DISTRIBUTED SYSTEMS
Principles and Paradigms
Second Edition

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Chapter 4
Communication

Layered Protocols (1)

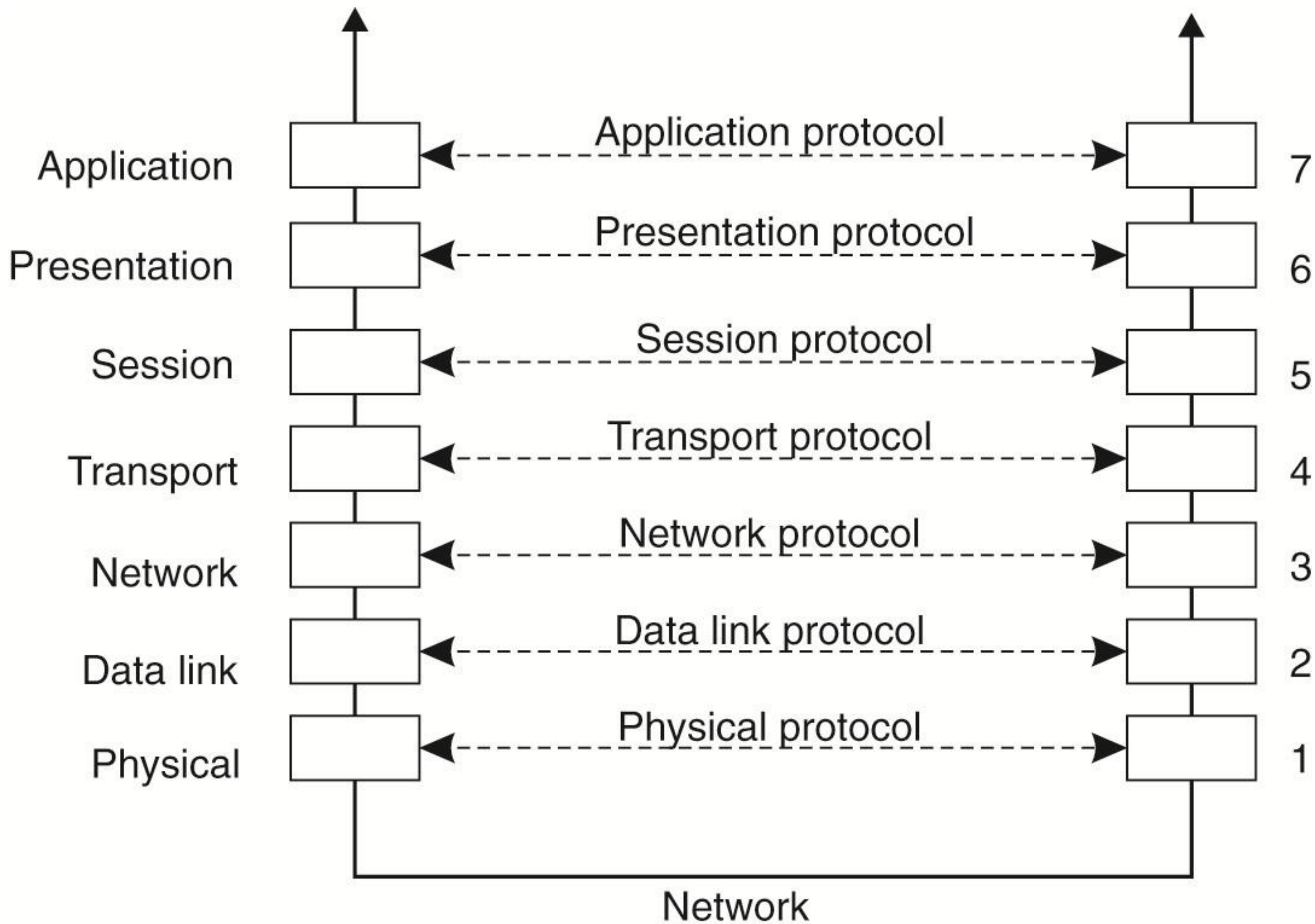


Figure 4-1. Layers, interfaces, and protocols in the OSI model.

Layered Protocols (2)

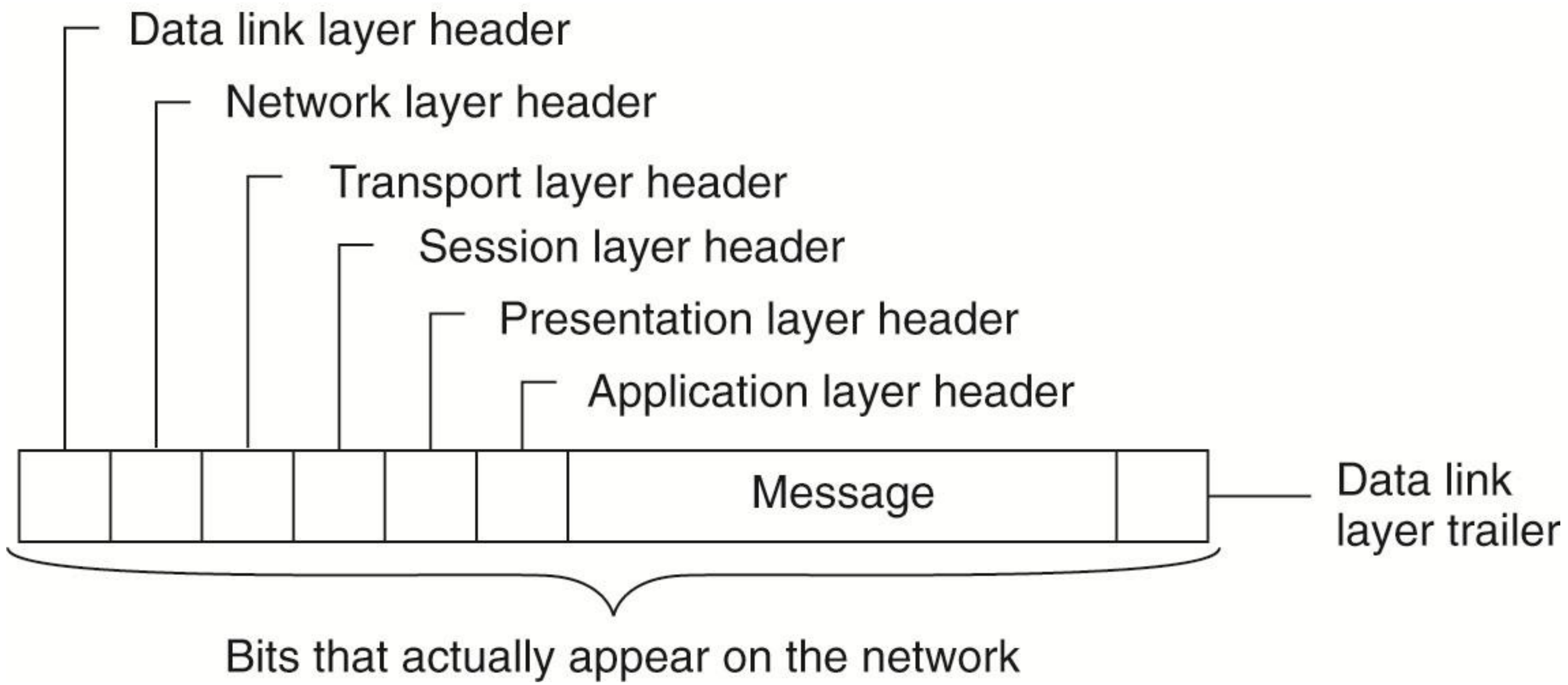


Figure 4-2. A typical message as it appears on the network.

Middleware Protocols

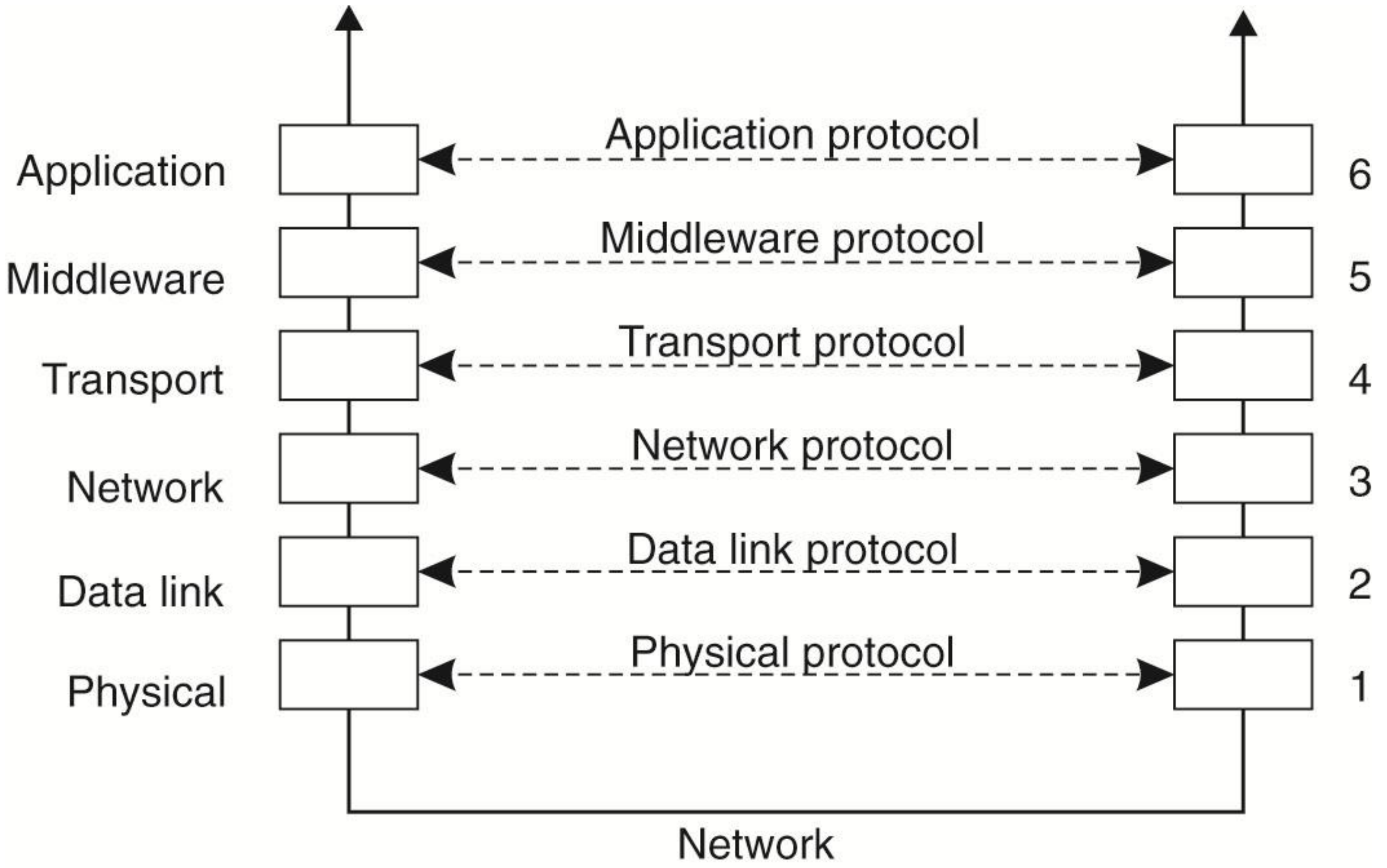


Figure 4-3. An adapted reference model for networked communication.

Types of Communication

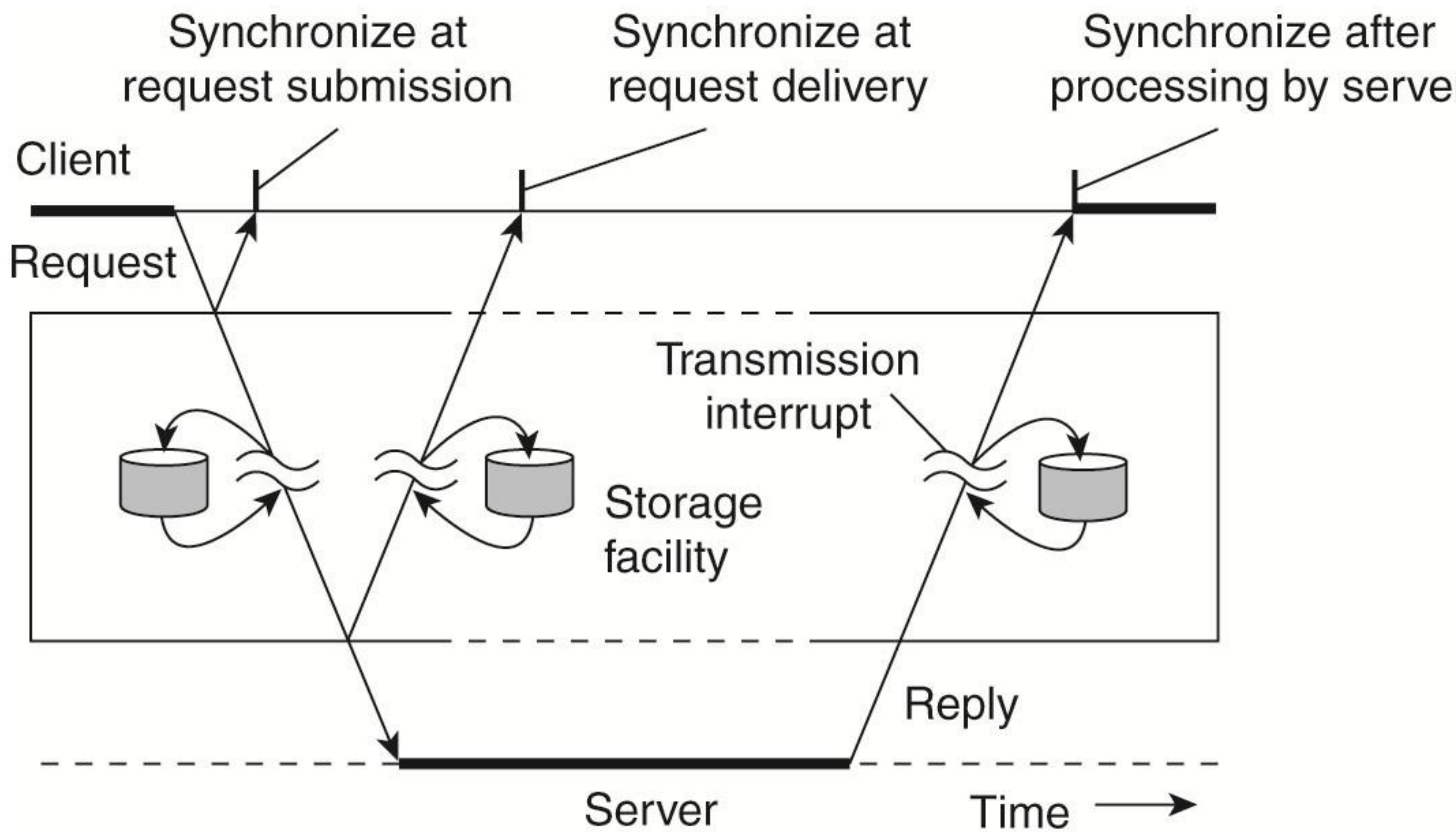


Figure 4-4. Viewing middleware as an intermediate (distributed) service in application-level communication.

Remote Procedure Call (RPC)

- RPC allows a program to transparently call procedures located on another machine. No message passing is visible to the programmer.
- A widely used technique that underlies many distributed systems.

Conventional Procedure Call

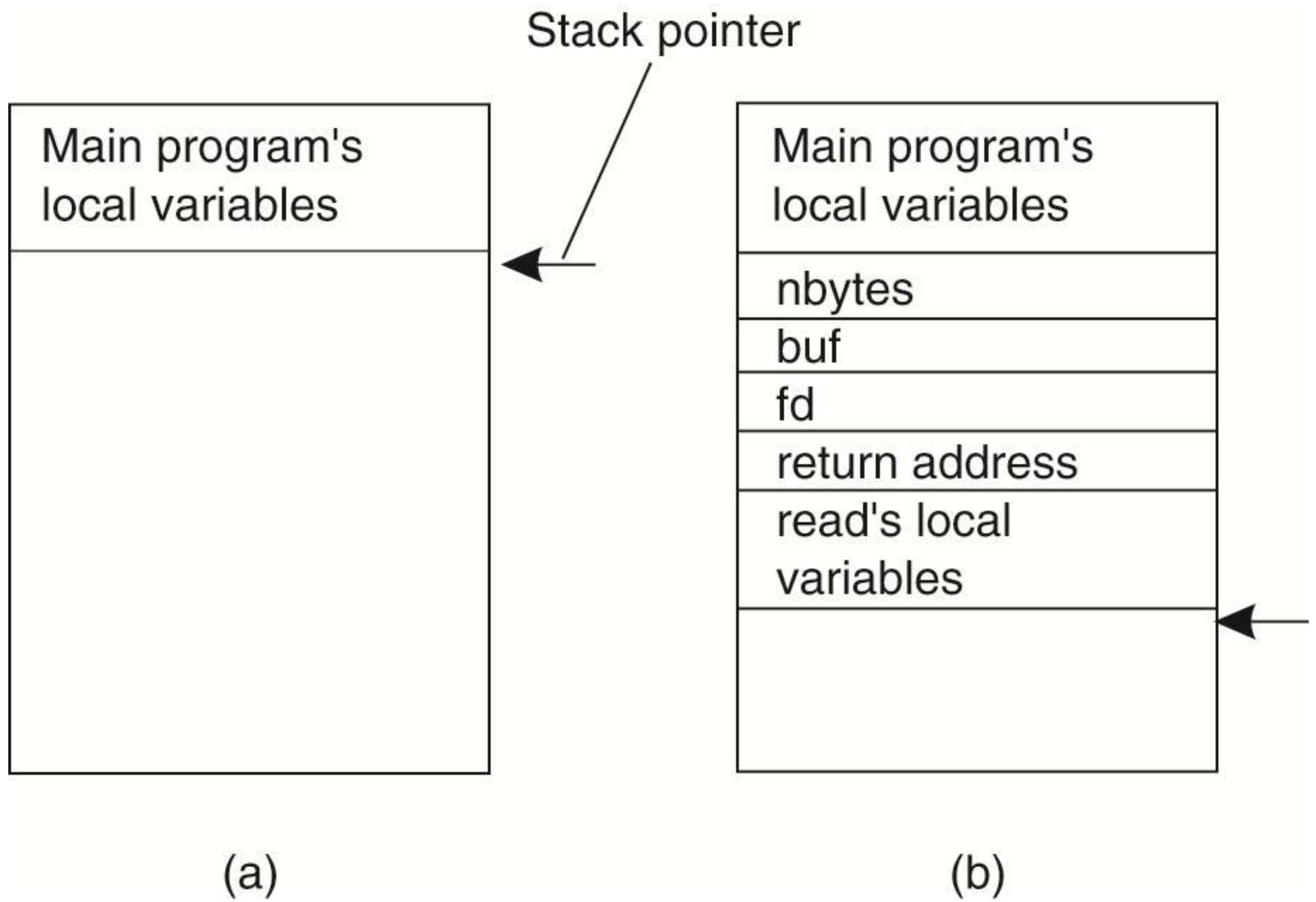


Figure 4-5. (a) Parameter passing in a local procedure call: the stack before the call to read. (b) The stack while the called procedure is active.

Parameter Passing in Procedure Calls

- Call-by-value: The variable is copied to the stack. The original value is left unchanged
- Call-by-reference: The address of the variable is copied to the stack so the called procedure modifies the same copy as the procedure calling
- Call-by-copy/restore: The variable is copied to the stack by the caller and then copied back after the call, overwriting the caller's original value
  How is call-by-copy/restore different from call-by-reference?

Client and Server Stubs

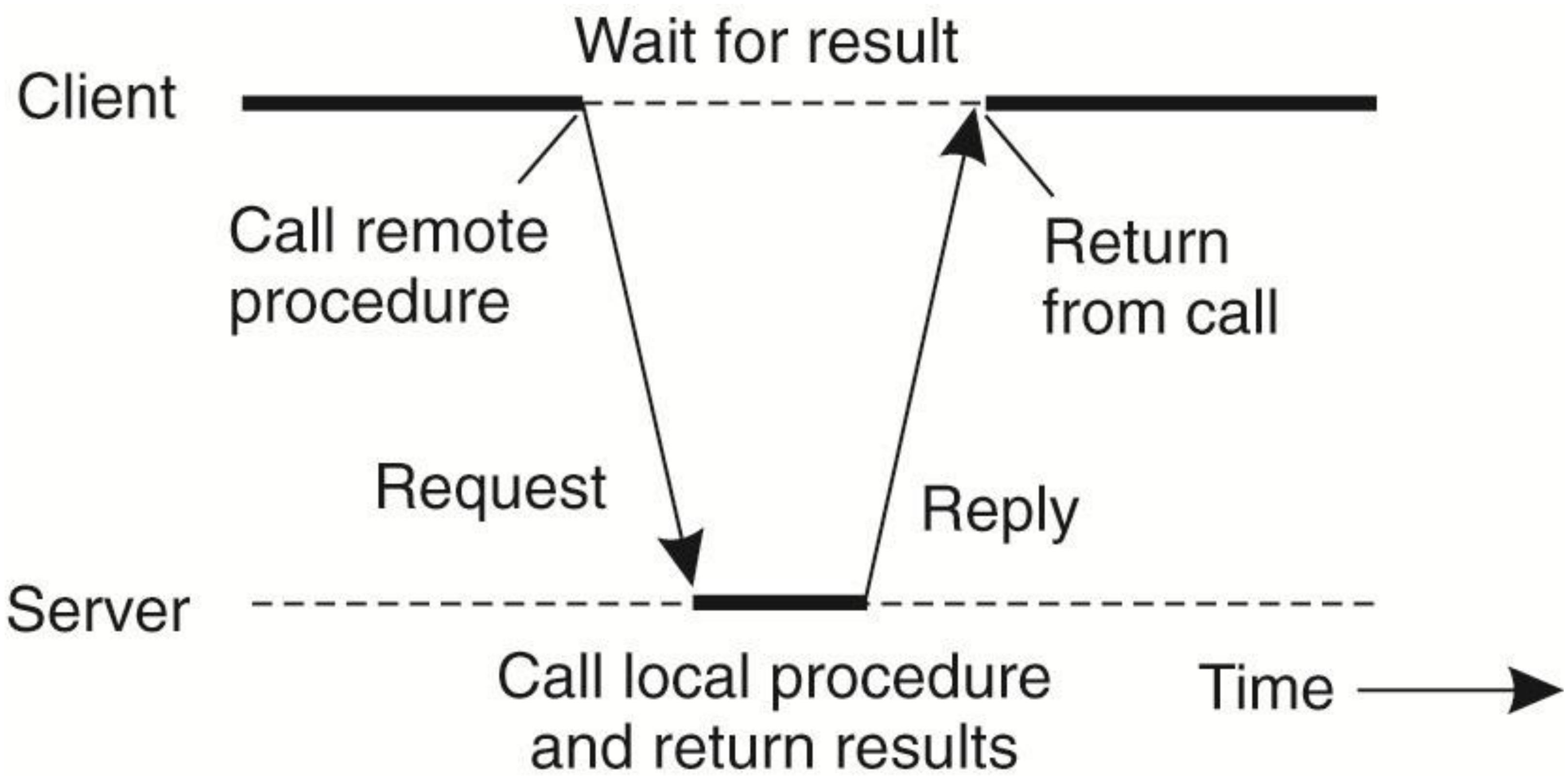


Figure 4-6. Principle of RPC between a client and server program.

Remote Procedure Calls (1)

A remote procedure call occurs in the following steps:

1. The client procedure calls the client stub in the normal way.
2. The client stub builds a message and calls the local operating system.
3. The client's OS sends the message to the remote OS.
4. The remote OS gives the message to the server stub.
5. The server stub unpacks the parameters and calls the server.

Continued …

Remote Procedure Calls (2)

A remote procedure call occurs in the following steps (continued):

6. The server does the work and returns the result to the stub.
7. The server stub packs it in a message and calls its local OS.
8. The server's OS sends the message to the client's OS.
9. The client's OS gives the message to the client stub.
10. The stub unpacks the result and returns to the client.

Parameter Passing

Passing parameters to RPCs can be tricky since it requires packing parameters into a message (*parameter marshaling*) to be interpreted correctly on another system. For example:

- Machines may use different character codes. EBCDIC versus ASCII versus Unicode
- Different representation of integers and floating-point numbers
- Different byte addressing: little-endian versus big-endian format
- How to pass reference parameters (like pointers) since an address will be meaningless on another system? Can we use call-by-copy-restore?
- How to pack types that take less space than a word? For example: a short or a character.
- How to pack an array?

Passing Value Parameters (1)

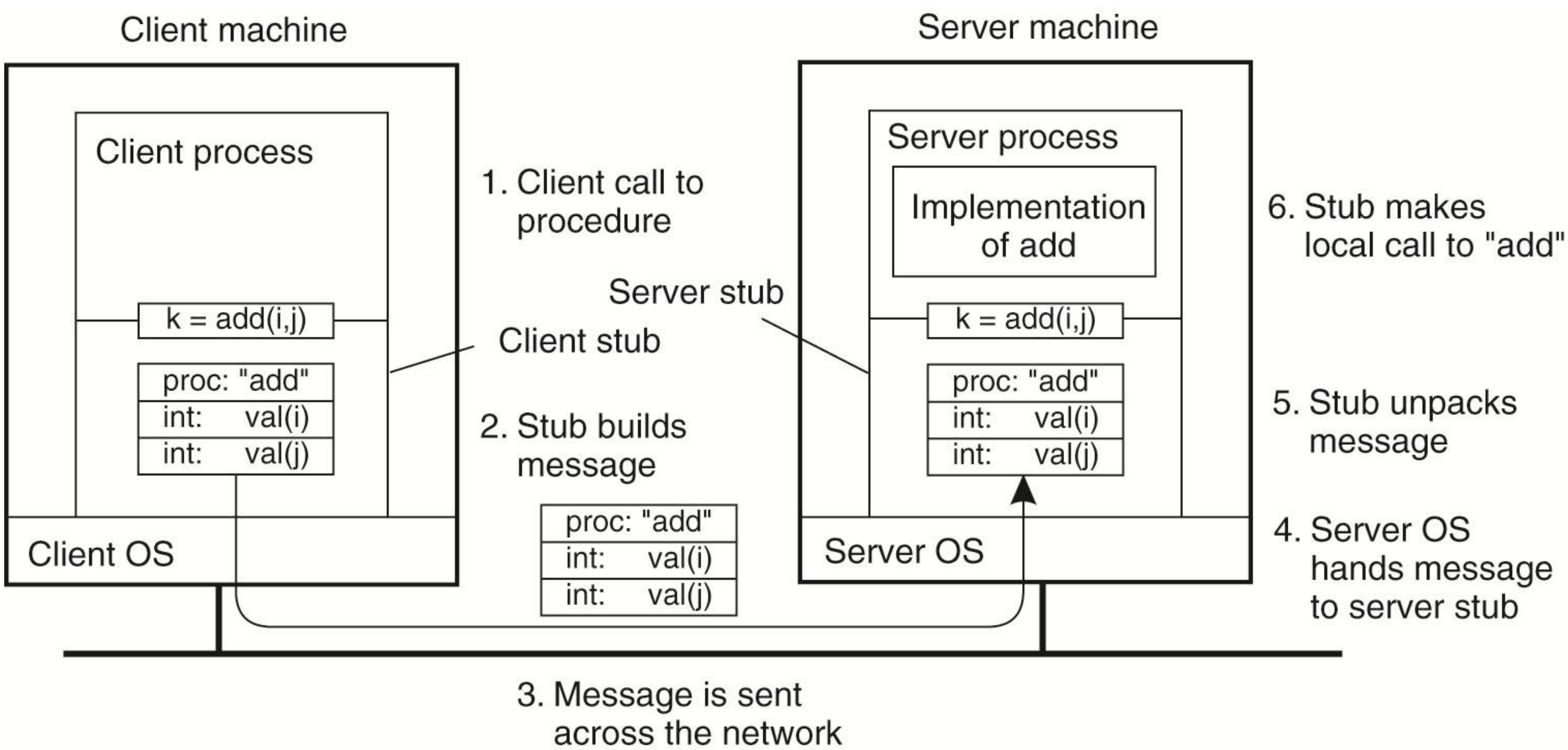


Figure 4-7. The steps involved in a doing a remote computation through RPC.

Passing Value Parameters (2)

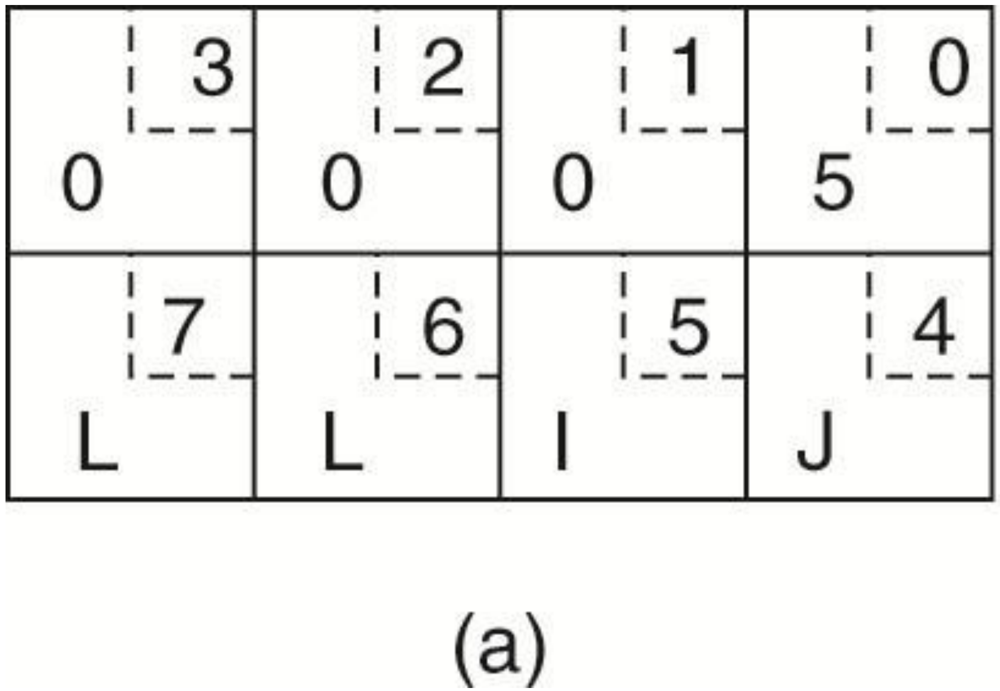


Figure 4-8. (a) The original message on the Pentium.

Passing Value Parameters (3)

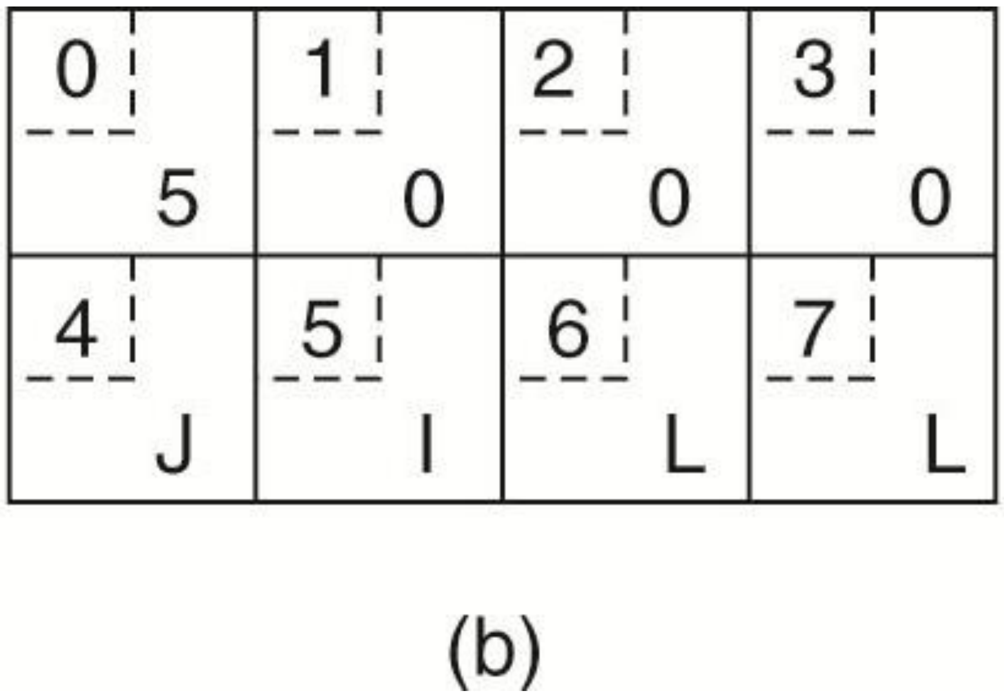


Figure 4-8. (a) The original message on the Pentium.

Passing Value Parameters (4)

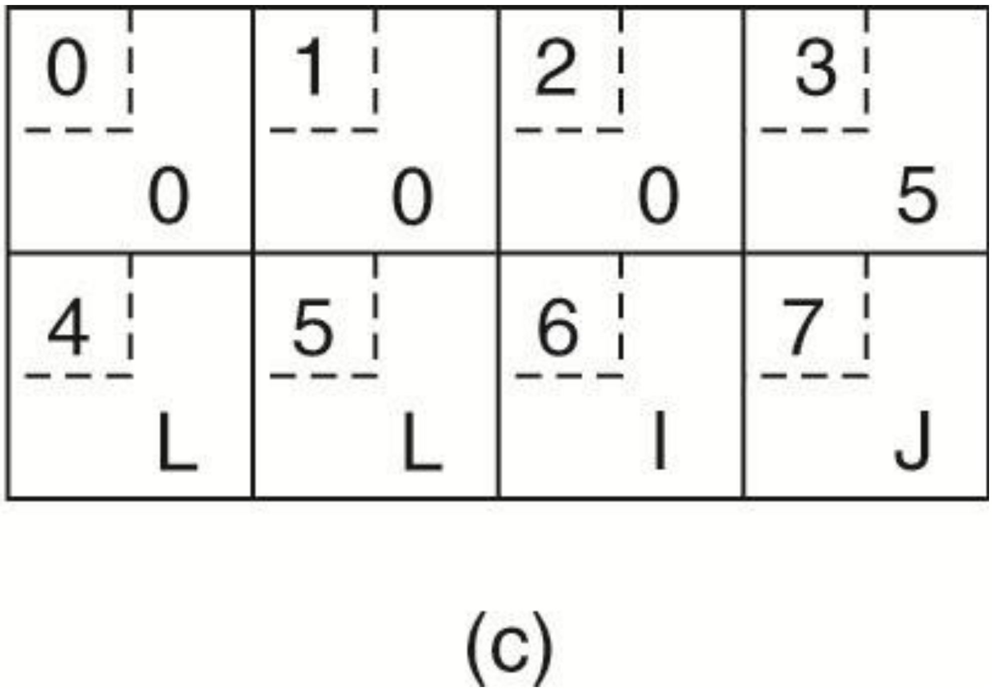
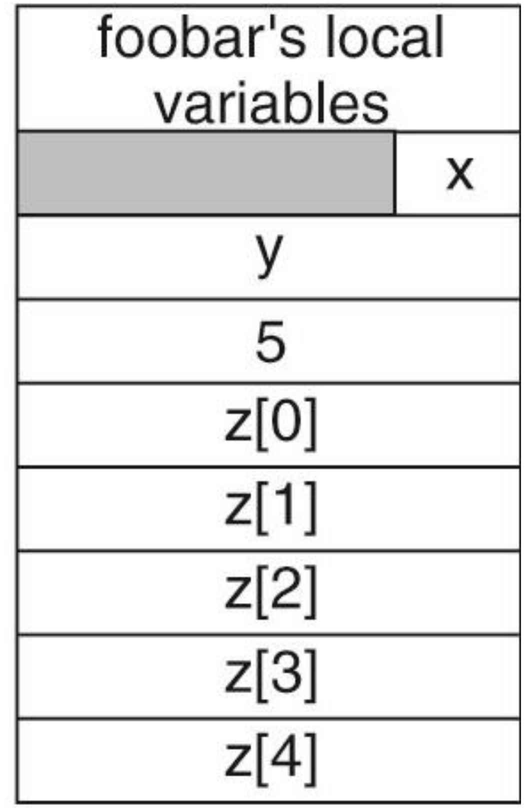


Figure 4-8. (c) The message after being inverted. The little numbers in boxes indicate the address of each byte.

Parameter Specification and Stub Generation

```
foobar( char x; float y; int z[5] )
{
   ....
}
```

(a)



(b)

Figure 4-9. (a) A procedure. (b) The corresponding message.

Asynchronous RPC (1)

- Asynchronous RPC: A client immediately continues once the server accepts the RPC request. The server excutes the RPC request after the acknowledgement
- Deferred asynchronous RPC: The client calls the server with a RPC request and the server immediately acknowledges it. Later the server does a *callback* to the client with the result.

Asynchronous RPC (2)

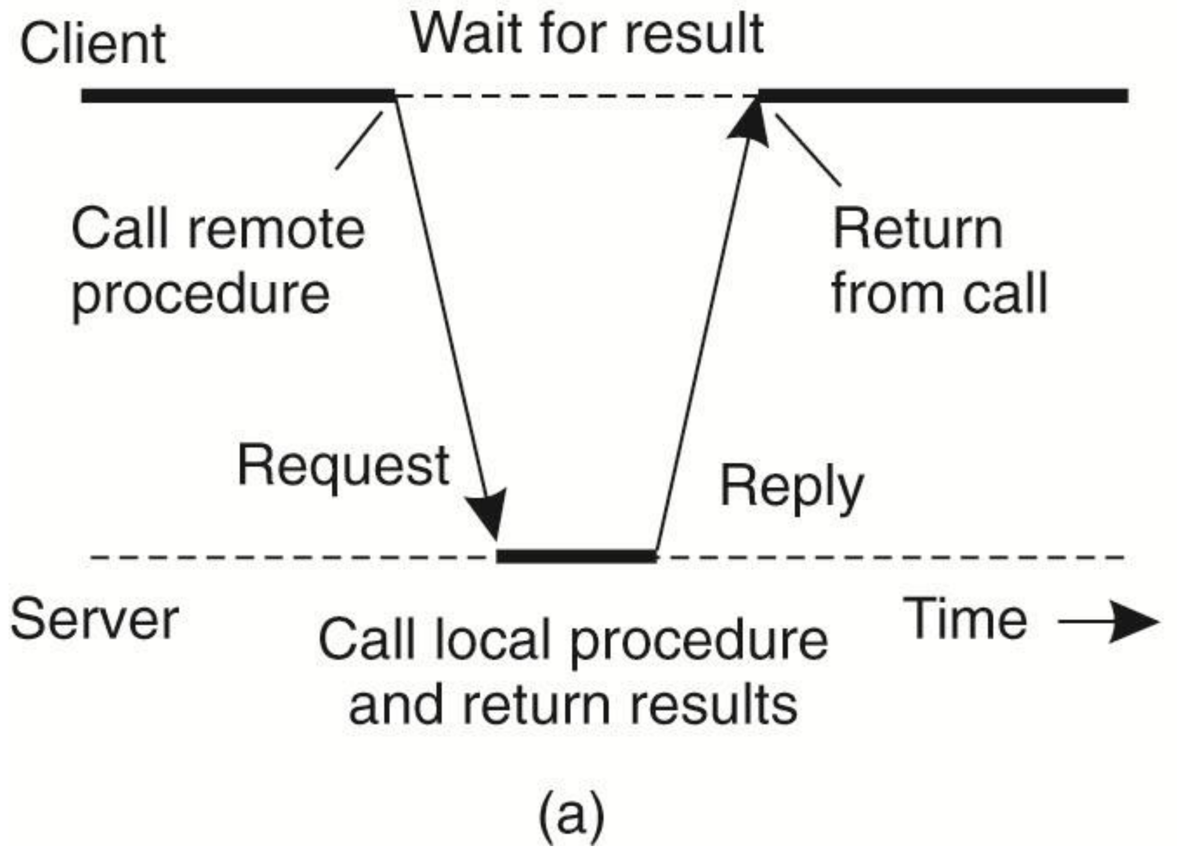


Figure 4-10. (a) The interaction between client and server in a traditional RPC.

Asynchronous RPC (3)

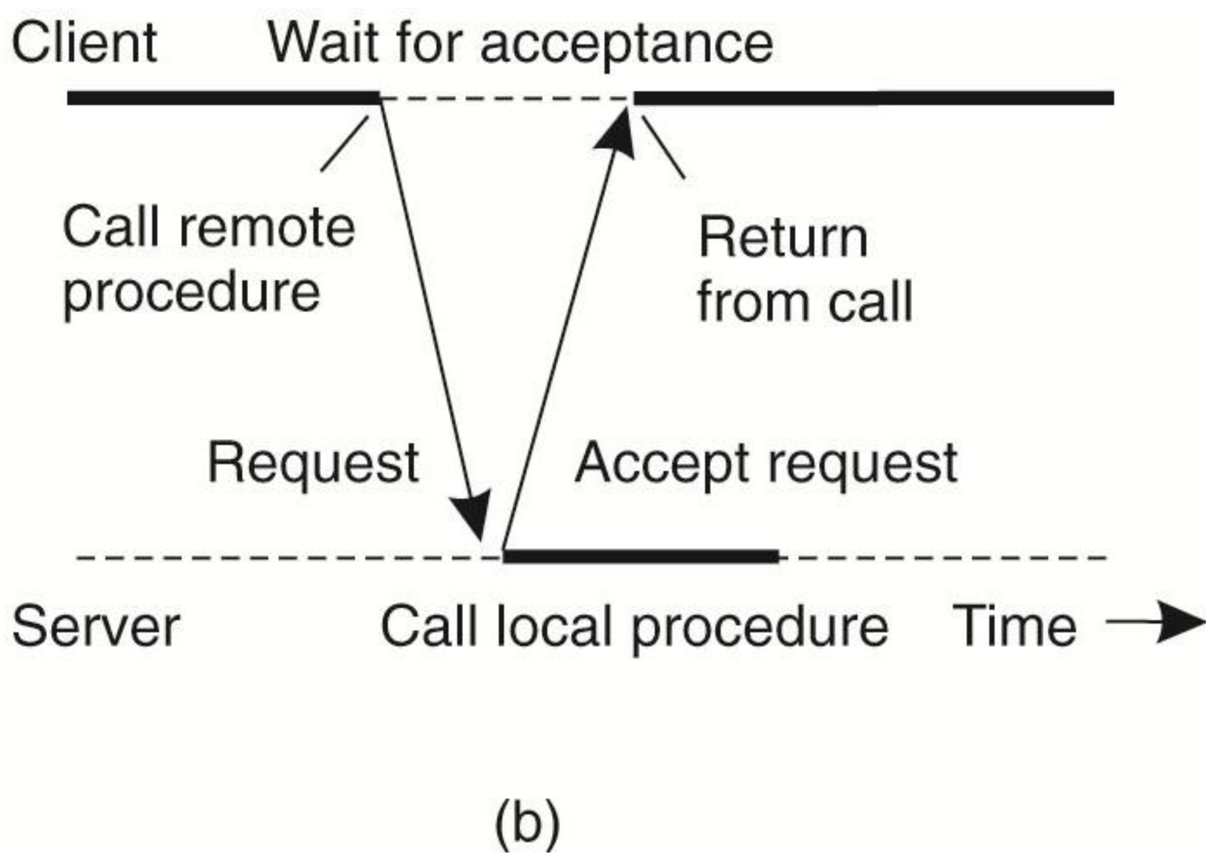


Figure 4-10. (b) The interaction using asynchronous RPC.

Asynchronous RPC (4)

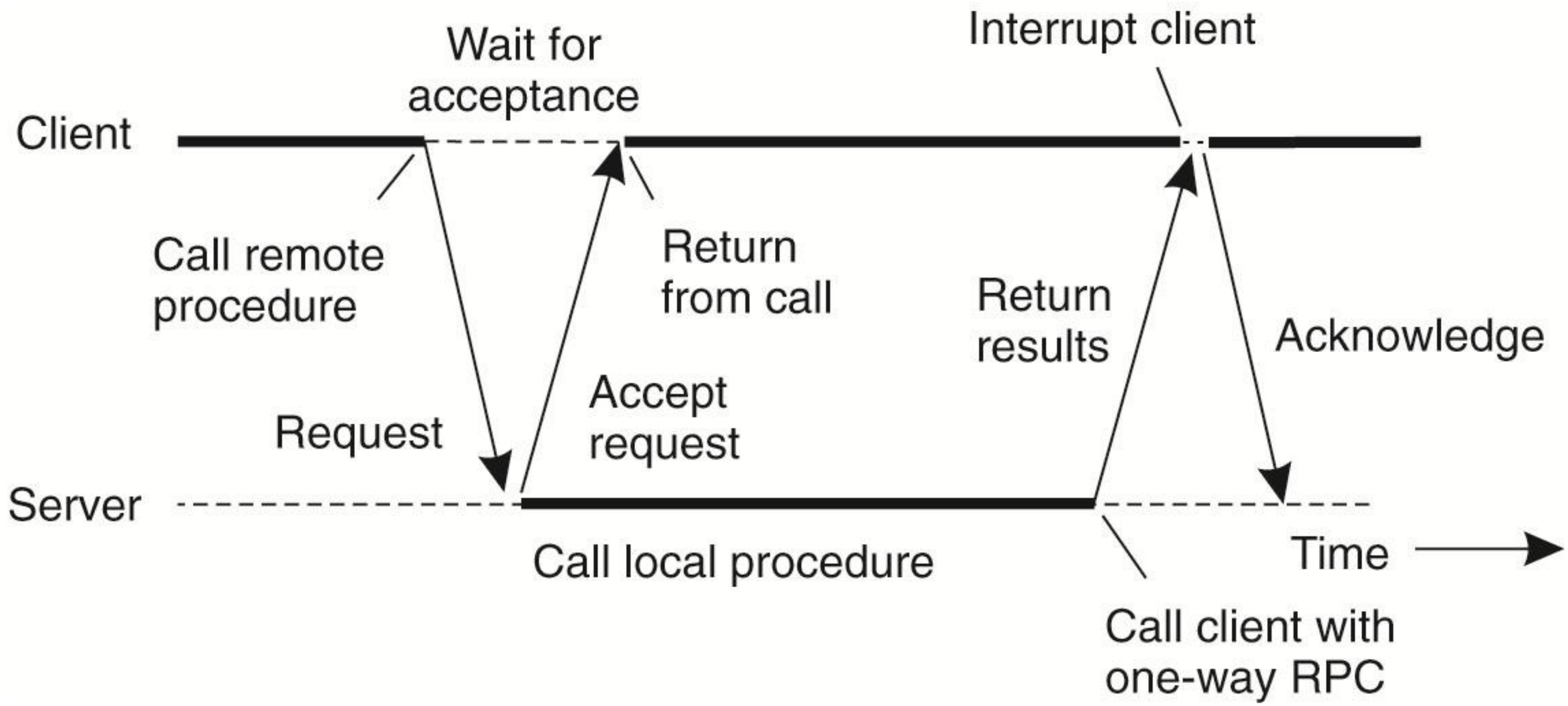


Figure 4-11. A client and server interacting through two asynchronous RPCs.

RPC Implementations

- Distributed Computing Environment / Remote Procedure Calls (DCE/RPC) was commissioned by the Open Software Foundation, an industry consortium now renamed as the Open Group. The DCE/RPC specifications were adopted in Microsoft's base for distributed computing, DCOM.
- Open Network Computing Remote Procedure Call (ONC RPC) is a widely deployed remote procedure call system. ONC was originally developed by Sun Microsystems as part of their Network File System project, and is sometimes referred to as Sun ONC or Sun RPC.

Writing a Client and a Server (1)

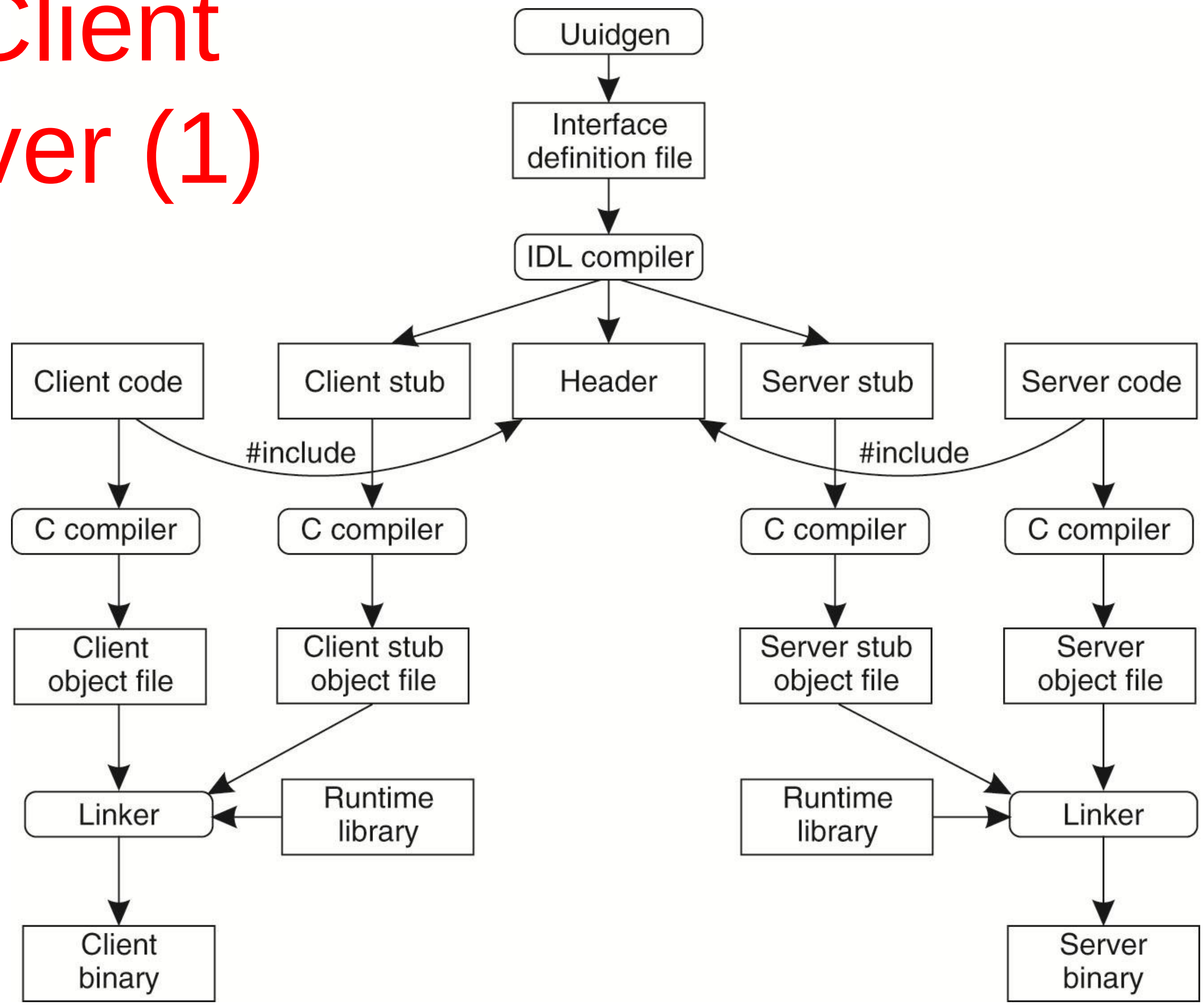


Figure 4-12. The steps in writing a client and a server in DCE RPC.

Writing a Client and a Server (2)

Three files output by the IDL compiler:

- A header file (e.g., `interface.h`, in C terms)
- The client stub
- The server stub

Binding a Client to a Server (1)

- Registration of a server makes it possible for a client to locate the server and bind to it
- Server location is done in two steps:
  1. Locate the server's machine
  2. Locate the server on that machine

Binding a Client to a Server (2)

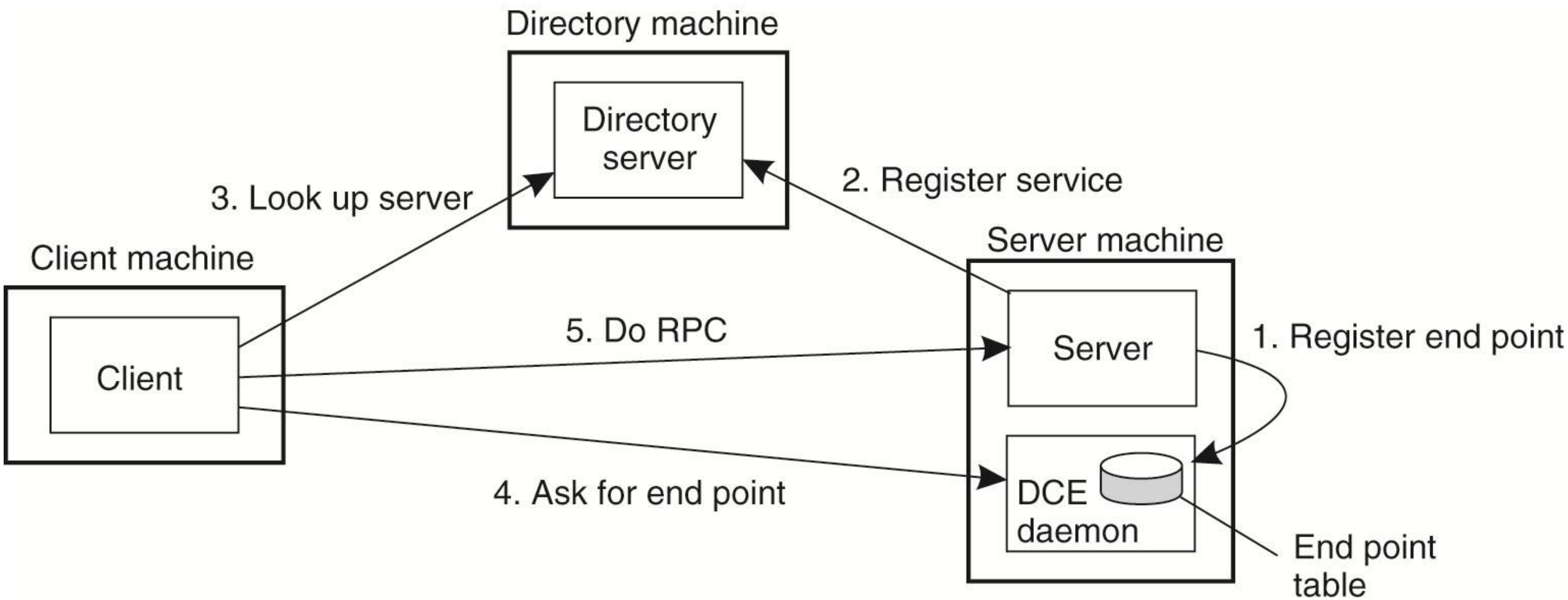


Figure 4-13. Client-to-server binding in DCE.

RPC style implementations

- Java RMI (Remote Method Invocation)
- XML-RPC and its successor SOAP: An RPC protocol that uses XML to encode its calls and HTTP as a transport mechanism
- Microsoft .NET Remoting: offers RPC/RMI facilities for distributed systems implemented on the Windows platform
- CORBA provides remote procedure invocation through an intermediate layer called the *object request broker*.
- Facebook's Thrift protocol and framework
- Google Protocol Buffers

Berkeley Sockets

Primitive	Meaning
Socket	Create a new communication end point
Bind	Attach a local address to a socket
Listen	Announce willingness to accept connections
Accept	Block caller until a connection request arrives
Connect	Actively attempt to establish a connection
Send	Send some data over the connection
Receive	Receive some data over the connection
Close	Release the connection

Figure 4-14. The socket primitives for TCP/IP.

The Message-Passing Interface (1)

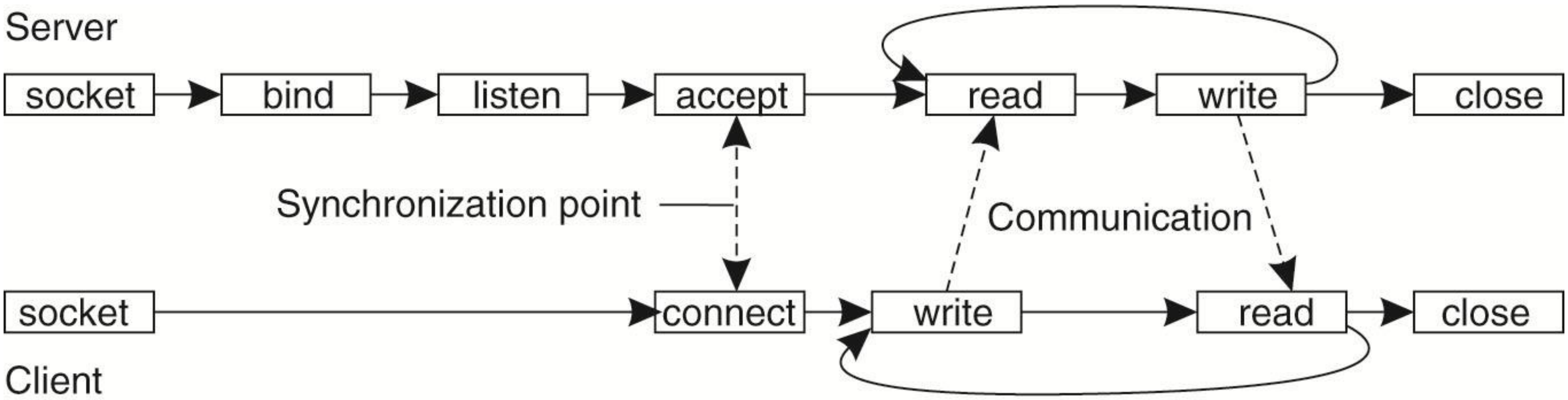


Figure 4-15. Connection-oriented communication pattern using sockets.

The Message-Passing Interface (2)

Primitive	Meaning
MPI_bsend	Append outgoing message to a local send buffer
MPI_send	Send a message and wait until copied to local or remote buffer
MPI_ssend	Send a message and wait until receipt starts
MPI_sendrecv	Send a message and wait for reply
MPI_isend	Pass reference to outgoing message, and continue
MPI_issend	Pass reference to outgoing message, and wait until receipt starts
MPI_recv	Receive a message; block if there is none
MPI_irecv	Check if there is an incoming message, but do not block

Figure 4-16. Some of the most intuitive message-passing primitives of MPI.

Message-Oriented Persistent Communication

Message-Oriented Middleware (MOM) or message-queuing systems support persistent asynchronous communication. These systems provide intermediate-term storage capacity for messages without requiring either the sender or receiver to be active during the message transmission.

Message-Queuing Model (1)

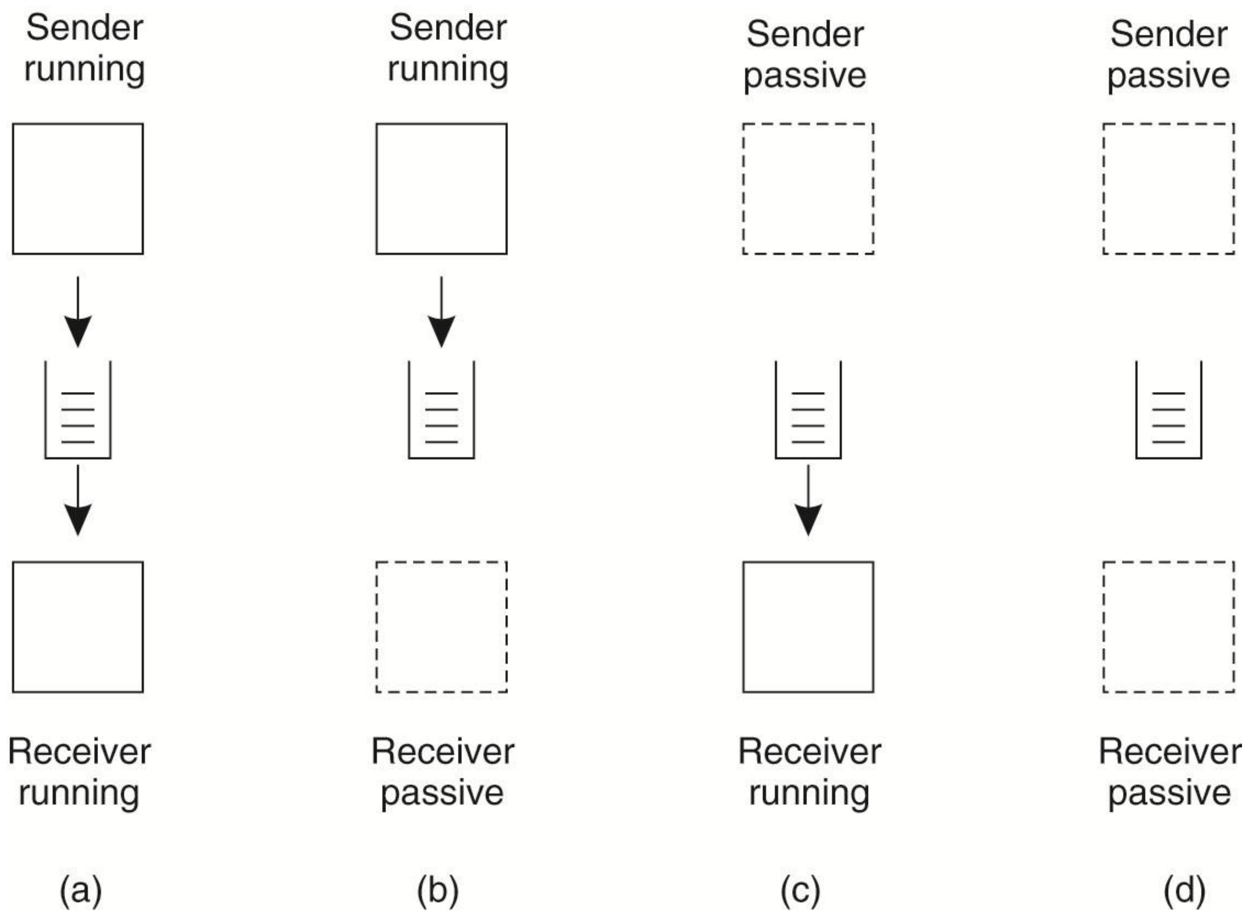


Figure 4-17. Four combinations for loosely-coupled communications using queues.

Message-Queuing Model (2)

Primitive	Meaning
Put	Append a message to a specified queue
Get	Block until the specified queue is nonempty, and remove the first message
Poll	Check a specified queue for messages, and remove the first. Never block
Notify	Install a handler to be called when a message is put into the specified queue

Figure 4-18. Basic interface to a queue in a message-queuing system.

General Architecture of a Message-Queuing System (1)

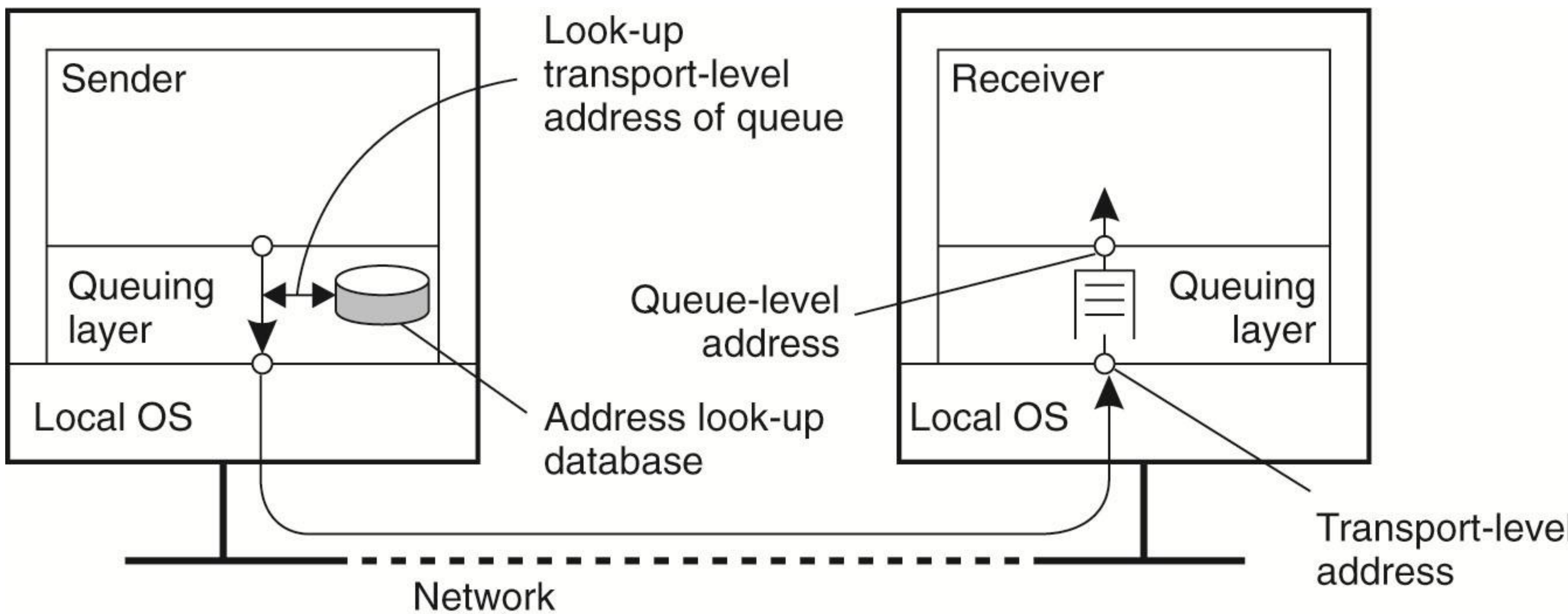


Figure 4-19. The relationship between queue-level addressing and network-level addressing.

General Architecture of a Message-Queuing System (2)

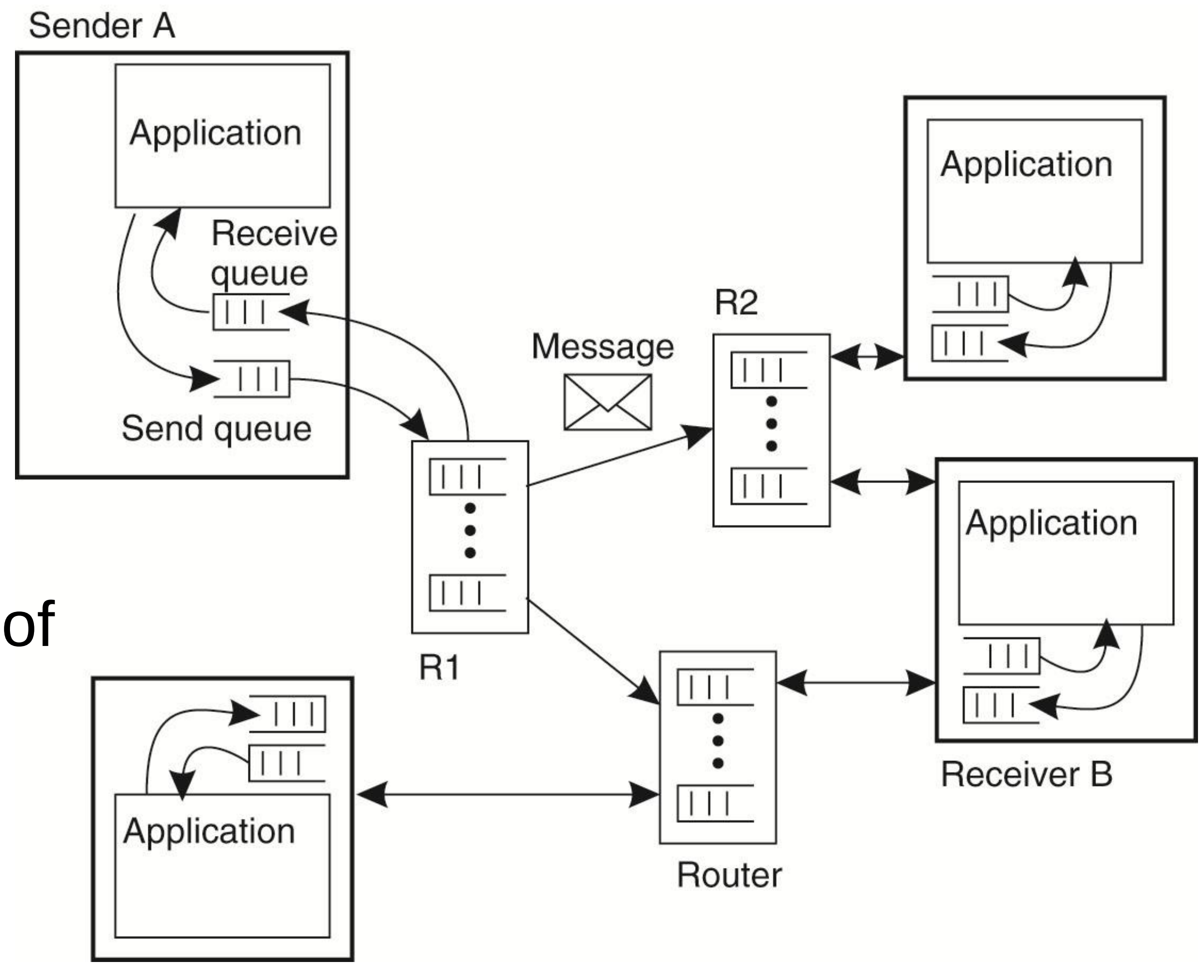


Figure 4-20. The general organization of a message-queuing system with routers.

Message Brokers

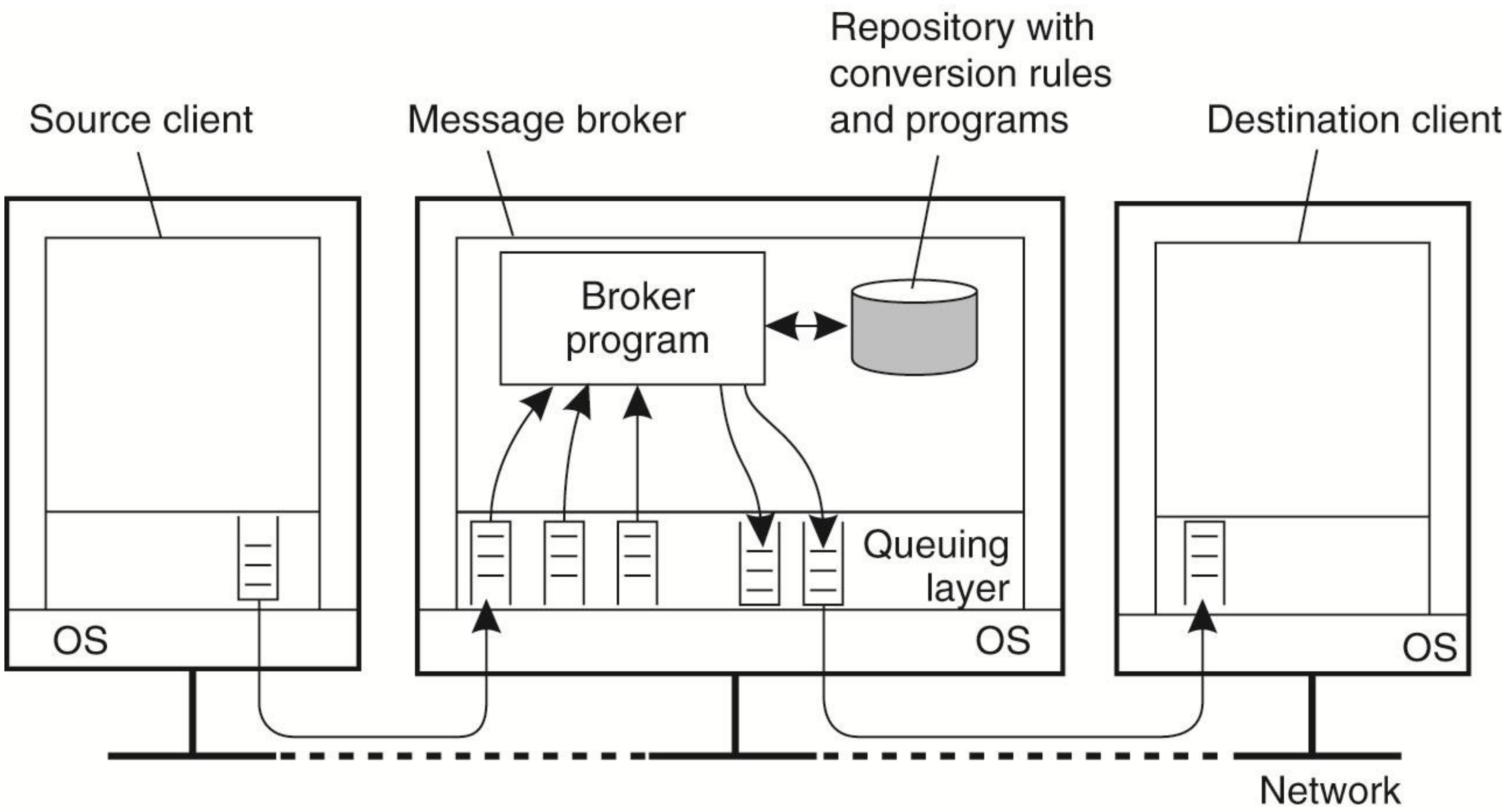


Figure 4-21. The general organization of a message broker in a message-queuing system.

Message-queuing versus Email

- Email systems are aimed at primarily supporting end users while message-queuing systems are usually not.
- Email systems need not provide guaranteed message delivery, message priorities, logging facilities, efficient multicasting, load balancing, fault tolerance and so on for general usage.
- Message queuing systems can be used to implement email, workflow, groupware and batch processing. But the most important usage is the integration of a collection of databases and applications into a federated system.

IBM's WebSphere Message-Queuing System

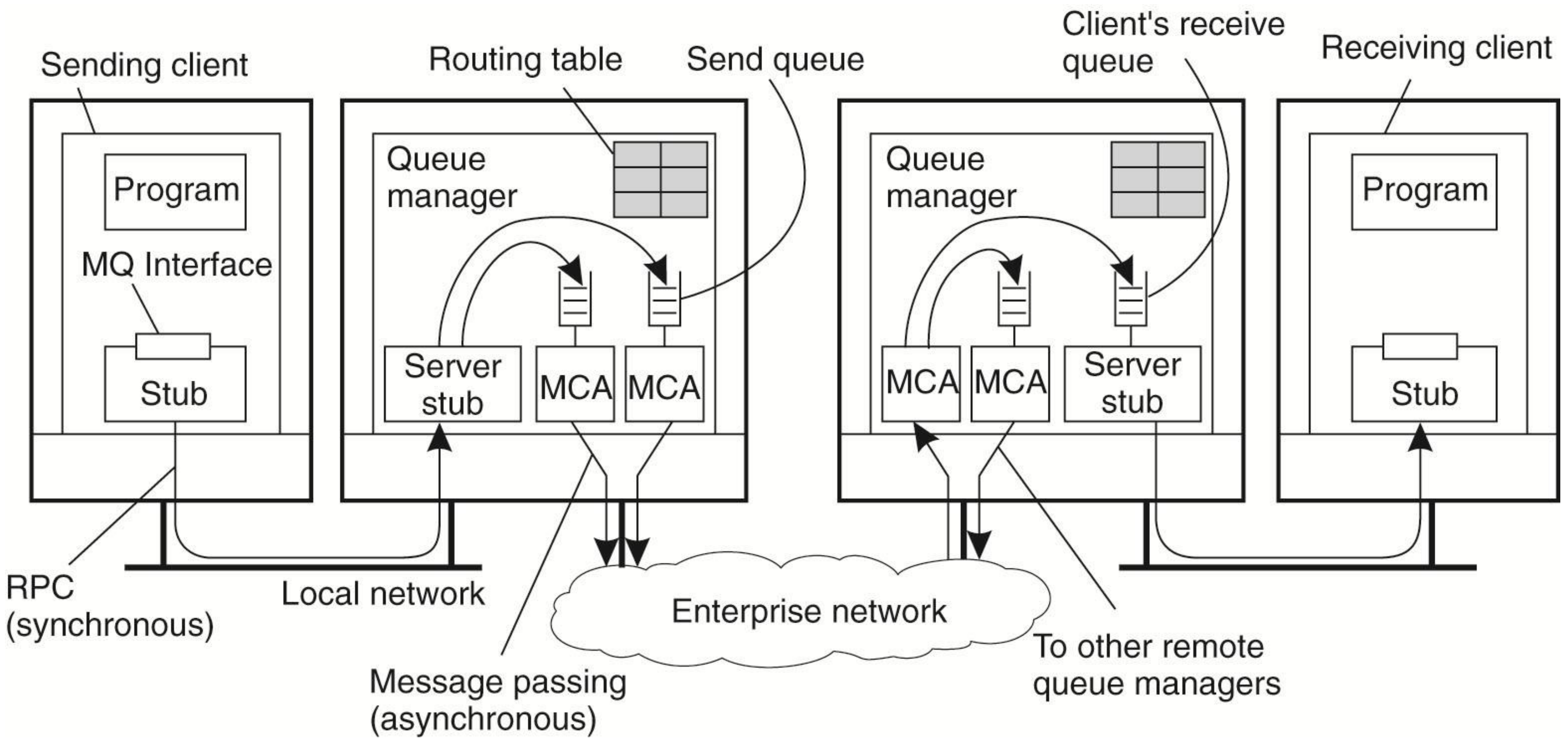


Figure 4-22. General organization of IBM's message-queuing system.

Channels

Attribute	Description
Transport type	Determines the transport protocol to be used
FIFO delivery	Indicates that messages are to be delivered in the order they are sent
Message length	Maximum length of a single message
Setup retry count	Specifies maximum number of retries to start up the remote MCA
Delivery retries	Maximum times MCA will try to put received message into queue

Figure 4-23. Some attributes associated with message channel agents.

Message Transfer (1)

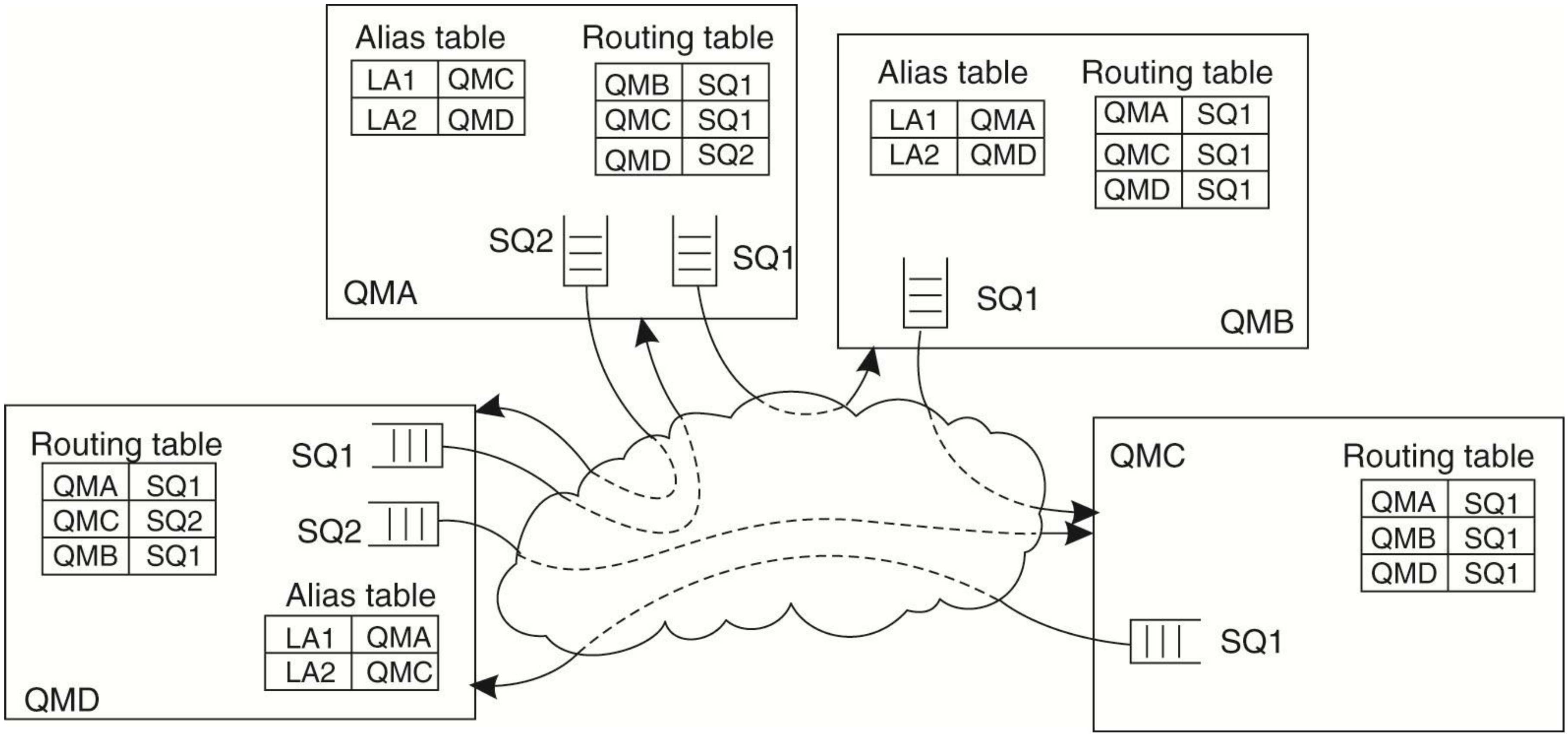


Figure 4-24. The general organization of an MQ queuing network using routing tables and aliases.

Message Transfer (2)

Primitive	Description
MQopen	Open a (possibly remote) queue
MQclose	Close a queue
MQput	Put a message into an opened queue
MQget	Get a message from a (local) queue

Figure 4-25. Primitives available in the message-queuing interface.

Data Stream

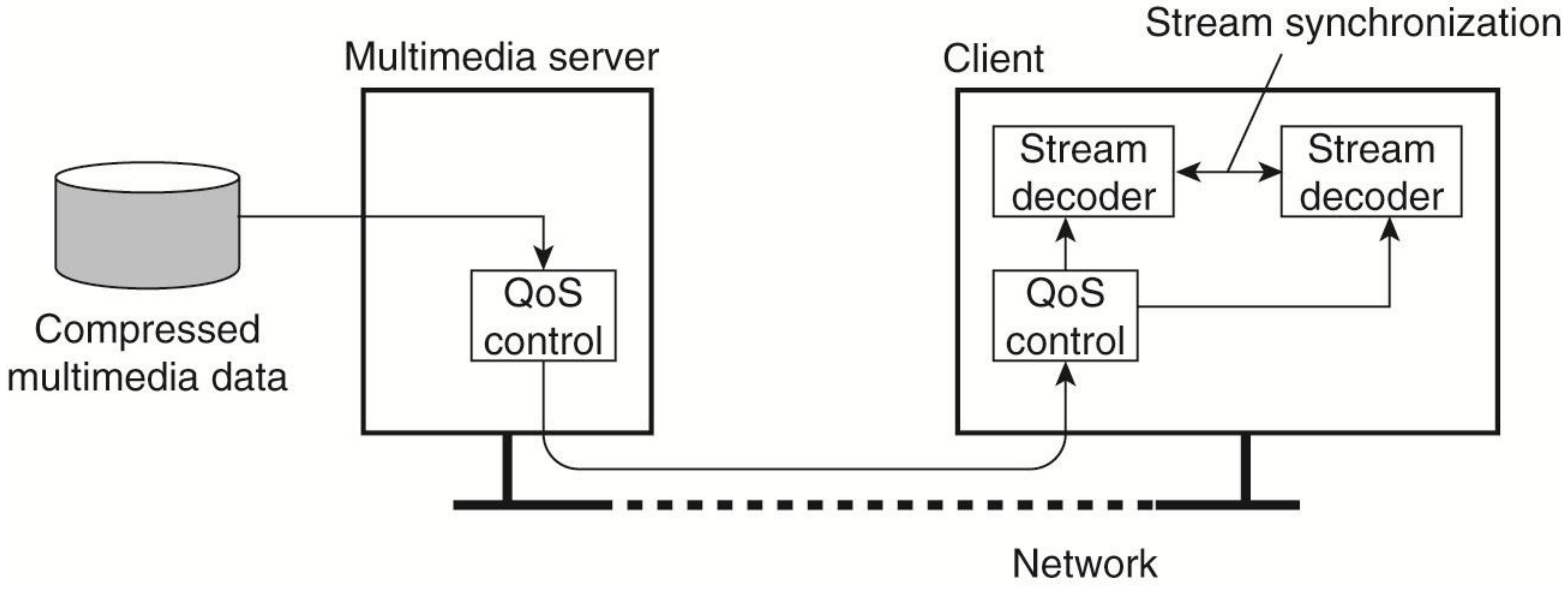


Figure 4-26. A general architecture for streaming stored multimedia data over a network.

Streams and Quality of Service

Properties for Quality of Service:

- The required bit rate at which data should be transported.
- The maximum delay until a session has been set up
- The maximum end-to-end delay .
- The maximum delay variance, or jitter.
- The maximum round-trip delay.

Enforcing QoS (1)

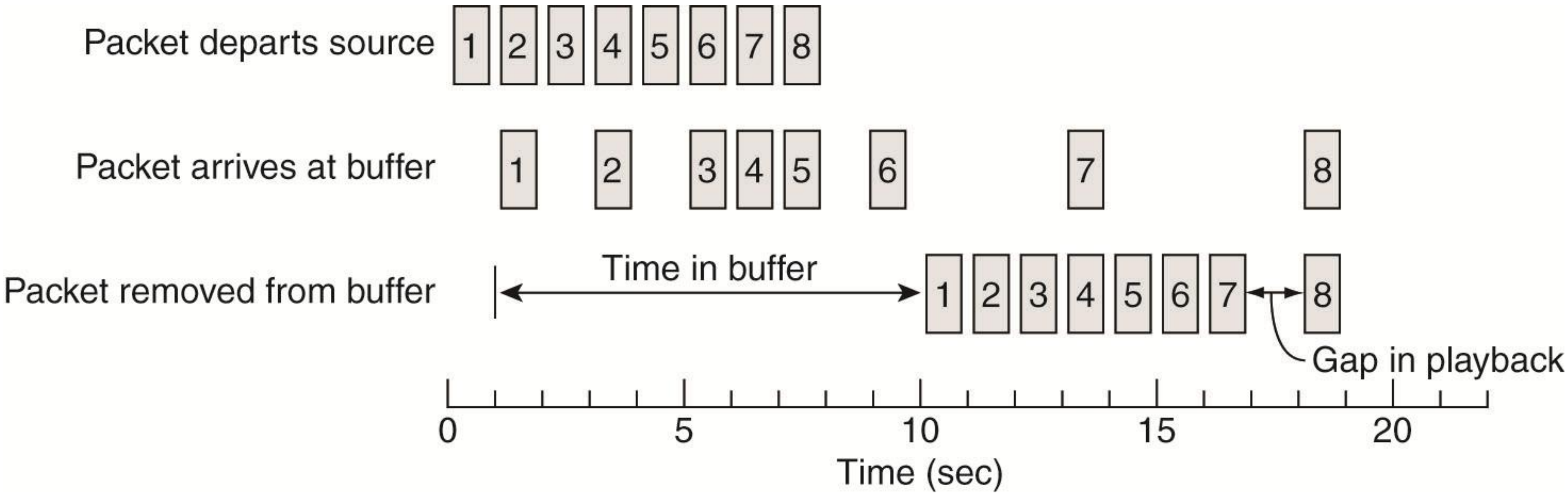


Figure 4-27. Using a buffer to reduce jitter.

Enforcing QoS (2)

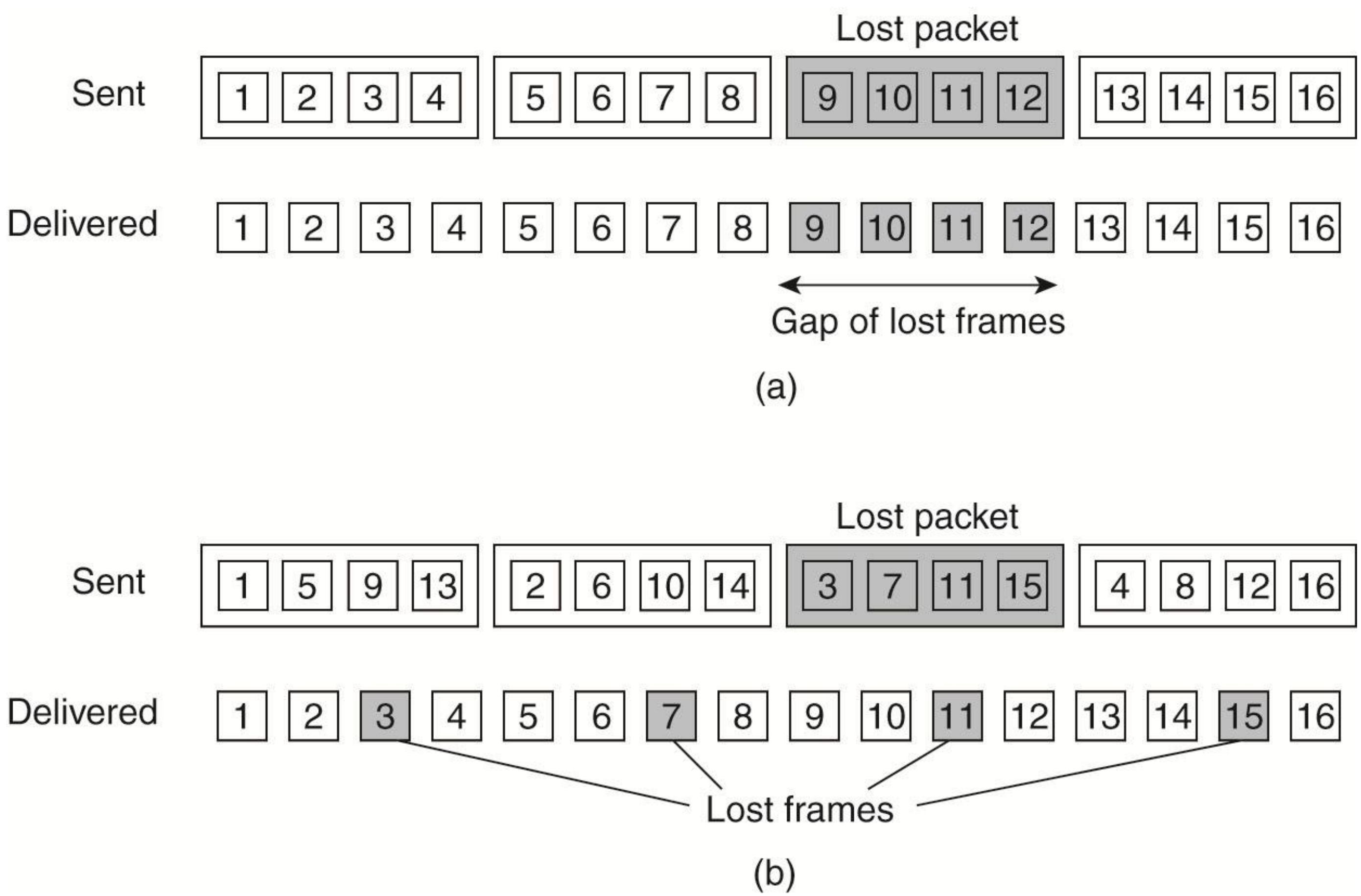


Figure 4-28. The effect of packet loss in (a) non interleaved transmission and (b) interleaved transmission.

Synchronization Mechanisms (1)

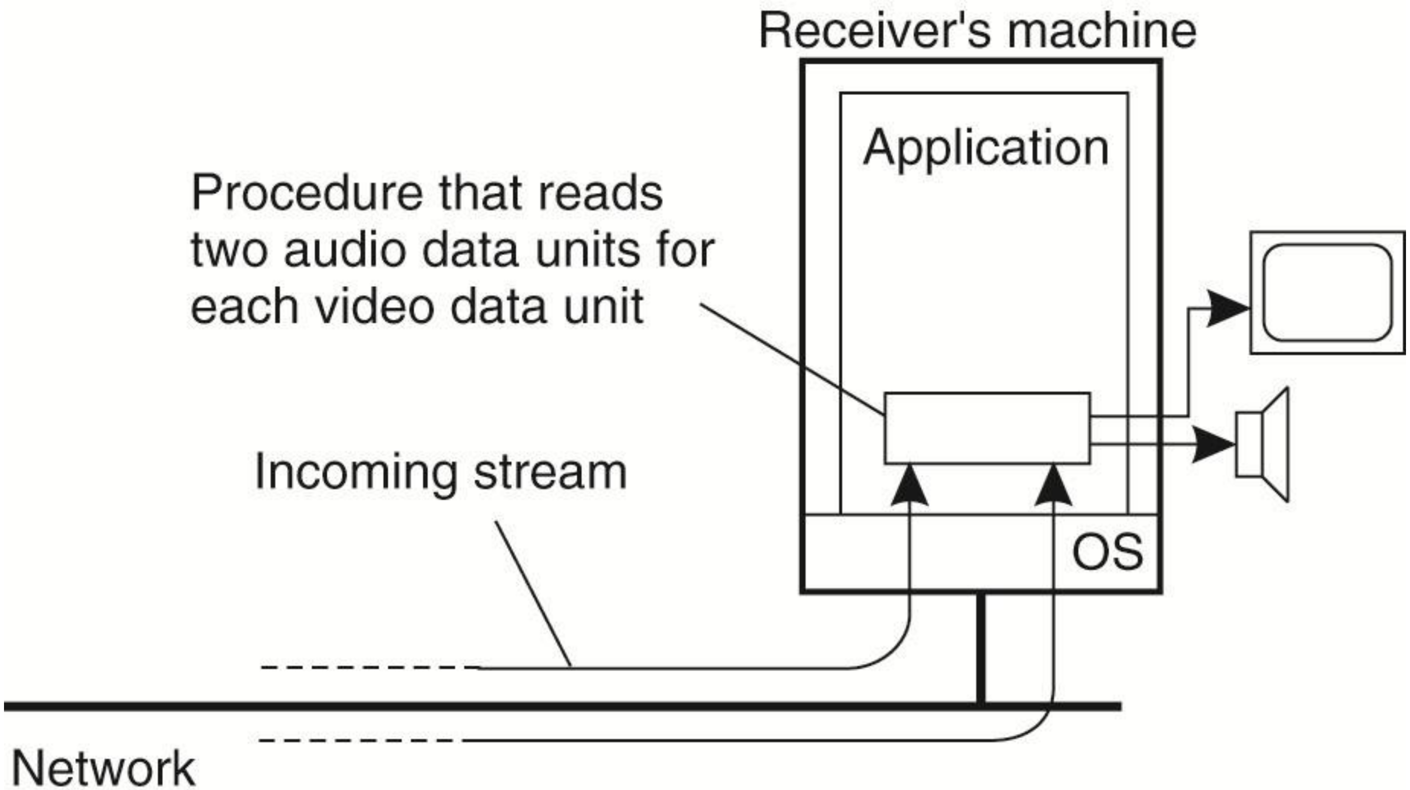


Figure 4-29. The principle of explicit synchronization on the level data units.

Synchronization Mechanisms (2)

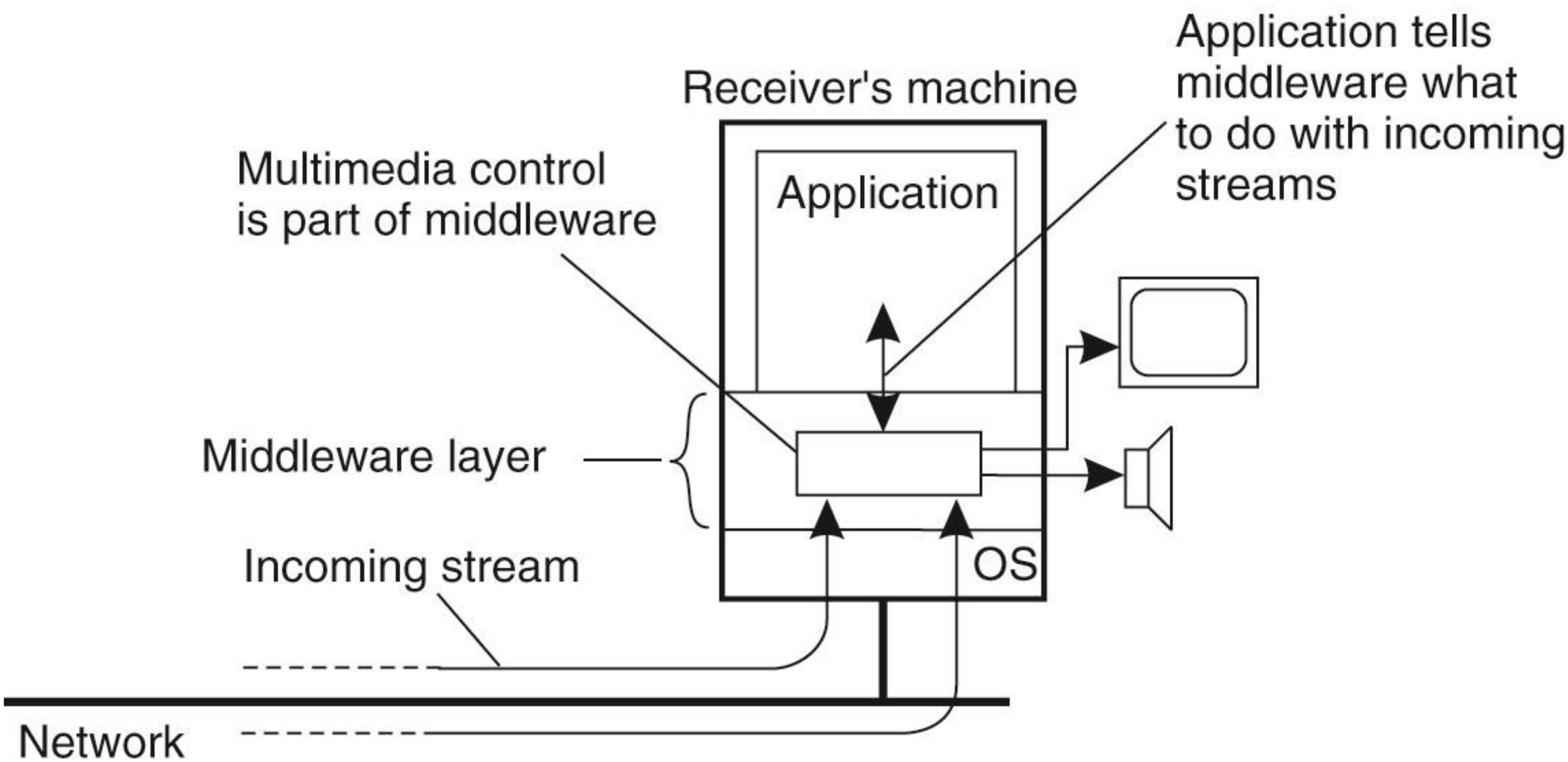


Figure 4-30. The principle of synchronization as supported by high-level interfaces.