Simulating the Distributed Coordination Function (DCF) of 802.11

ECE 578: Fundamentals of Computer Networks

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Introduction:

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is a multiple access network protocol that utilizes a collision resolution protocol to transmit contesting packets on a shared medium. We will demonstrate CSMA/CA in two different topologies. Topology A contains four different stations, A and C transmitting to B and D respectively, on a shared medium with a single collision domain while Topology B has three stations, A and C both transmitting to B. Furthermore, topology B can best be specified as a hidden terminal topology. While CSMA/CA works well for topologies similar to A where transmitters can sense the energy on the medium to avoid collisions, it is unreliable in topologies similar to the Hidden Terminal topology, as the stations are out of range from each other to use sensing as a means to avoid collisions. This inability to sense the medium will lead to an increase in collisions which will increase the contention windows to a very large amount for both transmitters, when one transmitter finally wins that contention, its window resets, in turn having a much larger probability to transmit frames over the medium compared to the other node.This is referred to as a node dominating the medium, which in turn results in a decreased fairness index. A solution to this problem is by implementing what is known as a Carrier Sense Multiple Access with Collision Avoidance and Virtual Carrier Sensing (CSMA/CA VCS). VCS introduces the Request to Send (RTS) and Clear to Send (CTS) packets which are sent over the medium to inform transmitters when they can each transmit a package. This leads to a more balanced fairness index (FI) which once again indicates how the medium is divided up, this result is due to the probability of collision being much smaller. We will be modelling CSMA/CA and CSMA/CA with VCS with Poisson distributed arrival times for both topologies using Python and plotting our results using MATLAB. Lewis Koplon was responsible for programming the model, and assisting with the Report of this project. Ramon Driesen was responsible for modelling the simulation, assisting with programming and simulation logic, as well as writing the report.

Simulation Development:

We developed our simulations by modeling the timing diagrams of each scenario and generalizing when successful transmissions would happen and when we could expect collisions. For the same collision domain, when collisions would happen is easy to determine, a collision would happen when station a and c tried to transmit a frame on the same slot. However, for the hidden terminal topology, there is no sensing the medium, so interference would happen far more frequently, the range that the system would experience a collision is when the two stations transmit in slots where the frames would overlap with each other.

Furthermore, for topology A using CSMA and CSMA with VCS, you can determine which station gets to transmit based on who wins the contention period. The contention period is defined as the arrival time of the packets at the top of the queue plus the DIFS delay and each transmitter's backoff value. If their contention periods are identical then they enter the collision resolution protocol which is that their contention windows are increased exponentially, and then a new backoff value is chosen. Otherwise, depending on which station has the oldest arrival time, and the smallest backoff will seize the medium

For topology B, since the transmitter at stations A and C cannot sense each other's energy on the channel, they will try to transmit when the DIFS cycle is over and their backoff decreases to zero, their backoff is never frozen, preventing from the transmission of a frame on a busy channel. CSMA without VCS will lead to a medium that is seized by one station, and has experienced many collisions, due to the fact that since the probability of collision is so great for small contention windows, that when the window grows to a very large size, one station will win the contention period, reset its back off counter, and occupy the channel, as the probability that the other station gets a backoff value less than the selfish station, is very slim.

CSMA with VCS, is a derivative of CSMA employed to mitigate this issue. We make use of small CTS and RTS frames which are sent to both transmitting stations and will decrease the number of collisions for the hidden terminal problem. In order to keep track of the transmission slots, we use a global clock value which is incremented periodically.

Finally, in our simulation we made use of a clock variable whose responsibility was to keep track of when arrivals happened and when the simulation was over time. The clock variable progressed to the end of the transmission of a frame, and was also used to simulate the arrivals that happened in the past arriving right as the frame was finished transmitting to simplify the conditional statements.

Analysis:

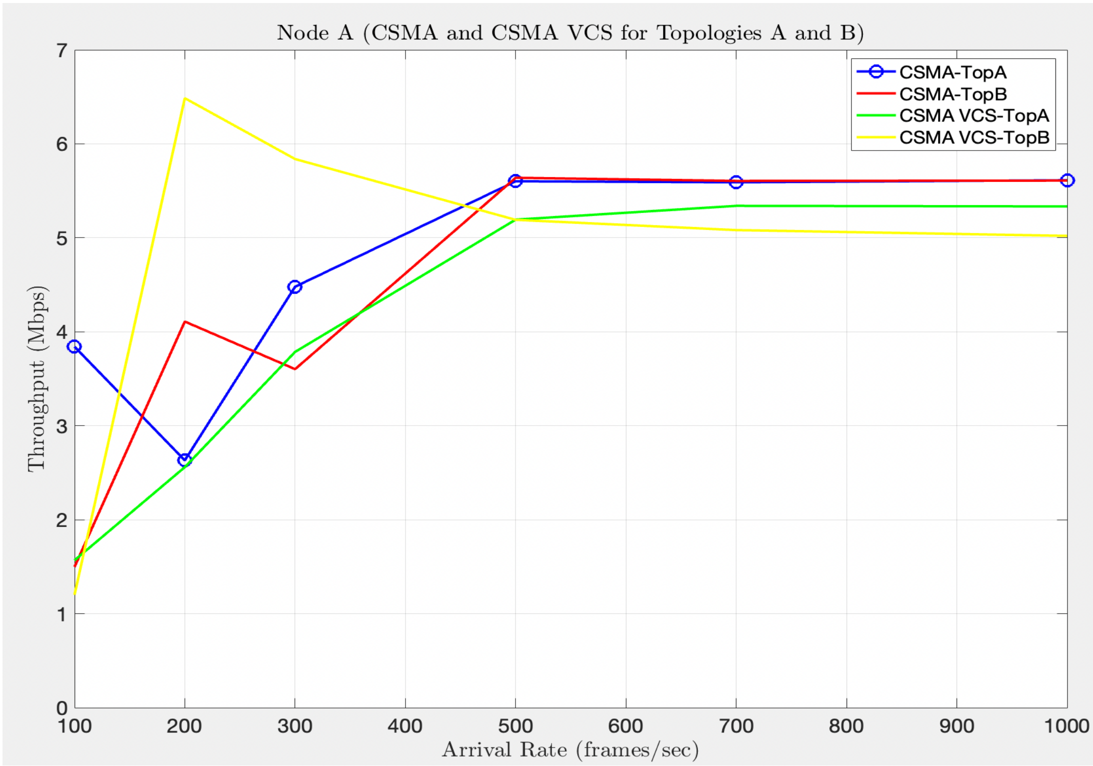

Figure 1: Node A CSMA and CSMA/VCS for Single Collision Domain and Hidden Terminal Topology

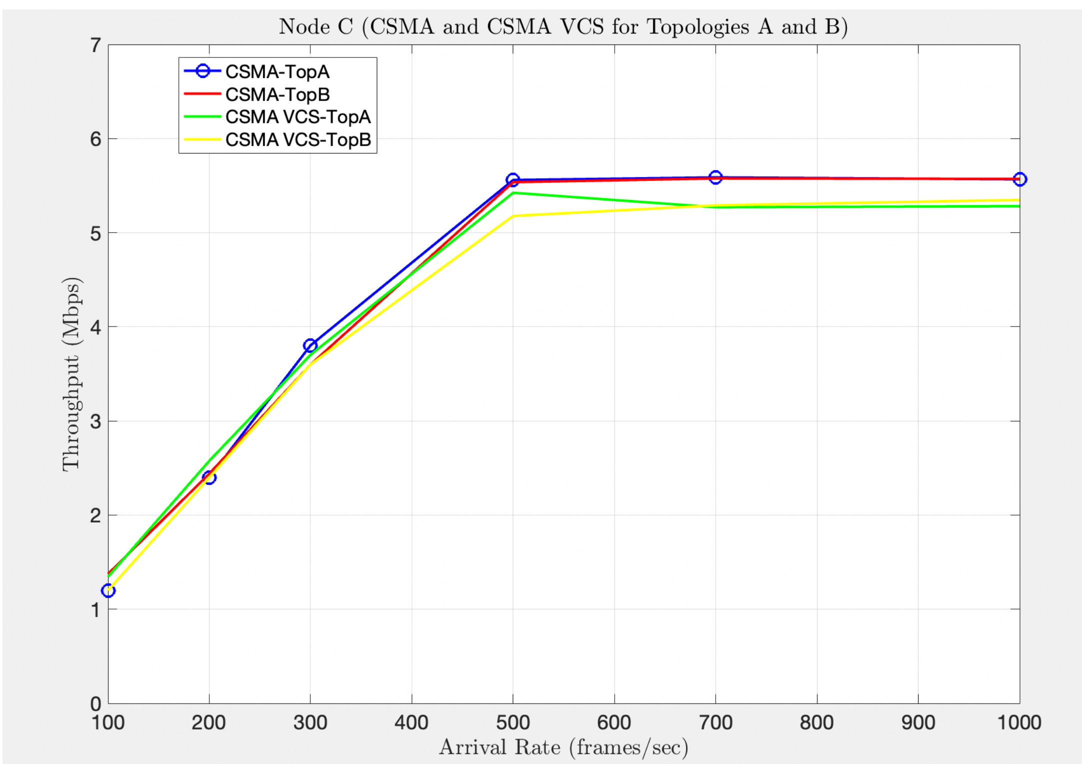

Figure 2: Node C CSMA and CSMA/VCS for Single Collision Domain and Hidden Terminal Topology

As observed in the plot, each throughput initially increases linearly before saturating at 5.5 Mbps corresponding to an arrival rate of 500 frames/sec, this is due to the fact that the contention is low and there are little collisions. While the throughput for each simulation behaves similarly, there are some subtle differences. In the next coming paragraphs, we will be enumerating them.

CMSA CA Single Collision Domain:

The blue line (Figure 1 or Figure 2) signifies the CSMA CA protocol in the single collision domain, this line has the highest throughput as stations are within sensing range and able to freeze their back off counters in the case that another station is transmitting. The throughput for this line is so high because it has the most amount of useful data put on the medium, there is one ACK, one SIFS, and one DIFS, where VCS (yellow and green lines) uses up to 3 SIFS, 1 ACK, an extra CTS and RTS frame that is not required for CSMA in the single collision domain. As the arrival rate increases for this protocol in this topology we notice that the throughput starts to saturate, this is due to the fact that there are so many arrivals stacked into each station's buffer that they are just processing each frame as soon as they can. Furthermore, something interesting to note is that as the buffer fills with arrivals, the chance for collision increases slightly, as the transmitter starts to perceive that they were delivered at the same time and the only factor that determines whether there is a collision is the back off value. Prior to this buffer becoming filled with arrivals, the time of arrival would have played a critical role in determining whether there would be a collision or not.

CMSA CA Hidden Terminal Topology:

Furthermore, the red line represents the CSMA protocol in the hidden terminal topology, the information displayed by this line is incorrect and it should have a much lower throughput as there are far more collisions experienced. Something else that you may see when observing the correct line, is that either station A (Figure 1) or station C (Figure 2) will experience a lower throughput, and that is due to the nature of the protocol in this topology. This happens because the contention window expands to such a large size for both of the transmitters that when one station eventually wins its contention round and resets its window, it will have a much higher probability of winning its contention rounds every time due to the fact that the back off will be picked from a much smaller window that is uniformly distributed, compared to the losing station who will have to pick a backoff value from [0, CW_max - 1]. So theoretically, the red line should have a very low throughput for one line and a very high for another.

CSMA and VCS Single Collision Domain:

The green line (Figure 1 or Figure 2) signifies CSMA using VCS in the single collision domain, we expect that this protocol will have a lesser throughput compared to CSMA CA protocol in the single collision domain as there are more slots wasted on mitigating precautions that are not necessarily useful for a single collision domain, an example of this is the CTS and RTS, along with each one of their SIFS, compared to CSMA which transmits frames and only needs one SIFS and an ACK. Once again, as for all of these lines, we see that they increase linearly and then saturate at large arrival rates, and that is due to the build up at the buffer, and these stations only being able to transmit their frames so fast.

CSMA and VCS Hidden Terminal Topology:

Finally, the yellow line denotes CSMA using VCS in the hidden terminal topology. This protocol in this topology has a throughput near the rest of the protocols and is far higher than where the red line should factually be. This protocol is actually a solution produced by CSMA and the hidden terminal topology, as it creates a much smaller area for collision due to feeling out the medium, and being given dedicated time to communicate with the receiver. Our line should should follow the general trend as the others where it increases up until 500 arrivals per second and then saturate, this is due to the low contention, however it will saturate at a higher throughput as the chance for collision compared to the CSMA in the hidden terminal topology is far lower, due to the NAV and the small RTS frames that are far less likely to collide with each other.

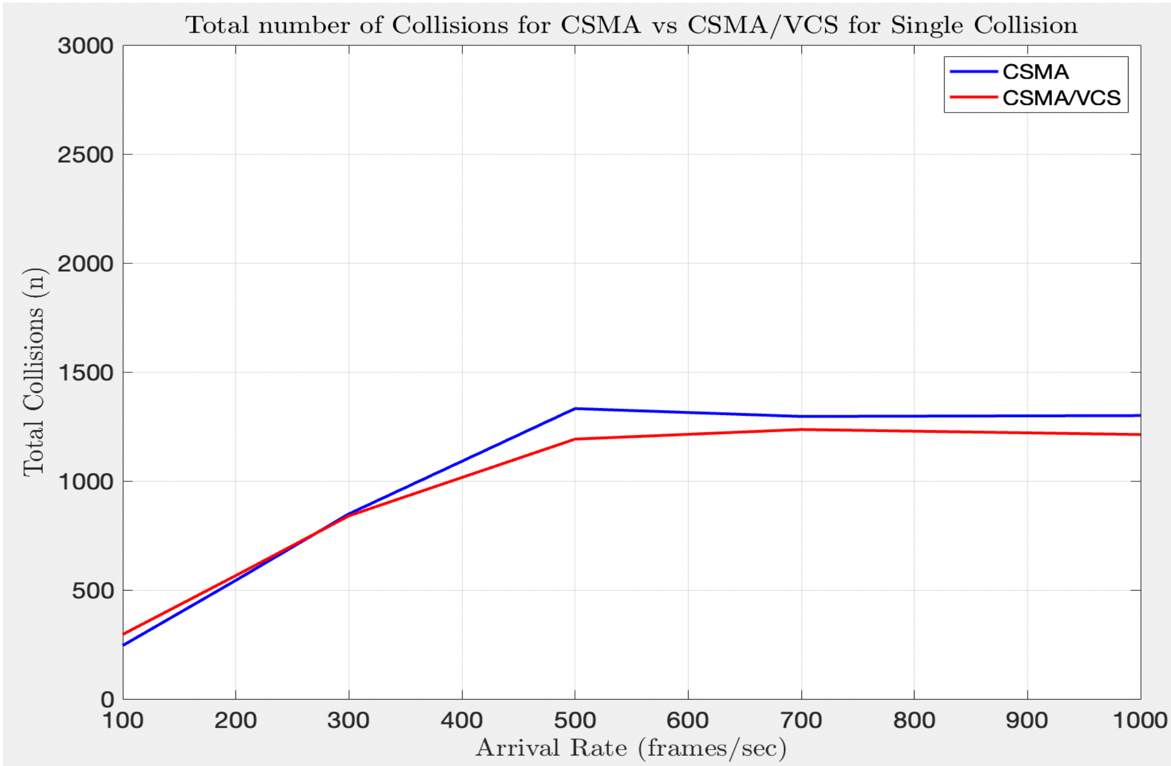

Figure 3: Collisions for CSMA and CSMA/VCS for Single Collision Domain Topology

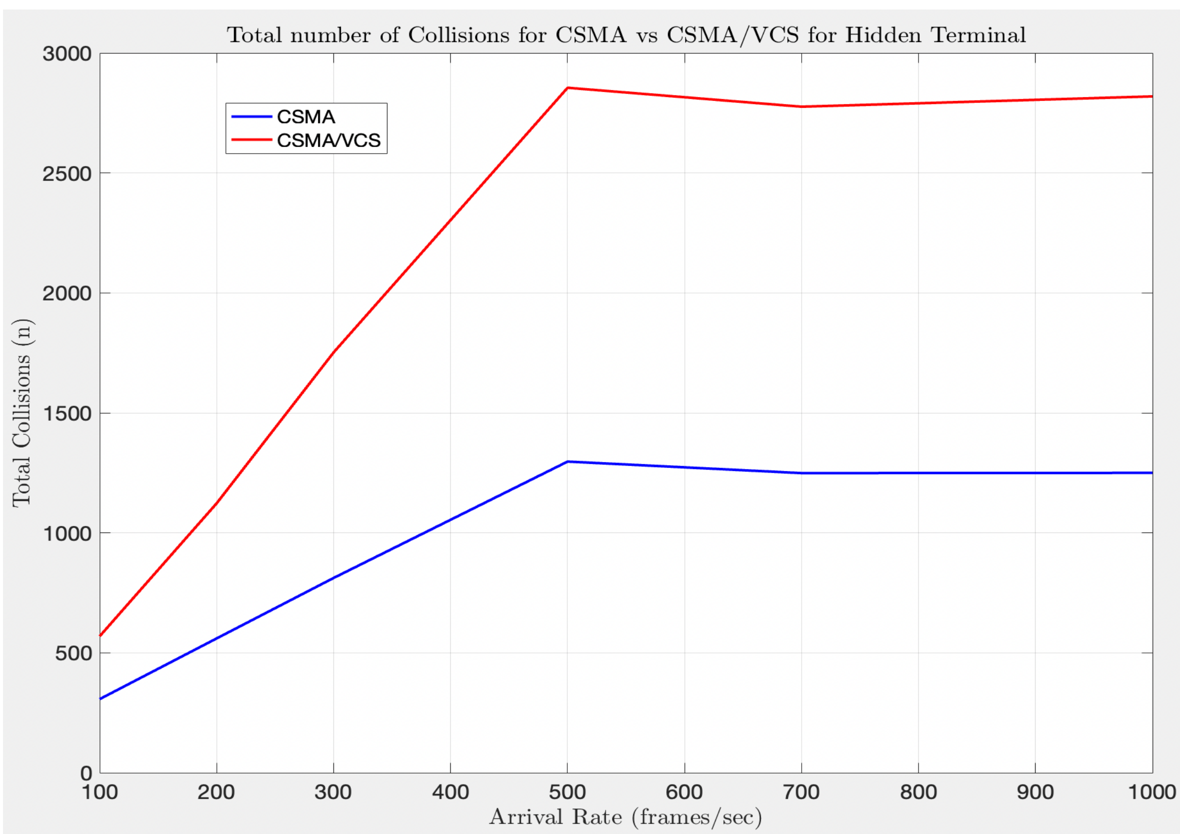

Figure 4: Collisions for CSMA and CSMA/VCS for Hidden Terminal Topology

Figures 3 and 4 represent the total number of collisions for both the Single Collision Domain as well as the Hidden Terminal problem. Each figure is represented by only two lines since we were unable to parse the collisions at each node from the total number of collisions. Similar to throughput, we observe the number of collisions in both Figures 3 and 4 initially increase linearly before saturating. In the case for the Single Collision Domain Topology, it saturates near 1250 collisions which corresponds to an arrival rate of 500 frames/sec. We see that the number of collisions for the Hidden Terminal problem, saturates at a much higher number than for the Single Collision Domain Topology. This was expected as we would overall expect the number of collisions to be greater in the Hidden Terminal problem than for the Single domain. We observe the behavior of increasing linearly and then remaining at a near constant value for high arrival rates, for the same reasons that throughput also saturates at high arrival rates. Due to the fact that with a higher arrival

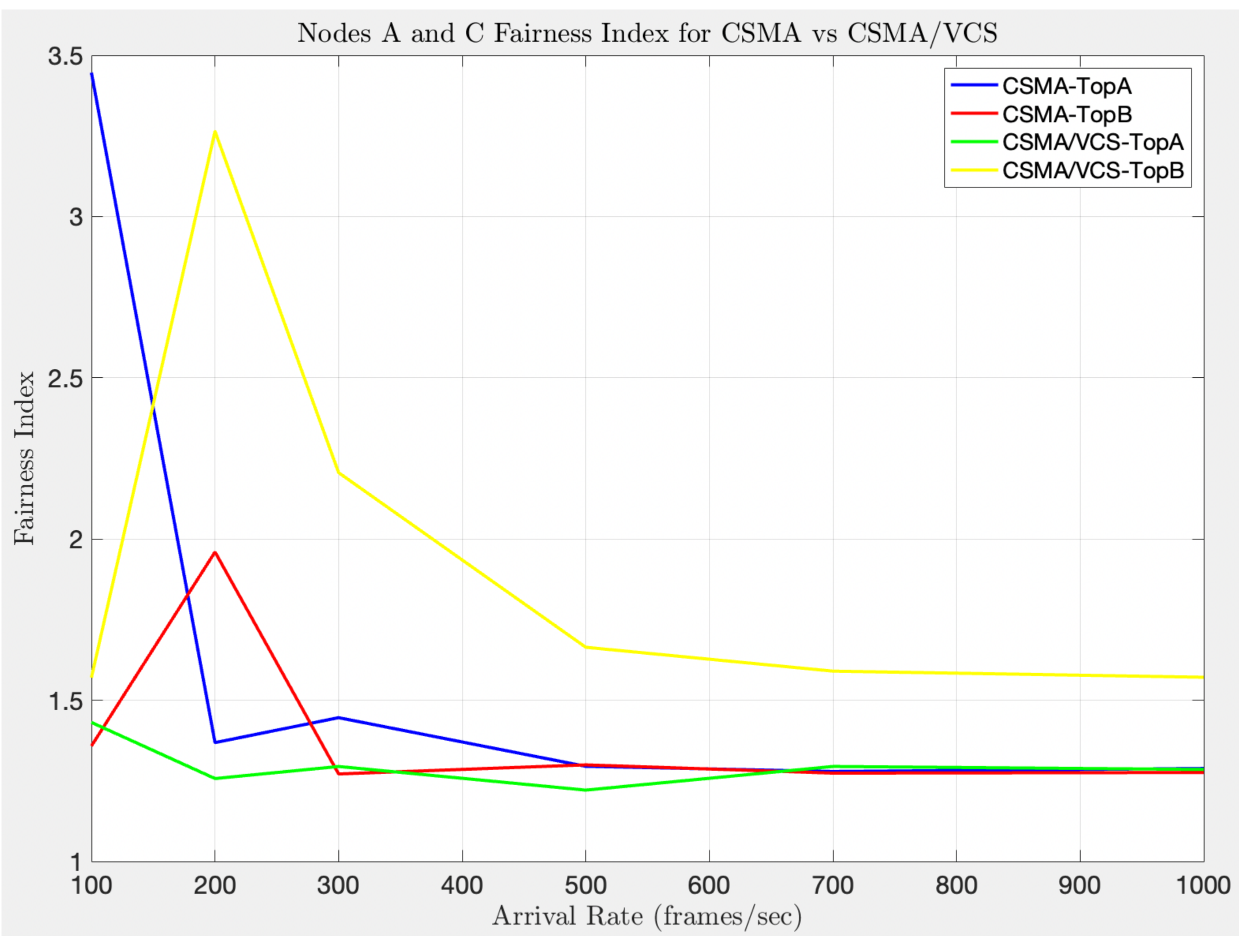

Figure 5: Fairness Index for all topologies and for both the Single Collision Domain and Hidden Terminal Problem

The fairness index for nodes A and C for CSMA and CSMA with VCS are completely incorrect and this is due to the fact that our simulation did not keep track of whose frames caused a collision, but rather kept track of frame collisions as a whole. So the reason why this graph looks like this is because we produced simulated values who assigned 0 blame to the station c. Moreover, we would get a fairness value higher than one due to this fact.

CSMA Hidden Terminal Domain:

The least fair protocol and topology would be CSMA in topology B as when one station seizes control of the medium, it is very unlikely that they will relinquish this control as the contention window of the other station has grown so large.

$$b_c = [0, CW_{max} - 1]$$

$$b_a = [0, CW_0 - 1]$$

The values are chosen uniformly, so if CW_max is 1024 like in our simulation and CW_0 is 4. Station A gets a back off of either 0 to 3, each with a probability of ¼ where c has to choose between a value of 0 to 1023, each with a probability of 1/1024. Furthermore, if station a were to get a backoff of 0, it would be impossible for station c to transmit before a. If station a were to get a backoff value of 1, it would be possible for station c to transmit before a, however with a probability of 1/1024, and so on.

Furthermore, as the arrival rate increases the amount of collisions will increase, and the contention window for one of the stations will become very large as stated in the paragraph prior.

CSMA Single Collision Domain:

This protocol would have a fairness value that is close to one at low arrival rates, as there are not many frames being buffered and they are being handled in the order that they arrive. Whereas later in higher arrival rates, the buffered will become filled, and frames will seem like they are arriving at the same time the transmitter transmits something, so the arrival time will be irrelevant to the decision of who gets to go first, only the back off will determine this. At this point there are more chances for collisions which would increase the contention window size, allowing for the possibility of a station seizing the channel at high arrival rates.

CSMA and VCS Single Collision Domain:

This protocol would have the fairness value that is closest to one at all arrival rates, as the chance for collisions is low, so the it would be unlikely that the one of the stations contention windows would grow much larger than the other one, however when arrival rates are high the chance to dominate albeit low, is still a possibility because the transmitter perceives all the frames in its buffer arriving at the same time, therefore their time arrivals do not play a factor in their collision but only their back off values do.

CSMA Hidden Terminal Domain: