# Problem Set #1 – CSCI 5273

Assume that 1 Kbps = $10^3$ bits/sec, 1 Mbps = $10^6$ bits/sec, 1 Gbps = $10^9$ bits/sec, and 1MB = $10^6$ x 8 bits. The capital 'B' typically means 'byte' while the lowercase 'b' indicates 'bit'.

1. What advantage does a circuit-switched network have over a packet-switched network?

Circuit switched networks allow for more reliable communication with predictable performance due to allowing a single connection to monopolize resources. This results in simpler forwarding and removes the need for packet headers, since once a connection is established in a circuit-switched network, no other communication can take place over the same data link.

2. What advantage does TDM have over FDM in a circuit switched network?

In circuit-switched networks, reliable and predictable performance is critical. Time-division multiplexing (TDM) provides this; when a node is given a timeslot, it is allowed to use the full available bandwidth on the link, guaranteeing the expected performance is attained. Frequency-division multiplexing (FDM), while allowing for multiple nodes to communicate simultaneously over the link, limits the bandwidth of any given node by some function of the number of nodes, which means that the performance becomes unpredictable

3. We consider sending real-time voice from Host A to Host B over a packet-switched network. Host A converts analog voice to a digital 65kbps bit stream and send these bits into 56-byte packets. There is one link between Hosts A and B and the transmission rate is 1 Mbps and its propagation delay is 20 msec. As soon as Host A gathers a packet, it sends it to Host B. As soon as Host B receives an entire packet, it converts the packet's bits into an analog signal. How much time elapses from the time a bit is created (from the original analog signal at Host A) until the bit is decoded (as part of the analog signal at Host B)?

We are given that the propagation delay $D$ = 20
ms = 0.02
s. The transmission time is
given as $P/R$, where $P$ = 56
B = 448
bits is the packet size and $R$ = 1
Mbps = $10^6$ bits/s is the transmission rate.
The time to transfer a single packet is given by the
end-to-end delay, $D_e = D + P/R$ = 0.02 s + $\frac{448 \text{ bits}}{10^6 \text{ bits/s}}$ = 0.020448 s.

The analog-to-digital conversion time is $\frac{448\ b}{65\ Kbps} \approx 0.0069\ s$ per packet. Thus, the total time from the creation of the first bit to the decoding of the first bit is $\frac{448\ b}{65\ Kbps} + D_e$ = 0.02734 $s$ = 27.34 $ms$.

4. Consider a Go-Back-N sliding window algorithm (1 packet is 250 bytes long) running over a 100km point-to-point fiber link with bandwidth of 100 Mbps.
a. Compute the one-way propagation delay for this link, assuming that the speed of light is 2 x $10^8$ m/s in the fiber .

The propagation delay is $D = \frac{M}{S}$, where $M$ = 100 $km$ is the link length and $S$ =2 × $10^8$ $\frac{m}{s}$ is the link propagation speed. So, $D = \frac{100\ km}{2 \times 10^8\ \frac{m}{s}} = \frac{1 \times 10^5}{2 \times 10^8\ \frac{m}{s}} = 0.5\ ms$.

b. Suggest a suitable timeout value for the algorithm to use. List factors you need to consider.

In order to determine a suitable timeout value, we must first determine the RTT. The RTT on this link is at least twice the propagation delay, 2(0.5 $ms$), plus the forward transmission time $\frac{250 \cdot 8\ bits}{100\ Mbps} = 2 \times 10^{-5}\ s = 20\ \mu s$.

Assuming reverse transmission time, since the size of the acknowledgement packet should be small relative to the size of data packets, the RTT is about 1.02 $ms$. Thus, a suitable timeout would be slightly longer than that, in order to account for minor delays and processing time. For example, a timeout of 1.1 $ms$ to 1.25 $ms$ would likely be reasonable.

c. Suggest N to achieve 100% utilization in this link.

Since the link has a round-trip BDP of 100 $Mbps \cdot 2(0.5)ms$ = 100 $Kb$, the link can fit a total of $\frac{100\ Kb}{250 \cdot 8\ bits/packet}$ = 50 packets at any given time. Thus, a send window size of $N$ = 50 packets would achieve 100% utilization.

(9pts) Suppose a 1-Gbps point-to-point link is being set up between the Earth and a new lunar colony. The distance from the moon to the Earth is approximately 385,000 km, and data travels over the link at the speed of light—3×$10^8$ m/s.

a. Calculate the minimum RTT for the link.

The minimum RTT is the RTT for transmitting a single bit, given as

$$RTT = 2\ (M/S + 1/R) = 2\ (3.85 \times 10^8\ m\ /3 \cdot 10^8\ \frac{m}{s} + 1\ b/1\ Gbps) \approx 2.567s.$$

b. Using the RTT as the delay, calculate the delay × bandwidth product for the link.

The BDP (using the RTT) is 2.567 $s \cdot 1\ Gbps$ = 2.567 $Gb$

c. What is the significance of the delay × bandwidth product computed in (b)? The BDP represents the amount of data which could be in transit across the link at any given time. To fully utilize this link, we would need to have 2.567 $Gb$, or about 320 $MB$, in transit at any given time.

6. Host A wants to send a 1,000 KB file to Host B. The Round Trip Time (RTT) of the Duplex Link between Host A and B is 160ms. Packet size is 1KB. A handshake between A and B is needed before data packets can start transferring which takes 2xRTT. Calculate the total required time of file transfer in the following cases. The transfer is considered complete when the acknowledgement for the final packet reaches A.

a. The bandwidth of the link is 4Mbps. Data packets can be continuously transferred on the link.
The transmit time of each 1 $KB$ packet over the link is $1\ KB\ /\ 4\ Mbps$ = 2 $ms$. The total transmission time is equal to the sum of the handshake time, the propagation delay of the first data packet, the combined transmission time of all 1000 data packets, and the reverse propagation time of the final acknowledgement. The two propagation delays along with the transmission time of the first packet and last acknowledgement can be combined as a single $RTT$, thus the total time required
for file transfer is $3 \cdot 160\ ms + 999 \cdot 2\ ms = 2.478\ s$.

b. The bandwidth of the link is 4Mbps. After sending each packet, A need to wait one RTT before the next packet can be transferred. Again, the transmit time is 2 $ms$. In this case, where A waits one RTT before sending the next packet, each packet requires one RTT plus the 2 $ms$ transmit time. Thus, the total transmission time is the sum of the initial handshake time and the time for each of the 1000 packets sent.

The total time is then: $2 \cdot 160\ ms + 1000 \cdot 162\ ms = 162.32\ s$.

c. Assume we have "unlimited" bandwidth on the link, meaning that we assume transmit time to be zero. After sending 50 packets, A need to wait one RTT before sending next group of 50 packets.

In this case, we only consider the initial handshake and the single RTT every 50 packets. Since the transmit time is zero, the RTT of waiting after the first group of 50 packets effectively begins right after the handshake is complete, overlapping with the forward propagation delay of the first bit sent. Further, the ack for the last packet will arrive at the end of the RTT wait on the last group of 50 packets. Thus, the total time is $2 \cdot 160\ ms + 160\ ms = 3.520\ s$.

d. The bandwidth of the link is 4Mbps. During the first transmission A can send one ($2^{1-1}$) packets, during the 2nd transmission A can send $2^{2-1}$ packets, during the 3rd transmission A can send $2^{3-1}$ packets, and so on. Assume A still need to wait for 1 RTT between each transmission.

Note that $1000 < 2^9 + 2^8 + \cdots + 2 + 1 = 1023$, thus it will require a total of ten transmissions to complete the transfer. The transmit time for the $k$th transmission is $2\ ms \cdot 2^{k-1} = 2^k\ ms$. So, the total time for the $k$th transmission (excluding $k = 10$) is $(2^k + 160)\ ms$. The final transmission does not use the full 512 available packets, instead only sending $1000 - 511 = 489$ packets. Thus, the total time is

$T = 2 \cdot 160 + (2 + 160) + (2^2 + 160) + \cdots + (2^9 + 160) + (2 \cdot 489 + 160)\ ms = 12 \cdot 160 + 2 \cdot 1000\ ms = 3.920\ s$.

7. (5pts) Determine the width of a bit on a 10 Gbps link. Assume a copper wire, where the speed of propagation is $2.3 * 10^8$ m/s.

The width of a bit is $\frac{1\ b}{10\ Gbps} \cdot 2.3 \times 10^8 \frac{m}{s} = \frac{2.3 \times 10^8 \frac{m}{s}}{10 \times 10^9 \frac{1}{s}} = 2.3 \times 10^{-2}\ m = 2.3\ cm$.

8. (12 pts) Suppose two hosts, A and B, are separated by 20,000 kilometers and they areconnected by a direct link of R=1Gbps. Suppose the propagation speed over the link is 2.5 x $10^8$ meters/sec.

a. Calculate the bandwidth delay product (BDP) of the link.
The BDP is given as $R \cdot D$, where $D = M/S$ is the propagation delay, $M = 20{,}000\ km = 2 \times 10^7\ m$ is the length of the link, and $S = 2.5 \times 10^8 \frac{m}{s}$ is the link speed. That is, $D = \frac{2 \times 10^7\ m}{2.5 \times 10^8 m/s} = 0.08\ s = 80\ ms$. Thus, the one-way BDP is $R \cdot D = 1\ Gbps \cdot 0.08\ s = 80\ Mb$s

If the two-way BDP is desired, it is $2 \cdot R \cdot D = 160\ Mb$.

b. Consider sending a file of 800,000 bits from Host A to Host B as one large message. What is the maximum number of bits that will be in the link at any given time?

Since the (one-way) BDP is 80 $Mb$, the entire message will fit in the link. Note that the transmit time of the message is $\frac{8 \times 10^5\ b}{1 \times 10^9\ b/s} = 8 \times 10^{-4}\ s = 0.8\ ms$. Since $0.8\ ms < D = 80\ ms$, the entire message will be transmitted before the first bit is received; that is, the entire 800,000 $bits$ will be in the link at the same time .

c.What is the width (in meters) of a bit in the link?
The width of a bit is $\frac{S}{R} = \frac{2.5 \times 10^8\ m/s}{10^9\ bit/s} = 0.25\ \frac{m}{bit}$.

d. Suppose now the file is broken up into 20 packets with each packet containing 40,000 bits. Suppose that each packet is acknowledged by the receiver and the transmission time of an acknowledgement packet is negligible. Finally, assume that the sender cannot send a packet until the preceding one is acknowledged.How long does it take to send the file?

Here, the transmit time for each packet is $\frac{4 \times 10^4\ b}{1 \times 10^9\ b/s} = 4 \times 10^{-5}\ s = 40\ \mu s$.

Assuming negligible transmit time on the acknowledgement packet, the RTT is $2D + 40\ \mu s = 160.04\ ms$. Since the sender must wait for the preceding ack
message to send the next packet, each sent packet requires one RTT. That is, the total time to send the file is $20 \cdot 160.04\ ms = 3.2008\ s$.

9. (9 pts) Suppose there is a 10 Mbps microwave link between a geostationary satellite and its base station on Earth. Every minute the satellite takes a digital photo and sends it to the base station. Assume a propagation speed of 2.4 x $10^8$ meters/sec. Geostationary satellite is 36,000 kilometers away from earth surface

a. What is the propagation delay of the link?

The propagation delay is $\frac{3.6\times10^7\ m}{2.4\times10^8\ m/s} = 0.15\ s = 150\ ms$.

b. What is the bandwidth-delay product, R x (propagation delay)?

The BPD is $10\ Mbps \cdot 0.15\ s = 1.5\ Mb$.

c. Let x denote the size of the photo. What is the minimum value of x for the microwave link to be continuously transmitting?

Since a photo is sent once per minute and the link bandwidth is $10\ Mbps$, the size of the photo must be $x \geq 10\ Mbps \cdot 60\ \frac{s}{min} \cdot 1\ min = 600\ Mb = 75\ MB$.

10. (6pts) Explain collision domain and broadcast domain with respect to a hub, switch, and a router.

The collision domain is all hosts whose messages have the possibility of colliding in the shared medium. The broadcast domain is the set of all hosts whose broadcast traffic will reach other hosts in that set.

*Hub*: For hubs, the collision and broadcast domains are both all hosts connected to the link, making hubs not ideal for network organization. Hubs do not segment the broadcast domain or collision domain, so all hosts will receive all messages sent in the medium (usually discarding those not addressed to them).

*Switch*: Switches allow for the collision domain to be segmented by ports, that is, non-broadcast traffic sent from a host connected to port A of the switch to another host connected to port B will only have the possibility of colliding with other traffic from hosts connected to port A or port B, assuming the forwarding table in the switch has accurate entries for both hosts. However, broadcast traffic (as well as traffic from hosts not present in the address table) will still reach all of the hosts connected to the switch, regardless of what port they are connected to; that is, switches do not usually segment the broadcast domain. Switches can sometimes segment broadcast domains through the use of VLANs, though.

*Router*: Routers serve to interconnect separate networks. Like switches, routers segment the collision domain. Unlike switches, routers also segment the broadcast domain; broadcast messages will not leave the network from which they originate

4. Consider the GBN protocol with a sender window size of N=4 and a sequence number range of 1,024. Suppose that at time t, the next in-order packet that the receiver is expecting has a sequence number of k. Assume that the medium does not reorder messages. Answer the following questions:

(a) What are the possible sets of sequence numbers inside the sender's window at time t? Justify your answer. (2 pts)
All sequence numbers are modulo $2^{10}$. If the next in-order packet expected has sequence number $k$, then the receiver has received and sent acknowledgement for $k-4$, $k-3$, $k-2$, and $k-1$. Suppose all these ACKs have been received by the sender. Then, the sender's LAR is $k-1$ and the sequence numbers inside the sender's window are $[k, k+3]$. On the other hand, if none of the ACKs have been received, the sender's LAR is $k-5$, leading to a window of sequence values $[k-4, k-1]$. Since these are the two extreme cases, the sender's window could be any 4 consecutive sequence numbers in $[k-4, k+3]$.

(b) What are all possible values of the ACK field in all possible messages currently propagating back to the sender at time t? Justify your answer. (2 pts)
All sequence numbers are modulo $2^{10}$. Since the receiver is expecting sequence number $k$, it must have received sequence number $k-1$. For sequence number $k-1$ to be sent, the sender must have received an ACK for $k-5$. Since the medium does not reorder packets, all ACKs currently in transit must have been sent after the first ACK with $k-5$ was sent. Depending on implementation, however, there may have been more than one ACK with sequence number $k-5$ sent. Suppose that at $t_0 < t$, the sender sends seq $k-8, \dots, k-5$. At $t_1$, with $t_0 < t_1 < t$, the receiver sends ACKs for $k-8, \dots, k-5$. Suppose the sender reaches a timeout before receiving the ACKs, causing the packets for $k-8, \dots, k-5$ to be resent. Right after, the sender receives the delayed ACKs sent at $t_1$, causing the sender to update its window and send packets $k-4, \dots, k-1$. Since packets are not reordered, the receiver will first get the duplicate packets $k-8, \dots, k-5$, most likely sending a cumulative ACK for $k-5$. Then, it receives packets $k-4, \dots, k-1$, updating its expected sequence number to $k$ and sending an ACK for each of $k-4, \dots, k-1$. If time $t$ is before the cumulative ACK for $k-5$ is received by the sender, then ACKs for $[k-5, k-1]$ will all be propagating back to the sender simultaneously.

11. (5pts) Consider the following networked computers connected by Bridge X and Y. Bridge X has interface 1,2 and 3. Bridge Y has interface 1 and 2. Assume at the beginning the address tables of Bridge X and Y are all empty. Write down the address tables of Bridge X and Y after the following communication finished (Assume that the receiver does not respond to the packet sent by the sender.).

1. A send a packet to C
2. B send a packet to D
3. C send a packet to E
4. E send a packet to A
5. D send a packet to A

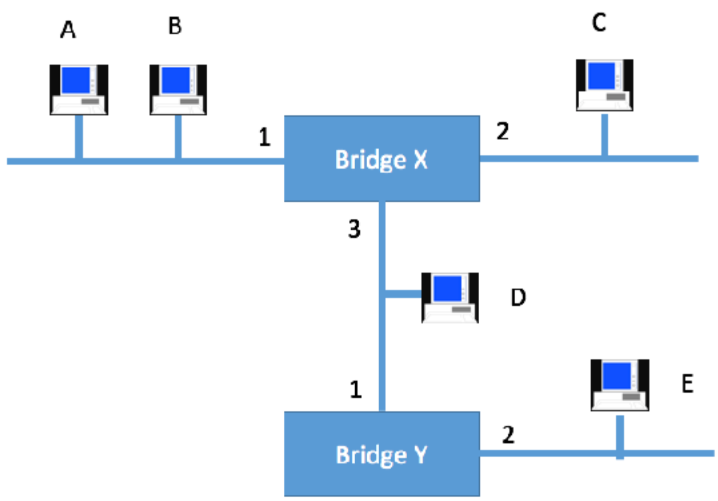
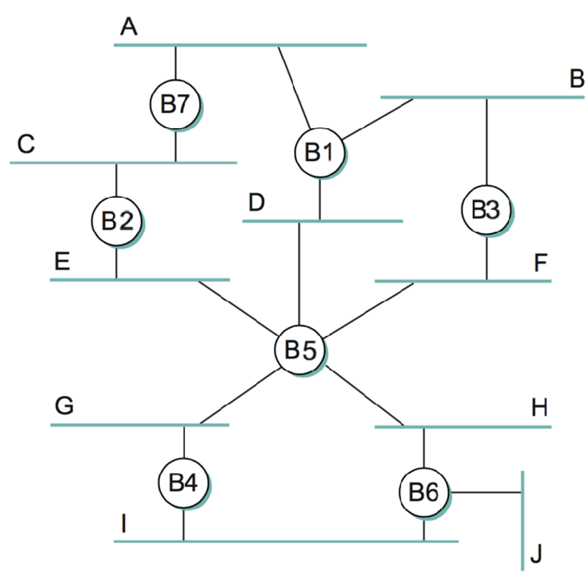


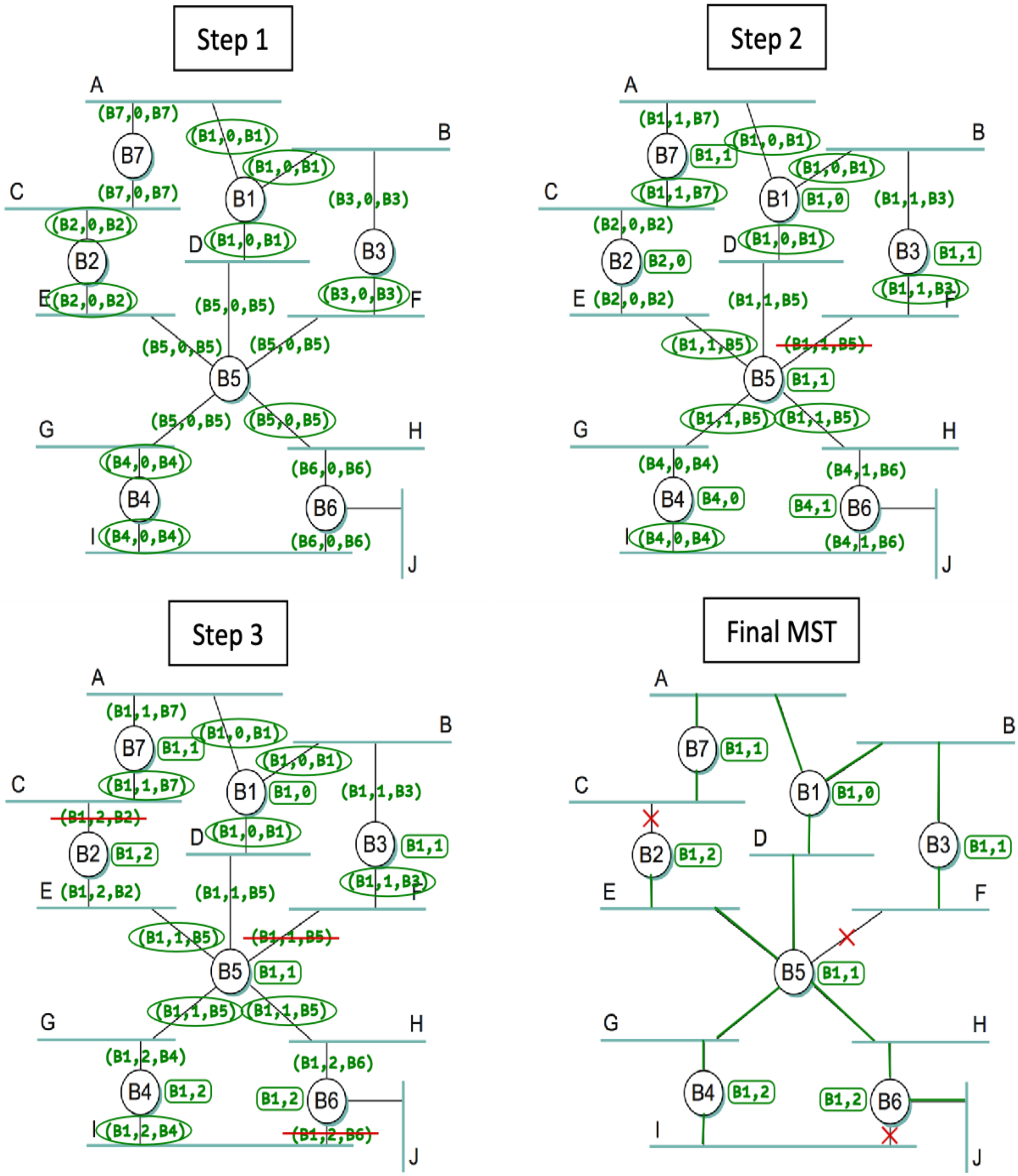

Figure 1

| Bridge X Address | Interface |
|---|---|
| A | 1 |
| B | 1 |
| C | 2 |
| E | 3 |
| D | 3 |

| Bridge Y Address | Interface |
|---|---|
| A | 1 |
| B | 1 |
| C | 1 |
| E | 2 |
| D. | 1 |

12. (5pts) Given the extended LAN shown in Figure 2, indicate which ports are not selected by the spanning tree algorithm. Note that the bridge with the smallest ID becomes a root. See each step of the distributed MST algorithm shown below. In the final MST, the retained paths are shown in green, while the removed paths are crossed out with a red X. Note that in general, only one side of a link is removed, as the other side is required to maintain a path to downstream hosts.




Step 1
A
B
C
D
E
F
G
H
I
J
B1
B2
B3
B4
B5
B6
B7
(B7,0,B7)
(B1,0,B1)
(B1,0,B1)
(B7,0,B7)
(B3,0,B3)
(B2,0,B2)
(B1,0,B1)
(B2,0,B2)
(B3,0,B3)
(B5,0,B5)
(B5,0,B5)
(B5,0,B5)
(B5,0,B5)
(B5,0,B5)
(B4,0,B4)
(B6,0,B6)
(B4,0,B4)
(B6,0,B6)
Step 2
(B1,1,B7)
(B1,0,B1)
B1,1
(B1,0,B1)
(B1,1,B7)
B1,0
(B1,1,B3)
(B2,0,B2)
B2,0
(B1,0,B1)
B1,1
(B2,0,B2)
(B1,1,B5)
(B1,1,B3)
(B1,1,B5)
~~(B1,1,B5)~~
B1,1
(B1,1,B5)
(B1,1,B5)
(B4,0,B4)
(B4,1,B6)
B4,0
B4,1
(B4,0,B4)
(B4,1,B6)
Step 3
(B1,1,B7)
(B1,0,B1)
B1,1
(B1,0,B1)
(B1,1,B7)
B1,0
(B1,1,B3)
~~(B1,2,B2)~~
B1,2
(B1,0,B1)
B1,1
(B1,2,B2)
(B1,1,B5)
(B1,1,B3)
(B1,1,B5)
~~(B1,1,B5)~~
B1,1
(B1,1,B5)
(B1,1,B5)
(B1,2,B4)
(B1,2,B6)
B1,2
B1,2
(B1,2,B4)
~~(B1,2,B6)~~
Final MST
B1,1
B1,0
B1,2
B1,1
B1,1
B1,2
B1,2