CPSC 441
COMPUTER NETWORKS

FINAL EXAM SOLUTION

Department of Computer Science
University of Calgary
Professor Carey Williamson

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This is a CLOSED BOOK exam. Textbooks, notes, laptops, personal digital assistants, tablets, and cellular phones are NOT allowed. However, **calculators are permitted**.

It is a 120-minute exam, with a total of 80 marks. There are 18 questions, and 10 pages (including this cover page). Please read each question carefully, and write your answers legibly in the space provided. You may do the questions in any order you wish, but please USE YOUR TIME WISELY.

When you are finished, please hand in your exam paper and sign out. Good luck!

Student Name: ______________________________

Student ID: ____________________

Score: ________ / 80 = _______ %

Multiple Choice

Choose the best answer for each of the following 12 questions, for a total of 12 marks.

1 1. One of the early pioneers of the TCP/IP protocol stack on the Internet was:

(a) Tim Berners-Lee

(b) Vint Cerf

(c) Carey Williamson

(d) Jim Kurose

(e) Jennifer Rexford

1 2. The main difference between HTTP and HTTPS is:

(a) HTTP is for IPv4, while HTTPS is for IPv6

(b) HTTP uses UDP, while HTTPS uses TCP

(c) HTTP uses TCP, while HTTPS uses UDP

(d) HTTP is unencrypted, while HTTPS is encrypted

(e) none of the above

1 3. A distinctive feature of Asynchronous Transfer Mode (ATM) networks is:

(a) a "best effort" datagram service model

(b) fixed-size 53-byte packets called "cells"

(c) 24-hour online access to the banking network each day

(d) monthly service charges for each cheque or withdrawal

(e) all of the above

1 4. A typical router in the core of the Internet has:

(a) multiple network interfaces, each with its own IP address

(b) a switching fabric between its input ports and output ports

(c) buffers to hold a queue of packets at input or output ports

(d) a scheduling algorithm to determine which queued packet goes next

(e) all of the above

1 5. On classic Ethernet, the Maximum Transmission Unit (MTU) for an IP datagram is:

(a) 64 bytes

(b) 1024 bytes

(c) 1500 bytes

(d) 8192 bytes

(e) 65536 bytes

1 6. Switched Ethernet is superior to shared Ethernet because:

(a) it isolates each station into its own collision domain

(b) each LAN segment can have different link speeds

(c) the Ethernet switch does selective forwarding between LAN segments

(d) the Ethernet switch understands and uses CSMA/CD on each LAN segment

(e) all of the above

1 7. The Internet Control Message Protocol (ICMP) is used by:

(a) Web and email applications

(b) FTP and email applications

(c) SNMP and NTP

(d) `ping` and `traceroute`

(e) DNS and ARP

1 8. In the Internet Protocol (IPv4), datagrams can be:

(a) lost enroute to their destination

(b) delayed enroute to their destination

(c) corrupted enroute to their destination

(d) successfully delivered to their destination

(e) all of the above

1 9. In a “Class B” IP address like 136.159.5.20, the network ID portion is:

(a) 8 bits long

(b) 16 bits long

(c) 24 bits long

(d) 32 bits long

(e) none of the above

1 10. In Classless Inter-Domain Routing (CIDR), the network ID in an IPv4 address is:

(a) always 8 bits long

(b) always 16 bits long

(c) always 24 bits long

(d) always 32 bits long

(e) none of the above

1 11. The key advantage of OSPF over RIP is:

(a) support for hierarchical management of a very large AS

(b) seamless integration of intra-AS and inter-AS routing

(c) dynamic switching between Distance Vector and Link State approaches

(d) dynamic switching between infrastructure mode and ad hoc mode

(e) a shorter acronym to memorize

1 12. The textbook authors refer to the Border Gateway Protocol (BGP) as:

(a) “the glue that holds the Internet together”

(b) “the most complicated routing protocol ever invented”

(c) “a top 10 networking research problem”

(d) “good news travels fast; bad news travels slowly”

(e) “this slide is VERY important”

Networking Concepts and Definitions

12 13. For each of the following pairs of terms, **explain each term**, making sure to identify the similarities (if any) and the **key differences** between the two terms.

(a) (3 marks) "DNS" and "ARP"

```
DNS: Domain Name Service          ARP: Address Resolution Protocol
- application-layer protocol      - low layer (DLL) protocol
- maps names to IP addresses      - maps IP addresses to MAC addresses
- typically uses UDP              - uses link-layer frames
```

(b) (3 marks) "IPv4 address" and "MAC address"

```
IPv4: Internet Protocol (v4)      MAC: Medium Access Control
- 32-bit address                  - 48-bit address
- network-layer address           - datalink-layer address
- software assigned               - assigned by manufacturer
- locally unique                  - globally unique
- hierarchical structure          - flat address space
  (network ID + host ID)
```

(c) (3 marks) "Internet checksum" and "Cyclic Redundancy Check (CRC)"

```
Internet Checksum:                 CRC:
- used by IP (NL), TCP/UDP (TL)    - used by Ethernet and WiFi (DLL)
- done in software (slow)          - done in hardware (fast)
- 16-bit arithmetic sum            - uses polynomial code to compute
  with wraparound carryover          R from M/G using modulo-2 (XOR)
- rather weak error detection      - extremely strong error detection!
```

(d) (3 marks) "video frame" and "Ethernet frame"

```
Video frame:                       Ethernet frame:
- logical data unit at AL for      - logical data unit at DLL for
  video streaming applications       Ethernet LANs
- variable size                    - variable size
- encoded (e.g., MPEG)             - carries payload (e.g., IP datagram)
- meta-data for frame ID           - has header and trailer
```

Network Layer

12 14. The goal of Internet routing is to deliver IP datagrams from a source host to a destination host. In class, we discussed the logical separation of the Network Layer into the data plane and the control plane, as well as the emerging paradigm of Software-Defined Networking (SDN). Use your knowledge of the Network Layer to answer the following questions.

(a) (3 marks) What is the **data plane**? What key function(s) take place in the data plane? At what time scale does it operate?

- lower-level function in NL routers that deals with the movement of datagrams from the input ports to the proper output ports (forwarding)
- uses forwarding table (routing table); does lookup for each datagram to make forwarding decision; done at every router, in hardware
- operates at link speed (e.g., microseconds)

(b) (3 marks) What is the **control plane**? What key function(s) take place in the control plane? At what time scale does it operate?

- higher-level function in NL routers that determines the network path to be used for the routing of datagrams
- routing decisions made here; can be local/global decisions using centralized/distributed algorithms; done in software in each router or using SDN controller; produces routing tables to use
- usually operates at time scales of minutes or hours

(c) (2 marks) What are the two main similarities between traditional Internet routing and the SDN approach to Internet routing?

- uses a forwarding table
- uses TCAM lookup
- uses longest-prefix matching (and/or wildcarding)
- forwarding needs to operate at link speed

(d) (4 marks) What are the four main differences between traditional Internet routing and the SDN approach to Internet routing?

- use of SDN controller for the network (match/action)
- where network info is collected (SDN controller vs router)
- where the routing table is calculated (SDN controller vs router)
- traditional routing uses destination-based forwarding, while SDN uses generalized forwarding based on ANY fields in the datagram header
- centralized view of network in SDN
- flexible control of routing paths vs proprietary routing algorithms
- simple generic routers in SDN vs proprietary hardware/software
- OpenFlow API for SDN controllers to exchange info with routers
- occasional extra delay for interactions with SDN controller

Logical Link Control (LLC) Protocols

12 15. There are two popular technologies for Local Area Network (LAN) design, namely IEEE 802.3 Ethernet and IEEE 802.11 WiFi. Use your knowledge of these technologies to answer the following questions.

(a) (3 marks) What Datalink Layer service model is provided by each of these LAN technologies? How are they similar? How are they different?

```
 - connection-less DLL service model for both
 - Ethernet is unacknowledged
 - WiFi is acknowledged
```

(b) (3 marks) List three similarities about LLC frames in Ethernet and WiFi.

```
 - uses 48-bit MAC addresses for source and destination
 - uses CRC-32 checksum for error detection in trailer of frame
 - supports variable size frames (length field)
 - transmits on a shared broadcast channel using a CSMA protocol
```

(c) (2 marks) Which of these two LAN technologies has the higher bit error rate, and why?

```
WiFi: unguided transmission over ‘‘air interface’’, which is subject
   to a lot of ambient interference and noise
 - usually half-duplex, with multi-path fading, and limited RF power
```

(d) (2 marks) Which LAN technology provides better support for mobile users, and how?

```
WiFi: wireless RF signals propagate omni-directionally; allows roaming
 - devices automatically associate with ‘‘best’’ AP signal strength
 - multiple APs can be configured as an extended service set (ESSID)
 - example: AirUC (or AirUC-secure)
```

(e) (2 marks) List and explain **any two other features** of WiFi technology that are not available (or even possible) in Ethernet LANs.

```
 - can adapt data rate based on signal quality (1,2,5.5,11 Mbps)
 - ad hoc mode to support mobile computing without Internet access
 - RTS/CTS protocol for handling hidden node problem
 - MAC-layer retransmission of unacknowledged frames
 - three types of frames: Management, Control, Data
 - backwards compatibility with earlier IEEE 802.11 standards
 - polling mode to support power-saving operation
```

Medium Access Control (MAC) Protocols

12 16. Within the Data Link Layer, we studied a variety of Medium Access Control (MAC) protocols to regulate access to a broadcast channel shared by many stations.

For each of the following MAC protocols, provide a brief description (either algorithmic or conceptual) of how it works. Where possible, clarify the new features in each protocol that improve upon the MAC protocols earlier in the list.

(a) (3 marks) Pure ALOHA

```
- random channel access protocol for packet radio networks (U. Hawaii)
- send when ready!
- very low channel access delay (zero), but prone to collisions
- max effective throughput is 1/2e = 18%
```

(b) (3 marks) Slotted ALOHA

```
- improves upon ALOHA by providing global timing synchronization (slots)
- when ready, wait until next slot boundary before sending
- slightly higher channel access delay, but fewer collisions
- reduces vulnerable period from two frame times to one frame time
- max effective throughput is 1/e = 37%
```

(c) (3 marks) CSMA

```
- Carrier Sense Multiple Access; requires carrier-sense capability
- listen to the channel before sending
- if idle, then send, else defer (wait until idle before sending)
- reduces collisions by a lot (but does not completely eliminate them)
- max effective throughput of approximately 55%
```

(d) (3 marks) CSMA/CD

```
- adds Collision Detection (CD); requires listening while transmitting
- if collision detected during transmission, then abort early
- avoids wasting channel time on lengthy collisions
- max effective throughput over 90%
```

Internet Protocol Performance

10 17. Many Internet protocols use **caching** of "soft state" information to improve protocol performance. That is, the protocol works correctly even without cached state information, but is much faster when this soft state information is already present.

(a) (6 marks) Among the many protocols that we studied in class, give **three examples** of different protocols or layers that use caching of state information. Make sure to clarify **what** information is cached, **where** it is cached (e.g., client side, server side, or elsewhere in the network), **why** it is cached (i.e., how it helps improve performance). and **how long** it is cached (e.g., seconds, minutes, hours, days).

```
- WWW/HTTP (AL): store copies of recently-retrieved Web objects in the
  browser cache or a proxy cache to avoid repeated retrievals of items;
  uses conditional GET in HTTP; reduces load on network and Web servers;
  objects might be stored for minutes, hours, or days
- Persistent HTTP (AL/TL): keeps a TCP connection to a Web server open
  for a bit just in case you want to retrieve another Web object;
  usually 10-15 seconds; avoids repeated TCP handshaking and slow start
- HTTP (AL): uses ``cookies'' to cache state information about users
  so that content can be customized; client and server; days or weeks
- DNS (AL): keeps DNS cache of recent mappings of domain names to IP
  addresses to avoid repeated lookups of things that rarely change;
  mappings kept for hours or days, depending on TTL (Time To Live)
- CDN (AL): pre-load CDN nodes with copies of popular content so that
  it is closer to the consumers (e.g., movies); used by Netflix and
  others to reduce response time and network traffic; days or weeks
- RIP (NL): re-computes routing table every 60 seconds, and keeps
  most recent version as a ``cache'' of best paths to use (DV hops);
  network topology does not change very frequently
- ARP (DLL): keeps ARP cache of recent mappings of IP address to MAC
  addresses to avoid repeated lookups of things that rarely change;
  typically cached for 20 minutes; used by Ethernet switches too
```

(b) (4 marks) Give **one other example** of an Internet protocol (past, present, or future) whose performance and/or scalability could be improved through the use of cached state information. Identify the layer at which this protocol operates, and why caching would be potentially useful. Again, please clarify what information is being cached, where it is being cached, why, and how long.

```
- HTTP/2 (AL): could use server push feature to provide content to clients
 even before it is requested; reduces latency using pre-fetching
- TCP (TL): could remember estimated cwnd for a recent particular IP
 destination to avoid having to do TCP slow start all over again
- Mobile IP (NL): could cache IP/MAC state information about mobile nodes
 and which network they are currently at (e.g., Home Agent, Foreign Agent)
```

Future Networked Systems

10 18. A recent proposal from researchers at Carnegie Mellon University (CMU) is to get rid of traditional traffic lights at city intersections, and instead use the wireless communication capabilities of future self-driving cars to dynamically negotiate and regulate vehicular traffic flow through intersections. By doing so, they claim that they can improve traffic flow, and reduce urban commute times by about 30%.

(a) (2 marks) Do you think that this approach is a **good idea** or a **bad idea**? Why?

Good idea: improves efficiency, human productivity, environmental impacts.
Bad idea: risky and dangerous!

(b) (3 marks) Given your knowledge of wireless networking, what are some of the technical challenges with this new approach? How could these be overcome?

- requires real-time reliable communication over wireless channel!
- limited range wireless transmissions, especially in fog/rain/snow
- high error rates in wireless communications due to noise/interference
- need compatible technology in all vehicles (new or old)
- bad guys can use jamming signals to produce traffic chaos!
- solutions: new protocols; international standards; govt regulations

(c) (3 marks) Given your knowledge of flow control and congestion control, what are some of the technical challenges with this new approach? How could these be overcome?

- high traffic volumes at rush hour
- bursty and unpredictable traffic
- heterogeneous speeds
- fairness issues (how to define and measure it)
- dynamically adapting to changing conditions (e.g., lane closures, accidents)
- left-turns are always problematic (impedes all other directions)
- solutions: real-time control protocols; conformance testing; traffic laws

(d) (2 marks) What other potential challenges (technical or non-technical) do you see with this new approach? How could these be overcome?

- cybersecurity issues: traffic system getting hacked by the bad guys
- rogue pedestrians disrupting traffic flow at intersections
- backward compatibility with human-driven vehicles
- solutions: strict government regulations; monitoring; penalties

*** THE END ***