- Hubs vs. Switches vs. Routers -

Layered Communication

Network communication models are generally organized into **layers.** The **OSI model** specifically consists of **seven layers,** with each layer representing a specific networking function. These functions are controlled by **protocols**, which govern end-to-end communication between devices.

As data is passed from the user application down the virtual layers of the OSI model, each of the lower layers adds a **header** (and sometimes a **trailer**) containing protocol information specific to that layer. These headers are called **Protocol Data Units (PDUs)**, and the process of adding these headers is referred to as **encapsulation**.

The PDU of each lower layer is identified with a unique term:

#	*Layer*	*PDU Name*
7	Application	**-**
6	Presentation	**-**
5	Session	**-**
4	Transport	**Segments**
3	Network	**Packets**
2	Data-link	**Frames**
1	Physical	**Bits**

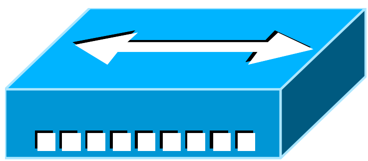
Commonly, network devices are identified by the OSI layer they *operate* at (or, more specifically, what *header* or *PDU* the device processes).

For example, **switches** are generally identified as Layer-2 devices, as switches process information stored in the **Data-Link** header of a frame (such as MAC addresses in Ethernet). Similarly, **routers** are identified as Layer-3 devices, as routers process *logical* addressing information in the **Network** header of a packet (such as IP addresses).

However, the strict definitions of the terms *switch* and *router* have blurred over time, which can result in confusion. For example, the term *switch* can now refer to devices that operate at layers higher than Layer-2. This will be explained in greater detail in this guide.

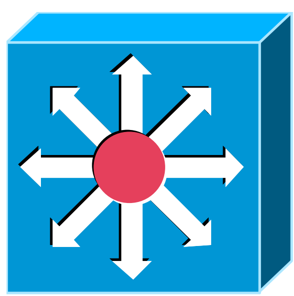
Icons for Network Devices

The following icons will be used to represent network devices for all guides on routeralley.com:

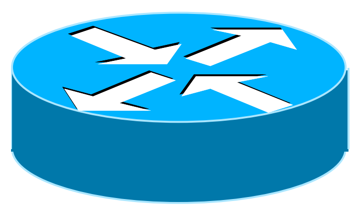


Hub

Switch



Multilayer Switch



Router

Layer-1 Hubs

Hubs are Layer-1 devices that physically connect network devices together for communication. Hubs can also be referred to as **repeaters**.

Hubs provide *no intelligent forwarding* whatsoever. Hubs are incapable of processing either Layer-2 or Layer-3 information, and thus cannot make decisions based on hardware or logical addressing.

Thus, hubs will always forward *every* frame out *every* port, excluding the port originating the frame. Hubs do not differentiate between frame types, and thus will always forward unicasts, multicasts, and broadcasts out *every* port but the originating port.

Ethernet hubs operate at **half-duplex,** which allows a host to either transmit or receive data, but not simultaneously. Half-duplex Ethernet utilizes **Carrier Sense Multiple Access with Collision Detect (CSMA/CD)** to control media access. *Carrier sense* specifies that a host will monitor the physical link, to determine whether a *carrier* (or *signal)* is currently being transmitted. The host will *only* transmit a frame if the link is **idle**.

If two hosts transmit a frame simultaneously, a **collision** will occur. This renders the collided frames unreadable. Once a collision is detected, both hosts will send a **32-bit jam sequence** to ensure all transmitting hosts are aware of the collision. The collided frames are also discarded. Both devices will then wait a *random* amount of time before resending their respective frames, to reduce the likelihood of another collision.

Remember, if *any* two devices connected to a hub send a frame simultaneously, a collision *will* occur. Thus, all ports on a hub belong to the same **collision domain**. A collision domain is simply defined as any physical segment where a collision can occur.

Multiple hubs that are uplinked together still all belong to *one* collision domain. Increasing the number of host devices in a single collision domain will increase the number of collisions, which will degrade performance.

Hubs also belong to only one **broadcast domain –** a hub will forward both broadcasts and multicasts out *every* port but the originating port. A broadcast domain is a logical segmentation of a network, dictating how far a broadcast (or multicast) frame can propagate.

Only a Layer-3 device, such as a router, can separate broadcast domains.

Layer-2 Switching

Layer-2 devices build **hardware address tables,** which at a minimum contain the following:

- Hardware addresses for hosts
- The port each hardware address is associated with

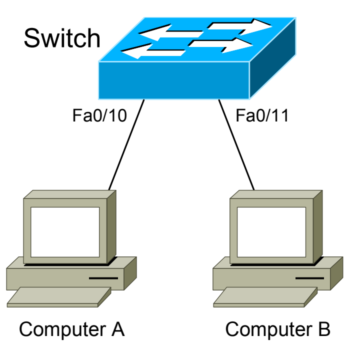
Using this information, Layer-2 devices will make intelligent **forwarding** decisions based on the frame (or data-link) headers. A frame can then be forwarded out *only* the appropriate destination port, instead of *all* ports.

Layer-2 forwarding was originally referred to as **bridging.** Bridging is a largely deprecated term (mostly for marketing purposes), and Layer-2 forwarding is now commonly referred to as **switching.**

There are some subtle technological differences between *bridging* and *switching*. Switches usually have a higher port-density, and can perform forwarding decisions at wire speed, due to specialized hardware circuits called **ASICs (Application-Specific Integrated Circuits).** Otherwise, bridges and switches are nearly identical in function.

Ethernet switches build **MAC address tables** through a dynamic learning process. A switch behaves much like a hub when first powered on. The switch will flood every frame, including unicasts, out *every* port but the originating port.

The switch will then build the MAC-address table by examining the **source MAC address** of each frame. Consider the following diagram:



When ComputerA sends a frame to ComputerB, the switch will add *ComputerA*'s MAC address to its table, associating it with port fa0/10. However, the switch will not learn *ComputerB's* MAC address until ComputerB sends a frame to ComputerA, or to another device connected to the switch. Switches **always learn from the source MAC address in a frame.**

A switch is in a perpetual state of learning. However, as the MAC address table becomes populated, the flooding of frames will decrease, allowing the switch to perform more efficient forwarding decisions.

<u>Layer-2 Switching (continued)</u>

While hubs were limited to half-duplex communication, switches can operate in **full-duplex.** *Each individual port* on a switch belongs to its *own collision domain*. Thus, switches create **more collision domains**, which results in **fewer collisions.**

Like hubs though, switches belong to only *one* **broadcast domain.** A Layer-2 switch will forward both broadcasts and multicasts out *every* port but the originating port. Only Layer-3 devices separate broadcast domains.

Because of this, Layer-2 switches are poorly suited for large, scalable networks. The Layer-2 header provides no mechanism to differentiate one *network* from another, only one *host* from another.

This poses *significant* difficulties. If *only* hardware addressing existed, all devices would technically be on the *same* network. Modern internetworks like the Internet could not exist, as it would be impossible to separate *my* network from *your* network.

Imagine if the entire Internet existed purely as a Layer-2 switched environment. Switches, as a rule, will forward a broadcast out *every* port. Even with a conservative estimate of a billion devices on the Internet, the resulting broadcast storms would be devastating. The Internet would simply collapse.

Both hubs and switches are susceptible to **switching loops**, which result in destructive broadcast storms. Switches utilize the **Spanning Tree Protocol (STP)** to maintain a loop-free environment. STP is covered in great detail in another guide.

Remember, there are three things that switches do that hubs do not:
- **Hardware address learning**
- **Intelligent forwarding of frames**
- **Loop avoidance**

Hubs are almost entirely deprecated – there is no advantage to using a hub over a switch. At one time, switches were more expensive and introduced more latency (due to processing overhead) than hubs, but this is no longer the case.

Layer-2 Forwarding Methods

Switches support three **methods** of forwarding frames. Each method copies all or part of the frame into memory, providing different levels of latency and reliability. **Latency** is *delay* - less latency results in quicker forwarding.

The **Store-and-Forward** method copies the *entire* frame into memory, and performs a Cycle Redundancy Check (CRC) to completely ensure the integrity of the frame. However, this level of error-checking introduces the highest latency of any of the switching methods.

The **Cut-Through (Real Time)** method copies only enough of a frame's header to determine its destination address. This is generally the *first 6 bytes* following the preamble. This method allows frames to be transferred at *wire speed*, and has the least latency of any of the three methods. No error checking is attempted when using the cut-through method.

The **Fragment-Free (Modified Cut-Through)** method copies only the *first 64 bytes* of a frame for error-checking purposes. Most collisions or corruption occur in the first 64 bytes of a frame. Fragment-Free represents a compromise between reliability (store-and-forward) and speed (cut-through).

Layer-3 Routing

Layer-3 **routing** is the process of forwarding a packet from one *network* to another *network*, based on the Network-layer header. Routers build **routing tables** to perform forwarding decisions, which contain the following:

- The destination network and subnet mask
- The **next hop** router to get to the destination network
- Routing *metrics* and Administrative Distance

Note that Layer-3 forwarding is based on the destination *network*, and not the destination *host*. It is possible to have *host routes*, but this is less common.

The routing table is concerned with two types of Layer-3 protocols:

- **Routed protocols** - assigns logical addressing to devices, and routes packets between networks. Examples include IP and IPX.
- **Routing protocols** - dynamically builds the information in routing tables. Examples include RIP, EIGRP, and OSPF.

Each individual interface on a router belongs to its *own collision domain*. Thus, like switches, routers create **more collision domains**, which results in **fewer collisions.**

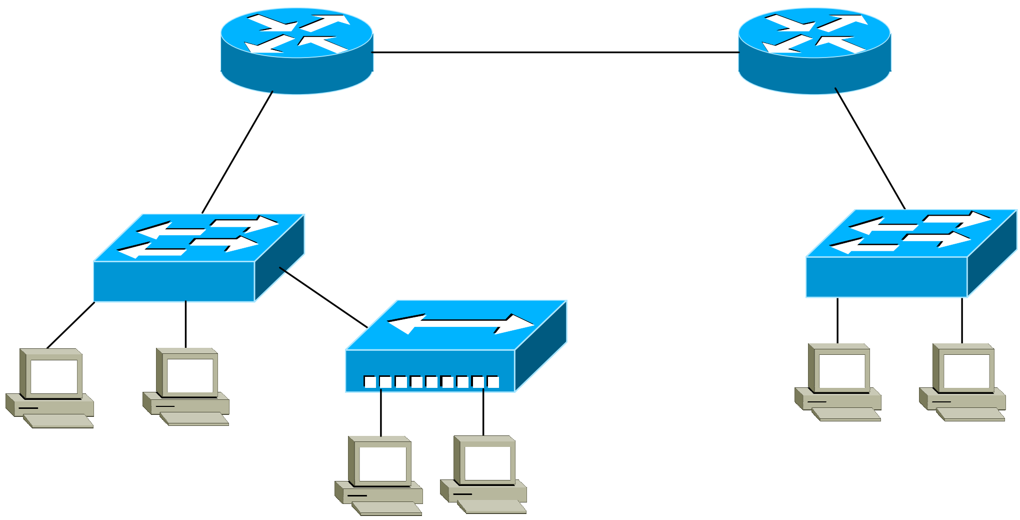
Unlike Layer-2 switches, Layer-3 routers also **separate broadcast domains**. As a rule, a router **will never forward broadcasts** from one network to another network (unless, of course, you explicitly configure it to). ☺

Routers will not forward multicasts either, unless configured to participate in a multicast tree. Multicast is covered in great detail in another guide.

Traditionally, a router was required to copy each individual packet to its buffers, and perform a route-table lookup. Each packet consumed CPU cycles as it was forwarded by the router, resulting in latency. Thus, routing was generally considered **slower** than switching.

It is now possible for routers to *cache* network-layer flows in hardware, greatly reducing latency. This has blurred the line between *routing* and *switching,* from both a technological and marketing standpoint. Caching network flows is covered in greater detail shortly.

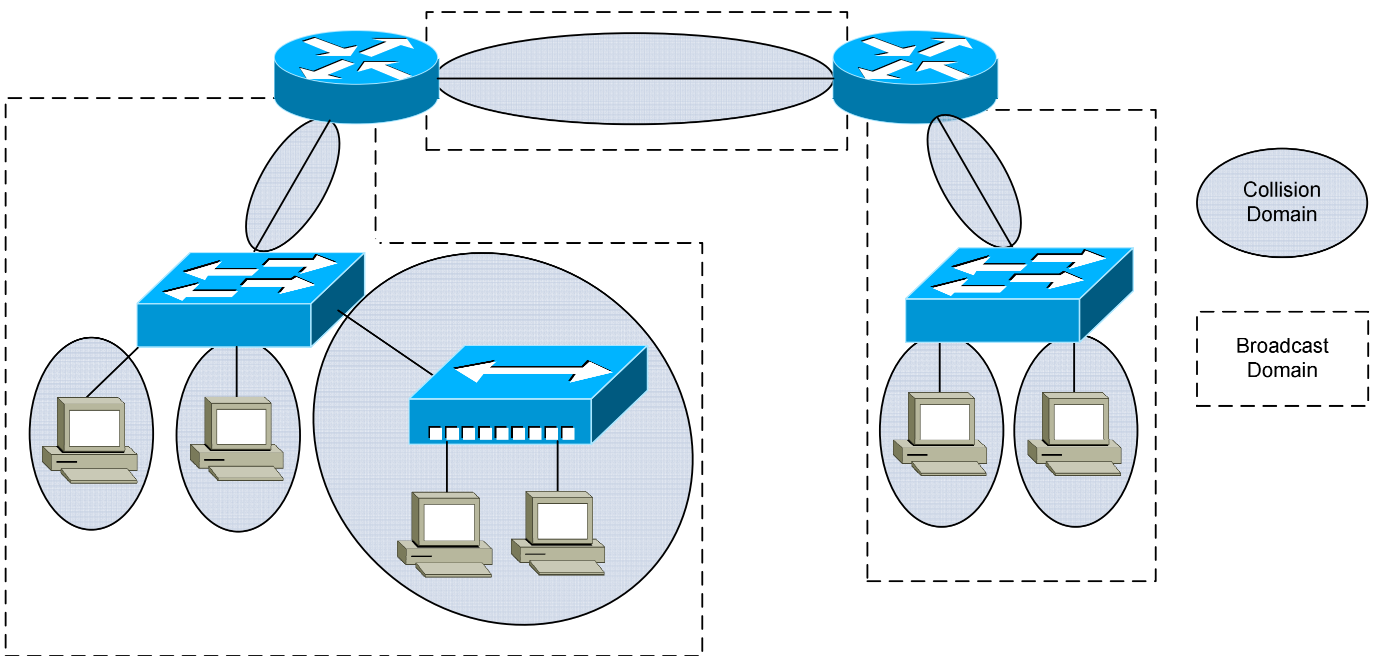
Collision vs. Broadcast Domain Example



Consider the above diagram. Remember that:

- Routers separate *broadcast* and *collision* domains.
- Switches separate *collision* domains.
- Hubs belong to only one *collision* domain.
- Switches and hubs both only belong to one *broadcast* domain.

In the above example, there are **THREE** broadcast domains, and **EIGHT** collision domains:



VLANs – A Layer-2 or Layer-3 Function?

By default, a switch will forward both broadcasts and multicasts out *every* port but the originating port.

However, a switch can be logically segmented into multiple broadcast domains**,** using **Virtual LANs** (or **VLANs**). VLANs are covered in extensive detail in another guide.

Each VLAN represents a unique broadcast domain:
- Traffic between devices within the *same* VLAN is switched (forwarded at Layer-2).
- Traffic between devices in *different* VLANs requires a Layer-3 device to communicate.

Broadcasts from one VLAN will not be forwarded to another VLAN. The logical separation provided by VLANs is **not a Layer-3 function.** VLAN tags are inserted into the **Layer-2 header**.

Thus, a switch that supports VLANs is not necessarily a Layer-3 switch. However, a purely Layer-2 switch cannot route between VLANs.

Remember, though VLANs provide separation for *Layer-3* broadcast domains, they are still a *Layer-2* function. A VLAN often has a one-to-one relationship with an IP subnet, though this is not a requirement.

Layer-3 Switching

In addition to performing Layer-2 switching functions, a **Layer-3 switch** must also meet the following criteria:

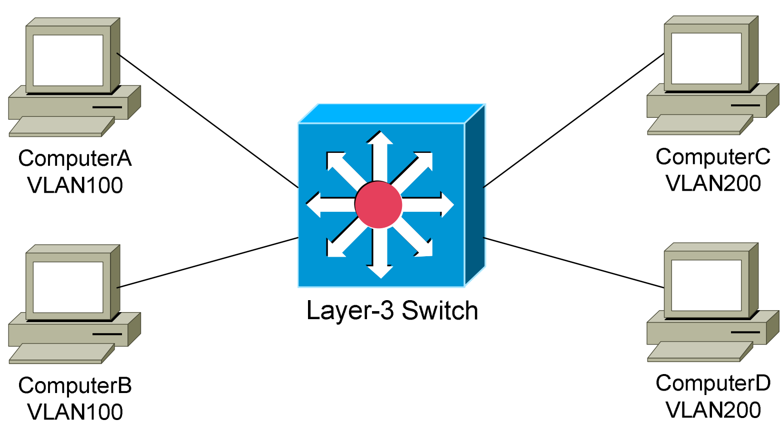
- The switch must be capable of making Layer-3 forwarding decisions (traditionally referred to as routing).
- The switch must cache network traffic flows, so that Layer-3 forwarding can occur in hardware.

Many older modular switches support Layer-3 route processors – this alone does not qualify as Layer-3 switching. Layer-2 and Layer-3 processors can act independently within a single switch chassis, with each packet requiring a route-table lookup on the route processor.

Layer-3 switches leverage ASICs to perform Layer-3 forwarding in hardware. For the first packet of a particular traffic flow, the Layer-3 switch will perform a standard route-table lookup. This flow is then *cached* in hardware – which preserves required routing information, such as the destination network and the MAC address of the corresponding next-hop.

Subsequent packets of that flow will bypass the route-table lookup, and will be forwarded based on the cached information, reducing latency. This concept is known as *route once, switch many.*

Layer-3 switches are predominantly used to route between VLANs:



Traffic between devices within the same VLAN, such as ComputerA and ComputerB, is *switched* at Layer-2 as normal. The first packet between devices in different VLANs, such as ComputerA and ComputerD, is *routed*. The switch will then cache that IP traffic flow, and subsequent packets in that flow will be *switched* in hardware.

Layer-3 Switching vs. Routing – End the Confusion!

The evolution of network technologies has led to considerable confusion over the terms *switch* and *router*. Remember the following:

- The traditional definition of a *switch* is a device that performs Layer-2 forwarding decisions.
- The traditional definition of a *router* is a device that performs Layer-3 forwarding decisions.

Remember also that, switching functions were typically performed in *hardware,* and routing functions were typically performed in *software*. This resulted in a widespread perception that switching was *fast,* and routing was *slow* (and *expensive*).

Once Layer-3 forwarding became available in hardware, marketing gurus muddied the waters by distancing themselves from the term *router*. Though Layer-3 forwarding in hardware is still *routing* in every technical sense, such devices were rebranded as Layer-3 switches.

Ignore the marketing noise. **A Layer-3 switch** is **still a router.**

Compounding matters further, most devices still currently referred to as *routers* can perform Layer-3 forwarding in hardware as well. Thus, both Layer-3 switches *and* Layer-3 routers perform nearly identical functions at the same performance.

There are some differences in *implementation* between Layer-3 switches and routers, including (but not limited to):

- Layer-3 switches are optimized for Ethernet, and are predominantly used for inter-VLAN routing. Layer-3 switches can also provide Layer-2 functionality for intra-VLAN traffic.
- Switches generally have higher port densities than routers, and are considerably cheaper per port than routers (for Ethernet, at least).
- Routers support a large number of WAN technologies, while Layer-3 switches generally do not.
- Routers generally support more advanced feature sets.

Layer-3 switches are often deployed as the backbone of LAN or campus networks. Routers are predominantly used on network perimeters, connecting to WAN environments.

(Fantastic Reference: http://blog.ioshints.info/2011/02/how-did-we-ever-get-into-this-switching.html)

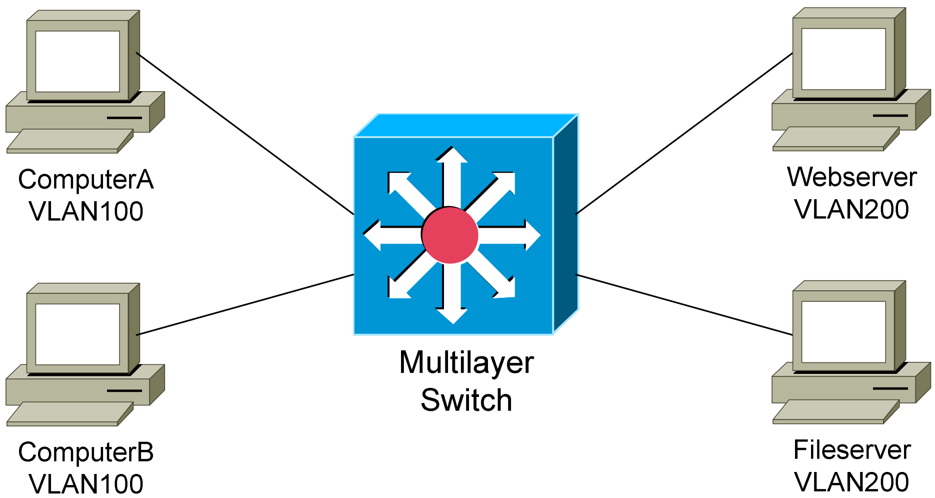
Multilayer Switching

Multilayer switching is a generic term, referring to any switch that forwards traffic at layers higher than Layer-2. Thus, a Layer-3 switch is considered a multilayer switch, as it forwards frames at Layer-2 and packets at Layer-3.

A **Layer-4 switch** provides the same functionality as a Layer-3 switch, but will additionally examine and cache **Transport-layer application flow** information, such as the TCP or UDP port.

By caching application flows, **QoS (Quality of Service)** functions can be applied to preferred applications.

Consider the following example:



Network and application traffic flows from ComputerA to the Webserver and Fileserver will be cached. If the traffic to the Webserver is preferred, then a higher QoS priority can be assigned to that application flow.

Some advanced multilayer switches can provide load balancing, content management, and other application-level services. These switches are sometimes referred to as **Layer-7 switches.**