Realization of correlation between Round Trip Time (RTT) and hop counts in packet switched networks

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Abstract: QoS in communication networks can be best predicted by RTT and hop counts. Usually, RTT is directly proportional to the incremental count of hops in communication networks. There persists a correlation between these two metrics but how robust this correlation is an open question. Several studies reported different opinions about the correlation between RTT and hop counts. Some authors reported *no correlation*, some predicted *weak correlation* and few others evidenced *strong correlation* between RTT and hop counts. What is the actuality behind these ambiguities related to RTT and hop count's relationship? In this paper we made an effort to realize the correlations between RTT and hop counts by considering two cases: (1) - Correlation between RTT and hop counts in an end to end path lies between client and server of any individual communication network. (2) - The mutual correlation between RTT and hop counts among the different set of end to end paths exist among different remote servers behind different networks with varying conditions of distances. We applied mathematics to measure the correlation by acquiring the experimental readings of both variables (RTT and hop counts) under active probing mechanism of networks testing. The correlation between RTT and hop count can be more effective to predict various network conditions like high load or congestion.

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1. Introduction

The determination of correlation between Round Trip Time (RTT) and hop counts have been actively noticed in recent research. Generally, RTT values grow up with growing number of hop counts but this condition varies upon different routes having variable distances. The utilization of joint RTT and hop counts metrics can predict best proximity of remote resources. RTT significantly correlates with hop counts (Hadighi and Gharib, 2012); and it is least expensive for measuring latency. On the other hand, hop count is best metric to predict network usages (Obraczka and Silva, 2000). According to our analysis, the relationship between hop counts and RTT can be measured in two ways: (1) - Correlation between RTT and hop counts in an end to end path lies between client and server of any individual communication network. (2) - The mutual correlation between RTT and hop counts among the different set of end to end paths exists among different remote servers behind different networks with varying conditions of distances. Two techniques: (1) active probing and (2) passive polling are used in prior studies to measure the correlation factor (r) between RTT and hop counts. In 1995, the authors of study (Crovella and Carter, 1995); used active probing while in 1999, McManus utilized passive polling technique (Yahaya et. al., 2011); for discovering the relationship between hop counts and RTT. In active probing some network traffic packets like ICMP echo requests are initiated by the user that modify the network traffic to get measurements between two end points that are linked with each other through a network. In passive polling, no ICMP echo request in the form of packet can be initiated, therefore, measurements are only taken with the existing network traffic between two directly connected nodes (peers). In other words passive monitoring relies measuring the peer by peer relationships of desired variables which mean passive polling has limited scope to capture data sets and to find correlation between required variable (Crovella and Carter, 1995).

The correlation between RTT and hop counts may essentially be substantial in case of congestion avoidance and routing mechanisms. Routing schemes deal with hop count's philosophy that is effectively significant to handle burst contention rather to the other schemes (Yahaya et. al., 2011). Similarly, RTT and intra-nodal processing delay affect the transmission with happening of congestion (Chan and Alam, 2012). Moreover, Congestion management is reliant on three steps: (1) detection, (2) notifications and (3) bandwidth adjustment (Lee et. al. 2012). Presently, most routers deploy Drop-Tail Mechanism to handle congestion (Khosroshahy, 2012). Usually congestion is happened nearest to the router's edge as compared to the core network (Khosroshahy, 2012). If any traffic takes 50 ms as an end-to-end delay in any communication network when the effect of other traffic is false then it means there is no congestion (Khosroshahy, 2012). Congestion degrades the overall quality of service in network communication with packet drops, jitter and latencies which are more critical in case of wireless networks because these factors badly affect the energy, efficiency, memory size, buffer size and throughputs (Lee et. al. 2012). So enhanced Quality of Service (QoS) of any network demands low latency with optimal congestion control mechanism. Our predicted correlation can make the RTT and hop counts as a new metric to detect congestion with the evidence to correlation between these two discussed parameters.

Active probing is widely used technique for measuring the QoS of remotely communicated network resources. The authors of studies (Shoukat et. al. 2012); (Shoukat et. al., 2011) used active probing method for analyzing the performance characteristics of remotely communicated servers running behind the global informative networks. In this paper, we also utilized active probing mechanism to find the correlation between hop counts and RTT. Firstly, we calculated the correlation factor against a specific end-point route lies between client and server with varying degree of number of hops as well as with variable values of RTT. To find the correlation between source and destination node in a specific end-point route (path) is more worth full in determining the QoS of any remote resource (Client and Server). However, we have also calculated the correlation factor among the different end-point routes of different remote servers residing on separate geographical loctions having variable distances.

The objective of this study is to escape the ambiguities related to RTT and hop count's correlation. Moreover, this study contributes that congestion is the actual cause of correlation variations despite the lengthy effect of distance or geographical locations concerned to the targeted server. Additionally, we made an effort to generate a new idea of detecting congestion through the correlation of RTT and hop courts. According to our best knowledge, we are the beginners to put-forward this kind of idea that can be utilized in future to predict congestion on the behalf of correlation between RTT and hop counts.

2. Related Work

Different authors have different opinions about the relationship between RTT and hop counts. According to the authors of study (Crovella and Carter, 1995); the relationship between number of hops and RTT is almost zero. McManus (McManus, 1999) measured strong correlation between RTT and hop counts in peer by peer which was limited in scope. Hadighi and Gharib (Hadighi and Gharib, 2012); said that there is correlation between RTT and hop counts but Qiu and Padmanabhan found weak relationship (Qiu and Padmanabhan, 2001); which was resembled the findings of the authors of study (Ballintijn et al.,). RTT is superlative metric to measure end-to-end latency of remote services. Latency of remote resources rely on the sum of Round Trip Times (Shoukat et. al., 2012); and end-to-end latency affects negatively under load and congestion (Shoukat et. al., 2012). In the mid of 2011, first time the authors of study (Shoukat and Iftikhar, 2011); provided sufficient imagination about the detection of congestion that can be made possible through RTT and hop counts because path is substantially amended and number of hops are greatly increased in congested situation. Their ultimate objective behind that effort was to invoke: RTT is not only correlated with hop counts but these both metrics also correlate with congestion and loaded situation too (Shoukat and Iftikhar, 2011). According to the discovered relationship between RTT and hop counts by the authors of study (Shoukat and Iftikhar, 2011); which is "if the degree of hop counts greater than 2 and the incremental factor in normal RTT is greater than or equal to (Normal RTT + Normal_RTT/2)" then the occurred situation will be called congested otherwise overloaded in packet switched networks.

Round Trip Time (RTT) linearly grows with the number of hop counts. In 2010, Chang and his fellows (Chang et. al. 2010); formed a linear relationship between hop counts and RTT as depicted in Figure 1. There is a negative correlation between hop counts and RTT as reported by the authors of study (Fujii and Goto, 2000). In contrast with this opinion Shegeki (Hall et. al., 2007) calculated the number of hop counts from Time to Live (TTL) Value and found robust correlation between hop counts and RTT. In 2009, the authors of study (Yakubu et. al., 2009) measured the correlation between hop counts and RTT by using regression analysis technique and their calculated correlation factor was 0.16 which shows weak positive correlation. The mutual distribution (Yakubu et. al., 2009); of RTT latency and number of hops is represented in Figure 2.

According to the observation of Obraczka and Silva (Obraczka and Silva, 2000); the RTT correlates 50% with hop count metric. Recently Arumugami and Venkatesh (Arumugam and Venkatesh, 2011); claimed a strong correlation (0.99236) between hop counts and RTT but there experimental data was limited to 12 hop counts in this case. They formed those remote resources that did not substantially vary in locations and distances.

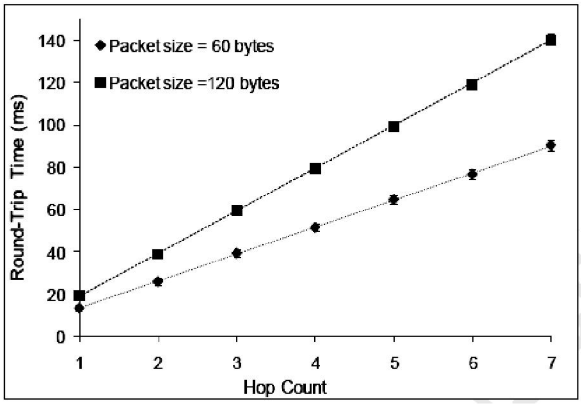

Figure 1. Linear Relationship between RTT and hop counts

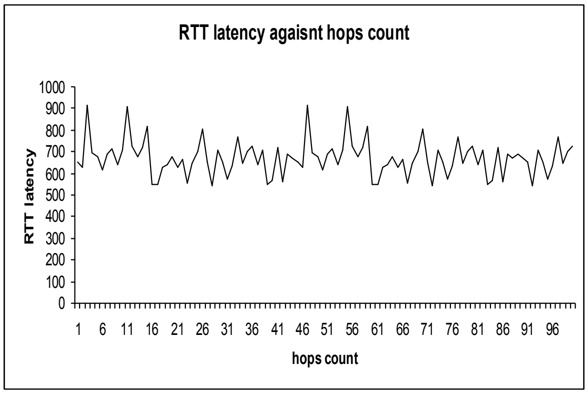

Figure 2. RTT Latency Distribution with hop counts

In case of minimum distance, there were smaller number of hops and lesser hops did not result substantial amendments in RTT variations, therefore there prediction about the said relationship may not truly representative in case of those remote resources that vary in distance, locations and large number of hop counts to fulfill given requests. Therefore, prior studies are limited in scope to record RTT and hop count's recordings in experimental phase. To overcome this limitation and to find out the actual correlation between hop counts and RTT, we considered well-know remote servers located over different geographical locations with different number of hop counts. This consideration clearly invokes the need of presented study.

3. Methodology and Experimentation

We selected different well-known and highly rushed remote servers located on different geographical locations worldwide. In order to measure end-to-end latency, we set the value of hop counts up to maximum number of hops. Normally, all end targeted remote nodes are remained accessible within the limit of 30 hop counts. We used *active probing technique* in order to initiate ICMP echo request-response process to record the RTT latencies however, numbers of hop counts were record through trace-route probing tool. We performed this experimentation in Computer Science Department, King Saud University, Kingdom of Saudi Arabia on windows 7 based machine having 2 GB RAM with core2duo processor (2.0 GHz.) The firewall was disabled and internet connection link speed was 160 MB per second.

This experimentation was repeated up to several weeks on randomly selected time spans in year 2012, however some recordings against RTT and hop counts were also captured in year 2010. Each time we accessed the same end-point remote server through unique IP address to record RTT and hop values. From a large set of experimental data, we selected most distinguishable recordings having more degree of variations in RTT and number of hops. The selection criteria of recordings against RTT and hop count parameter was maximum RTT with maximum number of hop counts, Average RTT with Average hop counts and minimum RTT with minimum hop counts. The master experimental data set acquired from large number of experimental recordings have been summarized in a Table 1. We measured the correlation coefficient between two variables (*Y= RTT and X= hop counts*) in two ways by considering the following cases:-

Case 1: Measuring the correlation coefficient (*r*) in an end-to-end path lies between client and server of any individual communication network through recording of *X* and *Y* values. The more distinctive and diverse values of *X* and *Y* have been selected to perform experiment. In this case the set of all *X* and *Y* values belongs to a single server. Mostly those average values of *X* and *Y* are selected that contain sufficient variances.

Case 2: Measuring the correlation coefficient r among many servers that were accessed from source to destination in order to get end-to-end average values of both variable *X* and *Y*. In this case the set of all *X* values and set of all *Y* values belong to different servers. Most diverse values of *X* and *Y* are selected from all sets of *X* and *Y* values against all selected servers.

Co-relation Coefficient Calculation

The following correlation coefficient method is used to calculated the value of "*r*"

$$r = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{\left(n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2\right)\left(n\sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2\right)}}$$

Where,
n: Total number of elements
X = hop counts
Y = Average Round Trip Time (RTT)
*Σ(X*Y) = Sum of the product of X and Y*
ΣX = Sum of hop counts

ΣY = *Sum of Avg. RTT*

ΣX^2 = *Sum of square X*

ΣY^2 = *Sum of square Y*

$x_i = (x_1, x_2, \ldots, x_n)$

$y_i = (y_1, y_2, \ldots, y_n)$

This correlation formula can results the value of r in between $-1 <= r <= 1$, where, 1 represents strong +ve correlation, -1 represents strong negative correlation, 0 represents no correlation. The correlation will as strong as it close to 1 and correlation will be weak as it close to 0.

3.1 Correlation Coefficient Calculations

Case 1: We considered the Case 1 to calculate the correlation coefficient "*r*" against single server having *IP address: 46.249.35.113*. By using the experimental recordings of (*X= hop-counts) and (Y= RTT* variables) as summarized in Table 1. Through employment of *X* and *Y* values, we can calculate the following transformations:-

$n = 11$, where "n" is number of elements

$$\sum_{i=1}^{n}(Xi)(Yi) = [(X_1 + X_2 + \ldots X_n)(Y_1 1 + Y_2 \ldots Y_n)] = 18406$$

$$\sum_{i=1}^{n}(Xi) = (X_1 + X_2 + \ldots . X_n) = 138$$

$$\sum_{i=1}^{n}(Yi) = (Y_1 1 + Y_2 + \ldots . Y_n) = 1448$$

$$\sum X_i^{\,2} = (X_1^2 + X_2^2 + X_3^2 + \ldots X_n^2) = 1740$$

$$\sum Y_i^{\,2} = (Y_1^2 + Y_2^2 + Y_3^2 + \ldots Y_n^2) = 197378$$

Now we put these values in the following correlation coefficient formula:-

$$r = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{\left(n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2\right)\left(n\sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2\right)}}$$

$$r = \frac{18{,}406 - 18{,}165.818}{\sqrt{(1{,}740 - 1{,}731.273)\ (197{,}378 - 190{,}609.455)}}$$

$$r = \frac{240.182}{\sqrt{(8.727)\ (6{,}768.545)}}$$

$$r = \frac{240.182}{\sqrt{59{,}070.942}}$$

$$r = \frac{240.182}{243.045}$$

$\boxed{r = 0.988}$ is the correlation coefficient against Case 1. Similarly we used the same above formula to calculate the individual correlation coefficient (*r*) against all other widely used servers by considering the case 1. The correlation calculation results are summarized in Table 2.

Table 1: Master Experimental Data Set extracted from large data set

Sr. No.	Server -1		Server -2		Server -3		Server -4		Server -5		Server -6	
	46.249.35.113		195.167.168.51		173.194.35.22		216.52.242.80		69.63.189.74		98.139.102.145	
	hop counts	Avg. RTT (ms)	hop counts	Avg. RTT (ms)	hop counts	Avg. RTT (ms)	hop counts	Avg. RTT (ms)	hop counts	Avg. RTT (ms)	hop counts	Avg. RTT (ms)
1	12	113	18	163	14	98	19	242	18	187	21	230
2	12	122	18	124	14	97	11	234	18	187	21	208
3	12	120	18	155	20	111	11	233	18	203	21	220
4	12	124	18	123	14	94	19	263	18	204	21	213
5	12	114	18	121	14	110	19	226	18	189	21	205
6	12	115	18	117	20	98	11	230	18	187	21	212
7	12	111	17	104			19	244	18	184	25	212
8	12	114	18	105			19	227	18	190	25	214
9	14	173					19	225			25	205
10	14	171					11	226			25	226
11	14	171									25	230

Table 2. Correlation against individual server (Case 1)

Remote Servers	**Correlation Coefficient (*r*)**
Server – 1: *IP Address: 46.249.35.113*	0.988
Server – 2 : *IP Address:195.167.168.51*	0.422
Server – 3: *IP Address: 173.194.35.22*	0.338
Server – 4: *IP Address: 216.52.242.80*	0.308
Server – 5: *IP Address: 69.63.189.74*	*Not Applicable*
Server – 6: *IP Address: 98.139.102.145*	0.154

Case 2: We produced a sample data set against X and Y variables taken from Table 1 in order to calculate mutual correlation among different servers located in different places with variable distances. The acquired experimental data set for X and Y is summarized in Table 3. In case 2 the value of n = 17. We applied the same correlation calculation procedure as applied in case 1 and as a result we found the mutual correlation coefficient value $\boxed{r = 0.228}$ among different servers located on different geographical locations with varying degree of distances.

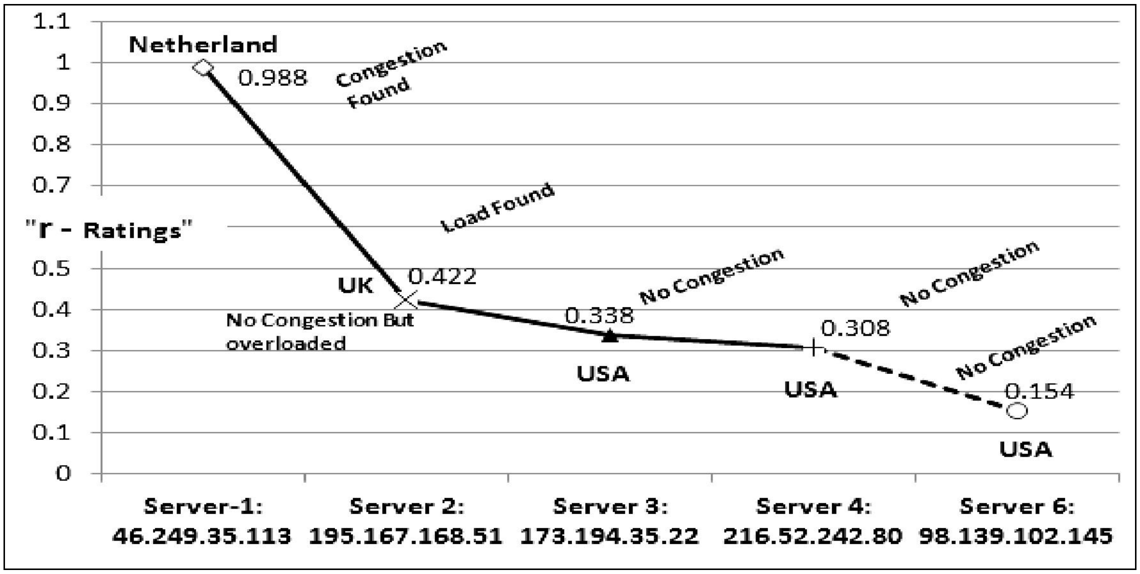

Figure 3: Correlation and Congestion linkage

Table 3. Selected Experimental Data for different Servers (Case 2)

Sr. No.	**Variable X = hop counts** $\sum_{i=1}^{n}(X_i)$	**Variable Y = RTT** $\sum_{i=1}^{n}(Y_i)$
1	12	113
2	12	124
3	12	173
4	17	104
5	18	155
6	18	163
7	18	104
8	18	187
9	14	98
10	20	111
11	20	98
12	14	110
13	11	230
14	19	226
15	19	263
16	21	208
17	21	230

4. Discussions

Limited number of hop counts did not grant efficient access ever in case of large latency. RTT is least expensive metric for measuring latency and hop count is best metric to predict network usages. RTT and hop count's correlation is robust in case of measuring correlation in end to end path against an individual server rather to the mutual correlation among different servers located on different geographical locations. We found that in case of loaded and congested situation the correlation becomes stronger between RTT and hop counts under case 1. Sometimes when number of hops increase but RTT remains consistence then according to case 1, the individual correlation results as a weak correlation but in this situation the server does not enter in overload or congested situation because the hops may be increased due to dead routers. Under case 1 when there is no high load or congestion, a positive correlation between RTT and hop counts persist but the value of "*r*" remains moderate. But in the presence of high load the correlation tends to increased and it becomes stronger in case of congested situation as shown in Table 4. According to case 2 there is also a weak but positive correlation (*r = 0.228*) between RTT and hop counts. The utilization of RTT and hop counts would be more beneficial to predict high load and congestion in communication networks. The correlation measurement under case 1 is more meaningful rather to the correlation calculation under case 2 because under case 1 the correlation can help to predict network situations in end-to-end path of an individual remote server. The prior studies that claim zero or negative correlation between hop counts and RTT have no significant reality.

In case of remote server with IP address: 46.249.35.113, the minimum average RTT is 111 ms with normal 12 hops and suddenly the when hops counts increased to 14 the RTT increased to 173 ms and request time was out in more than one routers. Therefore, the situation was found congested. This server (46.249.35.113) is located in Netherland accessed from Saudi Arabia. Similarly, in case of server with IP address: 195.167.168.51 the hop counts remained 17 with RTT 104 ms and 18 with 163 mile seconds. Hop counts did not found to sufficient increment that indicates only overloaded situation under the evidence of 163 ms total raise in RTT. Therefore, no congestion found in case of remote server with IP address: 195.167.168.51. Similarly, in case of server with IP address: 69.63.189.74, no congestion is found. In case of server with IP address: 173.194.35.22, normal hop counts are 14 and in case of 20 hop counts two different degree of RTT (111 ms, 98 ms) is found. This is actually due to the effect of dead routers but there is no congestion found.

In case of servers-2 and Server-3 the correlation is not strongest but these servers belong to different countries having different locations with different miles of distances as summarized in Table 4. Similarly, the server 4 and Server 6 belong to same country but correlation values is too small however, one thing is common among all these servers (Server-3,Server-4, Server-6) that is no congestion which means correlation relies on happening of load and congestion rather to locations (country wise). In case of Server-1 again the location and distance is different but stronger correlation is found due to the occurrence of congestion. In case of server-2 there is no congestion but situation is found to be loaded with rise of RTT from 105 ms up to 163 ms that results the increase of correlation rather to server-3, server-4 and server-6. When the server-3, Server-4 and Server-6 belong to same country but have different correlations and the correlation is not stronger because of no congestion. Hence, this observation invokes that the robustness of correlation between RTT and hop counts significantly reliant on the occurrence of network traffic situations (loaded or congested) rather to distance or server locations (country wise) as depicted in Figure 3.

Table 4. Correlation relationship with Network Situations

Server IP	(*r*)	Traffic behavior	Distance (Source – Destination)
Server-1: 46.249.35.113	0.988	Congestion found	Saudi Arabia – Dronten (Netherland)
Server 2: 195.167.168.51	0.422	No Congestion but overloaded	Saudi Arabia – Southampton (UK)
Server 3: 173.194.35.22	0.338	No Congestion	Saudi Arabia - Mountain View (US)
Server 4: 216.52.242.80	0.308	No Congestion	Saudi Arabia - Santa Moncia (US)
Server 6; 98.139.102.145	0.154	No Congestion	Saudi Arabia - Sunnyvale (US)

The predicted correlation of many prior studies (Crovella and Carter, 1995); (Qiu and Padmanabhan, 2001);(Ballintijn et al., 2000); (Fujii and Goto, 2000); did not retain reality. The authors of some other studies (Yakubu, et al., 2009); (Hall et. al., 2009); (Obraczka and Silva, 2000); (Arumugam and Venkatesh, 2011) found different opinions about the correlation of RTT and hop counts. The discrepancies of all these studies are their limited no of hop counts as well as limited criteria of investigation upon the selection of correlation judgment cases as discussed by us. No such study has been reported yet that considered two judgment cases as we have considered in this study. The comparison of our study with the prior studies is summarized in Table 5. Most of authors reported that correlation varies upon geographical distances and the location of the desired server(s) but our observation found that rather to distance the robustness of correlation is dependent on happening of congestion as depicted in Figure 3. The resultant analysis of Table 5 invokes the significance of presented study. While predicting the correlation of RTT and hop counts all possible measurement cases are not considered in any prior study as we have considered in this study.

We investigated the correlation under two possible cases with maximum number of hop counts. Prior studies utilize limited number of hop counts with limited investigation criteria due to which their findings did not truly represent the correlation reality between RTT and hop counts. Furthermore, the summarized contribution of this research determines that congestion is the actual cause of correlation variations rather to distance or geographical locations of concerned servers. It has been depicted in Figure 3, how this correlation co-relates with the happening of congestion. Additionally, we made an effort to generate a new idea of detecting congestion through the correlation of RTT and hop courts as discussed in Figure 3. The strongest correlation between RTT and hop counts means congestion is happened in transmission. This kind of effort has not been reported yet which clearly justifies that our study is many times superior to prior studies.

Table 5. Comparison with prior studies

Prior Studies	Predicted Correlation between RTT and hop counts	Cause of Correlation Robustness is discussed	Congestion effect upon correlation is considered	Possible cases are considered
(Crovella and Carter, 1995)	*Zero*	×	×	×
(Qiu and Padmanabhan, 2001)	*Weak correlation*	×	×	×
Ballintijn et. al. 2000)	*Weak correlation*	×	×	×
Fujii and Goto, 2000)	*Negative Correlation*	×	×	×
Yakubu et. al., 2009)	*Weak +ve Correlation*	×	×	×
Hall et. al., 2007)	*Robust*	×	×	×
Obraczka and Silva, 2000)	*50% Correlation*	×	×	×
Arumugam and Venkatesh, 2011)	*Strong Correlation Limited hop counts: 12*	×	×	×
Our proposed Study	*Strong Correlation (in case of congested situation)*	√	√	√
	Moderate +ve Correlation (in normal transmission)			

5. Conclusion

Prior studies reported either wrong correlation between RTT and hop counts or the judgment criteria of such studies was based on limited number of hop counts. There is no *zero* or *negative* correlation between hop counts and RTT. The robustness of correlation between these two variables significantly relies on network conditions and the effect of dead routers rather to distance or server locations. RTT positively correlates with hop counts and in correlation measurements; *case-1* as discussed in methodology section is more meaningful. Network traffic-load triggers reasonable degree of correlation between hop counts and RTT but this correlation magically becomes stronger in case of network congestion. Under the congested situation, the value of correlation coefficient $r = 0.988$ invokes the stronger correlation between RTT and hop counts. Server-3, Server-4 and Server-6 belong to same country but the correlation differs because of no congestion therefore, the robustness of correlation greatly relies on happening of congestion and slightly grew up as much as network load grows. However, in case of normal transmission condition the correlation results as moderate ($r = 0.422$, $r = 0.338$, $r = 0.308$) between hop counts and RTT. The mutual committee of both RTT and hop count metrics would be an ideal heuristic to predict highly loaded and congested network conditions in near future.

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