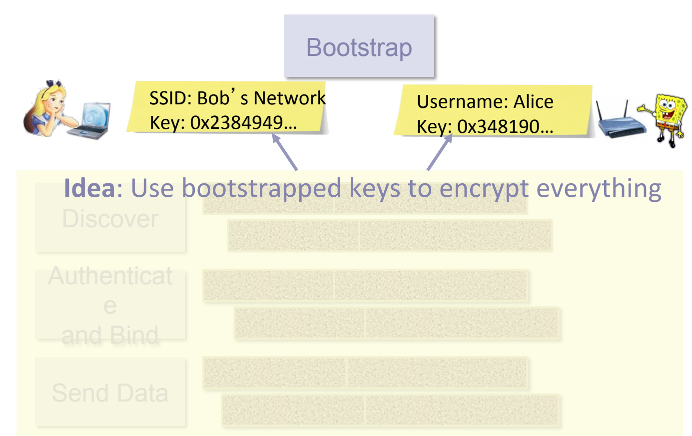
Straw man: MAC Pseudonyms

- **Idea**: change MAC address periodically
  - Per session or when idle [Gruteser '05, Jiang '07]
- Other fields remain (e.g., in discovery/ binding)
  - No mechanism for data authentication/encryption
  - Doesn't hide network names during discovery or credentials during authentication
- Pseudonyms are linkable in the short-term
  - Same MAC must be used for each association
  - Data streams still vulnerable to side-channel leaks

Solution Summary

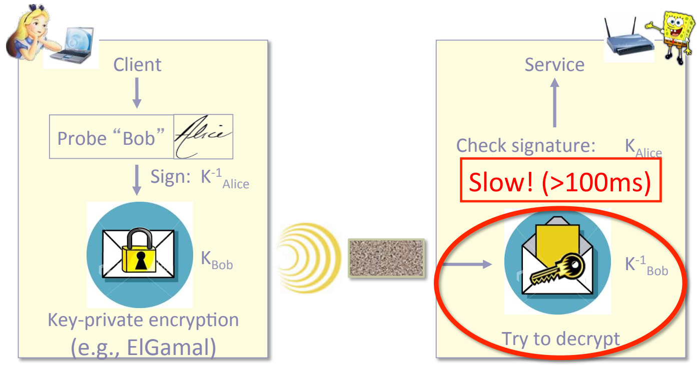
	Confidentiality	Authenticity	Integrity	Unlinkability	Efficiency
802.11 WPA	Only Data Payload	Only Data Payload	Only Data Payload	🚫	✓
MAC Pseudonyms	🚫	🚫	🚫	Long Term	✓
Public Key Symmetric Key					
SlyFi: Discovery/Binding					
SlyFi: Data packets					

Straw man: Encrypt Everything



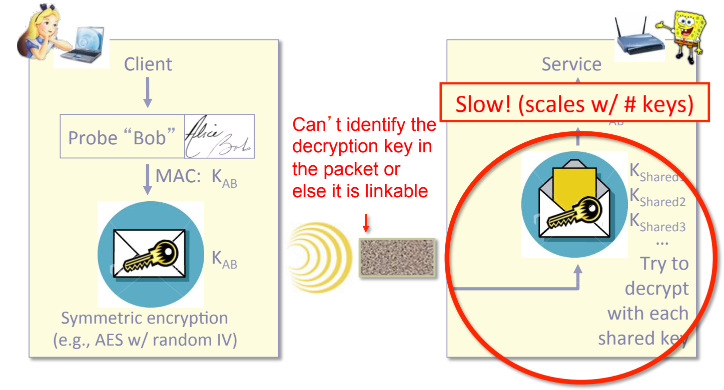
Idea: Use bootstrapped keys to encrypt everything

Straw man: Public Key Protocol



Based on [Abadi '04]

Straw man: Symmetric Key Protocol



Different symmetric key per potential send

Solution Summary

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802.11 WPA	Only Data Payload	Only Data Payload	Only Data Payload	🚫	✓
MAC Pseudonyms	🚫	🚫	🚫	Long Term	✓
Public Key Protocol Symmetric Key Protocol	✓	✓	✓	✓	🚫
SlyFi: Discovery/Binding					
SlyFi: Data packets					

SlyFi

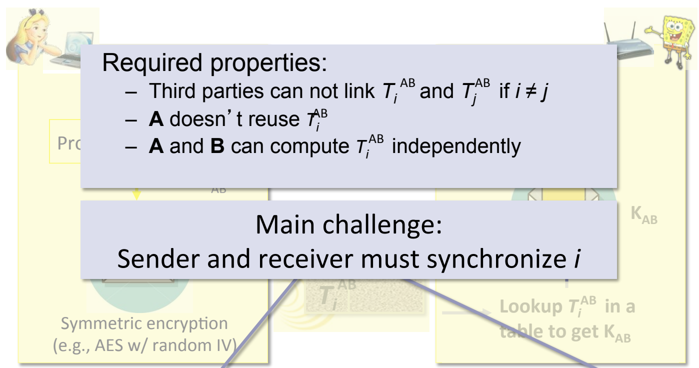
- Symmetric key almost works, but tension between:
  - Unlinkability: can't expose the identity of the key
  - Efficiency: need to identify the key to avoid trying all keys
- **Idea**: Identify the key in an unlinkable way
- Approach:
  - Sender **A** and receiver **B** agree on tokens: T_1^{AB}, T_2^{AB}, T_3^{AB}, …
  - **A** attaches T_i^{AB} to encrypted packet for **B**

SlyFi

Required properties:

- Third parties can not link T_i^{AB} and T_j^{AB} if $i \neq j$
- **A** doesn't reuse T_i^{AB}
- **A** and **B** can compute T_i^{AB} independently

Main challenge:
Sender and receiver must synchronize *i*



T_i^{AB} = AES$_{K_{AB}}$(*i*) T_i^{AB} = AES$_{K_{AB}}$(*i*)

SlyFi: Data Transport

- Data messages:
  - Only sent over established connections
  - ⇒ Expect messages to be delivered
  - ⇒ Use implicit transmission number to synchronize *i*

T_i^{AB} = AES$_{K_{AB}}$(*i*)   where *i* = transmission #

SlyFi: Data Transport

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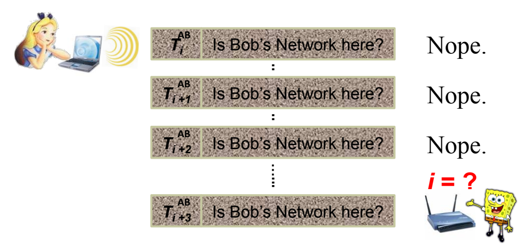
T_i^{AB} = AES$_{K_{AB}}$(*i*)   where *i* = transmission #

- On receipt of T_i^{AB}, **B** computes next expected: T_{i+1}^{AB}
- Handling message loss:
  - On receipt of T_i^{AB} save T_{i+1}^{AB}, … , T_{i+k}^{AB} in table
  - Tolerates *k* consecutive losses (*k*=50 is enough)
  - No loss ⇒ compute one token per reception

SlyFi: Discovery/Binding

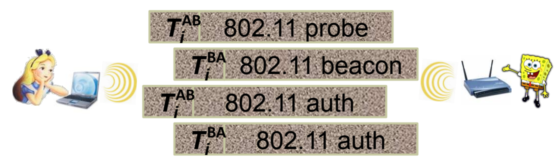
- Discovery & binding messages:
  - Often sent when other party is not present
  - ⇒ Can't expect most messages to be delivered
  - ⇒ Can't rely on transmission reception to synchronize *i*



SlyFi: Discovery/Binding

- Discovery & binding messages:
  - **Infrequent**: only sent when trying to associate
  - **Narrow interface**: single application, few side-channels
  - ⇒ Linkability at short timescales is usually OK
  - ⇒ Use loosely synchronized time to synchronize *i*

$$T_i^{AB} = \mathrm{AES}_{K_{AB}}(i) \qquad \text{where } i = \lfloor \text{current time}/5\text{ min} \rfloor$$



61

SlyFi: Discovery/Binding

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$$T_i^{AB} = \mathrm{AES}_{K_{AB}}(i) \qquad \text{where } i = \lfloor \text{current time}/5\text{ min} \rfloor$$

- At the start of time interval *i* compute T_i^{AB}
- Handling clock skew:
  - Receiver **B** saves $T_{i-s}^{AB}, \dots, T_{i+s}^{AB}$ in table
  - Tolerates clock skew of $5 \cdot s$ minutes

62

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MAC Pseudonyms	🚫	🚫	🚫	Long Term	✔
Public Key Symmetric Key	✔	✔	✔	✔	🚫
SlyFi: Discovery/Binding	✔	✔	✔	Long Term	✔
SlyFi: Data packets	✔	✔	✔	✔	✔

63

Next Lecture…

- No next lecture ☺
- Exam
  - Much like the midterm
  - 1.5hrs on Dec 1st
  - Mostly on 2nd half of semester but with some coverage of 1st half
- Project
  - 6-8pg writeup – due Dec 5th
  - 10min presentation – on Dec 2nd or 3rd
    - Incorporate feedback into final writeup

64

Overview

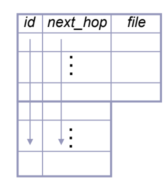
- P2P Privacy

Freenet

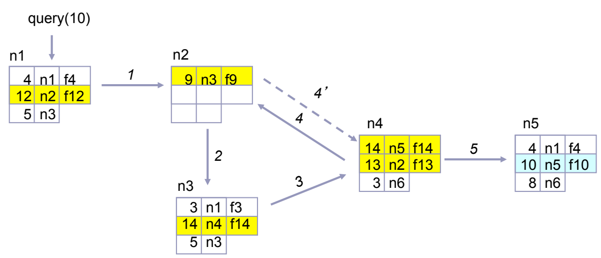
- Addition goals to file location:
  - Provide publisher anonymity, security
  - Resistant to attacks – a third party shouldn't be able to deny the access to a particular file (data item, object), even if it compromises a large fraction of machines
- Files are stored according to associated key
  - Core idea: try to cluster information about similar keys
- Messages
  - Random 64bit ID used for loop detection
  - TTL
    - TTL 1 are forwarded with finite probablity
    - Helps anonymity
  - Depth counter
    - Opposite of TTL – incremented with each hop
    - Depth counter initialized to small random value

Data Structure

- Each node maintains a common stack
  - *id* – file identifier
  - *next_hop* – another node that store the file id
  - *file* – file identified by *id* being stored on the local node
- Forwarding:
  - Each message contains the file *id* it is referring to
  - If file *id* stored locally, then stop
    - Forwards data back to upstream requestor
    - Requestor adds file to cache, adds entry in routing table
  - If not, search for the "closest" *id* in the stack, and forward the message to the corresponding *next_hop*



Query Example

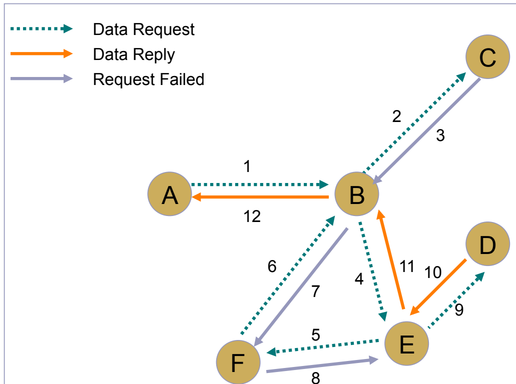


Note: doesn't show file caching on the reverse path

Freenet Requests

- Any node forwarding reply may change the source of the reply (to itself or any other node)
  - Helps anonymity
- Each query is associated a TTL that is decremented each time the query message is forwarded; to obscure distance to originator:
  - TTL can be initiated to a random value within some bounds
  - When TTL=1, the query is forwarded with a finite probability
- Each node maintains the state for all outstanding queries that have traversed it → help to avoid cycles
- If data is not found, failure is reported back
  - Requestor then tries next closest match in routing table

Freenet Request



Freenet Search Features

- Nodes tend to specialize in searching for similar keys over time
  - Gets queries from other nodes for similar keys
- Nodes store similar keys over time
  - Caching of files as a result of successful queries
- Similarity of keys does not reflect similarity of files
- Routing does not reflect network topology

Freenet File Creation

- Key for file generated and searched → helps identify collision
  - Not found ("All clear") result indicates success
  - Source of insert message can be change by any forwarding node
- Creation mechanism adds files/info to locations with similar keys
- New nodes are discovered through file creation
- Erroneous/malicious inserts propagate original file further

73

Cache Management

- LRU Cache of files
- Files are not guaranteed to live forever
  - Files "fade away" as fewer requests are made for them
- File contents can be encrypted with original text names as key
  - Cache owners do not know either original name or contents → cannot be held responsible

74

Freenet Naming

- Freenet deals with keys
  - But humans need names
  - Keys are flat → would like structure as well
- Could have files that store keys for other files
  - File /text/philiosophy could store keys for files in that directory → how to update this file though?
- Search engine → undesirable centralized solution

75

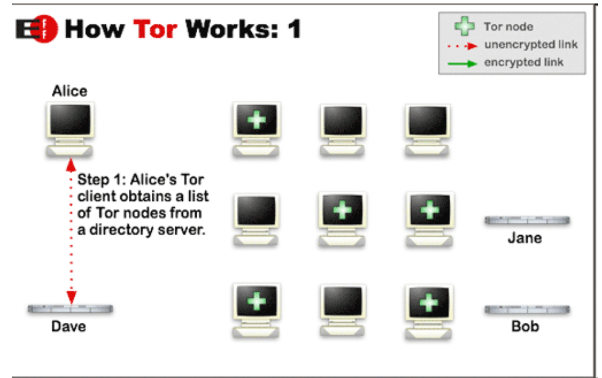
Freenet Naming - Indirect files

- Normal files stored using content-hash key
  - Prevents tampering, enables versioning, etc.
- Indirect files stored using name-based key
  - Indirect files store keys for normal files
  - Inserted at same time as normal file
- Has same update problems as directory files
  - Updates handled by signing indirect file with public/private key
  - Collisions for insert of new indirect file handled specially → check to ensure same key used for signing
- Allows for files to be split into multiple smaller parts

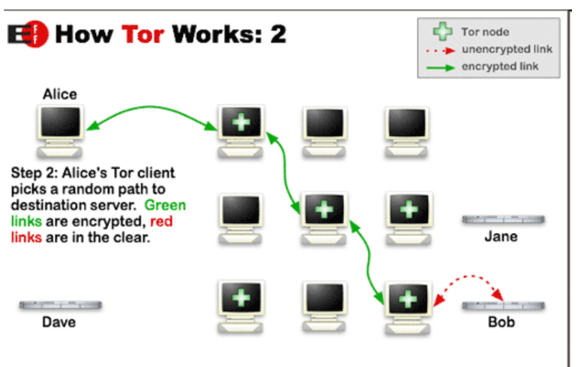
76

77

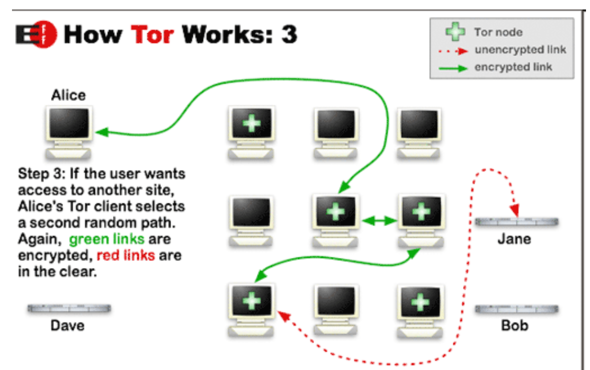
How does Tor work?



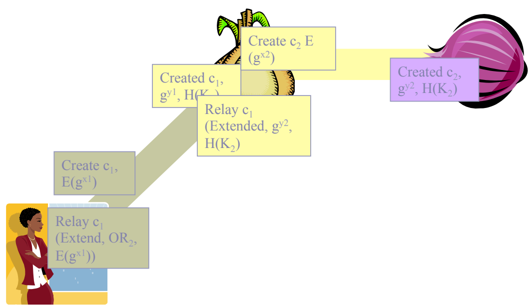
How does Tor work?



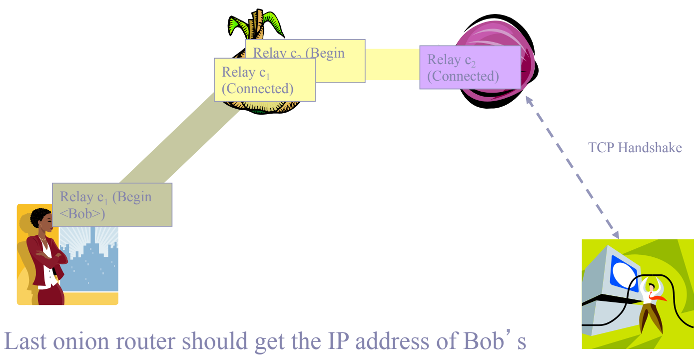
How does Tor work?



Building a circuit



Fetching a web page



Last onion router should get the IP address of Bob's website to protect Alice's anonymity.