Introduction to Campus Network Design & Operations

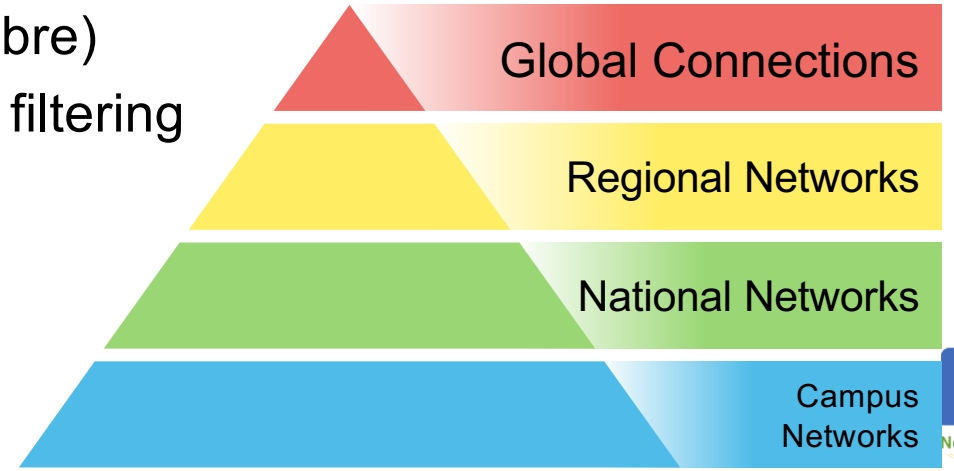
UNIVERSITY OF OREGON

Last updated 23rd June 2019

NSRC
Network Startup Resource Center

Research & Education Network Ecosystem

- Research & Education Network = REN
  - NREN = National REN
- Characteristics:
  - High bandwidths: 10Gbps is typical, 40G and 100G rolling out
  - Research needs uncongested networks
    - RENs are lightly used, with lots of capacity (headroom)
  - Low latency (terrestrial fibre)
  - Open Networks with **NO** filtering
- Hierarchical model



Research & Education Network Ecosystem

- NREN Service Models
  - Peering network
    - Connects campuses together
    - Provides connectivity to international R&E
    - Peers at local IXPs
    - Implications: Campuses also need connectivity from ISP
  - REN provides all Internet connectivity
    - REN is the ISP for the campuses
    - Implications: Simplest for campuses – only one connection to manage

Research & Education Network Ecosystem

- Campus is the foundation of successful R&E network
- But, many:
  - Do not have any structure
  - Make heavy use of NAT and Firewalls limiting performance
  - Are built using unmanaged equipment
  - Are forced do dual home, without skills to manage this
  - Are built using outdated fibre and copper that cannot support high speeds

Campus Design Principles

- Simple design rules:
  - Minimise number of network devices in the path
  - Use hub & spoke (star topology), not daisy chains
  - Segment the network with routers in the core
  - Services at the core, not the edge
  - Always buy managed devices
  - Think very carefully about positioning of firewalls and NAT
    - Firewalls are for protecting servers and the services they host
    - Treat public campus network as untrustworthy as the Internet

Campus Cabling Best Practices

- Two types of cabling:
  - Unshielded twisted pair (UTP): for use inside racks and inside buildings
  - Fibre optic cabling: provides service between buildings and between network racks
- UTP
  - Cat5e – supports up to 1Gbps ethernet to 100metres
  - Cat6 – similar to Cat5e but costs more
  - Cat6a – 4x cost of Cat5e, for supporting 10Gbps over copper – not required for desktop yet
- Fibre Optics:
  - Multi-mode: outdated; expensive; short range; only found in equipment racks now
  - Single-mode: inexpensive; distances up to 80km; speeds over 100Gbps

Switching Architectures: Spanning Tree

- Switching Loops:
  - Unprotected means network traffic swamps network leading to outage
  - Good loops provide backup in case of link or device failure
- Spanning Tree Protocol
  - Runs on all switching devices
  - Calculates optimum path through a network between all L2 devices
  - STP, RSTP, MST flavours – RSTP recommended on all L2 devices
  - Careful selection of Bridge Priorities required
    - Root of the tree needs to be the core switch etc

Switching Architectures: VLANs

- Maximum number of devices on any one L2 broadcast domain should be kept under 100
- Beyond that, introduce virtual LANs
  - Allows one switch to support several different broadcast domains (LANs)
  - Allows the campus network to scale
- Best Practice Design:
  - One or several VLANs per building
  - Do NOT span VLANs across buildings
  - Never use VLAN 1
  - Route between VLANs in the core

Switching Architectures: Advanced L2

- Link Aggregation
  - Bundling more than one link between switches
  - Increasing bandwidth between two devices
  - Standard: LACP (Link Aggregation Control Protocol)
- LLDP or CDP
  - Link Layer Discovery Protocol / Cisco Discovery Protocol
  - Allows admin to discover other devices on the campus backbone
- BPDU Guard
  - Blocks Bridge PDUs on interfaces where not expected

Routing & Forwarding

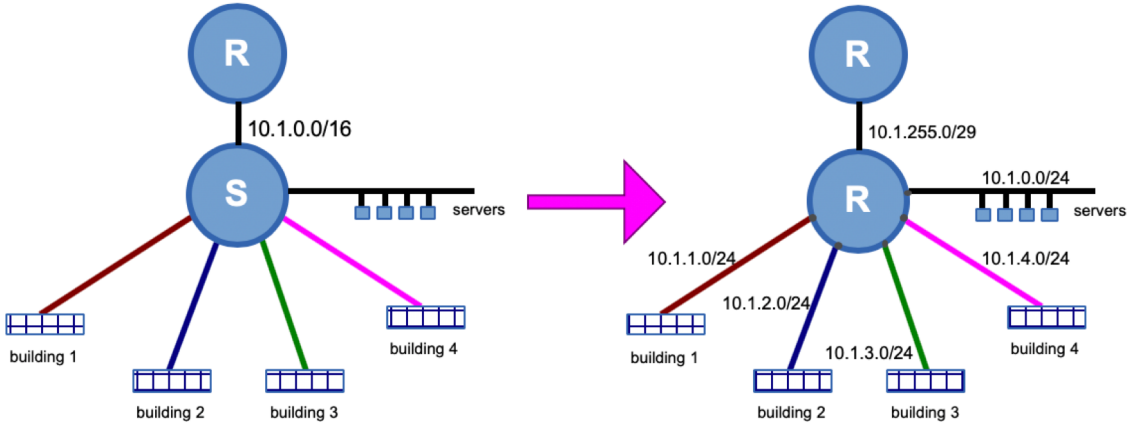
- Routers
  - L3 devices, routing packets between broadcast domains
- Routing
  - Building tables of destinations based on information shared between routers by routing protocols
- Forwarding
  - Moving packets between interfaces based in information from the routing table
- Routing Protocols:
  - Static
  - Dynamic: OSPF, IS-IS, BGP

L3 Switches

- Contradiction:
  - L2 = switch
  - L3 = router
  - L3 Switch??
- An ethernet switch with some routing capability
- Core of the Campus needs to be a L3 Switch
  - Switch with many interfaces, but able to route at wire-speed between all the VLANs terminating on it
  - And host connection to campus services and link to campus border router

Migrating from Flat to Routed

- Many campuses are one huge flat network
  - Doesn't work, doesn't scale
- Migrate to VLANs + core router
  - Star network, not daisy-chain



- Best practices:
  - Design a migration plan! With rollbacks
  - Design an address plan (IPv4 & IPv6)
  - Deploy new VLAN scheme in one building first
    - Core → Distribution → Edge
  - Test connectivity at each stage
  - Migrate users, turn off VLAN 1, and move to next Building

Selecting Campus Devices

- Edge Switch
  - L2 only! (No L3 needed)
  - VLANs, RSTP, Encrypted Management, DHCP Snooping, RA Guard
  - Managed! (CLI, serial console, at least SNMPv2)
  - 24 or 48 10/100/1000 ports, fibre uplinks (1Gbps, 10Gbps better)
- Distribution Switch
  - Same basic specification as Edge switch
  - 12 or 24 copper or fibre ports, 10Gbps fibre uplink

Selecting Campus Devices

- Core Router
  - L3 Switch – Lots of fibre ports (1G/10G)
  - Robust line rate forwarding at L3
  - Sufficient ARP (IPv4) and NDP (IPv6) entries
  - DHCP relay/helper, full management (SSH, SNMPv2/3)
  - OSPF (v2 & v3), HSRP, Mirror/Span port
  - 2x Small form factor (1RU 48 port) rather than one “redundant” chassis
- Border Router
  - Robust line rate forwarding at L3
  - IPv4/6, OSPF (v2 & v3), BGP, NAT, full management (SSH, SNMPv2/3)
  - Small form factor (few ports needed) rather than one “redundant” chassis

Wireless on Campus

- Two wireless frequency ranges:
  - 2.4GHz – 802.11b/g/n
    - Provides only 4 non-overlapping channels (1, 6, 11, 14)
  - 5 GHz – 802.11a/n/ac
    - Provides 25 non-overlapping channels
- Design:
  - Not all Access Points are created equal – cheap AP → small CPU → few users
  - Avoid channel overlaps, pay attention to physical obstacles
  - Estimate number and type of users per AP
  - 802.11ac means 1Gbps access to the AP
  - Bring Your Own Device is standard today: 2-4 devices per person!

Wireless on Campus

- SSID:
  - “Wireless name”, the network users join
  - SSID planning: names matter, trade-off for roaming
  - Avoid tempting names
  - Users prefer seamless roaming
    - Where? Within a building? Across the whole campus?
- Authentication:
  - MAC address: easily defeated
  - Pre-Share Key: who knows the password? Fine for temporary setups only.
  - Captive Portal: better than PSK
  - 802.1x: WPA2-AES is the global standard, allows for EduRoam too

Dynamic Routing: OSPF

- OSPF:
  - Dynamic Routing protocol using SPF algorithm (same as used for Spanning Tree)
  - IETF standard, must be implemented on all L3 devices (routers)
- Essential next step beyond static routes
  - Small campus would have static default on core to border, and static routes from border to core for VLANs
  - Larger campuses deploy OSPF for scalability and to allow redundancy in the core

NAT

- Was developed to allow entities with non-routable address space to connect to global Internet
  - Now used to prolong IPv4
- Network Address and Port Translation, translates multiple IP addresses into one other IP address
  - TCP/UDP port distinguishes flows
- NAT Best Practices:
  - Deploy IPv6 – offloads majority of content traffic from NAT
  - As close to campus border → on border router!
  - Minimise translation time outs to allow efficient use of public address pool
  - Use different public address pools for different campus user categories

Campus Operations Best Practices

- DNS:
  - Local on-campus resolver, sub-millisecond RTT for cached DNS lookups
  - User experience: webpages load quickly
  - **unbound** software is simple to install and operate
- DHCP:
  - Without an address, nothing can get a connection
  - Make sure address pools are large enough, and lease times appropriate (short for wireless, longer for fixed ethernet)
- NTP:
  - Without time synchronisation across network devices, authentication protocols and DNS may fail, and security incidents hard to trace across devices

Campus Operations Best Practices

- Many other recommendations!
- Examples:
  - Implement anti-spoofing filters on all access ports (core router interfaces facing users)
  - NAT must only translate addresses used internally for campus
  - Block TCP/25 (SMTP) out bound apart from authorised email relays
  - Rate limit UDP rather than blocking it
    - Bittorrent will just move to TCP if UDP is blocked
  - Deploy IPv6
    - Reduces load on campus NAT device
    - Avoids situation where Bittorrent and other clients tunnel using IPv6

Campus Security Overview

- **Security is Hard – it is NOT a one box solution**
- Campus networks need to be open
- There will always be people being bad
- Security is a Process:
  - Assessment of what's at risk
  - Protection: efforts to mitigate that risk
  - Detection of intrusions
  - Response
  - Repeat!

UNIVERSITY OF OREGON

NSRC
Network Startup Resource Center

Campus Security Overview

- Policy Framework: Acceptable Use Policy
  - Without an AUP there is nothing a Campus Admin can do to enforce a security policy
- Network Management
  - MUST have managed equipment in the network
  - MUST run network monitoring tools (LibreNMS, NfSen, smokeping etc)
- Encryption
  - Disable clear text password protocols – deploy **letsencrypt** for mail servers and websites – no self-signed certs!
- Virus Protection
  - Viruses arrive by email or clickable links (all encrypted)
  - Firewall is useless for this, yet we still deploy firewalls to stop them!
- Authentication
  - Who is using our network? Each user must have account (LDAP or AD)

Campus Security Overview

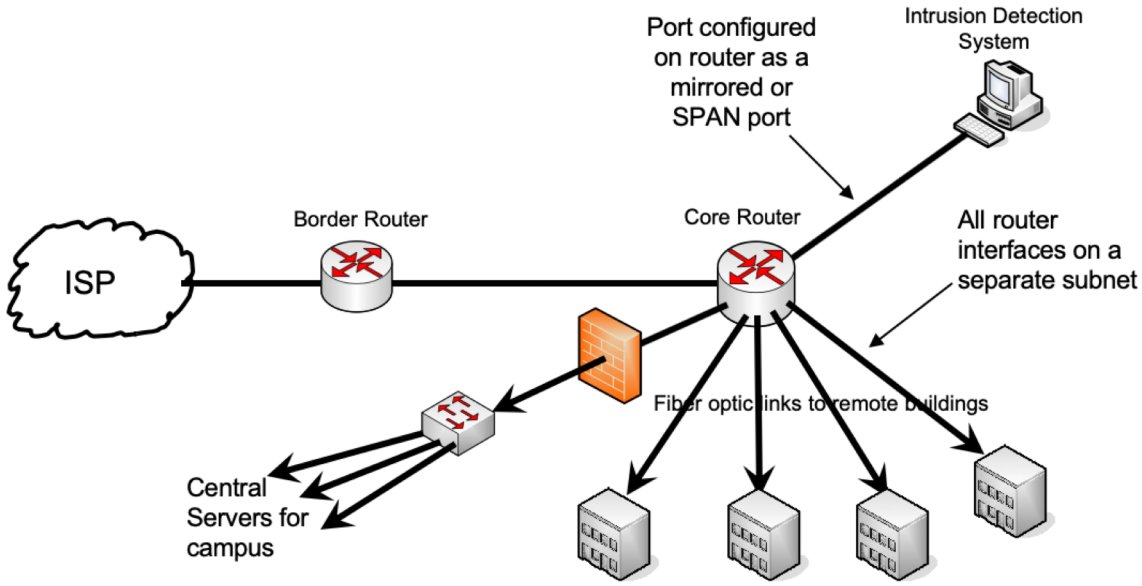
- Wireless:
  - Who may install APs?
  - 802.1x authentication against central database
- Blocking Traffic:
  - **Default needs to be to allow traffic, not block it**
  - Block vulnerabilities – border router with simple filters can do this
  - Monitoring system needs to be in place tracking unusual trends
  - Blocking outbound ports seriously inconveniences visitors
  - Remember, Universities are designed to attract clever people, they will work around port blocking

Campus Security Overview

- Bandwidth Shaping
  - Per user? Per department? Some users have legitimate needs to move large datasets around → AUP to the rescue.
- Deep Packet Inspection
  - Won't work for encrypted traffic. What's the difference between encrypted humorous cat video and encrypted veterinary medicine video?
  - In-line controls are very expensive and are a serious bottle-neck
- Performance
  - Today's 100Mbps campus backbone will become tomorrow's 1Gbps campus backbone, and then on to 10Gbps. Which Firewall/DPI box??

Campus Security Overview

- Conclusion:
  - Firewalls are useless
  - Bandwidth shaping is useless
  - DPI is useless



- Solution:
  - Scalable campus design
  - Security policy including an AUP at its core
  - Monitoring! Monitoring!
  - Firewalls belong in front of servers in campus core

Network Monitoring & Management

- What & Why We Monitor
- Baseline Performance & Attack Detection
- Network Attack Detection
- What & Why We Manage
- Network Monitoring & Management Tools – large number of open source tools
- The NOC: Consolidating Systems – not necessarily a place, but an organizational concept

Network Monitoring & Management

- Examples of monitoring & management systems for a Campus

Tool	Function
RT	Request Tracker – ticketing system for tracking requests
RANCID	Device configuration tracking & management
LibreNMS	Monitoring device health, traffic and interface loads
NfSen	NetFlow/IPFIX traffic flows crossing border router/NAT
Smokeping	Monitoring connection health, RTT, response time, jitter within campus and to the REN/ISP
Nagios	Device availability

Questions?

UNIVERSITY OF OREGON

NSRC
Network Startup Resource Center