Effects of a Non-linear Packet Drop Probability Function on RED Performance

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Summary

In 1993, the random early detection (RED) algorithm was created, and in the nearly 30 years since, many scientists have proposed enhanced versions. However, the use of a pure linear function to compute packets drop probability has led to the problem of significant delays. To address this issue, researchers suggest using both linear and non-linear (such as, exponential) functions for packet drop probability. We have proposed a revised RED algorithm that introduces nonlinearity to the packet drop probability. We have used a combination of linear and exponential drop functions where each part is varied with a multiple of a nonlinearity constant gamma. At low and moderate network traffic loads, the proposed algorithm employs the linear drop function, while at high traffic loads, it uses the exponential function to calculate the packet drop probability rate. We can observe some performance change of networks by optimizing nonlinearity degree of the packet drop probability with other parameters.

Introduction

When the amount of incoming data packets is greater than the network's available resources, it leads to network congestion. This can result in poor quality of service with high delays, loss rates, and low throughput. Routers play a crucial role in controlling network congestion, leading to improved network performance. To manage network congestion, a router can drop packets at an early stage using active queue management (AQM) algorithms. These algorithms, such as random early detection (RED), help prevent the buffer from becoming full and send feedback signals to sources to reduce transmission rates. RED is the most common AQM algorithm and is used as the basis for many new AQM algorithms. When a packet arrives at the router, RED updates the average queue size ($\bar{q}$) to detect congestion.

To perform this work, the current status of the queue is examined. If the router's queue is not empty, average value ($\bar{q}$) is determined with the help of a predefined queue weight ($w_q \in [0, 1]$), the previously calculated average queue size ($\bar{q}'$) and the current queue size (q) using the following equation:

$$\bar{q} = (1 - w_q)\overline{q'} + (w_q \times q)$$

(1)

The probability drop function of original RED depends on the $\bar{q}$ in the following manner:

$$P(\bar{q}) = \begin{cases} 0, & if\ \bar{q} \le q_{min} \\ P_{max}\left(\dfrac{\bar{q} - q_{min}}{q_{max} - q_{min}}\right), & if\ \bar{q} \in (q_{min}, q_{max}) \\ 1, & if\ \bar{q} \ge q_{max} \end{cases}$$

(2)

Here, q_{min} is the router's minimum queue threshold, q_{max} is the router's maximum threshold, P_{max} is the maximum packet drop probability and P($\bar{q}$) is the initial packet dropping probability.

The final packet drop probability P is as follows:

$$P = \frac{P(\bar{q})}{1 - count \times P(\bar{q})}$$

(3)

Here, count is the number of packets that arrived since the last dropped packet.

Modified RED

The proposed algorithm is a combination of linear and exponential drop functions in an aim to change the performance of the original RED algorithm. The probability drop function modified for this report is given below:

$$P(\bar{q}) = \begin{cases} 0, & if\ \ \bar{q} \in [0, minTH) \\ P_{max}\left(\dfrac{\bar{q} - q_{min}}{q_{max} - q_{min}}\right) + P_{max} \times \gamma\ , if\ \ \bar{q} \in [minTH, target) \\ P_{max}\left(\dfrac{\bar{q} - q_{min}}{q_{max} - q_{min}}\right) e^{\gamma\left(\frac{\bar{q} - q_{min}}{q_{max} - q_{min}} - 1\right)}, if\ \ \bar{q} \in [Target, maxTH) \\ 1, & if\ \ \bar{q} \geq maxTH \end{cases}$$

(4)

In which

$$Target = \frac{maxTH + minTH}{2}$$

(5)

It can be mentioned that Target distinguishes between two traffic scenarios: lower and moderate buffer occupancies, and higher buffer occupancies.

Simulations

The proposed modified RED algorithm is implemented using ns-2.35 simulator. The effectiveness of this algorithm is evaluated by varying the non-linearity constant gamma from 0-15 with an interval of three. Three types of topologies are used, namely, a wired dumbbell topology, a wireless static topology with standard 802.11 and a wireless mobile topology with standard 802.15.4.

WIRED TOPOLOGY

The RED with $P(\bar{q})$ defined by Eq. (4) was applied to the router R1 while Tail-Drop, that is the most basic control algorithm for the buffers, was implemented in the router R2. The parameter values in our simulations are summarized in Table 1 and Table 2. The network traffic was simulated for 40 s. The topology is shown in Figure 1.

Network Parameter	Value
Access Link Capacity [Mbps]	100
Bottleneck Link Capacity [Mbps]	10
Propagation Delay (Access Link) [sec]	5
Propagation Delay (Bottleneck Link) [sec]	100

Maximum window size rwnd [packet]	500
Packet Size [bits]	8032
Buffer Size [packet]	500
Number of TCP connections N	18, 38, 58, 78, 98
R1 queue length, q [packet]	[10, 50] * 2

Table 1 : Network Parameters (Wired)

RED Parameter	Value
Minimum Threshold, q_{min} [packet]	q*0.2
Maximum Threshold, q_{max} [packet]	q*0.7
Queue Weight, W_q	1
Maximum Packet Drop Probability, maxP	0.05
Mean Packet size [bits]	1000
Non-linearity constant, γ	0-15

Table 2: RED parameters (Wired)

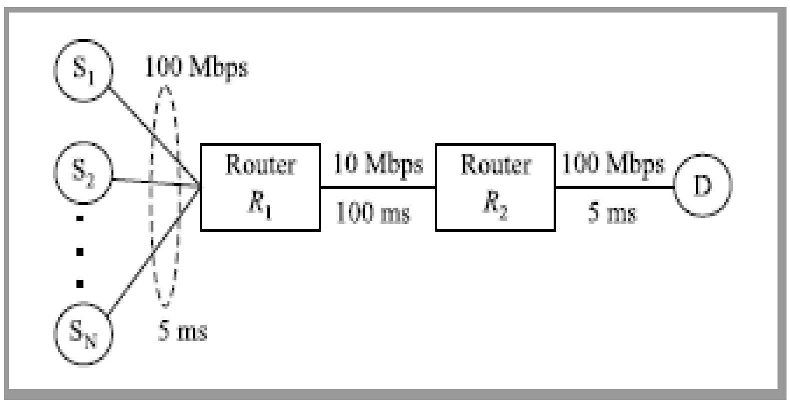


Figure 1: Network Topology

WIRELESS TOPOLOGY WITH 802.11-STATIC NODES

For this part, we have used a grid topology with 802.11 wireless standard and static nodes. For this topology we have chosen a destination node randomly and then sources are selected based on the number of flow given. The parameter values in our simulations are summarized in, Table 3, Table 4 and Table 5. The network traffic was simulated for 40 s. The topology is shown in Figure 2.

Network Parameter	Value
Channel Type	WirelessChannel
Radio-propagation model	TwoRayGround
Antenna type	OmniAntenna
Link Layer Type	LL
Network Interface Type	WirelessPhy
Interface Queue Type	RED

Interface Queue Length, q [packet]	15*(number of flows)
MAC type	802.11
Adhoc Routing Protocol	DSDV
Agent Layer Protocol	TCP Tahoe
Application Layer Protocol	FTP

Table 3: Network Parameters (wireless 802.11)

Energy Parameter	Value
Energy Model Type	EnergyModel
Initial Energy [J]	1000
Idle Power [W]	1.0
rxPower [W]	1.0
txPower [W]	1.0
Sleep Power [W]	0.001
Transition Power [W]	0.2
Transition Time [sec]	0.005

Table 4: Energy Parameter (wireless 802.11)

RED Parameter	Value
Minimum Threshold, q_{min} [packet]	q*0.2
Maximum Threshold, q_{max} [packet]	q*0.7
Queue Weight, W_q	1
Mean Packet size [bits]	1000
Non-linearity constant, γ	0-15

Table 5: RED parameters (Wireless 802.11)

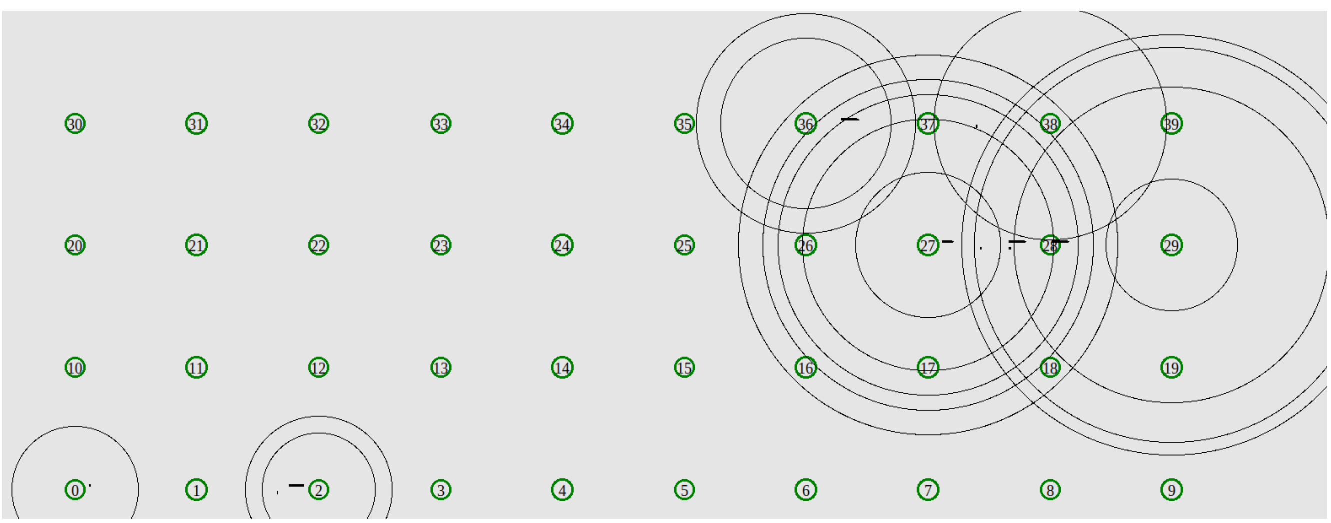


Figure 2: Network Topology (Wireless 802.11)

WIRELESS TOPOLOGY WITH 802.15.4-MOBILE NODES

For this part, we have used a grid topology with 802.15.4 wireless standard and mobile nodes. For this topology we have chosen source and destination nodes with a numbered difference of 2 each equal to the number of flows and created a flow between each pair. The parameter values in our simulations are summarized in Table 6, Table 7 and Table 8. The network traffic was simulated for 20 s. The topology is shown in Figure 3.

Network Parameter	Value
Channel Type	WirelessChannel
Radio-propagation model	TwoRayGround
Antenna type	OmniAntenna
Link Layer Type	LL
Network Interface Type	WirelessPhy/802.15.4
Interface Queue Type	RED
Interface Queue Length, q [packet]	2*(number of flows)
MAC type	802.15.4
Adhoc Routing Protocol	DSDV
Agent Layer Protocol	TCP Tahoe
Application Layer Protocol	FTP

Table 6: Network Parameters (wireless 802.15.4)

Energy Parameter	Value
Energy Model Type	EnergyModel
Initial Energy [J]	15
Idle Power [W]	0.45
rxPower [W]	0.9
txPower [W]	0.4
Sleep Power [W]	0.05
Transition Power [W]	0.2
Transition Time [sec]	0.005

Table 7: Energy Parameter (wireless 802.15.4)

RED Parameter	Value
Minimum Threshold, q_{min} [packet]	q*0.2
Maximum Threshold, q_{max} [packet]	q*0.7
Queue Weight, W_q	0.002
Maximum Probability, P_{max}	0.02
Mean Packet size [bits]	50
Non-linearity constant, γ	0-15

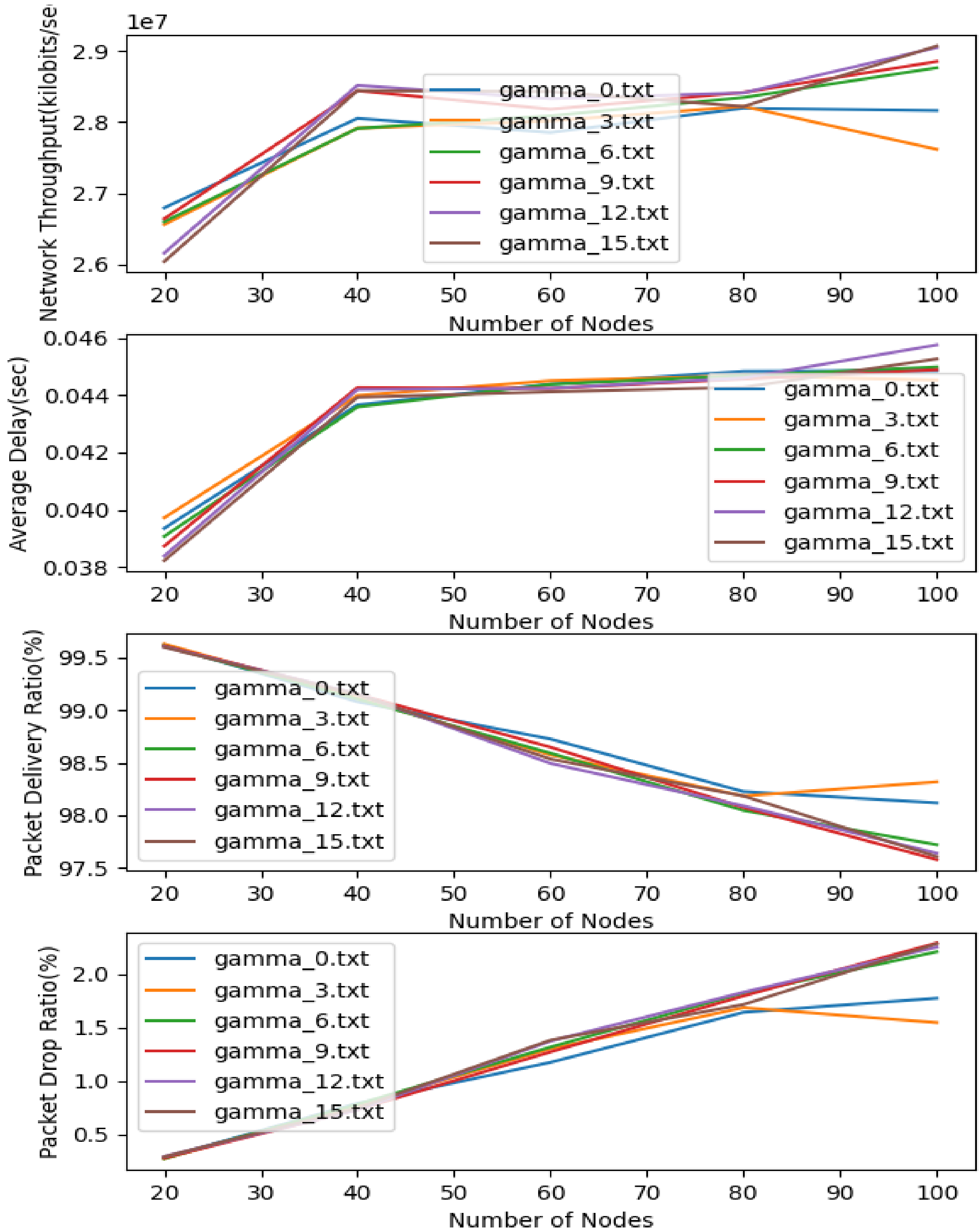
Table 8: RED parameters (Wireless 802.15.4)

Figure 3: Network Topology (Wireless 802.15.4)

Simulation Result

WIRED

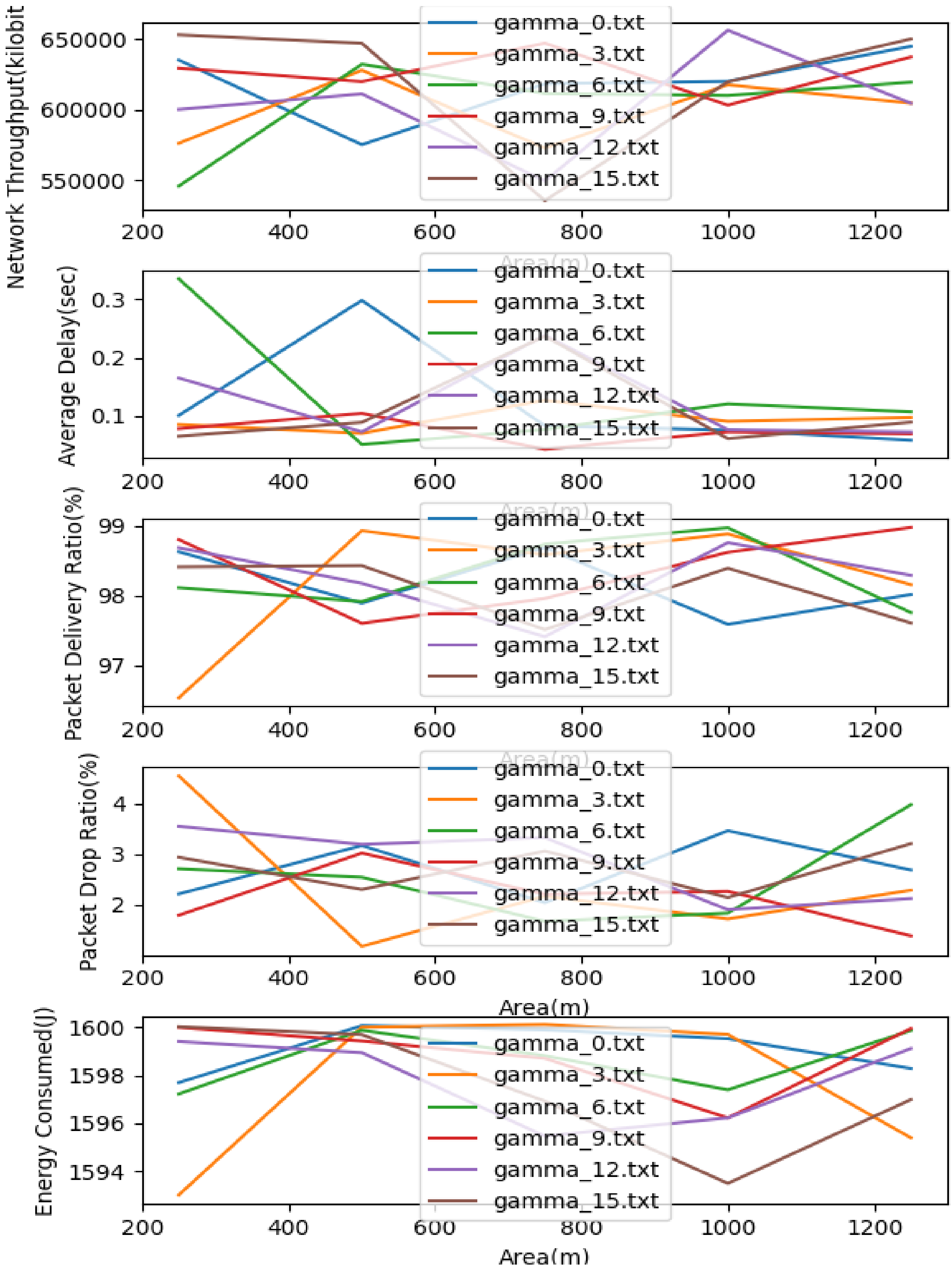
Varying Number of Nodes



Graph 1: Varying Number of Nodes for Wired Topology

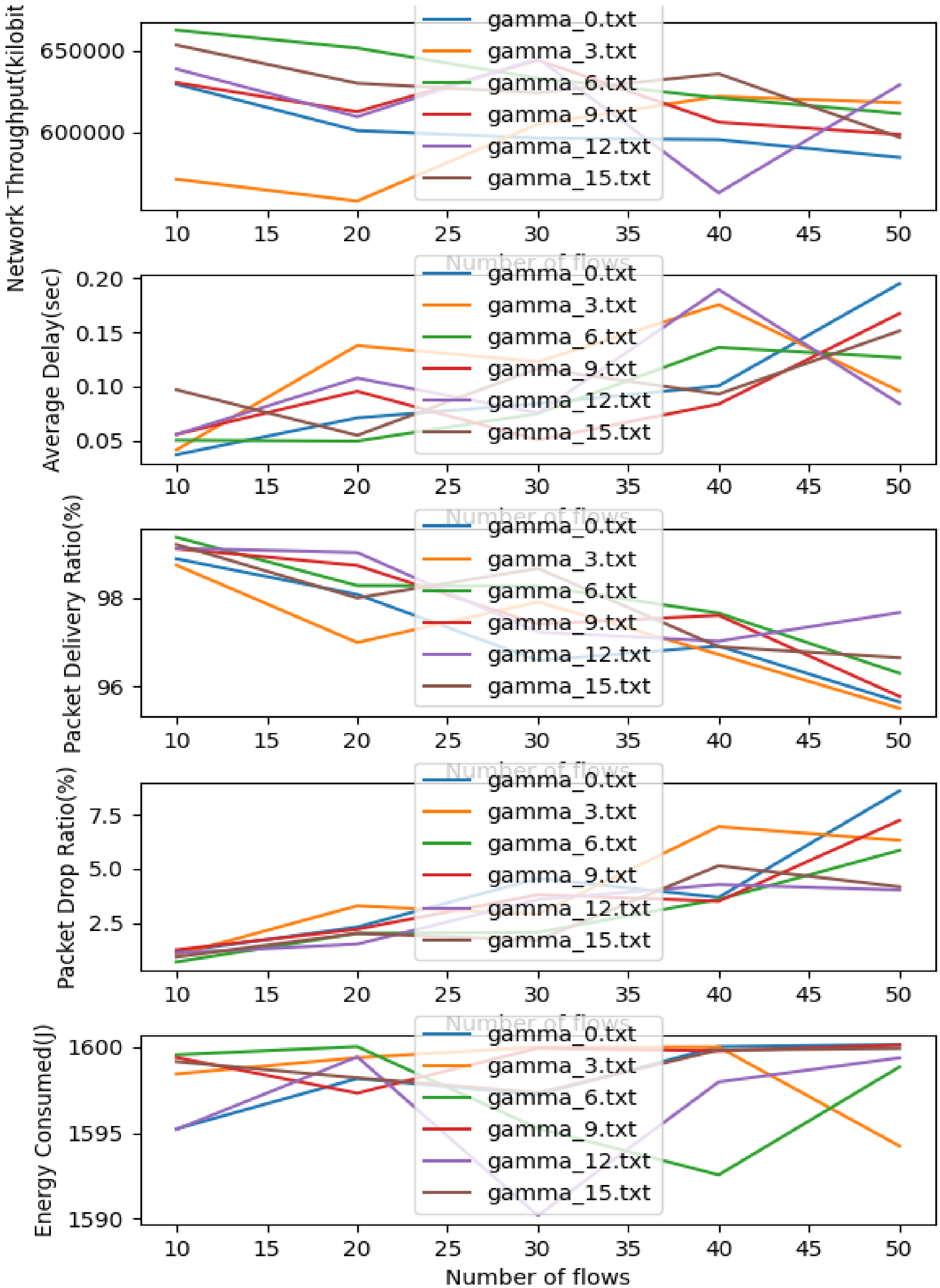
WIRELESS 802.11- STATIC NODES

Varying Area Size



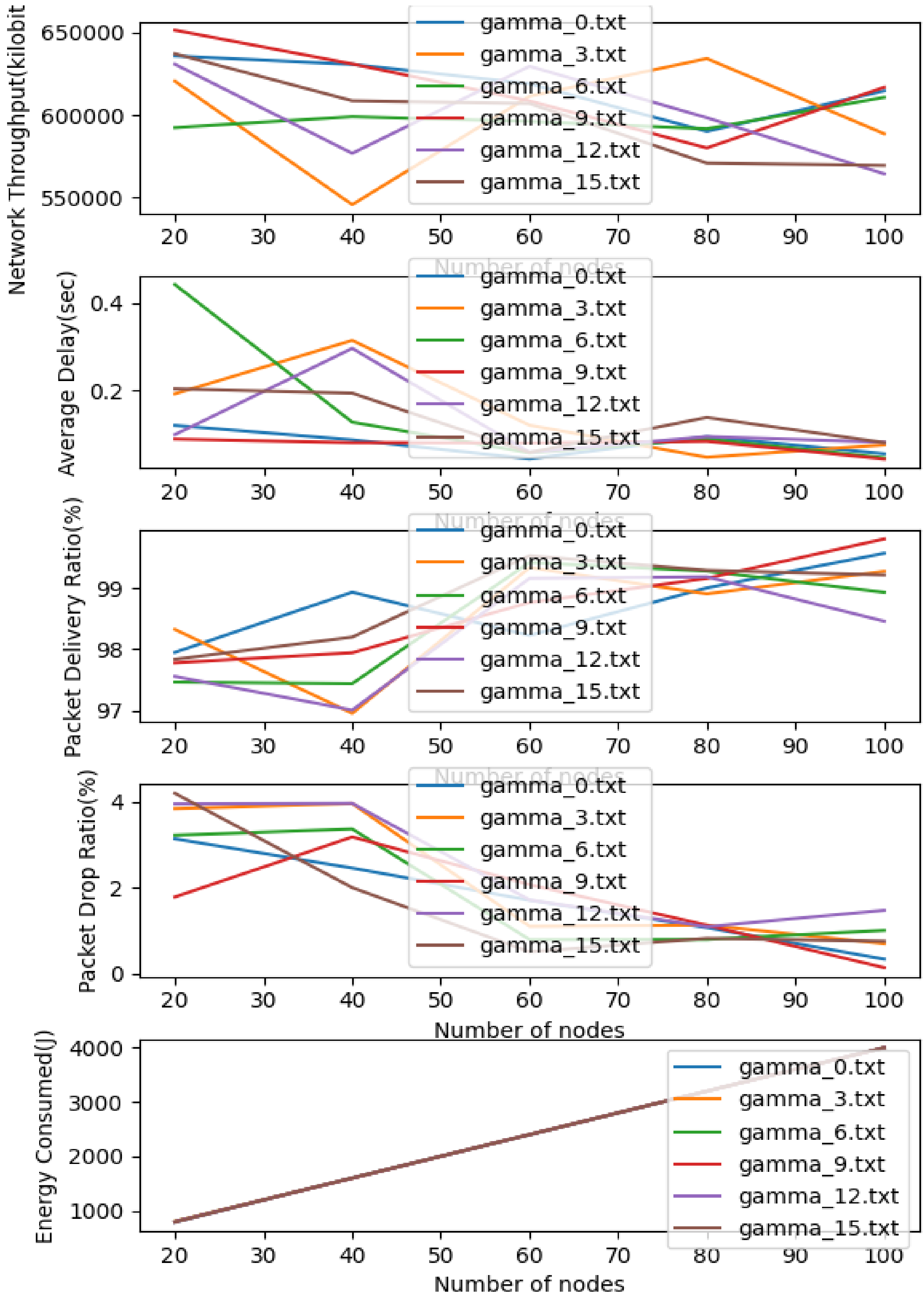
Graph 2: Varying Area for 802.11 static topology

Varying Number of Flows



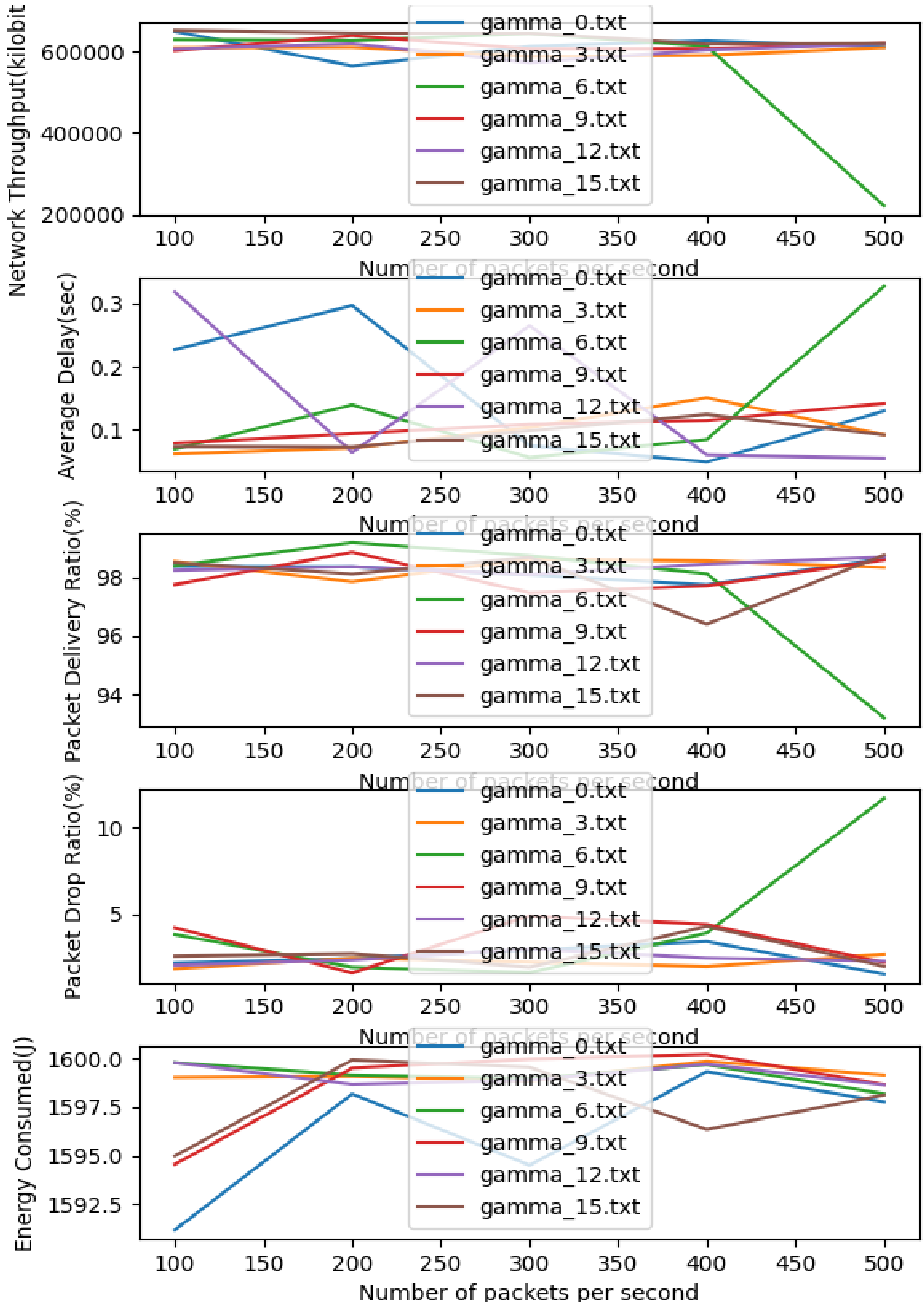
Graph 3: Varying Number of Flows for 802.11 static topology

Varying Number of Nodes



Graph 4: Varying Number of Nodes for 802.11 static topology

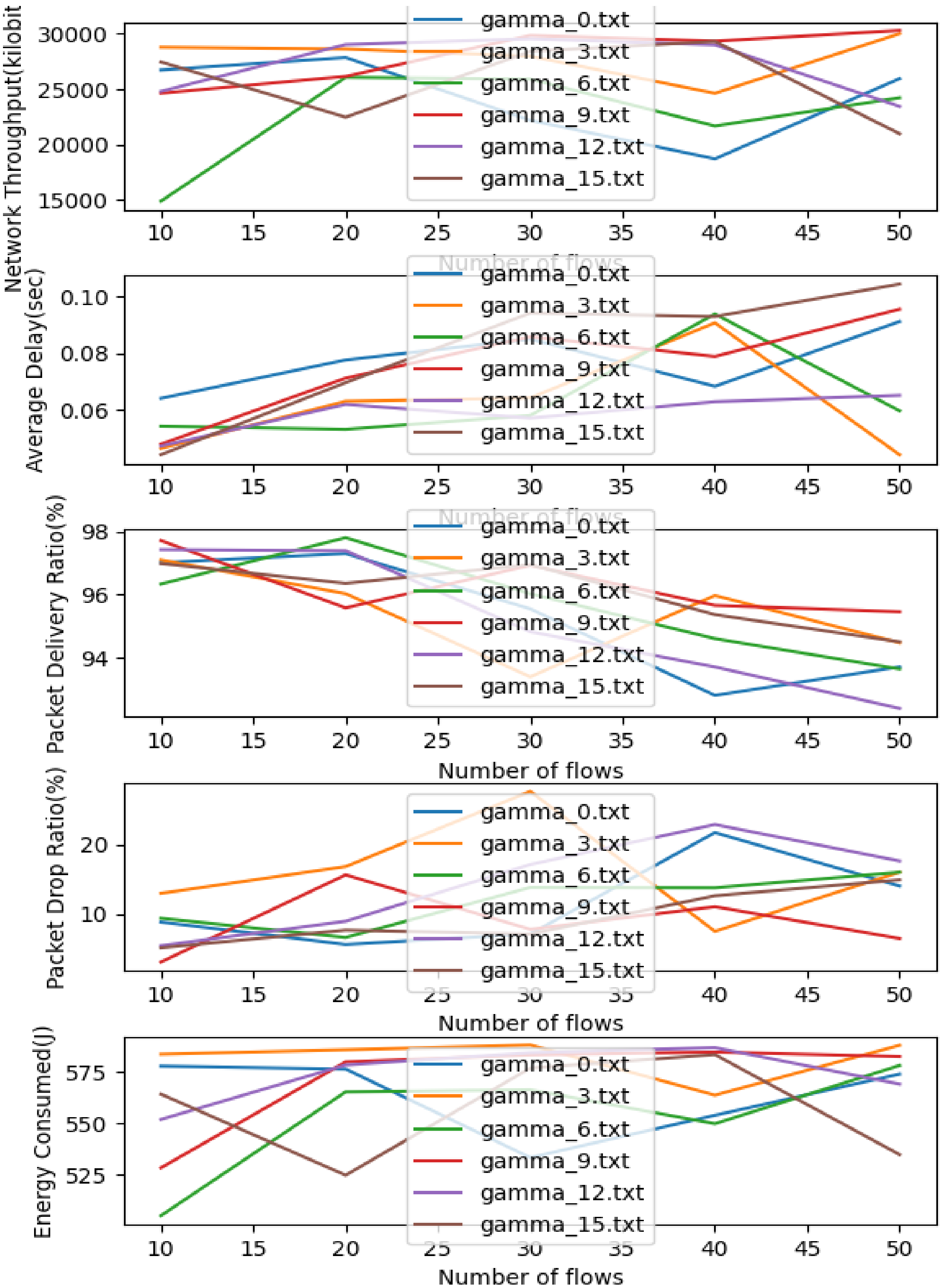
Varying Number of Packets per Second



Graph 5: Varying Packet Rate for 802.11 static topology

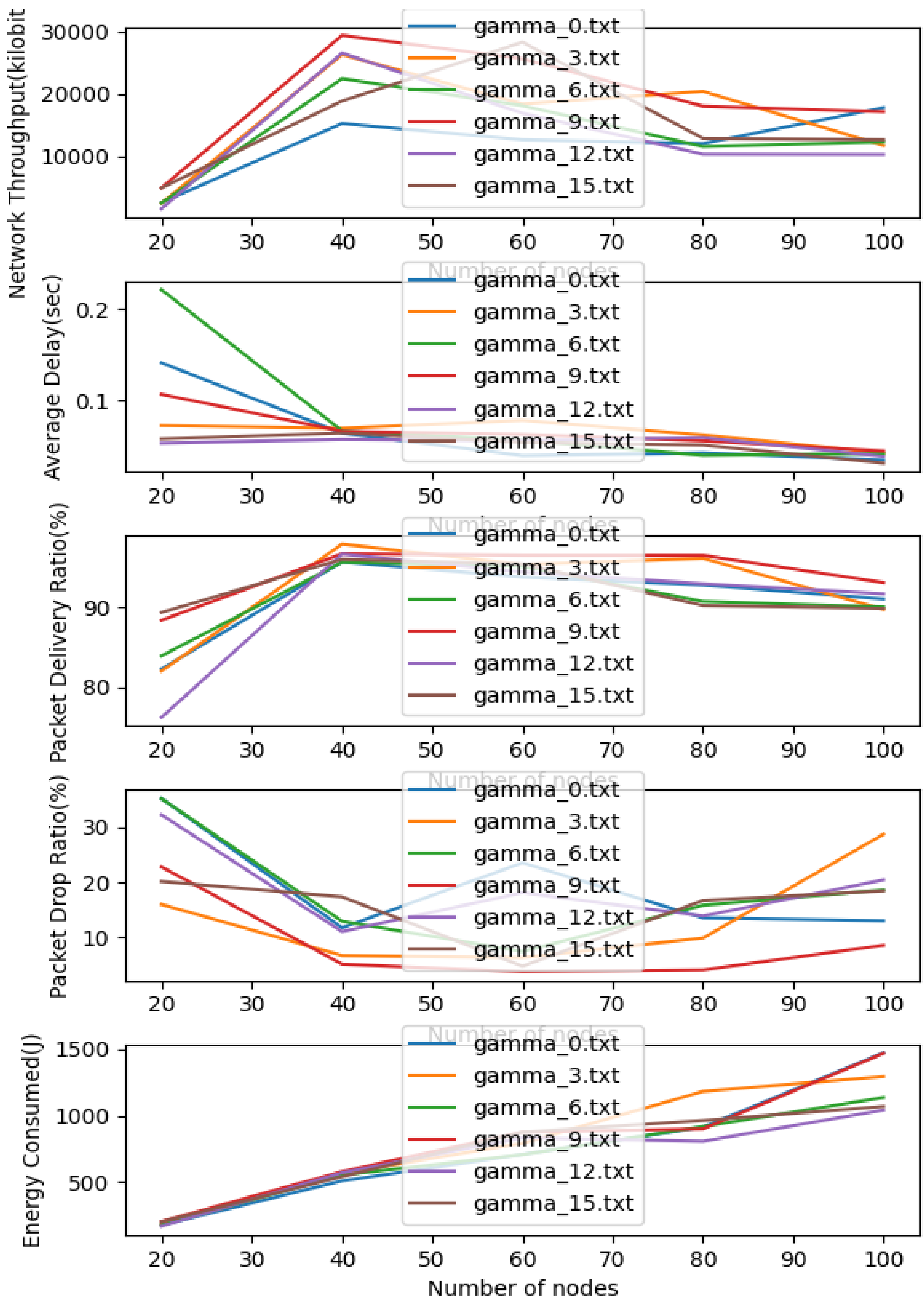
WIRELESS 802.5.4- MOBILE NODES

Varying Number of Flows



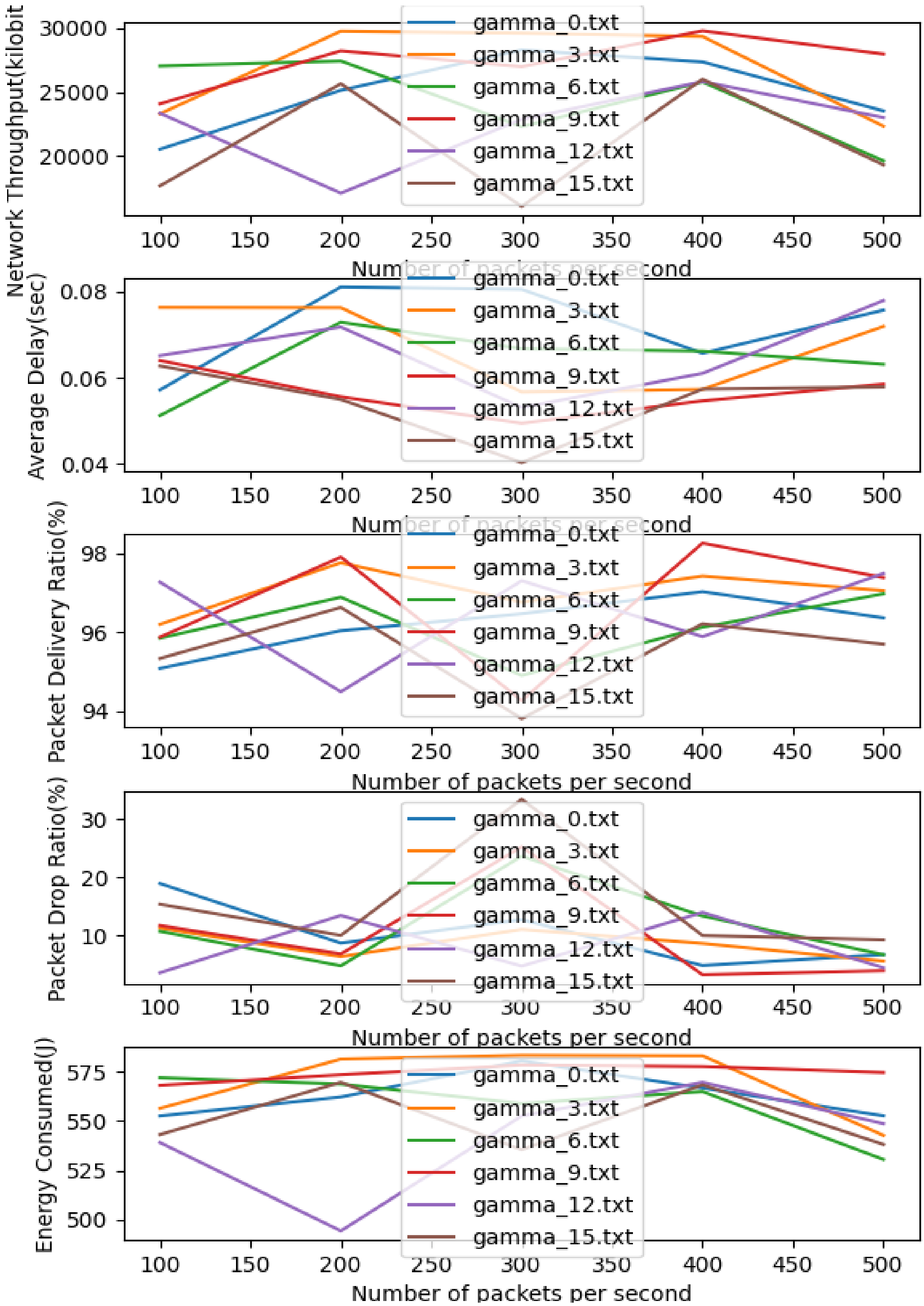
Graph 6: Varying Number of Flows for 802.15.4 mobile topology

Varying Number of Nodes



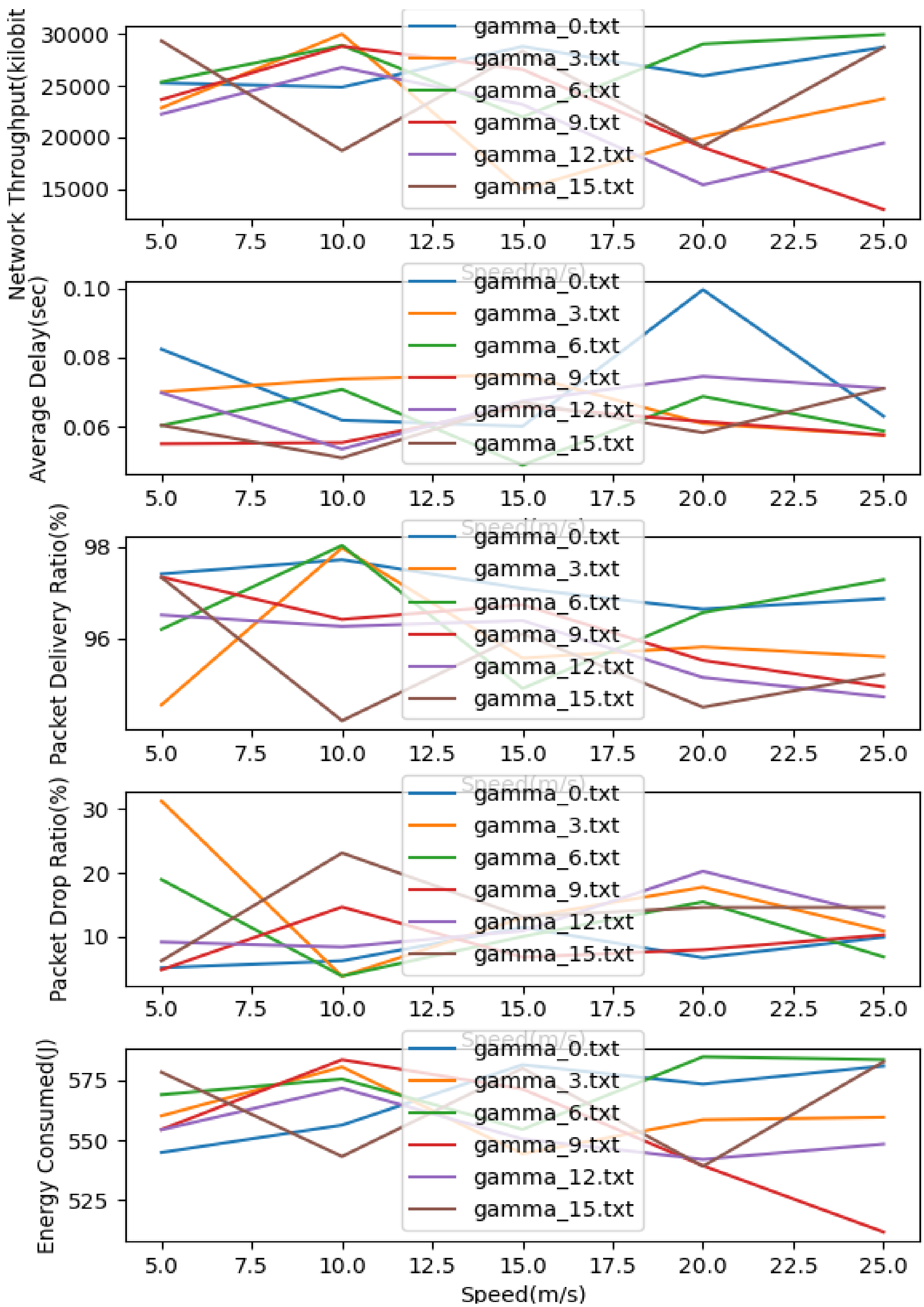
Graph 7: Varying Number of Nodes for 802.15.4 mobile topology

Varying Number of Packets per Second



Graph 8: Varying Packet Rate for 802.15.4 mobile topology

Varying Speed of Nodes



Graph 9: Varying Speed of Nodes for 802.15.4 mobile topology

Discussion

WIRED TOPOLOGY

The original paper contains a dumbbell wired topology with N sources and N destinations with a bottleneck link connecting them. In this project we have showed a dumbbell topology that has N number of sources but one destination only. We wanted to show the effect of change of the modified algorithm and since all the parameters of the original network is not provided we could not reproduce the same network. We can see from the graph that for gamma=3, the delivery ratio and the drop ratio outperform the curves corresponding to others values of gamma (Graph 1). Surprisingly, this is also obtained from the original paper. The average delay also decreases with the increase in number of nodes for gamma=3. Unfortunately, the best throughput is not obtained for gamma=3. Finally, a noteworthy observation is that, throughput improves whenever non-linearity is introduced compared to where it is not used.

We did not get any reference for a wireless topology for a RED queue, so we designed the topology on our own accord. As a result, we have not got very promising result as of yet.

WIRELESS TOPOLOGY-802.11-STATIC

In this topology, we have introduced randomness, as a result, none of the graphs seem promising enough to give any decisions.

One thing that can be observed from the graphs is that the throughput generally increases for any value of gamma other than 0 that is any version of modified RED. While varying the area size, the throughput for a particular value of gamma should have been constant all throughout the variation, but due to randomness we do not see this trend (Graph 2). When we vary the number of flows, congestion generally increases, thus the packet delivery ratio decreases and the packet drop ratio increases. From the graph we see that the trend of decrease of delivery ratio or increase of drop ratio is a bit slower for higher values of gamma (Graph 3). For variation in the number of nodes, with a fixed flow, congestion decreases and delivery ratio increases while drop ratio decreases. In this case also, for higher gamma, the change rate is slower (Graph 4). While we vary the packet rate, we do not really notice any versatility in the graph (Graph 5).

WIRELESS TOPOLOGY-802.15.4-MOBILE

Firstly, we increase the number of flows keeping the number of nodes fixed, which causes increase in congestion. We can observe that when congestion increases non-linear REDs perform better than the original RED in all five output parameters (Graph 6). Then, we vary the number of nodes, number of packets per second and speed of nodes but we do not really get any significant result from these data though we designed a deterministic topology (Graph 7)(Graph 8)(Graph 9).

It is also mentionable that, for 802.15.4 standard we faced an error as follows:

[wpan/p802_15_4phy.cc::PD_DATA_request][12.927402](node 19) Invalid PSDU/MPDU length: type = message, src = 19, dst = -1, uid = 12817, mac_uid = 2522, size = 135

For this standard the maximum packet size is 127 bytes. Even though we have set the packet size as 50 bytes only we have still faced this error for some of the combinations. While the program runs successfully even with this error, the output of the program becomes erroneous. We could not get rid of this error in any way.

Conclusion

We have introduced a linear-nonlinear combination packet drop probability function with an adjustable nonlinearity parameter that covers the original linear function in the RED. The effects of nonlinearity on the network performance were evaluated in terms of the throughput, average end to end delay, delivery ratio and drop ratio of packets. We have observed that there is generally an increase in throughput when non-linearity is introduced to the probability drop function. For wired topology, gamma=3 can be a promising value.

Reference

https://www.ieice.org/publications/proceedings/summary.php?iconf=NOLTA&session_num=A2L-E&number=A2L-E-03&year=2022

Conference: International Symposium on Nonlinear Theory and Its Applications 2022

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Appendix A

Some terminologies that are used in this report are defined below:

TWO-RAY GROUND PROPAGATION MODEL:

The two-ray ground-reflection model is a multipath radio propagation model which predicts the path losses between a transmitting antenna and a receiving antenna when they are in line of sight (LOS). Generally, the two antenna each have different height.

Ns-2 can have two other types of propagation models namely, Free Space Model and Shadowing Model.

OMNIDIRECTIONAL ANTENNA

An omnidirectional antenna is a wireless transmitting or receiving antenna that radiates or intercepts radio-frequency (RF) electromagnetic fields equally well in all horizontal directions in a flat, two-dimensional (2D) geometric plane.

DSDV

Destination-Sequenced Distance-Vector Routing (DSDV) is a table-driven routing scheme for ad hoc mobile networks based on the Bellman-Ford algorithms. Each entry in the routing table contains a sequence number, the sequence numbers are generally even if a link is present; else, an odd number is used. The number is generated by the destination, and the emitter needs to send out the next update with this number. (Source: Wikipedia)
The main advantage of this routing protocol is the availability of paths to all destinations in the network which results in the less delay in path setup. On the contrary, DSDV requires a constant bandwidth for the routing tables even when the network is idle. Also, this protocol is not suitable for highly dynamic or large scale networks.
Other types of routing protocols are DSR and AODV but they result in segmentation fault with RED.

AGENT LAYER: TCP TAHOE

Transmission Control Protocol is a layer 4 protocol in the OSI reference model. This protocol uses a network congestion-avoidance algorithm that includes various aspects of an additive increase/multiplicative decrease (AIMD) scheme, along with other schemes including slow start and congestion window (CWND), to achieve congestion avoidance.

TCP Tahoe consider retransmission timeout (RTO) and duplicate ACKs as packet loss events. If three duplicate ACKs are received (i.e. four ACKs acknowledging the same packet, which are not piggybacked on data and do not change the receiver's advertised window), Tahoe performs a fast retransmit, sets the slow start threshold to half of the current congestion window, reduces the congestion window to 1 MSS, and resets to slow start state.

There are other types of protocols such as UDP and different other variations of TCP (such as, Reno, Vegus, Cubic etc.)

APPLICATION LAYER: FTP

The File Transfer Protocol (FTP) is a standard communication protocol used for the transfer of computer files from a server to a client on a computer network.

Other types of protocols are Telnet, HTTP, DHCP and there can be CBR or Exponential traffic.

(Source: Wikipedia)