

Cambridge International AS and A Level Computer Science

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Topic 3.2.1 Protocols

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Introduction

How to use this guide

The aim of this guide is to facilitate your teaching of the Cambridge International AS and A Level Computer Science topic 3.2.1 Protocols, part of the advanced theory topic 3.2 Communication and internet technologies. This guide concentrates on the learning objectives relating to protocols and the TCP/IP protocol suite. The guidance and activities in this resource are designed to help teachers devise programmes of study which provide teaching time devoted to theory work as well as activities that consolidate learning.

Section 1 lists some key terms used in this topic and their definitions. Section 2 introduces protocols, the OSI model and the TCP/IP protocol suite. Section 3 lists some online resources that you or your learners may find useful, Section 4 gives ideas for class and homework activities.

Learning objectives

Using this document should help you guide learners in the following syllabus learning objectives:

- show understanding of why a protocol is essential for communication between computers
- show understanding of how protocol implementation can be viewed as a stack, where each layer has its own functionality
- show understanding of the function of each layer of the TCP/IP protocol suite
- show understanding of the application of the TCP/IP protocol suite when a message is sent from one host to another on the internet.

Prior knowledge

Before you begin teaching this topic you should:

- understand what protocols are and why they are needed for communication
- be familiar with the OSI seven-layer model
- be familiar with the TCP/IP protocol suite and how the functions of the layers compare to those of the OSI model
- understand how the TCP/IP protocol implements data communication between host computers connected to the internet.

1. Key terms

Word/phrase	Meaning
Internet Protocol (IP)	A protocol that specifies the size of the packets that a message is broken down into, and the address of the recipient device
IPv4	A method of addressing that uses 32-bit numbers to specify internet/network addresses
IPv6	A method of addressing that uses 128-bit numbers to specify internet/network addresses
layer	A division of the OSI and TCP/IP models that contains a protocol that implements a specific aspect of communication
OSI model	A model that defines standards for communication between any two devices and across any network
protocol	A set of rules governing communication between computers
Transmission Control Protocol (TCP)	A protocol in the TCP/IP suite that handles the transfer of data from one computer to another
TCP/IP Layer Model	A model that defines standards for communication over the internet
TCP/IP suite	A collection of protocols including IP, TCP and UDP that handles communication between two computers across the internet
User Datagram Protocol (UDP)	A protocol in the TCP/IP suite that broadcasts data across a network

2. Theory

2.1 What is a protocol?

Modern computers are designed with communication in mind. At a basic level, computers may need to communicate with peripherals such as a printer, or to send messages to other computers, which may be connected across a local area network (such as in a business, or a school), a mobile phone cellular network, or the internet.

Before one computer can communicate with another, there must be a set of agreed rules in place that manage how the communication is to take place. These rules are known collectively as a protocol.

To illustrate the need for rules when two or more objects communicate, we will look at some rules used when humans talk to each other. For example, we:

- use sound to send messages
- use a common language that we both understand
- listen when the other person is talking, so we can hear them speak
- speak at a rate that allows us to clearly transmit words and receive them
- have ways of checking that the other person has heard what we have said.

Without such rules, communication becomes difficult, or even impossible.

Similarly to human communication, computers use rules, and these form the protocols that are used for computer communication. Protocols need to specify several aspects of communication, for example:

- the communication medium to be used, such as wired or wireless
- the transmission type, such as duplex or simplex
- whether the handshake is hardware or software in nature
- the method of error checking to be used
- the bit rate
- the character set that will be used.

The protocols allow messages to be transmitted in a structured, specific manner, so that the receiving device is able to process the data sent from the sending device. Protocols therefore make sure that communication between any two devices is successful. Different communication protocols exist to specify rules for different types of communication, for example:

- Hyper Text Transfer Protocol (HTTP) – handles transmission of data to and from a website
- Simple Mail Transfer Protocol (SMTP) – handles email transmission
- File Transfer Protocol (FTP) – handles transmission of files across a network
- TCP/IP – handles communication over the internet.

2.2 Layering and the OSI model

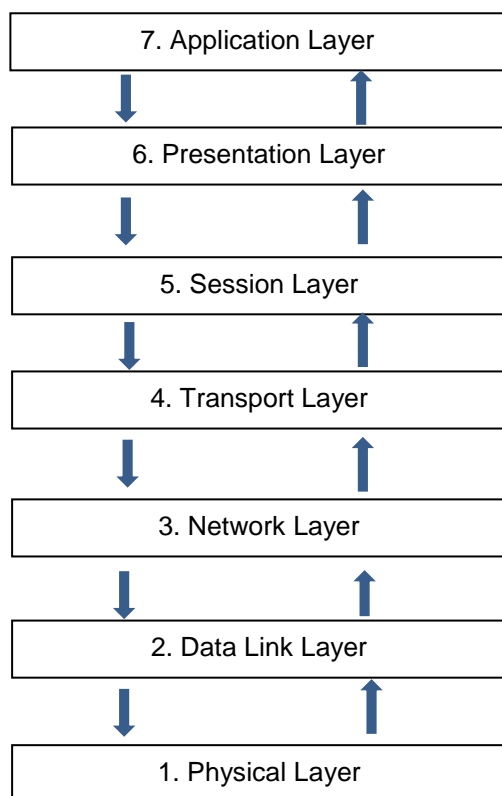
Many types of computer – for example, personal computers, laptops, servers, tablets and smartphones – exist, and they are made by many different manufacturers. As a result, it is important to have standards in place that designers and equipment manufacturers can follow to make sure their products can communicate with others’.

The Open Systems Interconnection model (OSI model) was introduced to form standards for computer communication. The model takes the various elements of communication and conceptually separates them into layers. Each layer can be treated individually, and is independent from the others. Each layer contains different protocols and handles a different part of the transmission.

The model specifies seven layers:

Layer	Description
Application Layer	The interface between applications and the network. Data/messages from applications are passed down to / received from the Presentation Layer.
Presentation Layer	Converts the data/message passed down from the Application Layer into a format usable by the layers below. Applications use data in different ways and in different formats. This layer makes sure all data/messages are standardised into one format.
Session Layer	Controls the communication. Every communication has a beginning and an end. The Session Layer initiates the communication and maintains it until it is terminated.
Transport Layer	Orders and assembles data packets for transmission across the network.
Network Layer	Delivers packets. This layer determines the address of the destination computer and works out a route for packets to be sent across the network.
Data Link Layer	Aids error-free transmission. This layer contains the error-checking rules and attempts to correct any transmission errors, as well as determining the flow rate. Devices may not be able to communicate at the same speed, so this layer makes sure data flows at a rate acceptable for both devices.
Physical Layer	Handles the physical characteristics of the hardware that handles the communication, such as the medium (e.g. wired or wireless) and transmission type.

The layers are numbered and sit one above each other, and can therefore be thought of as a stack. The output from one layer provides the input for the next. Each layer interacts only with the layer directly above it and/or below it, and at the bottom of the stack, the Physical Layer transmits data between the source and destination devices:



Dividing protocols into layers provides several benefits:

- Different media (e.g. wired and wireless) are able to use the same protocols in most layers above the Physical Layer. This makes it easier for a manufacturer to introduce a new transmission medium.
- Similarly, when testing new equipment, developers only have to test the layers that contain protocols specific to that equipment (e.g. for a new router, testing would be needed at the Network Layer, but not the Transport Layer).
- Protocols are sometimes updated, and as the layers are separate and independent, the rules within them can be changed without affecting the rules contained in the other layers, as long as the interface to the layers above and below is kept the same.
- Transmission faults are more easily traced, as the type of error is often specific to a layer. A tester only has to investigate that layer to find the cause of the problem.

2.3 TCP/IP

The development and growth of the internet required specific protocols for internet communication. Two protocols – Internet Protocol (IP) and Transmission Control Protocol (TCP) – were developed as a result. Known collectively as the TCP/IP suite, each protocol is responsible for different aspects of communication:

- Internet communication uses ‘packet switching’ to handle data transfers from the sending device to the receiving device – that is, transferred data, such as a downloaded file, is not sent across the network in a single message, but is broken down into ‘packets’ of smaller pieces of data. IP specifies the size of the packets that the message is broken down into, and the address of the receiving device.
- TCP handles the transfer of data between the sending and receiving devices – the ‘end-to-end’ communication. It establishes a connection, then makes sure the packets are sent and received correctly and in the right order. If a packet does not arrive, TCP re-sends the packet. TCP differs from some other networking protocols in that it does not broadcast data across a network – instead it is used for one-to-one communication between two devices. Another protocol, the User Datagram Protocol (UDP) is used for broadcasting data. Unlike TCP, UDP does not guarantee the packet will safely arrive.

2.3.1 IP addresses

The Internet Protocol version 4 (IPv4) uses 32-bit numbers to specify internet addresses. These addresses are broken down into four numbers in the range 0 to 255, and they are separated by a dot. For example:

192.168.0.1

Each number is converted to 8 bits:

192 . 168 . 0 . 1
 11000000 . 10101000 . 00000000 . 00000001

The four 8-bit numbers form one 32-bit number:

11000000101010000000000000000001

However, using 32 bits limits the total possible number of internet addresses to 4,294,967,296 (2^{32}) addresses (4.3 billion). Although this appears to be a very large number, the huge number of computer devices currently running in the world means that the number of free addresses is running out. As a result, a new version of the protocol, IPv6, using 128 bits, is now also in use. This gives 2^{128} possible addresses!

2.4 The TCP/IP layer model

The TCP/IP layer model pre-dates the OSI model, but shares similarities. Whereas the OSI model contains seven layers, the TCP/IP model has just four. The following table shows how the TCP/IP layers map to the OSI model layers:

TCP/IP model	OSI model
Application Layer	Application Layer
	Presentation Layer
	Session Layer
Transport Layer	Transport Layer
Internet Layer	Network Layer
Network Interface Layer	Data Link Layer
	Physical Layer

The TCP/IP layers handle similar communication rules compared to their OSI model equivalents:

Layer	Description
Application Layer	The interface between applications (e.g. file transfer, e-mail, web browsing) and the network. Data/messages from applications are passed to / received from the Transport Layer.
Transport Layer	Orders and assembles data packets for transmission across the network. The Transmission Control Protocol resides in this layer, as does the User Datagram Protocol.
Internet Layer	Exchanges packets between networks, making all connected individual networks appear as one big network. The Internet Protocol is the main protocol in this layer.
Network Interface Layer	Defines how to transfers packets between adjacent nodes on a wide area network and within a local area network.

2.5 A TCP/IP communication example

If we want to view a webpage on the internet, the TCP/IP suite handles the communication between our device and the webpage's webserver:

1. Our browser uses the Hyper Text Transfer Protocol (HTTP) to send a request to the Application Layer.
2. The Application Layer protocol (HTTP) sends the request to the Transmission Control Protocol (TCP) in the Transport Layer. The TCP communicates with the Internet Layer to establish a connection with the webserver across the network(s).
3. The Internet Protocol in the Internet Layer establishes the address of the webserver and converts the request into packets. The packets are sent to the Network Layer.
4. The Network Layer uses its protocols to send the packets over the internet to the webserver.
5. At the webserver the process is reversed. The packets are sent up through the protocols in the layers, and re-assembled into the request. The request is passed through the Application Layer protocols for the webserver to service.
6. In the same manner the webserver uses the protocols in the layers to send the webpage data back to our device.

3. Online resources

The following are useful resources for understanding protocols.

The content of websites is dynamic and constantly changing. Schools are strongly advised to check each site for content and accessibility prior to using it with learners. Cambridge International Examinations is not responsible for the accuracy or content of information contained in these sites. The inclusion of a link to an external website should not be understood to be an endorsement of that website or the site's owners (or their products/services).

3.1 Websites

Scottish Qualifications Authority Higher National Computing website – covers most areas of the topic, including the OSI model, TCP/IP, IPv4 and IPv6, and includes some useful diagrams:

www.sqa.org.uk/e-learning/HardOSEss04CD/index.htm

An alternative explanation of the OSI model, including example technologies and protocols for each layer:

<http://compnetworking.about.com/od/osimodel/tp/The-Seven-Layers-of-the-OSI-Model-Illustrated.htm>

Explanation, using examples, of the TCP/IP protocol:

www.hardwaresecrets.com/how-tcp-ip-protocol-works-part-1/

4. Class and homework activities

4.1 Quiz

1. A protocol is:
 - a. a message sent from one computer to another
 - b. a program used to send messages between computers
 - c. a set of rules governing communication between computers

2. The OSI Model was developed to:
 - a. allow communication between two devices
 - b. define standards for communication
 - c. allow communication over the internet

3. An advantage of layering is:
 - a. transmission faults are easier to trace
 - b. computers can communicate without error
 - c. the transmission medium can be specified

4. The purpose of the Transmission Control Protocol is to:
 - a. allow packets to be sent over a network
 - b. allow packets to be sent over the internet
 - c. specify packet sizes and allocate packet numbers

5. The purpose of the Internet Protocol is to:
 - a. determine the address of the recipient computer
 - b. allow packets to be sent over the internet
 - c. specify the transmission medium

4.2 Homework questions

1. Explain how protocols allow communication between computers
2. Describe three advantages of layering
3. Explain the purpose of the TCP and IP protocols