Destination	Next Hop
(1, anything)	interface 1
(3, anything)	interface 4
(2, anything)	local computer

Figure 16.2

ROUTING IN A WAN:

As there will be more computers there will be more traffic of information. We can add capacity to WAN by adding more links and packet switches. Packet switches need not have computers attached. There are two types of switch according to the attached computers.

INTERIOR SWICH:

The switch that has no attached computers is called an interior switch.

EXTERIOR SWITCH:

The switch that has computers attached with it is called exterior switch.
Both interior and exterior switches forward packets and they also need routing tables. The routing table must have two things.

UNIVERSAL ROUTING:

It should have next hop for each possible destination.

OPTIMAL ROUTES:

The next hop in table must be on shortest path to destination.

MODELING A WAN:

To model a WAN, we use a graph in which the nodes model switches and the edges model direct connection between switches. The modeling captures essence of network and it ignores attached computers as shown in the figure below. Modeling of a specific WAN is shown.

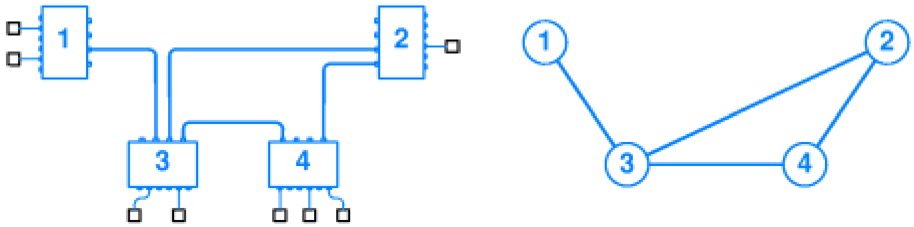

Figure 16.3

ROUTE COMPUTATION WITH A GRAPH:

We can represent routing table with edges as shown in the figure below:

destin-ation	next hop
1	-
2	(1,3)
3	(1,3)
4	(1,3)

node 1

destin-ation	next hop
1	(2,3)
2	-
3	(2,3)
4	(2,4)

node 2

destin-ation	next hop
1	(3,1)
2	(3,2)
3	-
4	(3,4)

node 3

destin-ation	next hop
1	(4,3)
2	(4,2)
3	(4,3)
4	-

node 4

Figure 16.4

The graph algorithms can be applied to find routes.

REDUNDANT ROUTING INFORMATION:

Notice duplication of information in routing table for node 1 as shown above in the figure. We see that switch has only outgoing connection, all traffic must traverse that connection.

DEFAULT ROUTES:

Routing table entries can be collapsed with a default route. If the destination does not have in explicit routing table entry, then it use a default route. Default routes for 4 nodes are shown in the figure below.

destin-ation	next hop
1	-
*	(1,3)

node 1

destin-ation	next hop
2	-
4	(2,4)
*	(2,3)

node 2

destin-ation	next hop
1	(3,1)
2	(3,2)
3	-
4	(3,4)

node 3

destin-ation	next hop
2	(4,2)
4	-
*	(4,3)

node 4

Figure 16.5

Lecture No. 17

ROUTING ALGORITHMS

BUILDING ROUTING TABLES:

There are basically two methods for building routing tables, which are as follows:

- Manual entry
- Software

Further there are two methods for computing routing table information.

- Static routing
- Dynamic routing

STATIC ROUTING:

It is done at boot time. It is simple and has low network overhead. It is inflexible.

DYNAMIC ROUTING:

It allows automatic updates by a programmer. It can work around network failures automatically.

COMPUTING SHORTEST PATH IN A GRAPH:

While computing shortest path, first we assume graph representation of network at each node then we use Djikstra's algorithm to compute shortest path from each node to every other node. Then extract next hop information from resulting path information and insert next hop information into routing tables.

WEIGHTED GRAPH:

Djikstra's algorithm can accommodate weights on edges in graph. The shortest path is then the path with lowest total weight (sum of the weight with all edges). It should be noted that the shortest path is not necessarily with fewest edges (or hops). For example as shown in the figure below:

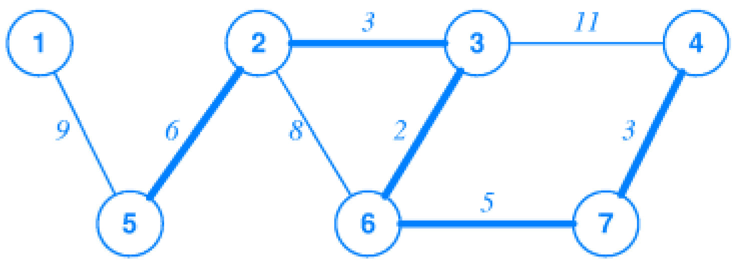

Figure 17.1

The shortest path in the figure from node 2 to node 6 is 2 to 3 and 3 to 6 as this path has the smallest weight so it is the shortest path.

DISTANCE MATRICS:

Weights on graph edges reflect cost of traversing edge. This cost may be in time, dollars or hop counting (weight == 1). The resulting shortest path may not have fewest hops.

DISTRIBUTED ROUTE COMPUTATION:

Each packet switch computes its routing table locally and sends messages to the neighbors. It also updates information periodically. If a link or a packet switch fails then the network adapts its failure. The packet switch then modifies the tables to avoid failed hardware.

DISTANCE-VECTOR ROUTING:

Local information is next hop routing table and distance from each switch. The switches periodically broadcast topology information i.e. destination, distance.

Other switches update routing table based on received information.

VECTOR-DISTANCE ALGORITHM:

It is explained in more detail below:

Packet switches wait for next update message and they iterate through entries in message. If entry has shortest path to destination, insert source as next hop to destination and record distance as distance from next hop to destination plus distance from this switch to next hop.

LINK-STATE ROUTING:

In link-state routing network topology is separated from route computation. Switches send link-state information about local connections. Each switch builds own routing tables. It uses link-state information to update global topology and runs Djikstra's algorithm.

COMPARISON:

DISTANCE-VECTOR ROUTING:

- It is very simple to implement.
- Packet switch updates its own routing table first.
- It is used in RIP.

LINK-STATE ALGORITHM:

- It is much more complex.
- Switches perform independent computations.
- It is used in OSPF.

EXAMPLE WAN TECHNOLOGIES:

Some multiple WAN technologies are discussed below.

ARPANET:

It began in 1960's. It was funded by Advanced Research Project Agency, which is an organization of US defense department. It was incubator for many of current ideas, algorithms and Internet technologies.

X.25:

It was early standard for connection-oriented networking. It began from IFU, which was originally CCITT. It predates computer connections, which are used for terminal/time sharing connection.

FRAME RELAY:

It is used for Telco service for delivering blocks of data. It is connection based service and must contract with Telco for circuit between two endpoints. It is typically 56kbps or 1.5Mbps and can run to 100Mbps.

SMDS:

Switched Multi megabit Data Service (SMDS) is also a Telco service. It is a connection less service. Any SMDS station can send information to any station on the same SMDS cloud. It is typically ranges from 1.5Mbps to 1000Mbps.

ATM (ASYNCHRONOUS TRANSFER MODE):

It was designed as a single technology for voice, video and data and has low jitter (variance in delivery time) and high capacity.

It uses fixed size, small cells, 48 octet's data and 5 octets header. It can also connect multiple ATM switches into a network.

Lecture No. 18

CONNECTION-ORIENTED NETWORKING AND ATM

LANs and WANs can both connect multiple computers, but they have different base technologies and meet different goals. ATM is a single technology that is designed to meet the goals of both LANs and WANs.
ATM uses the concept of connection-oriented networking.

ASYNCHRONOUS TRANSFER MODE (ATM):

Telephone companies (Telco's) introduced ATM to meet several goals. It provides universal service for all subscribers and support for all users for voice, video and data. It has a single unified infrastructure (no separate LANs and WANs). It gives guaranteed service when it is appropriate and support for low cost devices.

JITTER:

Jitter is the term used for variance in transmission delays.
Jitter is significance for voice, video and data. In LANs, jitter can occur when a packet is delayed because the network is busy.

PACKET SIZES:

Large packets result in fewer overheads because a smaller fraction of the packet is used for header information.
Optimum networks use 4kB packets or larger.

Large packets can't easily be used for voice for example 8-bit samples (at 125usec per sample) would require half a second to fill a 4kB packet. Echo cancellation can only be used with low transmission delays.

ATM CELLS:

To meet its goals, ATM uses small, fixed sized packets called cells. Each cell has 53 octets. VPI/VCI fields identify the cells destination.

PRIO tell if cell can be discarded CRC checks the header bits only. ATM header is about the 10% of the cell. Ethernet can have overhead of only 1%. Engineers sometimes call the ATM overhead the cell tax. An ATM is shown below.

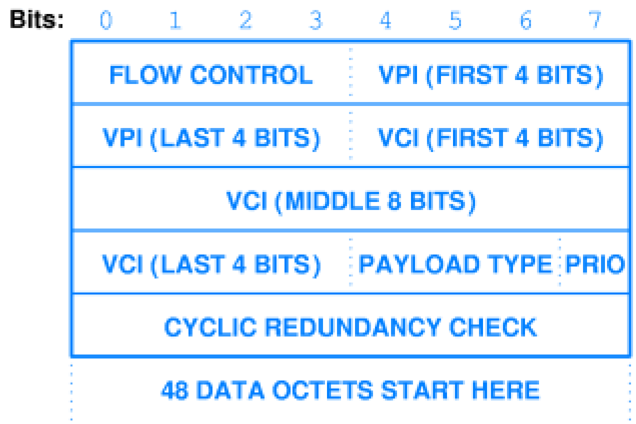

Figure.18.1

CONNECTION-ORIENTED SERVICE:

The connection-oriented service paradigm for networking is similar to the manner in which telephones are used. This is given as follows:

A caller dials a number of the destination. The telephone at the destination signals the arrival of a connection request. If the called person does not answer; the caller gives up after waiting for a timeout. If the called person does answer, then the connection is established.

In data communication, as binary connection identifier is given to each of the two parties to enable identification of the connection.

VIRTUAL CHANNEL (OR CIRCUITS):

Connections in ATM are called virtual channels (VC) or virtual circuits (a term preferred by some). These are called virtual, since connections are formed in ATM by starting values in memory locations (tables) in ATM switches as opposed to making actual electrical connections.

The VC is identified by a 24-bit value formed from the VPI or Virtual Path Indicator (8-bit), which identifies a particular path through the network and the VCI or Virtual Channel Indicator (16-bits), which identifies the channel in the virtual path being used by the connection.

Most frequently, the 24-bit pair is treated as just a single connection identifier by computers.

Lecture No. 19

ATM: VIRTUAL CIRCUITS

LABELS AND LABEL SWITCHING:

An ATM network is built from interconnected ATM switches. The attachment points or ports can be connected to computers or other ATM switches. As cells arrive at an ATM switch, their VPI/VCI is modified using a forwarding table that gives the new VPI/VCI for the next leg of the cell's trip.

The forwarding table is essentially indexed by the incoming cell's VPI/VCI and the contents yield the new VPI/VCI.

LABEL REWRITING:

The replacement of the incoming cell's VPI/VCI with a probably different VPI/VCI is called rewriting.

ATM is thus called a label rewriting or label switching system. Thus two computers with a connection through an ATM network will likely have different VPI/VCI values for each end of the connection as shown in the figure below.

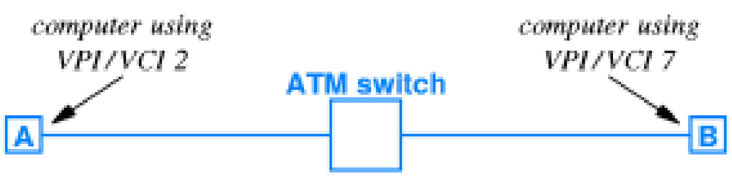

Figure 19.1

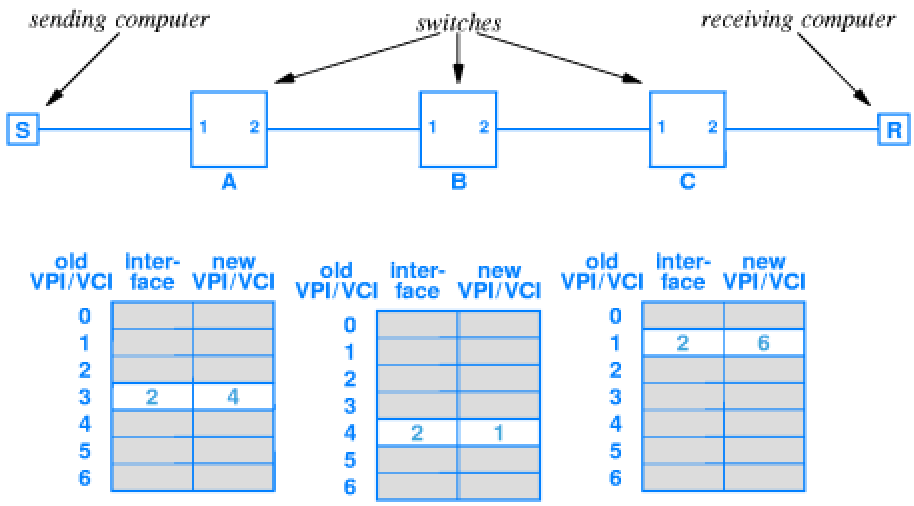

Figure 19.2

EXAMPLE:

As an example, in the figure we see that the sending computer S uses a VPI/VCI of 3 and sends a cell.

Switch A receives the cell and looks up 3, then rewrites the VPI/VCI as 4, and sends the cell out of its port 2.

Switch B receives the cell and looks up 4 then rewrites the VPI/VCI as 1 and sends the cell at its port 2.

Switch C receives the cell and looks up 1 then rewrites the VPI/VCI as 6 and sends the cell out of its port 2.

The receiving computer R receives the cell with a VPI/VCI of 6, which is the value it is using for the connection. Forwarding tables in each switch must be coordinated to define meaningful 'paths' through the network.

PERMANENT VIRTUAL CIRCUITS:

ATM can provide customers with virtual circuits that look like traditional leased digital circuits. Such permanent virtual circuits (PVC) last as long as the customer pay the periodic fee for its use. The forwarding tables are automatically restored after power of equipment failure. The forwarding table entries for such permanent VC's are statically configured, the terms used by Telco's for this is provisioning.

Provisioning requires two steps:

1. To determine a complete path (that is, identify the switches that will be used).
2. To choose appropriate VPI/VCI for each step in the path, and configure each adjacent pair of switches (easy, since each switch rewrites the VCI/VPI).