Problem 1. OpenFlow. Consider the 6-host, 3-switch SDN Openflow network shown in the figure below. The MAC address for a host with IP address 10.0.0.i is 00:00:00:00:00:i.

Specify the 11-tuple flow table entries, and indicate at which switch/router the rules are installed to obtain the following forwarding behaviors. In the case that you have multiple entries a flow table, indicate their priority order.

a. Static switching. All hosts can forward to all other hosts, over the shortest path. Specify this rule using MAC addresses rather than IP addresses.
b. Static routing. All hosts can route to all other hosts, using shortest path routing. Specify this rule using IP addresses rather than MAC addresses.
c. Modified static routing. The same as in 1. Above, except that hosts h5 and h6 route to h3 or h4 via switch s1.
d. Modified static routing. The same as in 1. Above, except that hosts h5 and h6 route to h4 directly, but route to h3 via switch s1.
e. h5 can only receive traffic from h4; all other traffic to h5 is dropped at s1.
f. h5 can only receive traffic from h4; all other traffic to h5 is dropped at the switch attached to a host trying to send to h5.
g. h5 can only receive TCP traffic, while h6 can only receive UDP traffic.
h. h1, h5, and h6 appear to be on their own broadcast LAN, so that when one of them sends a link layer frame, that frame is delivered to the other two hosts, but to no other hosts. Do not use the VLAN ID field.
i. h1, h5, and h6 appear to be on their own broadcast LAN, so that when one of them sends a link layer frame, that frame is delivered to the other two hosts, but to no other hosts. Implement this using the VLAN ID field.

Problem 2. Analysis of discrete time CSMA/CD. In class I presented an informal derivation of an expression for the system throughput of CSMA/CD in terms of the offered load. In this
Define $S$ and $G$ as in class. Also assume that the arrival process of all packets is Poisson with rate $G$. Assume that time is divided into fixed length intervals of length $a$ (equal to the end to end propagation delay). Further assume that the time to transmit a packet is 1 and that $1/a$ is an integer. Suppose that $k$ users generate packets in the $i$-th interval. Then at the start of the $(i+1)$-th interval, all $k$ users sense the channel and if it is idle, start to transmit. If $k = 1$, then the user transmits over $1/a$ time intervals. One additional interval is required for the channel to clear. If $k > 1$, then a collision occurs and the users become aware of it at the end of the $(i+1)$-th time interval. An additional time interval is needed for the channel to clear.

- Derive an expression for $S$ in terms of the offered load $G$. How does this compare to what we derived in class.
- Consider a variant of the system that is used in 802.11 (WiFi). Here a user senses whether or not the channel is idle. If so, it transmits, otherwise it waits a random amount of time. As with CSMA/CD, a collision may occur if two or more users transmit during the same slot. Unlike CSMA/CD however, a user cannot detect a collision. Consequently all users transmit their entire data. They then learn of the collision when the base station returns a negative acknowledgment (or a lack of an acknowledgment). Assume that again users use backoff timers to reschedule their retransmissions and that transmissions and retransmissions can be captured by a Poisson process where packets (original transmissions and retransmissions) are offered at rate $G$. As before, derive an expression for the system throughput $S$ as a function of $G$ and the propagation delay. This is referred to as carrier sense multiple access (CSMA).
- Plot $S$ vs $G$ for both CSMA and CSMA/CD. What is lost in the wireless setting when users no longer have the ability to detect collisions?

**Problem 3. Randomization and Indirection: Crowds.** Read the paper, M. Reiter, A. Rubin, "Crowds: Anonymity for Web Transactions" *ACM Transactions on Information and System Security*. You only need to read sections 1, 2 and 4. What are randomization and indirection used in this protocol? Pick two examples of randomization and indirection that we studied in class, and compare and contrast the use of randomization and indirection in Crowds, and in these two protocols.