ECE 578: Fundamentals of Computer Networks

Project # 1. The Distributed Coordination Function (DCF) of 802.11

1 Preliminaries

- Read the project description very carefully.
- You can form a group of up to two people. If you do not have a partner please post on Piazza to find one. Utilize available online resources (Zoom, github) for collaboration to make the experience smoother.
- You are free to use a programming language of your choice.

2 Project Description

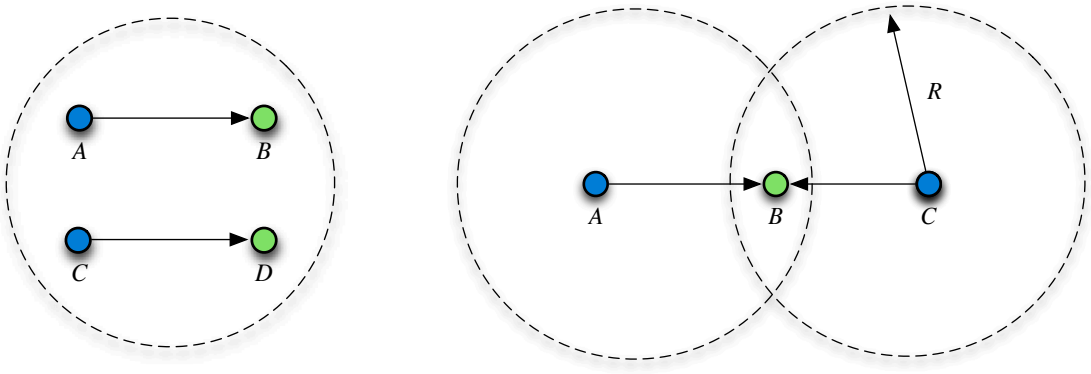
You are to study the performance of multiple access protocols in a wireless setting. Consider the network shown in Figure 1. The circles denote the communication range R of each station. We are interested in the following two scenarios:

A. Single Collision Domain: Stations A, B, C, and D of Figure 1(a) are within the same collision domain (any transmission is received by all). Communication takes place between pairs $A \rightarrow B$ and $C \rightarrow D$. Traffic is generated at A and C according to a Poisson arrival process with parameters λ_A and λ_C, respectively (more on this in the Appendix).

B. Hidden Terminals: Stations A, B, and C of Figure 1(b) belong to two collision domains. Stations A and C cannot hear each other, whereas B can hear both Communication takes place between pairs $A \rightarrow B$ and $C \rightarrow B$. That is A and C compete to send traffic to the same destination C. Traffic is generated at A and C according to a Poisson arrival process with parameters λ_A and λ_C, respectively.

For each scenario, compute relevant performance metrics for the following multiple access protocols. A time-slotted system is assumed.

1. *CSMA with Collision Avoidance (CSMA/CA) according to the 802.11 DCF function.*
   (a) Time is slotted and frame transmissions can only start at the beginning of a slot.
   (b) A station Tx is ready to transmit when a frame is written from the upper layers of the network stack. The times that a frame arrives to the station for transmission are determined by the Poisson process. When a frame arrives in the transmission queue, the Tx selects a random backoff value $b \in [0, CW_0 - 1]$ slots. It then senses the channel for an initial period of DIFS slots.
   (c) If the channel is busy, Tx monitors the channel until it becomes idle. When the channel becomes idle for a period of DIFS slots, Tx decrements his backoff counter b by one with every additional idle slot. If the channel becomes busy before the counter b reaches zero , Tx freezes its backoff counter. The backoff counter resumes to count down after the channel has become idle again (which is determined by sensing for DIFS slots). When the counter reaches zero, Tx transmits its frame.



(a) (b)

Figure 1: (a) Topology for parallel transmissions within the same collision domain, (b) topology for parallel transmissions when A and C are hidden terminals.

(d) If the frame is successfully received (no collision) by Rx, the station Rx replies with an ACK frame after SIFS slots. This completes the transmission round and the protocol repeats for the next transmission. For successive transmissions, the station has to sense for DIFS time before starting the countdown.

(e) If a collision occurs, the stations that collided double their contention window CW and repeat the backoff process. After k collisions, the backoff value is selected from $[0, 2^k CW_0 - 1]$. The CW value cannot exceed threshold $CW_{\max}$.

2. *CSMA/CA with virtual carrier sensing enabled:* RTS and CTS frames are exchanged before the transmission of a frame. If RTS transmissions collide, stations invoke the exponential backoff mechanism outlined in Step 1(d). Otherwise, stations that overhear an RTS/CTS message defer from transmission for the time indicated in the NAV vector.

3 Simulation parameters

Parameter	Value	Parameter	Value
Data frame size	1,500 bytes (50 slots)	ACK, RTS, CTS size	2 slots
Slot duration	10 μs	DIFS duration	2 slots
SIFS duration	1 slot	Transmission rate	24 Mbps
CW_0	4 slots	$CW_{\max}$	1024 slots
$\lambda_A = \lambda_C$	$\{200, 300, 500, 1000, 2000\}$ frames/sec	Simulation time	10 sec

4 Performance Metrics

Evaluate the protocol performance with respect to the following metrics:

Throughput T: The individual station's throughput as a function of λ.

Collisions N: The number of collisions (data and RTS/CTS) as a function of λ.

Fairness Index FI: The fraction of time that the channel is occupied by pair $A \to B$ over the fraction of time that the channel is occupied by pair $C \to D$ as a function of λ.

5 Project Report

Include with your report:

- A brief introduction describing the project. In this section, include the responsibilities of each team member with references to which parts/steps he/she completed.
- A description on how you developed your simulations.
- Graphs for each of the simulated scenarios.
  1. Throughput T
     (a) **Node** A**:** Throughput T (Kbps) vs. rate λ (frames/sec) for scenarios A and B, and CSMA implementations 1 and 2 (four lines in total).
     (b) **Node** C**:** Throughput T (Kbps) vs. rate λ (frames/sec) for scenarios A and B, and CSMA implementations 1 and 2 (four lines in total).
  2. Collisions N
     (a) **Node** A**:** Number of collisions N vs. rate λ (frames/sec) for scenarios A and B, and CSMA implementations 1 and 2 (four lines in total).
     (b) **Node** C**:** Number of collisions N vs. rate λ (frames/sec) for scenarios A and B, and CSMA implementations 1 and 2 (four lines in total).
  3. Fairness Index FI
     (a) Fairness Index FI vs. rate λ (frames/sec) for scenarios A and B, and CSMA implementations 1 and 2 (four lines in total).
- **Justification for the results shown in your graphs. The majority of your grade will be based on your interpretation of the results, not the results themselves, so spend adequate time explaining them.**

Appendix 1 - Poisson Traffic

Generating Poisson-distributed traffic: To generate Poisson-distributed traffic, it is sufficient to generate a series of exponentially-distributed inter-arrival times. Such times can be generated using the inverse CDF transformation method.

Step 1: Generate a series of uniformly distributed numbers $U = \{u_1, u_2, \ldots, u_n\}$ with $u_i \in (0, 1), \forall i$. To compute how many numbers are needed in the series you can simply multiply the rate of arrivals with the simulation time. For instance, when $\lambda = 200$ frames per second, you will need approximately 2,000 frames to fill arrivals for 10 seconds. That means you need to draw 2,000 at random in (0, 1).
Step 2: Convert the series U to series $X = \{x_1, x_2, \ldots, x_n\}$ of exponentially distributed numbers with parameter λ, as

$$X = -\frac{1}{\lambda}\ln(1 - U) \tag{1}$$

Here, you get another series of n numbers that are exponentially distributed. Using X, you can determine the time that each frame is written from the upper layers to the transmitter's queue. Since X corresponds to inter-arrival times, the first frame is ready to transmit at time x_1, frame 2 is ready to transmit at time $x_1 + x_2$, etc. Please note that this are not the actual transmission times, but the time that packets are placed in the queue. Once the queue, the CSMA/CD protocol needs to be executed to determine the exact transmission time.

For simplicity of accounting, you can convert all your times into slots. The above process will give you times in seconds. By dividing with the slot duration, you will get the arrivals times in slots.

Appendix 2 - Implementation tips

- You are asked to implement an event-driven simulation. In this simulation, you are focusing your implementation around events of interest. Arrival, transmission, collision, etc. So rather than counting the time per slot, you advance the simulation time to the next event that occurs. Your algorithmic part is to determine which event will occur next out of the competing possibilities, (e.g., which node will get his backoff timer to zero first).
- DO NOT RUN your simulation for 10 seconds until you have verified that it works correctly. It is very difficult to figure out if the outcomes are correct this way. Initially, rather than working with random arrivals, fix the timings of you arrivals for just a few frames to create test cases for (a) successful transmission from A, (b) successful transmission of C, (c) collision of A and C, (d) collision of RTS with frame in the hidden terminal scenario, (e) other test cases. For each test scenario, draw out the timeline of events by hand and compare to the timeline in your simulation.
- To get one data point for your plots, you fix the arrival rate λ, generate the appropriate number of frame arrivals for each transmitting station, then count the number of successful frames for each station and the collisions. You repeat with different λ's to get the next data points in your plots.
- When you get final results use qualitative reasoning to see if they are correct. If the medium capacity is 24Mbps and your simulation yields a sum of rates for A and C that exceeds 24Mbps, something is wrong. If your throughput is low at high lambdas but you have close to zero collisions something is wrong.

Plotting tips:

1. Label your axes and use appropriate units
2. Make sure the scales on both axes are appropriate. If you are to use the same variable on multiple plots (e.g. throughput) use the same scale on all plots so they can be compared
3. Do not superimpose more than 4-5 plot lines on the same plot.
4. If more than one plot lines are present in the same plot make sure to individually label each one
5. For individual plot lines use different marker shapes so they can be distinguishable.
6. Keep in mind that colors do not show on a black and white printout. So if you color code your lines, use some other discernable labeling such as dashed lines to differentiate between plot lines.

MATLAB code for generating good figures. You can port your data to Matlab and use this code to generate figures.

```
close all; % closes all open figure windows

set(0,'defaulttextinterpreter','latex'); % allows you to use latex math
set(0,'defaultlinelinewidth',2); % line width is set to 2
```

```
set(0,'DefaultLineMarkerSize',10); % marker size is set to 10
set(0,'DefaultTextFontSize', 16); % Font size is set to 16
set(0,'DefaultAxesFontSize',16); % font size for the axes is set to 16

figure(1)
plot(X, Y1, '-bo', X, Y2, '–rs', X); % plotting three curves Y1, Y2 for the same X
grid on; % grid lines on the plot
legend('CSMA', 'CSMA w. virtual Sensing');
ylabel('$T$ (Kbps)');
xlabel('$λ$' (frames/sec));
```