Measurement & Evaluation of Packet Reordering Over Internet

Advisor: Professor Anura P. Jayasumana

Bin Ye

ECE

Colorado State University

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Outline

- Introduction
- Contribution
- Part I – Measurement of Packet Reordering over Internet
- Part II – Cascade of n Similar Subnet Problem
- Part III – Packet Reordering & Packet Delay
- Summary

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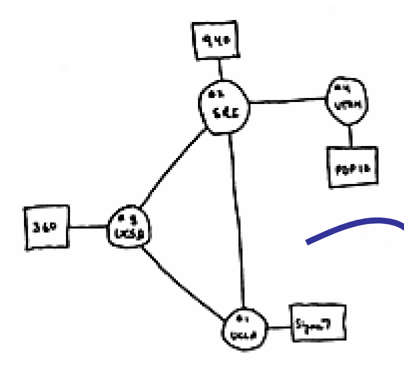
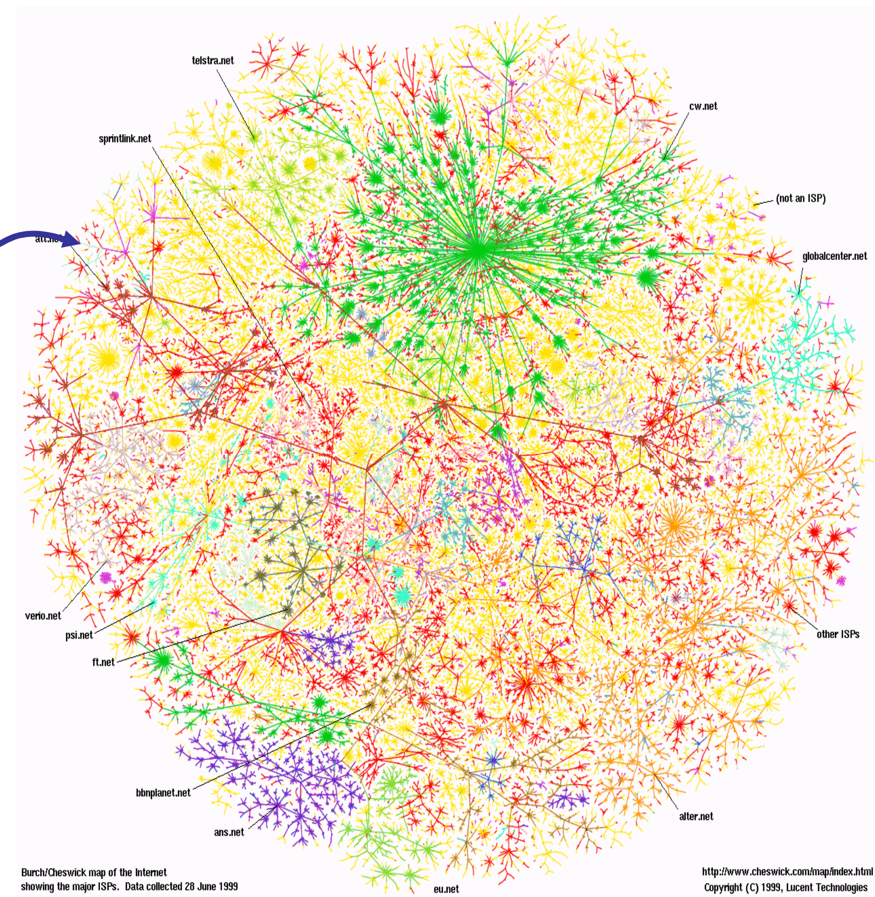
Internet



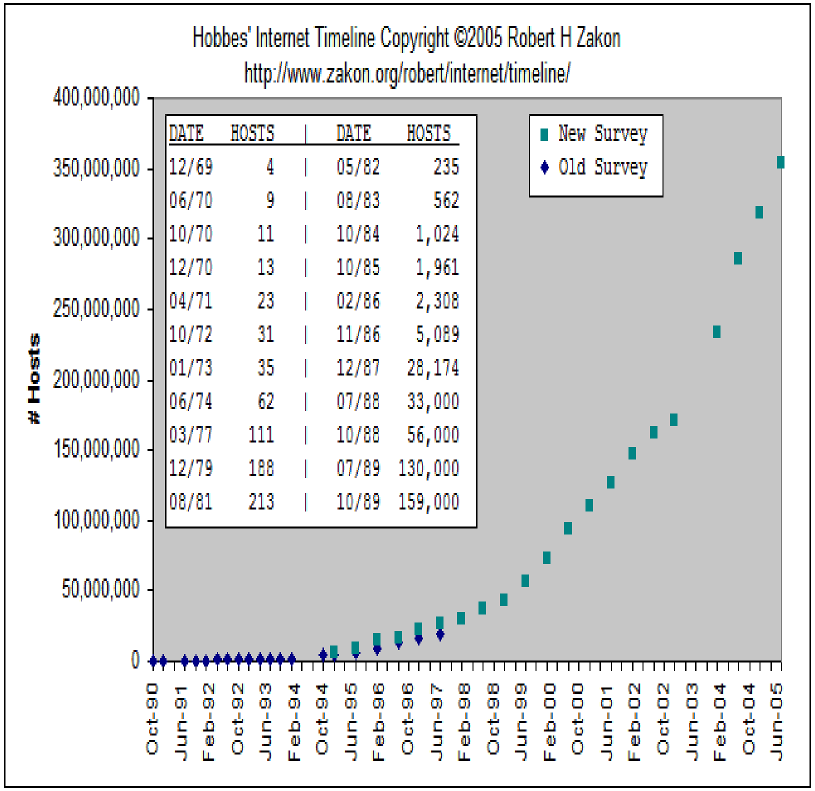


- Big
- Heterogeneity
- Time-varying Behavior

Internet is still growing !

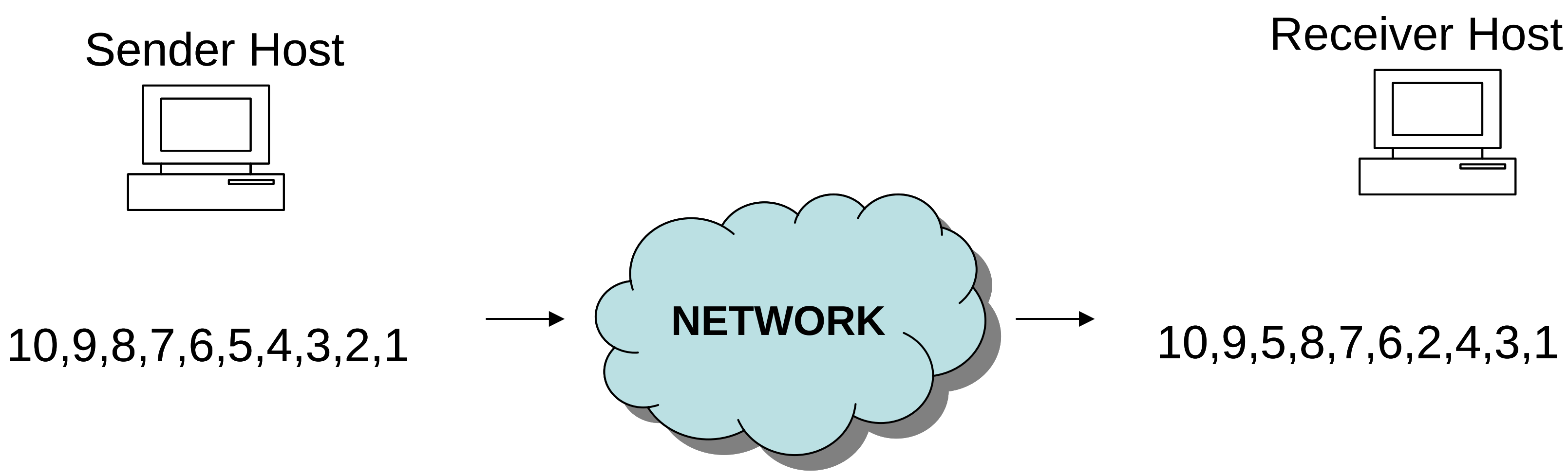
- Internet traffic growth
- Internet hosts growth

Trend	Doubling period
Semiconductor performance	18 months (Moore's law)
Internet traffic (1969-1982)	21 months
Internet traffic (1983-1997)	9 months
Internet traffic (1997 -2008)	6 months



Packet Reordering

- Packet send in order do not reach the receiver in order



Effect of Reordering

- Affects TCP performance
  - Forces TCP into false retransmissions
  - That reduces the congestion window size
  - That reduces the bandwidth utilization

- Affects UDP application performance
  - Applications have to re-sequence packets
  - Affects performance of real-time applications such as IP telephony and live streaming video

Causes of Packet Reordering

- Parallel processing
- Multi-path routing
- Diffserv Scheduling
- Mobile Ad-hoc network

Reorder Density

Packet Reordering: m $(m + d_m)$

Arrival	1	2	4	5	3	7	6
Receive_index	1	2	3	4	5	6	7
Displacement (d_m)	0	0	-1	-1	2	-1	1

- Reorder Event $r(m, d_m)$: If the receive_index assigned to packet m is $(m+d_m)$, with $d_m \neq 0$ then a reordered event $r(m, d_m)$ has occurred
- Earliness/Lateness: A packet is late if $d_m > 0$, and early if $d_m < 0$

Reorder Density – (2)

- Packet Reordering: Packet reordering is completely represented by the union of reorder events,

$$R = \bigcup_m \{ r(m, d_m) \mid d_m \neq 0 \}$$

- For the above sequence R = {(3, 2), (4, -1), (5, -1), (6, 1), (7, -1)}

- D_T : A threshold on the displacement of packets that allows the metric (RD) to classify a packet as lost or duplicate.

Reorder Density – (3)

- Let S[k] be a subset of R s.t.

$$S[k] = \{r(m, d_m) \mid d_m = k\}$$

- Then

$$RD[k] = |S[k]| / N' \text{ for } k \neq 0$$

- Where N' is the total non-duplicate packets received and |S[k]| is cardinality of set S[k].

$$RD[0] = 1 - \sum_{k \neq 0} |S[k]| / N'$$

Properties of RD

- Property 1 :

$$RD[i] \geq 0, \forall i \in Z$$

- Property 2:

$$\sum_i RD[i] = 1$$

- Property 3:

$$\sum_i (i \times RD[i]) = 0$$

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Contribution

- New singleton packet reordering metrics
  - P_L and P_E
  - M_D, M_L and M_E
  - E_R
- Measurement of packet reordering over Internet for 336 hours
- Give the general expression of RD on CNSS problem
- Provide the estimation of E_R on CNSS problem
- Simulation study on the relation between end-to-end packet delay, end-to-end packet reordering and Inter Packet Gap
- Related Publications
  - B. Ye, A. P. Jayasumana and N. M. Piratla, "On End-to-End Monitoring of Packet Reordering over the Internet," Proc. International Conference on Networking and Services (ICNS 2006), Silicon Valley, USA, Jul. 2006 (BibTex).

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Why we need more metrics?

- Long time period observation, capture the variation of packet reordering
- Different angle
- Bridge to an existing theory

Singleton Metrics (1)

- Percentage of Late Packets (P_L)

$$P_L = \sum_{i=+1}^{i=D_T} RD[i]$$

- Percentage of Early Packets (P_E)

$$P_E = \sum_{i=-D_T}^{i=-1} RD[i]$$

Singleton Metrics (2)

- Mean displacement of packets (M_D)

$$M_D = \frac{\left| \sum_{i=-D_T}^{i=D_T} (|i| \times RD[i]) \right|}{\left| \sum_{i=-D_T}^{i=+D_T} RD[i] \right|}$$

Singleton Metrics (3)

- Mean displacement of late packets (M_L)

$$M_L = \frac{\left[\sum_{i=1}^{i=+D_T} (i \times RD[i]) \right]}{\left[\sum_{i=1}^{i=+D_T} RD[i] \right]}$$

- Mean displacement of early packets (M_E)

$$M_E = \left| \frac{\left[\sum_{i=-D_T}^{i=-1} i \times RD[i] \right]}{\left[\sum_{i=-D_T}^{i=-1} RD[i] \right]} \right|$$

Singleton Metrics (4)

- Reorder Entropy (E_R)

$$E_R = (-1) \times \sum_{i=-D_T}^{i=+D_T} (RD[i] \times \log_e(RD[i]))$$

- When

$$RD[i] = \frac{1}{(2D_T + 1)}, i \in [-D_T, D_T]$$

- Maximum E_R :

$$E_R = \log_e(2D_T + 1)$$

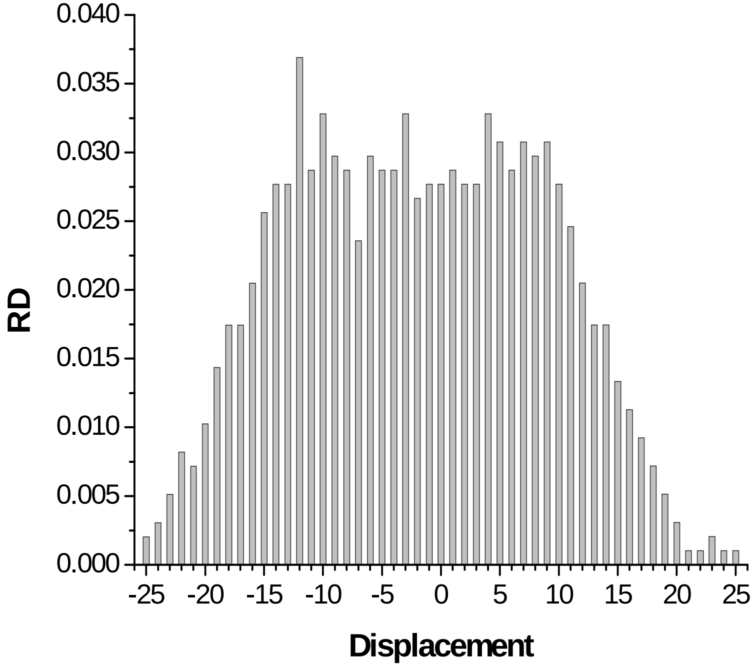
Websites for measurement

Net	Destination	IP address	D	SD	Hop Count
1	ftp.chg.ru	193.233.9.194	181.56	3.68	13
2	ftp.debian.skynet.be	195.238.1.7	135	2	22
3	www.mara.org.za	196.21.144.10	317.36	22.6	17
4	informatics.nic.in	164.100.52.6	334.5	2.5	26
5	www.olympus.co.jp	203.178.83.188	144.56	1.05	13
6	Download.microsoft.com	4.78.212.30	3.78	0.59	9

Note: Mean RTT delay and standard deviation of delay in milliseconds, all the readings are obtained from lamar.colostate.edu at 9:05am (MST) 28th April, 2006.

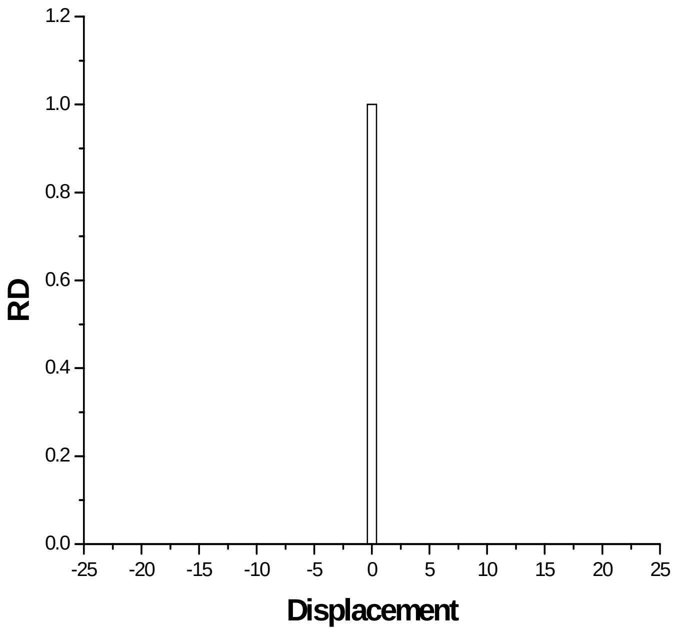
Results (1)

- E_R get the maximum value



Reorder Density on Net-5 observed at 9:52am August 26, 2005 (DT = 25)

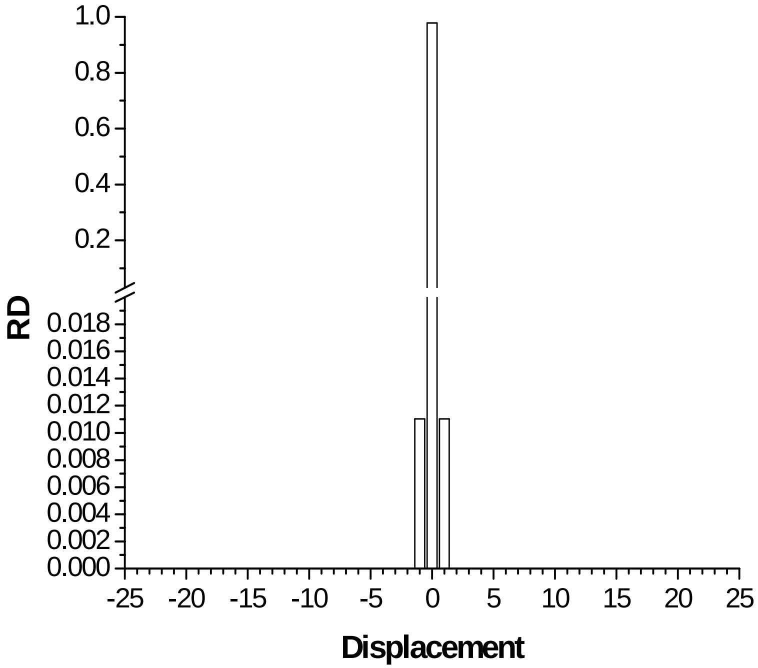
- E_R =0



Reorder Density on Net-5 observed at 8:00am Sep 24, 2005 (DT = 25)

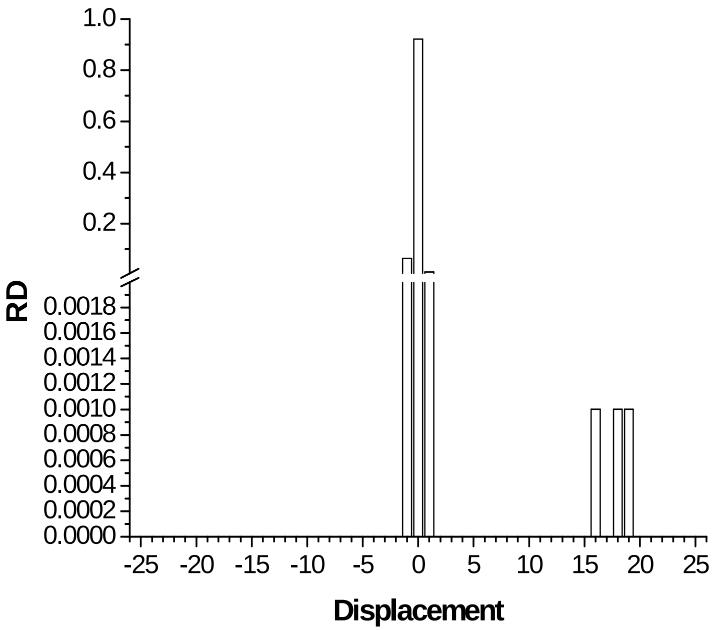
Results (2)

- $M_L = M_E = 1$



Reorder Density on Net-5 observed at 8:00am Sep 24, 2005 (DT = 25)

- $M_L > M_E$



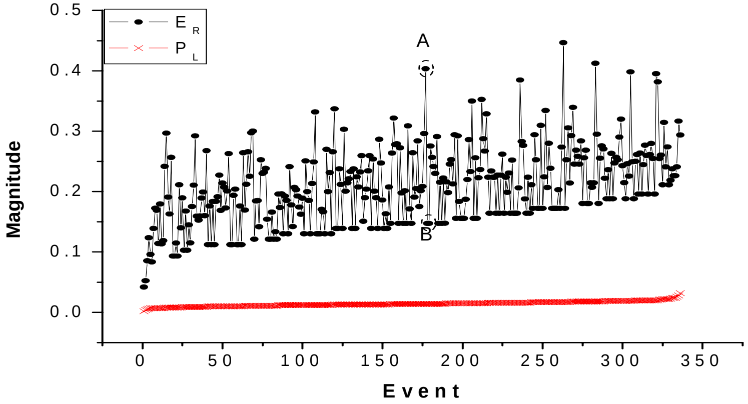
Reorder Density on Net-5 observed at12:00am Sep 24, 2005 (DT = 25)

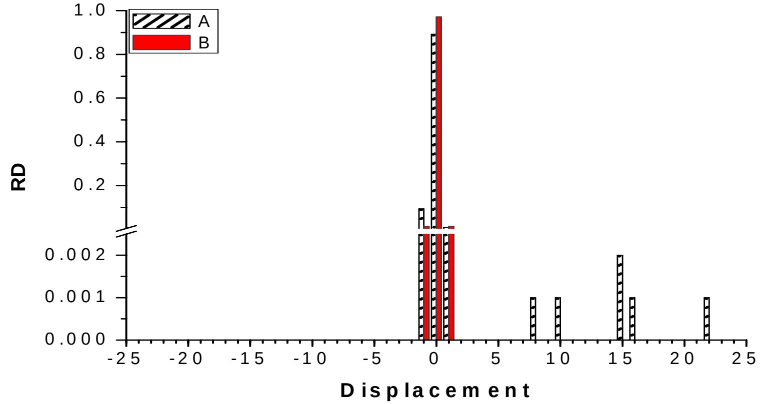
Statistic Data about 5 Websites

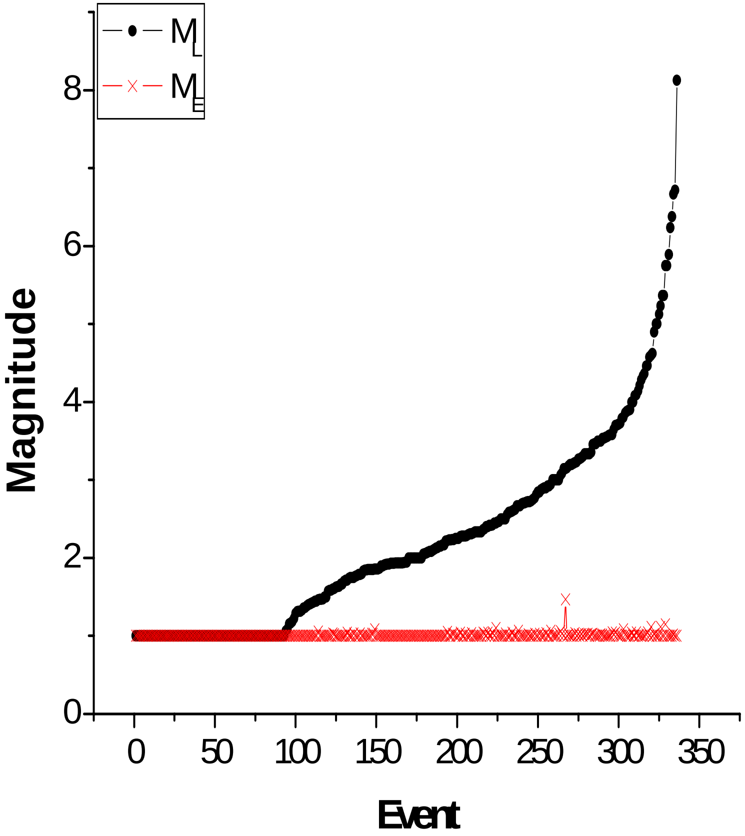
Net	Mean of E_R	Maximize E_R Value	E_R >0	
			Times	Percentage
1	0.20	2.96	236	70.12
2	0.032	0.44	146	43.50
3	0.067	0.84	98	29.00
4	0.091	1.43	120	36.10
5	0.21	0.45	336	100

Note: The total number of measurement for each net is 336 hours(Sep 24 – Oct 8, 2005)

Result – (3)

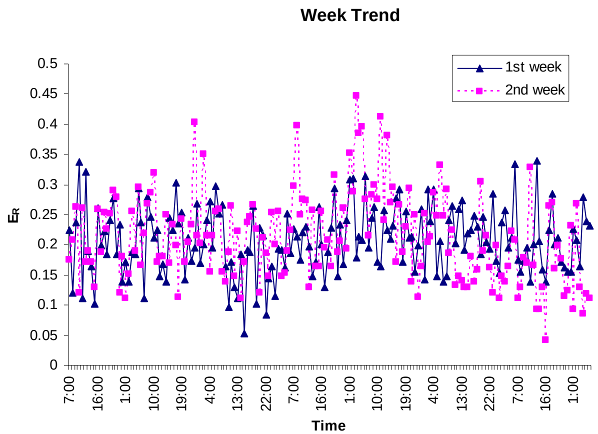


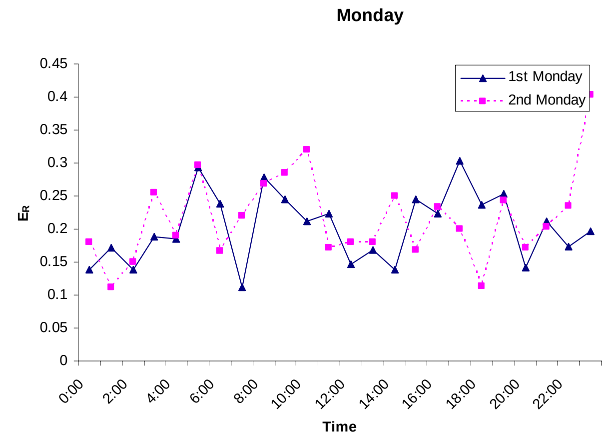


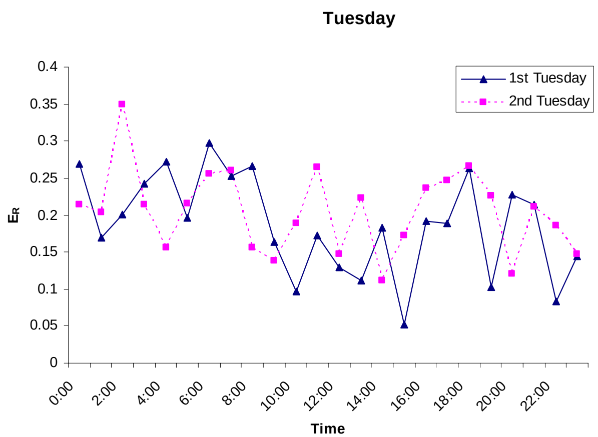


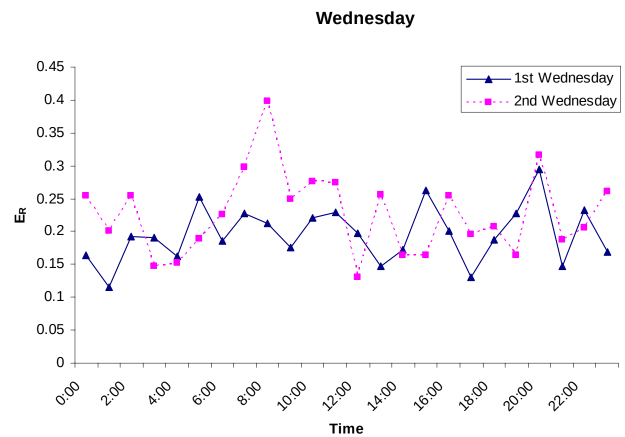
RD of points A and B (A –Oct 3rd 23:00 on Net – 5, B – Oct 4th 23:00 on Net - 5)

Result – (4)









Observation over 2 weeks on Net – 5 (Sep 24 – Oct 8, 2005)

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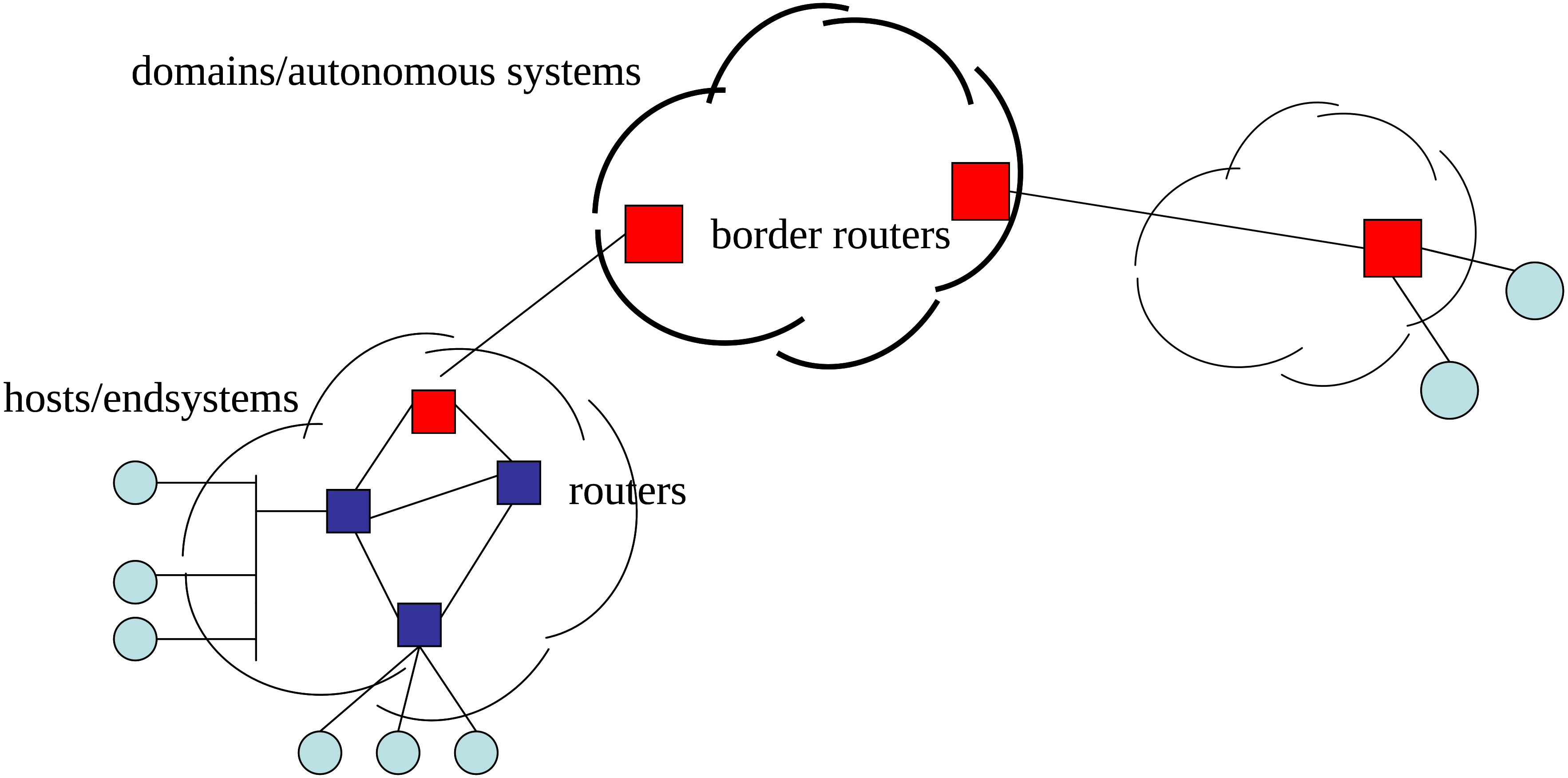
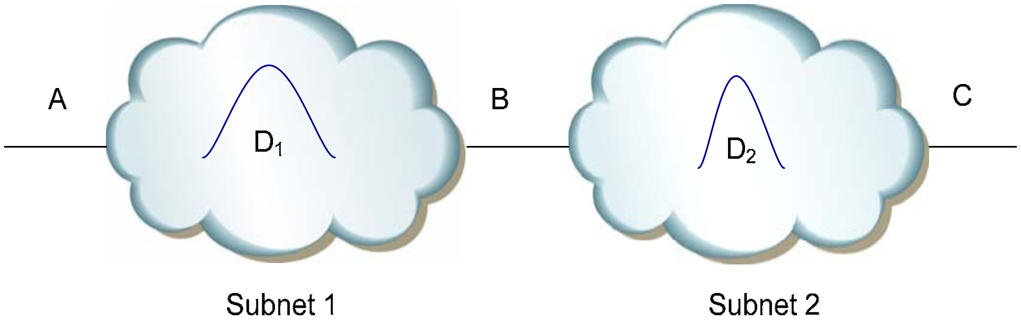
AS Topology View of Internet

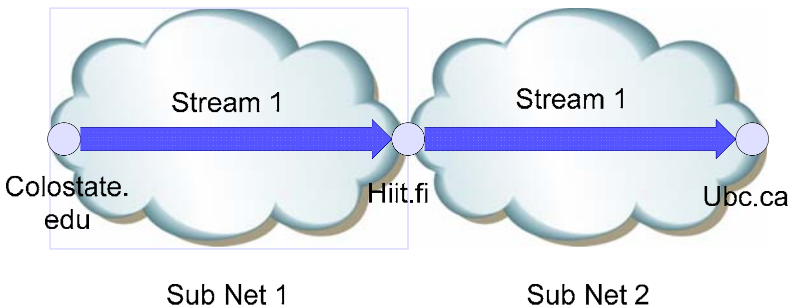


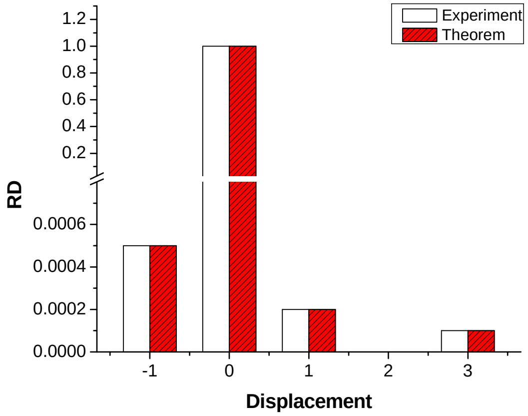
Convolution between 2 subnets

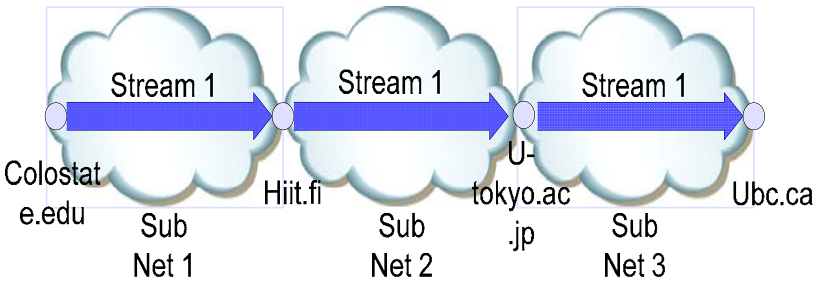
- *Theorem: The reorder response **J**[k] of a network formed by cascading two subnets, with reorder responses **J1**[k] and **J2**[k], respectively, is given by the convolution of J1[k] and J2[k] , i.e., J[k] = J1[k] * J2 [k].*

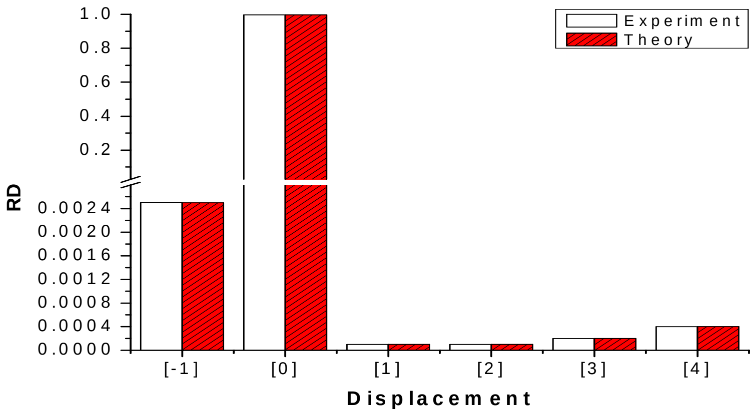


Verification over Internet









CNSS Statement

- Conditions:

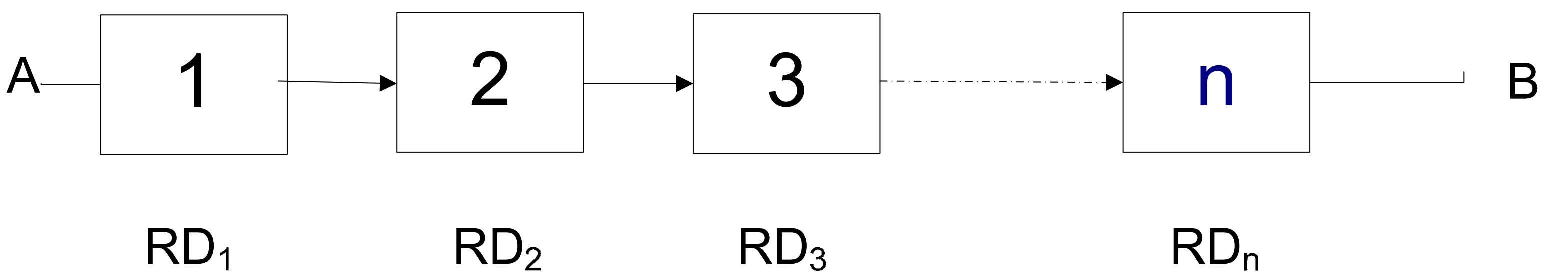
$$RD_i = RD_j, \forall i, j \in Z$$

$$\text{Var}(D_i) = \sigma_0^{\ 2}$$

$$Y = \sum_{i=1}^{n} D_i$$

- Question: Can we evaluate following parameters ?

$$RD^{(AB)} \qquad E_R^{(AB)}$$

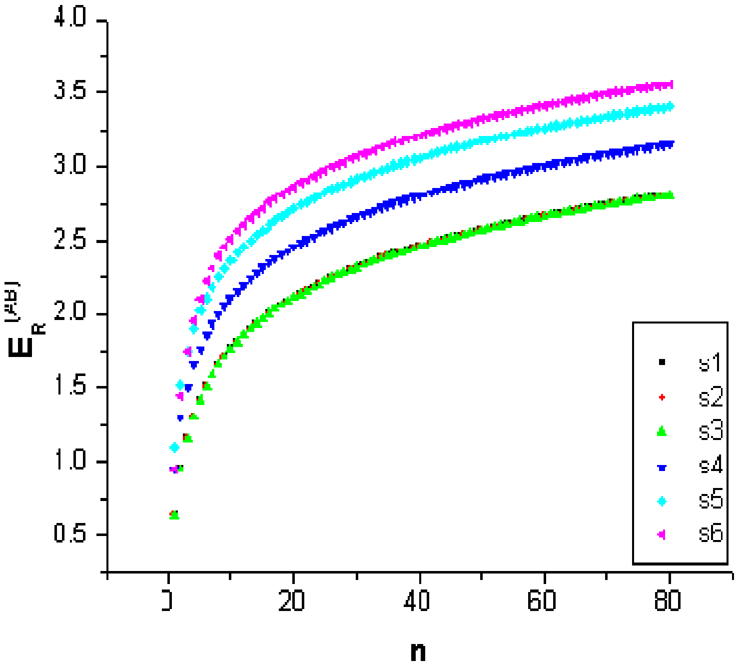


- For RD_i , $P\{D_i = j\} = RD[j], \forall j \in \square, j = -D_T, ..., 0..., D_T,$

Simulation Result On CNSS

- Symmetric Group
- Symmetric means RD is about RD[0]
- n = 80

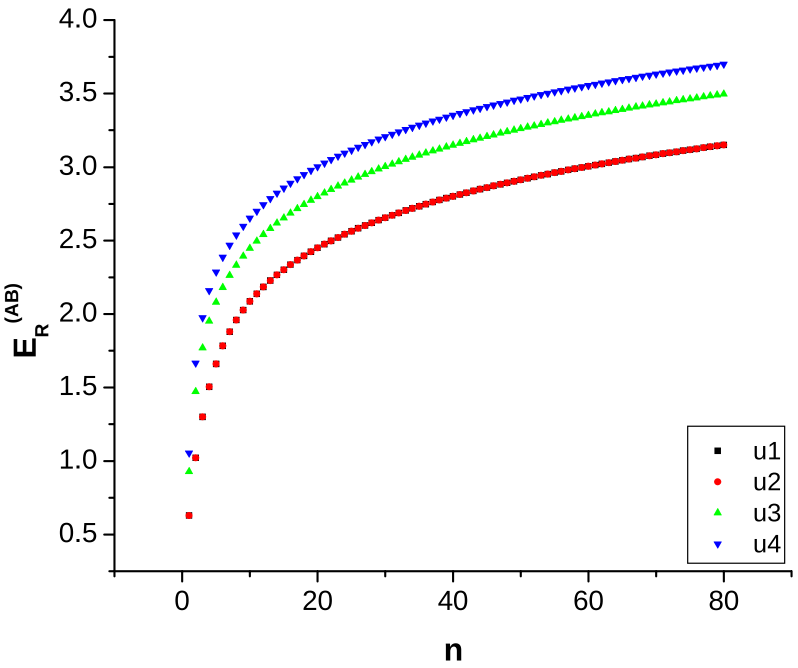
Case Name	-3	-2	-1	0	1	2	3
s1			0.1	0.8	0.1		
s2		0.1	0	0.8	0	0.1	
s3	0.1	0	0	0.8	0	0	0.1
s4			0.2	0.6	0.2		
s5			0.333	0.3334	0.333		
s6			0.45	0.1	0.45		



Simulation Result On CNSS

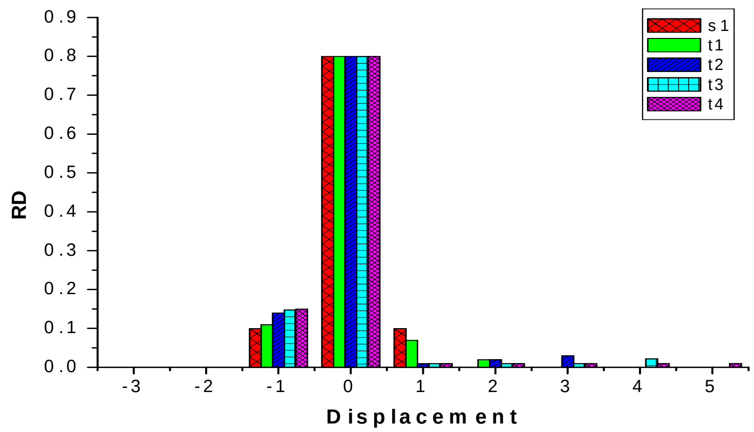
- Asymmetric Group
- n = 80

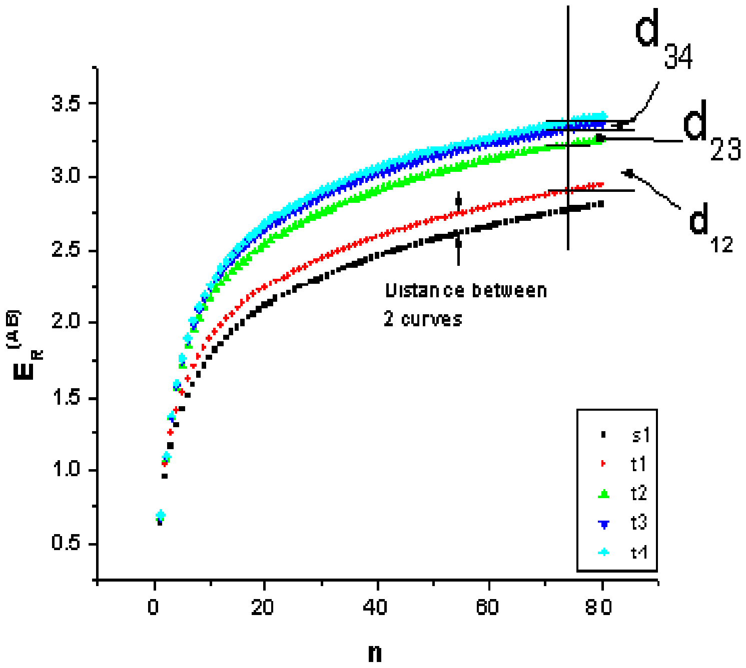
Case Name	-2	-1	0	1	2
u1	0	0.133	0.8	0	0.067
u2	0.067	0	0.8	0.133	
u3	0	0.267	0.6	0	0.1333
u4	0	0.4	0.4	0	0.2



Simulation Result On CNSS

Case Name	-1	0	1	2	3	4	5
s1	0.1	0.8	0.1				
t1	0.11	0.8	0.07	0.02			
t2	0.14	0.8	0.01	0.02	0.03		
t3	0.148	0.8	0.01	0.01	0.01	0.022	
t4	0.15	0.8	0.01	0.01	0.01	0.01	0.01





Theoretical Analysis

- General Expression of RD on CNSS (By generation function express)

$$\sum_{k_1,k_2,k_3,\cdots,k_m} \binom{n}{k_1,k_2,k_3,\ldots,k_m} (RD[-D_T]s^{-D_T})^{k_1} \cdots (RD[0])^{k_i} \cdots (RD[D_T]s^{D_T})^{k_m}$$

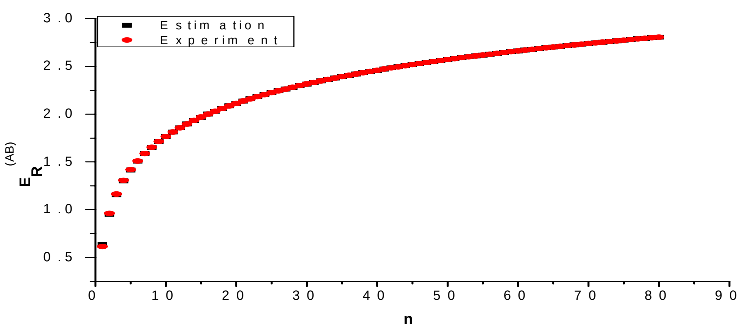
- Where $\sum_{i=1}^{m} k_i = n$ $\binom{n}{k_1,k_2,k_3,\ldots,k_m} = \frac{n!}{k_1!k_2!k_3!\cdots k_m!}$

- Estimate of Reorder Entropy on CNSS

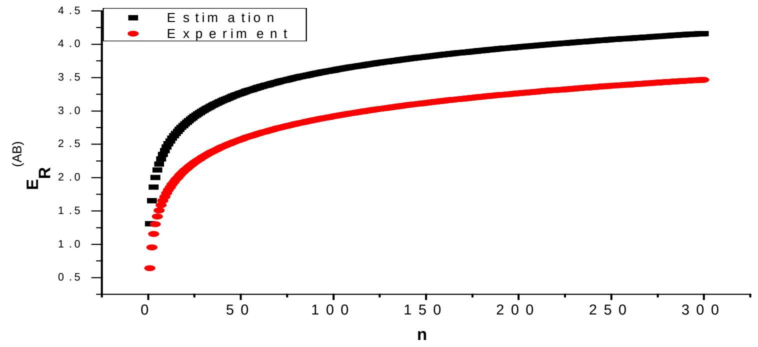
$$E_R^{(AB)} = \frac{1}{2} + \frac{1}{2}(\ln 2\pi) + \frac{1}{2}(\ln n) + \ln(\sigma_0)$$

Comparison

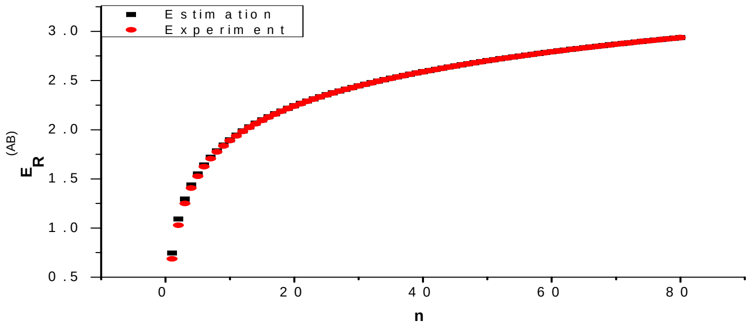
- s1



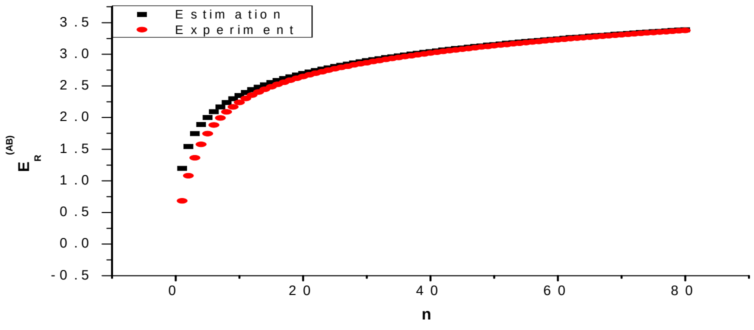
- s2



- t1



- t4



Estimation on RD[0]

$$RD[0] = P(Y > 0) - P(Y > 1)$$

$$= \Phi(\frac{1 - nm}{\sigma_0 \sqrt{n}}) - \Phi(\frac{0 - nm}{\sigma_0 \sqrt{n}})$$

$$= \Phi(\frac{1}{\sigma_0 \sqrt{n}}) - \Phi(0)$$

Case Name	s1	s2	s4	t1	t2	u4
Estimation value of RD[0]	0.099	0.049	0.070	0.087	0.060	0.0398
Experimental value of RD[0]	0.100060103	0.100060103	0.070469	0.087906	0.063559	0.040598

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Simulation Parameters

- Gamma Distribution
- BestFit 4.0 generate the Independent packet delay
- Use Reorder Entropy to evaluate packet reordering
- Changing the Inter Packet Gap
- Strategy

- Gamma Distribution

$$f(x;k,\theta) = x^{k-1}\frac{e^{-\frac{x}{\theta}}}{\theta^k\Gamma(k)}, \forall x > 0$$

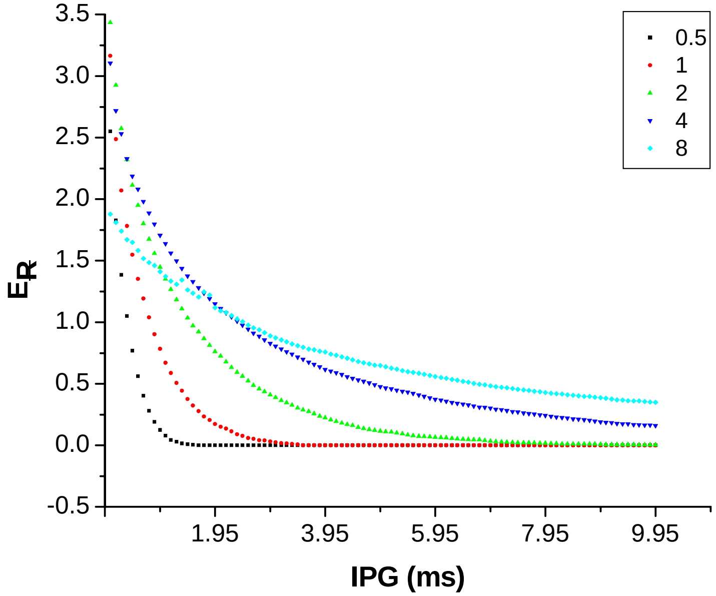
- Parameters

Parameters	Expression
Mean	$k\theta$
Variance	$k\theta^2$
Coefficient of Variation	$\frac{1}{\sqrt{k}}$

Simulation Result

- Gamma-distribution parameters for Group 1 with fixing the mean at a constant value of 1008 millisecond (ms)

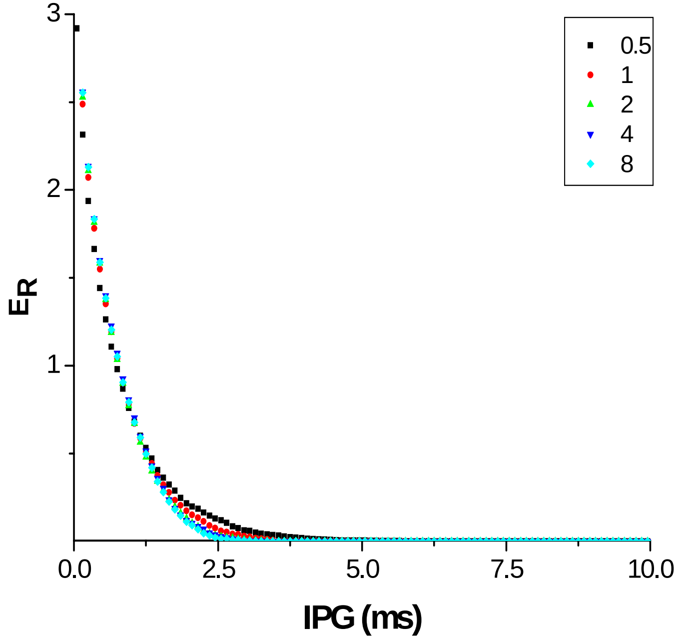
Mean Constant	Target Standard Deviation change ratio	Target Standard deviation	K	θ
1007.86358	0.5	307.6417232	10.7328	93.905
1007.86358	1	615.2834464	2.6832	375.62
1007.86358	2	1230.566893	0.6708	1502.48
1007.86358	4	2461.133786	0.1677	6009.92
1007.86358	8	4922.267571	0.041925	24039.68



Simulation Result

- Gamma-distribution parameters for Group 2 with fixing the SD at a constant value of 615 millisecond

Constant Standard Deviation	Target Mean change ratio	Target Mean	K	θ
615.283446	0.5	503.931792	0.6708	751.24
615.283446	1	1007.863584	2.6832	375.62
615.283446	2	2015.727168	10.7328	187.81
615.283446	4	4031.454336	42.9312	93.905
615.283446	8	8062.908672	171.7248	46.9525



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Summary

- Some Internet path display the weekly and daily trend on packet reordering, where others are in random. Packet reordering is time varying
- Give the general expression of Reorder Density on CNSS and Estimation of Reorder Entropy of CNSS
- Simulation on IPG, packet delay and packet reordering, shows that higher SD of end-to-end packet delay results in a higher level of packet reordering. For the same packet delay distribution, the level of packet reordering decreases with the increase in Inter Packet Gap.

Future

- Could the Internet be an application of existing theory about entropy ?
- Is it possible to predict the network condition by packet reordering?

- Questions ?
- Thank You