ΥΣ13 - Computer Security

Network Security

Κώστας Χατζηκοκολάκης

Context

- Computers connected in a network
  - but also: smartphones, fridges, IoT devices, …
- Each device has an IP address
- Packets are routed via intermediate nodes
- Still using IPv4 (almost 40 year old!)
  - very very hard to replace

Context

- **Attacker model**
  - Intercept packets
  - Modify packets
  - Inject packets
  - Participate in any protocol
- Useful to consider combinations of the above

Internet protocol suite

Four layers (7 in the OSI model)

- **Link**
  - Physical addresses
  - Physical aspects of communication
- **Internet**
  - Addressing (source/dest IP)
  - Routing
  - Time to live

Internet protocol suite

Four layers (7 in the OSI model)

- **Transport**
  - Source/dest ports
  - Ordering of packets (Sequence numbers)
  - ACKs, checksums
- **Application**
  - The “real data”, application-dependent

Internet protocol suite

Protocols

- **Link**
  - Ethernet
  - WiFi
  - DSL
  - …
- **Internet**
  - IP
  - ICMP
  - …

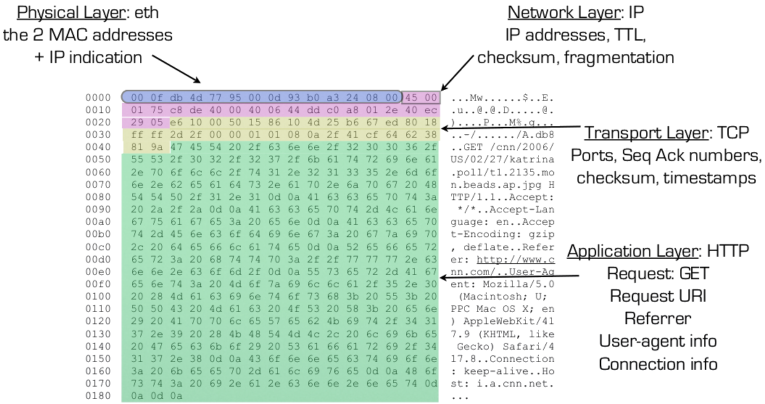
Internet protocol suite

Protocols

- **Transport**
  - TCP
  - UDP
  - ...
- **Application**
  - HTTP / HTTPS
  - SSH
  - SMTP
  - ...

Internet protocol suite

Packet example



IP

- Connectionless communication
  - using only source/dest IP addresses
- Routing
  - communication across network boundaries
  - routing tables kept by routers
  - no authentication
- Fragmentation & reassembly
  - No reliability

TCP

- Connection-based communication
  - identified by source/dest IP + port (multiplexing)
- Server process “listens” to a port
  - Often determined by the application protocol (HTTP, SMTP, etc)
- Client process connects to dest IP+port
  - Source port selection usually random
- Connection established by handshake
- Reliability

UDP

- Connectionless communication over IP
- Fast alternative to TCP
  - Only 8 bytes overhead, no handshakes
  - Stateless
- Some higher-level features
  - addressing based on IP+port (multiplexing)
  - checksums
- But many missing
  - No ACKs (unreliable)
  - No ordering
- Often used for “streaming”-like applications

Traceroute

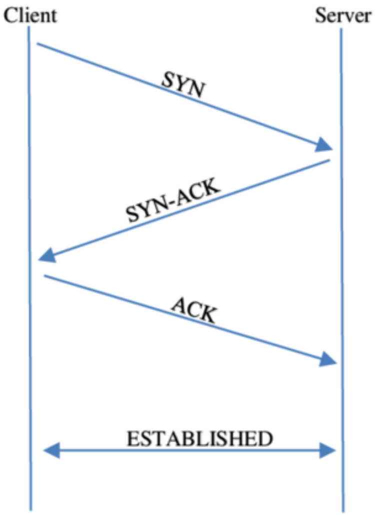
```
traceroute to google.com (216.58.215.46), 30 hops max, 60 byte packets
1  _gateway (195.134.67.1)  0.715 ms  0.789 ms  0.884 ms
2  uoa-ilisia-1-gw.kolettir.access-link.grnet.gr (62.217.96.172)  0.763 ms  0.796 ms  0
3  grnet-ias-geant-gw.mx1.ath2.gr.geant.net (83.97.88.65)  1.574 ms  1.630 ms  1.620 ms
4  ae0.mx2.ath.gr.geant.net (62.40.98.140)  31.556 ms  31.650 ms  31.547 ms
5  ae2.mx1.mil2.it.geant.net (62.40.98.150)  25.654 ms  27.861 ms  27.793 ms
6  72.14.203.32 (72.14.203.32)  25.593 ms  25.766 ms  25.500 ms
7  108.170.245.73 (108.170.245.73)  64.548 ms 108.170.245.89 (108.170.245.89)  73.238 m
8  209.85.142.221 (209.85.142.221)  72.001 ms 72.14.238.21 (72.14.238.21)  71.999 ms  6
9  216.239.35.201 (216.239.35.201)  78.302 ms  78.299 ms  78.277 ms
10  209.85.251.217 (209.85.251.217)  54.466 ms 72.14.238.54 (72.14.238.54)  54.472 ms 1
11  108.170.245.1 (108.170.245.1)  52.509 ms  52.443 ms  50.669 ms
12  108.170.235.15 (108.170.235.15)  54.116 ms  51.975 ms  51.967 ms
13  par21s17-in-f14.1e100.net (216.58.215.46)  51.943 ms  54.241 ms  54.202 ms
```

Traceroute

- Time to live (TTL)
  - IP header
  - Decreased at every hop
  - If 0 the router discards and notifies the originator
- Traceroute: repeatedly send packets
  - with TTL = 1, 2, …
  - 3 packets for every value
  - Until we reach the host (or a threshold)
  - Routers might not respond

TCP 3-way handshake

- Connection identified by source/dest address/port
- Sequence numbers (SN) in every message
- Handshake
  - SYN(SNc)
  - SYN(SNs)-ACK(SNc)
  - ACK(SNs)
  - Data-exchange (bidirect.)



Three-Way Handshake

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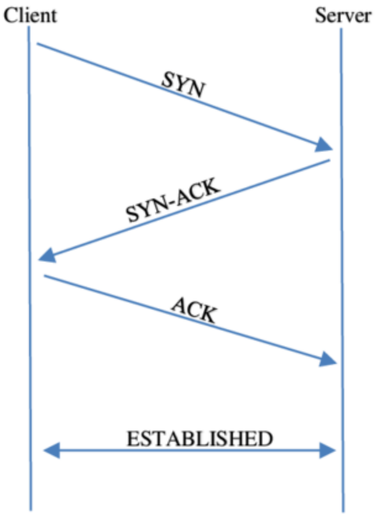
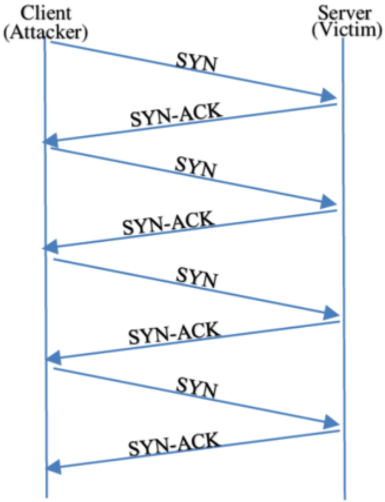
- What can go wrong here?



Three-Way Handshake

SYN flood

- Flood the server with SYNs
- But no ACK!
- Connections stay "half-open" on the server until they timeout
  - Keeping state consumes resources
  - Can lead to Denial of Service (DoS)



TCP-SYN Flood Attack

SYN flood

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- Connections stay "half-open" on the server until they timeout
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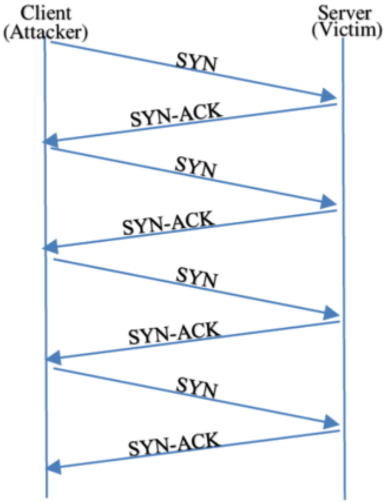
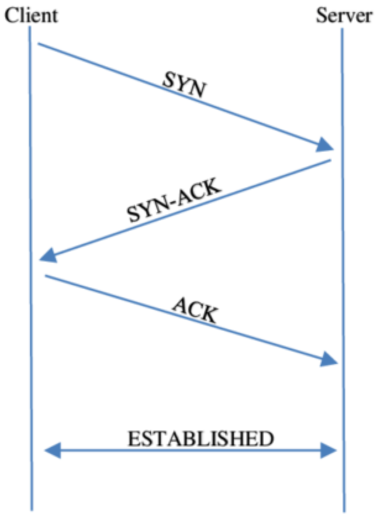
  - Can lead to Denial of Service (DoS)
- Can the server limit the number of SYNs from the same host?
  - No! the attacker can easily "spoof" the sender IP



TCP-SYN Flood Attack

IP spoofing

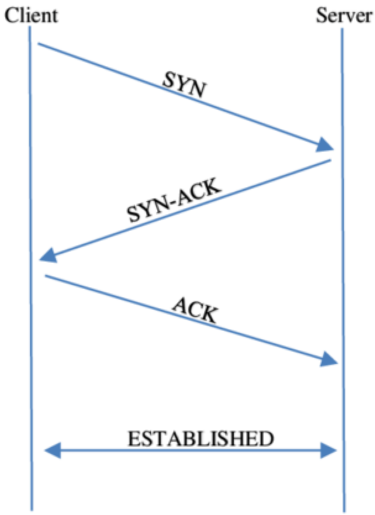
- Can we impersonate a client?



Three-Way Handshake

IP spoofing

- Can we impersonate a client?
  - Trivial if we control an intermediate router!
  - If we don't?



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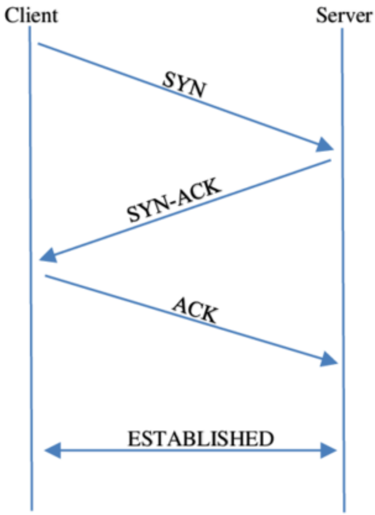

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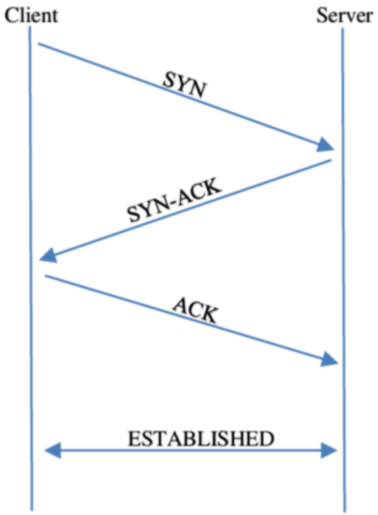
  - If we don't?
- We cann still send packets with a spoofed IP, without access to the replies
  - It's sufficient to guess SNs for the ACK!
  - A(C)$\rightarrow$ S : SYN(SNa)
  - S $\quad\rightarrow$ C : SYN(SNs)-ACK(SNa)
  - A(C) $\rightarrow$ S : ACK(SNs)



Three-Way Handshake

IP spoofing

- Can we guess the server's SN?
- Initial Sequence Number
  - Counter incremented over time and for every new connection
  - Predictable!
- Routers expect ISN to be increasing
  - Protocol bugs are hard to fix (compared to implementation bugs)

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  - Different ISN for each client! How?
  - RFC 6528:
    ISN = Timer + PRF(localip, localport, remoteip, remoteport, secretkey)
  - Why we include secretkey?

IP spoofing

Why is it bad?

- Bypass IP-based authorization
  - Still widely-used today
  - SMTP, web-services, firewall IP white/black-listing, etc
- Inject data to existing connection
  - DNS response (UDP, no SN at all!)
- Reset existing connections (RST)
  - SNc is needed, but only approximately
  - Denial of service, or exploit to break some other protocol

Conclusion : For serious security we need to build on top of TCP

Denial of Service

- Remotely consume a resource of the server
  - Bandwidth,
  - CPU
  - Memory
  - ...
- Until the resource is depleted
  - no more clients can connect

Denial of Service

- Typically involves some sort of flooding
- SYN flooding

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- SYN flooding
- Ping flooding
  - ICMP echo request

```
~$ ping google.com
PING google.com (216.58.215.46) 56(84) bytes of data.
64 bytes from par21s17-in-f14.1e100.net (216.58.215.46): icmp_seq=1 ttl=47 time=52
```

  - Low-level protocol (no use of TCP), can send packets fast
  - The server sends a reply back

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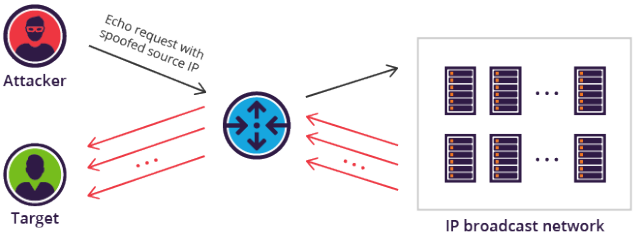
  - Low-level protocol (no use of TCP), can send packets fast
  - The server sends a reply back
- We need more resources than the server
  - Use many senders at once

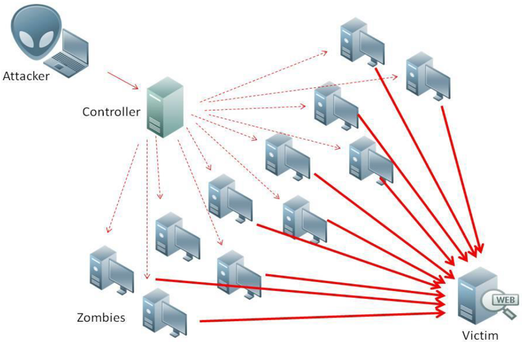
Smurf attack

- Send an Echo to a broadcast address
- Spoof the sender IP with the sender's
- All machines flood the victim



Distributed Denial of Service (DDoS)

- Compromise hosts via virus, worm, etc
- Coordinate the attack
- Hard to distinguish from legitimate users



Fork Bomb

- Another kind of Dos
- Fork, and keep forking in the children
  - exponential growth
- Consumes OS resources for process management
- Try this in your own machine!

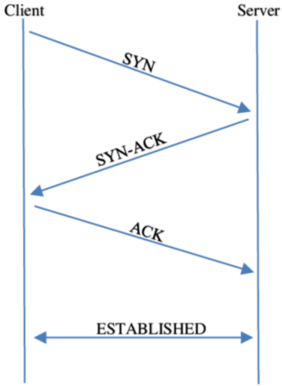
```
~$ :(){ :|:& };:

# some other terminal
~$ ls
bash: fork: retry: Resource temporarily unavailable
```

Preventing SYN floods

Crucial properties

- Packets need to arrive from multiple source IPs
  - otherwise trivial to filter
- The adversary spoofs the sender IP
  - but does not get replies!
- The server needs to keep state for all fake clients



Three-Way Handshake

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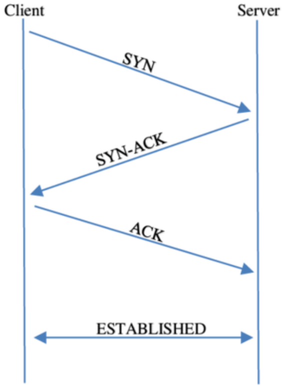
Idea

- Make the client store the state!
- Only store state in the server for clients that have proven to get our replies



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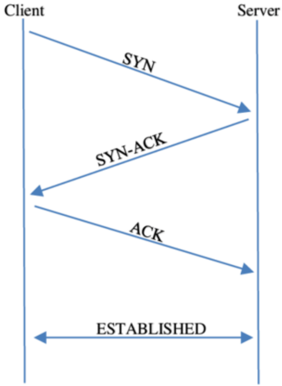
Preventing SYN floods

SYN cookies

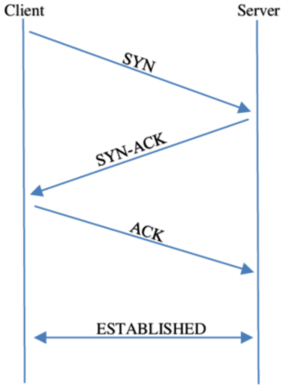


Three-Way Handshake

Preventing SYN floods

SYN cookies

- Encode the state in the SNs send to client
  - Then forget about the connection (no state!)
- Check the SNs contained in the client's ACK
  - Store state only if ok
- Spoofing the source is useless
  - The adversary needs to control the users or the network



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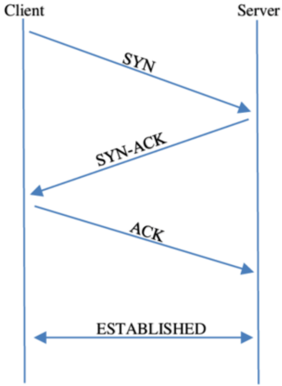
- One approach
  - SNs = H(ports, ips, key, time) || time



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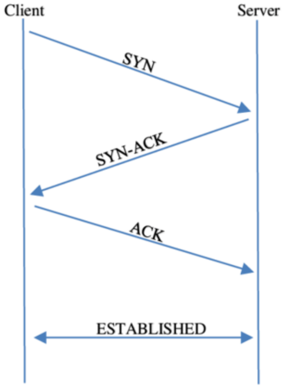
- One approach
  - SNs = H(ports, ips, key, time) || time
- Protocol compliant, but problematic if ACK is lost



Three-Way Handshake

Preventing DoS

- Client needs to solve a puzzle to connect
  - Eg: brute-force a hash (within a controlled range of values)
- Generic solution, also used to prevent spam
- But requires changes to both client and server

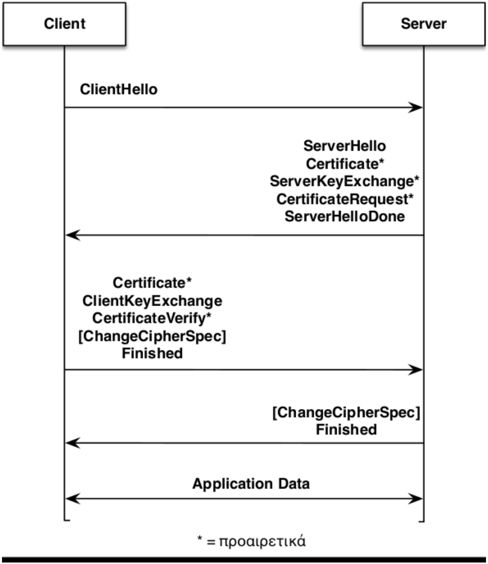
Achieving secure communication

- TCP is an inherently insecure protocol
  - no security against an adversary who controls the network
  - limited security against an adversary who simply participates
- Solution
  - Use crypto to build a secure connection over an insecure network
- Most widely used: TLS
  - Also: IPSec, SSH, …
- We can also tunnel the traffic of an entire network
  - Secure VPN

TLS

- Widely used in web-browsers
- Crucial use of crypto:
  - Assymetric-crypt: exchange keys
  - Symmetric crypto: encrypt the main traffic
  - Digital signatures: authentication

TLS handshake



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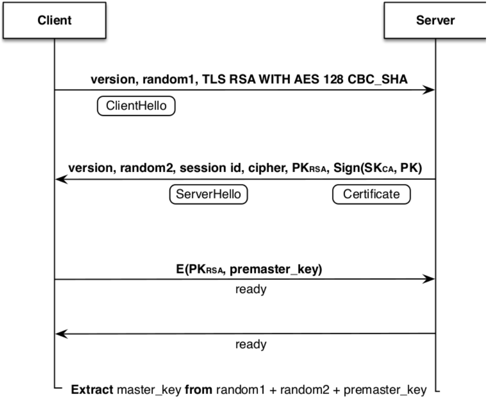

References

- Ross Anderson, Security Engineering, Chapter 21
- A look back at ”security problems in the TCP/IP protocol suite
- SYN cookies
- Bypassing domain control verification with DNS response spoofing