Exercise Sheet 4
Networking in Space

B4 – Space Networks

Exercise E4.1
Assume two nodes start to transmit a packet of length L at the same time over a broadcast channel of rate R. Let d_{prop} be the propagation delay between the two nodes. Will there be a collision if $d_{prop} < \frac{L}{R}$? Justify your answer briefly.

Exercise E4.2
Why do collisions occur in CSMA despite all nodes performing carrier sensing before transmission?

Exercise E4.3 *(Slotted Aloha)*
Let $p \in [0, 1]$ be an arbitrary but fixed probability. Recall that in Slotted Aloha, each node handles a collision by retransmitting the collided frame in each subsequent slot with probability p until the frame is transmitted without a collision.

We call a slot *successful* if exactly one node transmits during this slot. Further, we define the *efficiency* of Slotted Aloha to be the long-run fraction of successful slots in the case when there are a large number of active nodes, each always having a large number of frames to send.

When there are N active nodes, the efficiency of Slotted Aloha is $N \cdot p \cdot (1-p)^{N-1}$ (how this formula is derived is an interesting combinatorial question that goes beyond the scope of this lectures). We will now derive the theoretical maximum efficiency of Slotted Aloha.

(a) Find the value of p that maximizes this expression.

(b) Using the value of p found in (a), find the efficiency of Slotted Aloha by letting N approach infinity.
Hint: $(1 - \frac{1}{N})^N$ approaches $\frac{1}{\mathrm{e}}$ as N approaches infinity.

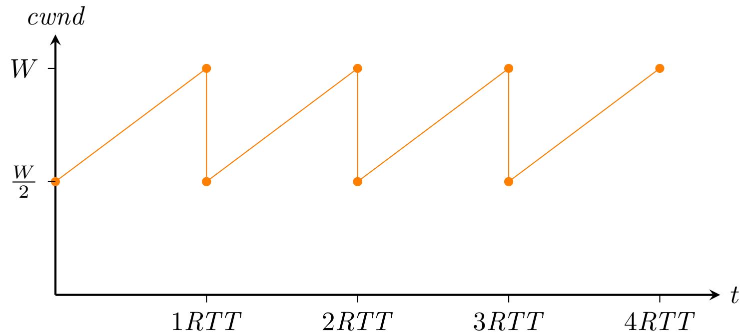
Exercise E4.4 *(Aloha)*
When there are N active nodes, the efficiency of pure Aloha is $N \cdot p \cdot (1-p)^{2(N-1)}$. Show that the maximum efficiency of pure Aloha is $\frac{1}{2\mathrm{e}} \approx 18\,\%$.

Hint: This exercise is easier if you have completed Exercise E4.3!

B5 – Transport Layer and Delay Tolerance

Exercise E4.5 *(Pacing)*
A sender has a line-rate of 1 Gbit/s and wants to send packets of size 1500 B. The receiver, however, can only receive packets at a rate of 50 Mbit/s. How long must the sender wait after each packet until it can send the next packet?

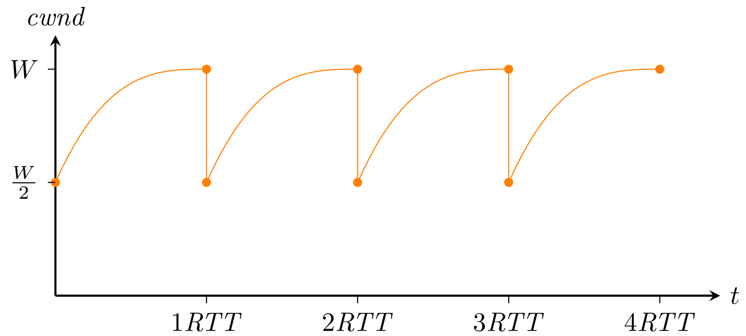
Exercise E4.6
In an idealized setting (where we ignore slow start and assume a constant round-trip time and that there is always data to be sent), the congestion window of TCP Reno over time looks as follows:



Explain how the average throughput of $\frac{3}{4}\frac{W}{RTT}$ can be derived.

Hint: When the window size is w bytes and the current round-trip time is t seconds, then TCP's transmission rate is roughly $\frac{w}{t}$ bytes per second.

Exercise E4.7
In an idealized setting (where we ignore slow start and assume a constant round-trip time and that there is always data to be sent), the congestion window of TCP CUBIC over time looks as follows:



Here, a cubic function is used rather than a linear function. The function has the general form $cwnd(t) = a \cdot (t-b)^3 + c$ for $a, b, c \in \mathbb{R}$ and has a saddle point at $(k \cdot RTT, W)$ for $k \in \mathbb{N}$.

Compute the average throughput.

Exercise E4.8
Recall that TCP uses *sequence numbers* to ensure ordered delivery of the received packets to the application. Assume that packets above the currently awaited sequence number are buffered.

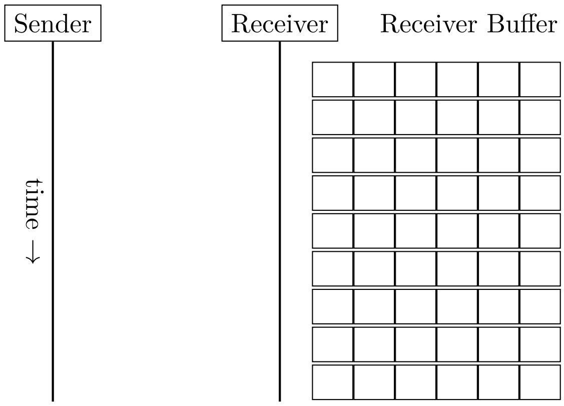
A sender now sends six packets that are received at the destination as specified in the following table:

Packet	1	2	3	4	5	6
Sent at	0	5	10	15	20	25
Received at	5	35	15	20	40	30

(a) Sketch the sending and arrival of packets in the diagram below by drawing arrows.

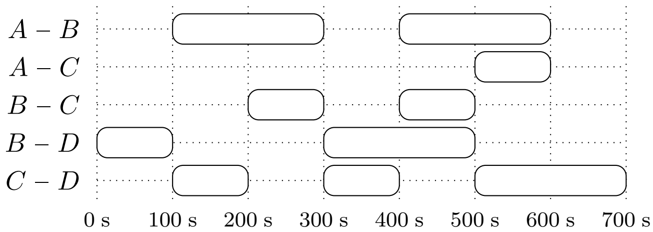
(b) Give the state of the receiver buffer at all time points where the state changes.

(c) State at which time each packet is delivered to the application.



Exercise E4.9 *(TCP Sequence Numbers)*
Explain why in the TCP window semantics, the sequence number space must be at least twice as large as the window size.

Exercise E4.10 *(Delay-Tolerant Networks)*
Assume the following scenario with unstable in-orbit connectivity.



(a) Assume a *Store-Carry-and-Forward* type of connection. How much data (in terms of seconds) can be transferred in total from A to D? You may assume that there are no propagation delays and that a node can simultaneously receive signals from multiple different sources.

(b) How much data can be transferred when classical TCP connections are used instead?