Simulating Information Transmission Process within Information Networks

Investigate the Robustness of Information Networks

CSE 6730 Project 2

Team 18

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Motivation

- Information is useable data, inferences from data, or data descriptions [1].
- Information exchange is critical for the performance of many networked systems, such as Internet, airline networks, emergency response systems etc [2].

- Congestion robustness, one desired performance indicators, is defined as the ability of a network to protect its component systems from information overload [2-11].
- To understand the dynamics of information exchange is the first step towards congestion robust network design.

Related Work and Simulation Object

- Three methods to investigate information transmission dynamics:
  - Analytical
  - Simulation
  - Hybrid
- Z. P. Hu etc. [12-14] investigated the effects of network structures, packet information generation rate, routing plans, and queue types and disciplines on the information exchange dynamics through simulation.
- Throughout, a congestion robust network implies the network should be relatively insensitive to changes in above mentioned factors, such as traffic fluctuations.
- This simulation study is based on the work of Z. P. Hu etc. [12-14] to investigate the congestion behaviors of different information networks considering traffic fluctuations through simulating the internal information transmission processes.

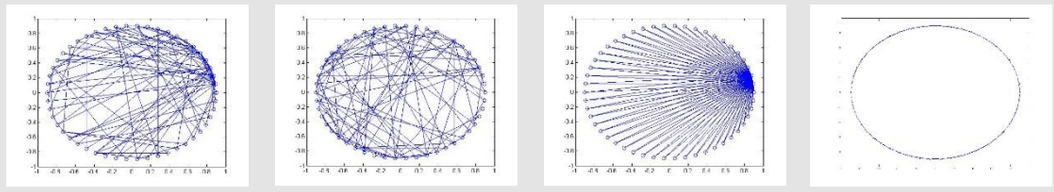
Factors Affecting Info Exchange Dynamics

- Packet generation rate
- Information processing behaviors
  - Queue capacity
  - Queue principle
  - Information transmit rate
- Information distribution behaviors within a network
  - Probability of information exchange existing between a node pair: Uniform
  - Probability of a information exchange path to include a particular node
    - Star-like
    - Scale Free
    - Random
    - Ring Lattice

Project Architecture

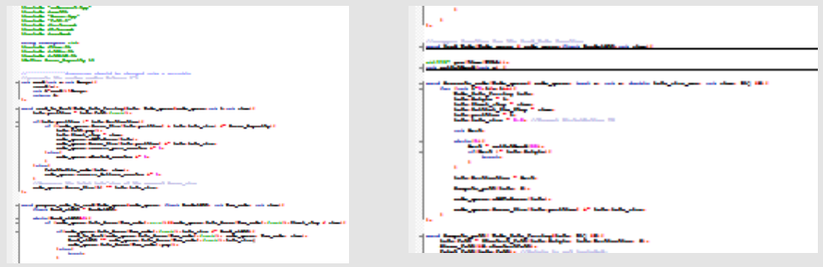
Georgia Tech

Network Module



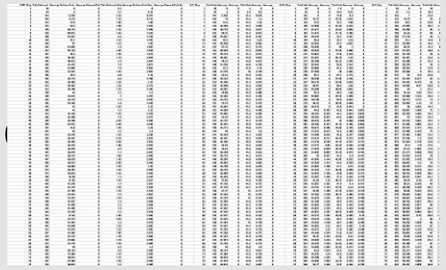
C++

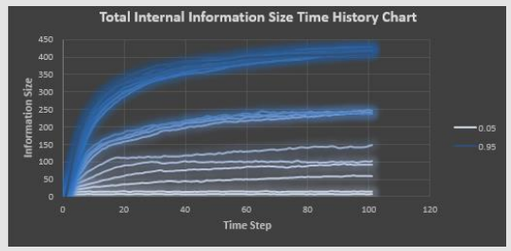
Simulation Module



MATLAB

Analysis Module

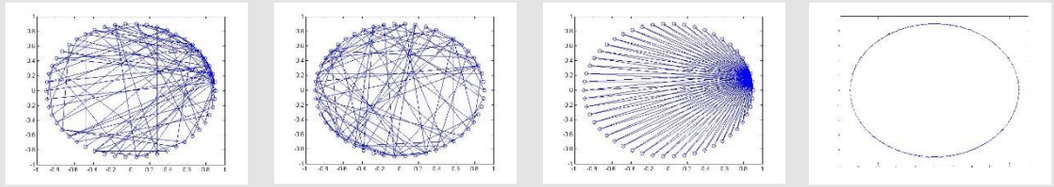




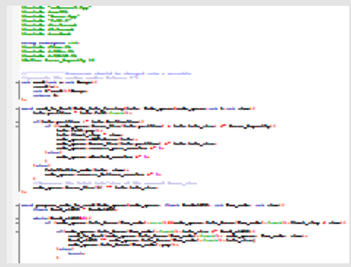
VBA

Network Module

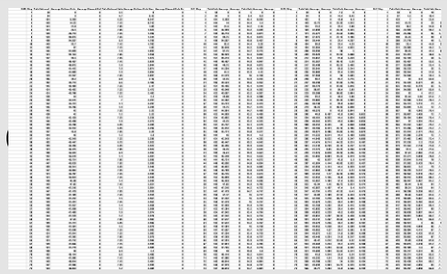
Network Module

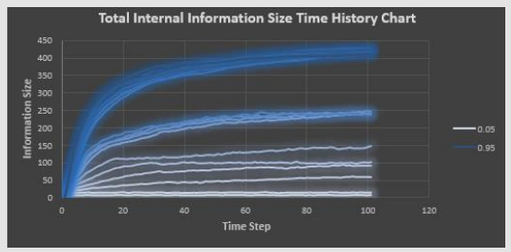


Simulation Module



Analysis Module

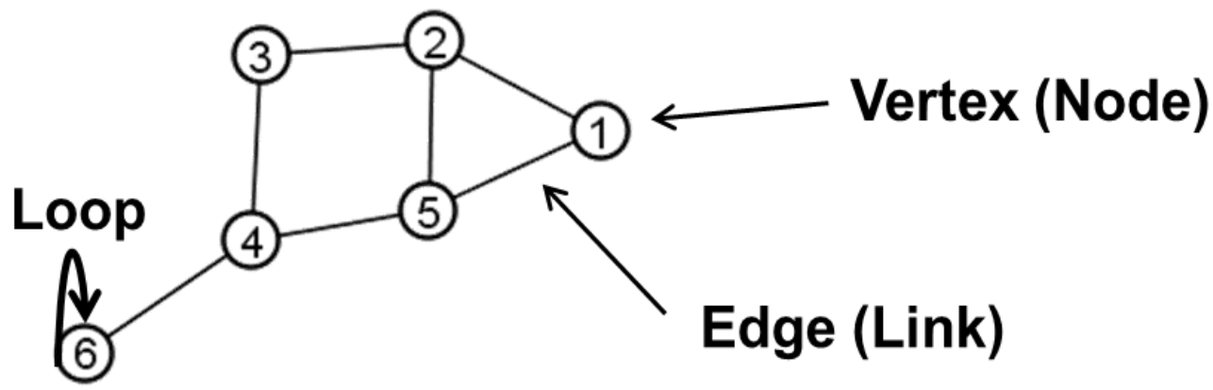


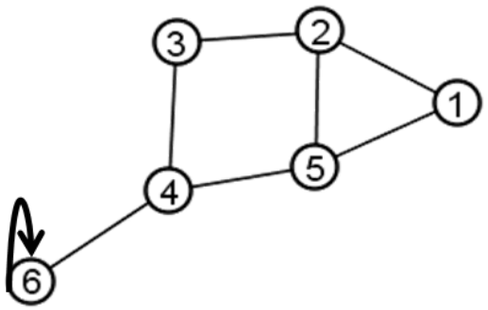


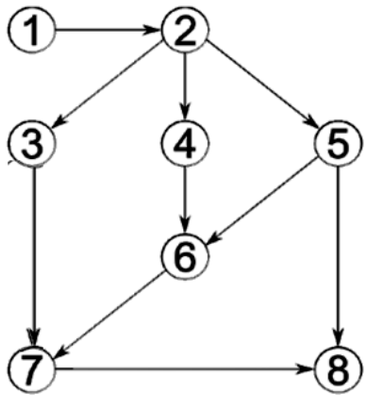
Network Topology

G = (V,E)

V = {1,2,3,4,5,6}
E = {(1,2),(1,5),(2,3),(2,5),(3,4),(4,5),(4,6)}





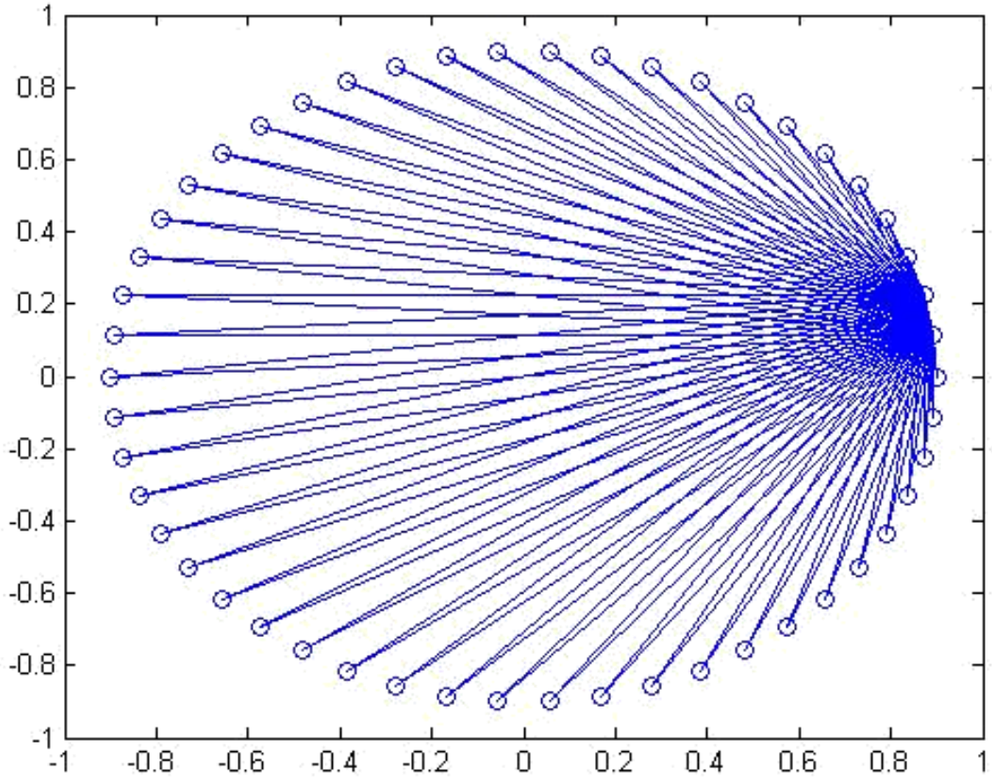


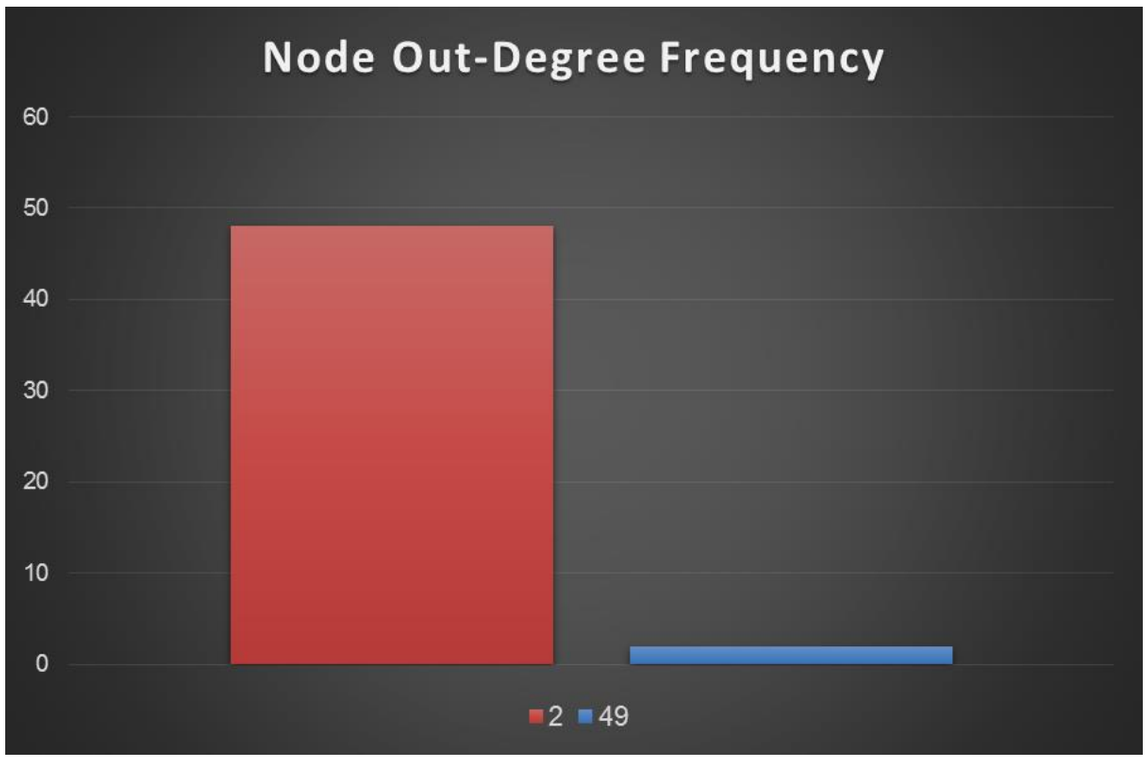
	1	2	3	4	5	6	7	8
1		1			1			
2	1		1					
3		1						
4					1	1		
5	1			1				
6				1		1		
7								
8								

	1	2	3	4	5	6	7	8
1		1						
2			1	1	1			
3							1	
4						1		
5						1		1
6							1	
7								1
8								

Network Models and Topologies

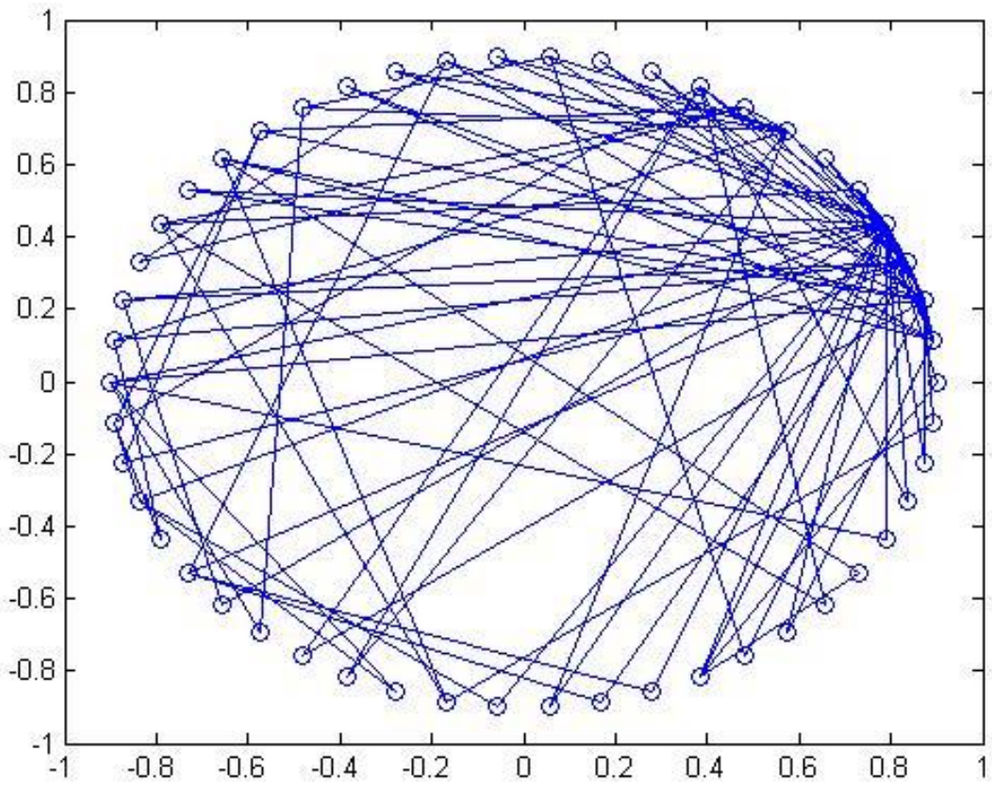
- Star-like Network (Star)
  - 2 “stars” are connected to each other and all the other 48 nodes are only connected to the two stars.
  - 50 nodes, 97 links

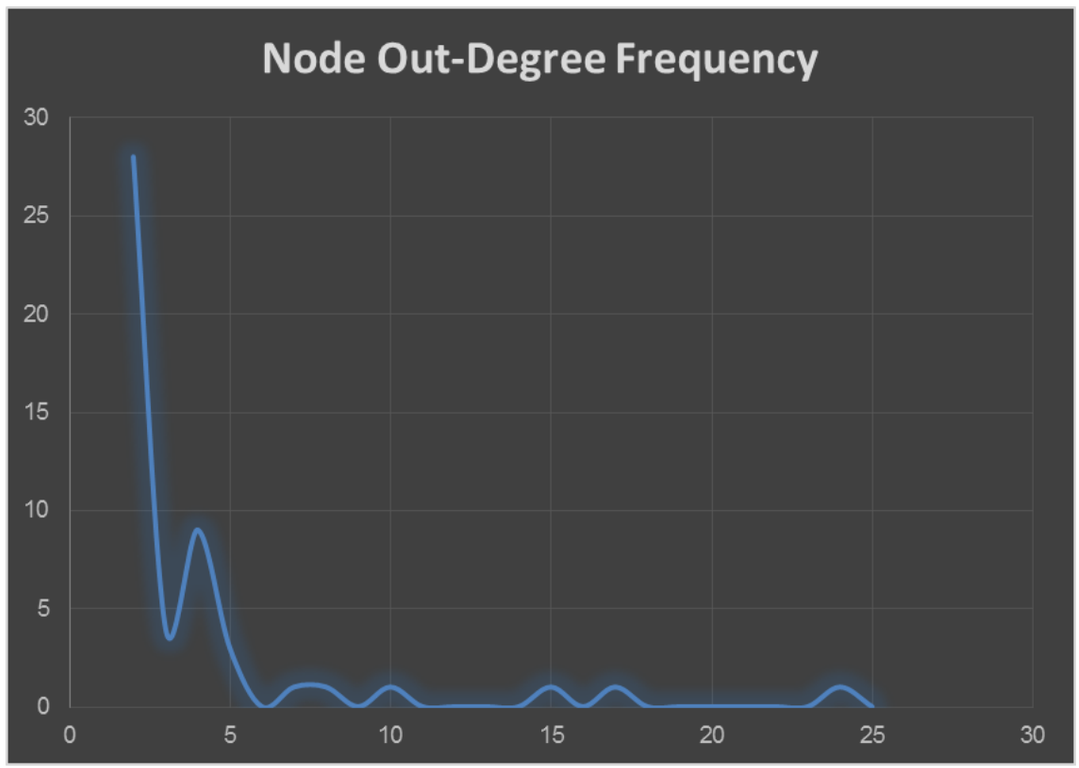




Network Models and Topologies

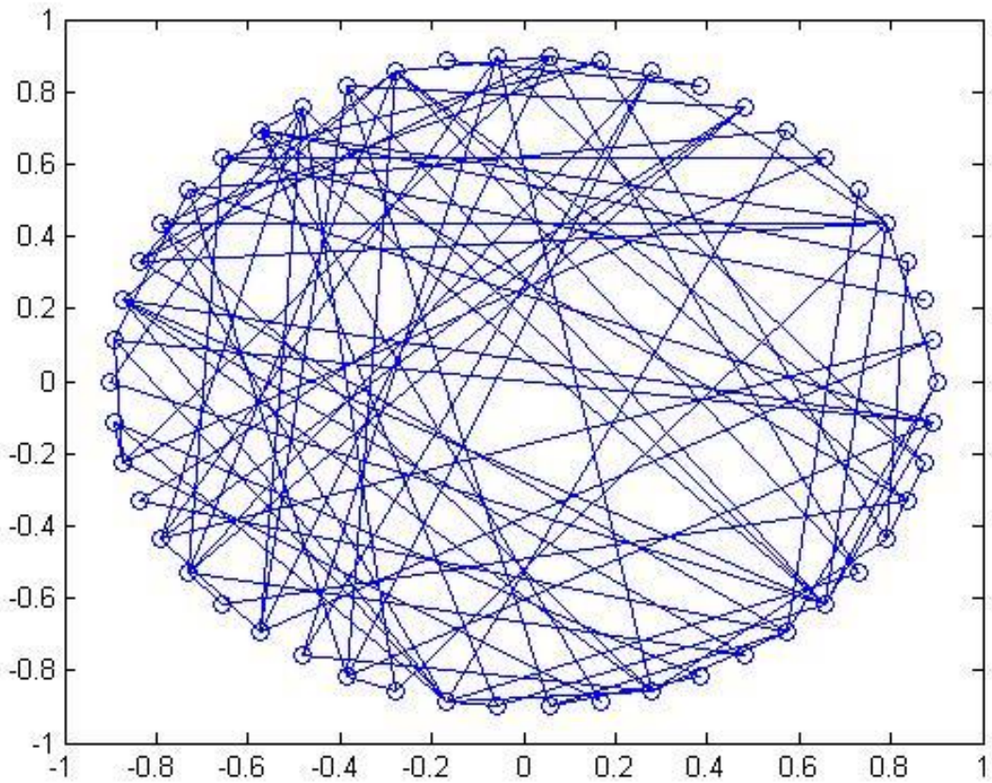
- Scale Free Network (SF)
  - Barabasi-Albert (BA) preferential attachment model [17]
  - 50 nodes, 100 links

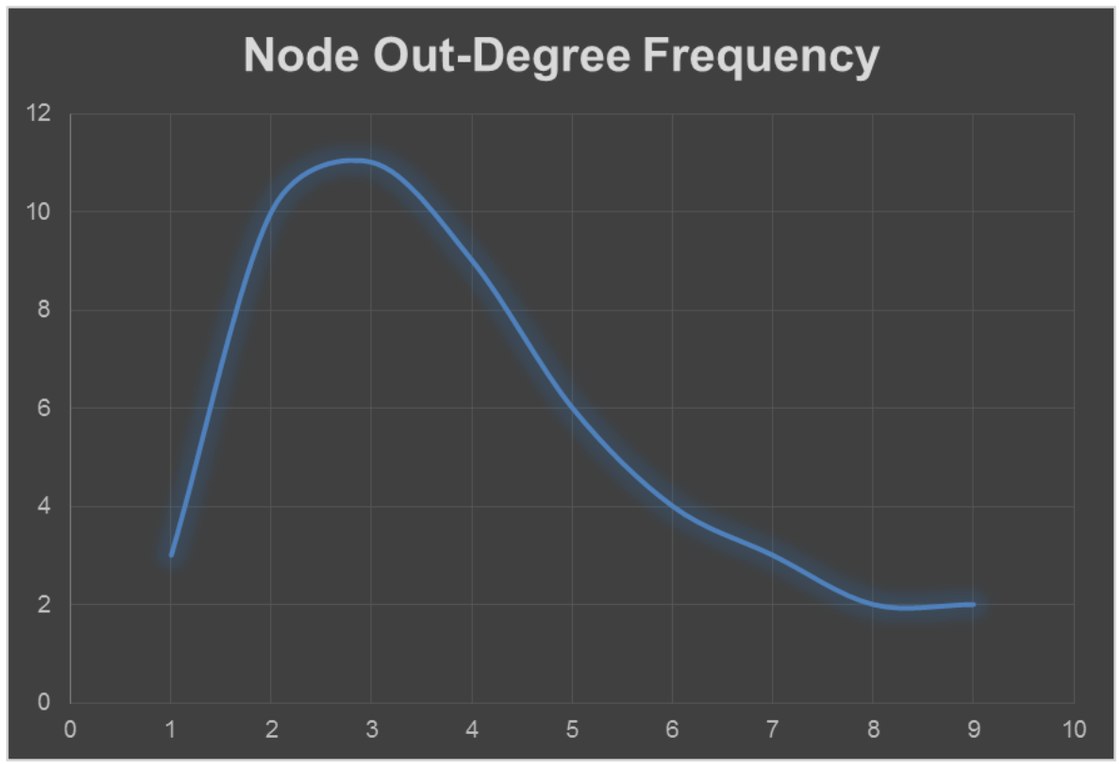




Network Models and Topologies

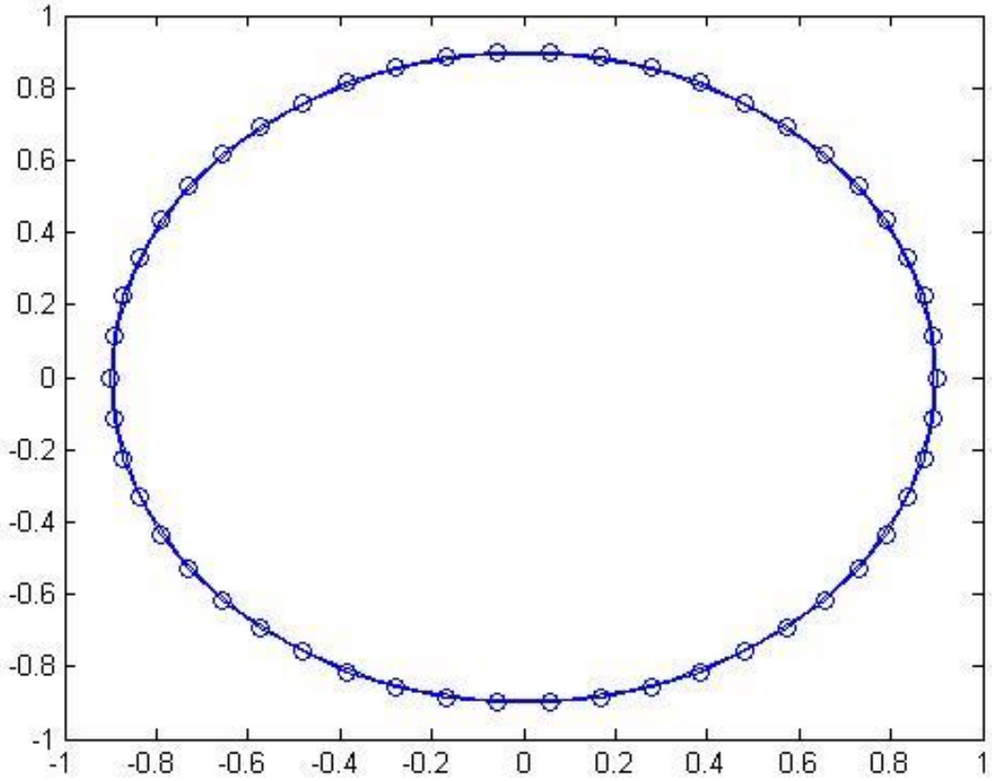
- Random Network (Rand)
  - Erdos-Renyi (ER) network model [18]
  - 50 nodes, 100 links

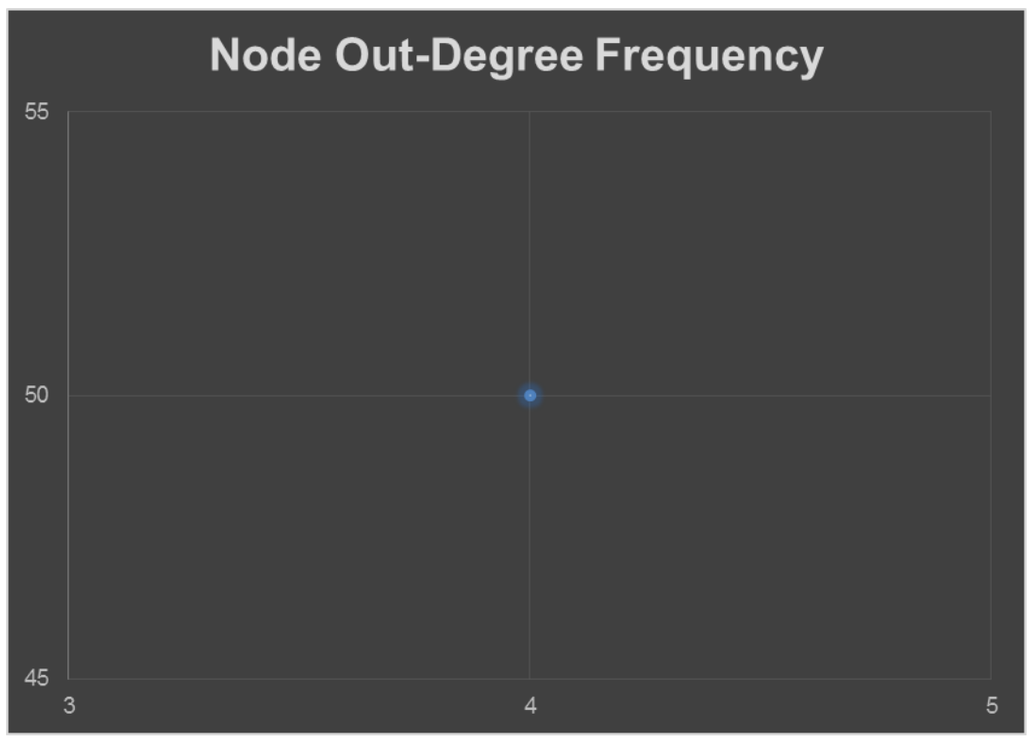




Network Models and Topologies

- Ring Lattice Network (Ring)
  - All the nodes have the same degree
  - 50 nodes, 100 links





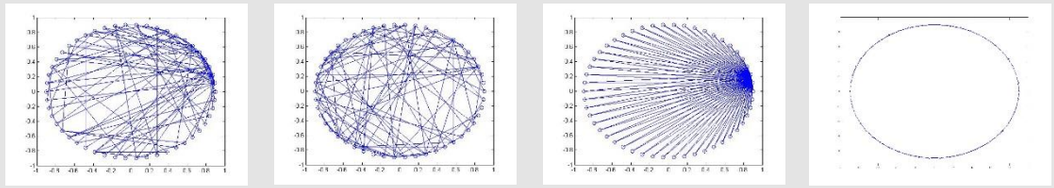
Network Model Metrics

- Structural Betweenness Polarization: $\pi_\beta = \frac{\beta_{max} - <\beta>}{<\beta>}$
- Structural Betweenness: β
- Average Shortest Path Length: $< D >$

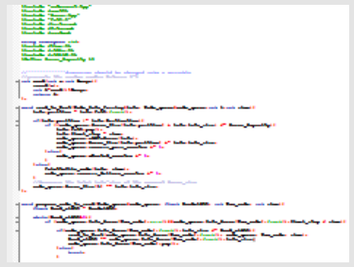
Network Topology Metrics		
	π_β	$< D >$
Star	7.57	1.92
SF	5.06	2.48
Rand	1.38	2.92
Ring	0	6.63

Simulation Module

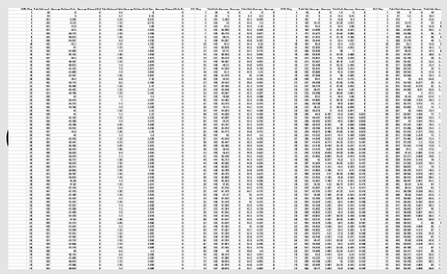
Network Module

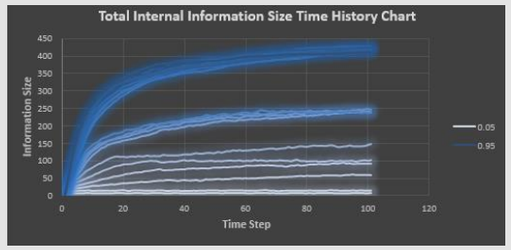


Simulation Module

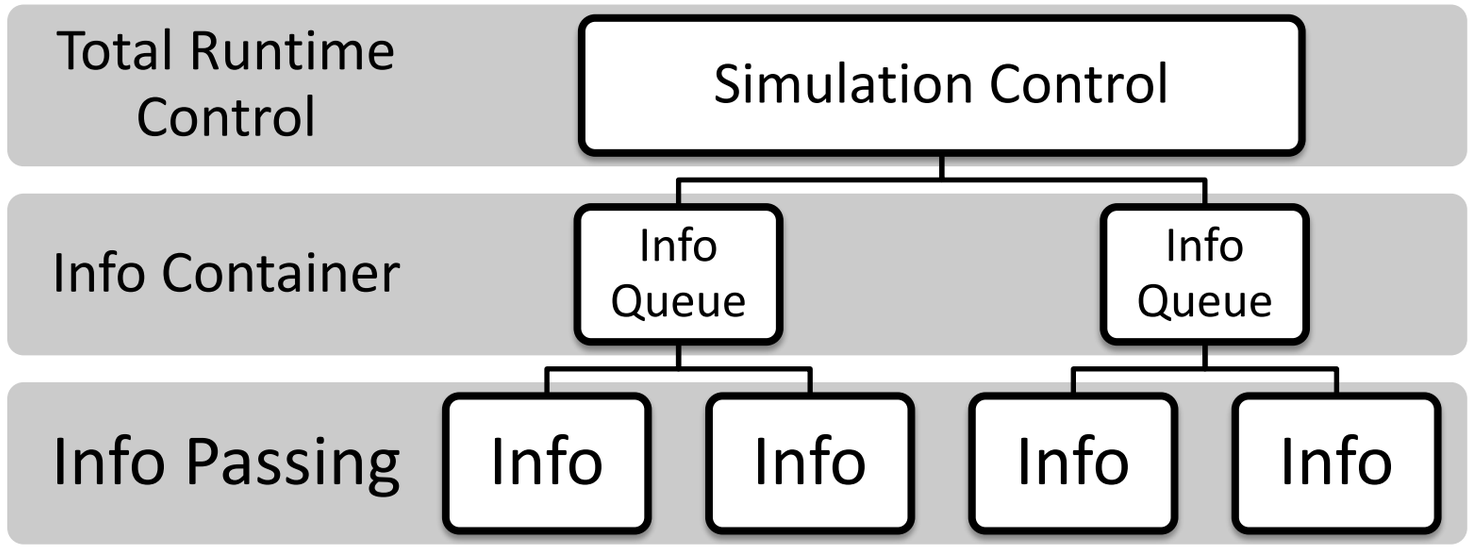


Analysis Module





Networks Modules Overview



- **Simulation Control:**
  1. Control the Simulation Overall run time
  2. Initializing the Graph for path calculation
  3. Determine the parameters read from file and input
  4. Determine the communication protocol for info sending and receiving
- **Info Queue:**
  1. Container for holding info
  2. State parameter which would pose influence on the info sending
- **Info:**

  Info Container for the simulation, containing Origin, Dest, Path, step ect. info

Assumptions

Information:

- Undividable information
  - A packet can only be sent as a whole at once
- No information addition or loss during transmission unless absorbed or discarded

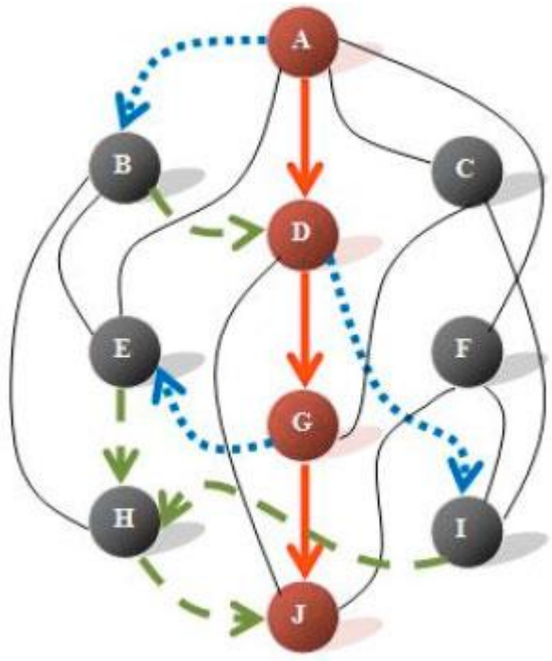
Node:

- Ignore the time required to process information.
- The information transmission time between any adjacent nodes is the same.

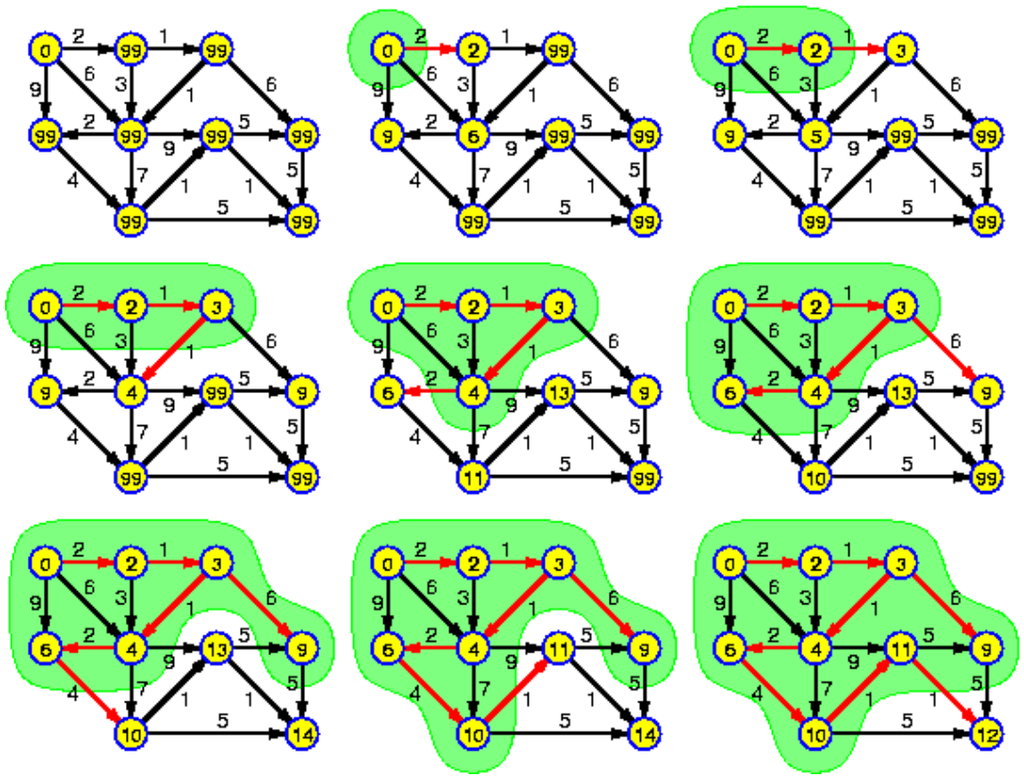
Simulation Settings

- Packet generation rate λ_i: Uniform, Normal Distribution (0,1)
- Information processing behaviors
  - Queue capacity: Limited, 10
  - Queue principle: FIFO
  - Information transmit rate: 1
- Information distribution behaviors within a network
  - Probability of information exchange existing between a node pair: Uniform: Uniform
  - Probability of a information exchange path to include a particular node: Shortest Distance, Network Topology (50 nodes 100 links)
    - Star-like
    - Scale Free
    - Random
    - Ring Lattice

PATH CALCULATION



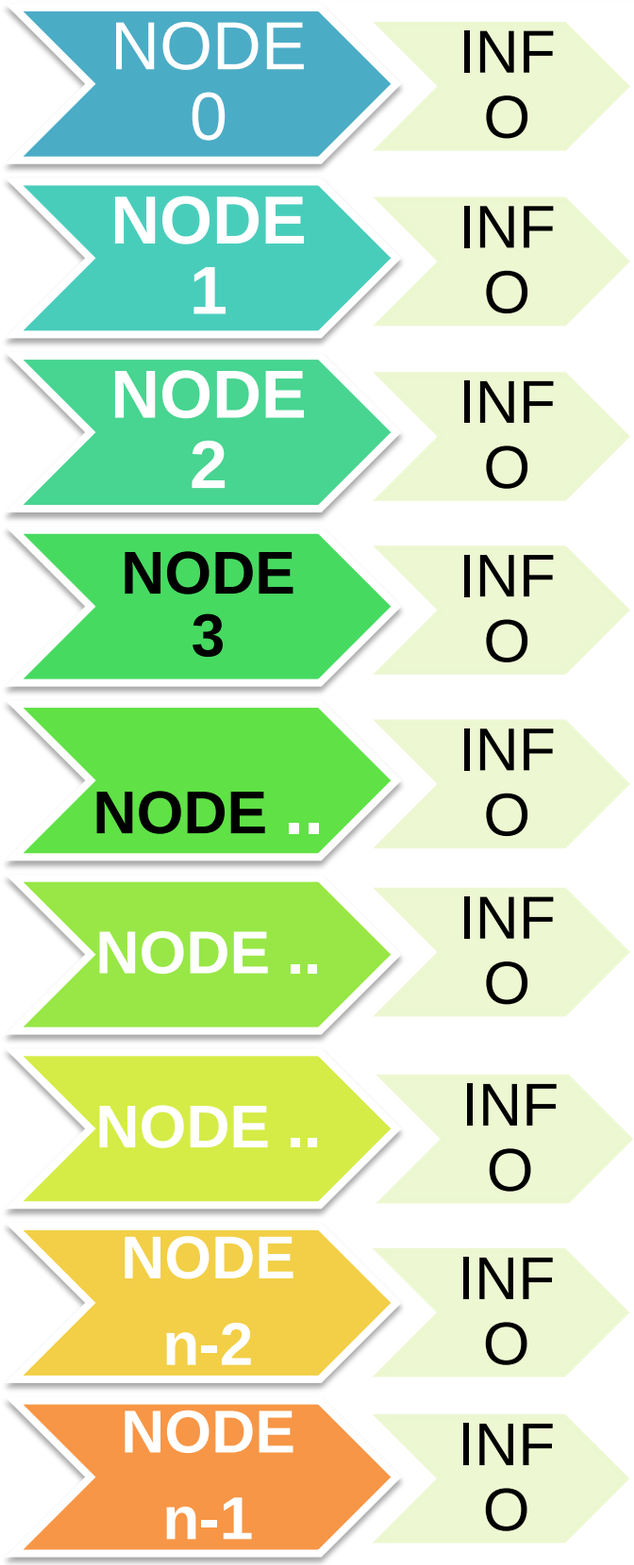
DIJKSTRA'S ALGORITHM



Path Determination:

- Dijkstra's algorithm to determine the shortest path
- Retrieve the path and assign to t he Info's path.
- Each step pop out the first eleme nt of the path to determine the In fo's next Destination

COMMUNICATION PROTOCOL



Communication Protocol:

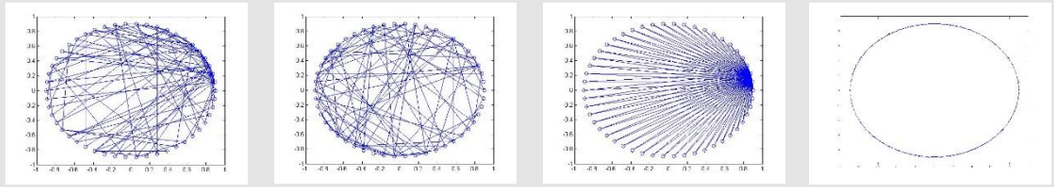
- **Each Node generate 1 piece of info per round**
  1. Mainly concentrate on the topologies' effect

- **Info send to the node according to the bandwidth**
  1. Limit the number of Info each node could send per simulation step
  2. Simulate the real Network bandwidth and its effect on the information transmission

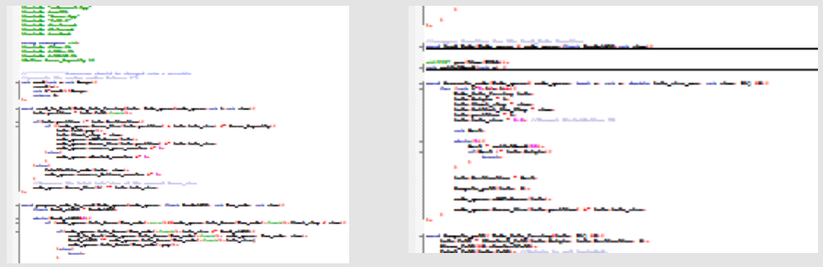
- **Node receive the info according to its capacity**
  1. If capacity allows, add to the node's queue
  2. If not, discard the info

Analysis Module

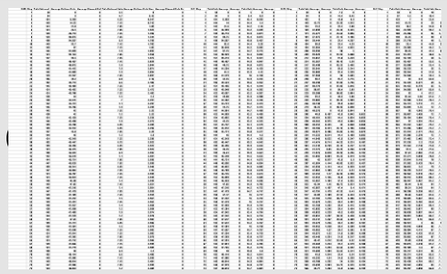
Network Module

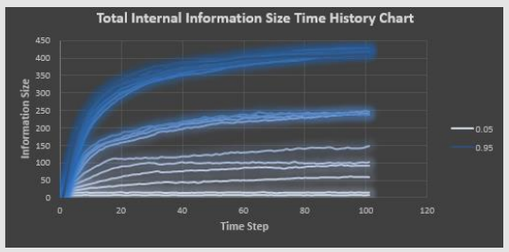


Simulation Module



Analysis Module





Characterize the Performance

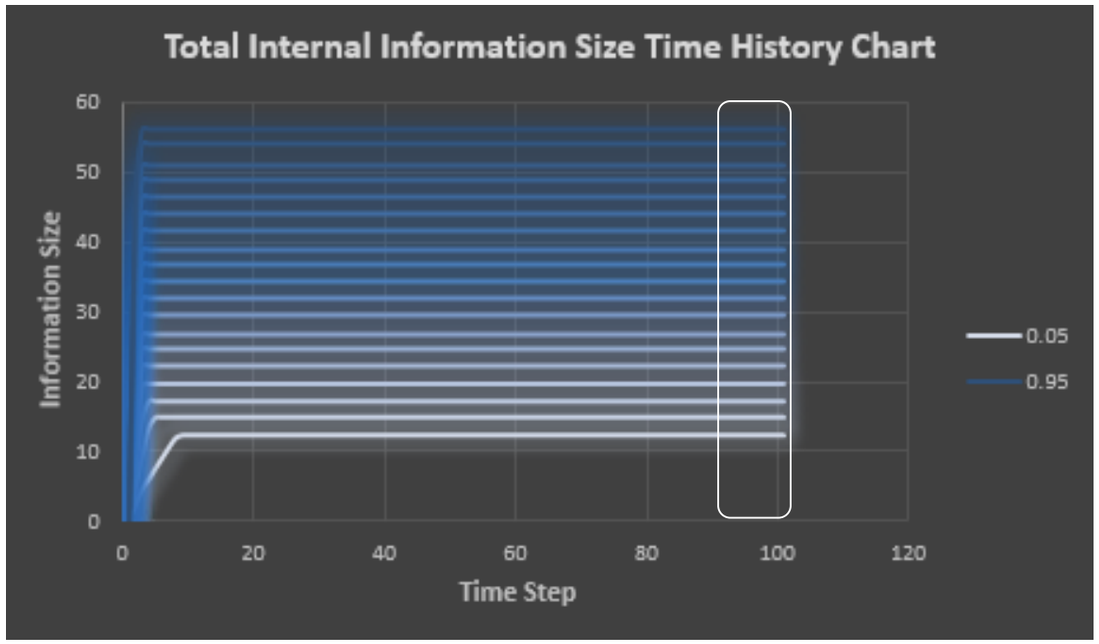
Four Performance Metrics [12-14]:

1. Total internal information size at time stamp t: $N(t)$
   - The total amount of information within a network at time stamp t.
2. Average delivery rate size: $O(t)$
   - The size of information delivery rate averaged from time stamp 0 to time stamp t.
3. Average discard rate size: $L(t)$
   - The size of information discard rate averaged from time stamp 0 to time stamp t.
4. Average deliver time: τ(t)
   - The time for a packet information to be delivered averaged from time stamp 0 to time stamp t.

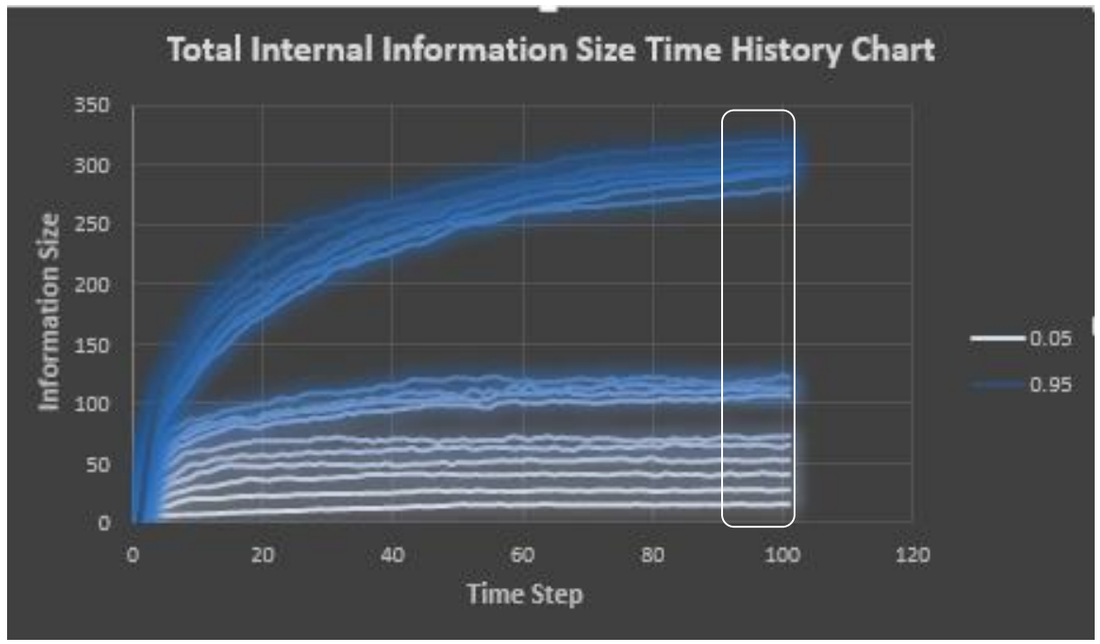
Three Hypothetical States [12-14]:

1. Light traffic state
   - $N(t)$ is small and remains almost unchanged as λ (output packet size) increases
2. Moderate congestion state
   - $N(t)$ increases as λ increases and stays on a moderate level
3. Heavy congestion state
   - $N(t)$ continuously increases as λ increases and stays on a very high level

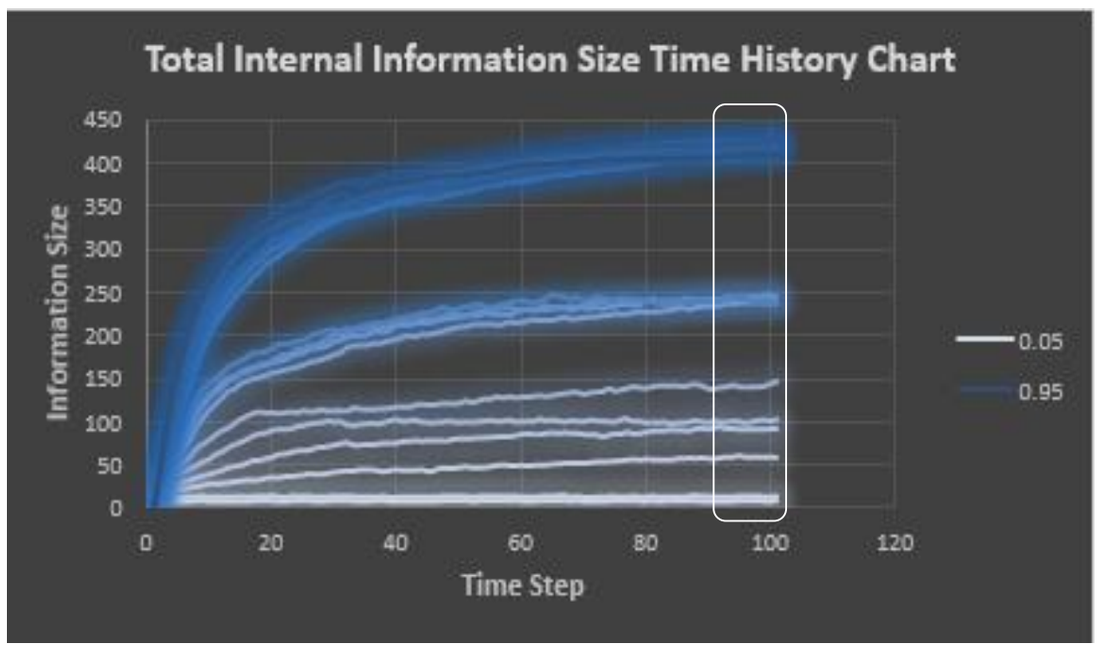
Output Analysis: Uniform Distribution



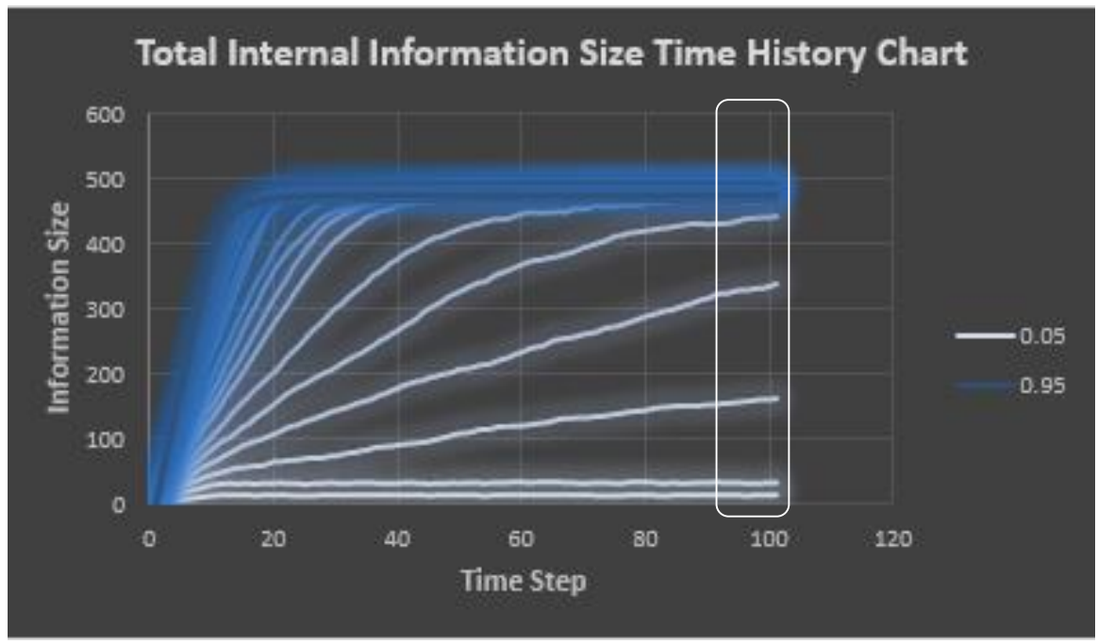
Star-like Network



Scale Free Network

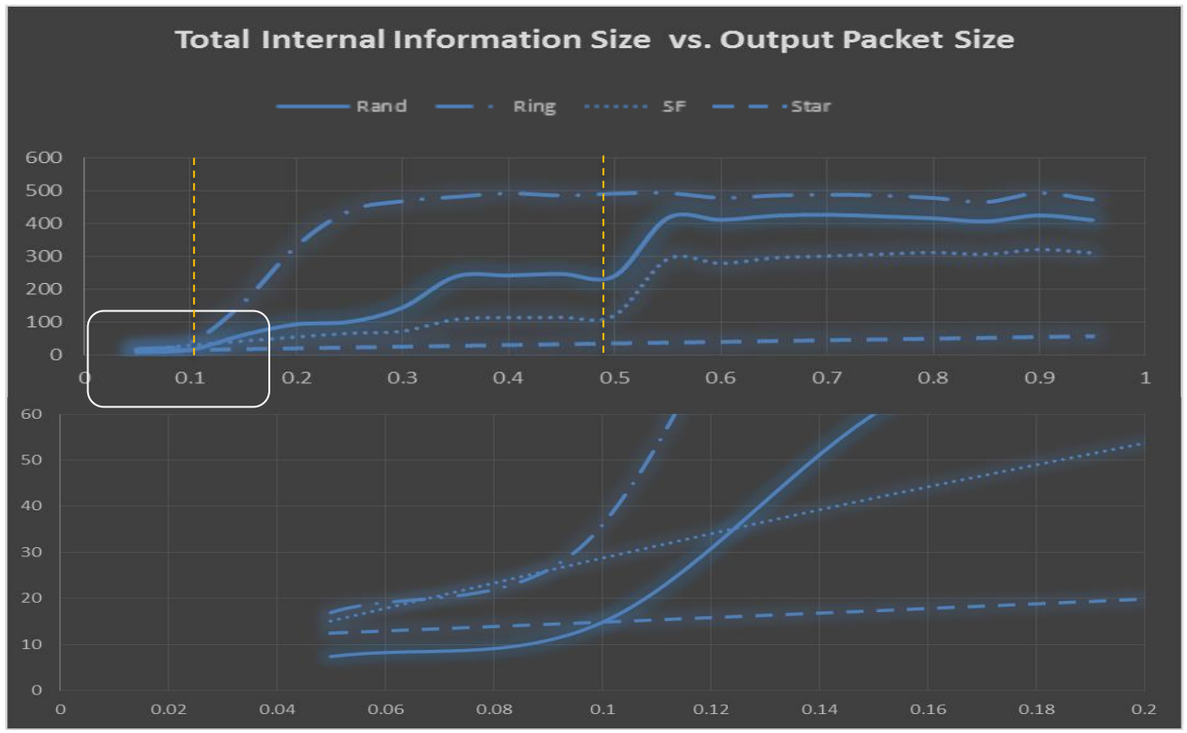


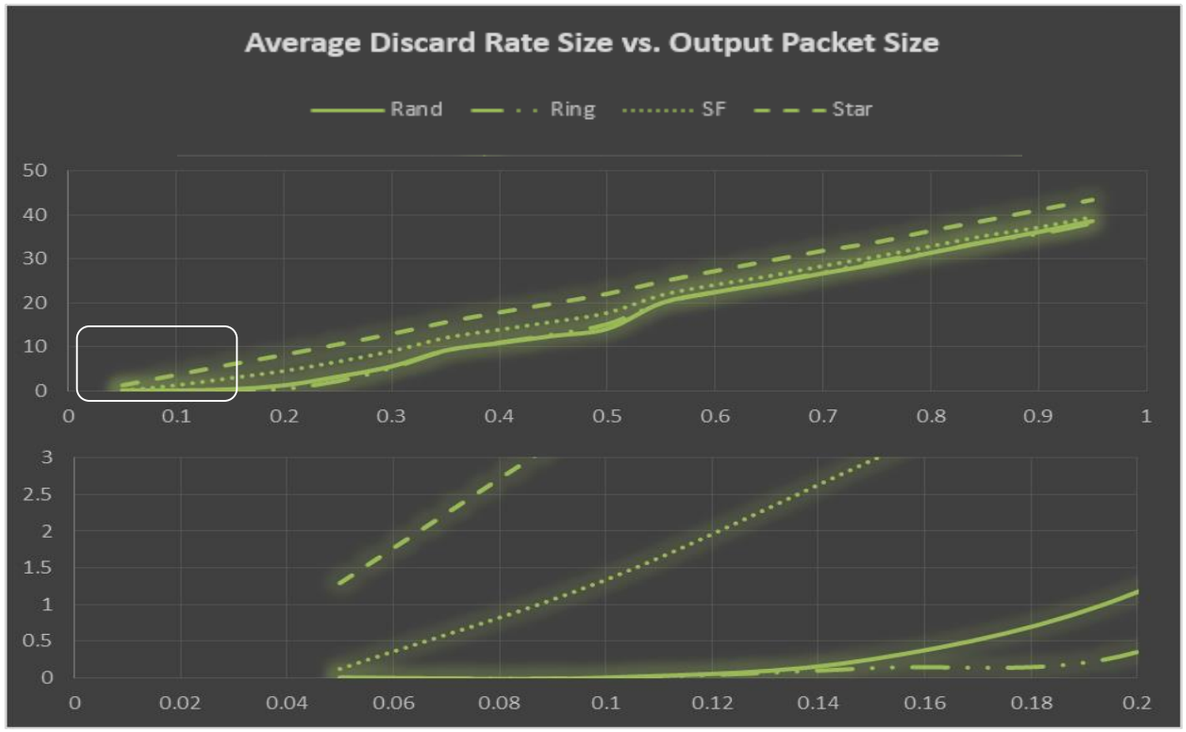
Random Network

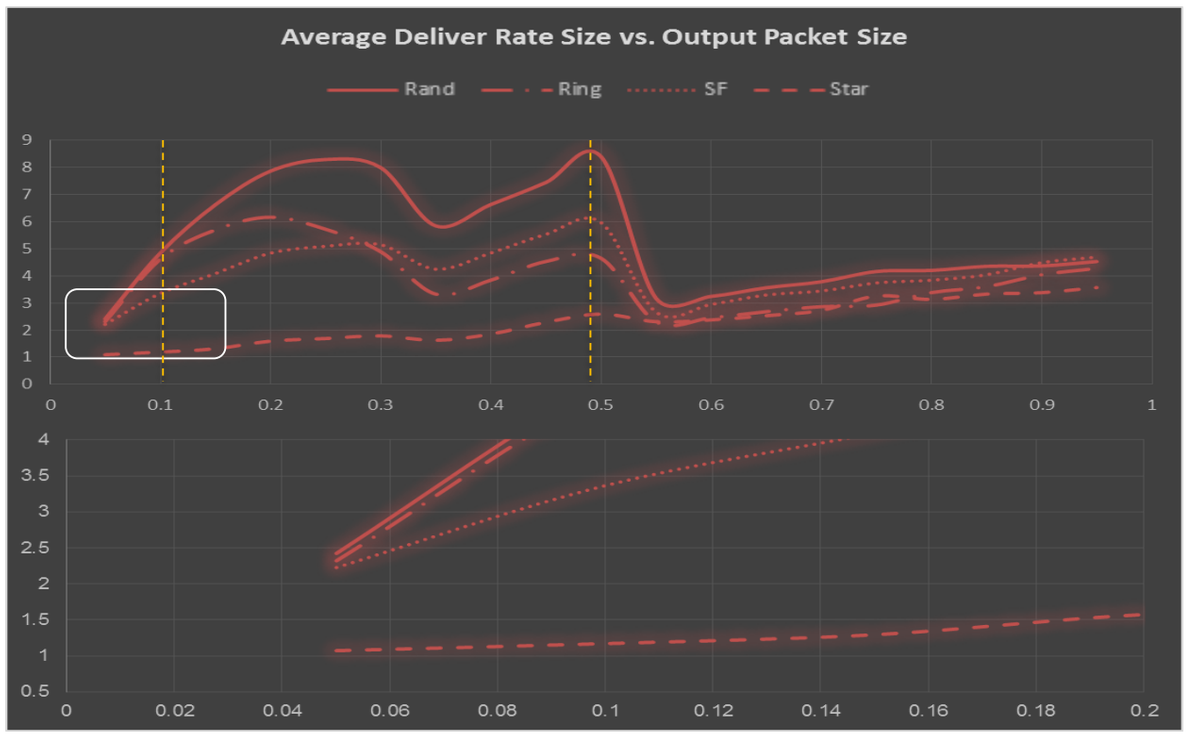


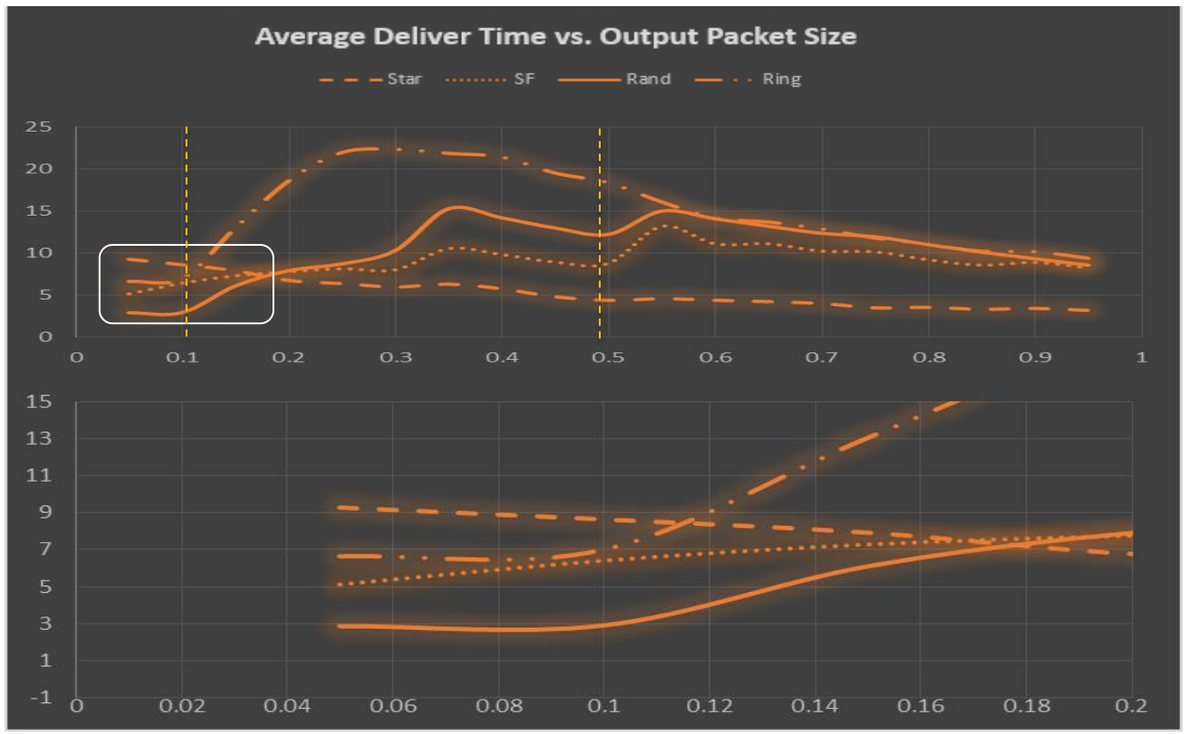
Ring Lattice Network

Comparison between Networks

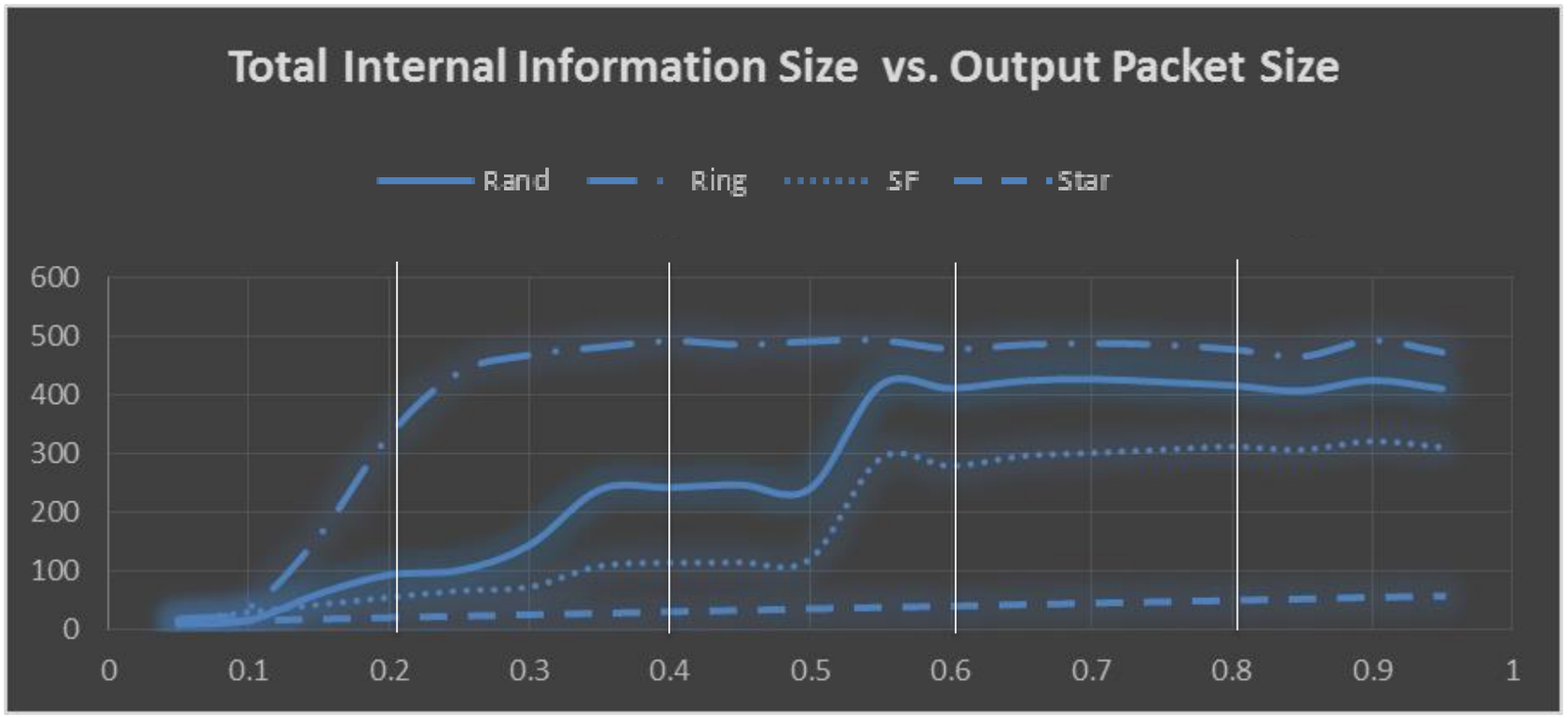


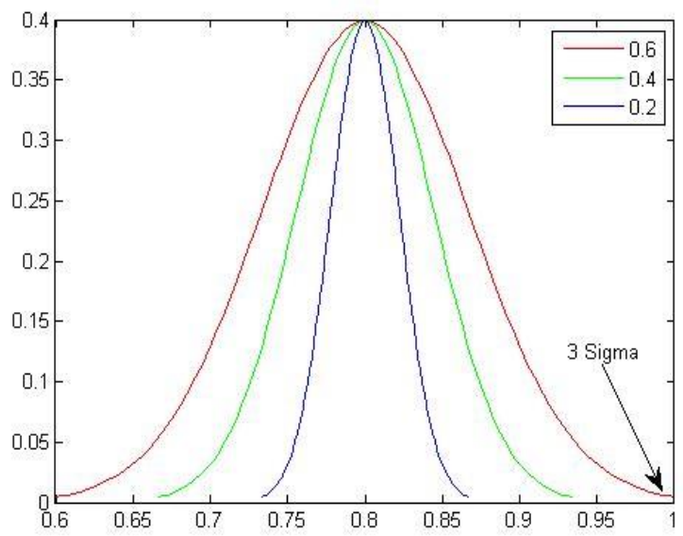






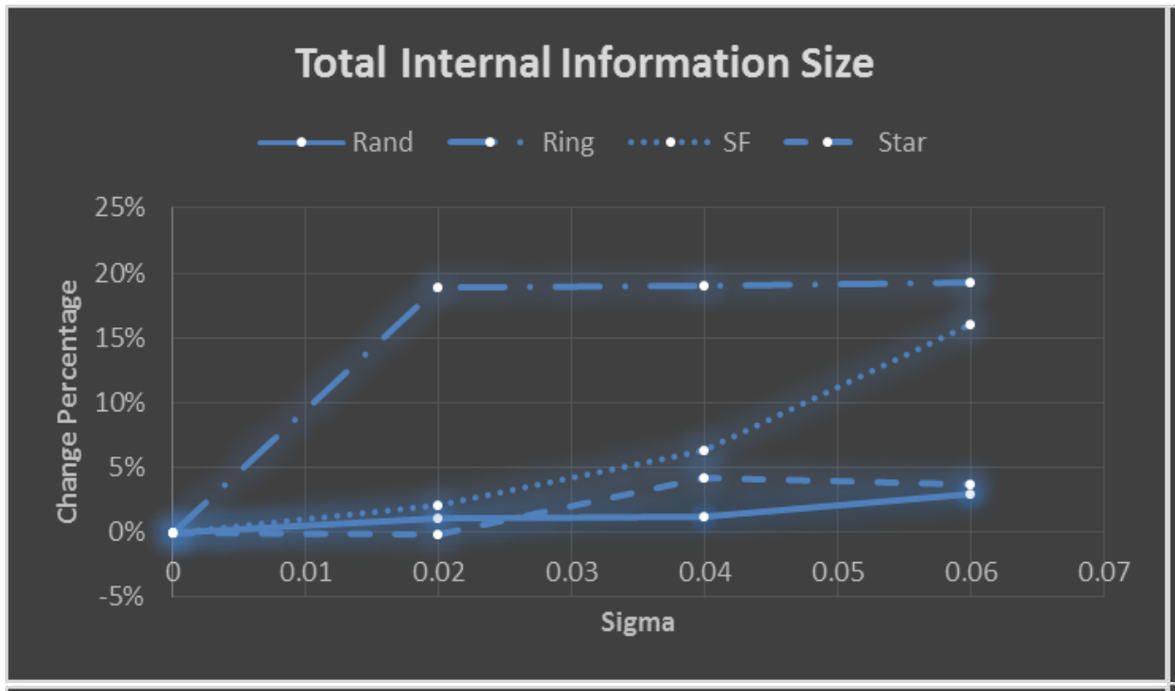
Output Packet Size: Normal Distribution

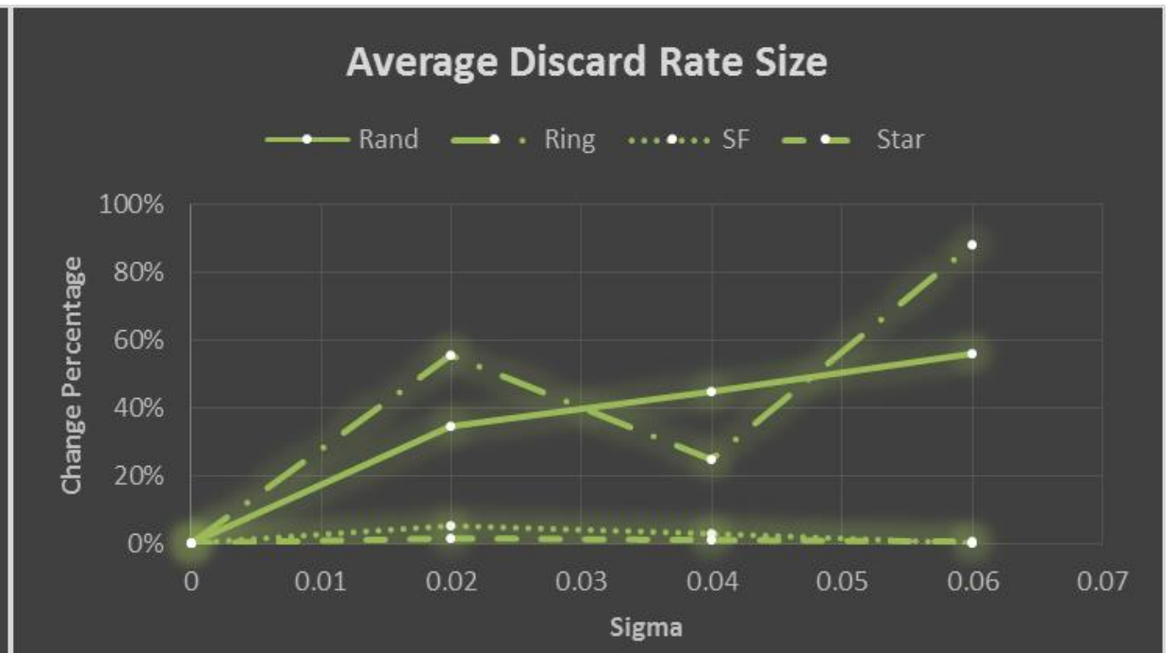


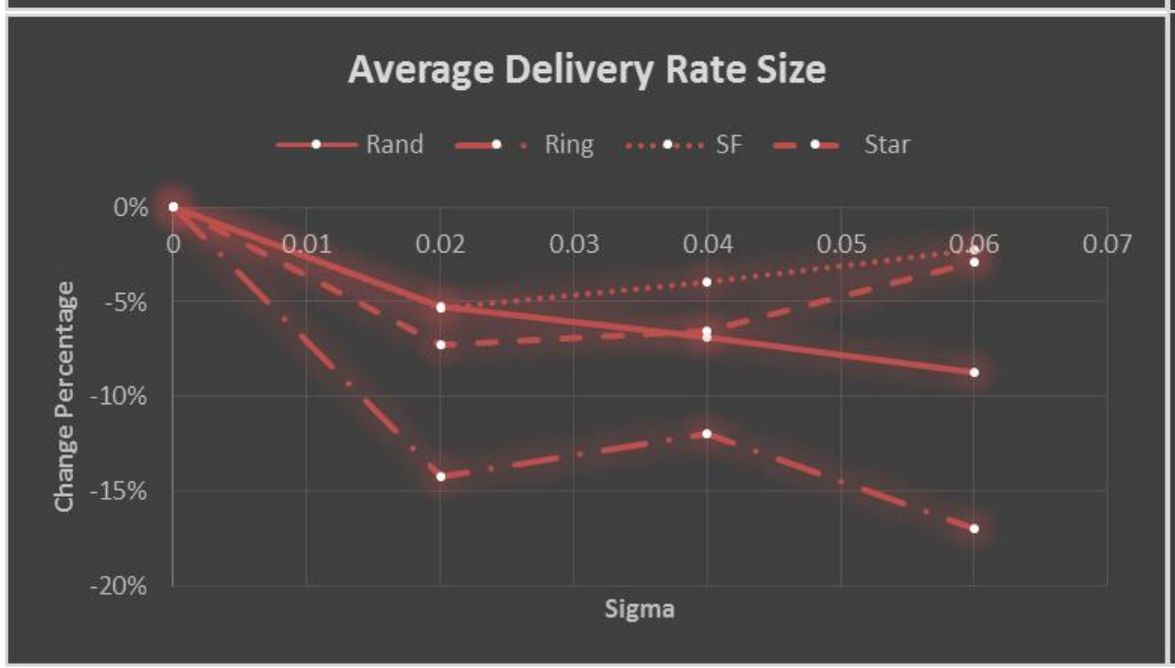


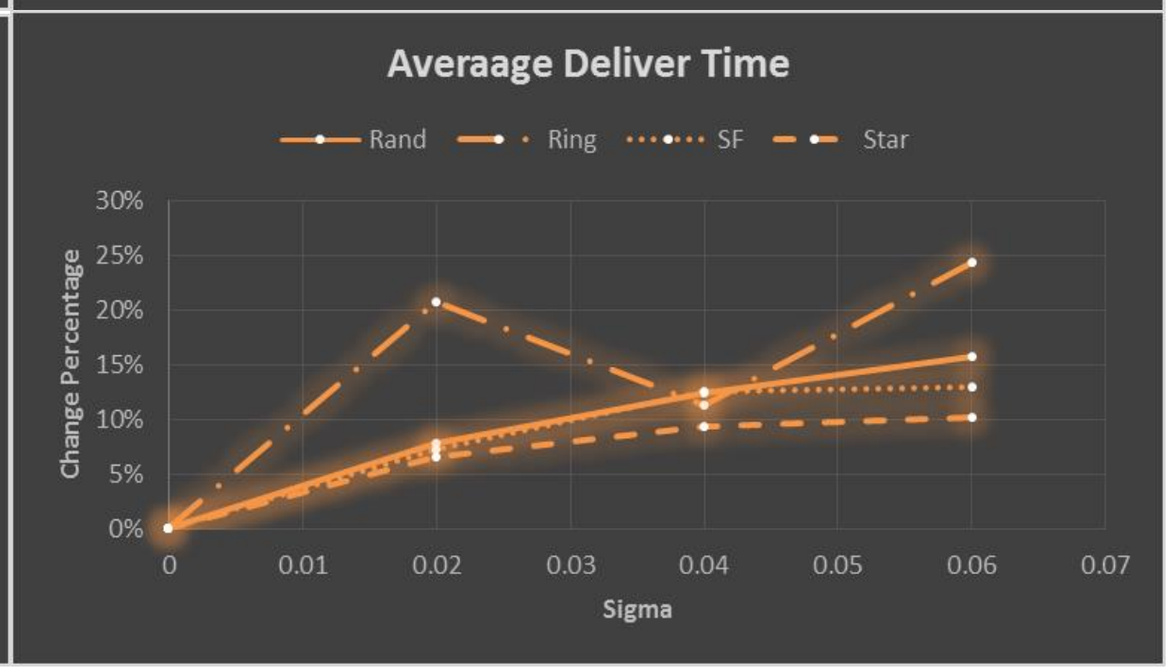
Comparison between Networks

$$\mu = 0.2$$









Conclusions

- Network topologies affect information transmission dynamics.
- The average deliver time highly depends on average shortest path length.
- Star-like network is the most prone to congestion due to a very high polarization value, which is a result of a very unbalanced degree distribution.
- At light traffic state, no big performance difference between the other three networks. As output packet size increases, random network has the best overall performance. That could be due to both a moderate polarization value and a moderate average path length.
- Low polarization networks are more sensitive to information fluctuation. As a result, Ring Lattice network has the highest sensitivity to information fluctuation.
- The observations and conclusions correspond with the results in [12-14]. Simulation can provide great insights into the interplay between network topologies and information transmission dynamics. Yet more and finer simulations are needed to guide the design of congestion robust networks.

Thank you !

Questions?

Dijkstra's Algorithm

Array Structure:

Keep the distance and the previous node information
Our implementation： Only keep the most recently visit
ed node, which would only give one path in the end

Tree structure:

Keep the information in the Tree structure and impleme
nt the breadth search to find the desired path.