3 Protocols, basic communication architectures and services

3.1 Protocols

Protocols are sets of rules for coordinating and regulating the exchange of messages between two communication partners, e.g. between two computers in a computer network.

Central tasks (services) of the protocols are

- Addressing of the communication units,
- Control of the data flow, flow control,
- Ensuring of data transmission, error detection and correction.

Two types of basic protocols are distinguished: **connection-oriented protocols** and **connectionless protocols**. Connection-oriented protocols realize a fixed connection for the duration of the data transmission. In connectionless protocols, the data packets are transported independently of each other, possibly also via different paths, from the sender to the receiver. The following table provides an overview of the functionalities and areas of application:

Type	Function	Field of application
connection-oriented	Establishing **virtual connection (*virtual circuit*)**, Three phases: - Connection setup, - Data transfer, - Disconnection, (comparable to phone call) virtual uninterrupted communication path: **„*End-to-End*“-Connection**	Phone call, Terminal session, Data transfer
connection-less	Transmission of self-contained data packets (Datagrams), Jumps from data distributor to Data distributor: **„*Hop-by-Hop*“ connection**	Letter, telegram and parcel services, Access to databases and directory services, Internet

To reduce the complexity of the normally highly structured software, the protocols and thus the information networks are often logically constructed in the form of layers. Each layer (N) offers certain communication services to the next higher layer (N+1).

3.2 Communication architectures

The network architectures most commonly used in communication networks at present are the ISO/OSI reference model and the TCP/IP reference model. The layers of the different architectures will be briefly considered and compared with each other.

3.2.1 ISO/OSI reference model

3.2.1.1 Construction of the layer model

The ISO/OSI reference model (ISO: International Standards Organization, OSI: Open Systems Interconnection) is based on a proposal by the International Standards Organization (ISO), an international organization for the discussion and introduction of standards. The basic idea of the model involves the establishment of communication possibilities between open systems, i.e. systems that are not self-contained and open to the outside world.

The ISO/OSI model represents the current internationally recognized standard in the entire field of telecommunications.

The ISO/OSI model is a communication model with seven hierarchically structured layers, i.e. it consists of layers that build on each other.

The following principles led to the construction of the seven-layer network architecture:

- Each layer shall characterize a new level of abstraction.
- Each layer shall introduce a new functionality and provide well-defined services.
- The function definitions shall take into account internationally standardized protocols.
- The information flow over the interfaces between the layers shall be minimal.
- The total number of layers should be so large that, on the one hand, each layer is used for only one functionality, but, on the other hand, the entire network architecture does not become bulky.

The ISO/OSI model is only a model for the design of hardware and software in the network. The design principles discussed are not design specifications. Depending on the task of a specific network, the structure and function can be changed.

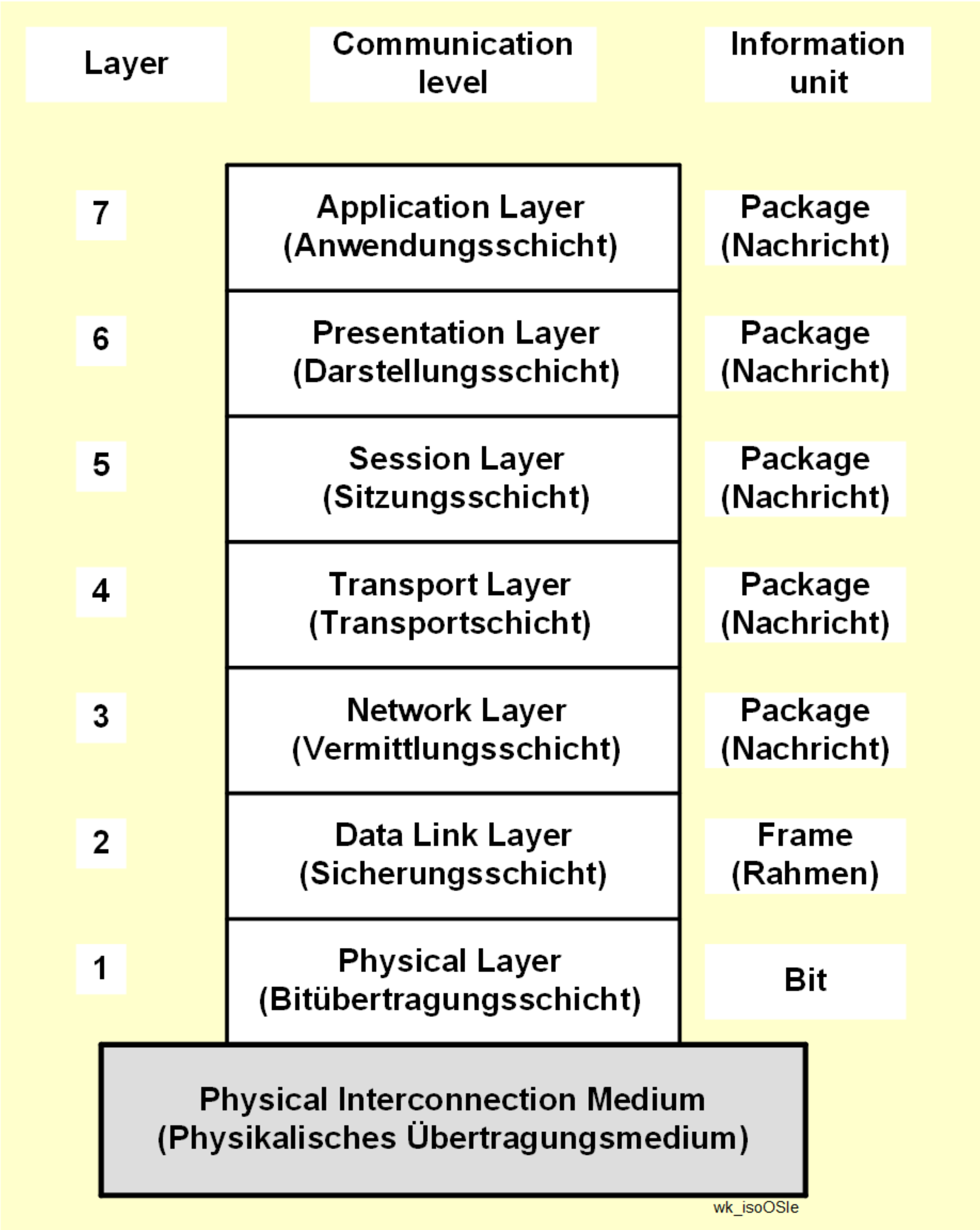

Fig. 3.2.1.1-1: Layer structure of the ISO/OSI reference model

The following overview gives a rough idea of the tasks of the seven layers of the ISO/OSI model:

Layer 1: Physical Layer

- Transmission of signals and data in the form of a bit stream,
- Description of cables, pins and connection technology (physical conditions),

Layer 2: Data Link Layer

- Preparation of the data for the actual transfer,
- Completing data packets with sender and recipient information,
- Releasing the connections,
- Detection and correction of data transmission errors,

Layer 3: Network Layer

- Management of routing through the network,
- Providing functions for establishing and terminating connections,
- logical channel switching,

Layer 4: Transport layer

- Responsibility for the correct transport of data,
- Determination of the form and sequence of data during transmission,
- Additional error correction possibilities by repeating the data transport,

Layer 5: Session layer

- Description of the activities of the dialog flow control, e.g. security queries (password queries),

Layer 6: Presentation Layer

- Definition of character representation with syntax and semantics,
- reformatting between different character codes (e.g., ASCII <-> UNICODE),

Layer 7: Application Layer

- Description of the interfaces to the actual applications, e.g. graphical user interfaces (GUIs).

3.2.1.2 Layer communication

A group of layers and protocols forms a network architecture. The protocols arranged on top of each other form the protocol stack.

Each layer can be composed of several hierarchically equivalent subsystems. Each subsystem can in turn consist of one or more instances (entities). Instances in the same layer are called peer entities (peers).

Peers in different hardware units communicate with each other according to standardized protocols (layer protocols, peer-to-peer protocols) that define the rules and conventions for exchanging information.

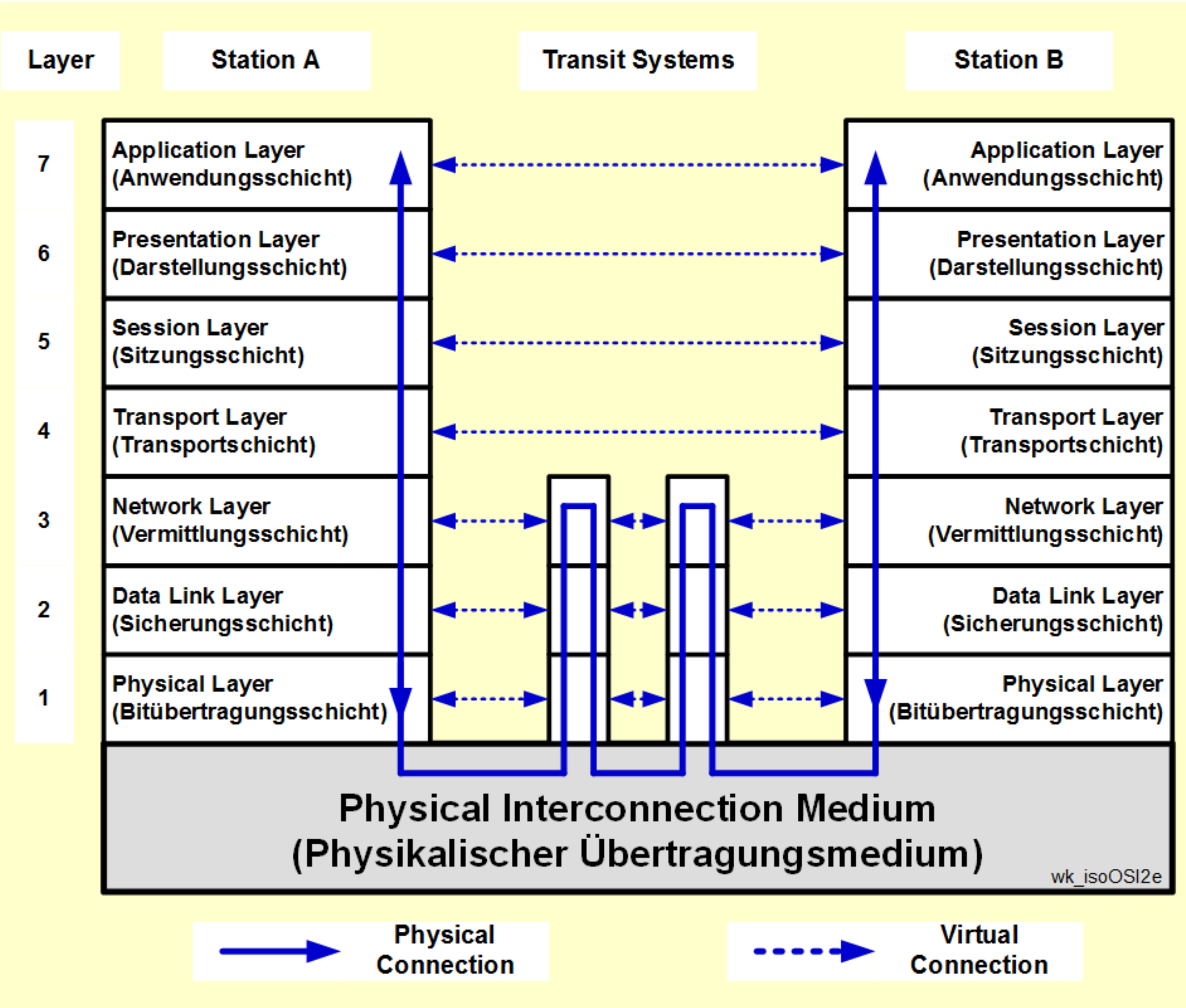

Fig. 3.2.1.2-1: Connections in the ISO/OSI layer model

Communication between identical layers of different communication partners (peer processes) is only virtual in nature. Physically, information is transferred from one layer to the neighboring layer by the sending layer appending control information and passing on the original data to the next layer down until the lowest layer is reached. This passes the information on to the receiver via the transmission medium (physical communication). There, the data is passed on step by step from the lowest layer via all intermediate layers to the application layer.

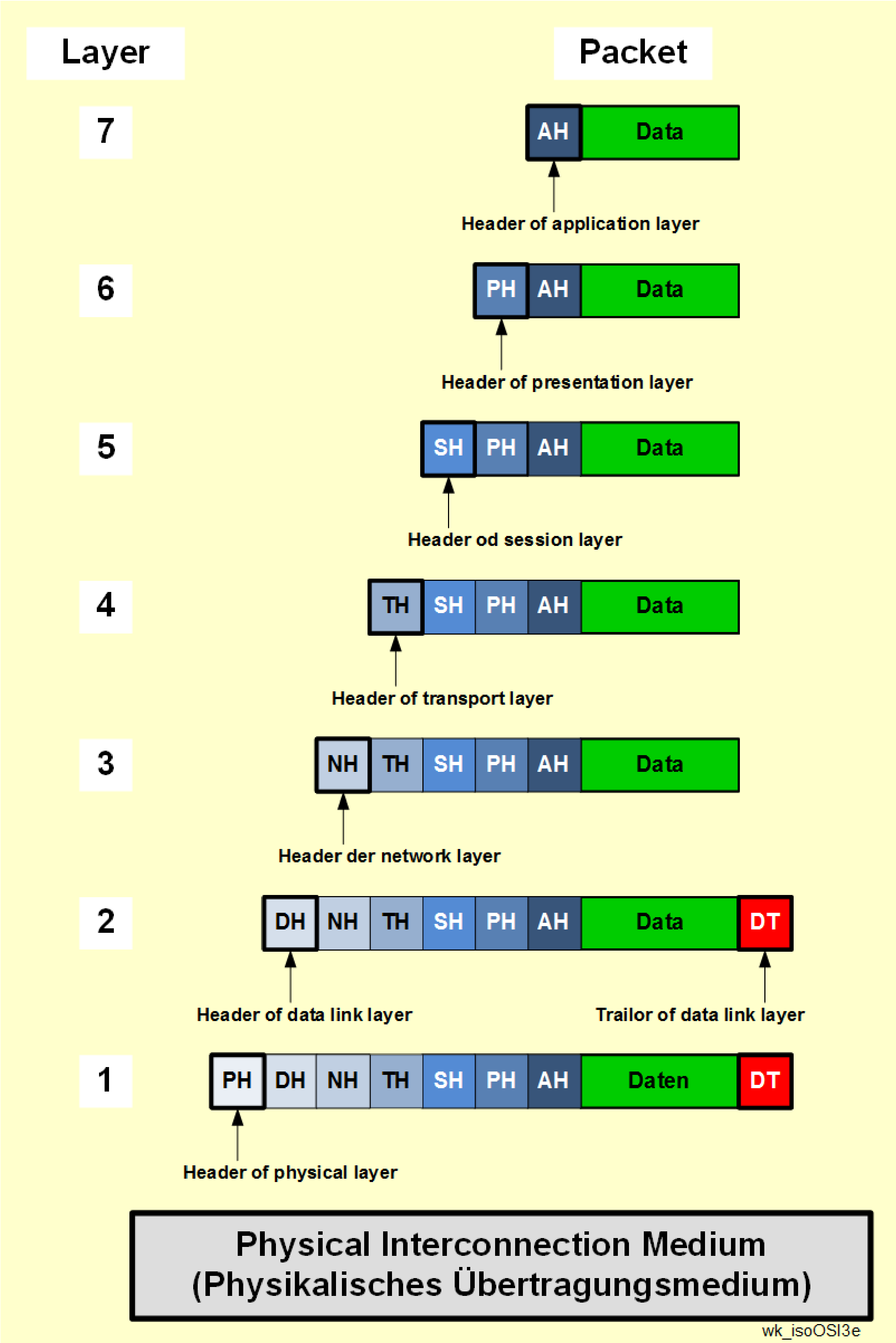

Fig. 3.2.1.2-2: Structure of the data packages composed of header information and user data

Between each layer there is an interface that defines all services that layer (N-1) provides to the next higher layer N and that layer N can request from layer (N-1). Interfaces where instances of adjacent layers exchange services are called service access points (SAP). Each service access point has a unique address.

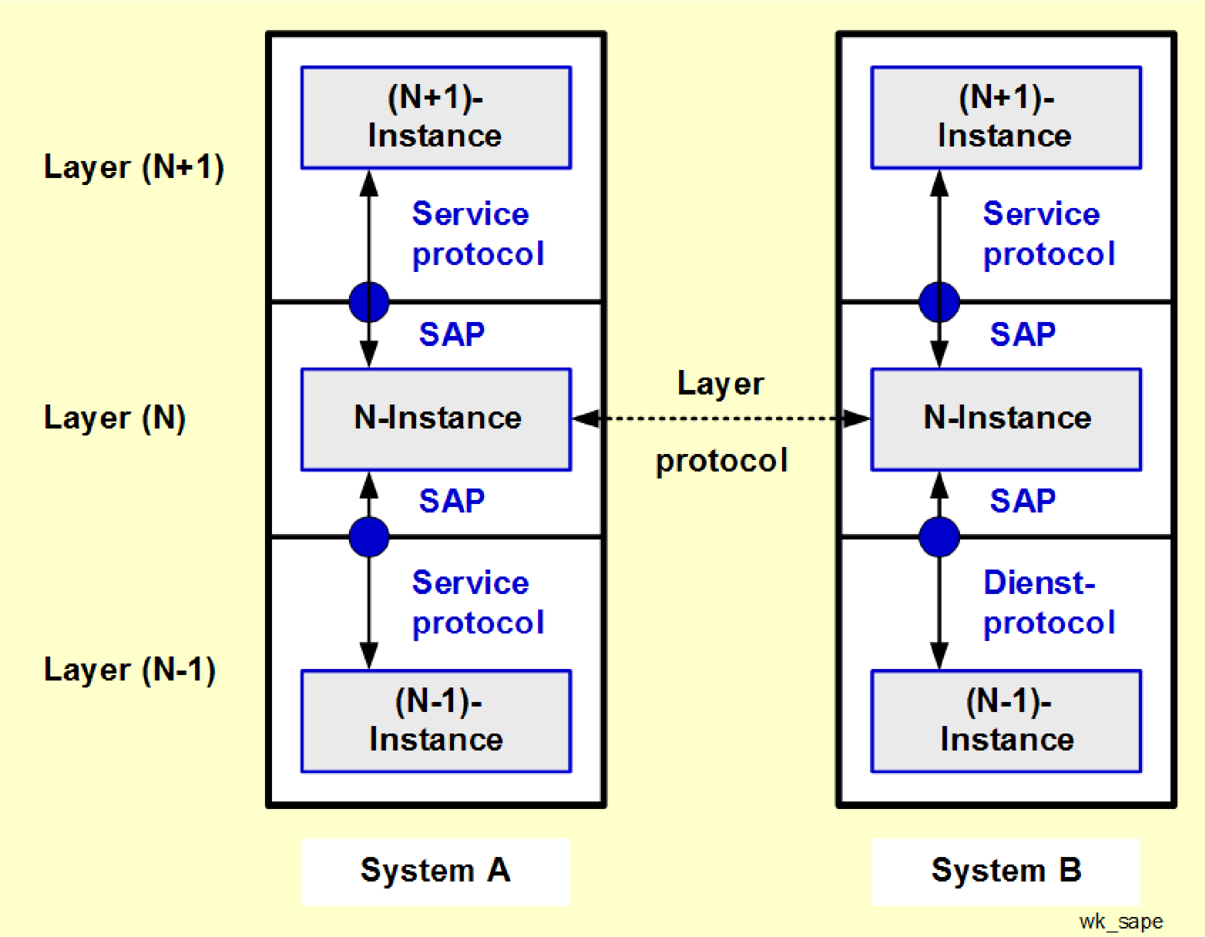

Fig. 3.2.1.2-3: Layer protocols and service protocols

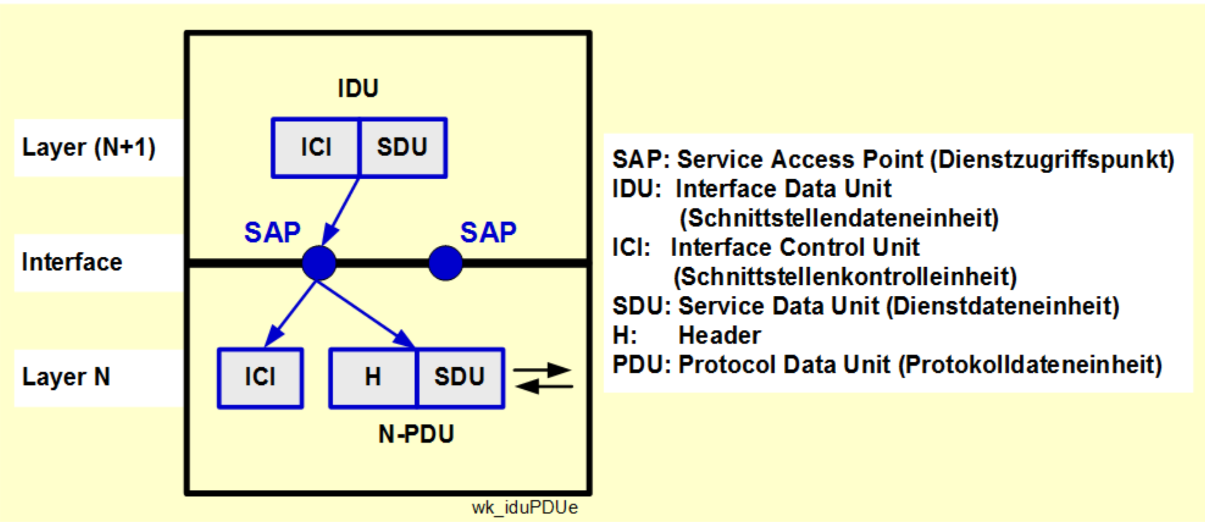

Fig. 3.2.1.2-4: Interface in the ISO/OSI architecture

Each layer N (except the highest layer) is the service provider for the next higher layer (N+1), the service user. The interaction of the layers can be described with the help of a recursive running instruction:

```
for (N = Nmax; N >= 1; N--)
    serviceOffer(N) = Functionality(N) + serviceOffer(N-1);
```

with N: number of the current layer, Nmax: number of the highest layer.

Data exchange between neighboring layers is regulated by the service protocols (Layer-to-Layer Protocol). During vertical data exchange between layer (N+1) and layer (N), layer (N+1) sends an interface data unit (IDU) to layer N for the service request. The interface data unit IDU is composed of the interface control information (ICI), e.g. information on the length of the user data, and the service data unit (SDU), the actual user data.

During horizontal data transfer between partner instances in the same layer, the service data units SDUs are divided into packets, provided with headers and sent in the form of protocol data units (PDU).

3.2.2 TCP/IP Reference Model

3.2.2.1 Introduction

The **TCP/IP reference model (TCP: Transmission Control Protocol, IP: Internet Protocol)** was originally developed for ARPANET (Advanced Research Project Agency), a network sponsored by the U.S. Department of Defense (DoD), and later transferred to the Internet.

Today, the TCP/IP protocols are the de facto market standard in the LAN and Internet area. The protocols are available for all major computer types. The basic principles of the TCP/IP protocol are stored in the so-called “Request for Comments (RFCs)”, which are freely available on the Internet.

The basic design considerations of the TCP/IP model were

- Seamless integration of different hardware in subnetworks
  (cable, satellite, wireless network, different host computers),

- "Survivability" of the network in case of destruction of subnetworks
  (intact network with functioning transmitter and receiver),

- flexible architecture for different applications
  (file transfer, real-time voice transmission, robot communication, ...).

Networks based on the TCP/IP protocol are packet-switched networks, based on an initially connectionless base layer. The protocol stack consists of four different protocol layers:

- Subnetwork layer (network access layer),
- Internet protocol layer (network layer),
- Transport layer,
- Application layer.

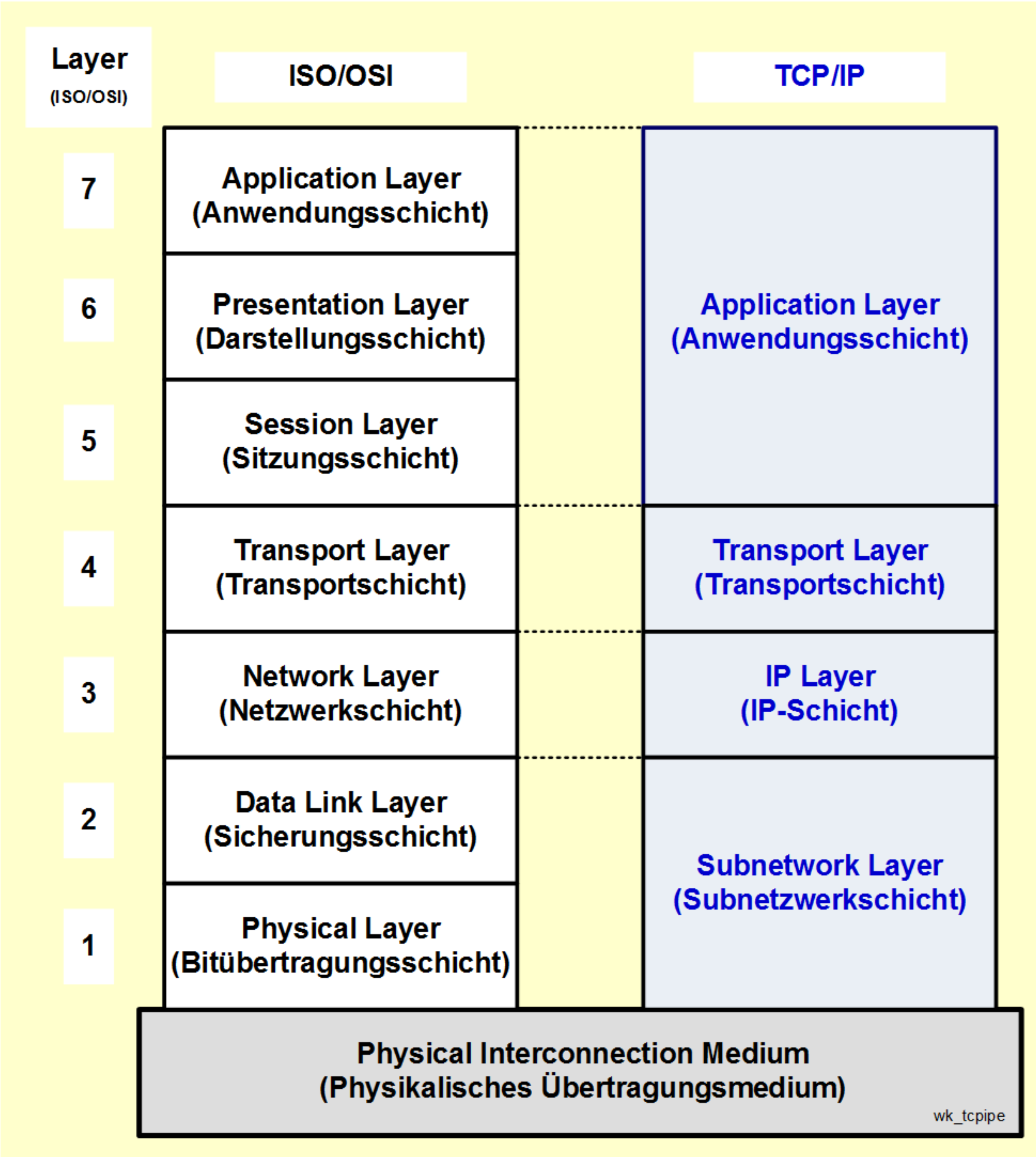

Fig. 3.2.2.1-1: ISO/OSI architecture (left) and TCP/IP protocol stack (right)

3.2.2.2 Subnetwork Layer

The **subnetwork layer (network access layer, host-to-host layer)** forms the lowest layer of the TCP/IP protocol. It is not clearly defined in the protocol. The communication model is satisfied with the reference to the fact that a host must connect to the network via a specific protocol in order to send IP packets. These protocols vary from host to host and from network to network (Ethernet, Token Ring, IEEE protocols, Bluetooth, IrDA, ...).

The subnetwork layer summarizes the physical layer and the data link layer of the ISO/OSI model.

3.2.2.3 Internet Protocol Layer

The **Internet Protocol layer (IP layer, Internet layer)** forms the basic "safety pin" that holds the entire network together. It enables the sender (host) to send information packets in any subnet and to send them connectionless to receivers in any subnet.
The IP layer corresponds in its functionality approximately to the network layer (layer 3) in the ISO/OSI model.

The Internet layer defines a packet format and a protocol (Internet protocol) for packet delivery. In addition to the main protocol of the network layer, the Internet protocol, this layer contains two auxiliary protocols:

- **Internet Control Message Protocol (ICMP):**
  - Generation of error messages (e.g., parameter problems) and information messages (e.g., routing) during communications,

- **Internet Group Management Protocol (IGMP):**
  - Based on Internet Protocol,
  - handling of multicast connections.

The most important subtasks of the Internet layer are

- Network Service:
  Adaptation of the higher layers to the different hardware protocols,

- Routing: Path selection between communication partners and networks,

- Support of addressing mechanisms,

- Error detection,

- Multiplexing.

3.2.2.4 Transport Layer

The **transport layer** is positioned above the Internet layer (IP layer) in the TCP/IP model, and it corresponds to the transport layer (layer 4) in the ISO/OSI communication model.
It enables two partner entities in the sender and in the receiver to communicate via two end-to-end protocols:

- **Transmission Control Protocol (TCP):**
  - **reliable connection-oriented protocol** for the error-free delivery of a byte stream between two entities in the Internet,
  - sender-side decomposition of the byte stream into individual messages,
  - data transport,
  - merging of the messages to an output stream on the target machine (data destination machine,
  - flow control to avoid "data flooding" in the case of different speed of the transmitting and receiving equipent,
  - Multiple use of communication links (multiplexing),
  - error handling.

- **User Datagram Protocol (UDP):**
  - **unreliable connectionless protocol** without flow control,
  - used for one-time queries in client/server systems, where speed has higher priority than reliability, e.g. for voice or image transmission of voice or images.

3.2.2.5 Application Layer

The **application layer (processing layer)** comprises all higher layers in the ISO/OSI communication model.

Some protocols of the application layer are

- **TELNET (virtual terminal):**
  - Logging in and working of a user on a remote machine,
- **SSH (Secure Shell):**
  - TELNET with secure data transfer (encryption, authentification, ...),
- **FTP (File Transfer Protocol):**
  - Transferring files between different machines,
  - Managing files independently of the computer environment,
- **SMTP (e-mail, Simple Mail Transfer Protocol):**
  - Sending and receiving electronic mail (e-mail),
- **DNS (Domain Name Service):**
  - Conversion of host names to network addresses,
- **HTTP (Hyper Text Transfer Protocol):**
  - Fetching pages from the World Wide Web (WWW),
- **HTTPS (Secure HTTP):**
  - HTTP protocol with secure data transfer (encryption, ...).

3.2.3 Application Protocols

3.2.3.1 General

In addition to the basic service and layer protocols, a large number of application protocols are defined in network communication that regulate communication between multiple nodes and various tasks.

Examples are

- Client/Server protocols,
- Producer/Consumer protocols,
- Producer/Subscriber protocols.

As an example, the client/server model will be briefly presented in this chapter.

3.2.3.2 Client/Server model and Peer-to-Peer connections

The client/server model is a design principle for the application layer of a network. It always is programmed above the transport layer in network operating systems.
In the simplest case, two partners (computers, processes) are required to set up a communication link. They communicate with each other via a transmission link. The client/server model divides such an application into two partners, the client and the server, which request information and respond to requests:

Client (Client-Programm)	**Server (Server-Programm)**
- Sending connection requests over the network to the server,	- Response to the requirements - often self initialization
- Request of information or services (e.g. login on a remote computer),	- Supply of special information and services (print server, email server, …) **- iterative server:** Sequential processing of all requirements, **- parallel server (concurrent server):** setting up parallel proceses and simultaneous processing of different requests (prerequisite: multitasking operating system).

The client/server model modularizes the software for data communication at the application layer level. It handles information transfer in the form of a virtual connection (virtual circuit without a physical communication line), which simulates a point-to-point connection between the application layers.

In the case of peer-to-peer connections, the communication partners are equal. Each partner can be used both as a client and as a server.

3.3 Services

Depending on the protocol type, different services are offered within a layer and between layers:

- **Connection-oriented services**
  (mostly reliable byte or message streams),

- **Connectionless services**
  (mostly unreliable datagrams).

The services are composed of a group of four basic operations (primitives):

Basic operation	Meaning
Request *(Anfrage)*	Request for a specific service by an instance, establishment of a connection,
Indication *(Anzeige)*	Information of an instance about an event, notification of the recipient,
Response *(Antwort)*	Response of an instance to an event, acceptance or rejection of the connection by the receiver,
Confirmation *(Bestätigung)*	Response to a previous request, information of the sender about the reaction (acceptance, rejection of the connection) of the receiver.

Exercises

E.2-1: What are the main purposes of the layered design of the ISO/OSI model?

E.2-2: Which ISO/OSI layers handle the following tasks:

- Transmission of bit streams,
- End-to-end communication,
- Addressing on the Internet?

E.2-3: Why are the three upper layers of the ISO/OSI model combined in one layer in the TCP/IP protocol stack?