**Ollscoil Mhá Nuad**

**Maynooth University**

**AUTUMN**

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# CS320

**Computer Networks**

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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 |  |

Enter any other instructions here or delete the box.

**[25 marks]**

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| **1** | (a)  (b)  (c)  (d)  (e)  (f)  (g)  (h)  (i)  (j) | **Short Questions**  Briefly in a few sentences explain the difference between circuit switching and packet switching. *Answer: Circuit Switching: Dedicated communication path, consistent quality, but less efficient resource use. Packet Switching: Independent data packets, flexible paths, efficient resource utilization, improved resilience, and statistically higher network efficiency.*  When packets get “lost” in the Internet on their way from source to destination, where (e.g., at what network component) does this loss usually occur? *Answer: Packet loss usually occurs at routers or network switches due to congestion, where these devices' buffers are full and unable to handle additional packets.*  What is a difference between a tier-1 and a tier-3 network, eg Vodafone and eir? *Answer: A tier-1 network can access the entire internet without needing to pay for transit from other networks, essentially operating on a global scale. In contrast, a tier-3 network typically relies on purchasing transit from higher-tier networks to reach parts of the internet.*  Does the Internet checksum always detect errors in the transmitted segment? Explain your answer in a sentence or two. *Answer: No. For example if two 16--‐bit word values are swapped, this would not be detected since the sum is unchanged.*  Suppose a TCP SYN message is sent from a client with IP address 128.119.40.186 and client port number 5345 to a server with IP address 41.123.7.94 and server port number 80 (HTTP )  1. Once the TCP connection has been established, what will be the client-side IP address, client‐side port number, server-side IP address and server-side port number of the TCP segment carrying the HTTP GET message. *Answer: exactly as specified in the problem statement.* 2. Will the TCP SYN message and the HTTP GET message be directed to the same socket at the server? Explain in one or two sentences. *Answer: NO. The GET will be directed to the new socket that was created when the TCP SYN messages was accepted (i.e., the socket returned from the wait on the .accept( ) on the welcoming socket ). Note that the TCP SYN and the GET will both be addressed to port 80 on the server, however.*  Where and why does packet loss occur within a router? *Answer: packet loss occurs in buffer in either the input or output line cards, because the memory in the buffer is finite, and the input rate to the buffer exceed the output rate of the buffer over some period of time.*  Suppose BGP router A sends a BGP path vector to BGP peer router B. BGP peer B is connected to BGP peer C. Must B advertise that path to C? *Answer: No. It is up to B’s internal policy about what routes to advertise to others. Recall that we discussed how an ISP will generally only carry traffic to/from its customers, and not carry transit traffic (i.e., traffic that is both sources and destined in non-customer networks )*  What is the purpose of the ARP protocol? *Answer: To learn a node’s MAC address, given its IP address. Once the MAC address is known, a link--‐layer frame can then be sent to that destination MAC address.*  Briefly explain the key differences between the ALOHA and slotted ALOHA protocols. *Answer:* *Time Synchronization: ALOHA does not require synchronization, while Slotted ALOHA operates on synchronized time slots. Collision Rate: ALOHA has a higher collision rate due to unsynchronized transmissions, whereas Slotted ALOHA's aligned time slots reduce collision chances. Efficiency: Slotted ALOHA is more efficient due to structured transmission times, as opposed to ALOHA's more random approach.*  Suppose that Bob and Alice have access to a public key system that makes their public keys available to each other. KB- and KB+ are Bob’s private and public keys, respectively. Each knows its own private key. Describe how Bob and Alice can use these keys so that Bob can know that when he is communication with Alice that (i) he is indeed communicating with Alice, and (ii) Alice is live (i.e., he is not receiving a playback of earlier info sent from Alice? *Answer: Bob creates a nonce and sends it to Alice and asks her to encrypt it with her private key. Bob then applies Alice’s public key to the nonce and if he recovers the nonce value, accepts Alice as live (since the nonce was signed ) and as Alice (since only Alice has access to her private key, and only Alice’s private has the property that KA+ KA- (m ) = m.* | [2.5 marks]  [2.5 marks]  [2.5 marks]  [2.5 marks]  [2.5 marks]  [2.5 marks]  [2.5 marks]  [2.5 marks]  [2.5 marks]  [2.5 marks] |

**[25 marks]**

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| **2** | (a) | **Delays, Throughput and Caches**  Consider the scenario shown in Figure 1 in which a server is connected to a router by a 100Mbps link with a 50ms propagation delay. Initially this router is also connected to two routers, each over a 50Mbps link with a 200ms propagation delay. A 1Gbps link connects a host and a cache (if present) to each of these routers and we assume that this link has 0 propagation delay. All packets in the network are 20,000 bits.    Figure 1.  What is the end--‐to--‐end delay from when a packet is transmitted by the server to when it is received by the client? In this case, we assume there are no caches, there’s no queuing delay at the routers, and the packet processing delays at routers and nodes are all 0. *Answer: If all packets are 20,000 bits long it takes 200 usec to send the packet over the 100Mbps link, 800 usec to send over the 25Mbps link, and 20 usec to send over the 1Gbps link. Sum of the three--‐link transmission is 1020 usec. Thus, the total end--‐to--‐end delay is 251.02 msec.* | [7 marks] |
|  | (b) | Here we assume that client hosts send requests for files directly to the server (caches are not used or off in this case). What is the maximum rate at which the server can deliver data to a single client if we assume no other clients are making requests? *Answer: Server can send at the max of the bottleneck link: 25Mbps.* | [3 marks] |
|  | (c) | Again we assume only one active client but in this case the caches are on and behave like HTTP caches. A client’s HTTP GET is always first directed to its local cache. 60% of the requests can be satisfied by the local cache. What is the average rate at which the client can receive data in this case? *Answer: We assume that requests are serially satisfied. 40% of the requests can be delivered at 25Mbps and 60% at 1Gbps. So the average rate is 610Mbps.* | [4 marks] |
|  | (d) | Now clients in both LANs are active and the both caches are on (similar to c). 60% of the requests can be satisfied by the local caches. What is the average rate at which each client can receive data? Answer: 25Mbps link remains bottleneck link which is not shared between LANs. *Answer is same as in c. Note that we assume that the 100Mbps link is shared at fine granularity, so that each client gets up to 50Mbps over that link.* | [4 marks] |
|  | (e) | Now consider Figure 2 where the network has been extended by two additional LANs, which are connected via 25Mbps links and the throughput of the server link is only 80Mbps. In all four LANs 60% of the requests can be satisfied by the local caches. What is the average rate at which each client can receive data? *Answer: Now the server link is the bottleneck link an equally shared by all clients, each getting 20Mbps. 40% of the client requests are served at 20Mbps and 60% of the requests are delivered at 1Gbps, resulting in an average rate of 608Mbps. Only a reduction by 2Mbps on average despite a 50% reduction in server link bandwidth. This shows how efficient caching can be!* | [7 marks] |

Figure 2.

**[25 marks]**

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| **3** |  | **Transport Layer Protocol**  Consider a TCP connection with a round trip time of 10ms and no congestion initially. The receive window is 24KB and the maximum segment size (MSS) is 2KB. You can take a KB to be 1000 bytes. Recall that the window size W can be defined in units of the maximum segment size: W=n×MSS. |  |
|  | (a)  (b)  (c)  (d)  (e)  (f) | How long does it take before the first window can be sent that can fully fill the received window?  After running with no congestion for a time (reaching full window as in part (a)), a timeout occurred, followed by 2 successful bursts followed by a timeout immediately after that. What is the minimum time it will take TCP to recover and reach maximum throughput?  Answer the previous question again, but this time the two packet loss events are indicated by triple duplicate ACKs and not by timeouts. Answer for both TCP Reno and TCP Tahoe.  What is the maximum data throughput seen by the application layer (bytes/sec)?  If a 100Mbps line is used, what is the line efficiency at the  throughput determined in (d)?  If the receive window was increased to the maximum supported by TCP what would the line efficiency be? | [5 marks]  [4 marks]  [4 marks]  [4 marks]  [4 marks]  [4 marks] |
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|  |  | *Solution:*  *(a) Time to Send First Full Window:*  *Slow start: 5 RTTs (Round Trip Times). Slot1-W=1, slot2-W=2, slot3-W=4, slot4-W=8, slot5-W=12*  *(b) Time to Recover and Reach Maximum Throughput After a Timeout:*  *After a timeout, the congestion window size (cwnd) is set to 1 MSS, and the slow start threshold is set to half of the current cwnd. It then enters the slow start phase, doubling the cwnd each RTT. So, it will take a minimum of 5 RTTs to reach the maximum throughput again (as calculated in part (a)).*  *(c) Time to Recover for TCP Reno and TCP Tahoe After Triple Duplicate ACKs:*  *TCP Reno: After triple duplicate ACKs, the cwnd is set to half of the current window size (12/2 = 6), and the slow start threshold is also set to this value. It then transitions to the congestion avoidance phase, where cwnd increases linearly so over the next two bursts it will increase to 8. The second loss will reduce this to 4 and it will take 8 RTTs to increase to 12.*  *TCP Tahoe: After triple duplicate ACKs, TCP Tahoe acts the same as if a timeout occurred. It sets cwnd to 1 MSS and sets the slow start threshold to half of the current cwnd, and then it enters slow start. So, it will take the same time as in part (b), which is 5 RTTs.*  *(d) Maximum Data Throughput (bytes/sec):*  *The maximum throughput would be the maximum segment size divided by the round trip time.*  *Throughput = MSS / RTT = 2000 bytes / 0.01 s = 200,000 bytes/s.*  *(e) Line Efficiency with a 100Mbps Line:*  *Line Efficiency = (Throughput / Bandwidth) \* 100*  *= (200,000 bytes/s \* 8 bits/byte) / 100,000,000 bits/s \* 100*  *= 16%*  *(f) Line Efficiency with Maximum TCP Receive Window:*  *The maximum TCP receive window size is 65,535 bytes (for TCP without window scaling option). With this window size, the Bandwidth-Delay Product (BDP) would be fully utilized, and the line efficiency would be close to 100% on a 100Mbps line, assuming no other overheads and ideal conditions.* |  |

**[25 marks]**

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| **4** | (a) | Routing Algorithms: Link State and Distance Vector  Consider the network shown in the figure below  Index of /~michael/kr1999/4-network    Show the operation of Dijkstra’s (Link State) algorithm for computing the least cost path from A to all destinations and based on this result define the least cost from F to A  *Solution*    *From F to A go backwards: F E D C B A*  Consider only the part of the network made up by the nodes H, G, and B and ignore all other nodes. Show the first two iterations of the distance-vector algorithm for this three-node network based on the Bellman-Ford Equation.  *Answer:* | [15 marks]  [10 marks] |

**[25 marks]**

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| **5** | (a)  (b)  (c) | **Link Layer**  Suppose the information content of a packet is the bit pattern 1110 0110 1001 1101 and an even parity scheme is being used. What would the value of the field containing the parity bits be for the case of a two-dimensional parity scheme? Demonstrate using your answer that two-dimensional parity checks can correct and detect a single bit error.  *Answer*  *1 1 1 0 1*  *0 1 1 0 0*  *1 0 0 1 0*  *1 1 0 1 1*  *1 1 0 0 0*  *Demonstrating a single bit error is straightforward (see notes).*  Suppose four active nodes—nodes A, B, C and D—are competing for access to a channel using slotted ALOHA. Assume each node has an infinite number of packets to send. Each node attempts to transmit in each slot with probability p. What is the probability that node A succeeds for the first time in the second slot?  *Answer:*  *The probability that A is successful in any slot is given by*  *P(A) = p(1 – p)3*  *Remember how we derived this in the lectures?..... It is equal to the probability of A being successful (p), multiplying by the probability B is not successful (1-p) multiplying by the probability C is not successful (1-p) multiplying by the probability D is not successful (1-p)*  *Therefore the probability that A is successful in slot 2 for the first time is*  *=(probability A is not successful in slot1) x (probability A is successful in slot2)*  *=(1-P(A)) x P(A)*  *=(1 - p(1 – p)3)p(1 – p)3*  Consider a broadcast channel with N nodes and a transmission rate of R bps.Suppose the broadcast channel uses polling (with an additional polling node) for multiple access. Suppose the amount of time from when a node completes transmission until the subsequent node is permitted to transmit (that is, the polling delay) is dpoll. Suppose that within a polling round, a given node is allowed to transmit at most Q bits. What is the maximum throughput of the broadcast channel?  *Answer:*  *The length of a polling round is*  *.*  *The number of bits transmitted in a polling round is . The maximum throughput therefore is* | [5 marks]  [6 marks]  [5 marks] |
|  | (d) | Consider three LANs interconnected by two routers, as shown in the figure below.   * Assign IP addresses to all of the interfaces. For Subnet 1 use addresses of the form 192.168.1.xxx; for Subnet 2 uses addresses of the form 192.168.2.xxx; and for Subnet 3 use addresses of the form 192.168.3.xxx. Assign arbitrary MAC addresses to all of the adapters. * Consider sending an IP datagram from Host E to Host B. Suppose all of the ARP tables are up to date. List the steps that take place. * Repeat the previous question, now assuming that the ARP table in the sending host is empty (and the other tables are up to date).   *Solution:* | [9 marks] |

*First part: you can assign ay numbers you want eg see figure below:*

A diagram of a network

Description automatically generated*Second part:*

* *Forwarding table in E determines that the datagram should be routed to interface 192.168.3.002.*
* *The adapter in E creates and Ethernet packet with Ethernet destination address 88-88-88-88-88-88.*
* *Router 2 receives the packet and extracts the datagram. The forwarding table in this router indicates that the datagram is to be routed to 198.162.2.002.*
* *Router 2 then sends the Ethernet packet with the destination address of 33-33-33-33-33-33 and source address of 55-55-55-55-55-55 via its interface with IP address of 198.162.2.003.*

*The process continues until the packet has reached Host B.*

*Third part*

*Answer: ARP in E must now determine the MAC address of 198.162.3.002. Host E sends out an ARP query packet within a broadcast Ethernet frame. Router 2 receives the query packet and sends to Host E an ARP response packet. This ARP response packet is carried by an Ethernet frame with Ethernet destination address 77-77-77-77-77-77.*

**[25 marks]**

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| **6** |  | **Security: Authentication Protocols** |  |
|  | (a) | Consider the authentication protocol in Figure X in which Alice authenticates herself to Bob. Now suppose that while Alice is  authenticating herself to Bob, Bob must authenticate himself to Alice. Give a scenario by which Trudy, pretending to be Alice, can now authenticate herself to Bob as Alice. (Hint: Consider that the sequence of operations of the protocol, one with Trudy initiating and one with Bob initiating, can be arbitrarily interleaved. Pay particular attention to the fact that both Bob and Alice will use a nonce, and that if care is not taken, the same nonce can be used maliciously.)    Figure X Simple Authentication Protocol  *Bob does not know if he is talking to Trudy or Alice initially. Bob and Alice share a secret key KA-B that is unknown to Trudy. Trudy wants Bob to authenticate her (Trudy) as Alice. Trudy is going to have Bob authenticate himself, and waits for Bob to start:*  *1. Bob-to-Trudy: “I am Bob” Commentary: Bob starts to authenticate himself. Bob’s authentication of himself to the other side then stops for a few steps.*  *2. Trudy-to-Bob: “I am Alice” Commentary: Trudy starts to authenticate herself as Alice*  *3. Bob-to-Trudy: “R” Commentary: Bob responds to step 2 by sending a nonce in reply. Trudy does not yet know KA-B(R) so she can not yet reply.*  *4. Trudy-to-Bob: “R” Commentary: Trudy responds to step 1 now continuing Bob’s authentication, picking as the nonce for Bob to encrypt, the exact same value that Bob sent her to encrypt in Step 3.*  *5. Bob-to-Trudy: “KA-B(R)” Bob completes his own authentication of himself to the other side by encrypting the nonce he was sent in step 4. Trudy now has KA-B(R). (Note: she does not have, nor need, KA-B*  *6. Trudy-to-Bob: “KA-B(R)” Trudy completes her authentication, responding to the R that Bob sent in step 3 above with KA-B(R). Since Trudy has returned the properly encrypted nonce that Bob send in step 3, Bob thinks Trudy is Alice!* | [20 marks] |
|  | (b) | Suppose Alice and Bob are communicating over an SSL session. Suppose an attacker, who does not have any of the shared keys, inserts a bogus TCP segment into a packet stream  with correct TCP checksum and sequence numbers (and correct IP addresses and port numbers). Will SSL at the receiving side accept the bogus packet and pass the payload to the  receiving application? Why or why not? *No, the bogus packet will fail the integrity check (which uses a shared MAC key).* | [5 marks] |