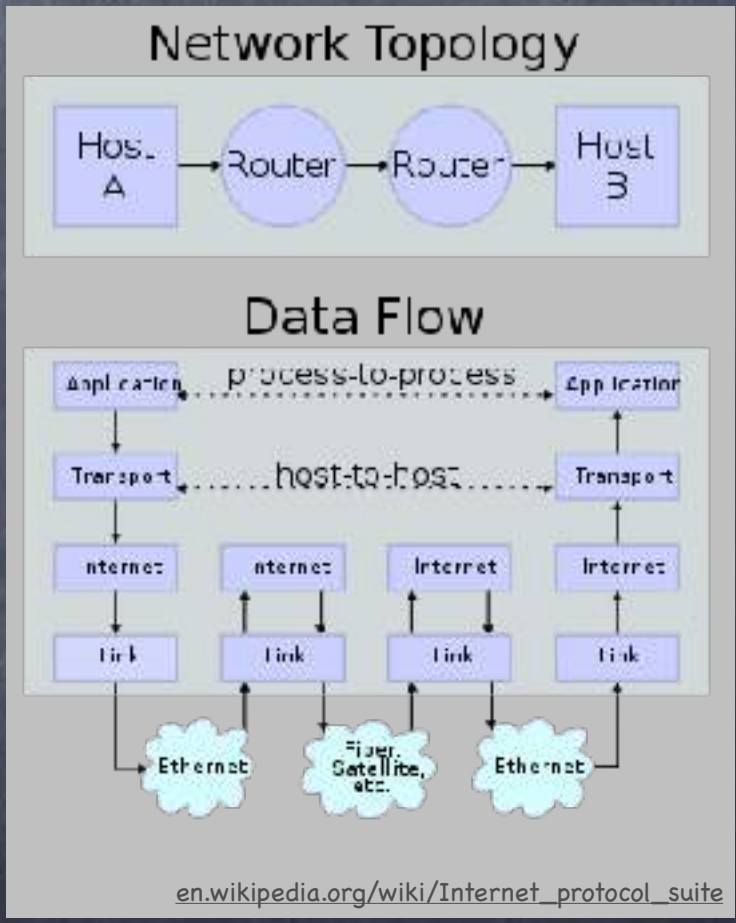
IPsec, BGPsec, DNSSEC

Lecture 20

Internet Protocol Suite

- TCP/IP: Developed in the 70's
- IP: at the internet layer.
  - Handles addressing and routing
- TCP: at the transport layer.
  - Setting up channels (between ports), with traffic control, error-correction etc.
- Link layer (e.g., ethernet,wifi) and Application layer (e.g., web, e-mail) are too specific for TCP/IP
  - Interfaces: Media Access Controller (MAC) and ports



en.wikipedia.org/wiki/Internet_protocol_suite

Internet Protocol Suite

- Some important protocols at the application layer help IP
- Domain Name Service (DNS)
  - Translating names to IP addresses
- Routing: whom to forward a packet to
  - Two-level Routing
  - Border Gateway Protocol (BGP): Routing across "Autonomous Systems" (AS)
  - Routing within an AS: Various protocols

Internet Protocol Suite

- Originally, TCP/IP designed assuming cooperating nodes
  - Focus on speed, scalability, inter-operability. No authentication, no encryption.
- Transport Layer can implement secure channels even if the lower levels of the network are adversarial (TLS)
  - But if the network is arbitrarily adversarial, cannot prevent Denial of Service
  - Also, secure channels don't hide traffic (source/destination, rate of communication)
- IPsec — and authenticated versions of DNS, BGP — to make the network less adversarial. (But does not try to anonymise traffic.)
  - Importantly, implement authenticated channels. (IPsec also provides the option of encryption.)

IPsec

- Four components:
  - Internet Key Exchange (IKE): public-key phase to establish symmetric keys for the remaining components.
    - Relies on certificates (from certificate authorities)
    - Uses Diffie-Hellman key-exchange
  - Authentication Header (AH): MAC
    - On top of the entire IP packet (including headers)
    - Uses HMAC with SHA2, SHA1 or MD5 as the compression function. (Collision in compression function not known to translate to an attack on HMAC.)
  - Encapsulating Security Payload (ESP): SKE
    - AH on top of ESP: Encrypt-then-MAC ✓
  - IP Payload Compression

BGP

- All IP addresses distributed among ~56000 ASes, including large (Tier 1) internet service providers, smaller ISPs, large and small institutions and corporations
- Inter-AS routing based on what they advertise to each other
  - Each AS re-advertises routes that it already learned
- Each AS uses a (business or optimisation) policy to choose a route from many advertised to it
  - A corrupt AS can send bogus routing information to another AS, and make it forward packets to it
    - The corrupt AS may analyse or drop (some of) the traffic sent to it
  - Several examples of incidents, sometimes resulting from misconfiguration, leading to outages

BGPsec

- An important class of attacks is when an AS advertises that it has an IP range (i.e., IP prefix) within it
  - AS "originates" the IP range
  - Makes it more likely for another AS to use this route to the targeted IP range
    - Even more likely, if it announces route to sub-ranges as ASes typically favour more specific IP ranges that contain the destination IP
- Route Origin Authorization (ROA): require a certificate from an authority when claiming to originate an IP range
  - Uses "Resource PKI," rooted at "Regional Internet Registries"
  - AS will accept only paths that end in the validated origin

BGPsec

- Using Route Origin Authorisation does not validate the entire path being advertised
- BGPsec requires each step in the path to be authorised, by the destination of that step (except the last step to an IP range, which is certified by an authority)
  - If Regional Internet Registries are trusted (and their keys known), then an honest AS will not use an "invalid" route
  - Cannot prevent ASes from advertising legitimate paths and then dropping traffic routed through them
  - Or colluding ASes to pretend there is a direct edge (one-hop path) between them

DNS

- Domain names (an.example.com) need to be translated to IP addresses (32 bit IPv4 address like 93.184.216.34 or 128 bit IPv6 address 9abc:def0:1234:5678:90ab:cdef:0123:4567)
- Solution: Domain Name servers which respond to a domain name with an IP address
- Most internet activities (web browsing, email, VoIP communication, IOT activity) start with a DNS lookup
- Multiple security concerns: Authenticity, Privacy and Distributed Denial of Service

DNS Security

- Problem 1: Any one can respond to a DNS query!
  - Causes DoS. Facilitates traffic analysis. And, if no transport layer security, serious problem, which will never be detected!
- Problem 2: The content of the DNS queries reveal a lot about user activity
- Easy fix for both: DNS-over-TLS (not common yet)
  - Ensures that the responses are from actual name servers

DNS Security

- But the actual name servers could be corrupt
  - In particular, can respond with wrong information
- Solution: Require name servers to store and return signed records, signed by a zone-owner
  - Called DNSSEC (two versions NSEC and NSEC3)
  - Note: Provides authenticity — but not secrecy — even without TLS
  - Note: Does not provide secrecy against the name server itself, even with TLS

DNSSEC

- NSEC: store and return signed records, signed by the zone-owner
  - But what if the name server says no record available?
  - Need to verify that!
  - Simple idea: server should return two consecutive entries (in sorted order) and show that they are consecutive
    - Zone-owner signs not just individual records, but also pairs of adjacent records
- New concern: Zone enumeration
  - Information gathering is a typical first step in an attack
  - Individual DNS records are not meant to be secret. But, we do not want DNS to help an adversary recover all domain names in a zone from an honest name server.

DNSSEC

- NSEC3: Tries to prevent zone enumeration using a simple variation on NSEC
  - Signed record pairs use H(domain-name), instead of domain name, where H is meant to be a random oracle
  - Default hash function used is SHA1!
- Still allows enumerating H(domain-name)
- Then, can use an offline attack for zone-enumeration (as domain names are structured, and may be guessed)
- Question: An efficient way to prove that an entry is missing, without revealing anything else?

Still in the current standard, from 2013, though SHA1 considered weak since 2005

DNSSEC

- Question: An efficient way to prove that an entry is missing, without revealing anything else?
- A recent proposal: NSEC5
  - Using "Verifiable Random Functions" (VRF)
- VRF is a PRF, with an additional public-key (SK & PK generated honestly)
  - Remains pseduorandom even given public-key
  - SK allows one to give a proof that $F_{SK}(x) = y$, without revealing SK. Proof can be verified using a PK.
    - A **Zero-Knowledge proof**!
  - NSEC5 proposes a Random Oracle based VRF (assuming DDH)

Next lecture

DNSSEC

- Using a VRF to protect against zone-enumeration
- Instead of H(domain name), use F_{SK}(domain name)
  - For a missing entry for a query Q, return:
    - Y, and a VRF proof that $F_{SK}(Q) = Y$
    - A pair of consecutive entries (Y_1, Y_2), signed by zone-owner, such that $Y_1 < Y < Y_2$
- Name server needs the VRF key SK (generated by the zone-owner) to compute $F_{SK}(Q)$ and the proof. But does not have access to the signing key.
- Adversary querying an honest name server learns the presence/absence of an entry (and an upper bound on the total number of entries)
- Corrupt name server learns all entries, and can also refuse to answer queries, but it cannot give a wrong response

DNSSEC

- Root Zone Signing Key (ZSK) is currently managed by Verisign
- The corresponding public key is signed by ICANN's Key Signing Key (KSK)
- ZSK renewed frequently (about twice every month), and gets signed in batches once every 3 months, in an elaborate Key Signing Ceremony
  - "Activation data" needed to use KSK in the ceremony is 3-out-of-7 secret-shared
  - KSK backed up encrypted, and the encryption key is 5-out-of-7 secret-shared

Summary

- IETF Standards for securing the internet
  - TLS for transport layer security
  - Extensions that aim to add security to the original (insecure) protocols used at the internet layer
    - IPsec, BGPsec, DNSSEC
- Also IEEE 802 standards at the link layer: MACsec (MAC meets MAC), protocols extending IETF's "Extensible Authentication Protocol" (EAP) like WPA2
- Complex standards that focus on efficiency, convenience, backward compatibility (given the millions of devices using older protocols), feasibility of deployment etc.