DCF255 Test 2 Review

Week 6: Routing and Switching

The two most common devices are switches and routers.

- Switches are layer 2 devices, data link layer, which means they forward frames, not packets, using the Media Access Control (MAC) address.
- Routers are layer 3 devices, Internet layer, which means they forward packets, not frames, using the IP address.

The basic device is the switch. Routing was built on top switching so that many independent single networks can be joined into a larger network in order to share resources and exchange data.

Data Link Layer

The data link layer is not a single layer, but 2 layers: Logical Link Layer and the Media Access Layer

- The Logical Link Layer is only used by 802.2 Ethernet (old Ethernet) and is also used by other LAN\WAN technologies. Modern Ethernet, is defined by the IEEE 802.3 standard and does not use the Logical Link Layer.
- All types of Ethernet have one thing in common- they all use the Media Access Layer to access the network. This layer uses a protocol called CSMA/CD to control how network PCs access the communications channel. CSMA/CD (Carrier Sense Multiple Access with Collision Detection).

How CSMA/CD Works?

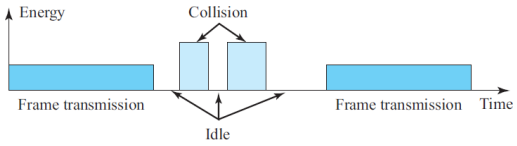
In CSMA/CD when a device wants to transmit data it must first access the transmission channel and determine whether the channel is free. If the channel is not free (noise level is high) it waits and checks again after a brief amount of time. If the channel is free, the mode transmits data. Any PC can transmit its data. However, if two nodes transmit at the same time a collision will occur which will destroy the data. This is where the third component Collision Detection comes in. If a collision occurs (a spike in the noise level), both devices stop transmitting. The NIC cards of each device will send a special 32-bit sequence that indicates to the rest of the network, that its previous transmission was faulty and that those

data frames are to be deleted. Each node then waits a random amount of time and, if the network channel is free, it automatically retransmits the data.

CSMA/CA (Carrier sense multiple access with collision avoidance)

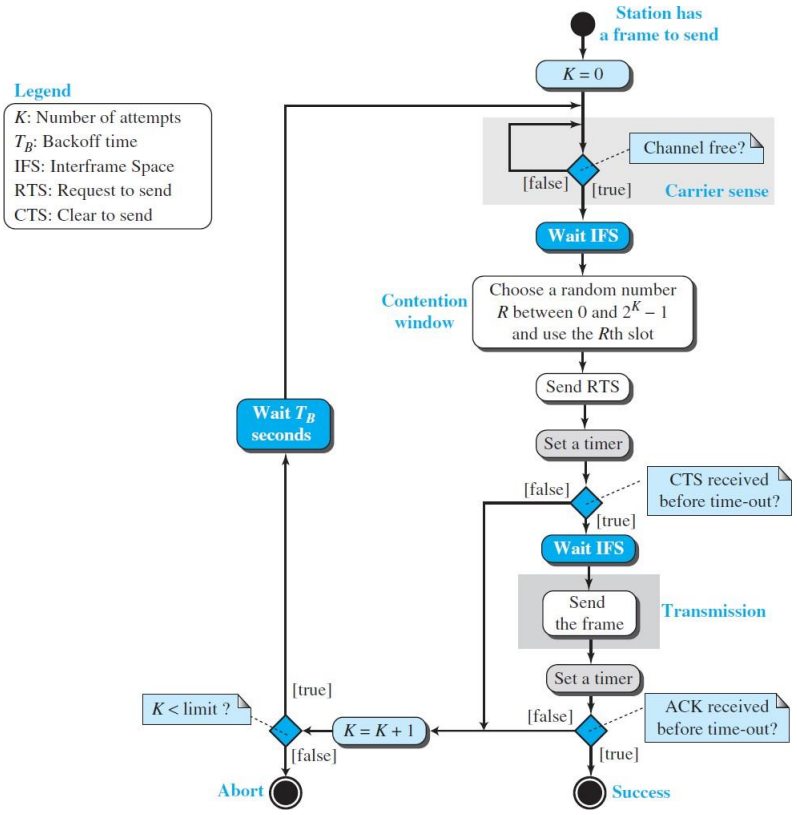
How collision can be detected:

- detecting voltage level on the line
- detecting power level
- detecting simultaneous transmission & reception



CSMA/CA

CSMA/CA uses three strategies: the **interframe space (IFS)**, **contention window**, and **acknowledgments**



Wireless Ethernet is a shared medium and the process use a protocol called CSMA/CA. It works like . It works like CSMA/CD, but has extra steps to avoid collisions). This is the CSMA protocol with collision avoidance.

Algorithm:

• The station ready to transmit, senses the line by using one of the persistent strategies. As soon as it find the line to be idle, the station waits for an IFS (Interframe space) amount of time. It then waits for some random time (contention window slot time) and sends the frame.

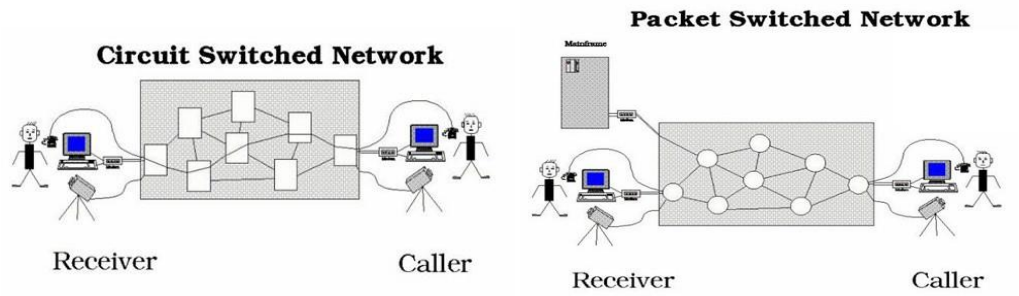
• After sending the frame, it sets a timer and waits for the acknowledgment from the receiver. If the acknowledgments are received before the expiry of the timer, then the transmission is successful. But if the transmitting station does not receive the expecteacknowledgmentnt before the timer expiry then it increments the back-off parameter, waits for the back-off time, and re-senses the line.

- Whenever the channel is found idle, the station does not transmit immediately. It waits for a period of time called interframe space (IFS), because it may be possible that the same distant station may have already started transmitting the signal of that distant station. Therefore, the purpose of IFS time is to allow this transmitted signal to reach other stations.

Switching

Switching is a process to forward frames coming in one port and forwarding out to the destination port which copies the MAC address of the device attached to it. It is much faster than routing. It is used to improve performance by minimizing broadcast and collision traffic which consume bandwidth. At a broad level, switching can be divided into two major categories:

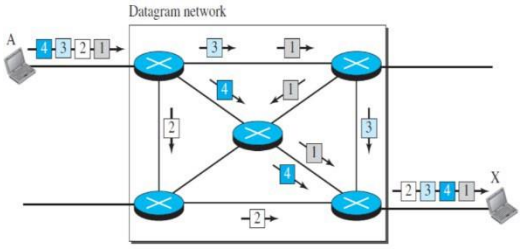
- **Circuit Switching:** In circuit switching a connection is established between two network nodes before they begin transmitting data. Bandwidth is dedicated to this connection and remains available until the users terminate the communication. Applications that use circuit switching may have to go
- through three phases: establish a circuit, transfer the data and disconnect the circuit. Example: PSTN, DSL.
    - **Pros and Cons:** A dedicated circuit is good for voice communication it is not good for transmitting digital data. The dedicated circuit is too inefficient in bandwidth when a million bits can be sent in a fraction of a second.



- **Packet switching:** packet Switching is the most popular form of connection for Ethernet and the Internet. Large messages are fragmented into small individual messages.
    - **Pros and Cons:** Efficient use of bandwidth by not holding a connection open until a message reaches its destination. Packet switching also enhances line efficiency as packets from multiple applications can be multiplexed over the carrier. The Internet uses packet switching; packet switching enables the user to differentiate data streams based on priorities. Packets are stored and forwarded based on their priority to provide quality of service. Because of the time, it takes to reassemble the packets into a message, packet switching requires speedy connections, if used for live audio or video transmission.

Two types of packet switched networks

1. **Datagram switching**



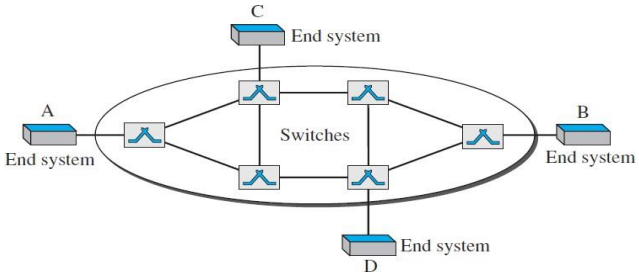
Datagram switching (Network layer)

In datagram switching each packet is treated independently to all other packets. Depending on the current network situation (congestion or unavailability of the next hop) packets may take different routes/paths to the destination. Datagram switching is a connectionless approach where no connection establishment or tear down take place.

2. **Virtual Circuits**

Virtual circuit is the combination of circuit switched and packet switched techniques where data is packetized and for sending it to the destination a temporary path known as virtual circuit is established. All the packets followed the same path to the destination during the session. The header of the packet contains the address of the next switch should be and the channel on which the packet is being carried, not end-to-end address like in datagram switching where the destination address is the IP address of the destination node. There are three phases of communication:
Three phases of communication:

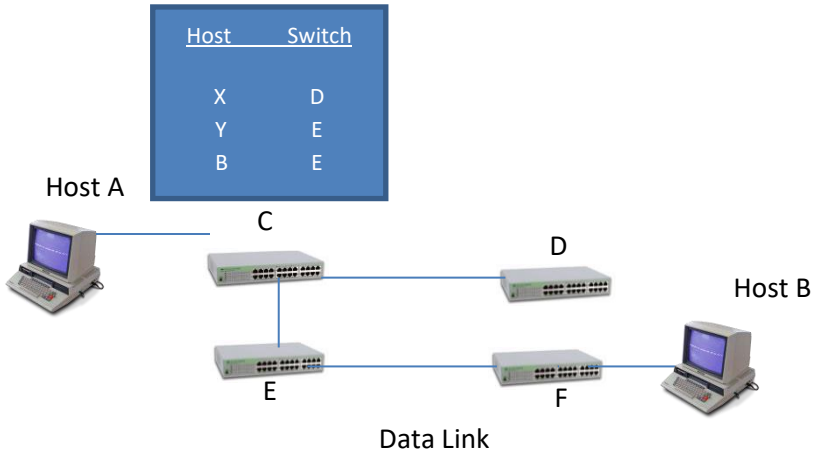
a. Connection establishment
b. Data transfer
c. Connection tear down



In Figure. The network has switches that allow traffic from sources to destinations. A source or destination can be a computer, packet switch, bridge, or any other device that connects other networks.

Switch Operation

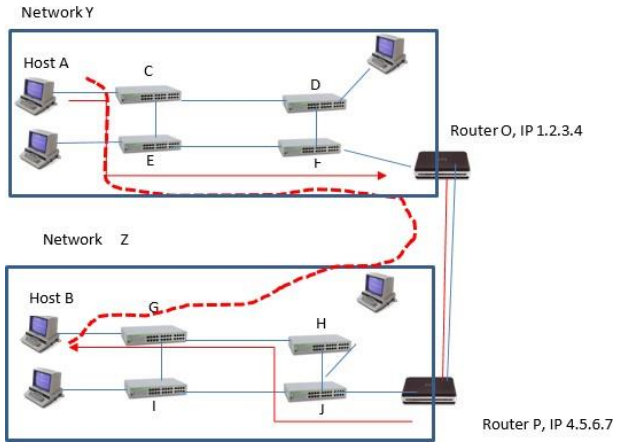
Suppose Host A wishes to send information to Host B. We can see there are 2 switched paths CDF and CEF. Switch C has a switching table with two columns: one for the destination of the frame, and the other for the switch to use to reach the destination host. This switch-by-switch decision making continues across each physical link until the final switch forwards the frame to Host B. Switches only know their neighbor; they do not know the entire path. The path from Host A to CEF and final to Host B is called a data link. There is only 1 data link across a single network, regardless of the number of switches used.



Router

Bob Kahn and Vint Cerf devised a new device to link single networks together which they called a "gateway" when ARPANET was developed. Today, we call this device a router (the term gateway is still used as a point of access to a network).

Routers connect different signal networks together. Single networks have no idea what a router is, they only know how to deliver frames to their neighbour. They do not open the packet and look inside to see the message in the frame. Routers work by acting as hosts on the network. Like a PC, a router has a NIC and a unique IP address.



- Unlike switches, routers and PCs have software that can open the frame to see the packet and view the source and destination IP addresses.
- Packets are routed across internets. Frames are switched across single networks.

Type	Number	Description
Physical Links	9	AC,CE,EF,FO,OP,PJ,JH,HG,GB
Data Links	3	AO,OP,PB
Frames	3	AO,OP,PB
Packet	1	AB
Route	1	AB

Example

Host A on Network Y, wants to send an application message to Host B on Network Z. On Network Y, the router acts as a destination host, accepting the frame across Network Y data link. Router O creates a new frame acceptable to Network Z. Looking at its routing table, Router O, knows that to reach Network Z, it needs to send the frame to interface 4.5.6.7. Router P acts like a host accepting the frame from Router O and forwards the frame to switch J. Switch J uses its switching table to forward the frame to switch H which in turn forwards it to switch G and finally to Host B.

Routing Operation

Switches which are organized in a hierarchical fashion and only have one path to the destination host, a router is organized in a mesh with multiple paths to the destination host. The rows in the routing table are in the thousands with each row identifying a destination path. Thus, the router must make a forwarding decision as to the best route making routing much slower than switching. Routers have specific routing algorithms to help in the decision making, but all routers follow a 3-step process when a packet arrives. This is true for IPv4 and IPv6 routing:

- The router finds the destination IP address. It does this by ANDing the IP address with the network mask. For example, suppose a packet was destined to MySeneca on the Seneca College network, IPv4 142.204.250.120. The router would apply the mask of 255.255.0.0
- The router then compares the network address of 142.204 to every row in its routing table. The router then compares the network address of 142.204 to every row in its routing table. From the list of matches, the router must decide which route is the best-match. The rule the router follows is which route is the longest match (to get the packet as close to the destination as possible). For example, if the routing table showed 2 routes to MySeneca, 142.204.0.0/16 and 142.204.0.0/24, and the packet was destined for network 142.204.250.120; the router would choose the destination row with the 24 bit host.
- Some rows may have the same longest match than the router uses some metric to break the tie. The metric will depend on the routing protocol used. Usually, the tie breaker will be the shortest distance.

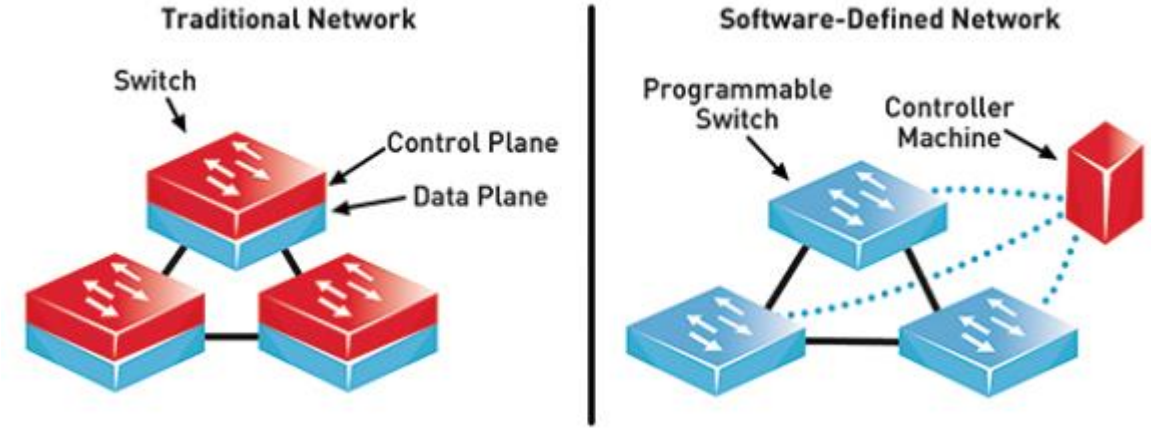
Network Virtualization

Network Virtualization (NV) is a software base that works as a traditional hardware base network device such as a switch, router, etc. by using NV, you can use one physical network device into separate, independent virtual networks. NV helps the network changes from static, inflex, and inefficient to a dynamic, responsive and enhanced. Nowadays, networks suppose to follow the demands for cloud base activities, distribute apps, and cybersecurity. With NV, you don't need to wait for a couple of days or weeks to upgrade your network system for supporting the new applications. Applications will be deployed to the system in minutes.

How does network virtualization work?

NV divides network services from the core hardware and uses a virtual system of a whole network. In this way,

NV makes it to use software to create, monitor, and manage networks. In the traditional network, devices such as switch and router have two main parts of working; Control Plane and Data Plane. The control plane gives the command to the data plane to how to deal with the coming data to the device and how to forward it.



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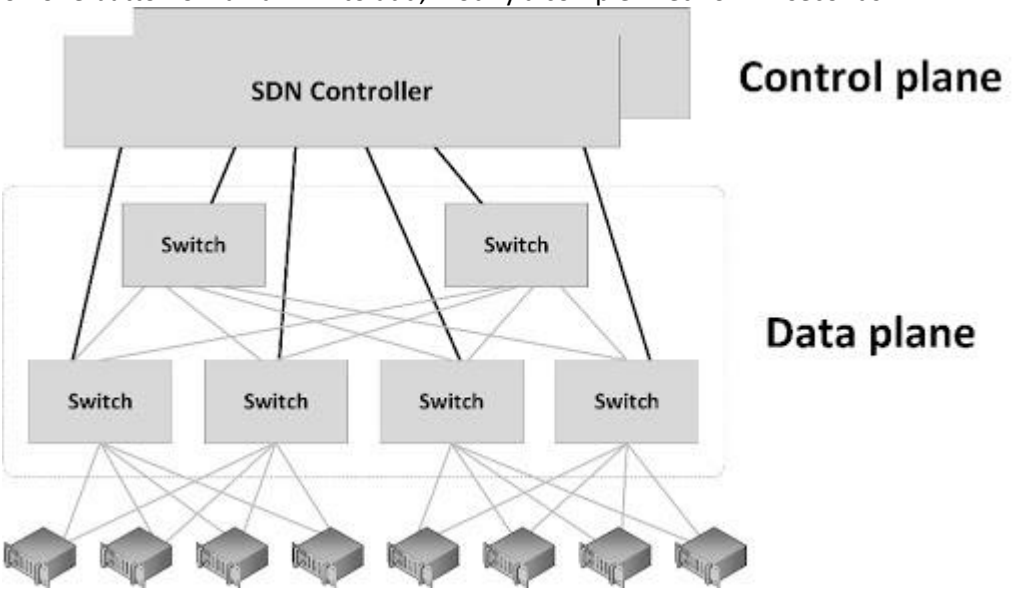
In NV, these two planes have been divided, and Control Planes set virtually on a server and they come as a central commander for Data Planes. The control plane in NV has been controlled by Software Define Networking (SDN). The SDN allows managing the physical network devices by using the software. SDN uses APIs to control, monitor and modify the network activities by sends commands to data plane devices. It provides to the network administrators to control and manage the network fast and easy. They can buy click on one button or run an API to add, modify a complex network in seconds.



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Example of Network Virtualization

In this example, there is an organization with 6 Virtual Machines (VM) such as VMWare, Hyper V. Each VM has different LAN IP addresses (they can't communicate to each other without using a router), and we have 6 LANs with 6 VMs. As you can see, the VMs need to pass the switch and router then communicate with other VM, Especially if both VMs are in the same Host. The system works perfectly, but it has much latency between the network devices. Imagin, the organization, has 300 VMs, and it will increase the VMs to 100 more. The organization is supposed to buy more network devices, and it will increase the network latency. It will cause more expenses, more spaces, and maintenance, plus spend time researching, ordering and installing the new devices.

If the organization uses a Network Virtualization (NV) system, there is a logical switch and routers, in which all the controls are centralized, and NV can handle all data communication between all VMs. The latency will be reduced rapidly, and the VMs can communicate faster. All the communications pass through the Logical Switch and Routers. If the VMs in different Hosts, then the data passing the hardware switch to reach to the other Host. But already Control Plane has been set in Logical router. If the organization has 300 VMs, and it needs to increase to 100 more VMs, the network administrator just needs to install virtual network devices on the server and set them all. It can happen in a couple of minutes. As you can see, NV increases the speeds of data communication, maintenance, and installation of new devices, plus decrease the cost of the hardware devices and spending time.

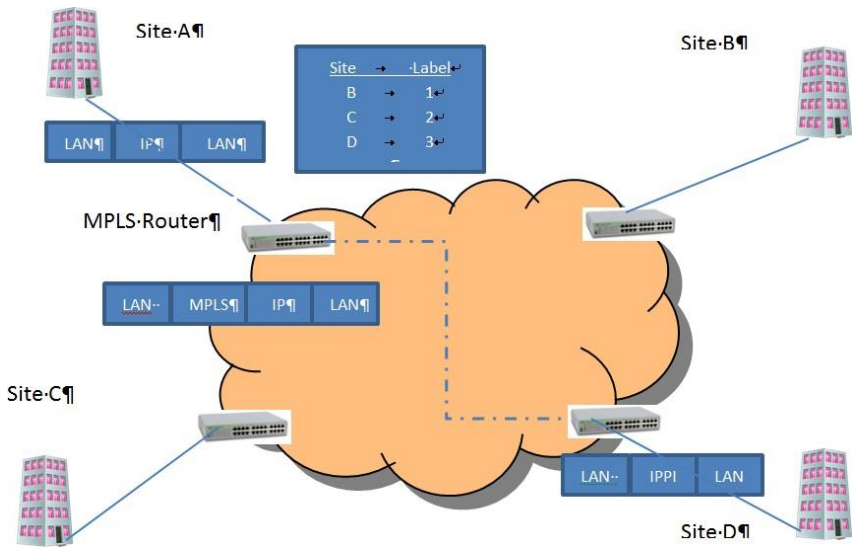
Benefits of Network Virtualization

Network Virtualization provides speeds, more flexible, and security by automating and make more specific many activities of running data center or cloud networking. The following are some critical benefits for NV:

- Increase the time of network supplying from weeks to minutes
- By using automation in NV instead of manual processing, it achieves greater efficiency in network operation.
- Network workloads can be placed and moved separately of the physical topology
- As security in the data center or cloud networking, NV improved networking security.

Multiple Protocol Label Switching (MPLS)

- Multiprotocol Label Switching (MPLS) is a new standard which greatly simplifies routing and basically allows the router to function like a switch. This technology can be used with any LAN technology, like Ethernet, but is currently being used by third parties to provide MAN and WAN configurations. MPLS operation is completely transparently to the sending and receiving host. MPLS adds a new header in between the existing LAN and IP headers (note: the LAN and IP headers are not changed). Can be used to avoid routing delays.
- On an MPLS network, when two hosts begin to communicate, they do not immediately send packets, Instead, they determine the best path for the packets. This best path is called the "label-switched path". This dedicated path is slow to set up, but once created all subsequent packets can be forwarded very quickly.



Voice Over IP (VoIP) Networks

Voice Over IP (VoIP) Networks

VoIP is a client/server architecture which uses data devices to send real time audio communication as

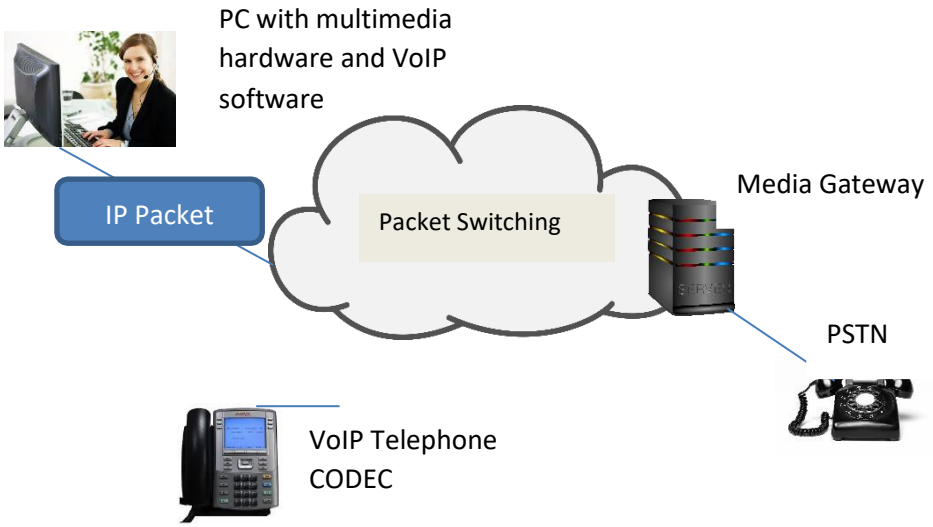
well as data over the TCP/IP Ethernet network. The servers set up the connection, and once made, the clients then send IP packets back and forth until the call has ended and the servers take down the connection.

Clients

The clients can be a PC with speakers and microphone and VoIP software. A client could also be a specialized VoIP telephone, that uses an RJ-45 connector. These telephones have built in codecs to convert the digital IP packet to analog voice. A traditional land line can also be a client provided the VoIP communication goes through a media gateway which does the conversion.

Servers

There are two major VoIP signaling protocols, H.323 which is an ITU-T standard or SIP (Session Initiation Protocol) created by the IETF. SIP is the newer standard and will probably replace H.323 in time. All of the major telcos and cable companies offer VoIP services. Most businesses and home users are buying the service from third party providers. But there is an open source version called OfficeSIP which works with Windows and can be downloaded onto any PC to act as a server.



- To provide better voice communication, the UDP, User Datagram Protocol is used. This protocol is connectionless, does not guarantee delivery and reduces the processing load an VoIP phones. To improve UDP the Real Time Protocol (RTP) is used in conjunction. This protocol places a RTP header in between UDP header and the application message.
- VoIP is highly sensitive to jitter
- A common kit for Windows is Ozeki VoIP SIP SDK and a cross platform, open source SDK is Asterisk

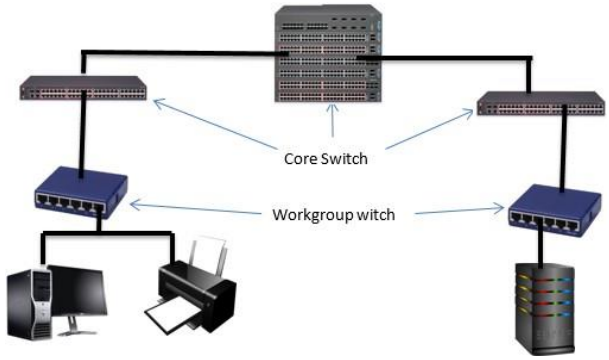
Week 8: Wired and Wireless Ethernet

Standards

Ethernet standards are controlled by the Institute for Electrical and Electronic Engineers (IEEE) and ISO. They are name IEEE 802.3 which is the most common local area network today with speeds of 100 Mbps speeds. Wireless Ethernet is controlled by the IEEE 802.11 standard.

Wired Ethernet: IEEE 802.3

An Ethernet network is built in a hierarchical manner using Core and Workgroup switches. Core switches are used to connect switches to switches. Workgroup switches join devices to the network such as printers, workstations and servers. This Switched Ethernet diagram below, is effectively upside down;



- Key design principle is that you have enough bandwidth to handle the aggregate speed of all devices on the network
  - 10 devices @ 100 Mbps connected to workgroup switch
  - Workgroup switch must be able to carry 1000 Mbps total aggregate speed. Most likely cable is 1000 BASE SX
- 6 Workgroup switches @ 1000 Mbps means that the core switch must carry 6 Gbps of total capacity
- Best – 10G core switch allows for future growth and over-provisioning
- Creating a hierarchical switched network provides the optimal balance between cost and performance. It allows combining less expensive cabling and switches with expensive switches and cabling and using them only were higher performance is required.
- A key design principle of a hierarchical network is that the cabling and switches must be able to accommodate the aggregate of the workgroup switches.

Types of Ethernet LAN Technology

Gigabit Ethernet: IEEE 802.3z

Gigabit Ethernet (GigE)was developed to meet the needs of multimedia applications and Voice over IP (VoIP) where real time transmission is required. It runs over copper or fiber-optic at speeds 10 times faster than 100Base-T . GigE is currently used for Ethernet backbones to interconnect high performance switches and servers. GigE is optimized for full duplex operation.

10 Gigabit Ethernet: IEEE 802.3ae

10 Gigabit Ethernet is the fastest and most recent of the Ethernet standards with a transmission rate 10 X GigE. Based entirely on the use of optical fiber connections and it is used as a high-speed backbone for high volume transmissions.

Power over Ethernet (PoE): IEEE 802.3-2012

PoE provides both power and data transmission over a single cable. This solution is ideal for surveillance equipment, access points and IP telephones where running power would be difficult or expensive. PoE supports fast data rates up to 100 meters in cable length while delivering 25.5 Watts of power.

Metro Ethernet

Metro Ethernet is a Metropolitan area network (MAN) technology based on Ethernet standards. It is commonly used to connect subscribers to a larger service network or the Internet. Larger businesses can

also use metropolitan-area Ethernet to connect their own offices to each other and greatly extend the concept of a LAN.

An Ethernet interface is much cheaper than any current MAN technology such as SONET (Synchronous Optical Network) or FDDI (Fiber Distributed Digital Interface) while providing similar bandwidth and speeds. Often metro Ethernet is combined with a IP/MPLS backbone which is used to connect to the service provider's switches and routers; these MPLS-based deployments are costly, but highly reliable, very scalable and are typically used by large service providers

The Evolution of Ethernet Standards to Meet Higher Speeds				
Date	**IEEE Std.**	**Name**	**Data Rate**	**Type of Cabling**
1990	802.3i	10BASE-T	10 Mb/s	Category 3 cabling
1995	802.3u	100BASE-TX	100 Mb/s*	Category 5 cabling
1998	802.3z 802.3z	1000BASE-SX 1000BASE-LX/EX	1 Gb/s	Multimode fiber Single mode fiber
1999	802.3ab	1000BASE-T	1 Gb/s*	Category 5e or higher Category
2003	802.3ae 802.3ae	10GBASE-SR 10GBASE-LR/ER	10 Gb/s	Laser-Optimized MMF Single mode fiber
2006	802.3an	10GBASE-T	10 Gb/s*	Category 6A cabling
2015	802.3bq	40GBASE-T	40 Gb/s*	Category 8 (Class I & II) Cabling
2010 2015	802.3ba 802.3ba 802.3bm	40GBASE-SR4/LR4 100GBASE-SR10/LR4/ER4 100GBASE-SR4	40 Gb/s 100 Gb/s 100 Gb/s	Laser-Optimized MMF or SMF Laser-Optimized MMF or SMF Laser-Optimized MMF
2016	SG	Under development	400 Gb/s	Laser-Optimized MMF or SMF
Note: *with auto negotiation				

Name	**IEEE Standard**	**Data Rate**	**Media Type**	**Maximum Distance**
Ethernet	802.3	10 Mbps	10Base-T	100 meters
Fast Ethernet/ 100Base-T	802.3u	100 Mbps	100Base-TX 100Base-FX	100 meters 2000 meters
Gigabit Ethernet/ GigE	802.3z	1000 Mbps	1000Base-T 1000Base-SX 1000Base-LX	100 meters 275/550 meters 550/5000 meters
10 Gigabit Ethernet	IEEE 802.3ae	10 Gbps	10GBase-SR 10GBase-LX4 10GBase-LR/ER 10GBase-SW/LW/EW	300 meters 300m MMF/ 10km SMF 10km/40km 300m/10km/40km

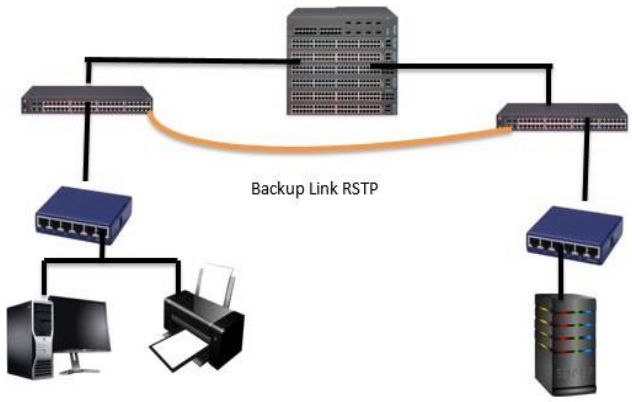
Types of Switches

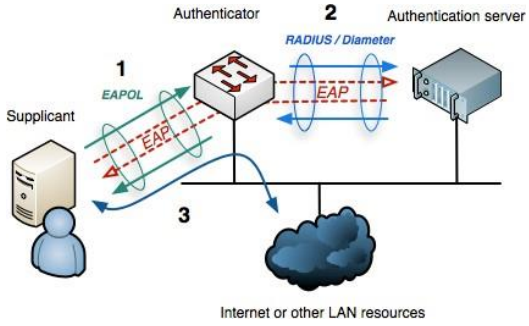
1. **Store and forward:** A store and forward switch stores each incoming frame and checks for errors. If the frame is good, it forwards it to its destination port, if not it deletes it. With a store and forward switch bandwidth is not wasted on invalid or damaged frames. The disadvantage is that it increases the latency of the switch slightly.
2. **Cut through**: A Cut Through switch, on the other hand, does not error check and begins forwarding the frame immediately upon receiving the destination Address. This results in lower latency, but can propagate errors from one subnetwork to another, wasting bandwidth on invalid or damaged frames. For a Cut Through switch to work, the speed of the transmission coming into the switch must be the same speed leaving the switch
3. **Hybrid:** combining the two types. This switch monitors the frame error rate, and if it is below a level set by the administrator, the switch will function in Cut Through mode, otherwise it uses Store and Forward mode.

Ethernet Security

RTSP

- To avoid single point failures, the IEEE 802.1 Working Group on Ethernet have provided a way to create backup links using the Rapid Spanning Tree Protocol (RSTP). On a hierarchical network, there can only be one path to each device, loops are prohibited. To avoid single points of failure, the RSTP protocol can be used to create backup links.
- The core switch on the left, before it forwards a packet, is constantly polling if the central core switch is alive. If the central core switch is alive and working the backup RSTP link is NOT used. On the other hand, if the cores switch determines that the central core switch is down, then the RSTP backup link is used to send the frame





802.1 x Port Security

- The 802.1x specification is designed to prevent unauthorized access to a data port.
- The 802.1x security protocol uses the Extensible Authentication Protocol (EAP) combined with a RADIUS (Remote Access Dial In User Service) server which stores user accounts and passwords. It divides each data port into 2 virtual switch ports; one for unauthenticated traffic and one for authenticated traffic. Until the user is authenticated all traffic passes through the unauthenticated port, and the only traffic allowed is EAP authentication traffic; all other traffic is dropped. In this sense the authenticator, the switch, acts like a security guard protecting the switch port from unauthorized use.

MAC Spoofing

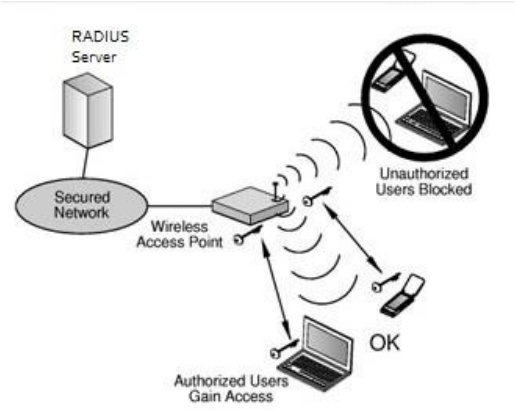
- Another security concern with switched Ethernet is the ability of a malicious person to "spoof" a MAC address. When two devices are communicating, such as when you PING someone, the devices exchange MAC addresses and store this information is memory called the ARP Cache. On a single network the MAC address is used not the IP address to forward frames and there is no way to prevent MAC address spoofing on the client, since the ARP cache must be regularly updated. Thus, it is possible for someone to change the MAC address of a device and replace it with his/her device's MAC address.
- **Solution:** Most enterprise switches have built-in intelligence to alert if someone is trying to spoof a MAC address. The switch will not allow the MAC address of the switch port to be changed with proper administrative authentication, or the switch may take proactive action and the block the switch port alert the administrator that some is tried to change an address, or there is a duplicate MAC address on the network.

Wireless Local Area Networks (WLANs) - 802.11

- Wireless LANs, or WLANs, use radio frequency technology to transmit and receive data over the air.
- The first WLAN specification was called WEP, (Wired Equivalent Privacy) this technology had some security problems
- WPA (Wi-Fi Protected Access) is backward compatible with WEP products, and uses the temporal key integrity protocol (TKIP) to ensure that keys have not been tampered with and scrambles the keys used for encrypted transmission during the session. WPA also provides user authentication with the extensible authentication protocol (EAP).
- WPA2 uses an encryption device that encrypts the network with a 256-bit key; the longer key length improves security over WEP. WPA2 was designed by the Wi-Fi Alliance standard organization and is basically the same as the IEEE 802.11i standard, with one exception. The WPA2 standard allows the sharing of keys when the network is formed.
- WPA2 works in 2 modes:

1. **Pre-shared key mode (Personal Mode):** It is ideal for small or temporary networks. The key is only used for initial authentication; after initial authentication, the wireless access point gives each user a new key to access the Internet and randomly changes the key during the session. This prevents attackers, who may be listening to the traffic from cracking the key which was a major problem with WEP.
2. **Enterprise mode (Infra-structure Mode):** works with IEEE802.11i to provide secure authentication and transmission

IEEE 802.11i is designed to work with enterprise switches using IEEE 802.1x. This provides better security than the shared key approach but requires an enterprise switch and a RADIUS authentication server.



Problem with WPA2

The Wi-Fi networks found in public locations, such as airports, hotels and coffee shops, are open and allow traffic to be sent over them that isn't routinely encrypted, and the traffic can sniffed or hacked during transmission

Solution WPA3

WPA3 fixes this by automatically encrypting all traffic between a device and the Wi-Fi access point by using a unique key, without the need for any prior setup by the user (Opportunistic Wireless Encryption (OWE) – RFC 8110), so even if someone sniffed the traffic but difficult decrypt it.

WPA3 works in 2 modes like WPA2 but with increased security

Personal Mode: Pre-shared key mode with Simultaneous Authentication of Equals (SAE) algorithm, that provides more protection to devices that do not have a strong password by preventing it to brute-force and dictionary password attacks

Enterprise Mode: offers an 192-bit minimum cryptographic strength with the combination protocols. A set of four cryptographic tools replace Wi-Fi 802.1x for WPA2-Enterprise, and the tools are combined together to provide better protection against attacks, such as password cracking on Wi-Fi networks.

Wireless Protocols

IEEE Standard	Year Adopted	Frequency	Max. Data Rate	Max. Range
802.11a	1999	5 GHz	54 Mbps	400 ft.
802.11b	1999	2.4 GHz	11 Mbps	450 ft.
802.11g	2003	2.4 GHz	54 Mbps	450 ft.
802.11n	2009	2.4/5 GHz	600 Mbps	825 ft.
802.11ac	2014	5 GHz	1 Gbps	1,000 ft.
802.11ac Wave 2	2015	5 GHz	3.47 Gbps	10 m.
802.11ad	2016	60 GHz	7 Gbps	30 ft.
802.11af	2014	2.4/5 GHz	26.7 Mbps – 568.9 Mbps (depending on channel)	1,000 m.
802.11ah	2016	2.4/5 GHz	347 Mbps	1,000 m.
802.11ax	2019 (expected)	2.4/5 GHz	10 Gbps	1,000 ft.
802.11ay	late 2019 (expected)	60 GHz	100 Gbps	300-500 m.
802.11az	2021 (expected)	60 GHz	Device tracking refresh rate 0.1-0.5 Hz	Accuracy <1m to <0.1m

Wireless Transmission Errors

A negative side, wireless transmission as security and propagation problems. Setting up a wireless network is difficult and expensive. In addition, to the errors of crosstalk, EMI, jitter and noise, wireless transmissions have special problems.

- **Attenuation:** A signal strength attenuates as it travels down a medium. With radio waves the attenuation is much greater because the signal travels in all directions at the same time. In addition, plants are the "natural enemy" of radio waves and cause "absorptive attenuation" which greatly limits signal travel.
- **Multipath interference**: Radio waves can bounce off walls and ceiling, and other objects which creates two signals, the original signal and a reflected signal. Often the two signals arrive at the access point out of phase; one signal may arrive at its highest amplitude, and the reflected signal, with a slight delay, arrives at its lowest amplitude, this causes the signal to be unreadable and will require a retransmission.

Wireless Frame Format: 802.11

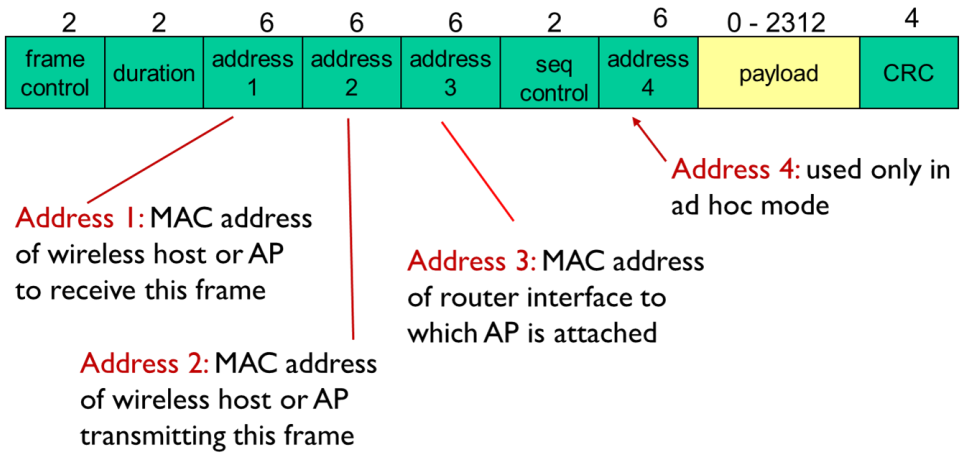


Figure 1: Wireless Frame Format

- The first part of the header is the 16-bit Frame Control field. This field contains flags that indicate the type of data frame, acknowledgement, etc. The Duration is a 16-bit field that is used to reserve the transmission channel to the sender. The Sequence control field contains a 12 bits' sequence number that is incremented for each data frame so the access point can tell the frames that go together or if there is a duplicate frame. Notice that a wireless frame has three 48-bits address fields. This is surprising compared to other protocols in the network and datalink layers whose headers only contain a source and a destination address. Then the next field is payload field. The payload size is variable. Like if the backbone ethernet LAN segment supports MTU of 1500 octets/bytes then wireless frame payload is 1460 octets/bytes. Similarly, if ethernet LAN segment supports jumbo frame the wireless frame payload can from2312 octets to 7895 octets. The last field in the header is the 4 octet/byte long CRC for the error detection.

Wireless Security

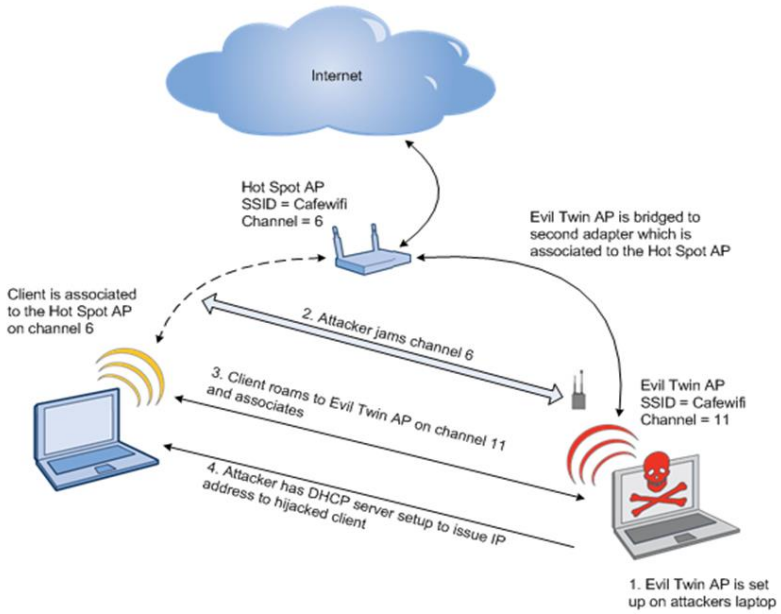
Wireless networks by nature are not as secure as wired networks. The two main threats from hackers are:

Rogue Access Points

A Rouge AP is a Wi-Fi access point that is installed on a network with the SSID as the network ID, but is not authorized by management. It can be used to steal data or create a Denial of Service (DoS) attack. Any client who connects to a rogue access point must be considered a rogue client because it is bypassing the authorized security protocols set by management.

Evil Twin

An evil twin is an access point that is operating at high power, usually in a public area, with the same SSID as the real access point. Wireless devices will connect automatically to the strongest signal; thus the



wireless client is associated with an imposter network that is operated by a hacker. The evil twin will establish a secure encrypted connection to the wireless client. The hacker now has access to all communication between the client and the access point. In a public area, this technique can be used to steal personal information. In a corporate environment, it is used to steal encrypted keys, trade secrets, or launch DoS attacks**.**

VPN (virtual Private Network (VPNs

A VPN network can be used to defeat the evil twin and MITM attacks. A virtual private network (VPN) is a cryptographic connection between the client and a server. VPNs provide end-to-end protection, including authentication.

The network VPN server encrypts outbound network traffic, then wraps the encrypted message in an unencrypted IPv4 packet so it can be routed. If a hacker captures the packet he/she will be unable to read it. The destination VPN server, removes the unencrypted IPv4 packet and decrypts the message to forward onto the destination host.

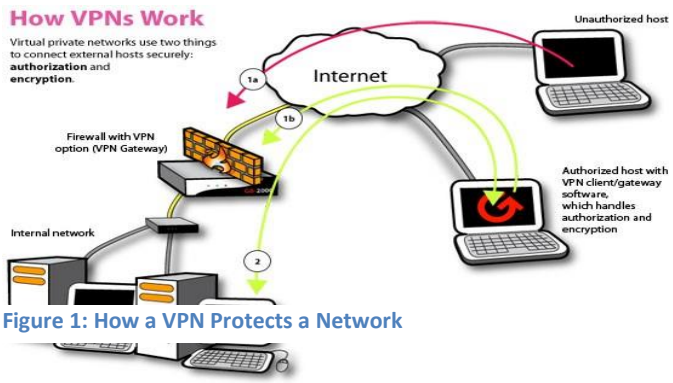


Figure 1: How a VPN Protects a Network

Week 9: Network Security and Management

The creation of new networks or the modification of an existing network is the every day work of networking professionals. Management will select the least expensive technology that will meet user needs. Networks are never static, they are continually changing to the needs and goals of the organization and personnel over time.

Cost and Decision Making

In networking, cost is a major constraint. User demand can never keep pace with corporate budgets. To aid in understanding how network changes can affect performance, management uses simulation tools like Riverbed Academic Modeler, which we are using in this class. There is never enough money to meet all user demands; management must make rational decisions and decide which product is best for the organization. To aid its decision making, management will use a Weighted Criteria Table.

		Product 1		Product 2	
Criteria	**Weight**	**Rating**	**Points**	**Rating**	**Points**
Price	5	10	50	8	40
Ease of Installation	4	7	28	5	20
Ease of Use	3	6	18	8	24
Total			96		84

Table 1: Weighted Criteria Table

In the table above, each criterion is given a weight from 1-5, 5 being the most important and 1 the least important factor to management. Then the products are rated by each criterion on a scale from 1-10. Once a product has been selected, it is managements responsibility to provide a multi-year budget to meet the network plan. Network projects have large capital outlays in some years and small outlays in others. The network administrator

Service Level/License Agreements (SLAs)

Users and consumers expect quality of service (QoS) today. The days of slow speeds, long delays and frequent power outages will no longer be tolerated. Consequently, when companies deal with service providers, such as cloud or web hosting services, they seek a written contract specifying the level of service expected. If the supplier is unable to meet the contractual minimum then a performance penalty will be

paid to the company. Some firms are even beginning to require SLAs as a performance measure for internal network staff. The two most common SLAs are **speed and latency**.

In addition to maintaining the network infrastructure and SLAs, managements main responsibility today is security. Regardless, of the industry today, all companies are primarily concerned with “data

processing". Protecting the collection, storage and retention of data on the network is necessary for management to make timely and relevant decisions.

Reasons for Network Security Failures

Reasons for Security Failures
• Human Factors (love, greed, extortion, ignorance) • Poor Assumptions (overly trusting on data input) • Hardware\Software Misconfigurations (system\application software) • Poor Policy Guidelines-> when management sees security as a "technology" problem and not a "management" problem.

Note: A vulnerability is a known weakness in the software that could be taken advantage by malicious individuals
An exploit is a tool designed to take advantage of a known vulnerability. A network break-in is also called an exploit.

Security Management

With the increased use of the Internet, network security has become more important. Currently, network administrators often spend more effort protecting their networks than they spend on the actual setup. They must make the following determinations:

- Who will have access to data?
- What resources will users have access to?
- When will users access the resources?

These questions evolve around different levels of trust.

- Divide network into trust spheres
    - Administrators – most trusted (The most trusted are network resources in an organization such as internal servers, domain controllers, and storage devices)
    - Users, DMZ (A de-militarized zone is a separate subnet which contains only public servers)– less trusted
    - Internet users, unauthorized and remote users – untrusted

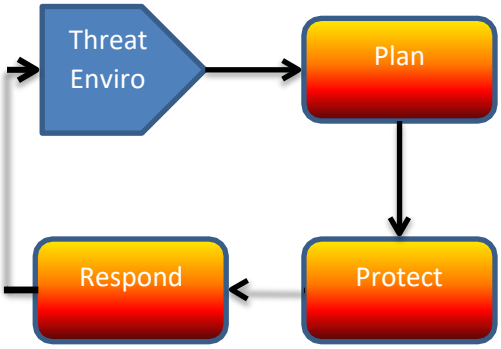
Plan Protect and Respond

Management of security involves three functions: Plan Protect and Respond. Management cannot protect a network unless it understands the "threat environment", the types of attacks and attacker methodologies.

- Planning involves understanding the goals of the company and what assets need protection and developing a comprehensive security policy which includes all aspects of the company and network.

- Protection involves the ongoing protection of the network from firewalls, to account and access control; for highly sensitive data, it could involve cryptography as well. Even the best efforts to protect a network will result in breaches from time to time.
- Respond dictates how management handles the compromise, from detecting and stopping the attack to prosecuting the attacker. The threat environment feeds into the process and as it changes, management must make changes, completing the cycle.

Planning Protect Respond involves three interrelated factors:



- Planning: Risk Analysis
- Protect: Defense in Depth
- Respond: Comprehensive Security Policy

Planning: Risk Analysis

Risk analysis involves assessing the cost of an attack with the protection required. The goal is not to eliminate risk, but to lower it to manageable levels. Good management requires that if the cost of the counter measure is greater than the lost from an attack, then management should not implement the counter measure. Risk is the value of the assets lost X the probability of a loss.

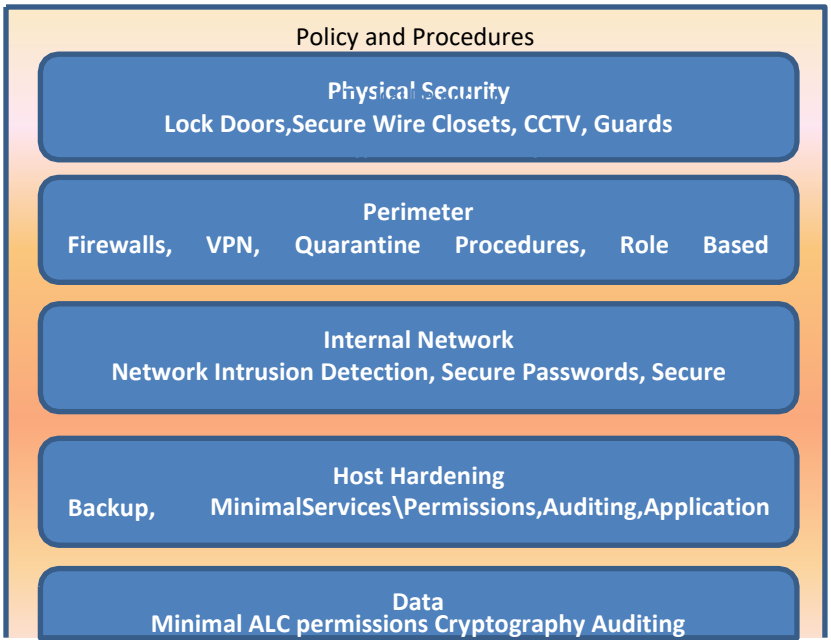
Description	Counter Measure A	Counter Measure B	Counter Measure C
Success Attack Damage	$500,000	$1,000,000	$1,000,000
Probability of an Attack	20%	20%	20%
Annual Probability of Loss	$100,000	$200,000	$200,000
Cost of Counter Measure	$25,000	$250,000	$50,000
Net Counter Measure Value	$75,000	-$50,000	$150,000
Implement Counter Measure	Yes	No	Yes

- **Risk = Value of the Asset X the probability of loss**
- Good Management is not to spend money on a counter measure if the cost is greater than the risk of loss

Protect: Defense in Depth

Defense in depth means that there a multiple layers of network security so that even if an attacker breaches one level there is another level protecting the network and may prevent the attack from succeeding.

Note: Rights refer to what you can and cannot do on the network, such as the right to log in or shut down a PC



Respond: Enforcement of Comprehensive Security Policy

A comprehensive security policy involves protecting the assets of the company by providing guidelines and standards for all employees to follow. An international standard for writing and implementing security policies is ISO 17799.

Hacking

- Hacking is when a person intentionally uses a computer resource without authorization or in excess of his/her authorization
- To protect a network you must understand the hacker motivation and methodology

Hacker Motive and Methodology

- Traditionally, hackers have been adolescents who break into networks or release malware. These individuals are driven by a desire for curiosity, power and peer "bragging" rights.
- The most dangerous group of hackers are "script-kiddies"; the latter are individuals who execute scripts written by others. They do not have a high level of technical knowledge, but their huge numbers make them very dangerous.

Types of Attacks

There are two types of attacks in general use today: random criminal attacks on individuals and targeted criminal attacks on corporations.

Criminal Attacks on Individuals

- To steal personal information, such as credit card or banking information. In this case, the goal is steal a victim's credit card number so you can make purchases.
- Or, the goal could be to steal several pieces of a victim's identity to impersonate the victim and get a loan from a financial institution.

In both cases, malware (evil software) is the tool used – viruses, worms or Trojan horses.

- Viruses are pieces of code that attach themselves to other programs. A virus executes when the infected program runs. Viruses can be spread by email attachments, links on a web site or file sharing using USB flash drives.
- Worms are stand-alone programs that do not need to attach to other programs because they are written in a macro language like VB. They propagate the same way as viruses. Viruses and worms have payloads, which can erase hard disks, or send users to pornographic sites, steal personal information, or download another program such as a keystroke logger. Sometimes the payload is hidden in a Trojan Horse. The latter is a container which has a legitimate looking purpose, but contains an illegitimate payload.

Criminal Attacks on Corporations

- Attacks on corporate networks are usually targeted attacks to break in and if that is not possible, initiate a denial of service attack. The attacker typically has a 3 step plan.

Stage 1

- Gather public information
- Web sites
- Whois database
- PING
- Social Engineering to steal information

Stage 2

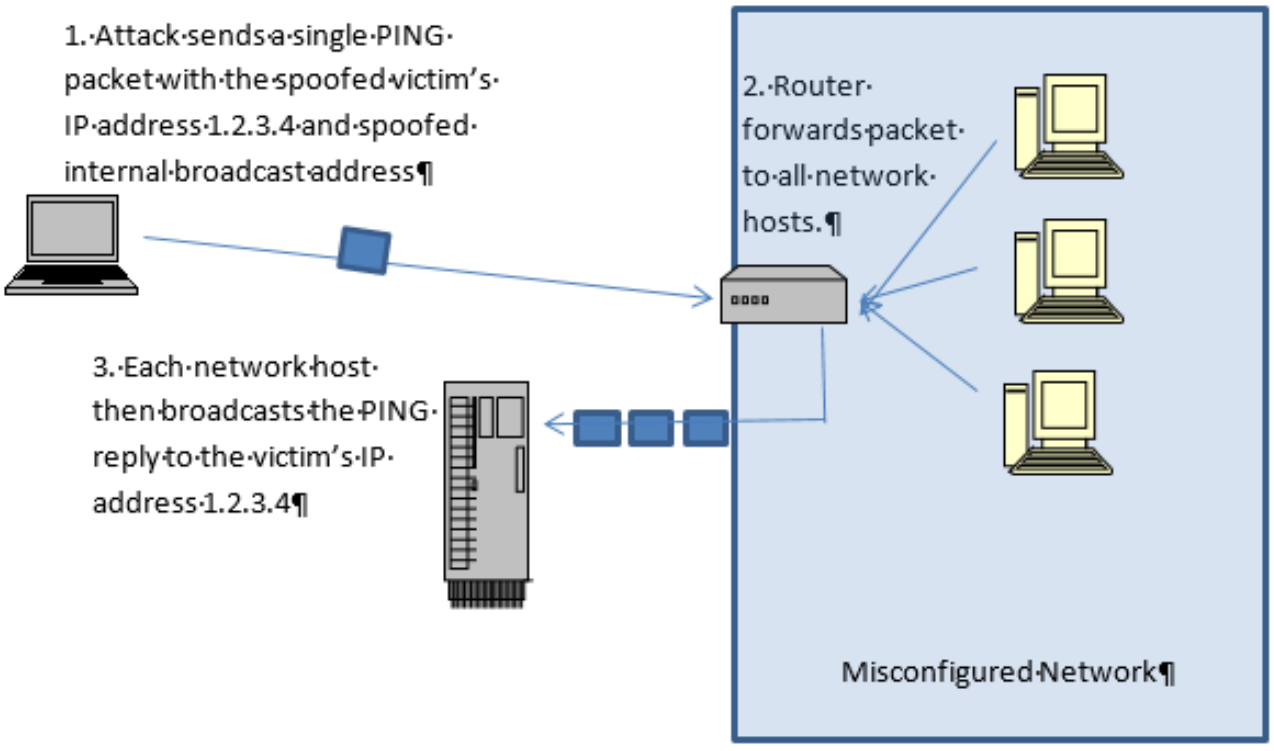
- Research known vulnerabilities
- Attacks increase AFTER patch released – all information to design a tool
- Trial and Error to find an exploit that works – use Metasploit

Stage 3

- Create back door with known password and full privilege
- Delete log files
- Install "keylogger" to steal information or account information

DoS Attacks

If the attacker cannot break-in, he/she will initiate a denial of service attack (DoS). Or the goal is to disrupt the company operations, the hacker does not need to break in. He/she can disrupt company servers or switches\routers.



Week 10: Application Security

Top 10 Vulnerabilities of Web Applications

Almost all the web vulnerabilities are a result of the programmer being overly trusting on how the

	A1- Broker Access Control	A2- Cryptographic Failures	A3-Injection	A4- Insecure Design	A5-Security Misconfiguration	A6- Vulnerable &Outdated Components	A7- Identification & Authentication Failures	A8-Software & Data integrity Failures	A9-Security Logging & Monitoring Failures	A10- Server side Request Forgery(SSRF)
C1: Define Security Requirements	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C2: Leverage Security Frameworks and Libraries	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C3: Secure Database Access	✓	✓	✓	✓	✓		✓			✓
C4: Encode and Escape Data			✓	✓						✓
C5: Validate All Inputs			✓	✓						✓
C6: Implement Digital Identity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C7: Enforce Access Controls				✓						✓
C8: Protect Data Everywhere		✓		✓						✓
C9: Implement Security Logging and Monitoring	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C10: Handle All Errors and Exceptions	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

application will be used. Building secure mobile applications is both an art and a science. It is an art in how the code base is written by the programmer, but it is also a science because we have learned from experience what procedures must be in place for software to be secure.

The top 10 application security vulnerabilities listed in ranked order of occurrence. The column across the top lists the vulnerabilities, and the row headings, lists the security practices which should have been built into the application development process to prevent the problem.

C1:Define security requirements

Security requirements provide needed functionality that software needs to be satisfied and should be derived from industry standards, applicable laws, and a history of past vulnerabilities.

Instead of having a customized approach standard methods should used, so they can be reuse again in future.

C2: Leverage Security Frameworks and Libraries

Secure code libraries and frameworks that have embedded security help software developers guard against security-related design and implementation flaws.

C3: Secure Database Access

Secure access to all data stores, including both relational databases and NoSQL databases.

1. Secure queries
2. Secure configuration
3. Secure authentication
4. Secure communication

C4: Encode and Escape Data

Encoding and escaping are defensive techniques meant to stop injection attacks. Encoding (commonly called “Output Encoding”) involves translating special characters into some different but equivalent form that is no longer dangerous in the target interpreter. Escaping involves adding a special character before the character/string to avoid it being misinterpreted.

C5: Validate All Inputs

All data that can be entered or influenced by the user must be treated as untrusted. Before being used, including displaying it back to the user, the data must be checked to ensure that it is in the right length (syntactically correct) and in the right format (semantically correct) (and in that order).

C6: Implement Digital Identity

Digital Identity is the way to represent the online transaction. Different levels of authentication should be implemented that may include Password, multifactor authentication and cryptographic authentication.

Every time a user needs to make an important action, such transferring money, or changing the shipping address, he/she should be required to re-authenticate. The server should generate a new session token which should never be written to the local machine.

C7: Enforce Access Controls

Access controls refer to the authorization of a user to access a resource. User or system access should be based on the principle of “least privilege” - granting the least amount of access to do the job for the least amount of time. Application design should check each user’s ability to access a resource and the access control policy and the application code should be separated into different layers.

C8: Protect Data Everywhere

It’s critical to classify data in your system and determine which level of sensitivity each piece of data belongs to. Each data category can then be mapped to protection rules necessary for each level of sensitivity. For example, public marketing information that is not sensitive may be categorized as public data which is ok to place on the public website. Credit card numbers may be classified as private user data which may need to be encrypted while stored or in transit.

C9: Implement Security Logging and Monitoring

Design your application to log all important application events in order audit activity and conduct compliance monitoring. Logging is essential for forensic analysis and intrusion detection and helps ensure that controls are aligned with real world attacks. Like user input, logging input needs to be checked and encoded to prevent “log injection” attacks prior to writing to the log file.

Mobile applications are at particular risk of data leakage because mobile devices are regularly lost or stolen yet contain sensitive data.

As a general rule, only the minimum data required should be stored on the mobile device.

C10: Handle All Errors and Exceptions

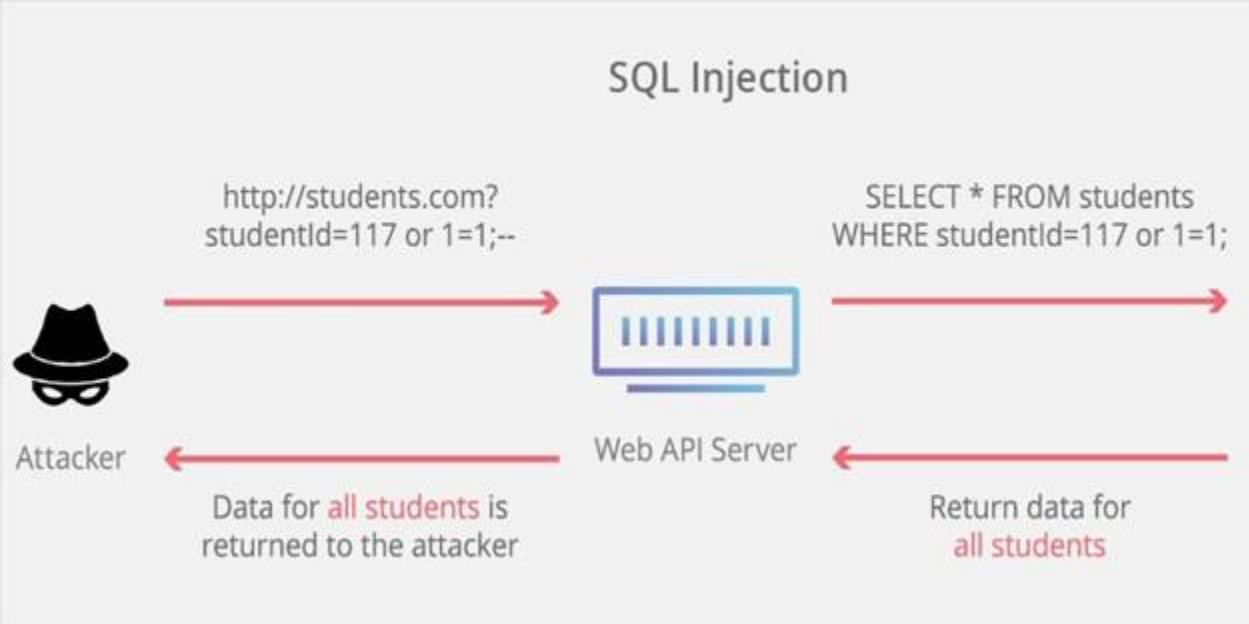
Research at the University of Toronto has shown that lack of error handling or minor mistakes in handling errors, can lead to catastrophic consequences in distributed systems. Error handling should be done in a centralized fashion and error messages to the user should not "leak" critical information about how the application works. All exceptions should be logged for forensic analysis.

Vulnerabilities Examples

Injection Attacks

1. **SQL injection Attack**

   SQL injection is a web security vulnerability that allows an attacker to interfere with the queries that an application makes to its database. let an attacker to view data that they are not normally able to retrieve. With this attack, an attacker can modify or delete this data, causing persistent changes to the application's content or behavior.




```
String query = "SELECT * FROM accounts WHERE
custID='" + request.getParameter("id") + "'";
```

This query can be exploited by modifying the "id" parameter value as follow:

```
http://example.com/app/accountView?id=' or '1'='1
```

This makes a request to the application to return all records from the account table, other similar and more severe injections can modify the data, and even cause a loss of data.

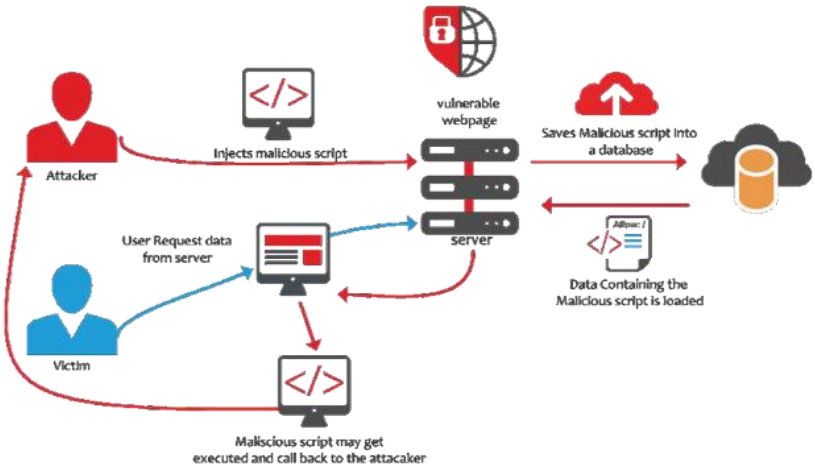
2. **Cross-site Scripting (XSS) Attack**

XSS attacks are essentially malicious injections (client-side) that are added to a web page or app through

user comments, form submissions, and so on.

3. Cryptographic Failures/Sensitive Data Exposure

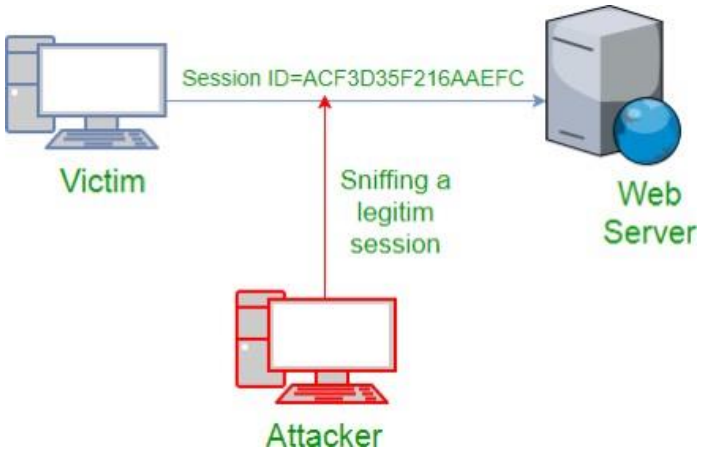
Sensitive data exposure has been one of the most popular vulnerabilities to exploit. It consists of an attacker compromising data that should have been protected. It differs from a data breach.



Data breach-> hacker attacks a network and gets control of the database

Data exposure->insecure transmission of data (data being transmitted in its original form), how data should be store (plain text or encrypted form)

4. Broken Authentication



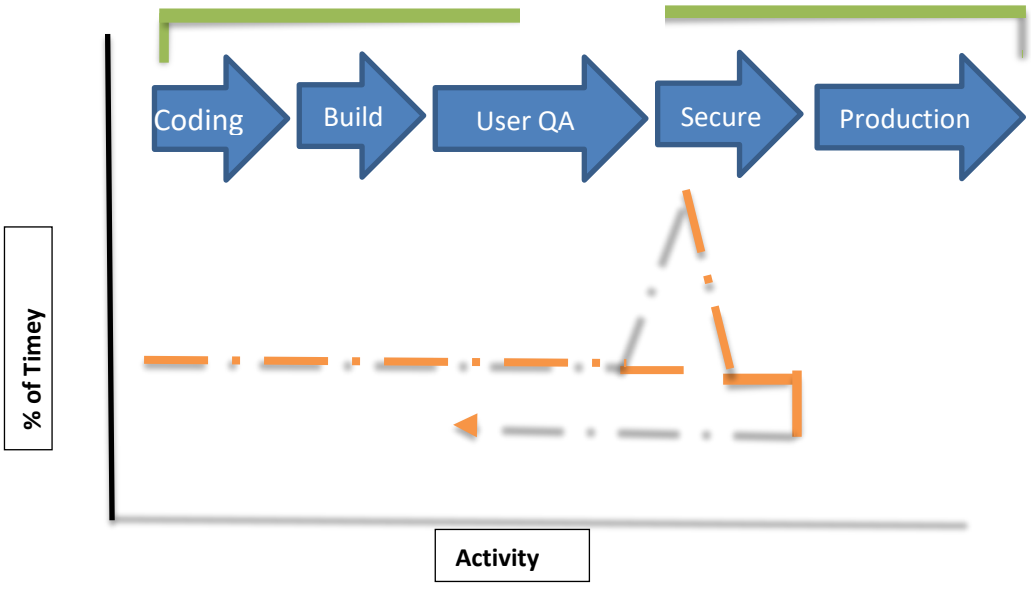
Broken authentication vulnerabilities allow attackers to use manual or automatic ways to gain control over any account in a system and even gain total control. It allows an attacker to either capture or bypass the authentication methods that are used by a web application. Broken authentication permits automated attacks such as credential stuffing, where the attacker has a list of valid usernames and passwords.

Server-Side Request Forgery

- Server-side request forgery (also known as SSRF) is a web security vulnerability that allows an attacker to induce the server-side application to make requests to an unintended location.
- In a typical SSRF attack, the attacker might cause the server to make a connection to internal-only services within the organization's infrastructure. In other cases, they may be able to force the server to connect to arbitrary external systems, potentially leaking sensitive data such as authorization credentials.

Typical SDLC Process: Resulting in Insecure Software

The systems development life cycle (SDLC), also referred to as the application development life-cycle, is a term used in systems engineering, information systems and software engineering to describe a process for planning, creating, testing, and deploying an information system.



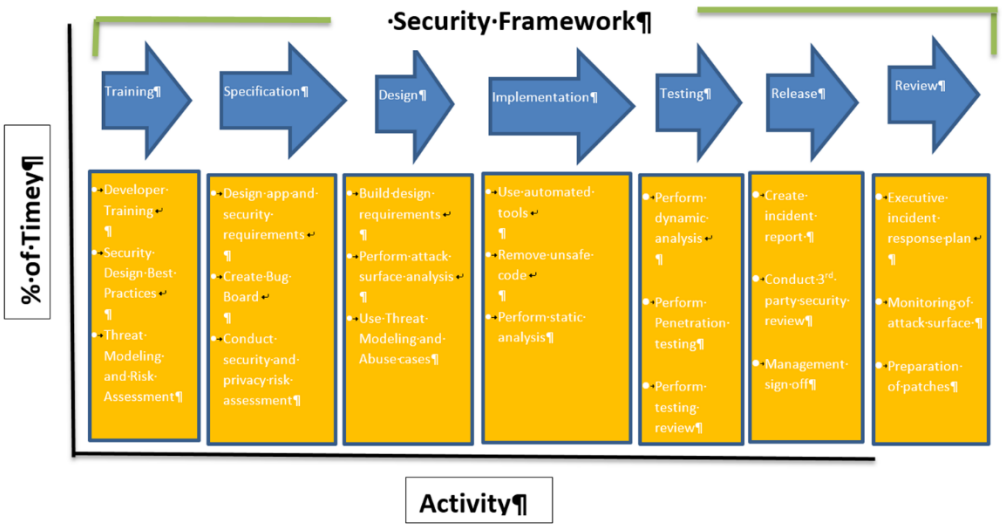
A New Paradigm: A Software Development Framework for Building Secure Software

- For secure software to be developed, attitudes must change. Software vendors should be treated like other businesses and be sued for faulty software.
- Developers should create a professional association and develop a code of ethics where security engineering is a performance criteria.
- Management should see secure software as an investment in building trust with its customers.
- Consumers should place secure software ahead of new features when they purchase software.

Security must be built into the SDLC process from the very beginning and tested throughout the process.

Training

The process begins with developers who are trained on building secure applications. Developers cannot build secure applications, or do proper penetration testing, if they do not understand the tools and methodology of the hacker.



Specifications

It refers to working with the users of the application to design an application which meets organizational and user goals. Notice that the application's security requirements are designed at the same time. During the design stage, developers should also research how the design is affected by governmental regulations and privacy considerations. This is also a good time to develop a "bug board". This a white board, centrally located, where all "bugs" that are identified in the coding are written down, the date, who identified it, who replicated it, and the date the bug was corrected.

Design

The design phase is the coding phase, where the coding is done to meet the requirements. Unlike the previous diagram, which allowed the entire code base to be built, prior to security testing, the security testing is done concurrently as the code is built.

Implementation

The implementation phase begins when the code base has been built into a working application.

At this point, a thorough security review is conducted to best for unsafe functions and removal.
Automated tools are employed because the work is very tedious and prone to human errors.
Static analysis refers to reviewing the code without executing the code. A popular static tool is Checkmarx; it identifies vulnerable lines of code as well as reviewing the code and giving remedial suggestions.

Testing

In the testing phase, dynamic code analysis is conducted in which the code is executed on a real or virtual processor. The application is first checked to see it performs to specifications. Then the code is reviewed for security faults. The programmer must enter input like a user to test different scenarios: What if the input is not in the length expected, what if the input is not in the format expected, what if the hard drive is full and the input cannot be written to a file. A popular tool is VeraCode which uses the same techniques a hacker uses to find vulnerabilities and design weaknesses.

Release

The first step of the release phase is when management signs off on the project - after the application has been thoroughly tested for performance and security. Typically, management will also, forward the project to a 3rd party security firm for independent review. Once the application is released, bugs will be discovered due to specific configuration issues on the client system which the developers could not anticipate. Thus, it is important to create an incident board to log all the issues, to study the root cause of the problem and develop workarounds and patches to fix them.

Review

Lastly, the development process never ends. The review phase is about ongoing monitoring of the application and testing of new attack surfaces, as they develop. As the product matures, patches and upgrades will be tested and developed. The plan outlines the procedures for handling security related issues from detection to remediation. All this work is done under the framework of a policy statement called the Incident Response Plan.

10 Best Practices for Building Secure Mobile Applications.

1. **Always Assign Security to a Champion** - security is best applied in a top-down fashion and needs a "champion" to get things done, build relationships with stack-holders, get funding, built a security "culture" and awareness of key projects. (Manager/ CISO (Corporate Information Security Officer))
2. **Always Model Threats During Software Development**- Security requirements for a project must be developed at the onset of the project when the design specifications are drafted. Security requirements for a project must be developed at the onset of the project when the design specifications are drafted.
3. **Always use Modular Code to Separate Parts of the Application**- Dividing your code into modules, submodules and internal APIs creates segregation in your code which isolates parts of the application.
4. **Always use Tested Code Libraries**- Only use encryption libraries that have been available for many years. The longevity of the library speaks for itself. Good libraries have good documentation.
5. **Always Test Application on Different Mobile Platforms and APIs**- Testing for security to ensure that each platform maintains the confidentiality, integrity and availability of the data. Mobile applications are written for IOS, Android, Windows, and other mobile platforms. Each platform uses programming interfaces (APIs) and must be independently tested for performance and security.
6. **Always Add Multiple Levels of Authentication**- Use Two-factor refers to an authentication system in which users are required to authenticate using at least two different "factors" something you

know, password/ pin, combined with something they have, smart phone or computer, before being granted access.As a programmer, you must strike the balance between ease of sign up/login with smart security measures which protect privacy and confidentiality.

7. **Always Require Minimal Data from the User**- When designing your application, focus on requesting the least amount of data possible from users; this limits the amount of data you must protect. As a programmer, ask yourself what information do you need for the software to function. Once you have made that determination, design your application to hold a signal "chock point".
8. Always Use Automated Tools and Auditors for Testing- Application developers should include static and dynamic automated tools to help the code review. These tools attempt to automatically identify security flaws in the code.Once the app is written, it should be sent to independent penetration testers.Always Use Automated Tools and Auditors for Testing
9. **Always Build User Trust -** To encourage users to download your app display your privacy policy and what you will do if a data breach occurs. Be clear and specific. Users look for how many downloads an app has had as indicator of trust (i.e. 250,000 downloads). They also look to user reviews of your app and court the "star" rating. (i.e. 4 stars indicates favorable reviews).

Application Security Testing Techniques

Static Application Security Testing (SAST)- used as a Source Code Analysis tool.

- White box testing approach that examines the application from the inside, searching its source code for conditions that indicate t security vulnerability prior to the launch of an application and used to strengthen code.
- It is used at a very early in the software development as it does not require a working application and can take place without code being executed.

Dynamic Application Security Testing (DAST)- find security vulnerabilities and weaknesses in a running application

- A black-box testing methodology in which an application is tested from the outside typically web apps.
- A tester using DAST examines an application when it is running and tries to hack it just like an attacker would.
- Some of the methods of security testing by DAST are: fault injection techniques on an app, such as feeding malicious data to the software, to identify common security vulnerabilities, such as SQL injection and cross--site scripting.
- DAST can also cast a spotlight on runtime problems like authentication and server configuration issues, as well as flaws visible only when a known user logs in.

Interactive Application Security Testing (IAST)

- combine the strengths of both SAST and DAST methods as well as provide access to code, HTTP traffic, library information, backend connections, and configuration information.
- IAST places an agent within an application and performs all its analysis in the app in real-time and anywhere in the development process -- IDE, continuously integrated environment, QA or even in production.

10. **Research and Stay Updated on Latest Exploits, Vulnerabilities, and Security Trends**- The threat environment is always changing and to a large extent, you will feel that you are playing "catch-up" to the hackers. In order to stay on top of the latest threats and how they may impact your software, you need to maintain regular subscription service. The three most important are:CERT,CVE and OWASP.

Week 11: Living in a connected world

The Internet of Things pertains to the concept of devices connected to the Internet where data gathered by such devices are reported to users. People can then act on the said data or the devices themselves are empowered to act on it. The ease of data transmission, reception and implementation are all meant to improve people's quality of life.

Electronic Communication

- Proven to be an effective vehicle for cybercriminals to distribute spam and malware.
- Malware hiding in email attachments, can install spyware or ransomware.
- Cybercriminals can distribute malware through drive by downloads, technique very popular with high volume online shopping websites.

To protect yourself always do the following:

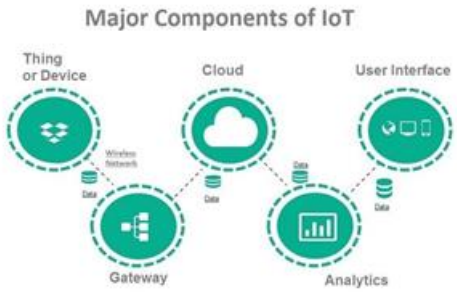
- Install and keep up to date antivirus and anti-phishing software on your personal PC.
- Don't open any email attachment unless you checked the source, even if the email is sent from one of your contacts.
- Never comparison shop using a search engine.
- Never buy goods from an unknown retailer, regardless of how good the deal seems. Think before you click.
- Make sure your PC has an antivirus and a good two-way firewall

Examples of IoT: Smart Home, Robots and Driverless cars

IoT

- Internet is medium which connects all people can be called as "Internet of People".
- IoT or Internet of things connects all things.
- The things can be sensors, actuators, home appliances, mobile devices, or anything that can communicate via internet.
- Concept of devices connected to the Internet where data gathered by such devices are reported to users.
- People can then act on the said data or the devices themselves are empowered to act on it.
- The ease of data transmission, reception and implementation are all meant to improve people's quality of life.

Components of IoT

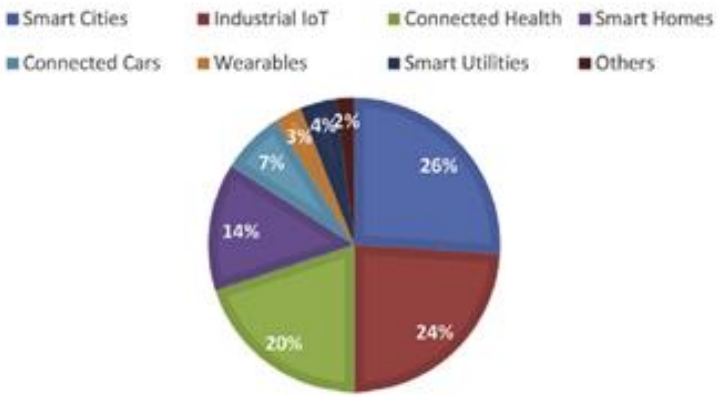


IoT Growth

Estimated number of IoT devices by the end of 2020 is between 30 to 50 billion, much more than the human population on the earth.

- 7 billion: IoT devices in 2018
- In 2019: active IoT devices reached 26.66 billion
- Every second 127 new IoT devices get connected to the web
- During 2020—experts estimate installations of 31 billion IoT devices
- By 2021—35 billion IoT devices will be installed worldwide
- By 2025—more than 75 IoT devices billion will be connected to the web

General Market Structure of IoT technologies



1. Things-Smart Devices / Sensors & Actuators

- Sensors, are low-powered devices that have the capability to monitor some physical or environmental phenomena, collect information for further processing.
- Sensor nodes have limited battery power, but now there are some sensors available that can recharge themselves.
- Consume very little battery power for their operation, so even if they cannot recharge the battery, they still can live on batteries for a long time.

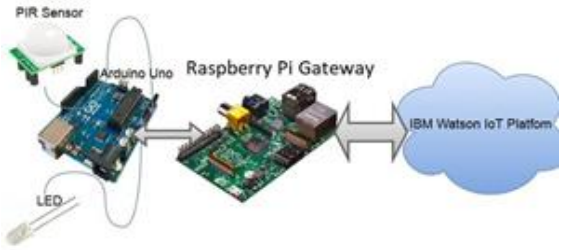
How do IoT things connect?

They make use of low-powered wireless technology is like ZigBee, WiFi, LoRa, ZWave, Bluetooth.

- Wi-Fi (Wireless Fidelity)-It is the most common and widely used wireless technology.
  - The formal protocol used is IEEE 802.11.
  - Operates in the frequency band of 2.4 GHz-5.0 GHz.
  - All communication is encrypted and can reach up to 0-100 meters.
- ZigBee-Used for WPAN (Wireless personal area networks).
  - Operates in the same 2.4 GHz frequency band as WiFi.
  - Highly secure and scalable offers good data transfer rates.
- Bluetooth- Most popular technology
  - very commonly available in all smart devices.
  - Operates 2.4 GHz, frequency band.
  - Offers short ranges of communication which is as per 3 classes are: <10m, equal to 10m, and equal to 100.
- LoRa-Long Ranged low power wide area networking (LoRaWAN) technology mainly developed for IoT devices.
  - Offers secure and encrypted communication.
  - Operates in a frequency band of 1 GHz and transmission range between 0-20 km.
  - Z-wave- Low power communication technology developed for home automation.
  - Uses ISM spectrum below 1 GHz range
  - Offers low data rates than WiFi technology.

2. IoT Gateways

- Manages bidirectional data traffic between different networks by bridging the gap between the local environment and the destination environment.
- Done by translating protocols running between the local and destination platform, to maintain interoperability between the two.
- Also performs preprocessing of collected data before transmitting it to the next intended destination.



Some IoT architectures includes edge computing devices and fog devices that acts as a middle layer between thing the and the cloud. A microcontroller/raspberry pi/aurdino processors are examples of edge devices.

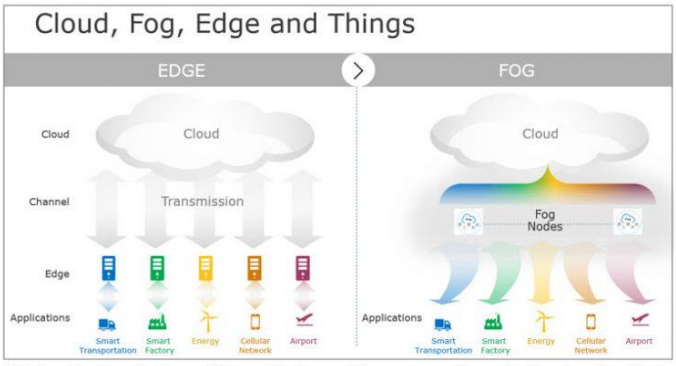
Edge Computing- usually performs directly on devices to which the sensors are attached or a gateway device that is physically "close" to the sensors.

Fog- Data is processed within a fog node or IoT gateway which is situated within the LAN.

- architecture uses edge devices to perform significant amounts of compute, storage, and networking functions locally and routed over the Internet.
- The fog extends the cloud to be closer to the things that produce and act on IoT data

3. Cloud

- Collection of computed data, storage and networking gear available in a centralized location such as a data center.
- Last phase of operation done at the cloud, where data received is processed according to nature of data as well as the type of application for which it has been collected.
- IoT cloud is a sophisticated high-performance network of servers optimized to perform high speed data processing of billions of devices, traffic management and deliver accurate analytics.
-



Side by side view of edge and fog architectures. Edge runs specific applications in a fixed logic location and provides a direct transmission service without data analysis. Fog works with edge to run applications in a multi-layer architecture that decouples and meshes the hardware and software functions, allowing for configuring / reconfiguring for different applications while performing intelligent transmission services with computing/storage/communication capabilities along the cloud to things continuum. Source: OpenFog Consortium, August 2017

4. Analytics

Analytics involves processing of the data collected by the sensor nodes, so that it can be interpreted and used for the detailed analysis which helps to find out thing's researchers are looking for. It helps in identifying irregularities both in the IoT setup as well as for the application domain for which data is collected. Careful

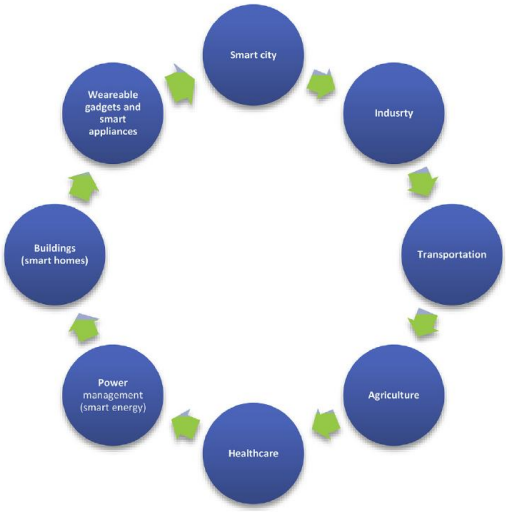
analysis also help organizations to predict trends in the market and plan ahead for a successful implementation.

5. User interface

The user's interface is the application used by users to monitor and control the data collected by the IoT devices. It engages customers with the data collected from their IoT devices and could be a mobile app, a website, a desktop application, or even a passive experience (something running at the back end) that no one interacts with directly. An effective and easily manageable user interface encourages users to use the IoT system. Some of them include touch panels instead of mechanical knobs and switches in household appliances and managing those devices via mobile and web applications.

IoT Applications

- Smart Home, Smart Grid, Smart refrigerator, Under water habitat monitoring, Smart cars, Smart industries, Smart cities



- Smart Cities:
  - Effective use of information to develop and deploy city infrastructure and services.
  - Improves quality of life, objective can only be achieved by the use of IoT devices, collects information, provides to application via network infrastructure in a seamlessly, time efficient data transfer to the cloud for the detailed data analysis can be done.

  - Includes utility services, energy conservation, waste management, traffic management, transport management, and many other utilities.
  - Smart street lighting in London and Quebec are examples where intelligent streetlights work as WIFI hotspots, have a surveillance camera, charging outlets for electric cars and phones ,and measures air quality as well.
  -

- street lighting in London and Quebec where intelligent streetlights work as WIFI hotspots, have a surveillance camera, charging outlets for electric cars and phone,s and measures air quality as well.

Advantages: Public safety, Faster commute, Economic prosperity, Greener environment
Challenges: coverage and capacity, digital security, legislation, and policies

Smart Home

- promises to change people's lives, from inside the home to right across society
- Internet creates convenience in sharing and receiving information between devices.
- Next step is for IoT devices and sensors to communicate with each other and automatically
- Perform a designated task or function without user intervention.
  - Household devices such as refrigerators, washing machines, microwave ovens, thermostats, and door locks, among others, will all be part of a household local area network.
  - Each device is equipped with computer chips, software, and access to the Internet making the "smart home" a reality.
  - No doubt this it will happen
    - the lower-cost computing today will be a boom for these smart devices.
    - In fact, Steve Furber, who was the principal designer of the ARM processor, believes IoT will be the next big growth area for ARM, for example, Nest thermostats.
- **Privacy**
- **Security**
- **Outdated technology**
- **Impact of an Internet outage**

Advantages and Disadvantages of Smart Home:

- Enhanced quality of life
  - Health monitoring of out-patient clients is easy with connected RX bottles and medicine cabinets.
  - Smart refrigerators, low food supplies that are on inventory and need immediate replenishment. Convenient to scan the barcodes of the fridge's contents, compare the result
  - "smart grid, utility companies can use wireless power meters to remotely read household meters.
  - Control the stove and other devices via the internet; the stove can be turned on and a nice meal, with music playing, is waiting for you when you get home.

Characteristics of Smart Cities

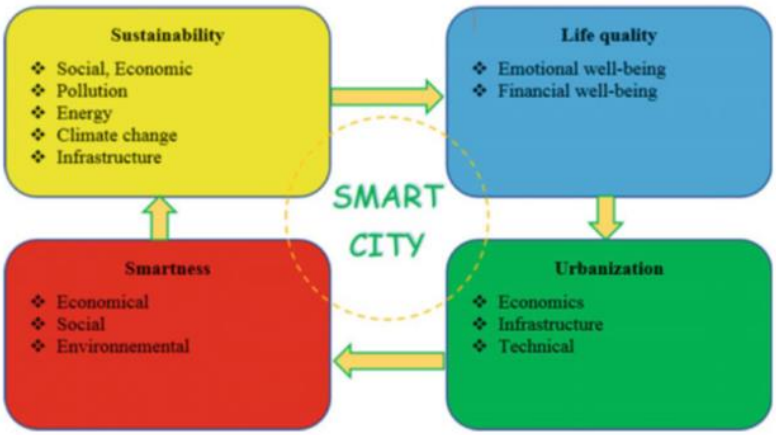


Fig. 7 Characteristics of Smart Cities

- Four attributes [10]

1. Sustainability- It is all about environment that includes climate change, pollution, energy and ecological systems
2. Quality of Life- This attribute seeks to improve the everyday life and well being of the citizens
3. Urbanization-It concerns with the technological, infrastructure, governing domains for the urban environment from the rural.
4. Smartness/Intelligence-It is the same as urbanization, which defines the desire to advance the social, environmental criteria of the city and its residents. It relates to the development of human and social capital. Their education, social diversity, integration, interaction and openness to the world.

Challenges [11]

1. Technology challenges with coverage and capacity. (Limitations of available technology and infrastructure and its effect when deployed in a diverse social environment)
2. Digital security (Securing the data from unwanted use, because when data is collected it is being shared on multiple devices/platforms, so it is necessary to secure the information obtained/shared/collection with the permission of the user.
3. Legislation and policies (workable policies and regulations, so to fully utilized the capabilities of the deployed smart project, but also keeping into consideration privacy and security of the citizens)
4. Lack of confidence or reluctance shown by citizens (lack of clarity around benefits).It includes educating citizens about the importance and advantages of the smart city project, so the resident of the city understands and onboard when the project is being launched
5. Funding and business models (securing funding for the project and making sure resources are available till the project ends)
6. Interoperability (For seamless operation all making sure that system supports all devices and communication among them)
7. Existing infrastructure for energy, water and transportation systems (Ensuring that all the concerned departments of the city are onboard and coordination between them during the project)

Robots and Driver-Less Cars:

- With RFID sensors installed, robots can clean the house, set the table, serve meals, and provide security, which will be common place by the end of the 2020s.
- Expand the concept of smart home to the neighborhood and robotic driver-less cars can operate.
- Some companies such as Uber and Tesla, have current drive-less models, fully automated driverless

cars will not become common place until 2040.

- Robots and driver-less cars:
  - Will help the aging or visually impaired loved ones from giving up their independence.
  - Time spent commuting could be time spent doing what you want to do.
  - Deaths from traffic accidents—over 1.2 million worldwide every year—could be reduced dramatically.
  - Sensors combined with onboard cameras help robot interpret its surroundings.
  - Software helps robot understand its present location, and predicts what will happen next.
  - Robot can make an intelligent decision to complete some function such as changing lanes on a street, or setting a table for dinner.

Stumbling Blocks Preventing IoT

- Lack of data protection
  - Lack of Protection Regulations
- Lack of Security
  - Lack of IoT Standardization
  - This is not an idle problem. According to a recent study, 70% of IoT devices are vulnerable to cyber- attacks. This list includes thermostats, TVs, webcams, sprinkler control systems, home alarms, and door locks- just to name a few.
- The third stumbling block of IoT is the cost issues
  - The lack of security and data protection can cause an enterprise a huge losses.
  - The cost of IoT is based on hardware, software, maintenance increases with the level of secure solutions available to the consumers.
  - IoT-enabled products include technology and service components that add ongoing value.

Some other issues are:

- Lack of IoT Standardization
- Lack of Internet Bandwidth

The other disadvantage is IoT devices need a lot of data and information about the environment in which they operate. This data can include personal schedules, shopping habits, medicine intake schedule and GPS location of the user at any given time. Each device only uses a small amount of bandwidth, but multiple this by an estimated 30 billion devices and the Internet bandwidth must greatly increase for IoT to become a reality

IoT standardization

There is a lack of connectivity standards for IoT devices. There are several proprietary networks, such as X10 and HomePNA. Presently, only products from the same vendor can be networked – similar to network operating systems in the early 80's. The new industry standard organization, AllSeen Alliance, was launched in December 2013, to improve interoperability.

The AllSeen Alliance proposes to unite industry leaders with a shared vision, a common language and a collaborative path to advance the Internet of Everything. The AllSeen Alliance proposes devices be AllJoyn certified. The latter is an open source universal software framework and core set of system services that enable interoperability among connected products. It lets

compatible devices and applications find each other, communicate and collaborate across the boundaries of product category, platform, brand, and connection type. Target devices include products in the Smart Home, but will later expand to Broadband Gateways and Driver-less cars. Presently, the communication layer (and thus hardware requirements) is limited to wi-fi. It merged with Open connectivity given by copen connectivity foundation(OCF) in 2016 as **"Iotivity".**
With the merger devices running either AllJoyn or Iotivity will be interoperable and backward compatible. AllJoyn provides several services that can be integrated with its core.

- Onboarding Service
- Configuration Service
- Notification Service
- Control Panel Service
- Common Device Model (CDM) Service

Programming Languages for IoT

Internet of Things (IoT) development projects are springing up at businesses all over the world. Choosing which language to use to write the project is as big a decision has which hardware platform to use. New languages and platforms are making it easier to engineer IoT projects than ever before. Prior to the IoT, your choice of hardware platform dictated your choice of language. However, with the AllSeen Alliance open source project modern platforms can support multiple languages, increasing developer flexibility. Here are the top 7 languages that you should consider:

C and C++

C was first developed to program telephone switches and it is still a contender for IoT projects. It's available on nearly every advanced embedded system platform and requires little processing power. The language is ideal for programmers who write for the lowest layer of software, the one closest to the hardware. The language hides nothing from you, and that means you can fiddle with every part of the code to squeeze out the best performance from an underpowered device. Every bit can be flipped. Every value on the stack is available. C++ is an alternative if the IoT device requires more complex tasks, think thermostats and smart toasters rather than devices that detect moisture or heat. C++ adds data abstraction, classes, and objects. All of these features make C++ a popular choice for those who are writing embedded and IoT code with an interface. This programming language still is going strong after more than 30 years in the field.

Java

The mentor of Java "write once, run anywhere makes it an ideal choice for an IoT project. Also, the Java compiler has very few hardware dependencies built into it. Developers can create and debug code on their desktop and then move it to any chip with a Java Virtual Machine. That means the code can run not just on places where JVMs are common (servers and smartphones), but also on the smallest machines. Today, most of the focus is on Java SE Embedded, which is much closer in capability to the Standard Edition. Developers can use the latest features of the Java 8 platform and then move their code to a smaller, embedded device.

Python

Python started as a scripting language to glue together real code, but has become one of the "go-to" language in Web development, and its use has spread to the embedded control and IoT world. The syntax is clean and simple, which greatly improves readability. If the project requires taking data and putting it into any sort of database format, then draw upon the tables for control information, Python is a very real contender provided the device has the processing power for the application. For very small devices there is MicroPython and a software package for very small microcontrollers optimized to run Python on a small board that's only a few square inches. Python is very flexible in many ways. For example, it is an

interpreted language that can either be submitted to a run-time compiler or run through one of several pre-compilers so that compact executable code may be distributed.

JavaScript

JavaScript is not an interpreted version of Java. It started as a scripting language, but has grown into a very full-featured language. The two languages were developed separately (JavaScript was developed by Netscape) and shares no syntax or semantics (however, there are libraries which allow Java and JavaScript to work together). JavaScript is heavily used for building Web-front-end applications. Forty-two percent of server based web applications use JavaScript. If you wanted to use the Apache server on a Raspberry Pi to gather data from a network of Arduino-based sensors, for example, JavaScript would be a good starting point for the effort. It's not for lightweight embedded controllers because its interpreted structure requires more processing power, but it works well with RaspberryPi.

Swift

Swift is an Apple programming language, replacing Objective C. The fact that many IoT devices will need to interface with iPhone or iPad makes Swift a good choice for an IoT project. There are other good reasons to use this language, Apple wants to make its iOS devices the center of the smart home network of sensors, so it's been creating libraries and infrastructure that handle much of the work. These libraries are the foundation of its "HomeKit" platform, which provides support for integrating the data feeds from a network of compatible devices.

B#

B# was designed from the ground-up as a very small, very efficient embedded control language. The embedded virtual machine (EVM) that allows B# to run on a variety of different platforms only takes 24k of memory -- much less than the overhead of other development languages. B# looks like C# (which will be familiar if you or your team is accustomed to working on Microsoft .NET projects), but it strips out many of the features not required for embedded projects and adds support for the real-time control functions that are critical when making things happen in the real world.

C#

C# is a good choice for an IoT project. Microsoft's strategy for IoT devices is to link them to the Azure cloud. Data collected from an almost limitless number of internet-connected sensors needs to be collated, analyzed and acted upon, and a public cloud is the logical route to do this. Presently, car companies such Corus, are using the cloud to provide mapping and integration to customers.
Microsoft has launched the Azure IoT Suite to aid developers in application development. The Suite acts as a bridge between customers' devices and the back-end application for storing, analyzing and acting on IoT data in real time. The Suite is scaled to handle billions of devices. The Suite supports multiple protocols and languages including C, Python, Java and JavaScript. Microsoft is positioning itself to use the cloud as an interface for end-to-end solutions of IoT devices from multiple vendors. This makes C# and Visual Studio a real contender for IoT projects.