Satellite Multi-Hop Queuing Models for the Space IoT

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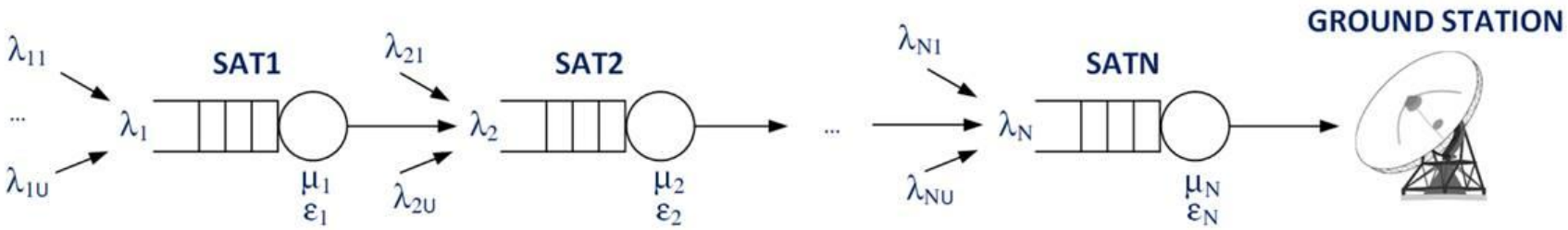
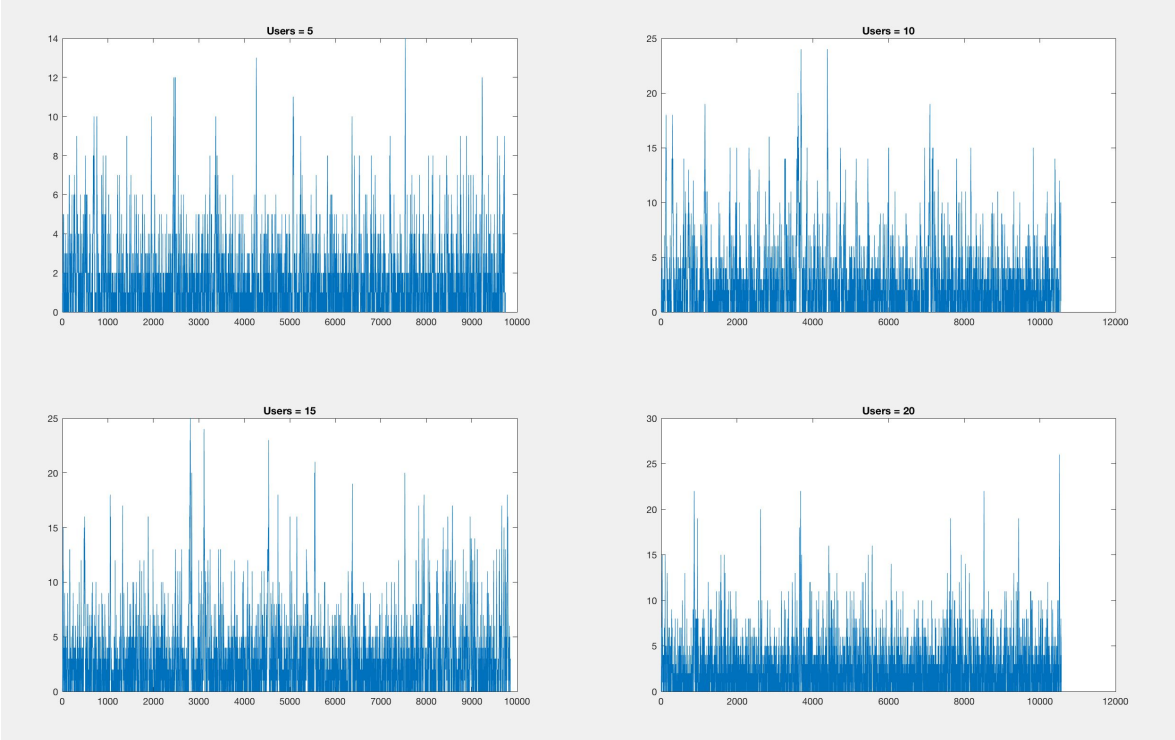
General System

- A relay network that has to carry the periodic reports from the earth



λ_{11}... are the parameters representing poisson or periodic traffic at each node.
μ_1, μ_2... are the parameters representing exponential servicing times at each nodes.
ε_1, ε_2... are the reliability parameters (probability of successful transmission from node i to i+1)
N represents the number of satellites or queues or nodes. **U** represents the number of users.

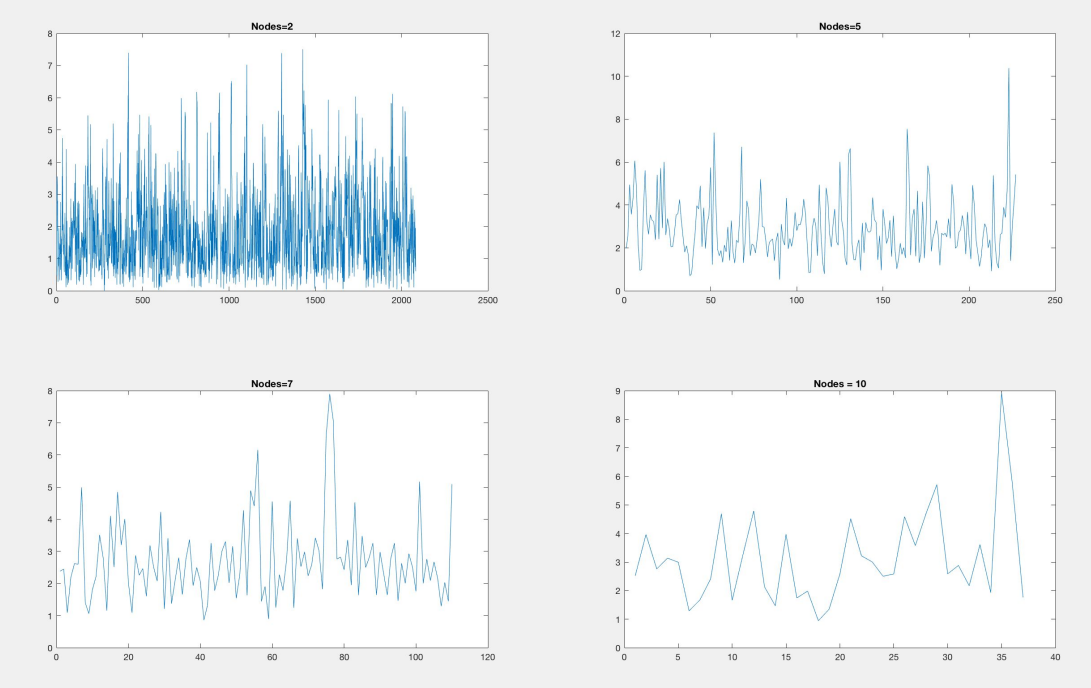
Buffer Length vs Time (Poisson Traffic)



Users: 5, 10, 15, 20
Number of nodes: 2

To verify if the server utilization is less than 1

Delay (end-to-end) vs Packet (Poisson Traffic)
(Considered for the packets received by the first node)



Users: 5
Number of nodes: 2, 5, 7, 10

As nodes increase, average delay increases and the number of ground packets decrease

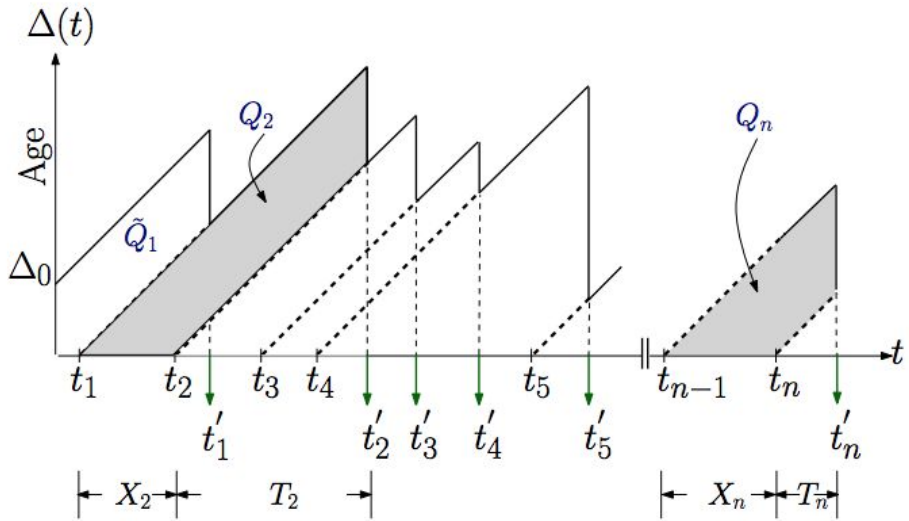
Objective

Minimizing the **Age of Information** for the general queuing system model shown

By understanding the effect of each parameter in the system

Age of Information

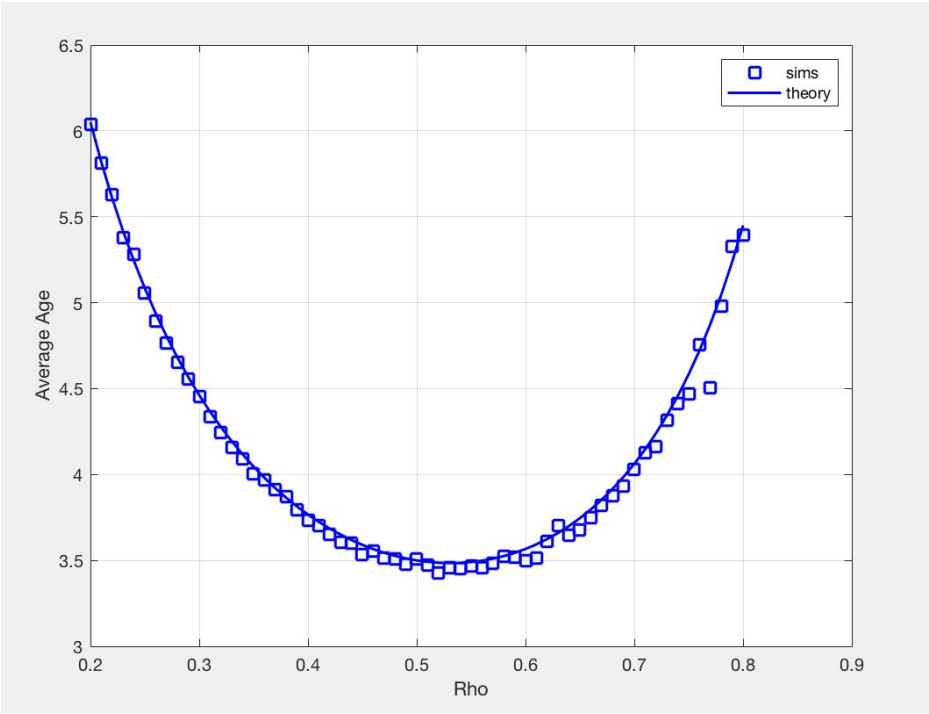
- Captures the freshness of the information at end-user
- Find uses in various applications: Weather, transportation, live traffic etc



Age: t - u(t)
u(t) - Time stamp of the most recently received update

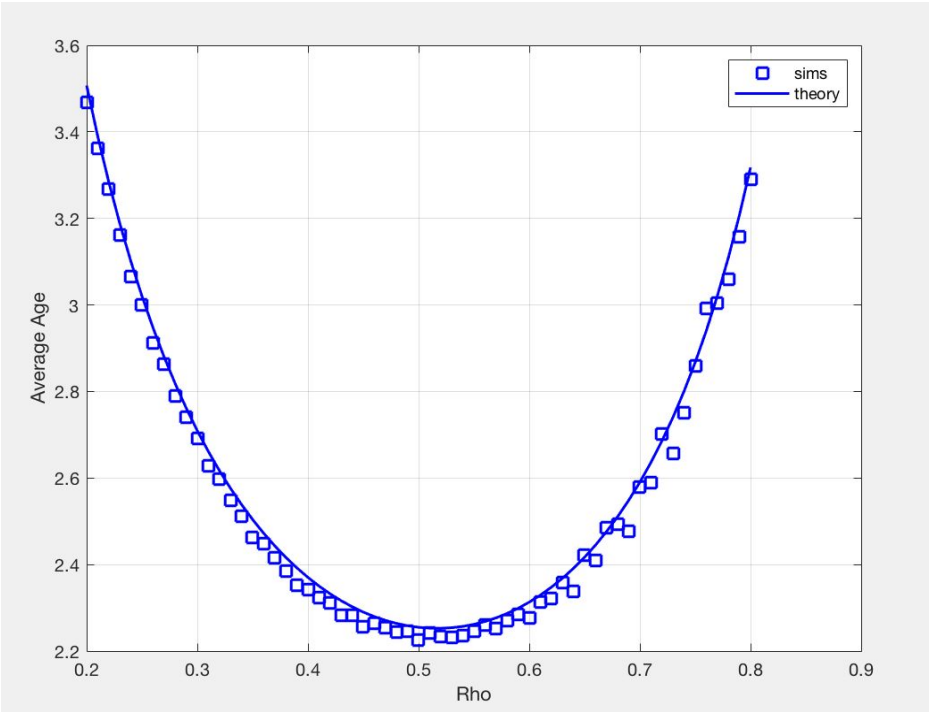
Source:
Real-Time Status: How Often Should One Update?

Single Node Characterization (Poisson Traffic)



Rho minimum (from sim) = 0.52
Rho minimum (from theory) ~ 0.53
Minimum AoI ~ 3.5

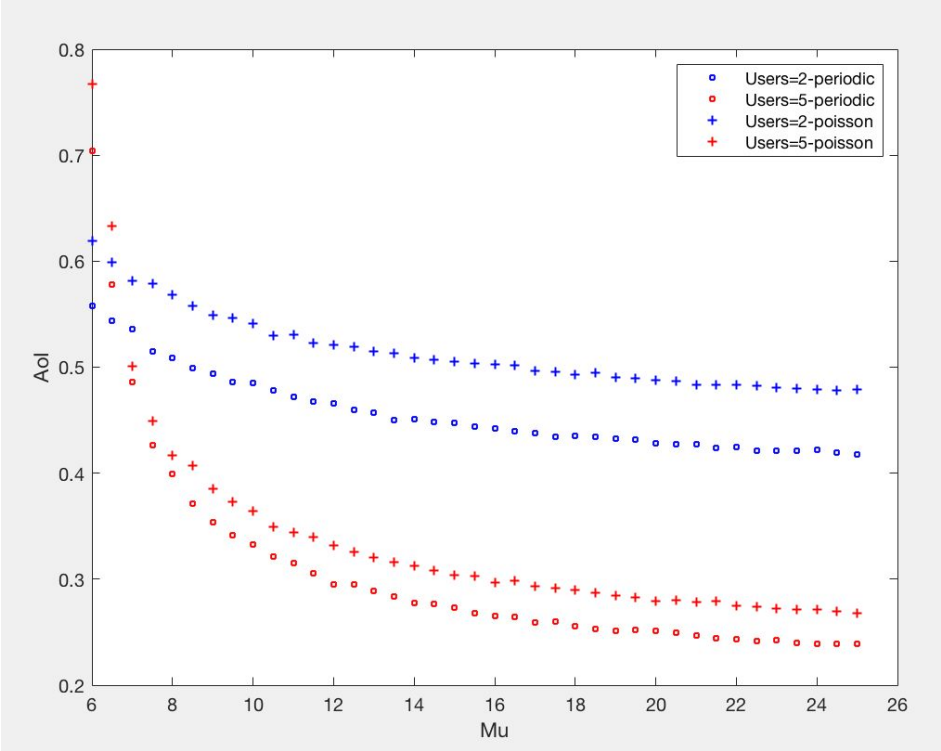
Single Node Characterization (Periodic Traffic)



Rho minimum (from sim) = 0.50
Rho minimum (from theory) ~ 0.515
Minimum AoI ~ 2.25

The optimum rho is different from that maximizes throughput (rho = 1) and that minimizes the end-to-end delay (small rho ~ 0)

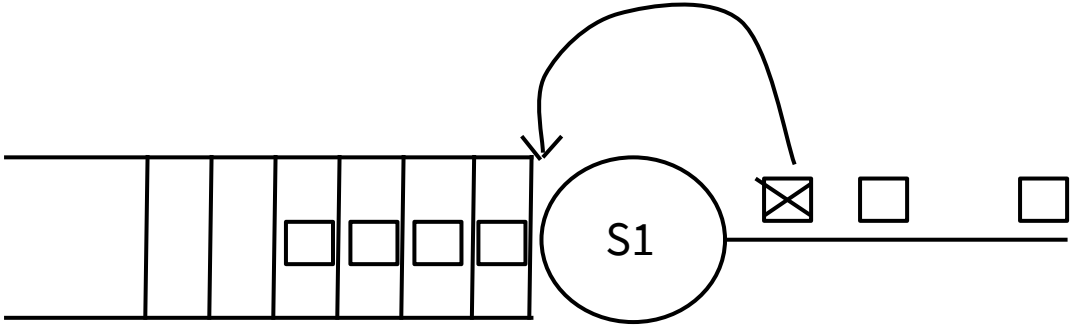
AoI vs Mu (for different users and traffics)



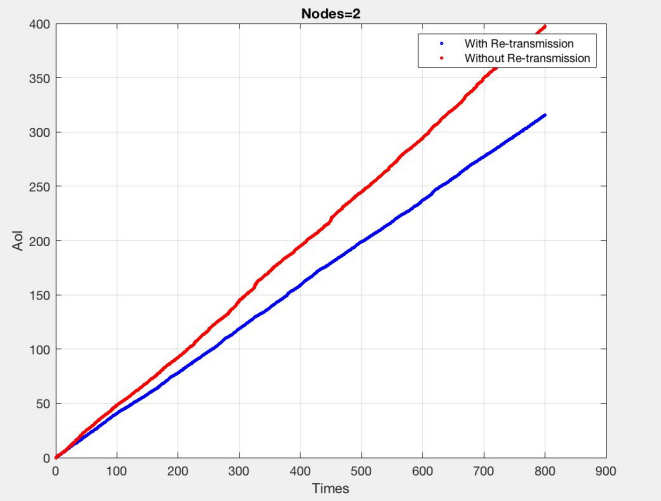
Nodes: 1
Users: 2, 5

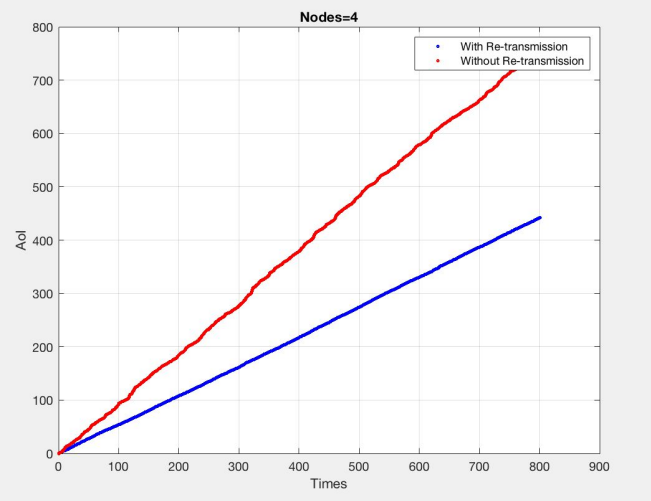
Periodic Queue shows a lower AoI for both the values of users

Re-transmission



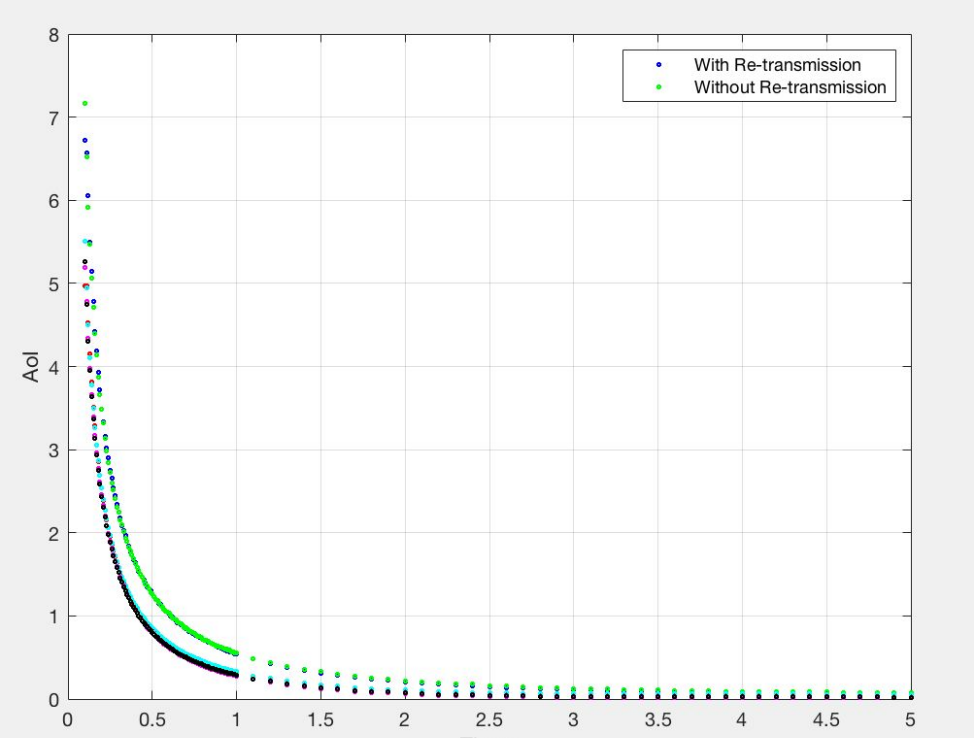
AoI vs Time (With & Without retransmissions)





For higher nodes, retransmission benefits the AoI

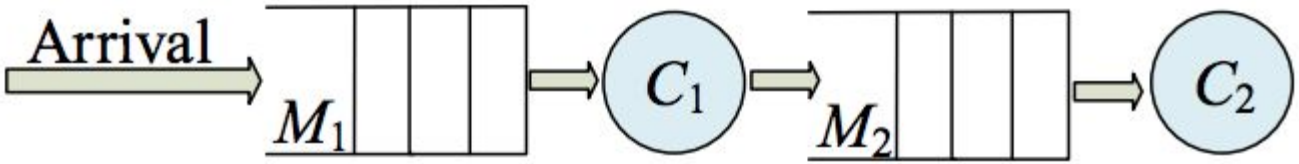
AoI with and without re-transmission (Periodic)



X-axis: Lambda or (1/period)
Y-axis: AoI

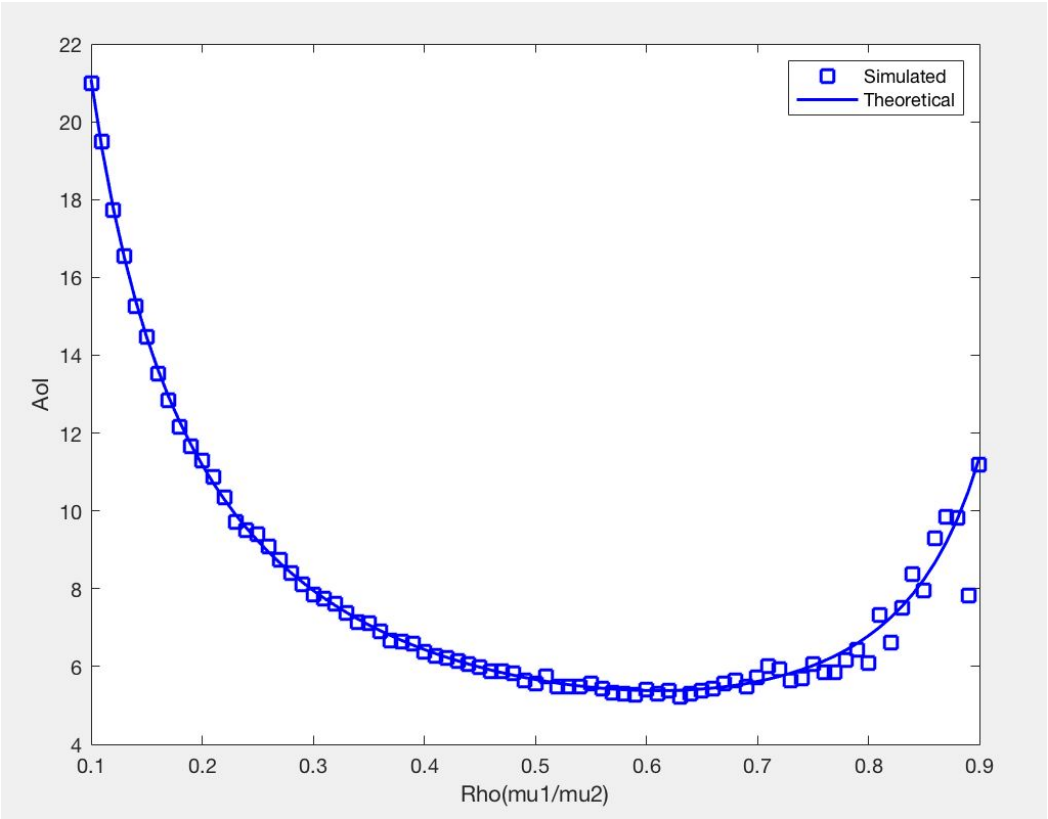
Max limit: 2
Number of users: 7
Number of nodes: 2
epsilon : 0.9

Zero-Wait Policy Tandem Queue



Arrivals to node1 : Zero-wait policy
Rho = mu_1/mu_2

Source of the image: Age-of-Information for Computation-Intensive Messages in Mobile Edge Computing



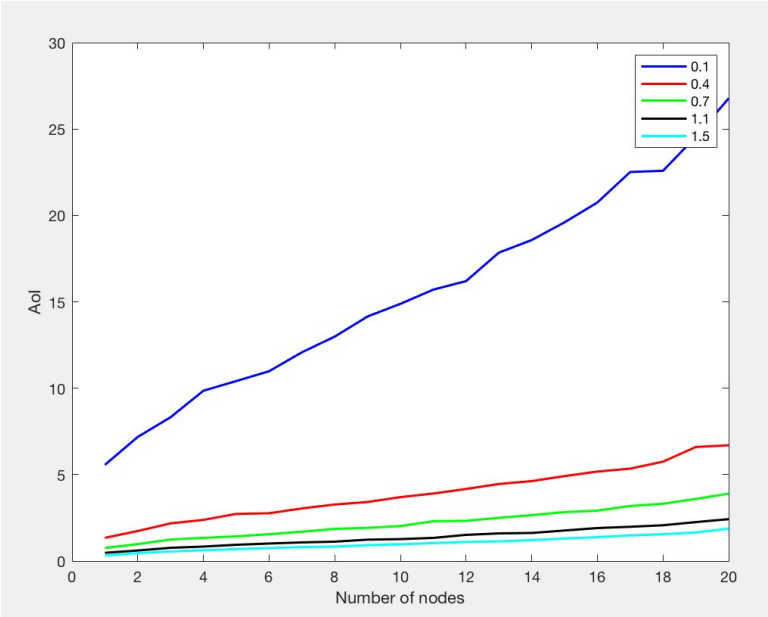
Mu_1 is like the lambda to queue 2 which is MM1

Initially, the rate of arrival is low leading to a high AoI

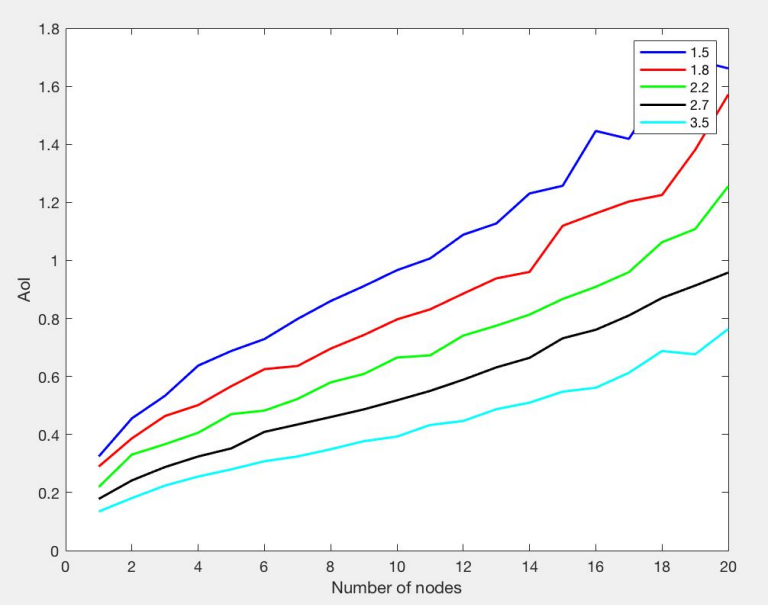
Later, the rate of arrival gets high resulting in larger waiting times leading to a high AoI

AoI vs Number of Nodes

(With Intermediate traffic, poisson traffic and without re-transmissions)

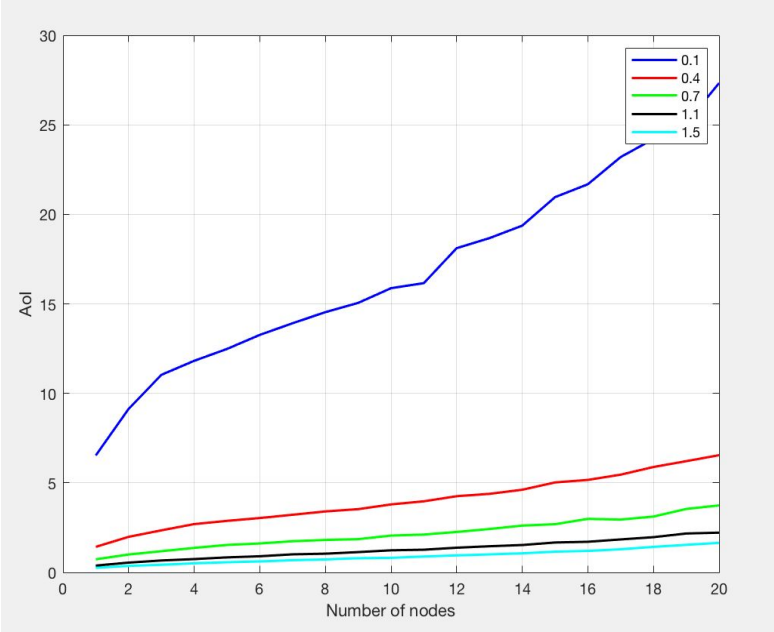


Epsilon: 0.9
Num_users: 5

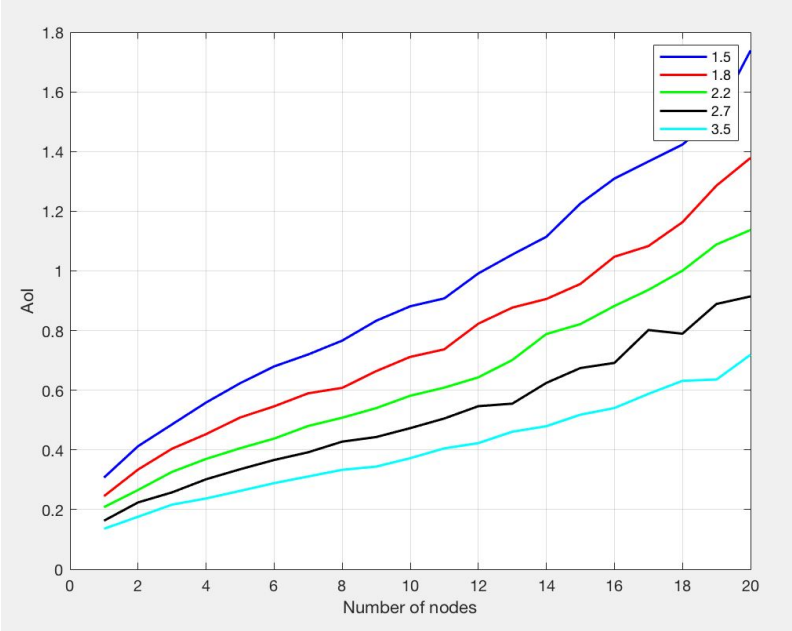


AoI vs Number of Nodes

(With Intermediate traffic, periodic traffic and without re-transmissions)

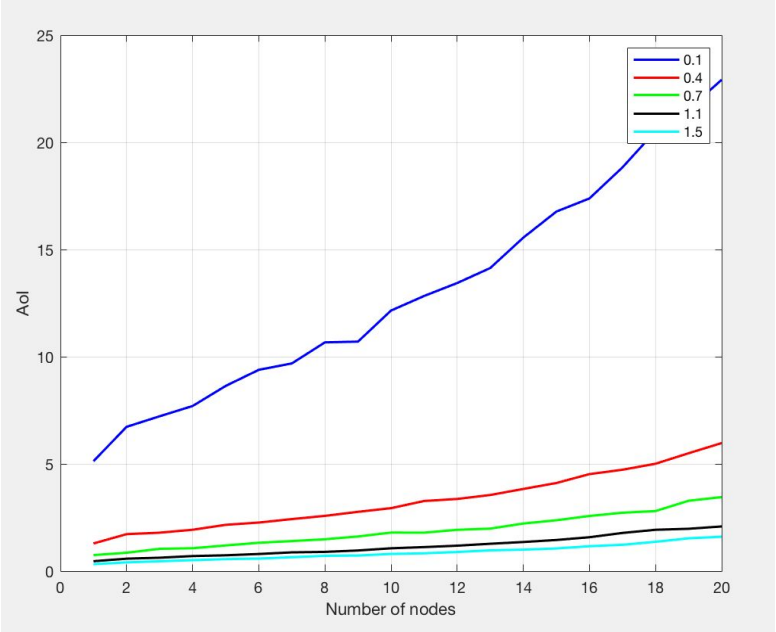


Epsilon: 0.9
Num_users: 5

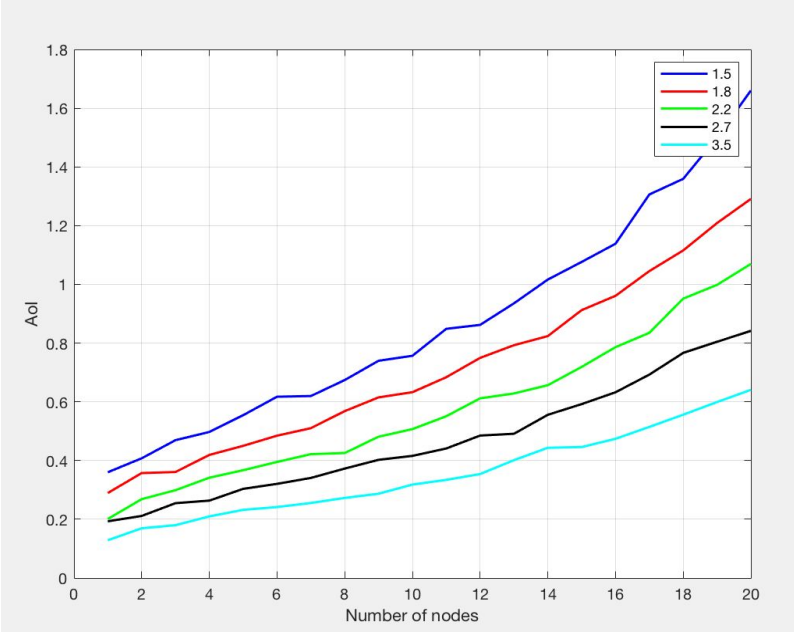


AoI vs Number of Nodes

(Without Intermediate traffic, poisson traffic and without re-transmissions)

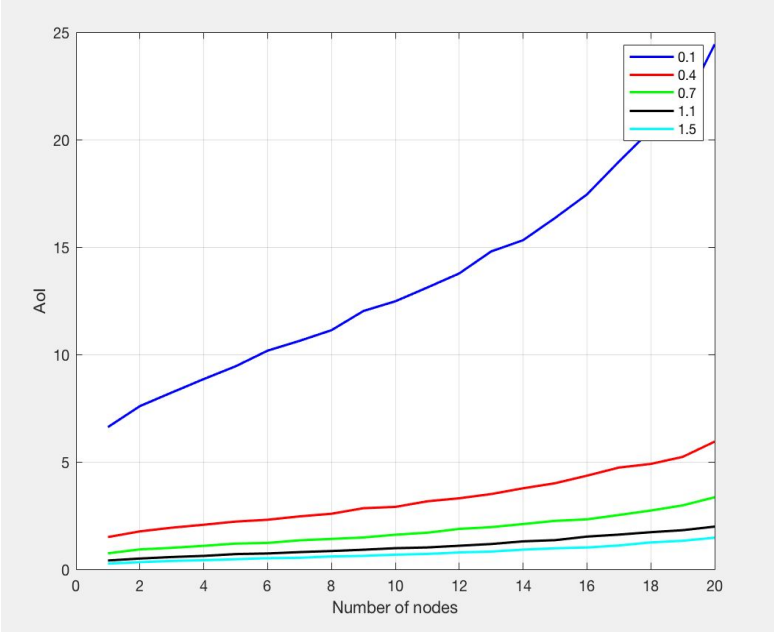


Epsilon: 0.9
Num_users: 5

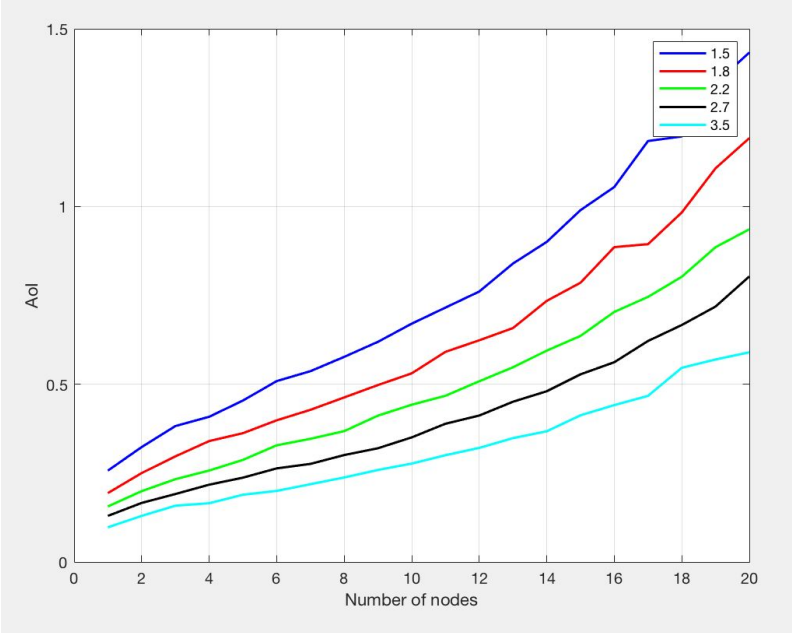


AoI vs Number of Nodes

(Without Intermediate traffic, periodic traffic and without re-transmissions)

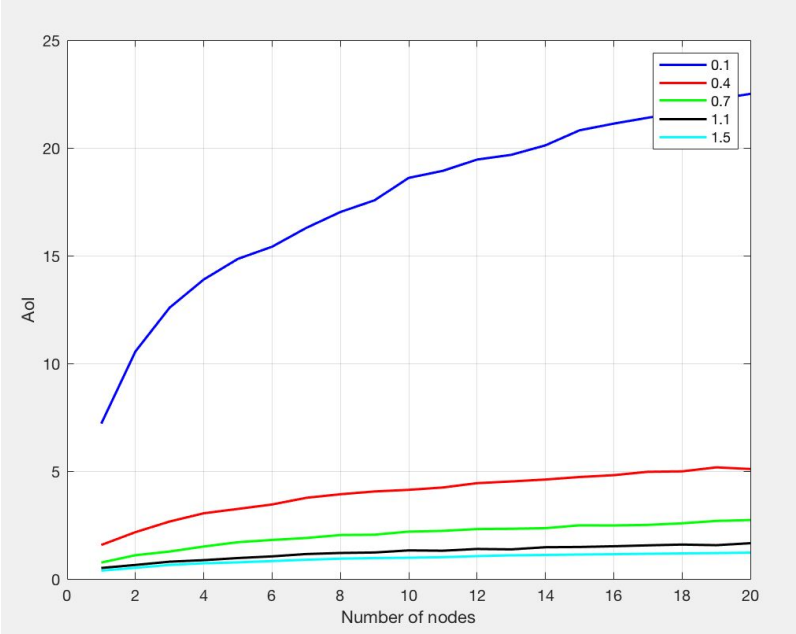


Epsilon: 0.9
Num_users: 5

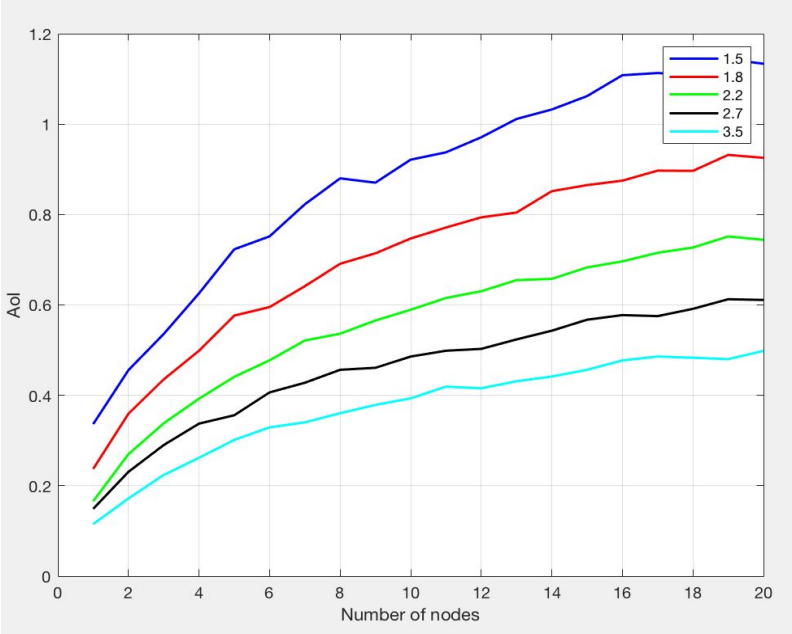


AoI vs Number of Nodes

(With Intermediate traffic, periodic traffic and with re-transmissions(limit:2))

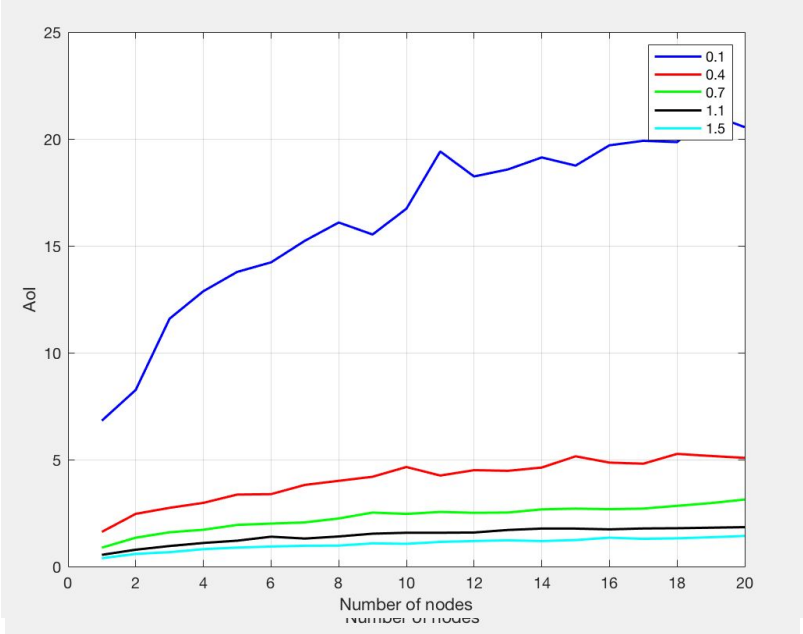


Epsilon: 0.9
Num_users: 5

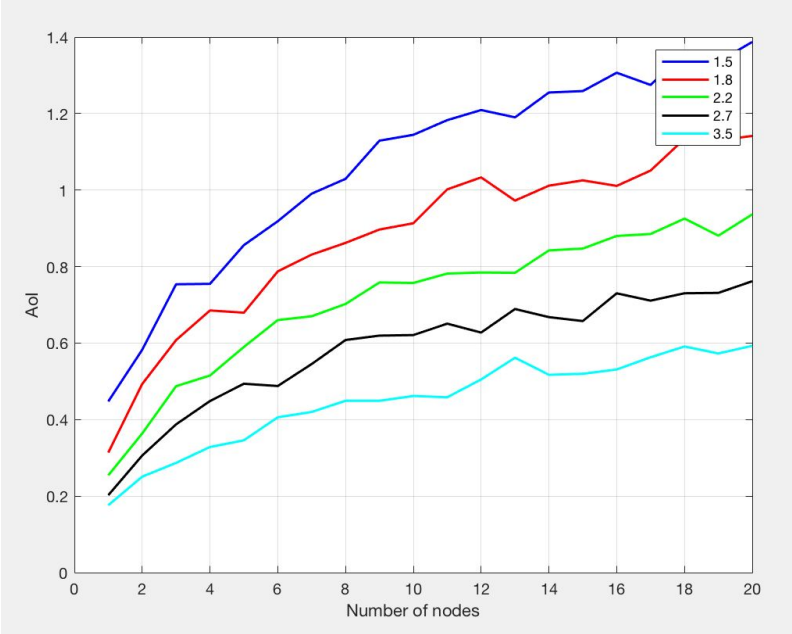


AoI vs Number of Nodes

(With Intermediate traffic, poisson traffic and with re-transmissions(limit:2))

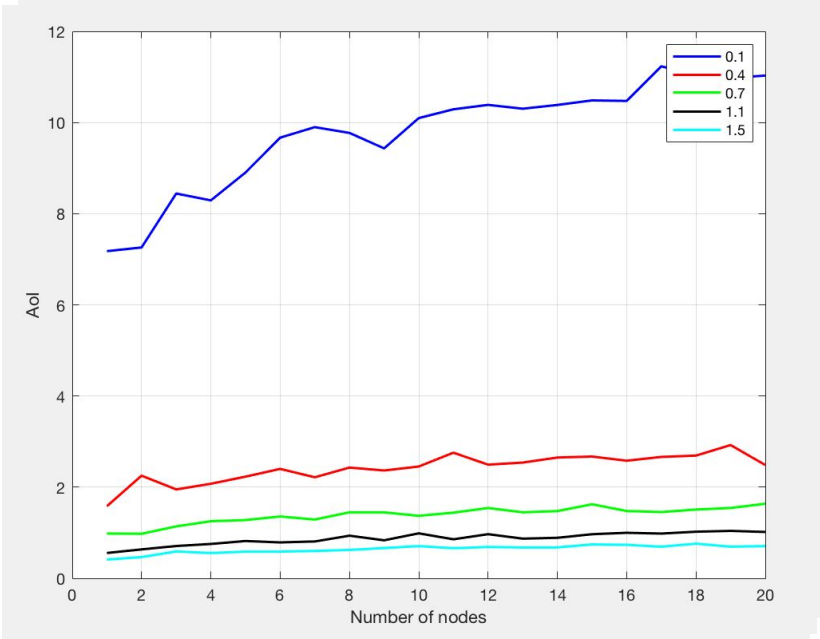


Epsilon: 0.9
Num_users: 5

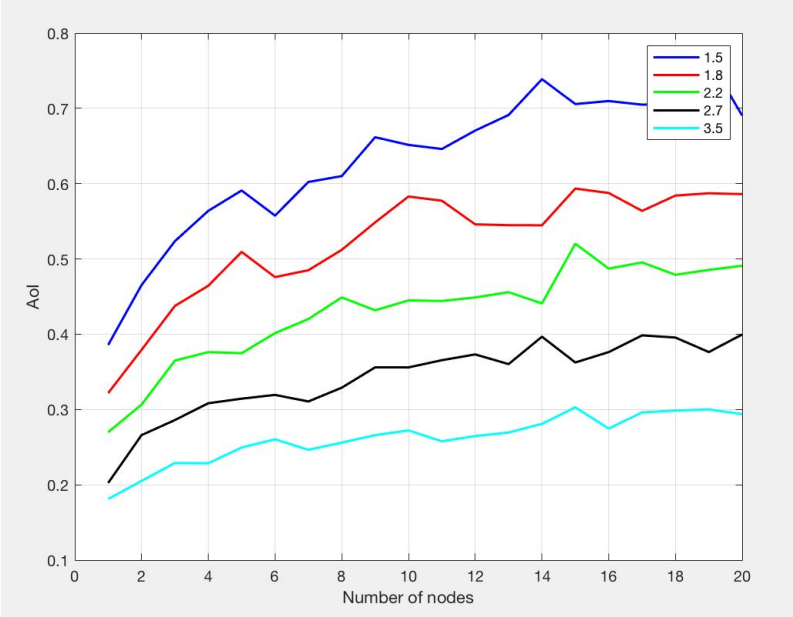


AoI vs Number of Nodes

(Without Intermediate traffic, poisson traffic and with re-transmissions(limit:2))

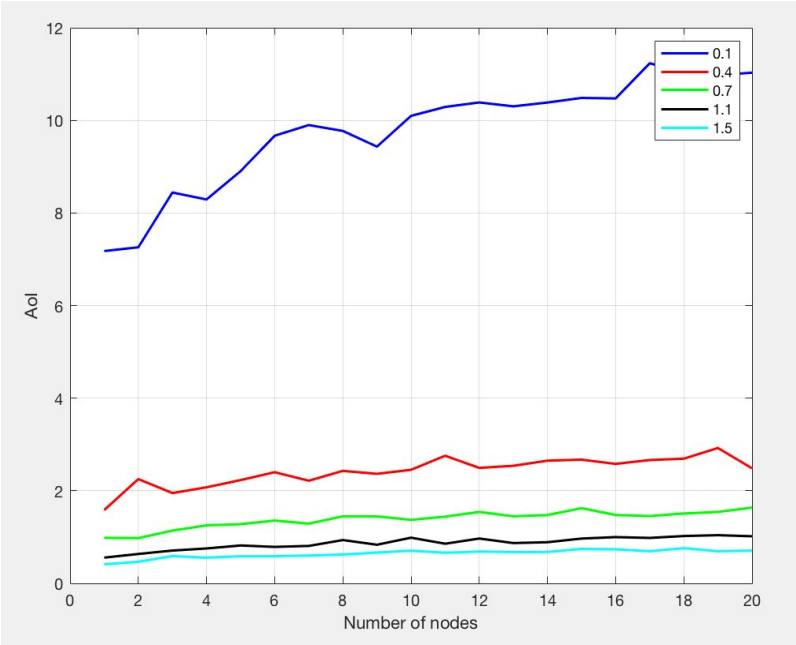


Epsilon: 0.9
Num_users: 5

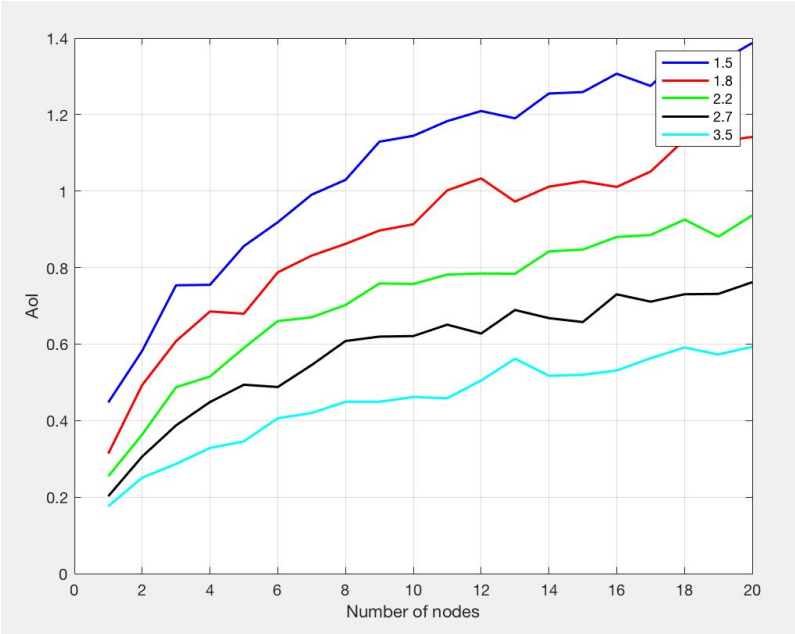


AoI vs Number of Nodes

(Without Intermediate traffic, periodic traffic and with re-transmissions(limit:2))

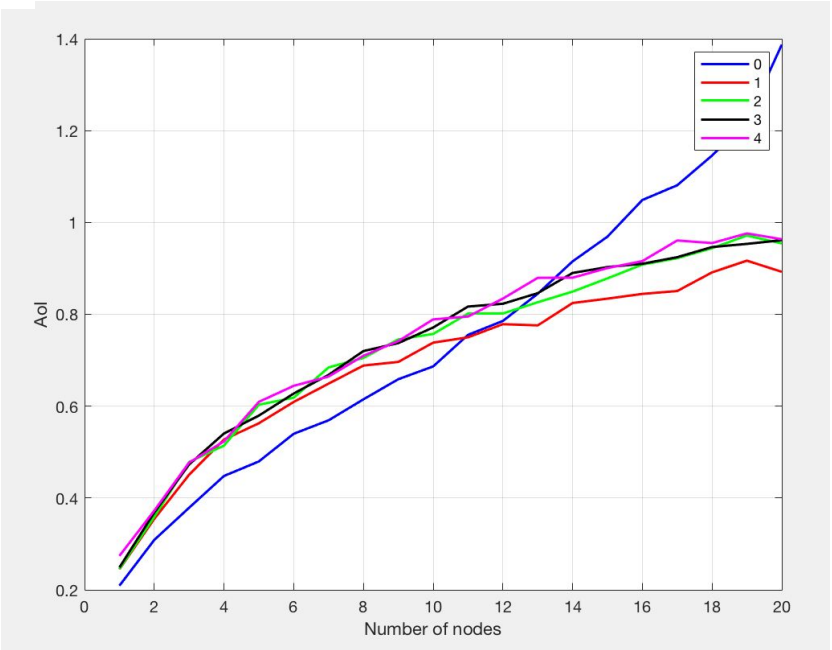


Epsilon: 0.9
Num_users: 5

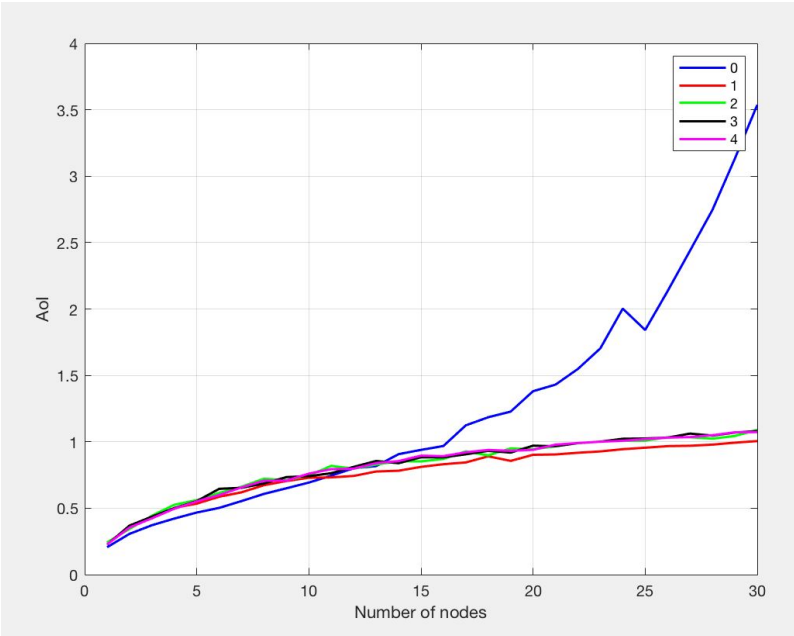


AoI vs Number of Nodes

(With Intermediate traffic, periodic traffic and retransmissions - (0, 1, 2, 3, 4))

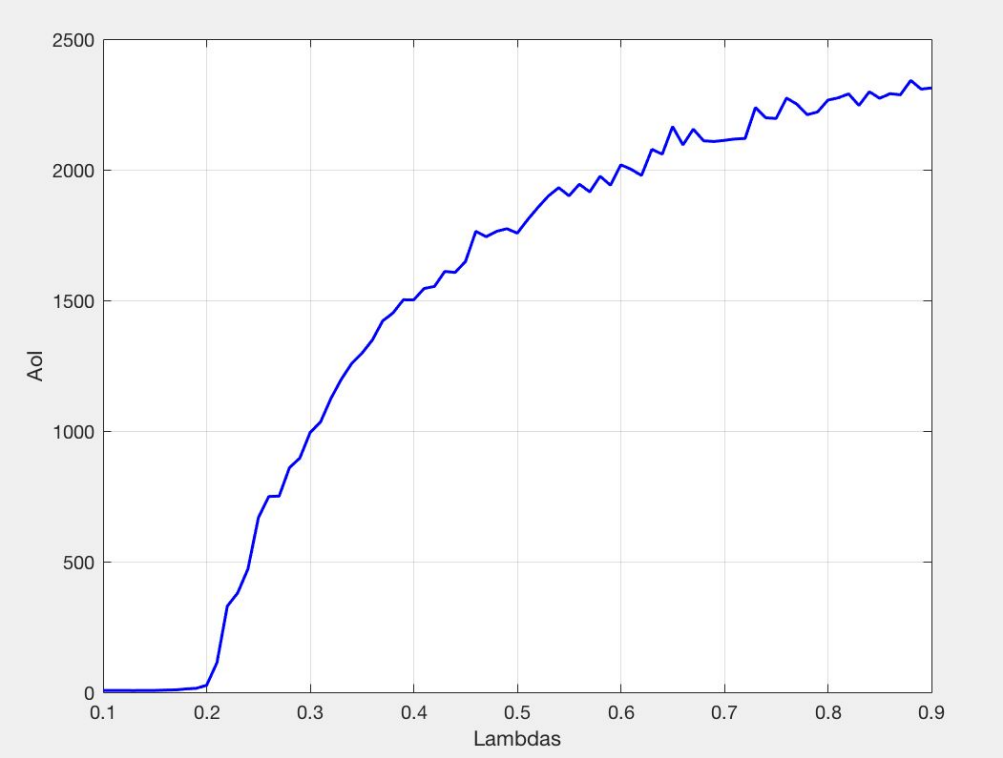


Epsilon: 0.9
Num_users: 5



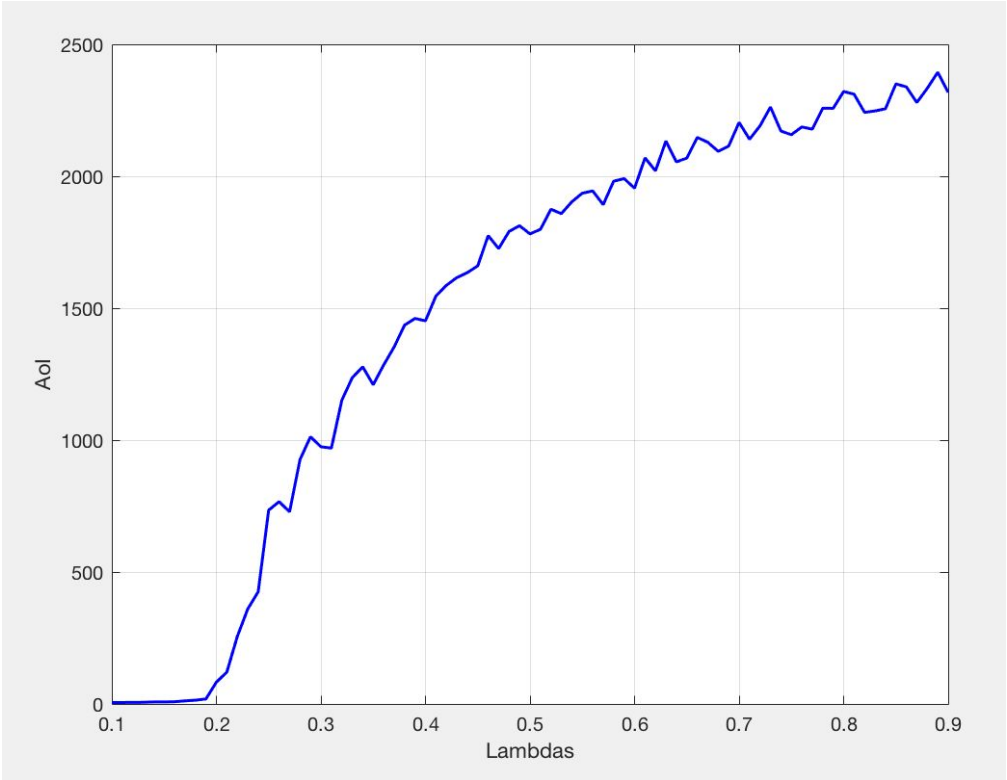
AoI vs Lambda (2-node system)

(Without Intermediate traffic, periodic traffic and no retransmissions, epsilon = 0.9)



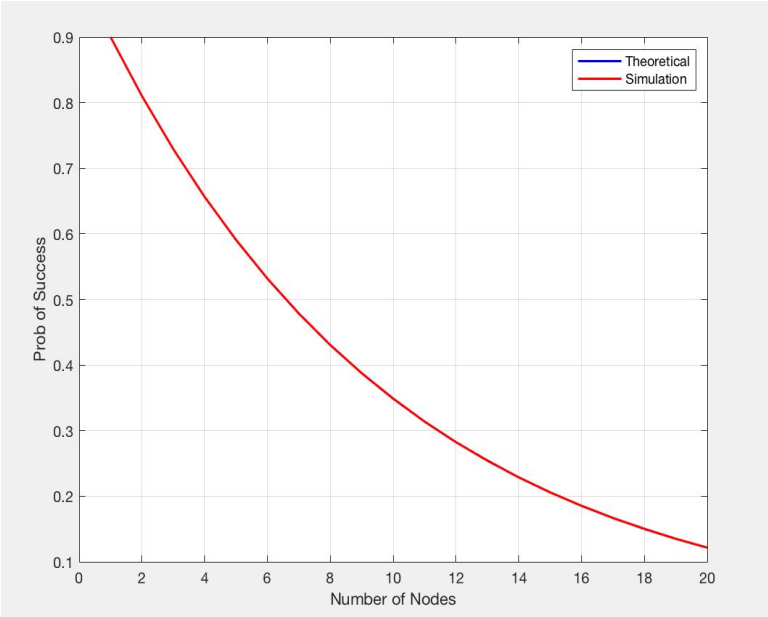
AoI vs Lambda (2-node system)

(Without Intermediate traffic, poisson traffic and no retransmissions, epsilon = 0.9)



Probability of Success vs Number of Nodes

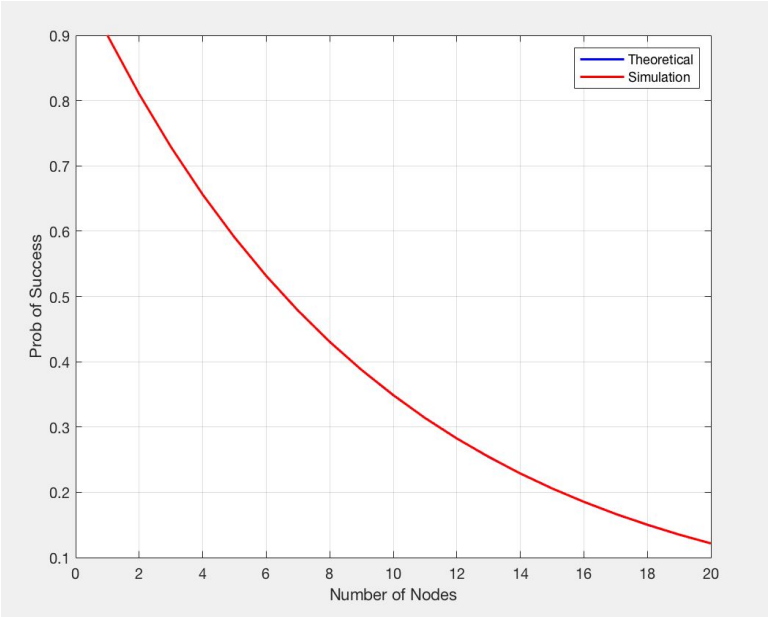
(Without Intermediate traffic, poisson traffic and without re-transmissions)



Epsilon: 0.9
Num_users: 5
Num_events = 5000

Probability of Success vs Number of Nodes

(Without Intermediate traffic, periodic traffic and without re-transmissions)



Epsilon: 0.9
Num_users: 5
Num_events = 5000