**Ollscoil Mhá Nuad**

**Maynooth University**

**AUTUMN**

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# CS320

**Computer Networks**

Dr. P. Healy, Dr. J. Timoney, Dr. B. Hennelly

Time allowed: 2 hours

You must answer Question 1 and any three other questions.

Your mark will be based on Question 1 and your best three answers from the remaining questions

**All questions** carry equal marks

**Instructions**

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|  | **Yes** | **No** | **N/A** |
| Formulae and Tables book allowed *(i.e. available on request)* |  | x |  |
| Formulae and Tables book required *(i.e. distributed prior to exam commencing)* |  | x |  |
| Statistics Tables and Formulae allowed *(i.e. available on request)* |  | x |  |
| Statistics Tables and Formulae required *(i.e. distributed prior to exam commencing)* |  | x |  |
| Dictionary allowed *(supplied by the student)* |  | x |  |
| Non-programmable calculator allowed |  | x |  |
| Students required to write in and return the exam question paper |  | x |  |

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| **1** |  | **SHORT QUESTIONS** | **[25 marks]** |
|  | (a) | Suppose two hosts, A and B, are separated by 50,000km and are connected by a direct link of *R* = 4Mbps. Suppose the propagation speed over the link is 2.5x108 meters/sec. How long does it take to send a file of 1Mbits from A to B. What is the width (in meters) of a bit in the link?  *Answer:Trans delay+Prop delay = 1M/4M+50e6/2.5e8=1/4+1/5=0.45s*  *Bits transmit at rate of 4M bits/second*  *And speed of 2.5e8 m/s*  *Length = 2.5e8/4e6 m/bit = 62.5m* | [2.5 marks] |
|  | (b) | What is meant by the term “encapsulation”?  *Answer: taking information from the layer above, and adding a header to make a new protocol data unit for this later of the protocol stack* | [2.5 marks] |
|  | (c) | What is the purpose of the IF-MODIFIED-SINCE field of an HTTP GET message?  *Answer: for the client to let the server know that it has a cached copy of a piece of content that was received at the specified time following the IF-MODIFIEDSINCE string* | [2.5 marks] |
|  | (d) | Suppose that Alice wants to send an email message to Bob. This will involve four entities: Alice’s mail client (for email composition and sending), Alice’s outgoing mail server, Bob’s incoming mail server, and Bob’s mail client (for email retrieval and viewing). Between which of these four entities does the SMTP protocol operate? What about the IMAP protocol?  *Answer: Alice-to-Alice’s server: SMTP, Alice’s mail server to Bob’s mail server: SMTP, Bob’s client retrieves mail from Bob’s mail server using IMAP.* | [2.5 marks] |
|  | (e) | Suppose that a TCP client using local port number 5555 and IP address 128.119.40.186 connects to a web server (port 80) at IP address 75.74.73.72. As a result, a new server-side socket is created for communication between client and server. When the client sends the HTTP GET message destined to this new socket, what are the source and destination IP addresses and port numbers on the IP datagram carrying this HTTP GET message? What are the source and destination IP addresses and port numbers on the IP datagram carrying the server-to-client reply to this HTTP GET message?  *Answer: For client-to-server message the source IP, source port, dest IP, dest port: 128.119.40.186, 5555, 75,74.73.72, 80. For server-to-client reply message the source IP, source port, dest IP, dest port: 75,74.73.72, 80, 128.119.40.186, 5555* | [2.5 marks] |
|  | (f) | Consider a router with N input lines, each with input link rate R and an internal switching fabric that is 2N times faster than R. Where in this router can packet queue form? Explain your answer.  *Answer: Queueing will only occur at the output ports. Since the switch is more than N times fast than the input rate, all arriving packets in a slot can be move from input port to output port in that slot.* | [2.5 marks] |
|  | (g) | What is meant by longest prefix matching?  *Answer: If the destination address of an incoming packet matches two (or more) entries in the router’s forwarding table, the router forwards the packet to the address with the larger number of specified address prefix bits.* | [2.5 marks] |
|  | (h) | Briefly explain how tunneling is used to allow IPv4 and IPv6 routers to interoperate.  *Answer: If two IPv6 routers need to communicate over a series of routers that are IPv4 only, the sending IPv6 router takes the IPv6 packet, encapsulates it inside an IPv4 packet, and addresses the IPv4 packet to the IPv6 router at the end of the series of IPv4 routers. The receiving IPv6 router removes the IPv6 packet and forwards the IPv6 packet to the next hop IPv6 router* | [2.5 marks] |
|  | (i) | In CSMA/CD, after the fifth collision, what is the probability that a node chooses *K* = 4? The result *K* = 4 corresponds to a delay of how many seconds on a 10 Mbps Ethernet?  *Answer: After the 5th collision, the adapter chooses from {0, 1, 2,…, 31}. The probability that it chooses 4 is 1/32. It waits 204.8 microseconds.* | [2.5 marks] |
|  | (j) | Why is an ARP query sent within a broadcast frame? Why is an ARP response sent within a frame with a specific destination MAC address?  *Answer: An ARP query is sent in a broadcast frame because the querying host does not which adapter address corresponds to the IP address in question. For the response, the sending node knows the adapter address to which the response should be sent, so there is no need to send a broadcast frame (which would have to be processed by all the other nodes on the LAN).* | [2.5 marks] |

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| **2** |  | **Question 2.**  Consider the scenario shown in the figure below in which a client want to access a web server. The web server is connected to the Internet by a link with a transmission capacity of 1,000,000,000 bits (a gigabit) per second. | **[25 marks]** |
|  | (a) | Suppose a web page (including all of its images, which are also stored on the web server) is 1,000,000 bits long. How long does it take for the server to send a web page (including all of its images) into the Internet over the gigabit (1,000,000,000 bits per second) link?  *Answer: time to send = 1,000,000/1,000,000,000 = .001 secs.* | [3 marks] |
|  | (b) | What is the maximum number of web pages that the web server can transmit per second, assuming all of the web pages (including all of its images, which are stored on the web server) are the same size as in (a)?  *Answer: 1000 pages per second*  Now let’s consider the case that the web server serves a base page, but that the base page has three advertisements, each of which is served by the ad server shown in the figure above.  . | [3 marks] |
|  | (c) | Suppose now that (i) the base web page takes X1 seconds to transmit into the Internet, and that the client-to-web-server RTT is RTT1, (ii) each advertisement takes X2 seconds to transmit into the Internet, and that the client-to-ad-server RTT is RTT2. How much time is taken from when the client first clicks on the link to access a web page containing these three ads until the page is displayed? You should remember that HTTP runs over TCP. You do NOT have to worry about DNS delays here. You can assume that “small” messages (i.e., messages that don’t contain a web page or an image) take zero time to transmit into a link, but do experience a propagation delay. Your answer should be in the form of a formula involving X1, RTT1, X2, and RTT2. Briefly explain how you arrived at your formula.  *Answer: note that we will need to account for the TCP handshake delays. To fetch the base page requires 2RTT1+X1 (one RTT1 for the TCP handshake and one RTT1 for the HTTP GET request and reply, and X1 time for the server to actually transmit the file into he link). Each ad similarly takes 2RTT2+X2, assuming non-persistent HTTP. So the overall delay is 2RTT1 + X1 + 6RTT2 + 3X2.* | [7 marks] |
|  | (d) | Now suppose that the client’s browser has a cache and the client has previously visited the web page. The web page at the server has changed since the client last viewed the web page, but the advertisements have not changed. Under the otherwise same assumptions as (c), how much time is taken from when the client first clicks on the link to access a web page containing these three ads until the page is displayed? Your answer should again be in the form of a formula. Briefly explain why your formula here differs from your answer to (c).  *Answer: one RTT2 is still needed to verify that each ad has not been modified (i.e., the client needs to send an IF-MODIFIED-SINCE HTTP GET to the ad server, and the ad server needs to respond with a 304 Not Modified. But the ad files themselves do not need to be transmitted. So the overall delay is 2RTT1 + X1 + 6RTT2.* | [6 marks] |
|  | (e) | Let’s reconsider (c) but now also account for DNS delays. Assume that the local DNS cache is empty. Assume that the time RTT between the client and the local DNS sever is D1, and that the time needed (including all message transmission and RTT times needed for the local DNS server to resolve a request through the root, TLD and authoritative name servers is D2. How much time is taken from when the client first clicks on the link to access a web page containing these three ads until the page is displayed, including the DNS delays? Briefly explain how you arrived at your formula.  *Answer: A DNS lookup is need to find the IP address of the web server. This will take time D1+D2, since the local cache is initially empty. The first ad request will also take D1+D2. The next two ad requests, however will only take D1, since the local DNS server will have cached the name-to-IP-address translation for the ad server. Thus the total delay is the delay in part (c) plus 4D1 + 2D2.* | [6 marks] |

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| **3** |  | **RELIABLE DATA TRANSFER PROTOCOL**  Consider the following scenario. At a requestor node, R, a high level process generates requests for data items that are stored at a remote node A that has an infinite supply of such data items (and so A always has a data item to send). Nodes R and A are connected to by a channel that can *lose* or *corrupt* messages, but *will not reorder* messages.  Design a requester protocol that operates at R and A, operating as follows. At R, requests for data items are received from above via a call **request(A)** that requests that the next item be retrieved from A. The request protocol at R eventually delivers a requested data item to the layer above, satisfying such a request, by calling **deliver\_data(data)**, where **data** is a data item received from A . You may assume that a call from above will not be made until the previous call from above requesting a data item has been satisfied via a **deliver\_data()** call.  R sends request messages to A; the fields in the request message are part of your protocol’s design. A sends data messages containing a requested data item to R; the fields in the data message are part of your protocol’s design.  You should design a protocol with which R requests, and A sends, data items, and that R delivers (to the caller above) exactly one copy of the data item requested. You should make sure that your protocol handles corrupted or lost messages on the R-to-A and A-to-R channel. *Hint*: using sequence numbers of only 0 and 1 will negate the need for ACKs. | **[25 marks]** |
|  | (a) | Give a FSM description for the data requesting protocol at R. *You do not need to specify the FSM at the level of detail in the text or notes.* But you should make clear what action is being taken an events occurs, and any necessary values/parameters associated with the event or action taken (e.g., message transmission or reception). *Answer: because messages can be lost, we’ll need a timer, and because there can be lost or repeated request messages, we’ll need to put a sequence number on each request message, just as we did in rdt 3.0 in the course. To see why, note that A needs to know whether a received request is a request for new piece of data, or a retransmitted request for the previous piece of data. Here is the FSM for R:* | [5 marks] |
|  | (b) | Give a FSM description for the data requesting protocol at A. *Answer: Note that R will be sending only a series of R(0)s followed by one or more R(1)s, followed by one or more (R(0)s, etc. This makes A pretty simple:* | [5 marks] |

**Answers:**

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| |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | **4** |  | **TCP CONGESTION CONTROL** | **[25 marks]** | | | |  |  | Consider four Internet hosts, each with a TCP session. These four TCP sessions share a common bottleneck link - all packet loss on the end-to-end paths for these four sessions occurs at just this one link. The bottleneck link has a transmission rate of R. The round trip times, RTT, for all fours hosts to their destinations are approximately the same. No other sessions are currently using this link. The four sessions have been running for a long time. |  | | | |  | (a) | What is the approximate throughput of each of these four TCP sessions? Explain your answer briefly.  *Answer: R/4 since TCP shares bandwidth fairly.* | [5 marks] | | | |  | (b) | What is the approximate size of the TCP window at each of these hosts? Explain briefly how you arrived at this answer.  *Answer. Recall that roughly throughput = W/RTT or W = throughput \* RTT = R\*RTT/4.* | [3 marks] | | | |  | (c) | Suppose that one of the sessions terminates. What is the new throughput achieved by each of the three remaining sessions? Briefly describe how this new throughput is reached (i.e., what do the TCPs in the remaining three hosts do that results in this new throughput being achieved).  *Answer: R/3 since TCP shares bandwidth fairly* | [3 marks] | | | |  | (d) | Now suppose that one of the three hosts starts a second session that also crosses this bottleneck link. What is the throughput achieved (in aggregate) by the one host with two sessions, and by each of the two hosts with one session each?  *Answer: each session will again get R/4, so the one host with two sessions will get R/2 in aggregate and the other teo hosts will each get R/4.* | [6 marks] | | | |  | (e) | Suppose again three hosts each have one TCP connection open and that one of the three hosts experiences a long sequence of lost packets detected by timeout (not by triple duplicate). What is the throughput of each host?  *Answer: The host experience ti,mouts will have effectively zero bandwidth while the other two will get R/2 bps. .* | [6 marks] | | | |  | (f) | Which is better:five parallel non persistent HTTP sessions in which 10 files must be downloaded or one persistent HTTP session that downloads the same 10 files with pipelining allowing all ten files to be sent/received simultaneously: |  | | | |  |  | *Answer: The second one is slightly better as it will take 1 RTT less.* | |  | |  |  |  |

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| **5** |  | **ROUTING ALGORITHMS** | **[25 marks]** |
|  |  | Suppose a node w has three directly-connected neighbors x, y, z, with a link connecting w to these three neighbors having a cost of 3, 1, and 5 respectively for nodes x, y and z, as shown in the figure below. There are no other links attached to nodes w, x, y, or z other than those shown in the figure. |  |
|  | (a) | Suppose that the minimum cost from x, y, and z, to some destination, A (not shown) is 21, 18, and 20 respectively. What is W’s minimum cost to A? Which neighbor of W is on the shortest path to A?  *Answer: w’s minimum cost is 19, via neighbor y.* | [3 marks] |
|  | (b) | Suppose again that the minimum cost from x, y, and z, to some destination, A (not shown) is 21, 18, and 20 respectively. Through which of its neighbors (u, y, or w) does x route through to get to destination A? Explain your answer.  *Answer: X must route through u since to route directly through y the cost would be 28, and through w (and then via y) would be 22. Given there is a path of cost 21, then that minimum cost path must be through u, since the min cost paths through and w are 28 and 22.* | [6 marks] |
|  | (c) | Suppose the link cost from w to z (and vice versa) changes from 5 to 4. How many distance vectors are sent and received by w as a result of this link cost change. Explain briefly.  *Answer: None. Since w’s minimum cost to y and z (and x) do not change, no updated distance vector is sent by w.* | [4 marks] |
|  | (d) | Suppose that the distance vector algorithm operates in a synchronous manner. At each time iteration, t = 1,2,3,4 …., nodes exchange distance vectors with their neighbors (as specified by the distance vector algorithm) and then re-compute their distance vectors, and again exchange their new distance vectors (if any) with their neighbors at time t+1, and so on. Recall that initially, all nodes only know their direct-one-hop cost to each directly connected neighbor. Suppose that the longest path (without loops) in the network has length d. What is the maximum number of iterations needed by the distance vector algorithm from when it first begins until all distance vectors have been computed in all nodes. Briefly explain your answer.  *Answer: it takes d-1 time slots for a path of length d to a destination to be learned by the source. Each iteration allows a node to learn about destinations one-hop more distant.* | [5 marks] |
|  | (e) |  |  |

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| **6** |  | **LINK LAYER AND NETWORK LAYER** | **[25 marks]** |
|  |  | Consider the figure below. |  |
|  | (a) | Assign IP address ranges to the subnets containing hosts A and B, and assign IP addresses in these ranges to hosts A and B. (You don’t have to assign IP addresses to any hosts except A and B, but you do need to specify the address range being used by each subnet). Your subnet addressings should use the smallest amount of address space possible.  *Answer: Because there are less than eight but more than 4 nodes in each subnet, we’ll need three address bits for each subnet. So let’s assign the left subnet XX.YY.ZZ.xxxx0\*\*\*/29, where the XX.YY.ZZ are 8 bit numbers. Each x is a bit and the three \*’s correspond to the three address bits for this network. For the right subnet, well use XX.YY.ZZ.xxxx1\*\*\*/29. A will have an IP address of XX.YY.ZZ.xxxx0000 and B will have an IP address of XX.YY.ZZ.xxxx1000.* | [5 marks] |
|  | (b) | What IP address range can the router advertise to the outside for all of the hosts reachable in these two subnets? Again, you should choose your answer in a) above so that the minimum-size address space is advertised here.  *Answer: XX.YY.ZZ.xxxx/28* | [3 marks] |
|  | (c) | Does the router interface with link-layer address **20:FF:3A:BC:01:4E** have an IP address? If so, what is the role of the IP address of the router’s IP interface in forwarding datagrams through the router.  *Answer: Yes. That’s the address that a host in the left network will use to determine the MAC address to send frames to, containing datagrams that need to be routed through the router. The router address however, won’t appear in the IP datagram.* | [3 marks] |
|  | (d) | Consider an IP datagram being sent from A to B using Ethernet as the link layer protocol in all links in the figure above. What are the *(i)* Ethernet source and destination addresses and *(ii)* IP source and destination addresses of the IP datagram encapsulated within the Ethernet frame at points (1), (2), and (3) in the above example for a datagram going from A to B.  *Answer:*  *(1): ETH source: aa:12;F3:5C:01:BC, ETH dest: 20:FF:3A:BC:01:4E IP source: XX.YY.ZZ.xxxx0000; IP dest: XX.YY.ZZ.xxxx1000 see (a) above*  *(2) same as (1)*  *(3) ETH source: 10:D4:E1:A\*:97:FO, ETH dest: BB:89:34:E7:01:3B IP source: XX.YY.ZZ.xxxx0000; IP dest: XX.YY.ZZ.xxxx1000 same as (1) above* | [5 marks] |
|  | (e) | Suppose all switches in the above example are learning switches. Consider the datagram being sent from A to B; neither A nor B have sent any frames or datagrams in the network before.   * How many of the 11 hosts in the network receive the frame containing the datagram sent by A? Explain your answer briefly.   *Answer: all 11, since no switch knows where B is located (since B hasn’t sent anything), all switches will broadcast the frame containing the IP datagram from A. Note that different frames are broadcast on the left and right subnets (e.g., the frames have different source and destination MAC addresses, see above), but both contain the datagram from A.*   * Suppose the server in the upper part of the *left* network sends a datagram to A shortly *after* the A-to-B datagram is sent. How many of the 11 hosts in the network receive the frame containing the datagram sent by this server? Explain your answer briefly*.*     *Answer: Only A will receive that, since all of the switches know the outgoing port leading to A, as a result of learning where A is, as a result of the initial A-to-B transmission.* | [5 marks] |
|  | (f) | Suppose A sends out an ARP request, and this ARP request is in the very first frame sent in the network above (i.e., even before the original A-to-B datagram). How many of the 11 hosts in the network receive the frame containing this ARP request? Explain your answer briefly.  *Answer: ARP broadcasts are restricted to a subnet and generally do not pass through the router, so all 5 other hosts in the left network will receive the ARP broadcast (as will the leftmost interface on the router).* | [4 marks] |