Chapter 9

Introduction To Data-Link Layer

Chapter 9: Outline

9.1 INTRODUCTION

9.2 LINK-LAYER ADDRESSING

Chapter 9: Objective

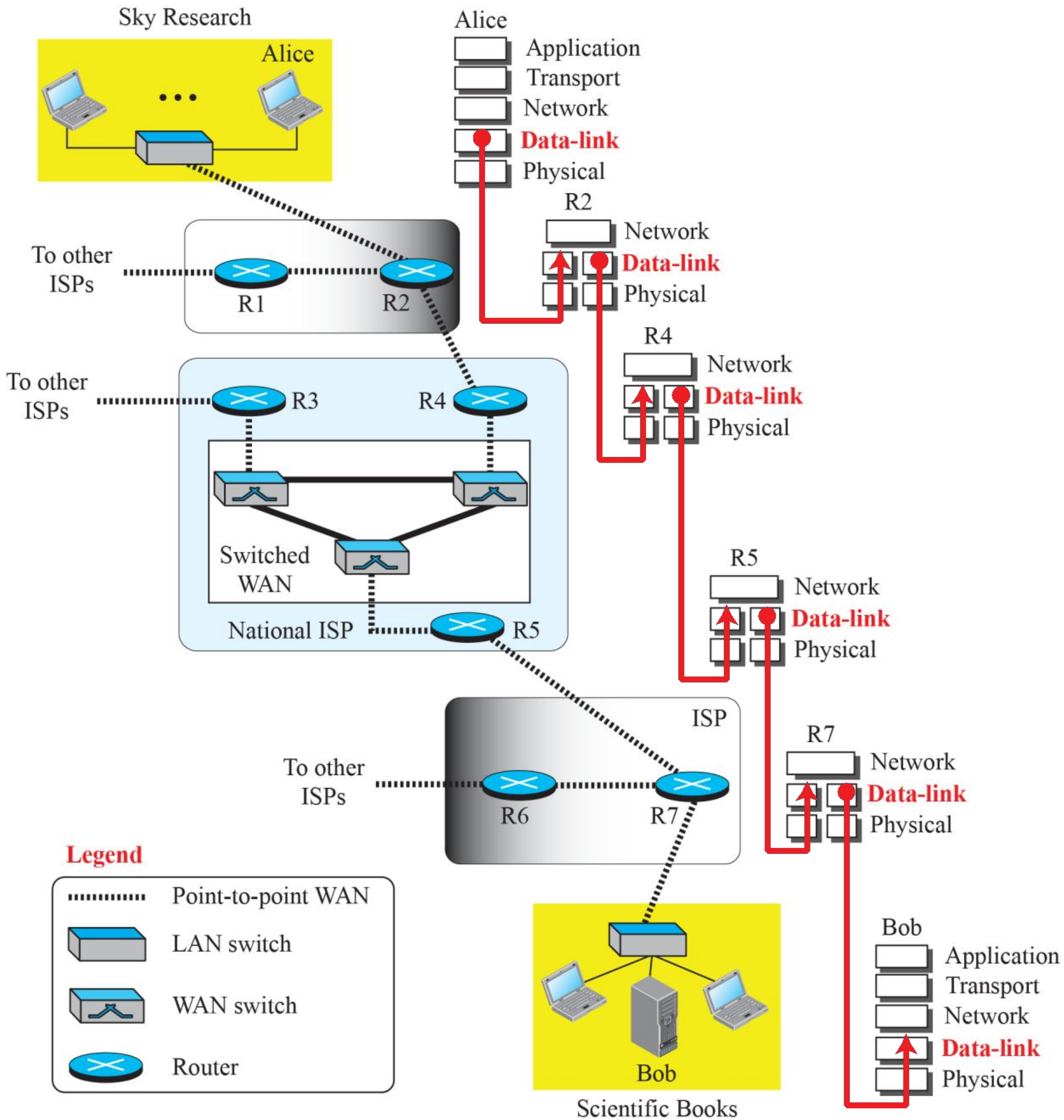
- The first section introduces the data-link layer. It starts with defining the concept of links and nodes. The section then lists and briefly describes the services provided by the data-link layer. It next defines two categories of links: point-to-point and broadcast links. The section finally defines two sub-layers at the data-link layer that will be elaborated on in the next few chapters.

- The second section discusses link-layer addressing. It first explains the rationale behind the existence of an addressing mechanism at the data-link layer. It then describes three types of link-layer addresses. The section discusses the Address Resolution Protocol (ARP), which maps the addresses at the network layer to addresses at the data-link layer.

9-1 INTRODUCTION

The Internet is a combination of networks glued together by connecting devices (routers or switches). If a packet is to travel from a host to another host, it needs to pass through these networks. Figure 9.1 shows the same scenario we discussed in Chapter 3, but we are now interested in communication at the data-link layer.

Figure 9.1: Communication at the data-link layer



Communication at the data-link layer is made up of five separate logical connections between the data-link layers in the path.

The data-link layer at Alice's computer communicates with the data-link layer at router R2.

The data-link layer at router R2 communicates with the data-link layer at router R4 and so on.

Finally, the data-link layer at router R7 communicates with the data-link layer at Bob's computer.

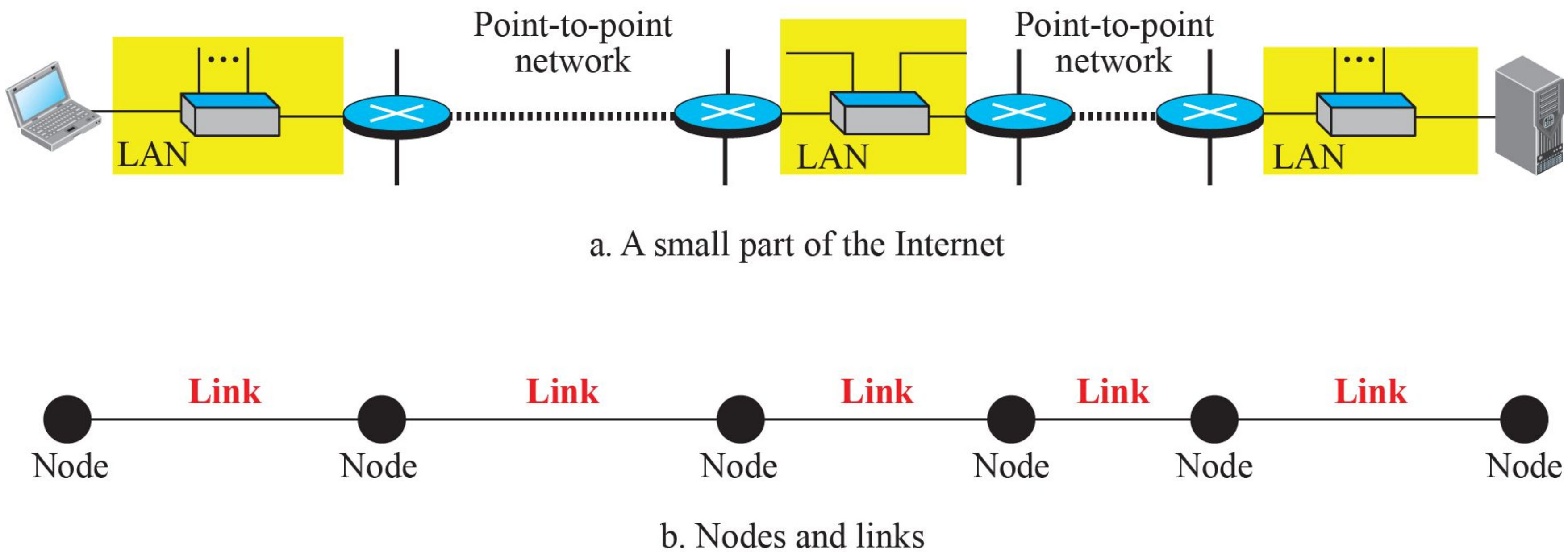
Only one data-link layer is involved at the source or the destination, but two data-link layers are involved at each router. The reason is that Alice's and Bob's computers are each connected to a single network, but each router takes input from one network and sends output to another network.

9.9.1 Nodes and Links

Communication at the data-link layer is node-to-node. A data unit from one point in the Internet needs to pass through many networks (LANs and WANs) to reach another point. Theses LANs and WANs are connected by routers.

It is customary to refer to:
The two end: hosts.
The routers: nodes.
The networks in between as: links.

Figure 9.2: Nodes and Links

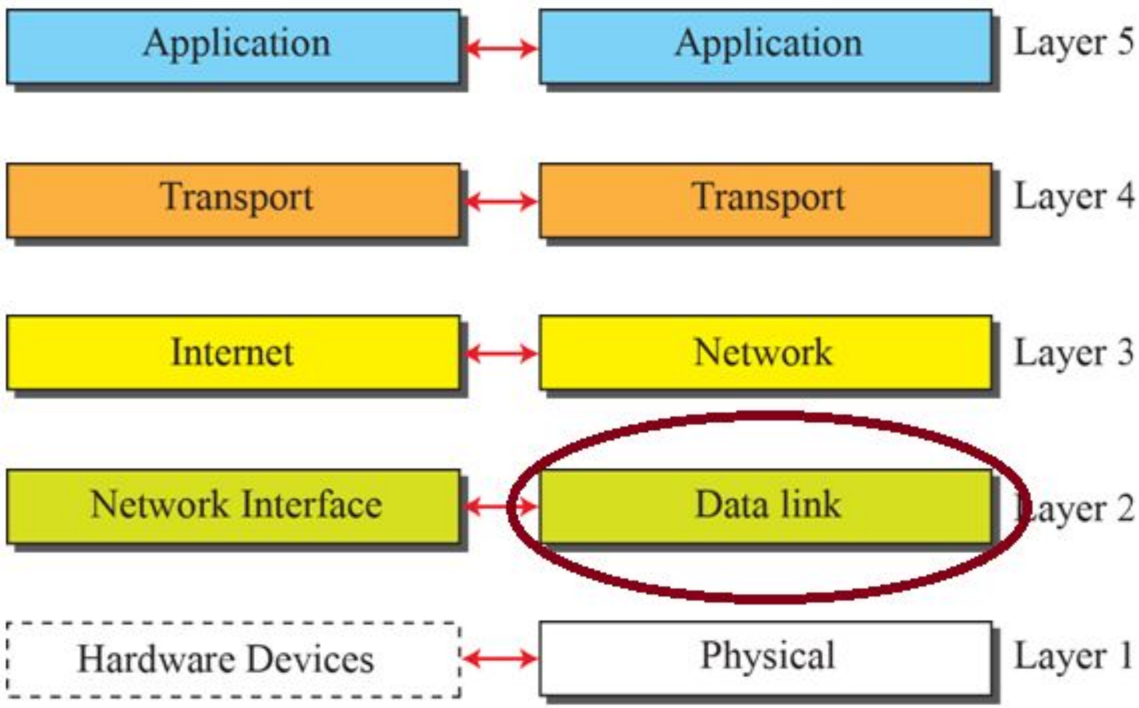


a simple representation of links and nodes when the path of the data unit is only six nodes.

9.9.2 Services

The data-link layer is located between the physical and the network layers.

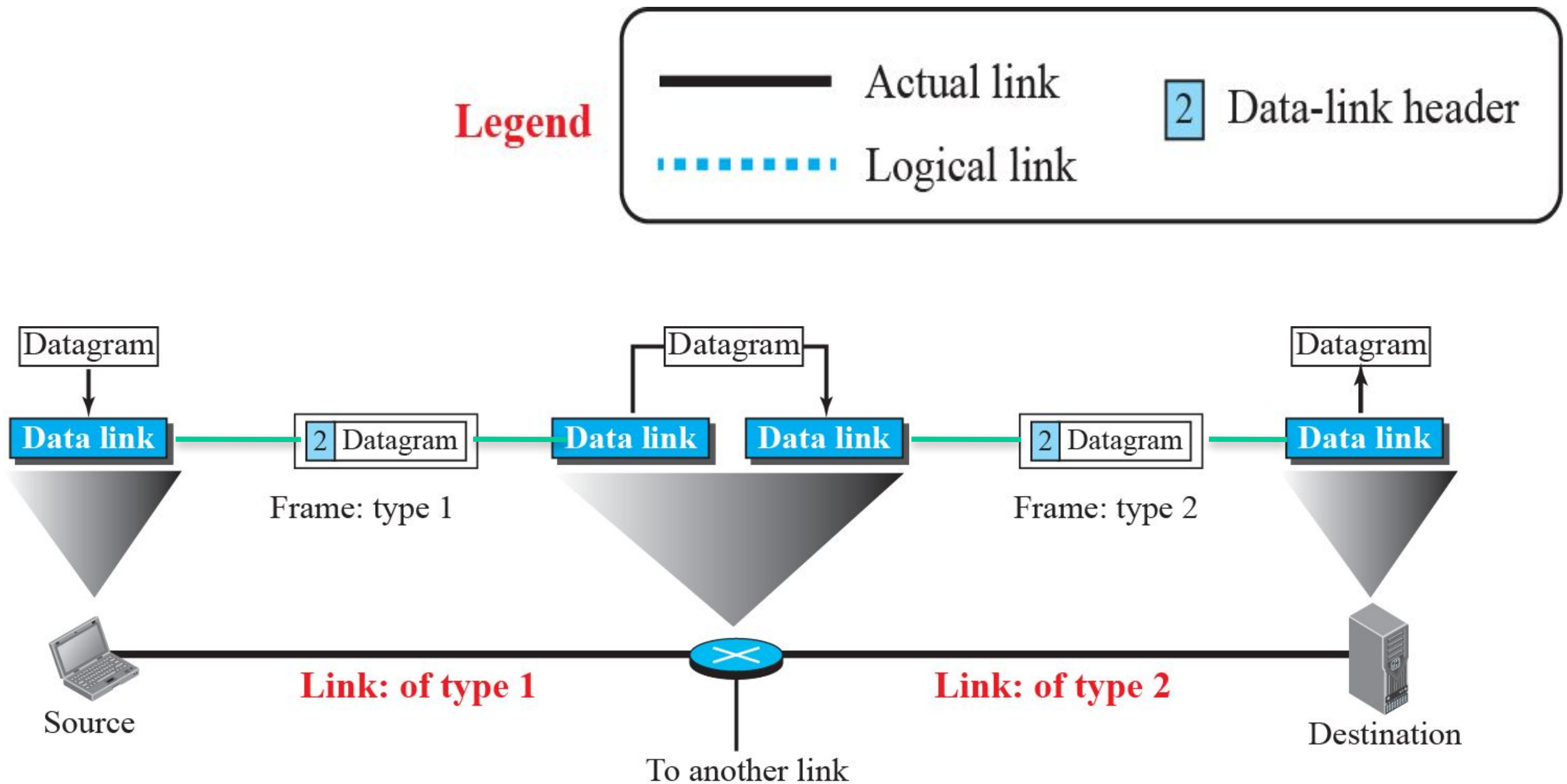
The data-link layer provides services to the network layer; it receives services from the physical layer.



a. Original layers

b. Layers used in this book

Figure 9.3: A communication with only three nodes



The datagram received by the data-link layer of the source host is encapsulated in a frame. The frame is logically transported from the source host to the router. The frame is decapsulated at the data-link layer of the router and encapsulated at another frame. The new frame is logically transported from the router to the destination host.

The Services provided by Data-Link Layer

- **Framing**: *The first service provided by the DLL*
- **Flow Control:** *Between a producer & a consumer*
- **Error Control:** *An issue in every layer*
- **Congestion Control:** *An issue in the network layer or the transport layer due to its end-to-end nature.*

The Services provided by Data-Link Layer…

Framing:

- The DLL at each node needs to encapsulate the datagram (packet received from the network layer) in a frame before sending it to the next node. The node also needs to de-capsulate the datagram from the frame received on the logical channel.
- Different DLLs have different formats for framing.

A packet at the data-link layer is normally called a frame.

Flow Control:

- If the producer produces items that cannot be consumed, accumulation of items occurs.
- The sending DLL at the end of a link is a producer of frames; the receiving DLL at the other end of a link is a consumer.
- If the rate of produced frames is higher than the rate of consumed frames, frames at the receiving end need to be buffered while waiting to be consumed (processed).

The Services provided by Data-Link Layer…

Flow Control:..

- We cannot have an unlimited buffer size at the receiving side. We have two choices,
  - Let the receiving DLL drop the frames if its buffer is full.
  - Let the receiving DLL send a feedback to the sending DLL to ask it to stop or slow down.
- Different data-link-layer protocols use different strategies for flow control. Flow control occurs at the transport layer, with a higher degree of importance.

Error Control:

- At the sending node, a frame in a data-link layer needs to be changed to bits, transformed to electromagnetic signals, and transmitted through the transmission media.
- At the receiving node, electromagnetic signals are received, transformed to bits, and put together to create a frame. Since electromagnetic signals are susceptible to error, a frame is susceptible to error.

The Services provided by Data-Link Layer…

Error Control:..

- At the sending node, a frame in a data-link layer needs to be changed to bits, transformed to electromagnetic signals, and transmitted through the transmission media.
- At the receiving node, electromagnetic signals are received, transformed to bits, and put together to create a frame. Since electromagnetic signals are susceptible to error, a frame is susceptible to error.
- The error needs first to be detected and it needs to be either corrected at the receiver node or discarded and retransmitted by the sending node.
- Since error detection and correction is an issue in every layer (node-to node or host-to-host).

Congestion Control: Although a link may be congested with frames, that results in frame loss, most DLL protocols do not directly use a congestion control to alleviate congestion, although some WANs do. In general, congestion control is considered an issue in the network layer or the transport layer because of its end-to-end nature.

9.9.3 Two Categories of Links

Although two nodes are physically connected by a transmission medium such as cable or air, we need to remember that the data-link layer controls how the medium is used. We can have a data-link layer that uses the whole capacity of the medium; we can also have a data-link layer that uses only part of the capacity of the link. In other words, we can have a point-to-point link or a broadcast link.

- In a point-to-point link, the link is dedicated to the two devices;
- in a broadcast link, the link is shared between several pairs of devices.

For example, when two friends use the traditional home phones to chat, they are using a point-to-point link; when the same two friends use their cellular phones, they are using a broadcast link (the air is shared among many cell phone users).

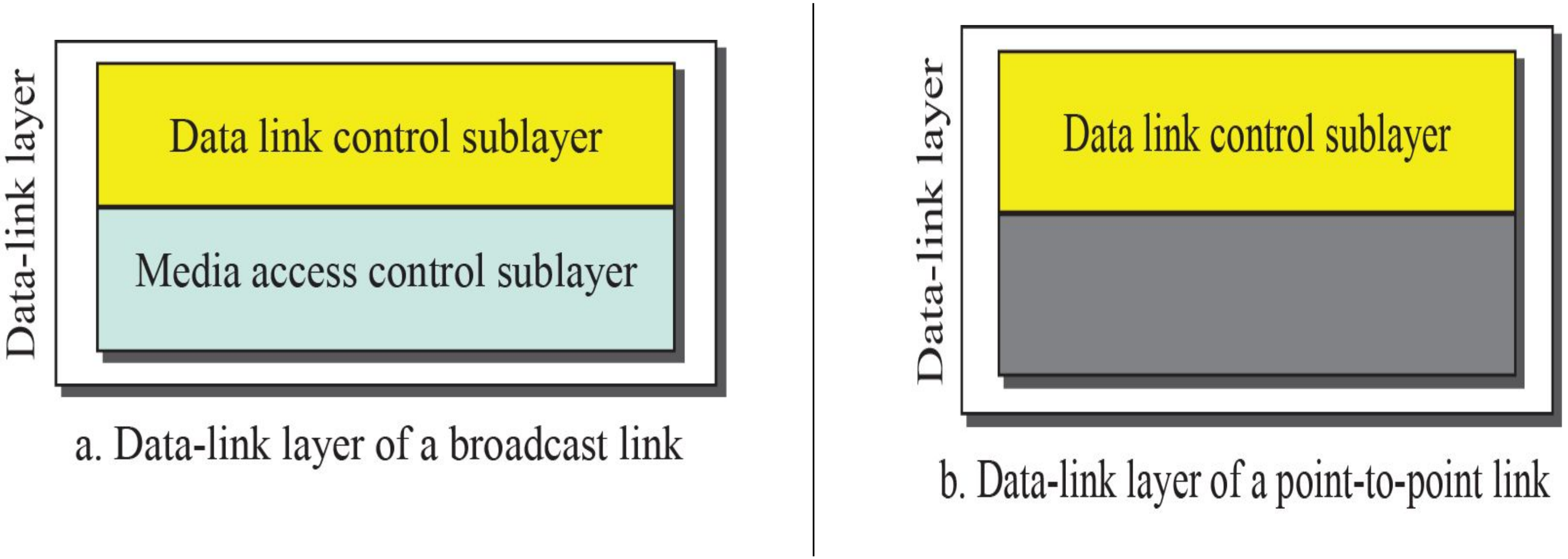
9.9.4 Two Sublayers

To better understand the functionality of and the services provided by the link layer, we can divide the data-link layer into two sub-layers:

- Data link control (DLC)
- Media access control (MAC).

This is not unusual because, as we will see in later chapters, LAN protocols actually use the same strategy.

Figure 9.3: Dividing the data-link layer into two sublayers



The DLC sublayer deals with all issues common to both point-to-point and broadcast links;

The MAC sublayer deals only with issues specific to broadcast links.

5-4 LINK-LAYER ADDRESSING

In an internetwork such as the Internet we cannot make a datagram reach its destination using only IP addresses.

The source and destination IP addresses define the two ends but cannot define which links the packet should pass through. The reason is that each datagram in the Internet, from the same source host to the same destination host, may take a different path.

Also, the IP addresses in a datagram should not be changed. If the destination IP address in a datagram changes, the packet never reaches its destination.

5-4 LINK-LAYER ADDRESSING (cont)

For that, we need another addressing mechanism in a connectionless internetwork:

The link-layer addresses of the two nodes.

A LINK-LAYER ADDRESS is sometimes called a link address, sometimes a physical address and sometimes a MAC address.

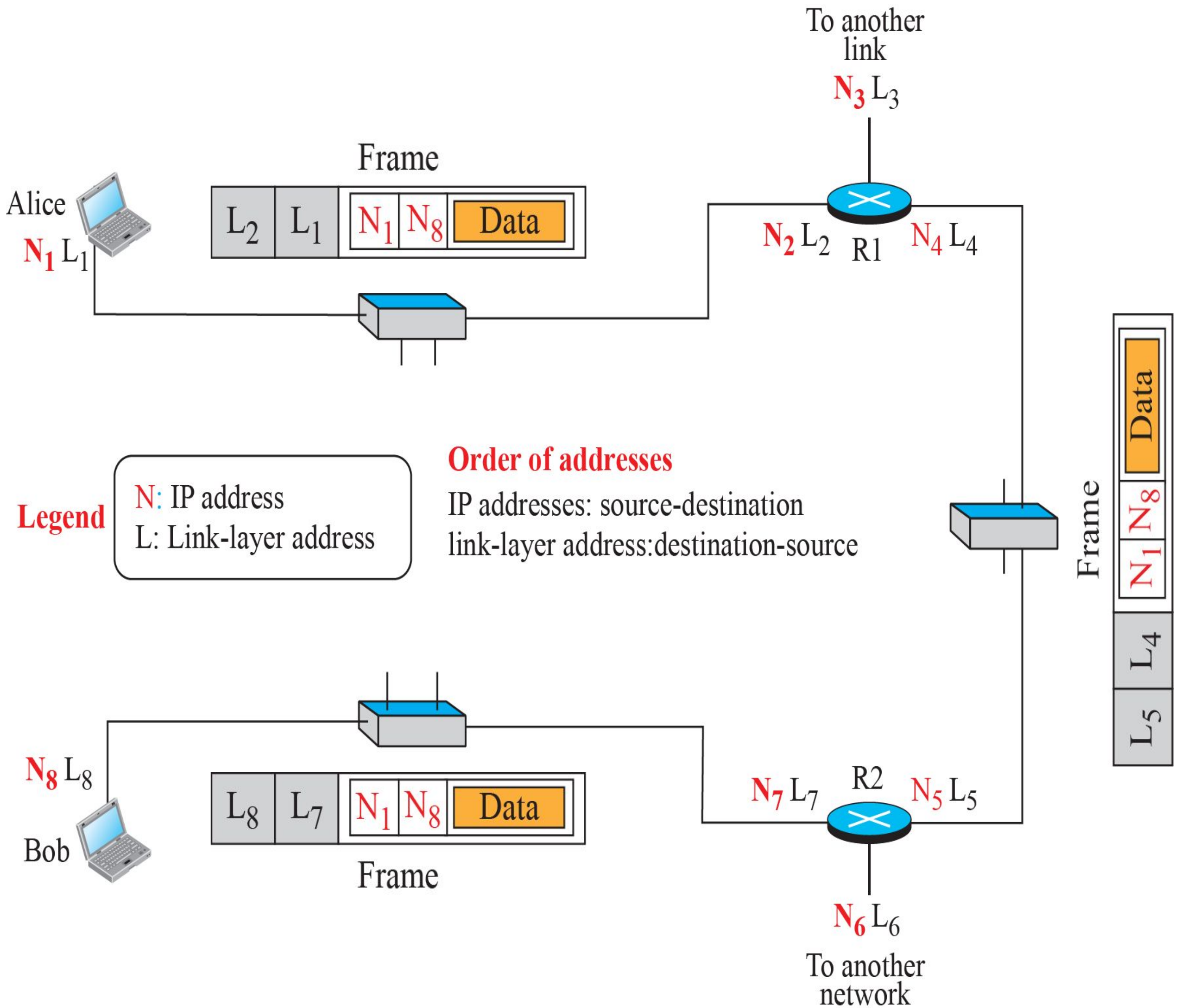
When a datagram passes from the network layer to the data-link layer, the datagram will be encapsulated in a frame and two data-link addresses are added to the frame header. These two addresses are changed every time the frame moves from one link to another.

Figure 9.5: IP addresses and link-layer addresses in a small internet

Each frame carries the same datagram with the same source and destination IP addresses (N1 and N8), but the link-layer addresses of the frame change from link to link.

In link 1, the link-layer addresses are L1 and L2. In link 2, they are L4 and L5. In link 3, they are L7 and L8.

Note that For IP addresses, the source address comes before the destination address; for link-layer addresses, the destination address comes before the source.



9.2.1 Three Types of addresses

Some link-layer protocols define three types of addresses:

1. Unicast: Each host or each interface of a router is assigned a unicast address. Unicasting means one-to-one communication. A frame with a unicast address destination is destined only for one entity in the link.

2. Multicast: one-to-many communication. However, the jurisdiction is local (inside the link).

3. Broadcast: one-to-all communication. A frame with a destination broadcast address is sent to all entities in the link.

Example 9.1 - unicast link-layer addresses

The unicast link-layer addresses in the most common LAN, Ethernet, are 48 bits (six bytes) that are presented as 12 hexadecimal digits separated by colons; for example, the following is a link-layer address of a computer. The second digit needs to be an odd number.

A3:34:45:11:92:F1

Example 9.2 - multicast link-layer addresses

The multicast link-layer addresses in the most common LAN, Ethernet, are 48 bits (six bytes) that are presented as 12 hexadecimal digits separated by colons. The second digit, however, needs to be an even number in hexadecimal.

The following shows a multicast address:

A2:34:45:11:92:F1

Example 9.3 - the broadcast link-layer addresses

The broadcast link-layer addresses in the most common LAN, Ethernet, are 48 bits, all 1s, that are presented as 12 hexadecimal digits separated by colons. The following shows a broadcast address:

FF:FF:FF:FF:FF:FF

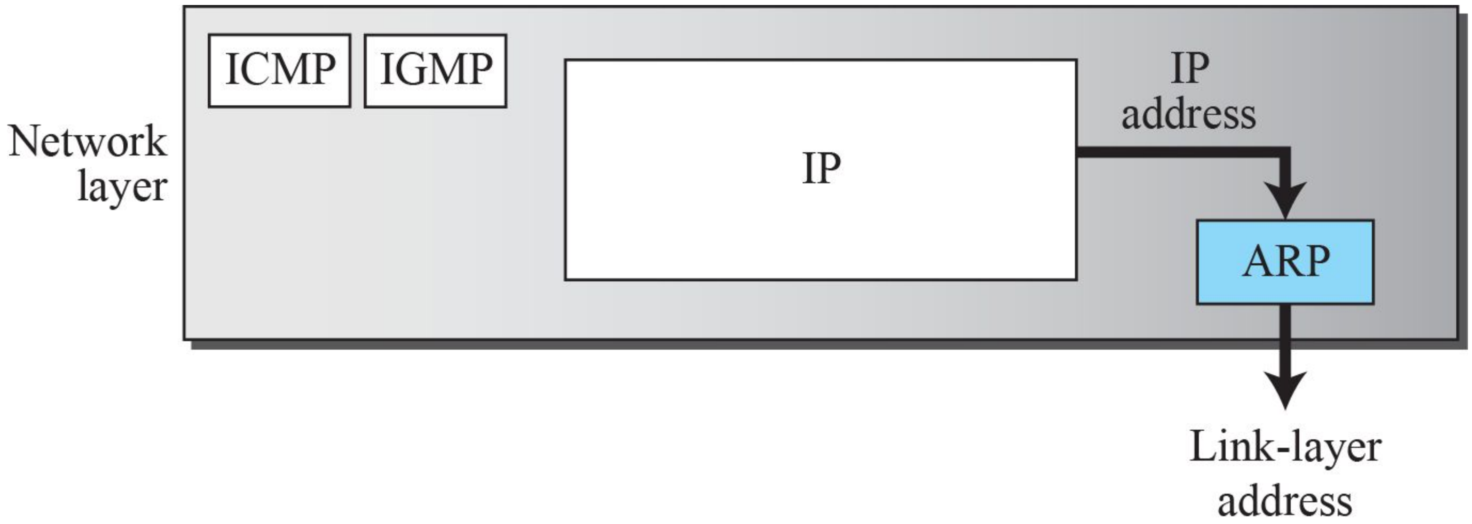
9.2.2 Address Resolution Protocol ARP

Anytime a node has an IP datagram to send to another node in a link, it has the IP address of the receiving node.

However, the IP address of the next node is not helpful in moving a frame through a link;

we need the link-layer address of the next node. This is the time when the Address Resolution Protocol (ARP) becomes helpful.

Figure 9.6: Position of ARP in TCP/IP protocol suite



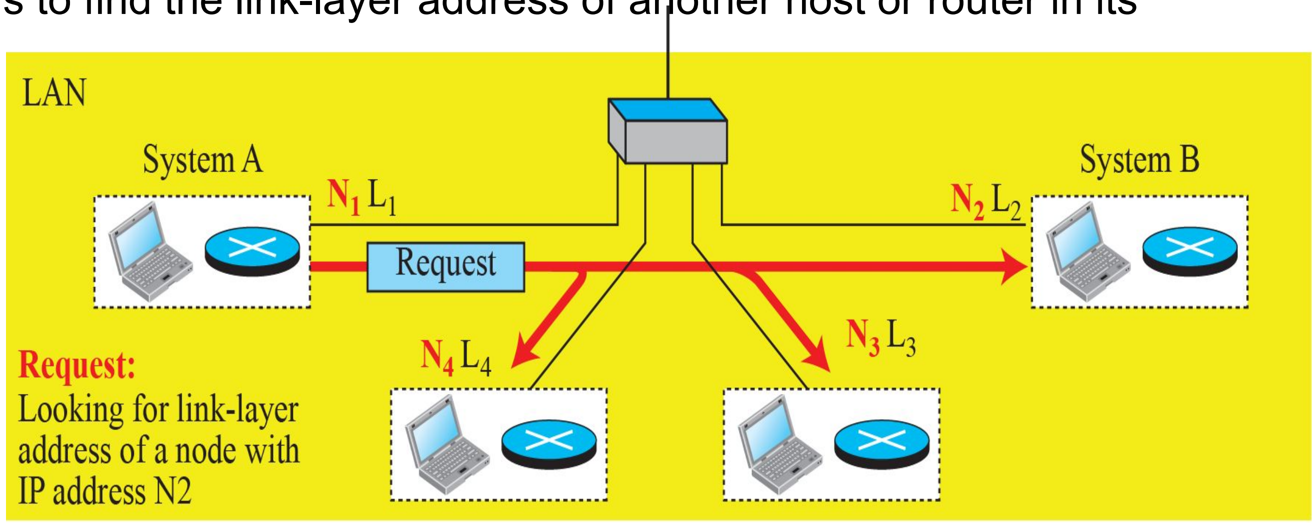
The ARP protocol is one of the network layer protocols.

ARP accepts an IP address from the IP protocol, maps the address to the corresponding link-layer address, and passes it to the data-link layer.

Figure 9.7: ARP operation

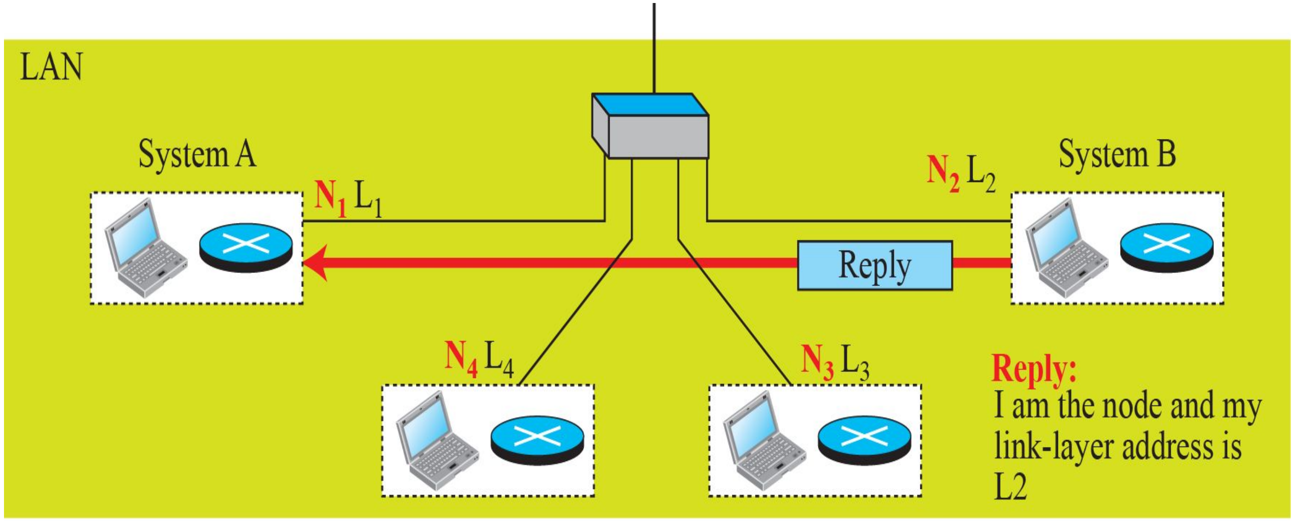
When a host or a router needs to find the link-layer address of another host or router in its network,

A host or a router sends an ARP request packet that includes the link-layer and IP addresses of the sender and the IP address of the receiver. Because the sender does not know the link-layer address of the receiver, the query is broadcast over the link using the link-layer broadcast address.



a. ARP request is broadcast

Every host or router on the network receives and processes the ARP request packet, but only the intended recipient recognizes its IP address and sends back an ARP response packet. The response packet contains the recipient's IP and link-layer addresses. The packet is unicast directly to the node that sent the request packet.



b. ARP reply is unicast

Figure 9.8: ARP packet

0	8	16	31
Hardware Type		Protocol Type	
Hardware length	Protocol length	Operation **Request:1, Reply:2**	
Source hardware address			
Source protocol address			
Destination hardware address (Empty in request)			
Destination protocol address			

Hardware: LAN or WAN protocol

Protocol: Network-layer protocol

*The hardware type field **defines the type of the link-layer protocol; Ethernet is given the type 1.***

*The protocol type field **defines the network-layer protocol: IPv4 protocol is (0800)16.***

The source hardware and source protocol addresses ***are variable-length fields defining the link-layer and network-layer addresses of the sender.***

*The destination hardware address and destination protocol address fields **define the receiver link-layer and network-layer addresses.***

An ARP packet is encapsulated directly into a data-link frame.

Figure 9.9: Example 9.4 *the ARP request and response messages.*

A host with IP address N1 and MAC address L1 has a packet to send to another host with IP address N2 and physical address L2 (which is unknown to the first host). The two hosts are on the same network.

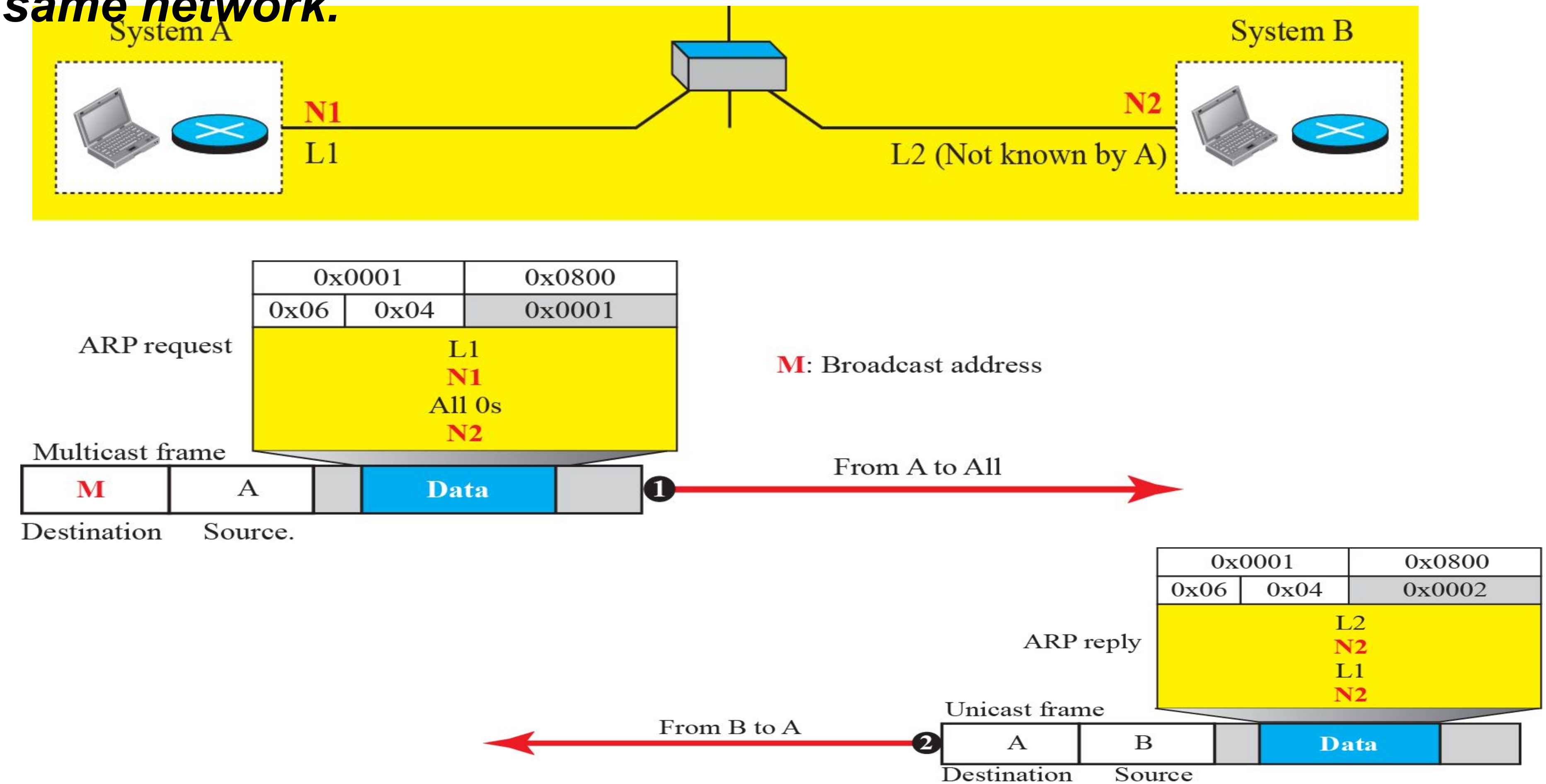
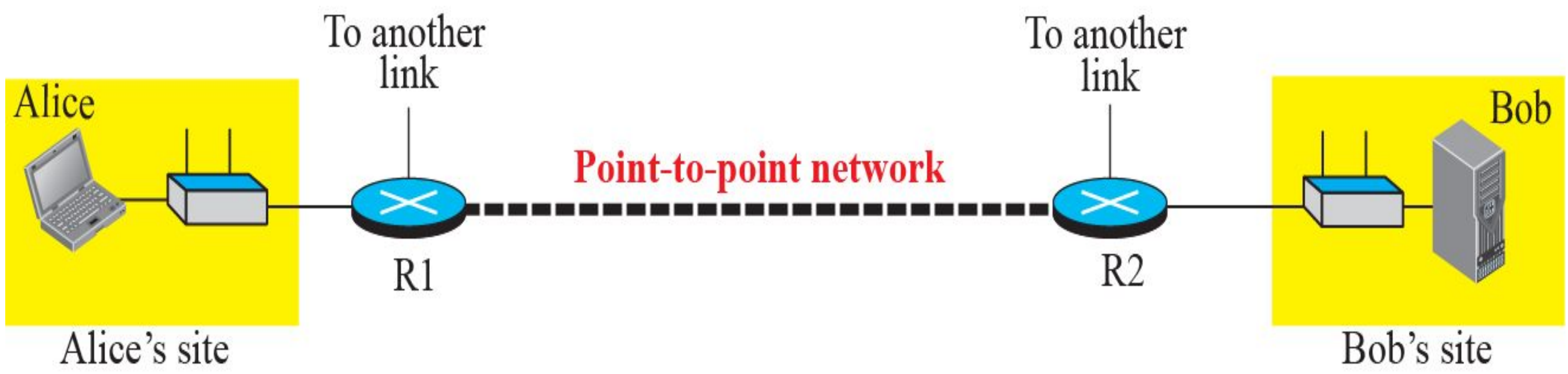


Figure 9.10: The internet for our example

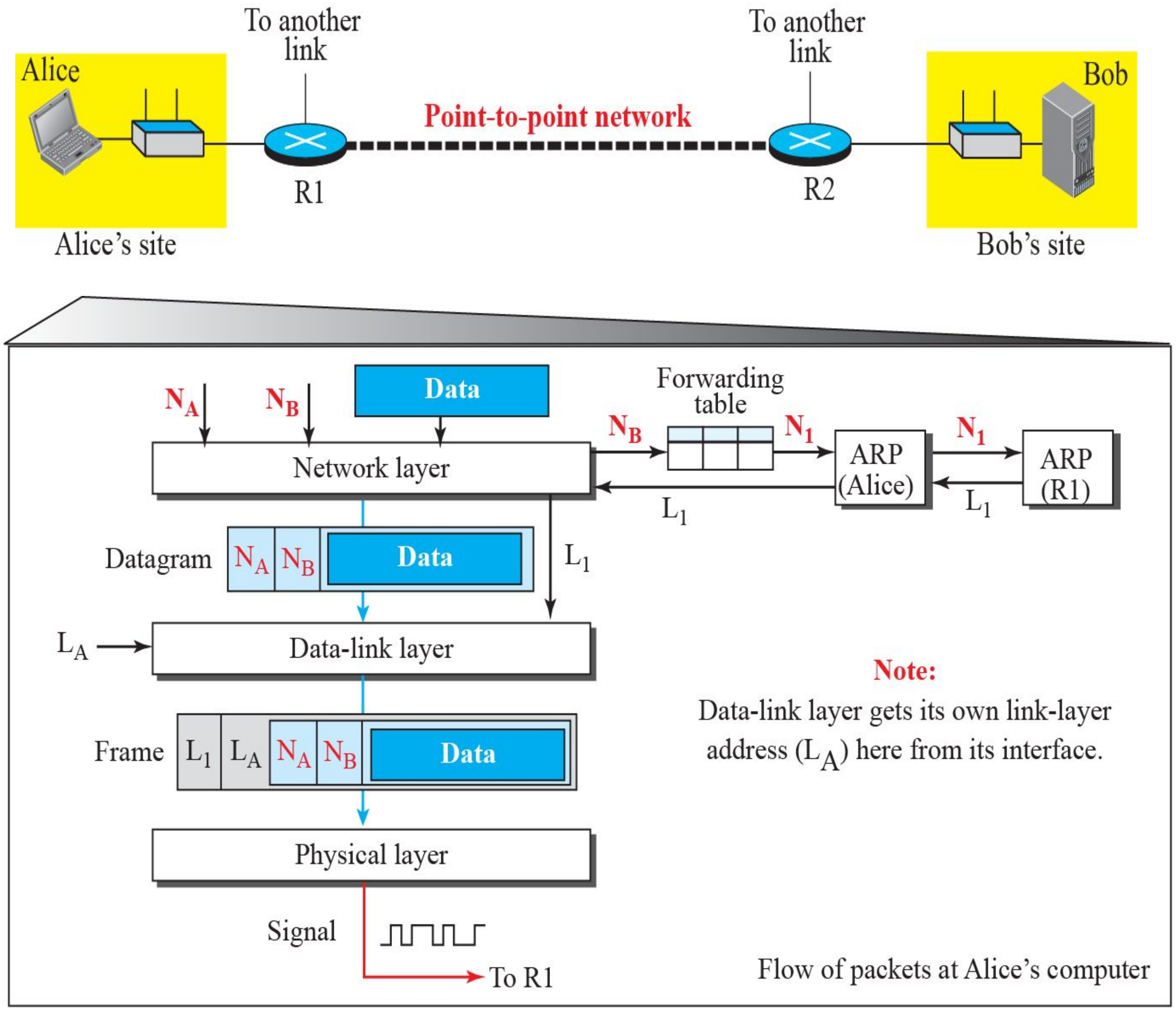


Assume Alice needs to send a datagram to Bob, who is three nodes away in the Internet.

Assume that Alice knows the:

- ***data to be sent.***
- ***The IP address of Alice's host (each host needs to know its IP address).***
- ***network-layer (IP) address of Bob.***

Figure 9.11: Flow of packets at Alice site



The network layer knows it's given NA, NB, and the packet, but it needs to find the link-layer address of the next node.

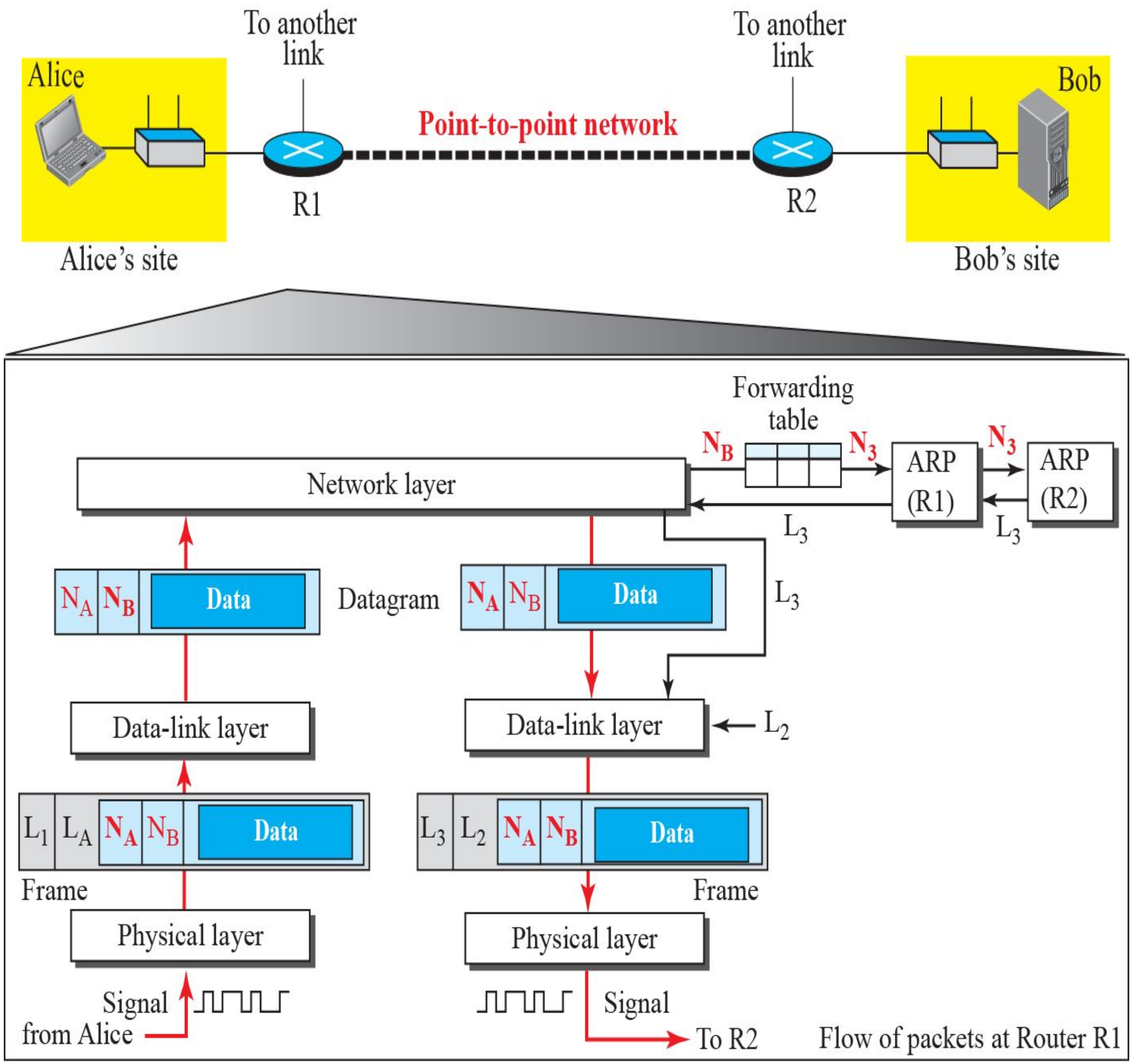
The network layer consults its routing table and tries to find which router is next for the destination NB. The routing table gives N1,

but the network layer needs to find the link-layer address of router R1. It uses its ARP to find the link-layer address L_1.

The network layer can now pass the datagram with the link-layer address to the data-link layer.

The data-link layer knows its own link-layer address, L_A. It creates the frame and passes it to the physical layer, where the address is converted to signals and sent through the media.

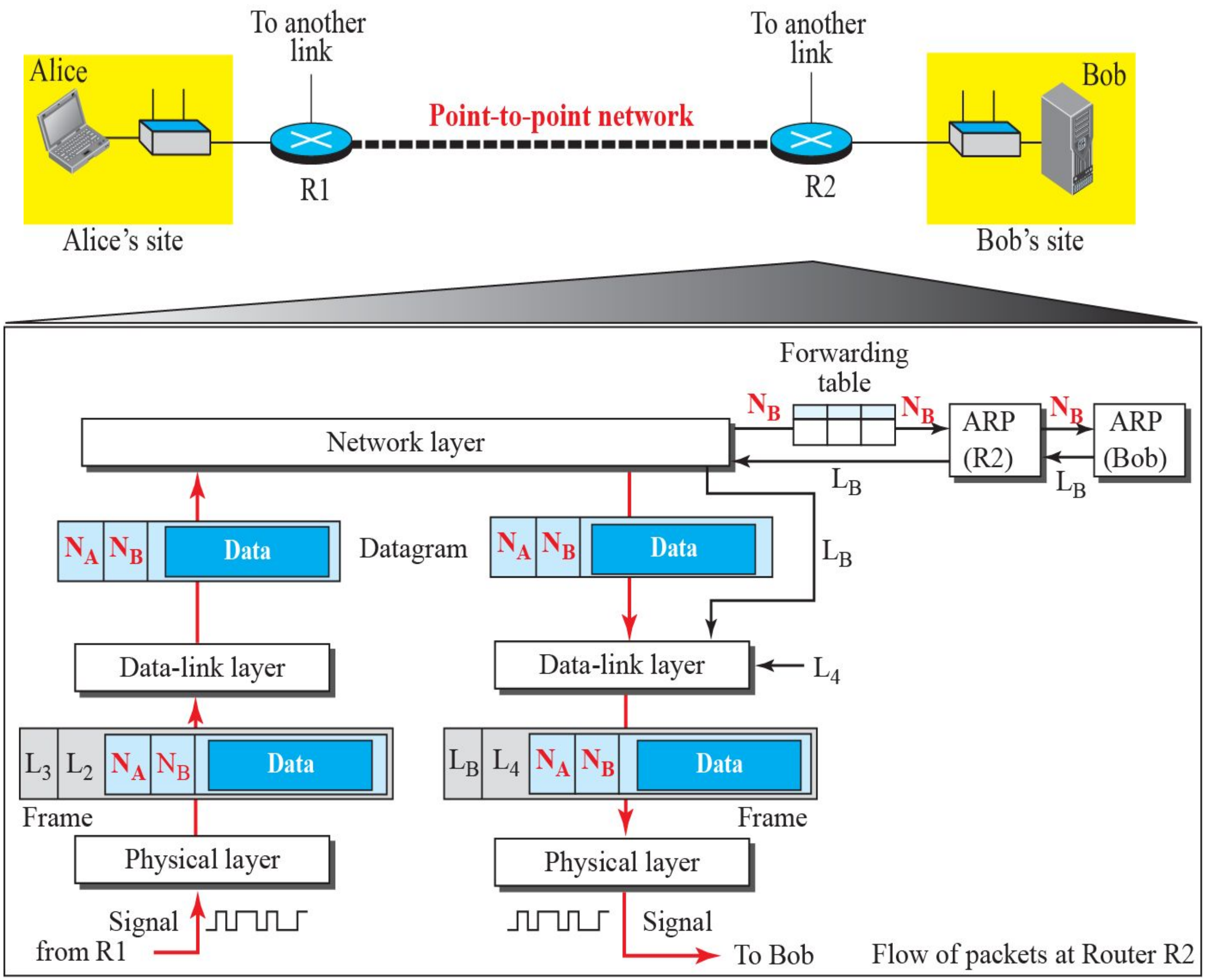
Figure 9.12: Flow of activities at router R1



Router R1 has only three lower layers. The packet received needs to go up through these three layers and come down.

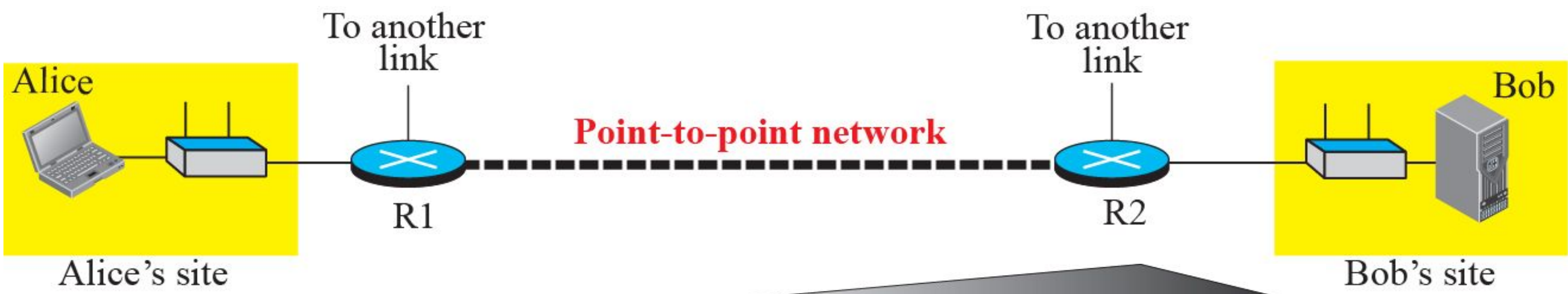
At arrival, the physical layer of the left link Change the signal received from the link to a frame and passes it to the data-link layer.
The data-link layer decapsulates the datagram and passes it to the net- work layer.
The network layer examines the network-layer address of the datagram and finds that the datagram needs to be delivered to the device with IP address N_B.
The network layer consults its routing table to find out which is the next node (router) in the path to N_B. The forwarding table returns N_3.
The IP address of router R2 is in the same link with R1. The network layer now uses the ARP to find the link-layer address of this router, which comes up as L_3.
The network layer passes the datagram and L_3 to the data-link layer belonging to the link at the right side.
The link layer encapsulates the datagram, adds L3 and L2 (its own link-layer address), and passes the frame to the physical layer
The physical layer encodes the bits to signals and sends them through the

Figure 9.13: Flow of activities at router R2



Activities at router R2 are almost the same as in R1

Figure 9.14: Activities at Bob's site



The signals at Bob's site are changed to a message. At Bob's site there are no more addresses or mapping needed.

The signal received from the link is changed to a frame.

The frame is passed to the data-link layer, which decapsulates the datagram and passes it to the network layer.

The network layer decapsulates the message and passes it to the transport layer.