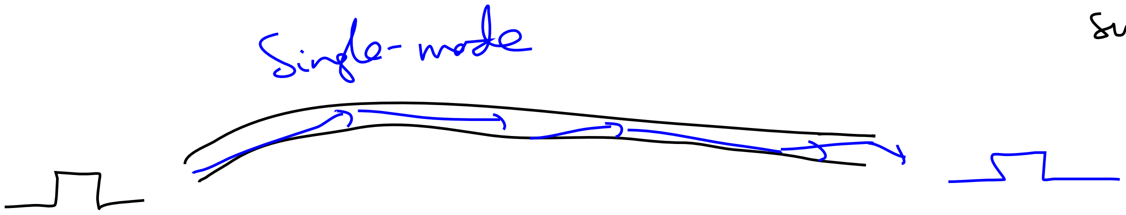
CS348, Mid-Semester Exam

Duration: 2 hours; Max. Marks: 60

1. (15 marks [2.5 each]) State if the following are **True or False and explain briefly (in about half page each) why**.
    a. A multi-mode optic fiber, in general, provides higher data rates than a single-mode optic fiber of the same length.

FALSE

Multimode fibres allow multiple modes of the same signal to pass through. These interfere with each other and hence cause dispersion at the receiver.



Since the signal is less distorted in single-mode, due to only 1 mode passing through, in general higher data rates are possible.

For example, laser pulses can be spaced closer at the input, thereby allowing higher data rates.

b. The Virtual Carrier sensing protocol of IEEE 802.11, which uses RTS/CTS, solves the exposed terminal problem in wireless networks.

FALSE.

Here only neighbours can hear and interfere with each other.

In theory $B \to A$ and $C \to D$ are possible simultaneously.

However, the RTS-CTS protocol does not allow this and the problem is called EXPOSED Terminal problem.

If B sends RTS to A and A replies with a CTS then C remains silent for NAV period specified in the RTS.

As a result C cannot send to D while B sends to A.

c. The receiver in a communication system using Differential Manchester coding is required to know the correct polarity of the transmitted signal to detect if a symbol transmitted represents a 1 or 0.

FALSE:

In differential manchester coding if

bit = 0 : voltage in 1st 1/2 of bit period is opposite last half of prev. bit

bit = 1 : —— " —— same —— " ——

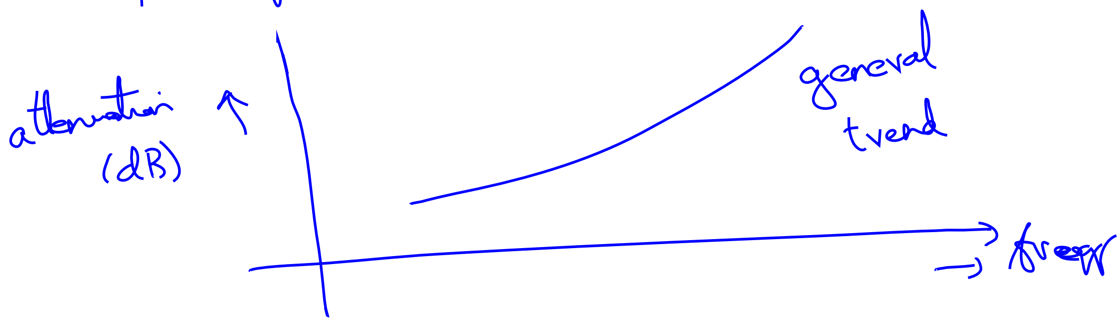
We can compare the voltage in last half of prev. bit period with that of 1st half in current bit period to determine if a '0' or '1' has been sent.

∴ the polarity is not required.

d. For a twisted pair wire, the attenuation is constant (i.e. does not vary) with the frequency of the input signal.

FALSE.

A twisted pair can be modeled as an R-L-C circuit. The inductance & capacitance (L, C) components are freq. dependent, due to which attenuation varies with input frequency.



Attenuation is generally higher for higher frequencies.

e. The CRC generator (also called divisor) polynomial $x^7 + x^5 + 1$ will detect all cases in which the number of bit errors in the transmitted codeword (i.e. data word concatenated with the CRC) has an ODD number of bit errors.

FALSE

Call the error polynomial $E(x)$

$$C(x) = x^7 + x^5 + 1$$

If $C(x)$ divides $E(x)$ then the error is NOT detected.

Consider $E(x) = x^j (x^7 + x^5 + 1)$ for any $j \geq 0$

$E(x)$ has 3 errors, which is an ODD number

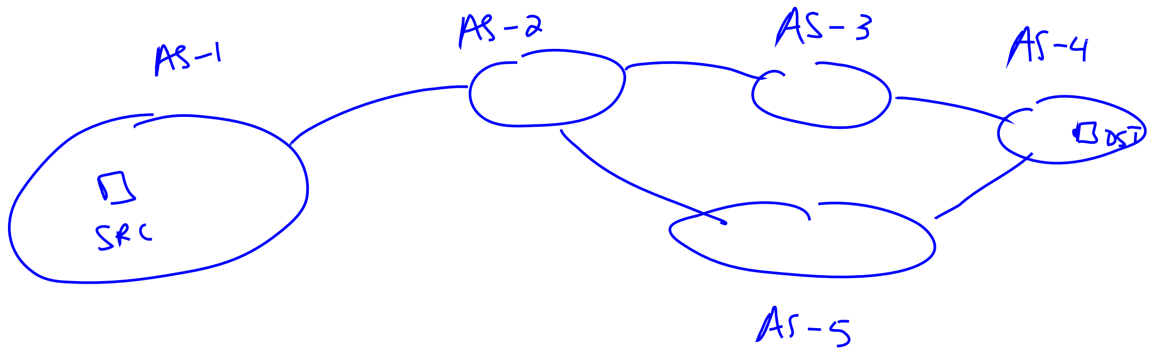
$E(x)/C(x) = x^j$ and hence $E(x)$ is not detected.

We have a counter-example here

f. The Internet guarantees that any IP packet takes the shortest path in terms of network latency (delay) from source to destination.

FALSE.

Consider the AS-level topology of the Internet.



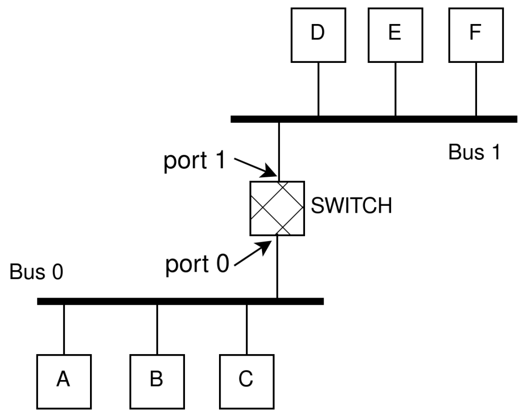
Each AS has its own internal routing protocol (IGP) Interior Gateway Prot.

The metrics used in the IGPs in different ASes can be different.

Hence the end-to-end path from source to destination will not follow the path with lowest latency in general.

2. (10 marks) An Ethernet Switch connects two different Ethernet segments (each segment is a bus with nodes connected to it) as shown in the figure below. The switch has two ports: port 0 and port 1, as shown. At time **t=0** seconds, the switch has an empty forwarding table. Suppose the forwarding table has columns (i) MAC address, (ii) Port number, (iii) Expiry time (expiry time is in absolute value in seconds, i.e. if the expiry time value is **T**, then that entry is slated to be removed at **t=T** seconds). Suppose every forwarding table entry has an expiry time of **15** seconds after it is created (**or renewed**) in the table. "Renewed" here means that if there is already an entry corresponding to a node in the table, and the switch hears another frame with that node as source at time "t", then the switch extends the expiry of that entry to "t+15" seconds. Let the MAC addresses of A,B,C etc. be represented by MAC(A), MAC(B), MAC(C) etc.

The following frames are generated by Ethernet nodes (other than the Switch). The time at which the frames are generated, and their source and destination MAC addresses are given below. Assume that no other frames are transmitted by the nodes A,B,C,D,E, F.



Give the **contents of the <u>full forwarding table</u>** at the switch immediately **AFTER EACH** of the above frames are heard by the Switch, **and** state if the frame is forwarded by the Switch, **and if so**, onto which port. Explain why it forwards or does not forward each frame. **Note:** You need to give the FULL contents of the forwarding table, not just the new entries added.

a) t=0 seconds; SRC MAC = MAC(D); DEST MAC=MAC(A)

MAC	Port	Expiry
MAC(D)	1	15

Forwarded to port-0 as no entry for MAC(A)

b) t=5 seconds; SRC MAC = MAC(B); DEST MAC=MAC(C)

MAC	Port	Expiry
MAC(D)	1	15
MAC(B)	0	20

Forwarded to port-1 as no entry for MAC(C)

c) t=12 seconds; SRC MAC = MAC(E); DEST MAC=MAC(D)

MAC	Port	Expiry
MAC(D)	1	15
MAC(B)	0	20
MAC(E)	1	27

<u>Not</u> forwarded to port-0, as D is on port-1 and frame heard on same port

d) t=18 seconds; SRC MAC = MAC(C); DEST MAC=MAC(D)

MAC	Port	Expiry
MAC(B)	0	20
MAC(E)	1	27
MAC(C)	0	33

Forwarded to port-1 as there is no entry for MAC(D) in table

e) t=20 seconds; SRC MAC = MAC(B); DEST MAC=MAC(A)

$t = 20 - \varepsilon \ (\varepsilon > 0)$

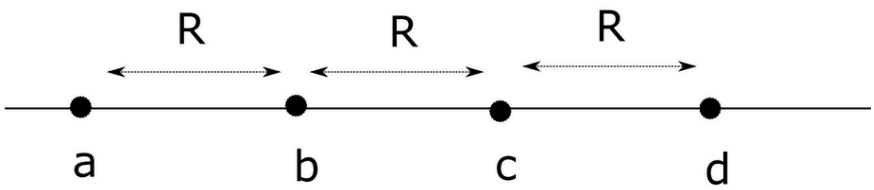
MAC	Port	Expiry
MAC(B)	0	35 → renewed
MAC(E)	1	27
MAC(C)	0	33

Forwarded to port-1, as no entry in table for MAC(A)

3. (8 marks) Four wireless nodes are placed on a straight line (see the Figure below). Let *D(i, j)* denote the distance between nodes *i* and *j* (note: "*i*" and "*j*" can be any 2 of the 4 nodes). Each node has a circular communication range, and carrier sense range, of $r = 1.5R$. This means that a frame transmitted by node *i* is received by a node *j* if and only if $D(i, j) < r$ and $D(k, j) > r$ for all $k \in T$, $k \neq i$, where *T* is the set of nodes transmitting data at the same time as *i*. Also, if node *i* is transmitting a frame, then node *j* can carrier sense (and hence know that the channel is busy) the signal transmitted by node *i* if and only if $D(i, j) < r$.

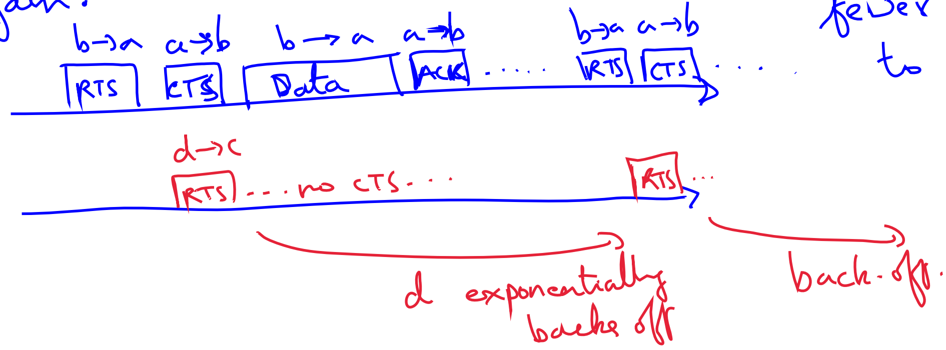
All nodes employ the RTS-CTS-DATA-ACK protocol with exponential-backoff (on collision) for transferring data that was discussed in class. Assume that **b** has an infinite amount of back-logged data to transmit to **a**. This means that **b** always has data to transmit to **a**. Similarly **d** has an infinite amount of data to transmit to **c**. Nodes **a** and **c** have no data to transmit.

In such a scenario it is very likely that the throughput from **d** to **c** is significantly lower than that from **b** to **a**. **Explain why this is true**. You should use details of the MAC protocol in your explanation. If necessary, make any reasonable assumptions and state them clearly. A rough qualitative explanation will do. (**Hint:** Keep in mind which nodes can hear which other nodes).



Suppose b sends an RTS to a, a sends CTS to b, and b sends DATA etc. Since d does not hear a or b, it may send an RTS to c during this time.
But 'c' cannot reply with a CTS as it is forced to remain silent for NAV mentioned in b's RTS.
Since d does not get a CTS from 'c', it assumes a collision has occurred and so doubles CWmax and retries later. This could repeat leading to CWmax doubling again. This causes the phenomena mentioned, as d gets fewer opportunities to transmit.

Illustration

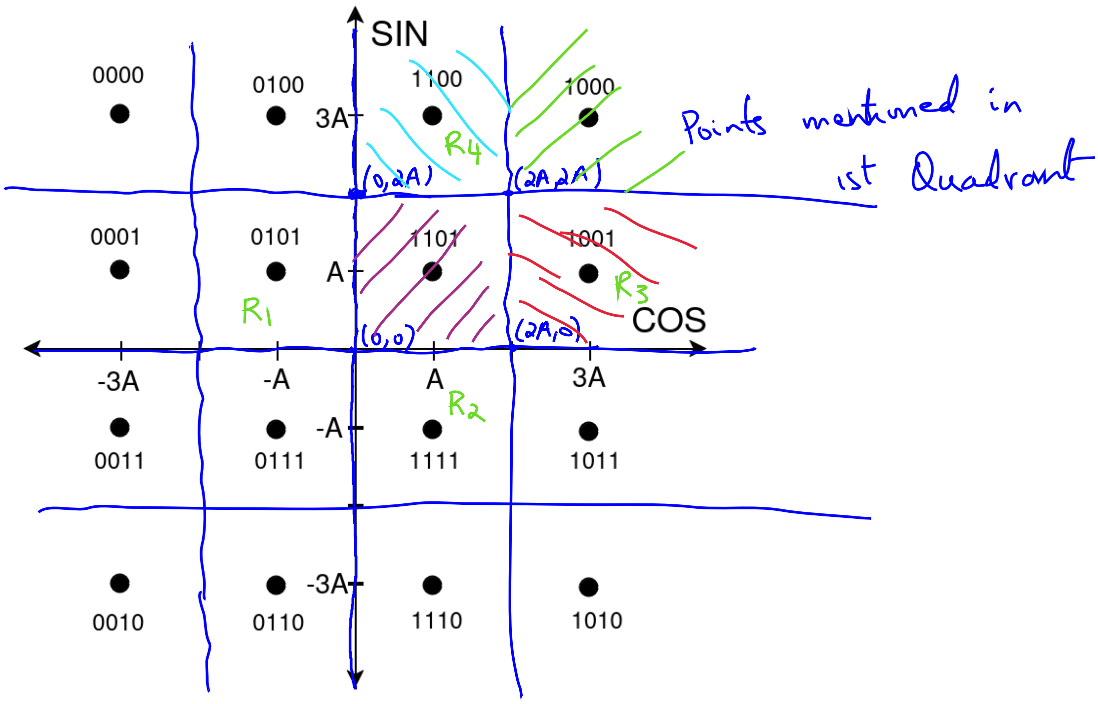


4. (15 marks) Consider a communication system that consists of a single transmitter and a single receiver. Let us assume that there is no attenuation and no phase change caused by the channel (i.e. we ignore attenuation and phase change due to the channel in this problem). However, the signal is corrupted by additive white Gaussian noise at the receiver. Denote the point in the two-dimensional constellation diagram (with cosine on X-axis and sine on Y-axis) corresponding to the transmitted signal *s(t)* by (s_x, s_y).

The unit vector on the x-axis is $\sqrt{2/T}\,Cos(2\pi f_0 t)$ (that is point (1,0)) and the unit vector on the y-axis (that is (0,1)) is $\sqrt{2/T}\,Sin(2\pi f_0 t)$, where T is the symbol duration (which is equal to $1/f_0$). We will assume that the transmitted energy of any symbol *s(t)* is given by $s_x^2 + s_y^2$.

The following figure shows a 16-QAM constellation diagram used by the transmitter. The coordinates of each constellation point have been shown in the diagram and also the 4 bits assigned to each constellation point. <u>Assume that all constellation points are equally likely to be transmitted.</u> The coordinates of the received constellation point are obtained by taking the inner product of the received signal with the unit vectors on the X and Y axes, as discussed in class.

a) (4 marks) In a diagram, show the regions in the constellation diagram which are to be mapped to each of the 16 constellation points at the receiver. **Mention the coordinates** of important points where the different regions intersect (at least in one quadrant).



Each region is mapped to the constellation point inside it.

b) (6 marks) Suppose that the transmitted symbol is *(A,A)* which corresponds to the four bits 1101. (In this question we are only interested in the case when this particular symbol is transmitted). Then the received constellation point is $r = (A + n_x, A + n_y)$, where n_x and n_y are i.i.d. Gaussian random variables with zero mean and variance $N_0/2$, where N_0 is the noise energy per symbol. Note that half the noise energy is in the X-axis direction and the other half in the Y-axis direction, which is why variance is $N_0/2$ in each direction. What is the probability that the receiver **correctly identifies** the transmitted constellation point as *(A,A)*? Write your answer in terms of the $Q(.)$ function defined as

$$Q(z) = \frac{1}{\sqrt{2\pi}} \int_z^{\infty} exp(-x^2/2)\, dx$$

Show your working.

The receiver identifies the constellation point correctly if the received point is within the square with corners $(0,0)$, $(2A,0)$, $(2A,2A)$, $(0,2A)$

In other words $-A < n_x < A$ and $-A < n_y < A$

Pdf of Gaussian (r.v. X) with variance σ^2 and zero mean is $f_X(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-x^2/2\sigma^2}$

$\sigma^2 = \frac{N_0}{2}$ for both n_x and n_y

$$Pr(n_x \geq A) = \frac{1}{\sigma\sqrt{2\pi}} \int_A^{\infty} e^{-x^2/2\sigma^2}\, dx$$

$\left(\text{let } z = x/\sigma \Rightarrow dz = \frac{dx}{\sigma}\right)$

$$Pr(n_x \geq A) = \frac{1}{\sqrt{2\pi}} \int_{A/\sigma}^{\infty} e^{-z^2/2} dz = Q(A/\sigma) \qquad \text{—— (1)}$$

Since the Gaussian (p.d.f.) is symmetric about the mean

$$Pr(-A < n_x < A) = 1 - 2\,Pr(n_x \geq A)$$
$$= 1 - 2\,Q(A/\sigma) \qquad \text{—— (2)}$$

Similarly $\Pr(-A < n_y < A) = 1 - 2Q(A/\sigma)$ —— 3

Since n_x and n_y are independent

$$\Pr\left(n_x \in (-A, A) \text{ and } n_y \in (-A, A)\right)$$

$$= \left(1 - 2Q(A/\sigma)\right)^2$$

$$= \left[1 - 2Q\left(A/\sqrt{\tfrac{N_0}{2}}\right)\right]^2$$

$=$ Ans

c) (5 marks) Suppose that the transmitted symbol is *(A,A)*. (In this question we are only interested in the case when this particular symbol is transmitted). Then what is the probability that **exactly 1 out of 4 bits** corresponding to this symbol is received in error? (**Hint:** find constellation points with Hamming distance of one from 1101).

If (A,A) is transmitted and the received point is in R_1, R_2, R_3 or R_4, then we get exactly 1 bit in error.

Let $P(R_j)$ denote the prob. that the received point is in R_j. $(j=1,2,3,4)$

$$P(R_3) = \Pr(n_x > A \text{ and } n_y \in (-A,A))$$

$$= Q(A/\sigma)\cdot[1-2Q(A/\sigma)]$$ (using independence and ① and ③)

By symmetry, we see that

$$P(R_4) = P(R_3)$$

$$P(R_1) = \Pr(n_x \in (-2A,-A) \text{ and } n_y \in (-A,A))$$

$\Pr(n_x \in (-2A,-A)) = \Pr(n_x \in (A,2A))$ since n_x is zero-mean Gaussian

$$= \Pr\left(Z \in \left(\frac{A}{\sigma}, \frac{2A}{\sigma}\right)\right) \quad \left(\text{where } Z = \frac{n_x}{\sigma}\right)$$

variance is 1

$$= \Pr(Z > A/\sigma) - \Pr\left(Z > \frac{2A}{\sigma}\right)$$

$$= Q(A/\sigma) - Q(2A/\sigma)$$

Thus $\Pr(R_1) = \left[Q\left(\frac{A}{\sigma}\right) - Q\left(\frac{2A}{\sigma}\right)\right]\left[1-2Q\left(\frac{A}{\sigma}\right)\right]$

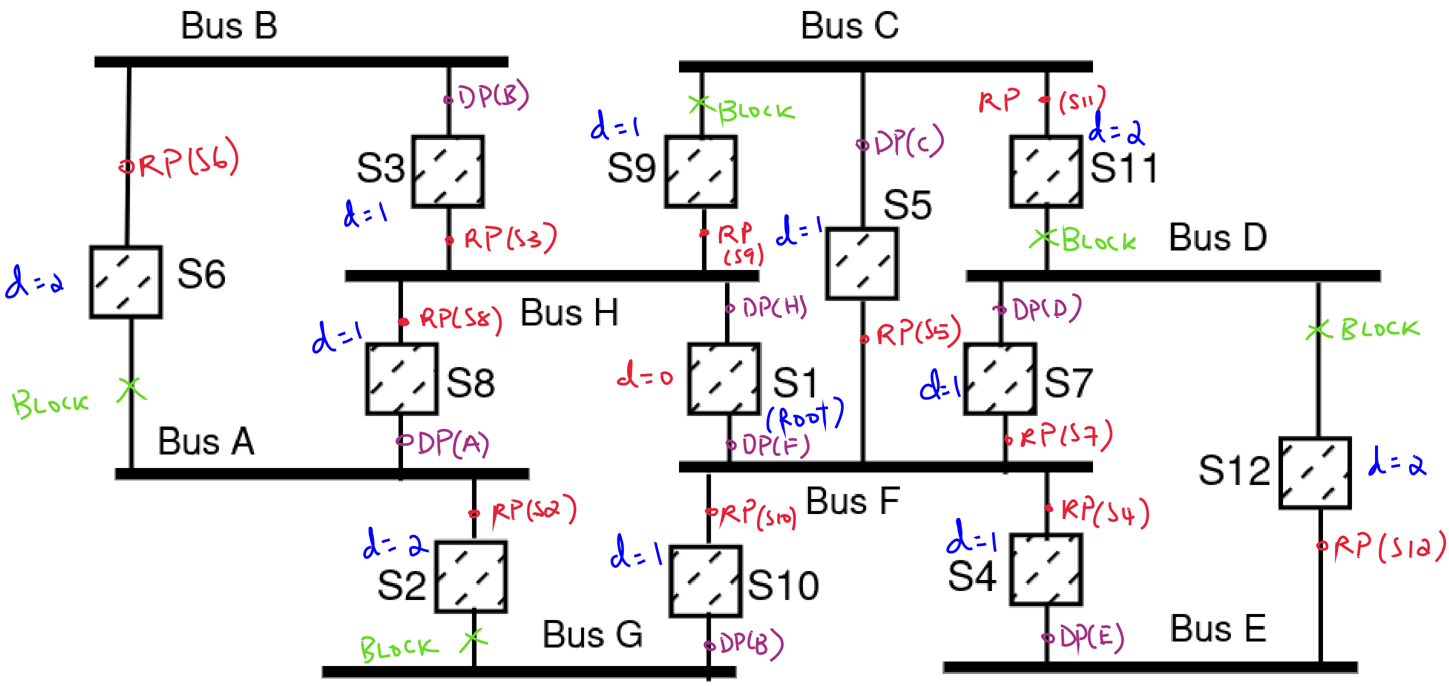
From symmetry, $P(R_2) = P(R_1)$

Hence $$\sum_{j=1}^{4} P(R_j) = [1-2Q(A/\sigma)]\left[2Q\left(\frac{A}{\sigma}\right) - 2Q\left(\frac{2A}{\sigma}\right) + 2Q(A/\sigma)\right]$$

$$= 2[1-2Q(A/\sigma)]\left[2Q\left(\frac{A}{\sigma}\right) - Q\left(\frac{2A}{\sigma}\right)\right]$$ where $\sigma = \sqrt{N_0/2}$

$=$ Ans

5. (12 marks) The following diagram shows several Ethernet Buses (sometimes called Segments) (Bus-A, Bus-B , etc.) connected by switches (also called Bridges) S1, S2, etc. Assume that the Bridge ID of S1 is smaller than that of S2, the Bridge ID of S2 is smaller than that of S3, and so on, with S12 having the largest Bridge ID. Suppose the switches finish running the spanning tree protocol discussed in class. Machines (other than the Switches) that are connected to various buses are not shown so as to make the figure less cluttered.



a) (1 marks) Indicate on a diagram which Switch is the root node and explain (in a few sentences) why.

S1 has the smallest Bridge ID and so becomes the root

b) (5 marks) Indicate which ports of each switch are root ports and briefly explain why.

The distance of different switches to the root are shown as "d = x" in the diagram

Each switch has 2 ports. If one port has a neighbouring switch whose distance is less than the distance of any neighbour on the other port, then the former port becomes the RP.

These are:

S_5, S_{10}, S_4, S_7's ports on Bus-F } hear root (S1) as neighbour, which has $d=0$
S_9, S_3, S_8's ports on Bus-H

The other ports of the above mentioned switches can only hear neighbours with $d \geq 1$.

Some switches have both ports equidistant from the root, that is the min. distance of neighbours on both ports are equal.

Here we use tie-breaking rule: find all neighbours with least distance, find min. Bride ID among them. Port connected to that neighbour is the RP.

These are: S12 has to choose between S4, S7 (both $d=1$) and so chooses port connected to S4

S11 has to choose among S5, S9, S11 (all $d=1$) and so chooses port connected to S5

S2 has to choose among S8 and S10 and so chooses port connected to S8

S6 has to choose between S3 and S8 (all $d=1$) and so chooses port connected to S3 as RP.

c) (4 marks) Indicate which ports are Designated ports of each Bus and briefly explain why.

Among all ports on a Bus, if one port is on a switch with smaller distance to root than all others, then that port becomes the DP of the Bus.

Such is the case for:

Bus-A : S8 is only switch with d=1, hence its port is DP

Bus-B : S3 ——— " ———

Bus-G : S10 ——— " ———

Bus-E : S4 ——— " ———

Bus-D : S7 ——— " ———

Bus-F : S1 is only switch with d=0, hence its port is DP

Bus-H : S1 ——— " ———

In case of a tie, the port of bridge whose ID is lowest becomes the DP

Such is the case for:

Bus-C : S5 & S9 both have d=1, hence port of S5 is DP

d) (2 marks) Indicate which ports are Blocked ports and briefly explain why.

Ports neither RP nor DP are Blocked.

These are

S6's port on Bus-A

S2's — " — Bus-G

S9's — " — Bus-C

S11's — " — Bus-D

S12's — " — Bus-D