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LAB 2

SETUP

Our simulation consists of four steps repeated cyclically: high-rate state, transition from high to low rate, low rate state, changing from low to high rate. The simulation ends after t_{MAX} seconds.

Dealing with queues, we will focus on customers (packets) and services (transmission of packets), meaning that we will talk about arrival rate and service time (pkt/s), which is the ratio between packet size and capacity. The bitrate can be then obtained by multiplying the capacity by the packet size.

Arrivals are scheduled with a Poisson process with a mean value equal to $1/\lambda_H$ or $1/\lambda_L$, depending on the current state. Departures are instead scheduled according to the current available capacity.

High-rate and low-rate intervals are modeled with a Markovian process with mean values equal to μ_{tH} and μ_{tL} respectively, but here we assume that they are equal.

We also assume that the transition times, from high to low rate and vice versa, are the same. During the transition from high to low rate, we set $\lambda = \lambda_L$ but we keep $C = C_H$. When changing from low to high rate, we have $\lambda = \lambda_H$ but we keep $C = C_L$. This choice was made in order to model the time required by the circuitry of the system to switch to a different output rate.

The total energy consumption is computed considering the power spent during high and low rate and during the transition time. In this last case we consider a power consumption which is the average among the other two states.

Summarizing, the parameters that we have to set are:

t_{MAX}: simulation time [s],

λ_H: arrival rate during high rate [pkt/s],

λ_L: arrival rate during low rate [pkt/s],

C_H: router capacity during high rate [bit/s],

C_L: router capacity during low rate [bit/s],

s_H: service time during high rate [s],

s_L: service time during low rate [s],

P_H: Power consumption during high rate [W],

P_L: Power consumption during low rate [W],

μ_{tH}: mean value of the high-rate state duration [s],

μ_{tL}: mean value of the low-rate state duration [s],

t_{HL}: transition time from high to low rate [s],

t_{LH}: transition time from low to high rate [s],

Q: queue size.

First, we verified the effect of changing the values of λ_H and λ_L in our system.

CASE 1: λ_H INCREASES

For this simulation we used the values reported in Figure 1.

λ_L	5
s_H	0.01
s_L	0.2
μ_{tH}	60
μ_{tL}	60
Q	10
t_{HL}	1
t_{LH}	1

Figure 1

The results are reported in Figure 2.

λ_H	10	50	100	150	200	250	300	350	400	1000
t_{MAX}	36000.03091	36000.04774	36000.13648	36000.00571	36000.29427	36000.00299	36000.00594	36000.02404	36000.00065	36000.03931
number of services	263736	946502	1723172	1817920	1679930	1928123	1787632	1922975	1911752	1905743
idle server probability	0.466015	0.272706	0.060505	0.0377	0.037933	0.034741	0.03812	0.035665	0.035109	0.036377
average time in the system	0.380151	0.119065	0.112414	0.14734	0.162166	0.148926	0.156396	0.149598	0.151221	0.152745
average number of users	2.784987	3.130695	5.380849	7.440591	7.567361	7.976333	7.766091	7.991121	8.030505	8.08589
lost users	4485	13516	105592	901638	1633380	2826122	3463112	4674914	5573443	16614488
total users	268221	960028	1828770	2719567	3313310	4754256	5250755	6597896	7485205	16777216
loss probability	0.016721	0.014079	0.057739	0.331537	0.492975	0.59444	0.659546	0.708546	0.744595	0.990301

Figure 2

Power and energy are not shown because they don't depend on the arrival rate.

As expected, the probability that the server is idle decreases if λ_H increases, while the loss probability goes to 1.

We see that for $\lambda_H > 300$, the number of sent packets does not increase, which means that the capacity is fully exploited. Nevertheless, there is still a small fraction of time during which the server is idle.

CASE 2: λ_L INCREASES

For this simulation we used the values of Figure 3.

λ_H	100
s_H	0.01
s_L	0.2

μ_{tH}	60
μ_{tL}	60
Q	10
t_{HL}	1
t_{LH}	1

Figure 3

Figure 4 shows the results of this simulation.

λ_L	0.1	0.5	1	2	3	4	10
t_{MAX}	36000.00186	36001.65279	36000.00398	36000.00003	36000.00683	36000.14913	36000.00185
number of services	1302928	1498473	1688980	1718405	1688792	1676867	1801427
idle server probability	0.628776	0.534598	0.43624	0.331451	0.236338	0.13868	0.031723
average time in the system	0.058371	0.059405	0.060402	0.063467	0.069033	0.082037	0.155986
average number of users	2.112609	2.472562	2.833838	3.029501	3.238378	3.821242	7.805487
lost users	62802	73830	85510	92567	93439	96915	195475
total users	1365740	1572303	1774491	1810980	1782233	1773784	1996907
loss probability	0.045984	0.046957	0.048188	0.051114	0.052428	0.054637	0.097889

Figure 4

Loss probability and average time in the system have a small increment, while the probability of having the server idle tends to zero as λ_L approaches 10 pkt/s.

CASE 3: RATE ADAPTATION IMPACT

Now, we compare two different systems: one with rate adaptation, the other without rate adaptation. In the second scenario, we always use the high-rate capacity (same service time) even if the arrival rate is λ_L, which means a constant power consumption equal to P_H.

We expect different loss probabilities, average delays and energy consumptions.

Parameters are set as shown in Figure 5.

	with rate adaptation	without rate adaptation
λ_H	100	100
λ_L	5	5
P_H	1	1
P_L	0.5	not used
s_H	0.01	0.01
s_L	0.2	not used
μ_{tH}	60	60
μ_{tL}	60	60
Q	10	10
t_{HL}	1	not used
t_{LH}	1	not used

Figure 5

In Figure 6, we report the different results obtained with and without rate adaptation.

	with rate adaptation	without rate adaptation
t_{MAX}	36000.13648	36000.21517
idle server probability	0.060505	0.531852
average time in the system	0.112414	0.055305
average number of users	5.380849	2.589046
loss probability	0.057739	0.042945
energy consumption	26740.21094	36000.21484

Figure 6

Here we note that by adding rate adaptation, the energy consumption decreases of 25.7%, despite an increment of 1.5% in loss probability and a higher value of queuing users. The different values of average queuing users and consequently loss probabilities are related to the fact that during the low rate without rate adaptation, the router is able to empty the queue.

This has an important impact on the idle server probability: 6% with rate adaptation, 53% without. A possible idea would be to switch off the router during the idle time, but this behavior could be worse in terms of energy if the idle periods are short and frequent, and the switching does not come with low power consumption.

CONFIDENCE INTERVALS FOR AVERAGE DELAY IN CASE OF RATE ADAPTATION

Here we want to obtain the confidence interval for the average delay in case of rate adaptation. We run the simulation 100 times, changing every time the seed value. We got a mean value x_m= 0.109512 and a variance s^2 = 0.000014 and a standard deviation s = 0.003735. If we want a 99% confidence, we get from the z table a value of 2.58. Multiplying this value by $s/\sqrt{N}$, we get 0.000964. This means that we are 99% confident that the mean m of the sampling distribution is in the interval [x_m - 0.000964; x_m + 0.000964].

INFLUENCE OF THE QUEUE SIZE

Repeating the experiment, but doubling the queue size, we get the numbers of Figure 7.

Q = 20	with rate adaptation	without rate adaptation
t_{MAX}	36000.00479	36000.14675
idle server probability	0.0407	0.458159
average time in the system	0.194188	0.102488
average number of users	9.711387	5.553151
loss probability	0.034633	0.022034
energy consumption	26925.82031	36000.14453

Figure 7

Here, the loss probability obviously decreases, but the difference between the two cases is almost the same: 1.26% here against the previous 1.5%. Same behavior for the saved energy, which is again around 25%. We also observe that both the average time spent in the system and the average number of users double, but the ratio between the values of the two different scenarios remain constant, meaning that increasing the queue size does imply an improvement on the performances, but only in absolute terms.

SWITCHING TIME EFFECTS

In order to consider the effect of the transition times, we tried different values for t_{HL} and t_{LH}.

In the simulations, we observed that during the transition from high to low rate, in which the arrival rate is low but the capacity is still high, we have a balanced situation in which arrivals and departures alternates. In the other transition, where we have a high arrival rate but we still use the low capacity, our system is unbalanced and the number of arrivals is much greater than the number of departures. This means that the queue and the loss probability increase. Since these intervals are small compared to the whole simulation time, their effects are small, but the longer the transition period, the higher the impact on the overall simulation. These conclusions can be verified in the table above where loss probability ranges from 4% up to 7% and the average time in the system from 0.1041 seconds to 0.1108 seconds.

$t_{HL} = t_{LH}$	0.1	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7	2
t_{MAX}	36000.00486	36000.00051	36000.04	36000.01	36000.14	36000	36000.08	36000.01	36000.02	36000.1
idle server probability	0.053329	0.053993	0.055892	0.057612	0.057824	0.059039	0.062068	0.061239	0.064672	0.065716
average time in the system	0.104145	0.109188	0.102718	0.112193	0.111388	0.109654	0.110931	0.118136	0.113812	0.110812
average number of users	5.393612	5.410412	5.390747	5.386261	5.41288	5.430779	5.370828	5.431827	5.395692	5.372135
loss probability	0.046404	0.048082	0.0498	0.052807	0.055829	0.058228	0.060641	0.064354	0.066979	0.07066
energy consumption	27391.64063	26970.09961	27571.24	26710.23	26863.03	27072.23	26869.65	26416.99	26737.99	26994.61

Figure 8