CS 549: Performance Analysis of Computer Networks

Lab Assignment 2

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what to measrue ?
- Network Throughput

How to measure ?
- Using the tool **wget**

Factors

Factors	Levels
File Size	1B , 1kB, 10kB, 100kB, 500kB , 1MB, 10MB, 100MB, 500MB
Download speed limit	-1 , 1 (low and high) (1Mb /s , 5Mb /s)
Number of concurrent file downloads running	1, 2, 3
Time of Day	Morning , Afternoon , evening

For simplicity considering :

Levels of File size as 3 ---- 10KB , 1MB, 100 MB

The experimental is conducted as follows:-

A full factorial design is implemented , with 3 repititions. This implies the total number of experiment to be done are :-

(3 for File size) * (2 for Speed Limit) * (3 for concurrrent dowloads) * (3 for time of day) * (3 for reps) = 162 in total.

The data collected by varying all levels of all factors is described in the below table. Note that the data is sorted based on highest value of througput first. (That's what we need for good performance).

Table -1

File Size	Speed Limit	Concurrent Downloads	Time of the day	Throughput (KB/s)⬆
10KB	5M	1	Morning	88268.8
10KB	5M	1	Afternoon	66355.2
10KB	100M	2	Afternoon	66201.6
10KB	100M	1	Afternoon	65 433.6
10KB	100M	2	Afternoon	63283.2
10KB	100M	2	Afternoon	61235.2
10KB	5M	2	Morning	59904
10KB	5M	3	Evening	59392
10KB	5M	1	Morning	59187.2
10KB	100M	1	Morning	58880
10KB	100M	2	Morning	58880
10KB	5M	3	Morning	58675.2
10KB	5M	2	Morning	58470.4
10KB	5M	1	Evening	58368
10KB	5M	2	Afternoon	57600
10KB	5M	2	Afternoon	57344
10KB	100M	1	Morning	54988.8
10KB	5M	3	Morning	54272
10KB	5M	1	Evening	53657.6
10KB	5M	3	Afternoon	52053.33
10KB	5M	3	Afternoon	51746.13
10KB	100M	3	Evening	51647.14
10KB	100M	3	Afternoon	51613.01
10KB	100M	1	Evening	51404.8
10KB	5M	1	Morning	50073.6
10KB	100M	1	Afternoon	49664
10KB	5M	3	Afternoon	45813.76
10KB	100M	1	Afternoon	40755.2

10KB	100M	3	Morning	40239.78
10KB	100M	1	Evening	39424
10KB	5M	2	Afternoon	39424
10KB	100M	3	Morning	37246.29
10KB	100M	3	Afternoon	35061.76
10KB	5M	3	Morning	33327.78
10KB	100M	2	Morning	31723.52
10KB	100M	2	Evening	31114.24
10KB	100M	2	Morning	30796.8
10KB	5M	2	Evening	30468.3
10KB	5M	2	Morning	30376.96
10KB	5M	1	Afternoon	28876.8
10KB	5M	3	Evening	22370.98
10KB	100M	3	Evening	20988.58
100MB	100M	3	Afternoon	11605.33
100MB	100M	3	Afternoon	11400.53
1MB	100M	3	Afternoon	10581.33
100MB	100M	3	Afternoon	10018.13
1MB	5M	2	Afternoon	9999.36
1MB	100M	3	Afternoon	9895.25
1MB	100M	1	Morning	9840.64
1MB	100M	3	Afternoon	9359.36
1MB	100M	2	Afternoon	9036.8
1MB	5M	1	Afternoon	8744.96
1MB	5M	1	Morning	8704
1MB	100M	1	Afternoon	8683.52
1MB	5M	3	Afternoon	8622.08
1MB	100M	1	Afternoon	8478.72
1MB	5M	1	Afternoon	8458.24
1MB	5M	2	Morning	8314.88
100MB	100M	1	Afternoon	7905.28
1MB	5M	2	Morning	7838.72
1MB	100M	1	Morning	7833.6

100MB	100M	2	Afternoon	7741.44
100MB	100M	1	Morning	7669.76
1MB	100M	1	Afternoon	7475.2
1MB	5M	3	Afternoon	7464.96
1MB	100M	2	Morning	7408.64
1MB	5M	2	Morning	7408.64
100MB	100M	1	Afternoon	7311.36
1MB	100M	2	Morning	7162.88
100MB	100M	1	Morning	7034.88
100MB	100M	2	Afternoon	6656
1MB	5M	3	Afternoon	6645.76
100MB	100M	1	Afternoon	6574.08
1MB	100M	2	Afternoon	6430.72
1MB	5M	3	Evening	6157.65
100MB	100M	3	Morning	6133.76
1MB	100M	3	Morning	6120.1
1MB	5M	3	Morning	6116.69
100MB	100M	3	Morning	5942.61
1MB	100M	1	Morning	5918.72
100MB	100M	2	Morning	5898.24
100MB	100M	2	Afternoon	5862.4
1MB	100M	2	Morning	5652.48
1MB	5M	1	Afternoon	5601.28
100MB	100M	3	Morning	5434.02
1MB	100M	3	Morning	5379.41
1MB	5M	3	Morning	5212.16
100MB	5M	3	Afternoon	5150.72
100MB	5M	3	Afternoon	5147.3
100MB	5M	1	Afternoon	5130.24
100MB	100M	2	Morning	5120
100MB	5M	1	Afternoon	5109.76
100MB	5M	3	Afternoon	5051.73
100MB	5M	1	Morning	5048.32

100MB	5M	3	Morning	5021.01
100MB	5M	2	Afternoon	5007.36
100MB	100M	2	Morning	4956.16
100MB	5M	1	Morning	4945.92
100MB	5M	2	Morning	4945.92
100MB	5M	2	Afternoon	4904.96
100MB	5M	3	Morning	4898.13
100MB	5M	1	Morning	4812.8
100MB	5M	3	Morning	4795.73
100MB	5M	1	Afternoon	4792.32
1MB	5M	3	Morning	4747.94
100MB	100M	3	Evening	4700.16
100MB	100M	1	Morning	4669.44
100MB	5M	2	Afternoon	4659.2
100MB	5M	2	Morning	4444.16
100MB	5M	2	Morning	4439.04
1MB	5M	1	Morning	4188.16
1MB	5M	2	Afternoon	4147.2
1MB	100M	2	Afternoon	4044.8
1MB	5M	1	Morning	3870.72
1MB	100M	3	Morning	3819.52
1MB	5M	2	Afternoon	3599.36
100MB	100M	3	Evening	3433.02
10KB	5M	2	Evening	3322.88
10KB	5M	2	Evening	3297.28
1MB	100M	2	Evening	2995.2
1MB	100M	3	Evening	2914.98
1MB	5M	3	Evening	2809.17
10KB	100M	3	Morning	2662.4
10KB	5M	1	Afternoon	2560
1MB	100M	2	Evening	2539.52
10KB	100M	1	Morning	2529.28
10KB	100M	2	Evening	2426.88

1MB	100M	3	Evening	2416.64
10KB	100M	3	Evening	2231.48
10KB	100M	3	Afternoon	2194.44
1MB	100M	3	Evening	2174.29
1MB	5M	3	Evening	2131.37
10KB	5M	3	Evening	2104.62
1MB	100M	1	Evening	2048
100MB	5M	1	Evening	2017.28
1MB	5M	1	Evening	1996.8
1MB	100M	1	Evening	1955.84
10KB	100M	2	Evening	1641.96
1MB	5M	2	Evening	1551.36
1MB	5M	2	Evening	1510.4
1MB	5M	1	Evening	1454.08
100MB	100M	3	Evening	1433.6
10KB	5M	1	Evening	1413.12
100MB	5M	3	Evening	1389.41
100MB	5M	1	Evening	1361.92
1MB	100M	2	Evening	1300.48
100MB	5M	2	Evening	1100.8
100MB	100M	2	Evening	1090.3
100MB	5M	3	Evening	1025.93
100MB	5M	3	Evening	944.66
1MB	5M	2	Evening	839
100MB	100M	2	Evening	808.5
1MB	100M	1	Evening	790
100MB	5M	1	Evening	752
100MB	5M	2	Evening	712
100MB	100M	1	Evening	706
1MB	5M	1	Evening	687
100MB	5M	2	Evening	666
100MB	100M	2	Evening	657
100MB	100M	1	Evening	586

| 100MB | 100M | 1 | Evening | 549 |
| 10KB | 100M | 1 | Evening | 24.9 |

Observation / Pattern **(Ranking Method)** :-

As marked with the Bounding boxed (green and red) , We can say :-

- If the file size is smaller (like 10KB in our case) – we most probably will get a higher throughput (green box).

- We are very likely to get very less throughput (even less than 1MB/sec) if the **time of day** is **evening** (red box). Very sad it is :(

Range Method :-

For this, we need to change our table a little bit (actually quite many changes)

One more column can be added here which will include all the throughput values for all levels and factors , but to keep the report short I have included the whole tables in appendix.

Table-2

Factor	Level	Average throughput	Range (max – min)
File size	10KB	38574.4	34126.78
	1MB	5390.34	
	100MB	4447.62	
Time of the day	Morning	18930.6	11055.66
	Afternoon	20268.7	
	Evening	9213.04	
Number of concurrent Downloads	1	17510.6	2330.3
	2	15721.5	

	3	15180.3	
Speed Limit	5MB	16862	1449.1
	100MB	15412.9	

From the above table :

- **File size** have the largest range , that means it is the most important factor.
- Secondly , **Time of the day** have the 2nd largest range , that implies it is the second most imp factor.

Allocation of Variation

We now know that the two primary factors are – file size and Time of the day, So now performing again some experiments by varying these 2 factors with 3 repetitions for each experiment as shown in the below table.

Table 3.

	Morning	Afternoon	Evening	Row Sum	Row Mean	Row effect
10KB	58470.4	57344	30468.3			
	59904	57600	3297.28	340207.82	37800.868	22382.491
	30376.96	39424	3322.88			
1MB	7408.64	9999.36	1551.36			
	8314.88	4147.2	1510.4	45208.92	5023.213	-10395.163
	7838.72	3599.36	839			
100MB	4945.92	4904.96	712			
	4439.04	5007.36	1100.8	30879.44	3431.0489	-11987.328
	4444.16	4659.2	666			
Column	186142.72	186685.44	43468.02	416296.18		

Sum					
Column Mean	20682.524	20742.827	4829.78		15418.377
COlumn effect	5264.147	5324.450	-10588.597		

Symbolizing File size as A – 3 levels , Time of Day as B – 3 Levels.

$$Y_{i,j,k} = \mu + \alpha_j + \beta_i + \gamma_{i,j} + e_{i,j,k}$$

Here $Y_{i,j,k}$ is the output for ith level of factor B, jth level of factor A and k th repetition of the experiment.

As we know,

$$
\begin{aligned}
\mu &= Y_{...} \\
\alpha_j &= \bar{y}_{.j.} - \mu \\
\beta_i &= \bar{y}_{i..} - \mu \\
\gamma_{i,j} &= \bar{y}_{i,j} - \bar{y}_{i..} - \bar{y}_{.j.} - \mu
\end{aligned}
$$

.....(i)

We also know

SSY = SSO + SSA + SSB + SSAB + SSE

$$
\begin{aligned}
SSY &= abr \sum_{i,j,k} Y_{i,j,k}^2 \\
SSO &= abr\mu^2 \\
SSA &= br \sum_j a_j^2 \\
SSB &= ar \sum_i \beta_i^2 \\
SSAB &= r \sum_{i,j} \gamma_{i,j}^2
\end{aligned}
$$

.....(ii)

The below table is for the Interactions between the two factors (the values can be verified as sum in row direction is 0 as well the sum in column direction)

[Reference : the-art-of-computer-systems-performance-analysis by Raj Jain]

	Morning	Afternoon	Evening
10KB	6518.770373	8330.68148	-14849.45185
1MB	-2433.280747	-4432.356303	6865.637033
100MB	-4085.486297	-3898.32852	7983.80815

Lets call this table as table 4.

Hence from equations in (i) and (ii):

SSY = (58470.4)^2 + (57344)^2 + ...+ (666)^2 = **17498538561**

SSO = 3 x 3 x 3 x (15418.37704) = **416296.18008**

SSA = 3 x 3 x [(22382.49185)^ 2+ (-10395.1637) ^2 ...] = **6774582654.9**
(sum of sq of row effects)

SSB = 3 x 3 x [(5264.147407) ^ 2 + (5324.44963)^2 ..] = **1513614591**
(sum of sq of columns effects)

SSAB = 3 * [(6518.770373) ^ 2 + (8330.68148)^2 + ...] = **500733806.9**
(Table 1.1)

SSE = SSY – SSO – SSA – SSB – SSAB = **8709191212.01992**

SST = SSY – SSO = 17498538561 − 416296.18008 **= 17498122264.81992**

Variation explained by A = 100 * SSA / SST **= 38.716055085 %**

Variation explained by B = 100 * SSB / SST **= 8.650154 %**

The variation explained by A is more than the variation explained by B (Time of the day) , we can also visualise this direclty from the data table 1.1.

Appendix :