CMPUT 313 – COMPUTER NETWORKS

Assignment #2

Comparison of Medium Access Control Protocols

Due Oct 23rd, 2014

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Abstract

The purpose of this assignment is to create a simulation to compare different back off strategies for the Slotted ALOHA protocol and the Time Division Multiplexing protocol. This simulation was written in Python 2.7, with some C# wrapper code to produce data and graphs.

Design

The simulation was programmed using Object-Oriented Design methodology by splitting the different protocols into custom classes with their own Station objects. The main script, *psim.py*, iterates through the trials and manages the protocol execution for the simulation. The required parameters from the implementation requirements include:

Protocol	Type of protocol: T: Time Division Multiplexing P: Slotted ALOHA with probabilistic back-off I: Slotted ALOHA with interval-based back-off B: Slotted ALOHA with a binary exponential back-off
N	Number of stations
p	Frame generation probability for each node
R	Total number of slots to simulate
T	Number of trials, followed by seeds for the trials

And the required outputs are as follows:

Input Parameters
Average throughput followed by confidence interval
Overall average per-frame delay followed by confidence interval

Protocol T – Time Division Multiplexing

This protocol was implemented using a Protocol and Station class. For every slot, each station first tries to generate a frame, then the designated station tries to transmit. The station is chosen from the description in the assignment description, where the index was simplified with the following equation: $index = slot \% station\_count$. Protocol's nature prevents collisions from occurring.

This is the simplest protocol implementation, where each protocol onwards expands its basic functionality.

Protocol P – Slotted ALOHA with probabilistic back-off

In this implementation, on the first slot, each station first tries to generate a frame. Next, all stations with frames try to transmit. If a collision occurs, the transmitting stations have a 1/N chance of transmitting in the next slot. This 1/N chance continues until the frame has successfully been transmitted, then the next generated frame is sent immediately. This loops for all slots and stations.

The slot loop and general logic take place in *Protocol*'s *run* method. The *Station* class expands from the previous protocol's implementation by keeping track whether the previous transmission was a collision.

Protocol I – Slotted ALOHA with interval-based back-off

For Protocol I, the Station objects were given a variable to keep track of the next slot they are expected to transmit on. This allows the executer to iterate through the stations and transmit those that are expecting to send.

Using this new implementation, if any collisions occur on transmission, each colliding station is given a random slot in the upcoming [1, N] interval. The station is assigned a slot immediately, and then it waits for its turn before transmitting again.

Protocol B – Slotted ALOHA with a binary exponential back-off

Protocol B is a more extensive version of Protocol I. The *Station* class is given the same *next slot* variable, but also keeps track of the number of sequential collisions that have occurred. When a collision occurs, *next slot*'s back-off interval is increased exponentially for every sequential collision. Once a transmission is successful, the collision counter is reset to prevent the next frame from already being backed-off.

Test Methodology

Our goal is to test the effectiveness of the protocol under two specific conditions. Namely high load and low load. The amount of load in the system is controlled by the probability that, at any point, a station will have a new message to send. The two values we care about in this system are the overall throughput of messages over the shared medium as well as the expected delay for a message being added to the system. As such a series of simulations with varying probabilities are run and the data collated. In this case the number of stations are assumed to be constant as increasing the number of stations has the same impact as increasing the probability, namely more messages will be available for sending at any given point. In this case the simulation assumes 20 stations run for 10 000 slot intervals with varying probability.

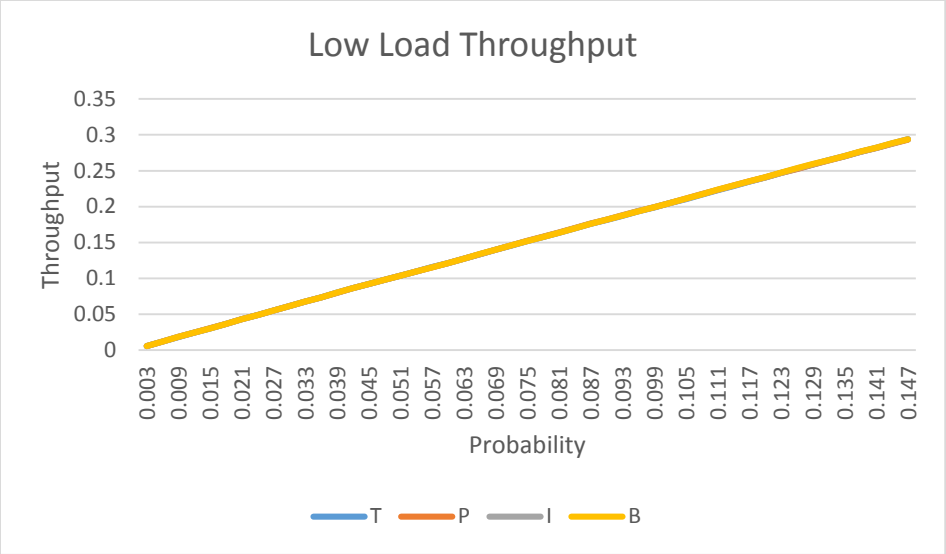
Assumptions

Our assumptions in the simulation are the following:

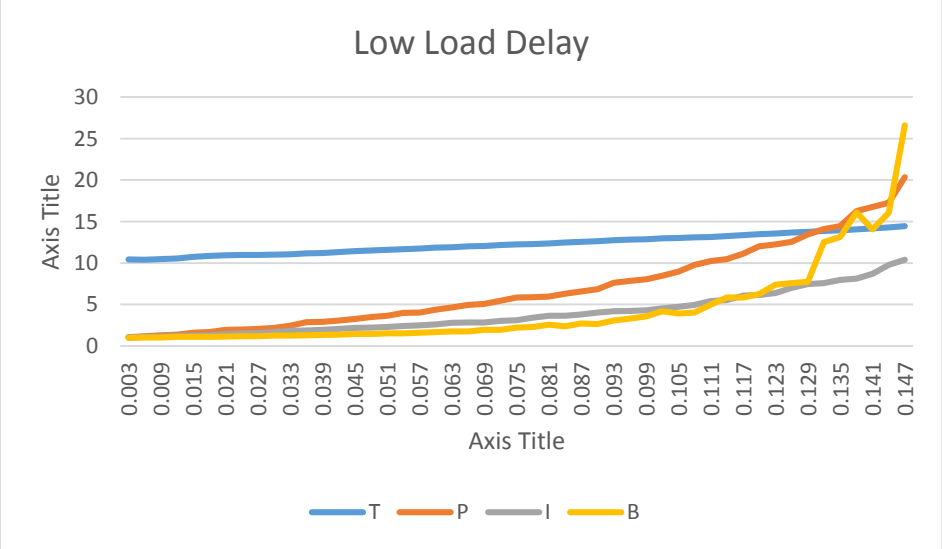
1. Executions respect the protocol and do not try to transmit until the next time slot.
2. Every stations tries to generate a frame every time slot.
3. All stations are expected to generate frames at an equivalent rate with a uniform distribution.
4. Un-transmitted frames are not used in delay calculations.
5. The t_value for a 95% confidence interval is 2.776.
6. Each station generates new frames independently of the rest.
7. All frames are of fixed and equal size.
8. The time it takes to transmit a single frame is exactly equal to a single slot time.
9. Each slot is seen by all stations simultaneously (no propagation delay).
10. Collision takes place if 2+ stations transmit in the same slot.

Results

The testing was carried out in two phases. One that exemplified a system under low load (ie. very low probability of message generation) and another that exemplified a system under high load (ie. High probability of message generation). Firstly the throughput and delay performance of the protocols running under low load are displayed below.



[Chart 1 – Low Load Throughput]



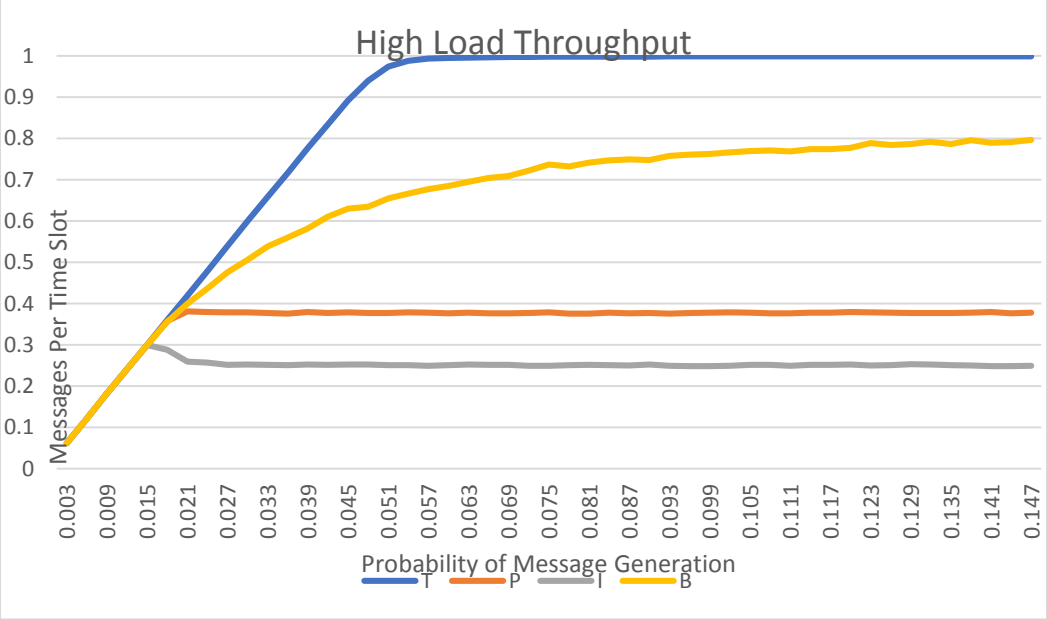
[Chart 2 – Low Load Delay]

These results are largely as expected with respect to the delay given the nature of the protocols. At a low throughput there are very few collisions and so the P, I and B protocols perform quite well with low delay compared to the T protocol. As the probability of generation approaches 0.015 the number of collisions begins to increase to the point that most of the probabilistic protocols begin to see delays comparable or greater than the collision free T protocol.

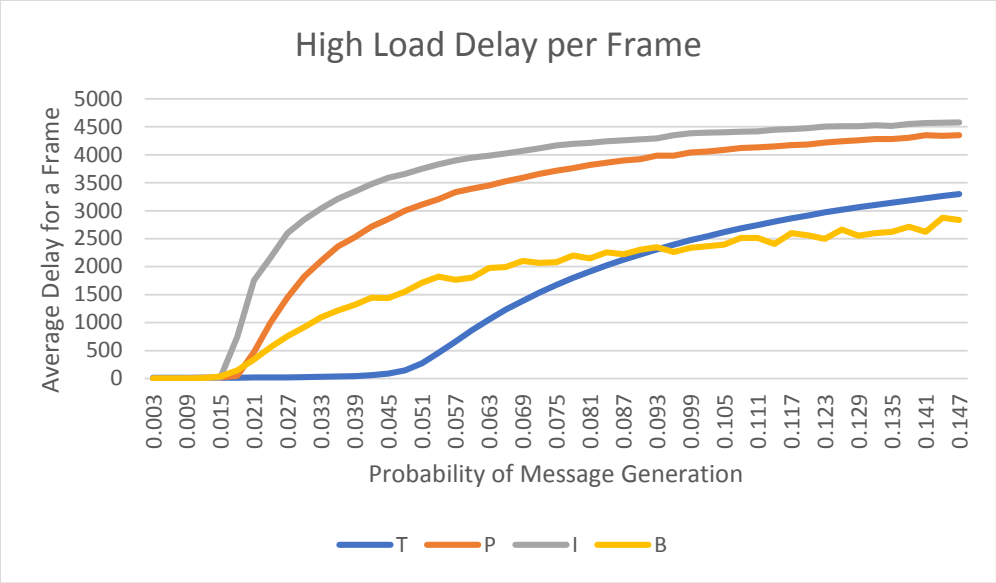
One interesting note is that the throughput of each protocol was about equal and grew linearly with respect to the increase in messages to transmit. Normally it would be expected that the collision free protocol T would perform slightly worse in this case due to having to wait for a time slot before transmitting despite the lack of a potential collision. However, it is likely that this behavior was not observed because the messages where generated in a uniformly distributed manner, rather than the more realistic burst generation. Further analysis would be needed to verify this hypothesis but for this particular statistical model of message generation it appears that each protocol produces approximately the same throughput in a low load environment.

An evident flaw in this source data is the rather odd variance in the B protocol near the right end of the delay graph. Normally it would not be expected for the delay to abruptly dip and then spike upwards as message density changes but this is what is observed. In all likelihood this is simply the result of an outlier in the data. However, it is also worth noting that the B protocol was observed to have the greatest variation over the course of the tests. This variance is further analyzed later.

Next is the high load environment; in this environment we expect the probabilistic protocols to begin to decay while the collision free protocol performs consistently well.



[Chart 3 – High Load Throughput]



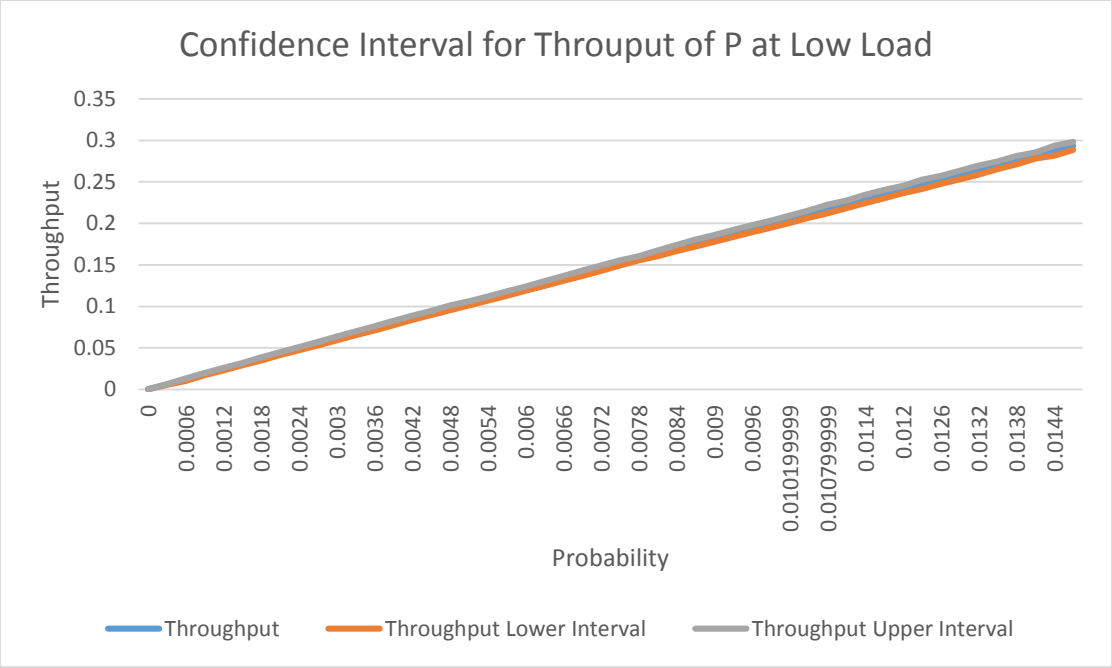
[Chart 4 – High Load Delay]

In this case we are largely observing the probabilistic protocols P, I, and B gradually degrade as they are overwhelmed by the number of collisions and the impact this has on throughput and delay. As expected the collision free algorithm performs quite well. However, what is more interesting is how each probabilistic algorithm decays. Protocols P and I maintain a fairly steady decay but P does appear to consistently outperform I in terms of both delay and throughput.

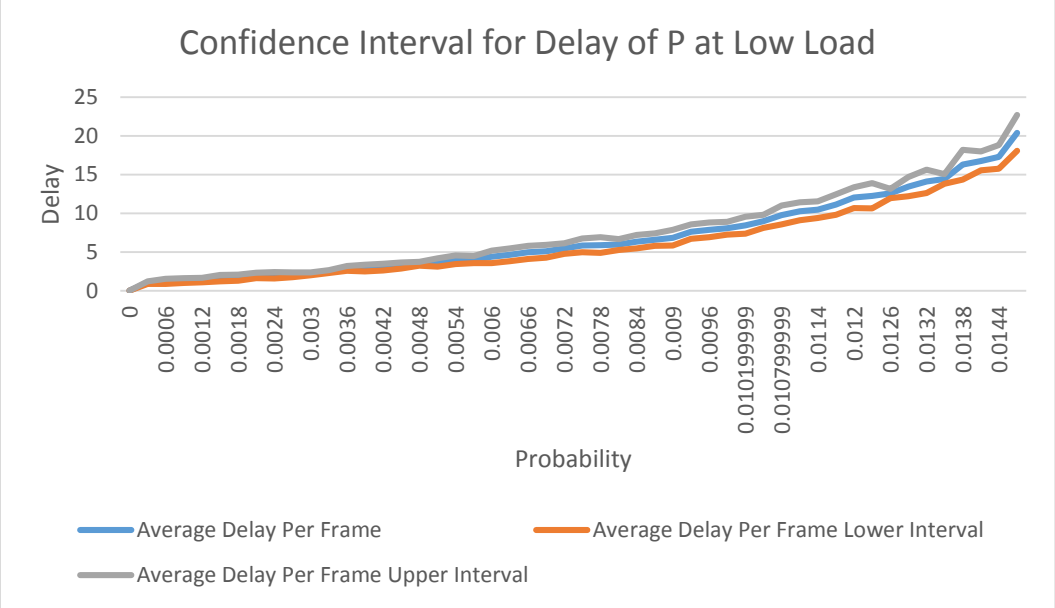
Oddly enough B appears to somehow be outperforming both I and P as well as the collision free algorithm T with respect to the delay achieved. This result is highly unexpected but it does indicate a problem in the testing methodology. The test mechanism does not measure any information about messages that have not been sent, only those that have been sent. As such when the test terminates any messages remaining in the queue and not yet sent would be disregarded and not have an impact on the delay value. Normally this could be compensated for by increasing the slot time of the simulation but in the case of this data the slot time was not sufficiently large to avoid a distorted result.

The reason for this distortion is likely the large potential wait time in protocol B relative the overall simulation time. The protocol allows for messages to wait for up to 512 time slots before trying again. Given the simulation time is 10 000 time units it is possible for a single message to wait over 5% of the overall simulation time under protocol B. As such the results for B should be ignored when comparing delay values as most of the messages would have still been waiting in the queue at the end of the simulation and so were not counted in the delay. This distortion of results is also a likely candidate for explaining the large fluctuations seen in the B protocol. Combatting this variance should be easy. However, increasing the simulation time also increases the time required to generate the data. The current data set took over 20 minutes to generate; presumably any significant increase would require the simulator to run overnight and is not feasible at this point in time.

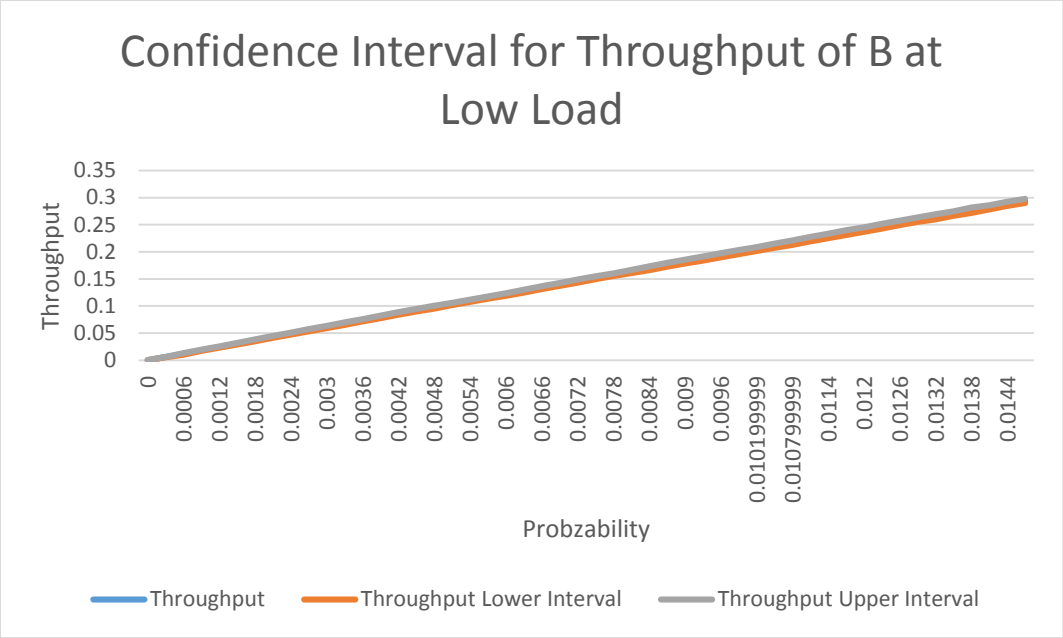
Finally two samples of the confidence intervals for the above data are show below. These comparisons show the confidence of measurements on the P and B protocols. However, the raw data found in **“./OutputData/”** contains the full details of the computed confidence for all tests.



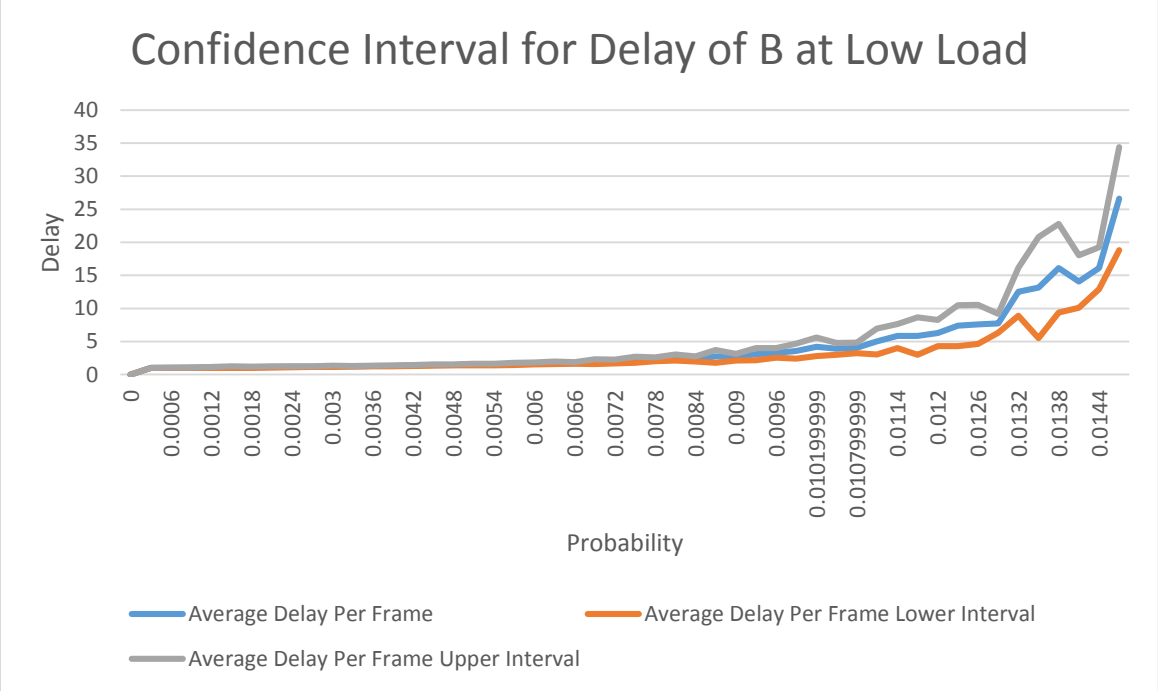
[Chart 5 – Confidence Interval for Throughput of P at Low Load]



[Chart 6 - Confidence Interval for Delay of P at Low Load]



[Chart 7 – Confidence Interval for Throughput of B at Low Load]



[Chart 8 – Confidence Interval for Delay of B at Low Load]

The charts indicate that the simulation has a very high degree of confidence on the throughput measurements for both B and P protocols. Additionally the high variance in B does not appear to affect the throughput measurements. This lack of variance makes sense as the queued messages do not affect throughput and so the flaw in the analysis of B had little impact. However, in the case of the delay measurements the variance is observed to be much higher in both protocols. B suffers for a particularly

large confidence interval that is also uneven in size indicating wide fluctuations for the results generated. Our conclusion is that the throughput values are trustworthy. However, the delay values may be distorted and less reliable.

Conclusion

In this report, we created a simulation to compare and analyze various back-off strategies and protocols for Medium Access Control. These protocols include Time Division Multiplexing and the following Slotted ALOHA strategies: probabilistic back-off, interval-based back-off, and binary exponential back-off. The results were largely as expected with low delays on the probabilistic protocols at low loads and high delays and limited throughput at high loads. Meanwhile the collision free protocol maintained performance at high load but was suboptimal at low load.

One major outlier in the simulation was the large amount of variance in the delay calculated for the B protocol. This protocol appeared to produce results that were better than possible and was attributed to an error in the test methodology. This simulation error appears to have also contributed to a disproportionately large confidence interval and variance in the delay values collected for protocol B. It appears likely this error could be reduced simply by increasing the simulation length.

Appendix A: Data for charts listed

[Chart 1 – Low Load Throughput]

Probability		T	P	I	B
0.0003		0.00584	0.00585	0.00585	0.00585
0.0006		0.01178	0.0118	0.01179	0.01179
0.0009		0.01841	0.01847	0.01843	0.01843
0.0012		0.0243	0.02434	0.02432	0.02432
0.0015		0.0304	0.03047	0.03041	0.03041
0.0018		0.03666	0.0367	0.03666	0.03667
0.0021		0.04301	0.04313	0.043	0.043
0.0024		0.04901	0.04912	0.04899	0.04901
0.0027		0.05518	0.05529	0.05515	0.0552
0.003		0.06141	0.06151	0.0614	0.06143
0.0033		0.06755	0.06767	0.06757	0.06757
0.0036		0.07358	0.0736	0.0736	0.07359
0.0039		0.07996	0.07991	0.07995	0.07996
0.0042		0.0862	0.08623	0.08623	0.08621
0.0045		0.09212	0.09223	0.09214	0.09215
0.0048		0.09804	0.09819	0.09803	0.09807
0.0051		0.10381	0.10383	0.10385	0.10379
0.0054		0.10964	0.10948	0.1097	0.10967
0.0057		0.11562	0.11549	0.11563	0.11558
0.006		0.12133	0.12137	0.12134	0.12137
0.0063		0.1273	0.12747	0.12736	0.12734
0.0066		0.13381	0.13386	0.13384	0.13396
0.0069		0.13973	0.13985	0.13984	0.13984
0.0072		0.14587	0.14611	0.14597	0.14609
0.0075		0.15198	0.15246	0.15205	0.15217
0.0078		0.15761	0.15798	0.1577	0.15784
0.0081		0.16354	0.16392	0.16368	0.1637
0.0084		0.16965	0.17039	0.16984	0.16985
0.0087		0.17584	0.17631	0.17602	0.17615
0.009		0.18144	0.18186	0.18176	0.18184
0.0093		0.18732	0.18797	0.18755	0.18771
0.0096		0.19332	0.19364	0.19366	0.19362
0.0099		0.19894	0.19909	0.19933	0.1993
0.0102		0.20479	0.2051	0.20503	0.20517
0.0105		0.21053	0.21114	0.211	0.21111
0.0108		0.21665	0.21737	0.21686	0.21695
0.0111		0.22289	0.22307	0.22314	0.22352

0.0114		0.2288	0.22952	0.22914	0.22936
0.0117		0.2348	0.23533	0.23499	0.23537
0.012		0.24055	0.24089	0.2408	0.24101
0.0123		0.2467	0.24712	0.24702	0.24722
0.0126		0.25279	0.25244	0.25322	0.25345
0.0129		0.25869	0.25837	0.25916	0.25936
0.0132		0.26462	0.26432	0.26486	0.2648
0.0135		0.27025	0.27013	0.2706	0.27054
0.0138		0.27615	0.27638	0.27654	0.27663
0.0141		0.28184	0.28174	0.28219	0.28197
0.0144		0.28798	0.28767	0.28813	0.28838
0.0147		0.29385	0.2934	0.29411	0.2938

[Chart 2 – Low Load Delay]

Probability		T	P	I	B
0.0003		10.41726	1.054098	1.04127	1.004762
0.0006		10.37785	1.196064	1.098434	1.024454
0.0009		10.4916	1.313115	1.132673	1.031221
0.0012		10.56648	1.369791	1.208375	1.09152
0.0015		10.75008	1.60753	1.261819	1.12236
0.0018		10.84381	1.691483	1.307554	1.116637
0.0021		10.93471	1.968271	1.448328	1.152904
0.0024		10.95613	1.987392	1.524542	1.187602
0.0027		10.97994	2.052633	1.558037	1.192246
0.003		10.99468	2.180945	1.684788	1.242106
0.0033		11.05963	2.456892	1.817761	1.26074
0.0036		11.15009	2.869233	1.883271	1.303907
0.0039		11.20289	2.91659	1.950946	1.319211
0.0042		11.31246	3.050976	2.067926	1.391731
0.0045		11.42203	3.244998	2.167418	1.451812
0.0048		11.50524	3.49254	2.23825	1.44728
0.0051		11.57326	3.649188	2.295365	1.516729
0.0054		11.66665	4.01074	2.401392	1.526898
0.0057		11.76522	4.024866	2.509888	1.605338
0.006		11.85355	4.38547	2.618246	1.689313
0.0063		11.91719	4.639884	2.799019	1.768405
0.0066		11.99783	4.954048	2.830926	1.75444
0.0069		12.05225	5.082032	2.835638	1.943363
0.0072		12.15423	5.446597	3.034277	1.963593
0.0075		12.23358	5.847471	3.099643	2.224023

0.0078		12.29866	5.891461	3.399012	2.313049
0.0081		12.36973	5.948167	3.632927	2.585153
0.0084		12.46203	6.322316	3.643553	2.36328
0.0087		12.55326	6.58174	3.819228	2.740205
0.009		12.63808	6.836213	4.04079	2.628389
0.0093		12.76074	7.611986	4.177233	3.087411
0.0096		12.83494	7.863351	4.215845	3.283592
0.0099		12.87301	8.055908	4.288072	3.556292
0.0102		12.96756	8.454095	4.528779	4.203518
0.0105		13.01761	8.960093	4.709143	3.905578
0.0108		13.09527	9.770322	4.941106	4.038055
0.0111		13.14702	10.24786	5.41012	4.999207
0.0114		13.23127	10.47398	5.549908	5.832701
0.0117		13.3528	11.1169	6.090221	5.842323
0.012		13.46973	12.0159	6.172666	6.272438
0.0123		13.55684	12.25244	6.370159	7.389162
0.0126		13.66154	12.55829	7.00329	7.591212
0.0129		13.76788	13.42636	7.466561	7.741005
0.0132		13.86866	14.11218	7.597506	12.51017
0.0135		13.96017	14.44006	7.948045	13.15357
0.0138		14.06547	16.26429	8.131627	16.09138
0.0141		14.18033	16.75648	8.705954	14.07673
0.0144		14.30965	17.2782	9.778328	16.08245
0.0147		14.45422	20.36197	10.41244	26.60158

[Chart 3 – High Load Throughput]

Probability		T	P	I	B
0.003		0.06141	0.06151	0.0614	0.06143
0.006		0.12133	0.12137	0.12134	0.12137
0.009		0.18144	0.18186	0.18176	0.18184
0.012		0.24055	0.24089	0.2408	0.24101
0.015		0.29969	0.29915	0.29995	0.29937
0.018		0.36004	0.35811	0.28792	0.35514
0.021		0.41902	0.38098	0.25945	0.39946
0.024		0.47826	0.37963	0.25667	0.43582
0.027		0.53951	0.37904	0.25188	0.47557
0.030		0.59948	0.37913	0.25225	0.50628
0.033		0.65843	0.37734	0.2513	0.53825
0.036		0.71722	0.37539	0.25097	0.55995
0.039		0.77628	0.37982	0.25249	0.58224

0.042		0.83402	0.37754	0.25175	0.61055
0.045		0.89181	0.37883	0.25219	0.62999
0.048		0.94009	0.3773	0.25267	0.63504
0.051		0.97419	0.37724	0.25115	0.65513
0.054		0.98829	0.37901	0.2506	0.66661
0.057		0.99336	0.37799	0.24949	0.67745
0.060		0.99521	0.37642	0.25071	0.68491
0.063		0.99638	0.37815	0.252	0.69548
0.066		0.99702	0.37683	0.25156	0.70411
0.069		0.99742	0.37662	0.25164	0.70913
0.072		0.99782	0.37751	0.24908	0.72247
0.075		0.99806	0.37897	0.2492	0.73687
0.078		0.99821	0.37543	0.2512	0.73213
0.081		0.99836	0.37532	0.25194	0.74132
0.084		0.99846	0.37822	0.25082	0.7472
0.087		0.99862	0.37622	0.2503	0.74973
0.090		0.99871	0.37741	0.25208	0.74806
0.093		0.99883	0.3753	0.24937	0.75798
0.096		0.99889	0.37702	0.24813	0.76133
0.099		0.99895	0.37802	0.24816	0.76249
0.102		0.99903	0.37845	0.2496	0.76621
0.105		0.99909	0.37813	0.25177	0.76964
0.108		0.99913	0.37682	0.25127	0.77078
0.111		0.99916	0.37666	0.24944	0.76869
0.114		0.9992	0.37821	0.25166	0.77403
0.117		0.99921	0.37793	0.25141	0.77406
0.120		0.99926	0.37989	0.25224	0.77758
0.123		0.99929	0.37911	0.24999	0.78899
0.126		0.99929	0.37774	0.25121	0.78405
0.129		0.99933	0.37744	0.25293	0.78691
0.132		0.99937	0.37705	0.25244	0.79179
0.135		0.9994	0.37693	0.2506	0.78696
0.138		0.99944	0.37819	0.24968	0.79626
0.141		0.99947	0.37935	0.24825	0.7897
0.144		0.99947	0.37649	0.24883	0.79112
0.147		0.99948	0.37815	0.24891	0.79682

[Chart 4 – High Load Delay]

Probability		T	P	I	B
0.003		10.99468	2.180945	1.684788	1.242106
0.006		11.85355	4.38547	2.618246	1.689313
0.009		12.63808	6.836213	4.04079	2.628389
0.012		13.46973	12.0159	6.172666	6.272438
0.015		14.55321	20.62322	11.5157	35.75674
0.018		15.85585	49.40732	747.9415	142.7697
0.021		17.42174	472.376	1750.759	338.8013
0.024		19.17841	1010.37	2172.707	565.1155
0.027		21.5318	1450.722	2599.743	757.891
0.030		24.6777	1823.843	2841.824	916.8842
0.033		28.66303	2100.22	3040.696	1095.349
0.036		34.39041	2359.165	3212.487	1216.932
0.039		42.88314	2527.611	3343.679	1317.258
0.042		57.67387	2713.542	3472.73	1442.868
0.045		85.76936	2849.711	3588.627	1439.923
0.048		147.7574	2999.526	3661.393	1552.025
0.051		273.4237	3107.233	3750.144	1710.634
0.054		461.6	3206.395	3830.268	1820.568
0.057		662.5389	3332.262	3898.496	1762.62
0.060		866.679	3398.152	3948.048	1803.138
0.063		1054.809	3450.833	3987.524	1974.831
0.066		1229.722	3526.184	4025.684	1995.597
0.069		1387.869	3592.216	4071.018	2101.594
0.072		1535.49	3661.251	4115.487	2068.935
0.075		1673.621	3718.589	4165.174	2078.675
0.078		1798.916	3764.15	4194.295	2197.274
0.081		1913.308	3820.451	4211.43	2147.615
0.084		2023.233	3856.978	4244.894	2254.813
0.087		2122.993	3897.585	4261.757	2220.957
0.090		2217.224	3922.781	4278.223	2302.902
0.093		2310.846	3983.405	4293.254	2348.415
0.096		2393.766	3986.81	4348.817	2262.704
0.099		2471.68	4040.949	4383.828	2337.902
0.102		2545.297	4059.591	4395.53	2362.635
0.105		2616.809	4090.615	4404.681	2396.453
0.108		2683.139	4122.539	4411.583	2515.968
0.111		2745.675	4134.878	4421.9	2515.98
0.114		2805.428	4148.899	4446.479	2407.652
0.117		2862.913	4173.64	4457.301	2598.989

0.120		2916.976	4182.386	4478.988	2562.112
0.123		2969.477	4221.786	4503.166	2498.481
0.126		3017.186	4241.884	4513.156	2660.517
0.129		3062.702	4257.442	4513.262	2551.763
0.132		3105.752	4281.625	4529.204	2599.256
0.135		3145.433	4283.657	4516.494	2624.86
0.138		3185.937	4307.005	4552.448	2711.926
0.141		3226.176	4353.486	4566.597	2623.402
0.144		3263.341	4341.018	4573.048	2873.566
0.147		3298.94	4351.685	4577.418	2834.021

[Chart 5 - Confidence Interval for Throughput of P at Low Load]

Probability		Throughput	Throughput Lower Interval	Throughput Upper Interval
0		0	0	0
0.0003		0.00585	0.005436	0.006264
0.0006		0.0118	0.010394	0.013206
0.0009		0.01847	0.017055	0.019885
0.0012		0.02434	0.022861	0.025819
0.0015		0.03047	0.029055	0.031885
0.0018		0.0367	0.034851	0.038549
0.0021		0.04313	0.041309	0.044951
0.0024		0.04912	0.047246	0.050994
0.0027		0.05529	0.053185	0.057395
0.003		0.06151	0.059264	0.063756
0.0033		0.06767	0.065229	0.070111
0.0036		0.0736	0.071105	0.076095
0.0039		0.07991	0.07726	0.08256
0.0042		0.08623	0.083646	0.088814
0.0045		0.09223	0.089689	0.094771
0.0048		0.09819	0.09538	0.101
0.0051		0.10383	0.10137	0.10629
0.0054		0.10948	0.106996	0.111964
0.0057		0.11549	0.112831	0.118149
0.006		0.12137	0.118747	0.123993
0.0063		0.12747	0.124566	0.130374
0.0066		0.13386	0.130996	0.136724
0.0069		0.13985	0.136661	0.143039
0.0072		0.14611	0.143008	0.149212

0.0075		0.15246	0.1495	0.15542
0.0078		0.15798	0.155366	0.160594
0.0081		0.16392	0.160434	0.167406
0.0084		0.17039	0.166759	0.174021
0.0087		0.17631	0.172104	0.180516
0.009		0.18186	0.177908	0.185812
0.0093		0.18797	0.183772	0.192168
0.0096		0.19364	0.189332	0.197948
0.0099		0.19909	0.194883	0.203297
0.0102		0.2051	0.200827	0.209373
0.0105		0.21114	0.206629	0.215651
0.0108		0.21737	0.212177	0.222563
0.0111		0.22307	0.218453	0.227687
0.0114		0.22952	0.22461	0.23443
0.0117		0.23533	0.230365	0.240295
0.012		0.24089	0.236567	0.245213
0.0123		0.24712	0.241413	0.252827
0.0126		0.25244	0.247648	0.257232
0.0129		0.25837	0.253176	0.263564
0.0132		0.26432	0.258807	0.269833
0.0135		0.27013	0.265408	0.274852
0.0138		0.27638	0.271363	0.281397
0.0141		0.28174	0.278003	0.285477
0.0144		0.28767	0.281669	0.293671
0.0147		0.2934	0.288585	0.298215

[Chart 6 - Confidence Interval for Delay of P at Low Load]

Probability		Average Delay Per Frame	Average Delay Per Frame Lower Interval	Average Delay Per Frame Upper Interval
0		0	0	0
0.0003		1.054098	0.883024	1.225172
0.0006		1.196064	0.858143	1.533984
0.0009		1.313115	1.019205	1.607024
0.0012		1.369791	1.097108	1.642474
0.0015		1.60753	1.201333	2.013726
0.0018		1.691483	1.291845	2.091122
0.0021		1.968271	1.614	2.322541

0.0024		1.987392	1.574657	2.400126
0.0027		2.052633	1.746668	2.358597
0.003		2.180945	1.983479	2.378412
0.0033		2.456892	2.271445	2.642339
0.0036		2.869233	2.569396	3.169069
0.0039		2.91659	2.487191	3.345989
0.0042		3.050976	2.613096	3.488856
0.0045		3.244998	2.863683	3.626312
0.0048		3.49254	3.247715	3.737365
0.0051		3.649188	3.106905	4.191472
0.0054		4.01074	3.451856	4.569625
0.0057		4.024866	3.56215	4.487581
0.006		4.38547	3.580545	5.190394
0.0063		4.639884	3.803352	5.476417
0.0066		4.954048	4.107738	5.800359
0.0069		5.082032	4.263766	5.900298
0.0072		5.446597	4.764687	6.128507
0.0075		5.847471	4.969123	6.725819
0.0078		5.891461	4.889083	6.893838
0.0081		5.948167	5.243135	6.653198
0.0084		6.322316	5.455892	7.18874
0.0087		6.58174	5.776781	7.3867
0.009		6.836213	5.816369	7.856057
0.0093		7.611986	6.682001	8.541971
0.0096		7.863351	6.912729	8.813973
0.0099		8.055908	7.224646	8.887171
0.0102		8.454095	7.353373	9.554817
0.0105		8.960093	8.111479	9.808708
0.0108		9.770322	8.558572	10.98207
0.0111		10.24786	9.084148	11.41157
0.0114		10.47398	9.395937	11.55202
0.0117		11.1169	9.780456	12.45335
0.012		12.0159	10.67272	13.35909
0.0123		12.25244	10.62381	13.88107
0.0126		12.55829	11.95786	13.15873
0.0129		13.42636	12.19252	14.66019
0.0132		14.11218	12.61623	15.60813
0.0135		14.44006	13.81855	15.06157
0.0138		16.26429	14.34122	18.18737
0.0141		16.75648	15.54207	17.97088
0.0144		17.2782	15.75176	18.80463
0.0147		20.36197	18.04489	22.67904

[Chart 7 - Confidence Interval for Throughput of B at Low Load]

Probability		Throughput	Throughput Lower Interval	Throughput Upper Interval
0		0	0	0
0.0003		0.00585	0.005436	0.006264
0.0006		0.01179	0.010399	0.013181
0.0009		0.01843	0.017057	0.019803
0.0012		0.02432	0.022909	0.025731
0.0015		0.03041	0.02902	0.0318
0.0018		0.03667	0.034893	0.038447
0.0021		0.043	0.041216	0.044784
0.0024		0.04901	0.04718	0.05084
0.0027		0.0552	0.053135	0.057265
0.003		0.06143	0.059269	0.063591
0.0033		0.06757	0.065218	0.069922
0.0036		0.07359	0.071318	0.075862
0.0039		0.07996	0.077439	0.082481
0.0042		0.08621	0.083675	0.088745
0.0045		0.09215	0.089725	0.094575
0.0048		0.09807	0.095386	0.100754
0.0051		0.10379	0.101508	0.106072
0.0054		0.10967	0.107562	0.111778
0.0057		0.11558	0.113302	0.117858
0.006		0.12137	0.118982	0.123758
0.0063		0.12734	0.124629	0.130051
0.0066		0.13396	0.131471	0.136449
0.0069		0.13984	0.137088	0.142592
0.0072		0.14609	0.143108	0.149072
0.0075		0.15217	0.149348	0.154992
0.0078		0.15784	0.155361	0.160319
0.0081		0.1637	0.160565	0.166835
0.0084		0.16985	0.166314	0.173386
0.0087		0.17615	0.172603	0.179697
0.009		0.18184	0.178242	0.185438
0.0093		0.18771	0.183932	0.191488
0.0096		0.19362	0.189811	0.197429
0.0099		0.1993	0.195462	0.203138
0.0102		0.20517	0.201688	0.208652
0.0105		0.21111	0.207287	0.214933
0.0108		0.21695	0.212672	0.221228
0.0111		0.22352	0.219415	0.227625

0.0114		0.22936	0.225339	0.233381
0.0117		0.23537	0.230919	0.239821
0.012		0.24101	0.236695	0.245325
0.0123		0.24722	0.242648	0.251792
0.0126		0.25345	0.249238	0.257662
0.0129		0.25936	0.255143	0.263577
0.0132		0.2648	0.259988	0.269612
0.0135		0.27054	0.266624	0.274456
0.0138		0.27663	0.271735	0.281525
0.0141		0.28197	0.278197	0.285743
0.0144		0.28838	0.284484	0.292276
0.0147		0.2938	0.289909	0.297691

[Chart 8 - Confidence Interval for Throughput of B at Low Load]

Probability		Average Delay Per Frame	Average Delay Per Frame Lower Interval	Average Delay Per Frame Upper Interval
0		0	0	0
0.0003		1.004762	0.989703	1.01982
0.0006		1.024454	0.988516	1.060392
0.0009		1.031221	0.996003	1.066439
0.0012		1.09152	1.019233	1.163808
0.0015		1.12236	0.997445	1.247275
0.0018		1.116637	1.013267	1.220007
0.0021		1.152904	1.034059	1.271748
0.0024		1.187602	1.102833	1.272372
0.0027		1.192246	1.132659	1.251833
0.003		1.242106	1.156206	1.328006
0.0033		1.26074	1.207333	1.314147
0.0036		1.303907	1.248313	1.3595
0.0039		1.319211	1.264096	1.374325
0.0042		1.391731	1.320455	1.463006
0.0045		1.451812	1.35814	1.545483
0.0048		1.44728	1.370777	1.523784
0.0051		1.516729	1.374931	1.658527
0.0054		1.526898	1.406972	1.646823
0.0057		1.605338	1.446809	1.763867
0.006		1.689313	1.531434	1.847192

0.0063		1.768405	1.571192	1.965619
0.0066		1.75444	1.652011	1.856868
0.0069		1.943363	1.5774	2.309325
0.0072		1.963593	1.667919	2.259267
0.0075		2.224023	1.764657	2.683389
0.0078		2.313049	2.01723	2.608867
0.0081		2.585153	2.131974	3.038332
0.0084		2.36328	1.984712	2.741848
0.0087		2.740205	1.780134	3.700275
0.009		2.628389	2.125004	3.131774
0.0093		3.087411	2.170819	4.004004
0.0096		3.283592	2.563101	4.004082
0.0099		3.556292	2.411946	4.700638
0.0102		4.203518	2.812988	5.594049
0.0105		3.905578	3.014063	4.797093
0.0108		4.038055	3.243229	4.832882
0.0111		4.999207	3.021127	6.977286
0.0114		5.832701	4.022074	7.643328
0.0117		5.842323	3.013505	8.671142
0.012		6.272438	4.300981	8.243896
0.0123		7.389162	4.292935	10.48539
0.0126		7.591212	4.655274	10.52715
0.0129		7.741005	6.311319	9.170691
0.0132		12.51017	8.889376	16.13097
0.0135		13.15357	5.4985	20.80863
0.0138		16.09138	9.378677	22.80409
0.0141		14.07673	10.09799	18.05547
0.0144		16.08245	12.91221	19.25269
0.0147		26.60158	18.79864	34.40452