Network Layer

Module 3

Network Layer

- Network layer provides host-to-host communication service.
- Unlike the transport and application layers, there is a piece of the network layer in each and every host and router in the network.
- Two important functions of the network layer are f**orwarding** and **routing.**
- Forwarding involves the transfer of a packet from an incoming link to an outgoing link within a *single* router.
- Routing involves *all* of a network's routers, whose collective interactions via routing protocols determine the paths that packets take on their trips from source to destination node.

Network Layer

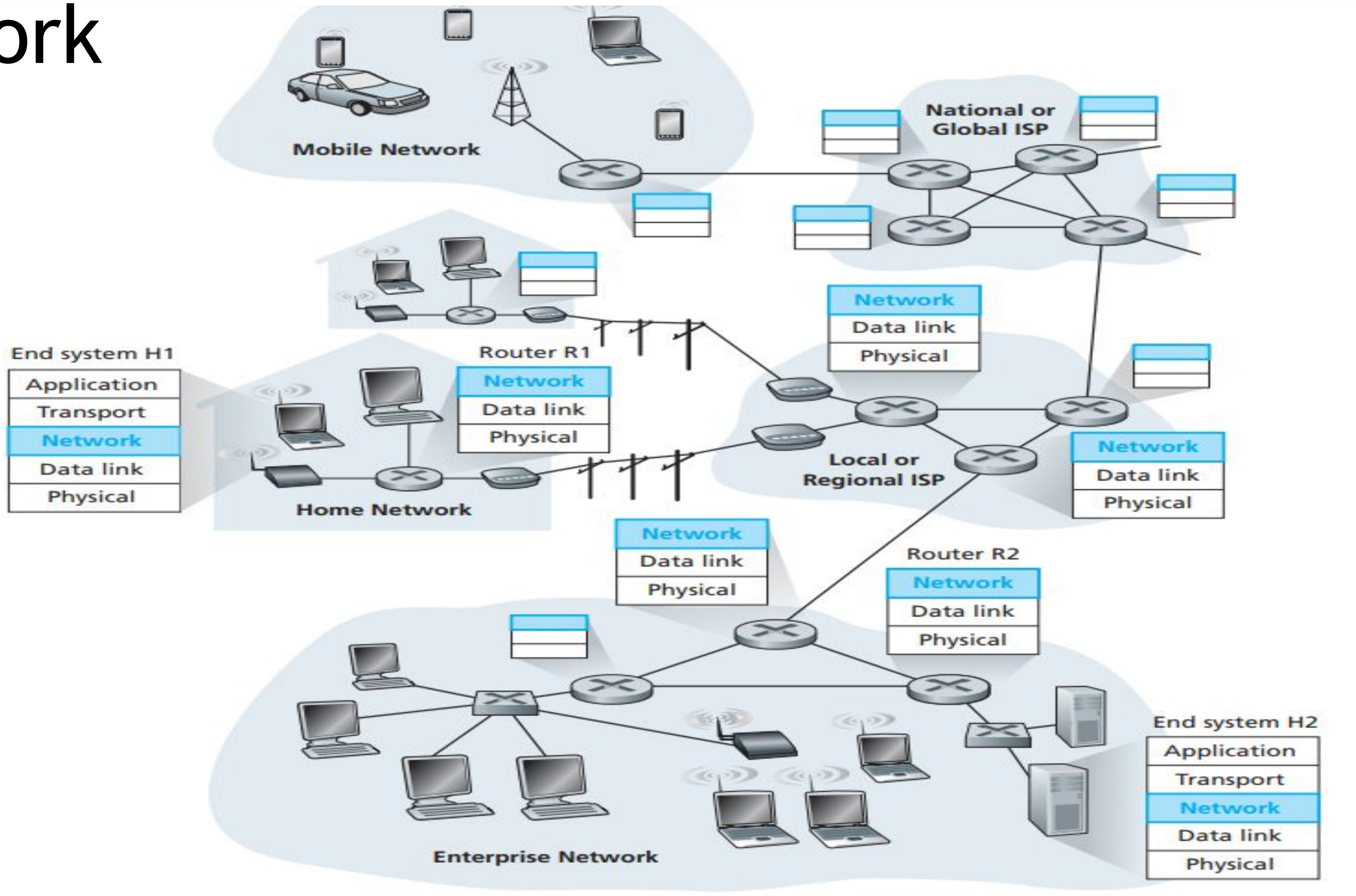


Figure 4.1 ◆ The network layer

Network Layer

- Figure shows a simple network with two hosts, H1 and H2, and several routers on the path between H1 and H2.
- Suppose that H1 is sending information to H2.
- The network layer in H1 takes segments from the transport layer in H1, encapsulates each segment into a datagram (that is, a network-layer packet), and then sends the datagrams to its nearby router, R1.
- At the receiving host, H2, the network layer receives the datagrams from its nearby router R2, extracts the transport-layer segments, and delivers the segments up to the transport layer at H2.
- **The primary role of the routers is to forward datagrams from input links to output links.**
- The routers are shown with a truncated protocol stack, that is, with no upper layers above the network layer, because (except for control purposes) routers do not run application- and transport-layer protocols.

Network Layer Functions : Forwarding and Routing

- The role of the network layer is to move packets from a sending host to a receiving host.
- To do so, ***two important network-layer functions can be identified:***
- *Forwarding:* When a packet arrives at a router's input link, the router must move the packet to the appropriate output link. For example, a packet arriving from Host H1 to Router R1 must be forwarded to the next router on a path to H2.
- *Routing* : The network layer must determine the route or path taken by packets as they flow from a sender to a receiver.
- The algorithms that calculate these paths are referred to as **routing algorithms**.
- A **routing algorithm** would determine, for example, the path along which packets flow from H1 to H2.

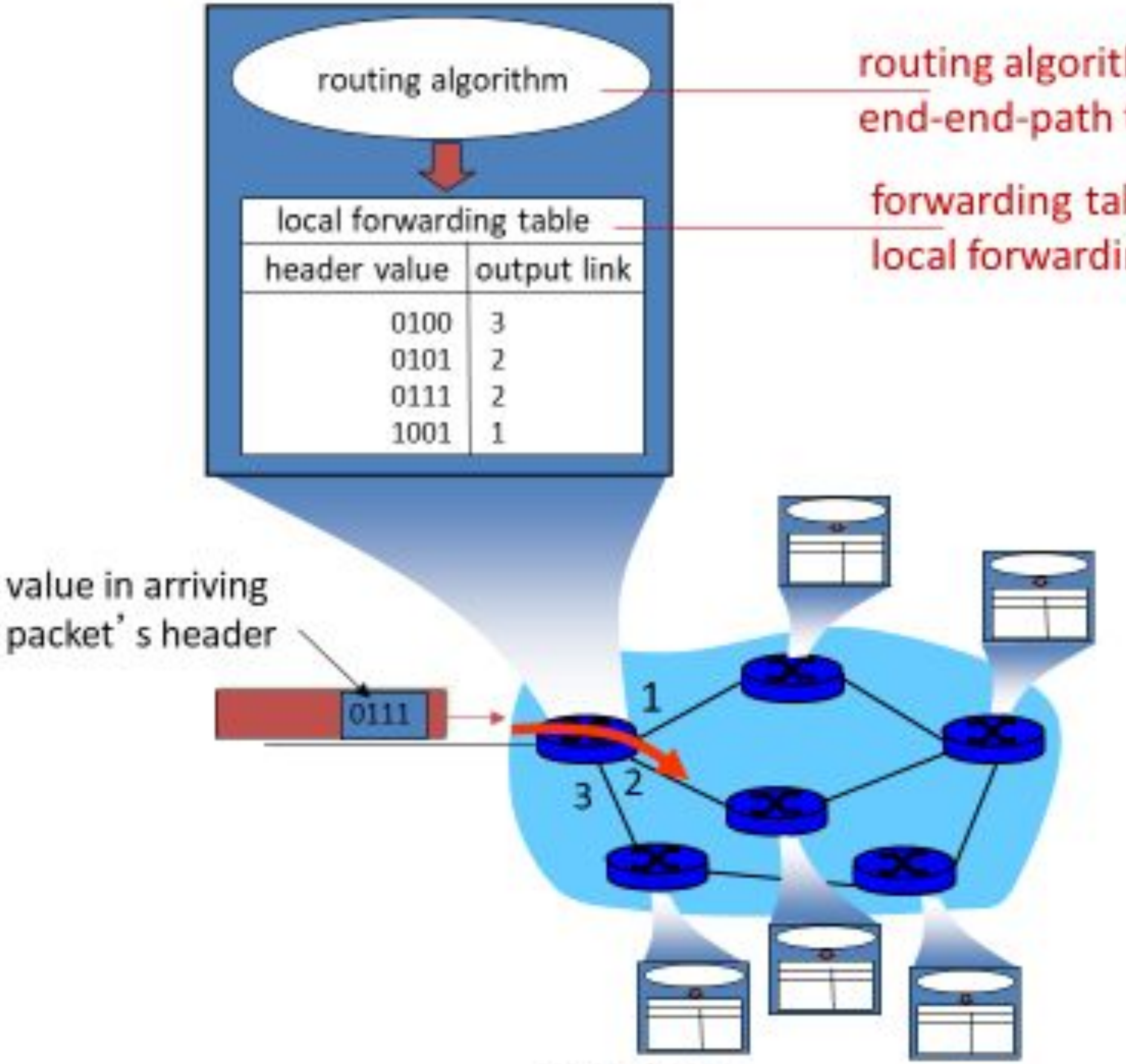
Forwarding and Routing

- **Forwarding** involves the transfer of a packet from an incoming link to an outgoing link within a *single router.*
- When a packet arrives at a router's input link, the router must move the packet to the appropriate output link.

- **Routing** *involves all of a network's routers, whose collective interactions via routing protocols* determine the paths that packets take on their trips from source to destination node.
- The network layer must determine the route or path taken by packets as they flow from a sender to a receiver.
- The algorithms that calculate these paths are referred to as routing algorithms.

Forwarding and Routing

- Every router has a **forwarding table**.
- A router forwards a packet by examining the value of a field in the arriving packet's header, and then using this header value to index into the router's forwarding table.
- The value stored in the forwarding table entry for that header indicates the router's outgoing link interface to which that packet is to be forwarded.
- Depending on the network-layer protocol, the header value could be the destination address of the packet or an indication of the connection to which the packet belongs.



routing algorithm determines end-end-path through network

forwarding table determines local forwarding at this router

- A packet with a header field value of 0111 arrives to a router.
- The router indexes into its forwarding table and determines that the output link interface for this packet is interface 2.
- The router then internally forwards the packet to interface 2.
- The routing algorithm determines the values that are inserted into the routers' forwarding tables.
- The routing algorithm may be centralized (e.g., with an algorithm executing on a central site and downloading routing information to each of the routers) or decentralized (i.e., with a piece of the distributed routing algorithm running in each router).
- In either case, a router receives routing protocol messages, which are used to configure its forwarding table.

Network Layer Function : Connection setup

- 3rd important function in *some* network architectures:
  - ATM, frame relay, X.25
- Before datagrams flow, two end hosts *and* intervening routers establish virtual connection
  - routers get involved
- network vs transport layer connection service:
  - *network:* between two hosts (may also involve intervening routers in case of VCs)
  - *transport:* between two processes

Network Service Models

The **network service model** defines the characteristics of end-to-end transport of packets between sending and receiving end systems.

- *Guaranteed delivery.* This service guarantees that the packet will eventually arrive at its destination.
- *Guaranteed delivery with bounded delay*. This service not only guarantees delivery of the packet, but delivery within a specified host-to-host delay bound (for example, within 100 msec).
- *In-order packet delivery.* This service guarantees that packets arrive at the destination in the order that they were sent.

Network Service Models

- *Guaranteed minimal bandwidth* As long as the sending host transmits bits (as part of packets) at a rate below the specified bit rate, then no packet is lost and each packet arrives within a prespecified host-to- host delay (for example, within 40 msec).

- *Guaranteed maximum jitter*. This service guarantees that the amount of time between the transmission of two successive packets at the sender is equal to the amount of time between their receipt at the destination.

- *Security services*. Using a secret session key known only by a source and destination host, the network layer in the source host could encrypt the payloads of all datagrams being sent to the destination host.

Network Architecture	Service Model	Bandwidth Guarantee	No-Loss Guarantee	Ordering	Timing	Congestion Indication
Internet	Best Effort	None	None	Any order possible	Not maintained	None
ATM	CBR	Guaranteed constant rate	Yes	In order	Maintained	Congestion will not occur
ATM	ABR	Guaranteed minimum	None	In order	Not maintained	Congestion indication provided

Table 4.1 ♦ Internet, ATM CBR, and ATM ABR service models

Virtual Circuit and Datagram Networks

- A transport layer can offer applications connectionless service or connection-oriented service between two processes.
- For example, the Internet's transport layer provides each application a choice between two services: UDP, a connectionless service; or TCP, a connection-oriented service.
- In a similar manner, a network layer can provide connectionless service or connection service between two hosts.
- Network-layer connection and connectionless services in many ways parallel transport-layer connection-oriented and connectionless services.
- For example, a network-layer connection service begins with handshaking between the source and destination hosts; and a network-layer connectionless service does not have any handshaking preliminaries

Virtual Circuit and Datagram Networks

- Although the network-layer connection and connectionless services have some parallels with transport-layer connection-oriented and connectionless services, there are crucial differences:

1. In the network layer, these services are host-to-host services provided by the network layer for the transport layer. In the transport layer these services are process to-process services provided by the transport layer for the application layer.
2. In all major computer network architectures to date (Internet, ATM, frame relay, and so on), the network layer provides either a host-to-host connectionless service or a host-to-host connection service, but not both. **Computer networks that provide only a connection service at the network layer are called virtual-circuit (VC) networks; computer networks that provide only a connectionless service at the network layer are called datagram networks.**
3. The network-layer connection service is implemented in the routers in the network core as well as in the end systems.

Virtual Circuit and Datagram Networks

- Virtual-circuit and datagram networks are two fundamental classes of computer networks.
- They use very different information in making their forwarding decisions

Virtual circuits

- While the Internet is a datagram network, many alternative network architectures— including those of ATM and frame relay—are virtual-circuit networks and, therefore, use connections at the network layer.

- These network-layer connections are called virtual circuits (VCs).

VC implementation

- A VC consists of
  (1) a path (that is, a series of links and routers) between the source and destination hosts,
  (2) VC numbers, one number for each link along the path, and
  (3) entries in the forwarding table in each router along the path.

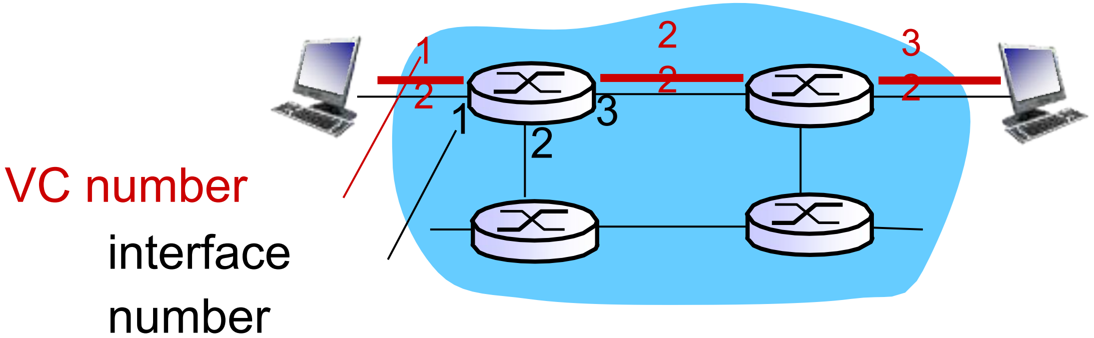
- A packet belonging to a virtual circuit will carry a VC number in its header.
- Because a virtual circuit may have a different VC number on each link, each intervening router must replace the VC number of each traversing packet with a new VC number.
- The new VC number is obtained from the forwarding table.

Virtual circuits

- Call setup,teardown for each call *before* data can flow
- Each packet carries VC identifier (not destination host address)
- *Every* router on source-destination path maintains “state” for each passing connection.
- link, router resources (bandwidth, buffers) may be *allocated* to VC (dedicated resources = predictable service)

VC forwarding table

forwarding table in router:



Incoming interface	Incoming VC #	Outgoing interface	Outgoing VC #
1	12	3	22
2	63	1	18
3	7	2	17
1	97	3	87
…	…	…	…

VC routers maintain connection state information!

Virtual circuit setup

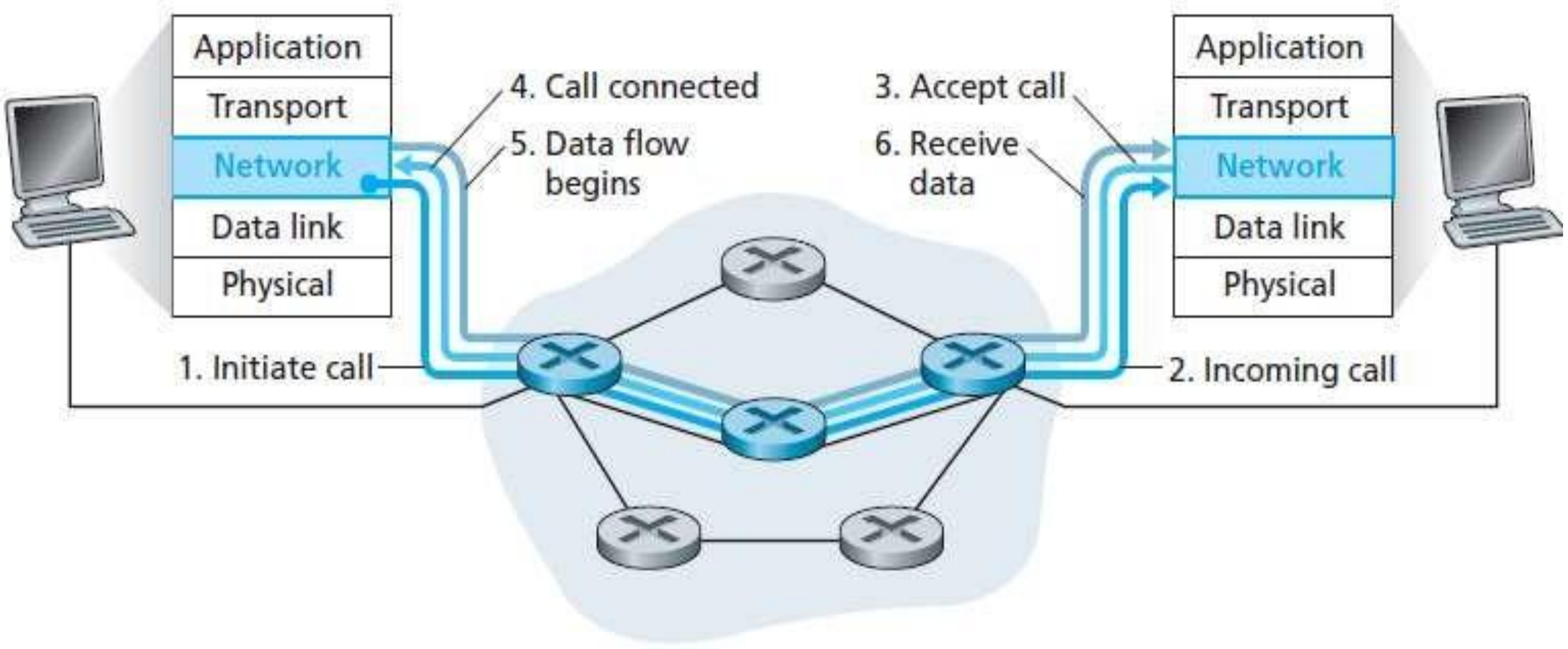


Figure 4.4 ♦ Virtual-circuit setup

Virtual circuit Phases

There are three identifiable phases in a virtual circuit:

1. *VC setup*
2. *Data transfer.*
3. *VC teardown.*

Virtual Circuit setup

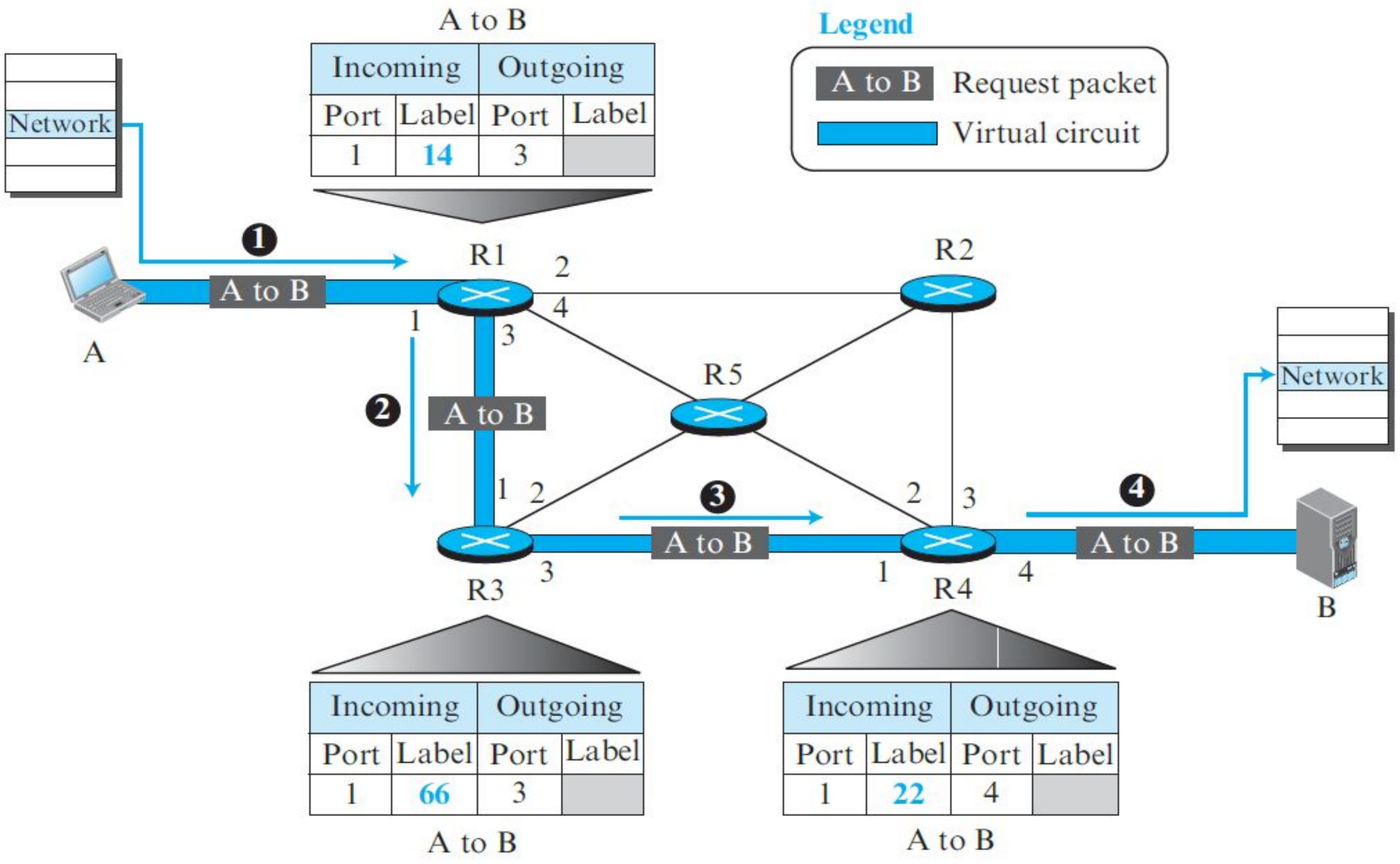
- *VC setup. During the setup phase, the sending transport layer contacts the network* layer, specifies the receiver's address, and waits for the network to set up the VC.

- The network layer determines the path between sender and receiver, that is, the series of links and routers through which all packets of the VC will travel.

- The network layer also determines the VC number for each link along the path.

- Finally, the network layer adds an entry in the forwarding table in each router

Figure 4.7 *Sending request packet in a virtual-circuit network*



Setup request in a virtual circuit

1. Source A sends a request packet to router R1.

2. Router R1 receives the request packet. It knows that a packet going from A to B goes out through port 3. For the moment, assume that it knows the output port. The router creates an entry in its table for this virtual circuit, but it is only able to fill three of the four columns. The router assigns the incoming port (1) and chooses an available incoming label (14) and the outgoing port (3). It does not yet know the outgoing label, which will be found during the acknowledgment step. The router then forwards the packet through port 3 to router R3.

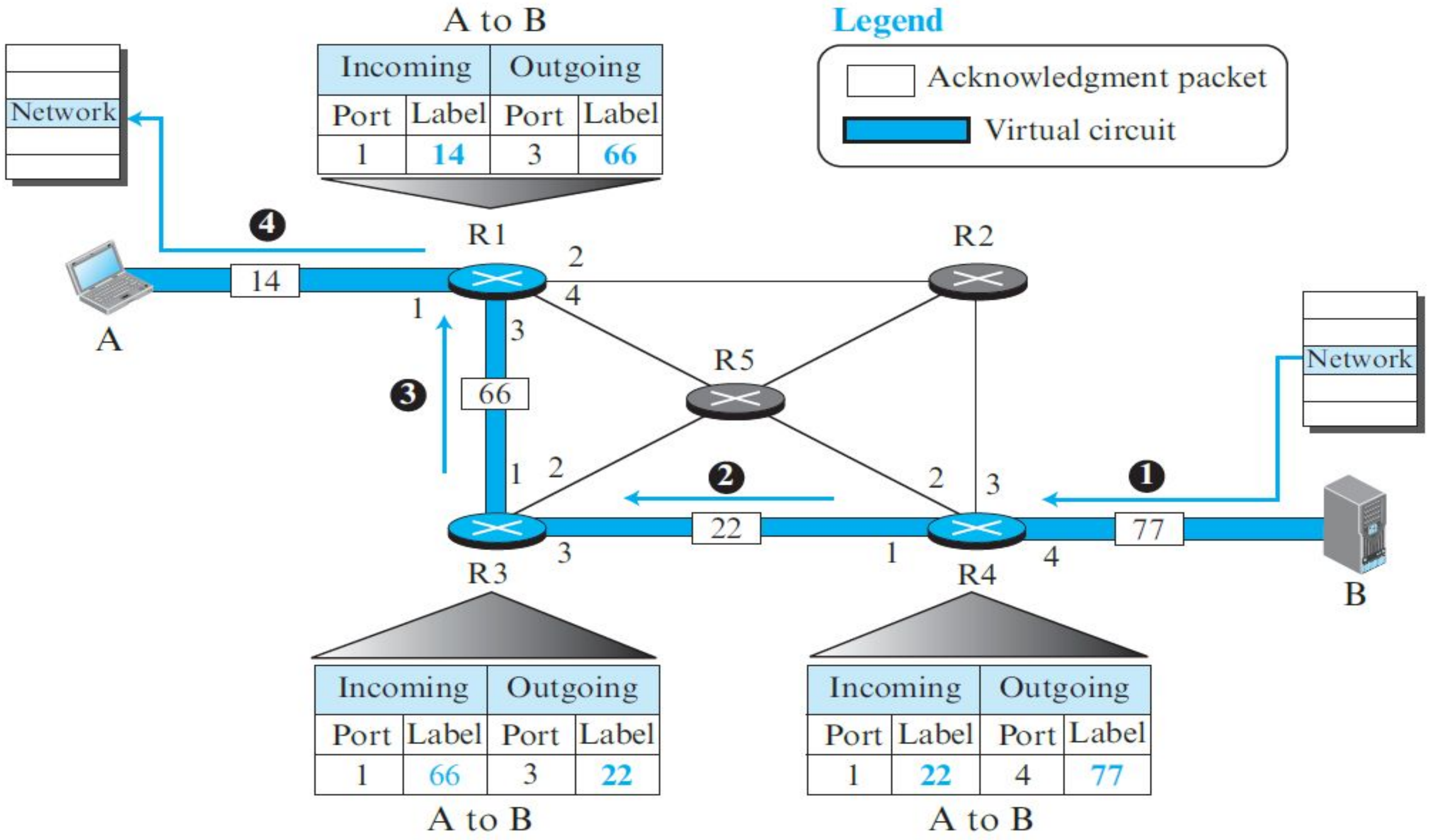
Setup request in a virtual circuit

3. Router R3 receives the setup request packet. The same events happen here as at router R1; three columns of the table are completed: in this case, incoming port (1), incoming label (66), and outgoing port (3).

4. Router R4 receives the setup request packet. Again, three columns are completed: incoming port (1), incoming label (22), and outgoing port (4).

5. Destination B receives the setup packet, and if it is ready to receive packets from A, it assigns a label to the incoming packets that come from A, in this case 77, as shown in Figure

Figure 4.8 *Sending acknowledgments in a virtual-circuit network*



Setup Acknowledgment Phase

1. The destination sends an acknowledgment to router R4. The acknowledgment carries the global source and destination addresses so the router knows which entry in the table is to be completed. The packet also carries label 77, chosen by the destination as the incoming label for packets from A. Router R4 uses this label to complete the outgoing label column for this entry. Note that 77 is the incoming label for destination B, but the outgoing label for router R4.

2. Router R4 sends an acknowledgment to router R3 that contains its incoming label in the table, chosen in the setup phase. Router R3 uses this as the outgoing label in the table.

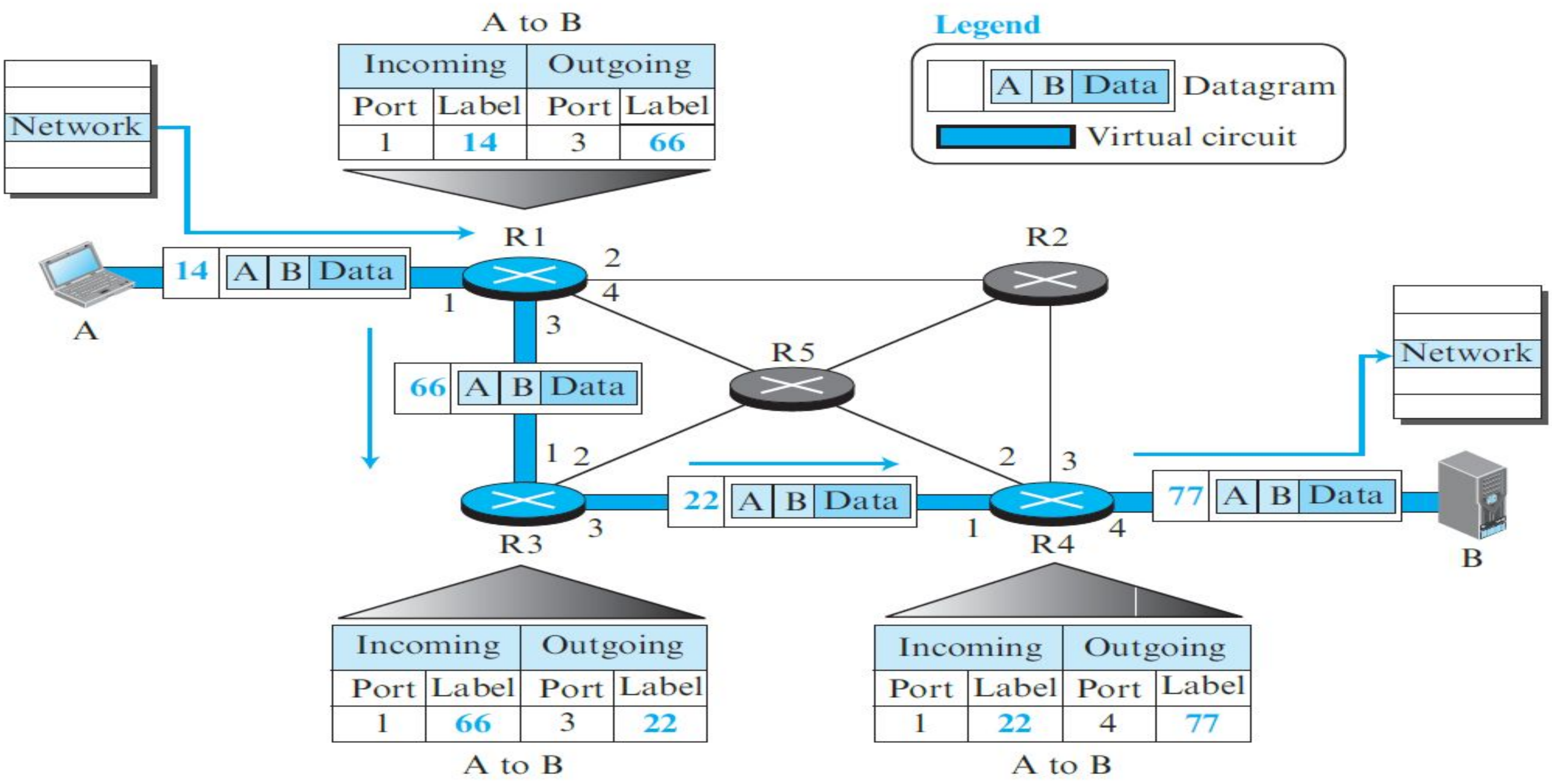
Setup Acknowledgment Phase

3. Router R3 sends an acknowledgment to router R1 that contains its incoming label in the table, chosen in the setup phase. Router R1 uses this as the outgoing label in the table.

4. Finally router R1 sends an acknowledgment to source A that contains its incoming label in the table, chosen in the setup phase.

5. The source uses this as the outgoing label for the data packets to be sent to destination B

Figure 4.9 *Flow of one packet in an established virtual circuit*



- *Data transfer. once the VC has been established, packets* can begin to flow along the VC.

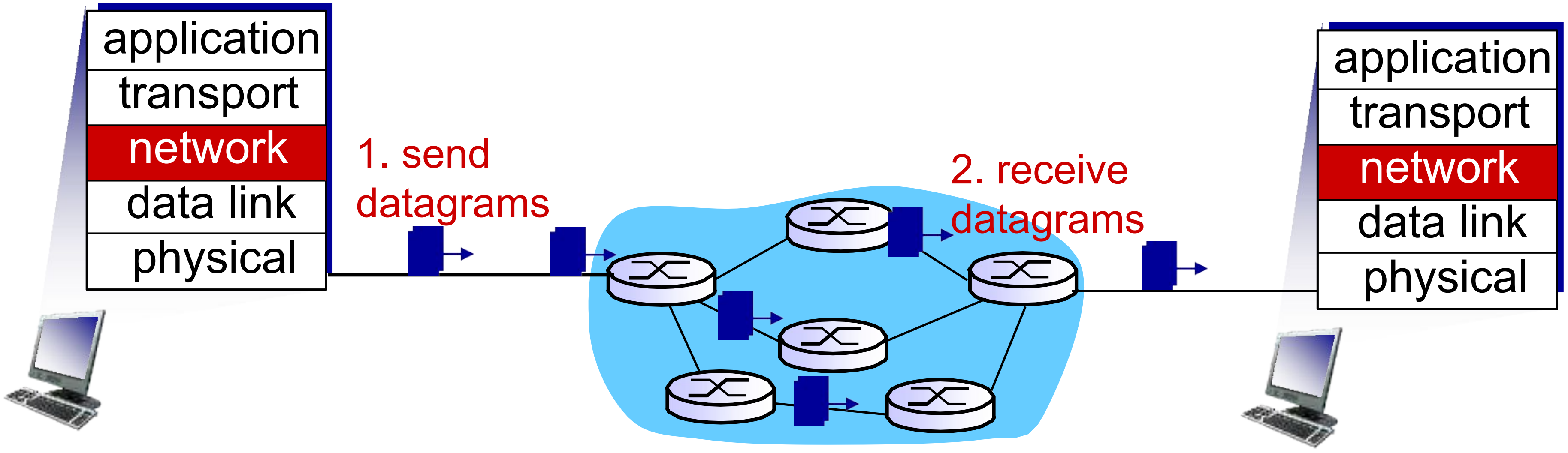
VC Teardown

- *VC teardown. This is initiated when the sender (or receiver) informs the network* layer of its desire to terminate the VC.

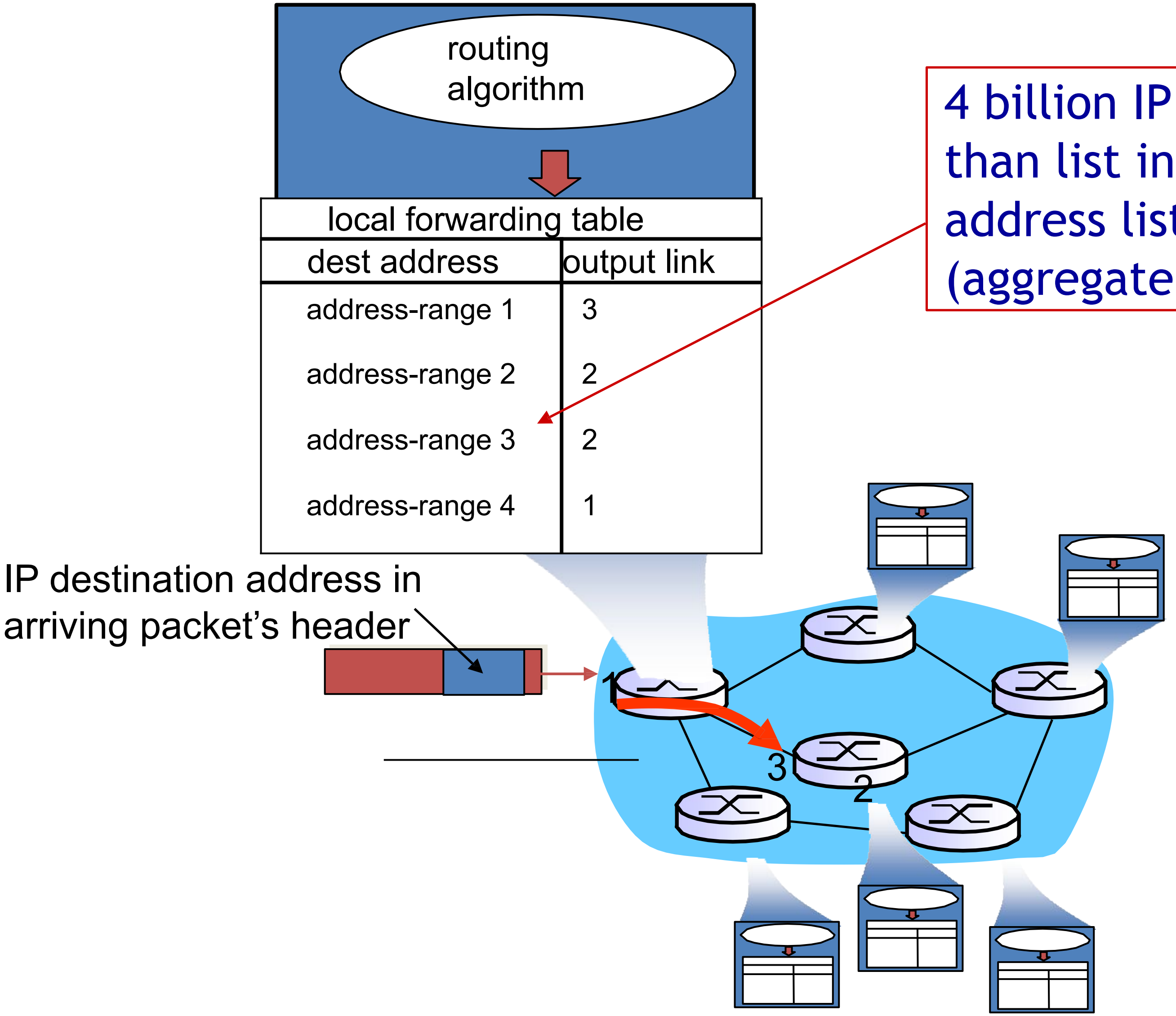
- The network layer will then typically inform the end system on the other side of the network of the call termination and update the forwarding tables in each of the packet routers on the path to indicate that the VC no longer exists.

Datagram networks

- no call setup at network layer
- routers: no state about end-to-end connections
  - no network-level concept of "connection"
- packets forwarded using destination host address



Datagram forwarding table



4 billion IP addresses, so rather than list individual destination address list *range* of addresses (aggregate table entries)

Datagram forwarding table

Destination Address Range	Link Interface
11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111	0
11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111	1
11001000 00010111 00011001 00000000 through 11001000 00010111 00011111 11111111	2
otherwise	3

Datagram forwarding table

- With this style of forwarding table, the router matches a **prefix of the packet's destination** address with the entries in the table; if there's a match, the router forwards the packet to a link associated with the match.
- For example, suppose the packet's destination address is 11001000 00010111 00010110 10100001; because the 21-bit prefix of this address matches the first entry in the table, the router forwards the packet to link interface 0.
- If a prefix doesn't match any of the first three entries, then the router forwards the packet to interface 3.

Datagram Forwarding Table

- It is possible for a destination address to match more than one entry.
- For example, the first 24 bits of the address 11001000 00010111 00011000 10101010 match the second entry in the table, and the first 21 bits of the address match the third entry in the table.
- When there are multiple matches, the router uses the **longest prefix matching rule; that** is, it finds the longest matching entry in the table and forwards the packet to the link interface associated with the longest prefix match.

Longest prefix matching

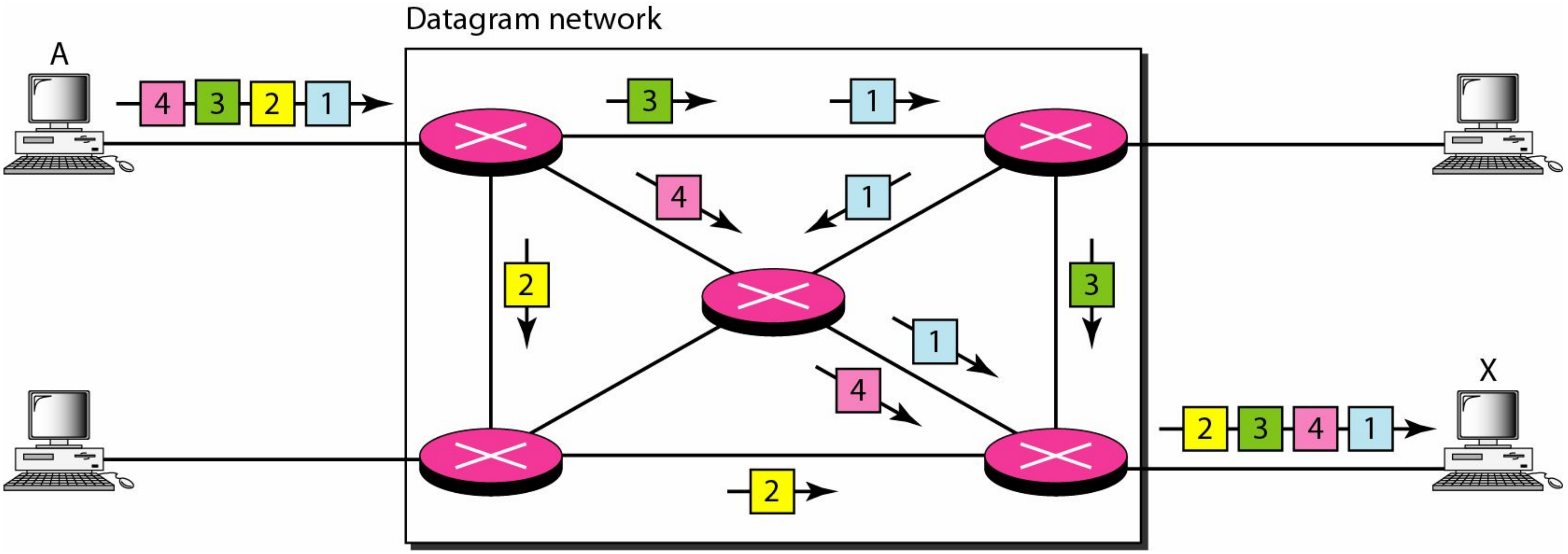
Longest Prefix Matching

when looking for forwarding table entry for given destination address, use *longest* address prefix that matches destination address.

Datagram

- Each packet treated independently of all others
- Packets can take any practical route
- Datagram switching is done at network layer
- These switches are called routers.
- Packets may arrive out of order
- Packets may go missing
- Up to receiver to re-order packets and recover from missing packets
- The connecting switches are not keeping information about connection state, hence it is also called connectionless networks
- No setup and teardown phases.

Datagram network



Router

- A router is a networking device that forwards data packets between computer networks.
- Routers perform the traffic directing functions on the Internet.
- A packet is typically forwarded from one router to another router through the networks that constitute an internetwork (e.g. the Internet) until it reaches its destination node.
- A router is connected to two or more data lines from different IP networks.
- When a data packet comes in on one of the lines, the router reads the network address information in the packet header to determine the ultimate destination. Then, using information in its routing table or routing policy, it directs the packet to the next network on its journey.