UNIVERSITÀ DI TRENTO

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FINAL DISSERTATION

TITLE

Subtitle (optionl)

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Summary

...summary....

Minimum Route Advertisement Interval (MRAI)

1 Introduction

- How is internet built
- the protocol that controls internet

1.1 Internet nowadays

- Use today studies to show how internet is today

1.2 Correlation between variables and convergence

- Expose the hypothesis of the correlation

Forget about the possibility to converge in seconds or even sub-seconds when we talk about internet routing convergence there are a lot of factors that influence it. The convergence time is mostly affected by some timers that rules the Internet. It could require up to different minutes to achieve a complete convergence, spread a new routing information to all the nodes.

One of the most effective timers is MRAI and it has been already proven FiXme: Insert citation that whith

1.3 Goal of this thesis

- Why is important understand this correlation?

2 BGP state of the art

- BGP de facto standard on the internet
- What is an AS
- interconnection between ASes

2.1 BGP

- High level of BGP
- BGP messages
- BGP Update messages
- BGP policies

2.2 BGP Wedgies

- What are wedgies?
- why are them important?
- which situations them occur?

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- What is MRAI?
- Previous works on MRAI
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- What is RFD?
- Why is used RFD?
- Evolution of RFD?
- RFD Today

3 Discrete Event Simulator

Experiments on Border Gateway Protocol (BGP) are not applicable on the Internet, for this reason different studies shows their results using a simulate environment [1] FiXme: Insert other citations. The majority of the studies uses small graphs, and each node of the graph simulate the behaviour of a BGP speaker. Each node represent also a single Autonomous System (AS) and the BGP speaker is it's own exterior router, for simplicity reduced to one speaker that handles all the connections.

For this reason I decided to use and expand a Discrete Event Simulator (DES) that permits to have different grades of freedom, respecting on the other side all the properties required for a reliable simulator environment. I decided to use the *Simpy*[1] package to make the environment evolve. I decided for this package for the extensive documentation and because it has been already used for different studies, demonstrating its adaptability [2, 3].

I developed the DES as a highly modular environment. In Figure 3.1 is possible to see the basic

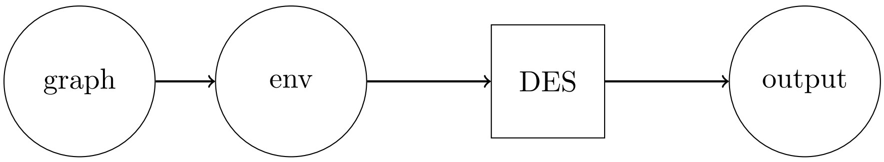


Figure 3.1: Discrete event simulator structure

idea of the simulator. The first component needed is a graph, represented by a *graphml* file, this file is descriptor of the network. it defines also all topological information and all the properties of each single node. FiXme: Look for a Cref implementation of this In Code 3.1 is possible to see an example of a *graphml* file, it describes that node 0 contains a single destination and that the edge between nodes 2 and 5 is controlled by the policy —2, 2, 2— that defines a servicer-provider policy. Policies are encoded using the convention described in [4].

```
<node id="0">
     <data key="d0">10.0.0.0/24</data>
</node>
<edge source="2" target="5">
    <data key="d2">2, 2, 2</data>
</edge>
```

Code 3.1: Graph example

The graph is then embedded in the environment file, this file is in *json* format and it describes how the environment is characterized, it gives the initial values for the Random Number Generator (RNG) so that each experiment is replicable and other properties, like where the output should be saved, and, most importantly how the experiment should be conducted. There are two possible evolution of the environment:

- ***Continuous evolution***: In this category all the nodes that contains at least a destination will continuously share and retrieve the destination accordingly with the distributions defined in the environment;
- ***Signaling evolution***: Is possible to define a precise signal that should be executed by the nodes that contains a destination, for example, the signal "AWA" defines that there will be an announce followed by a withdraw and the an other announce.

[1] Simpy website

The DES take as input this *json* file where all the information are described, it creates an object for each node in the graph file, with each own characteristics. After the initialization all the nodes that contains a destination will schedule the first advertisement of it to their neighbour. The simulation run will terminate only if there are no more events scheduled or if the maximum simulation time is reached.

The DES will then produce a *CSV* output, with all the events that can be analyzed to see the evolution of a specific node or to evaluate the whole network.

3.1 DES Environments

Thanks to the environment codification in a *json* file is possible to define experiments with a high grade of freedom. Is possible to define multiple delays as probability functions vectors that will provide multiple runs possibility. For example, if we have 5 different possible seeds and 3 different delays, the total number of runs combinations is 15, as showed in Code 3.2. is possible to run one of the possible combination of parameters through the identifier of the single run.

```
"simulation" : {
    // seed(s) to initialize RNG
    "seed" : [0, 1, 2, 3, 4],
    ....
    // Multiple withdraw distributions
    "withdraw_dist": [{"distribution": "unif", "min": 5, "max": 10, "int": \
   0.1},
                      {"distribution": "unif", "min": 8, "max": 10, "int": \
   0.1},
                      {"distribution": "unif", "min": 2, "max": 3, "int": \
   0.1}],
    ....
}
```

Code 3.2: Environment example

In the environment is possible to define also the processing time, this time is used inside each BGP node to emulate the processing of information or the evaluation of a packet. Though the *delay* parameter is possible to define the default delay on the edges, is important to remember that the links are FIFO so there is no reordering of messages in the same link, there is also no messages lost. That because it was out of the scope of this thesis to study the evolution of the protocol with packet loss, but it could be a future work.

3.1.1 Clique environment

One of the special environment that I used it's composed by a clique graph graph of different dimensions, an example of clique graph is given in Figure 3.2.

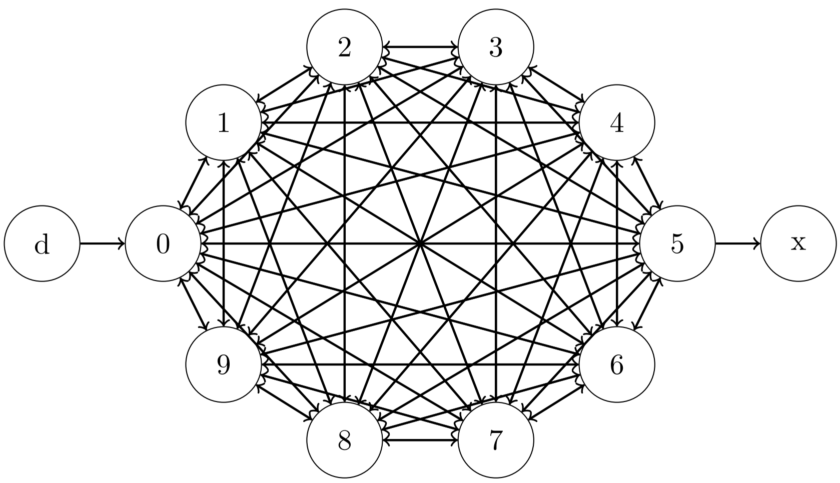


Figure 3.2: Clique graph example

The only node that shares a destination is the node "d", the node 0 will then spread the knowledge to the whole network, and the node "x" will act as a black hole for all the possible paths that the node 5 will share. This topology is used to enforce the path exploration problem.

3.1.2 Fabrikant environment

Another interesting chase to test the path exploration problem is the one presented in [5]. In that study Fabrikant et al. presents how particular MRAI setting could make the network converge with an exponential behaviour because of the path exploration problem. I used the basic example of their study to investigate how the choose of MRAI is fundamental for the network convergence. An example of the network used is presented in Figure 3.3.

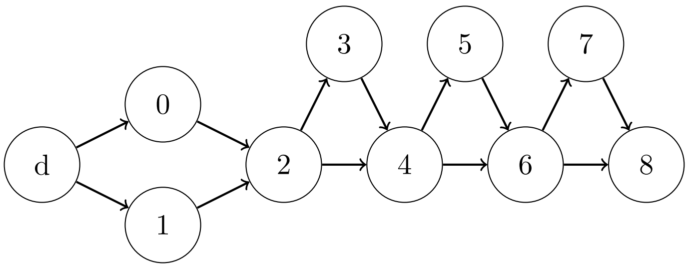
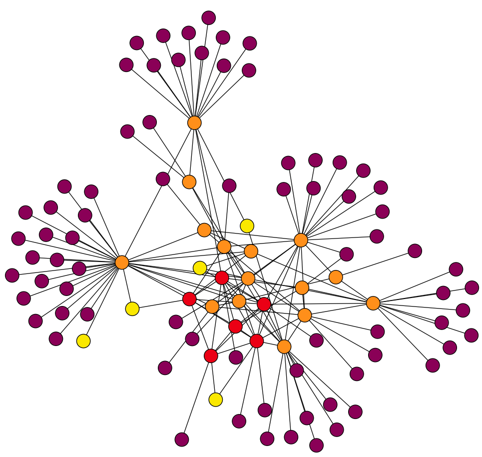


Figure 3.3: Fabrikant chain graph example

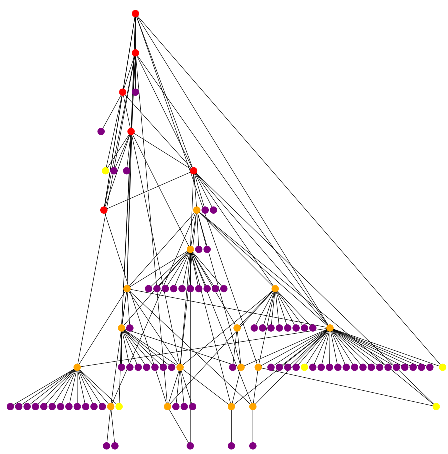
The path exploration problem is caused by the delay on the node 0-2 edge. The node 2 will receive the destination through node 1, after a small amount of time the network will converge to the best path (without using the backup links). But, after a while, node 2 will receive the network also through node 0 and it will prefer this new path, provoking then the reconfiguration of all the other nodes that will use the backup links for a while, announcing their new path. A wrong configuration of MRAI can provoke the entire exploration of the possibility set.

3.1.3 Internet-like environment

The last noteworthy environment is the one whose purpose is to simulate Internet behaviour. This has been possible thanks to the study by Elmokashfi et al. [6] and the internet like graph generator present in Networkx [2] (a python library famous for graph and network studies). An example with a small set of nodes is presented in Figure 3.4



(a) Internet like graph with an "explosive" layout



(b) Internet like graph with a "hierarchical" layout

Figure 3.4: Internet like graph colored to show the hierarchically structure, 4 types of nodes, T (tier 1 mesh), M, CP, C (Customers, purple one)

[2]Networkx internet as graph generator

The different nodes are colored accordingly with the node type represented. The tier one nodes that generate the central clique are colored in red, and is possible to notice in Figure 3.4b that them are in the highest levels of the networks. This environment has been used to study the behaviour of the network with topologies resembling the real internet.

4 Protocols as a Finite State Machine

An Finite State Machine (FSM) could be useful for a lot of purposes, to debug the protocol, to understand what is happening, to analyze leeks. It has been already done for a lot of protocols FiXme: insert citations, but not for BGP.

FiXme: Give more examples on what a protocol FSM is useful for

4.1 BGP generalization

The main idea behind the BGP FSM is to represent the knowledge as states and different set of messages as transitions. The knowledge is represented by the actual routes that the node knows to reach a single destination. Transitions encode the messages that a node has received to change state, on the edges are also inserted the response messages that the node will transmit.

FiXme: Insert image and table for an example

In BGP messages transmit information about routes, there could be the advertisement or the withdraw of the route.

Thanks to MRAI the evaluation of multiple messages could be delayed and provoke then the compression of them. For this reason on the edges we can see multiple messages, for example "A1W1A1", that will be compressed in "A1" and then evaluated.

The concept for a BGP FSM has been "taken" from [7].

- BGP as an FSM main idea
- signaling transmutation

4.2 BGP FSM experiments

The first experiments, about the translation of a single node evolution in a FSM, goal is to reproduce what has been showed in [7]. The graph used for the study is presented in Fig. 4.1.

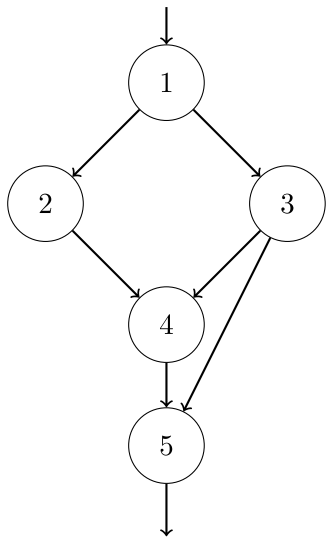


Figure 4.1: Graph from fig 4 of [7] used to study the FSM of the nodes

This topology, Figure 4.1, present an Stable Paths Problem (SPP) with five nodes [8]. The SPP model is used to eliminate much of the complexity of BGP. The arrows in the graph represent the flow of information, node 1 is the one that will receive a new route to reach an hypothetical destination and it will spread this information through an advertisement (ADV) to all it neighbours. The translation to the Communicating Finite-State Machine (CFSM) will use an enumeration to encode all the paths that a single node will encounter, for example the path "5 3 1" will be converted in *a3*, each path has its own identifier. In case of withdraw the route will be encoded as *w3*.

The properties of the environment for this experiment are listed in Table 4.1.

Property	Value
Seeds	$[1, 50]$
Signaling	"AW"
Withdraws delay	Uniform distribution between 20 s and 30 s
Announcement delay	Uniform distribution between 20 s and 30 s
MRAI	0 s for every link
Link delay	Uniform distribution between 0.001 s adn 1 s, uniform distribution between 0.012 s and 3 s

Table 4.1: FSM example environment properties

The total number of runs generated by this environment is 100.

FiXme: this paragraph is cumbersome The two nodes of more interest are node 4 and node 4. The first one can receive multiple combination of messages from node 2 and 3, for sure there will be two announcements and two withdraws, because node 1 has to respect a predefined signaling. but, those messages could be reordered in different ways, and for each sequence of them we can encounter a different sequence of output messages through node 5. Giving that the routes from node 2 and 3 will have respectively as ID 2, 3 the table Table 4.2 All possible inputs of node 4 are the shuffle of all possible outputs of nodes 2 and 3 preserving the local order.

Input signal	Output signal
$a2a3w2w3$	$a4w4$
$a2a3w3w2$	$a4w4$
$a3a2w2w3$	$a5a4a5w5$
$a3a2w3w2$	$a5a4w4$
$a2w2a3w3$	$a4w4a5w5$
$a3w3a2w2$	$a5w5a4w4$

Table 4.2: Node 4 different possible inputs and output

The node 5 will receive all the possible outputs from node 3 and 4 increasing the number of possible signals from 6 of node 4 up to 71 but some of them produce the same output signal, so we have in total 52 unique output signals from node 5.

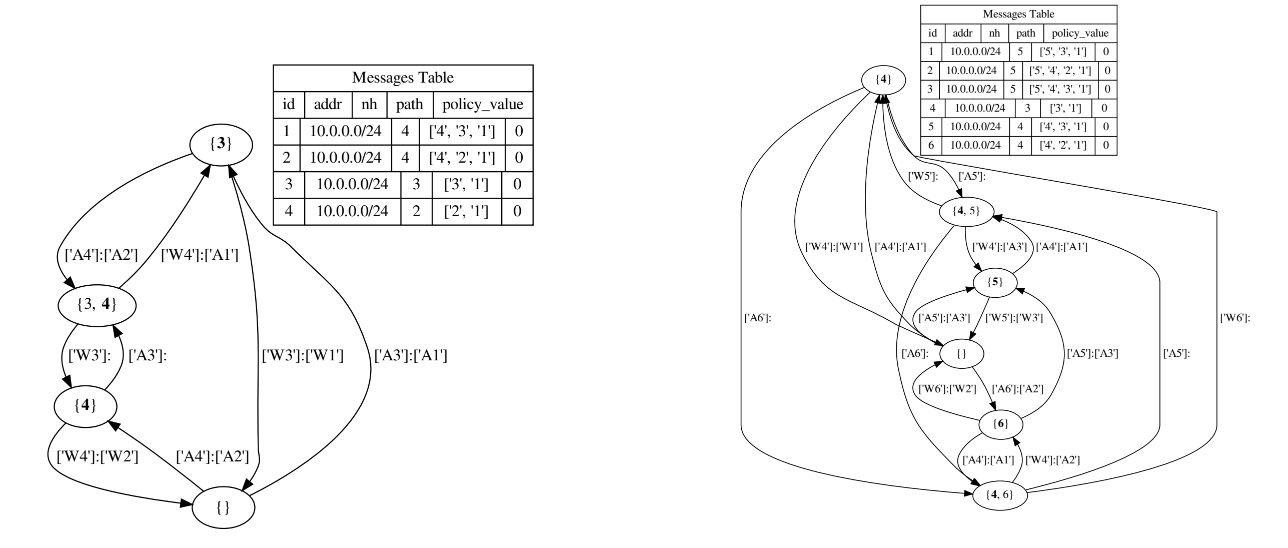
From the 100 total runs we can generate the CFSM of node 4 and node 5, in order to be able to study how the nodes reacts to different input signals. The two CFSM are presented in Figure 4.2.

FiXme: Remove message table from Figure 4.2?

The states of the CFSM in Figure 4.2 are represented by the knowledge of the nodes, composed by the routes that are in the Routing Information Base (RIB) of the node. The bold value is the actual best route to the destination chosen by the node. If in the state transition to a new state the best path is not affected then the node will not transmit the new route to it's neighbours, for an example take a look to Figure 4.2a from the state $\{1\}$ to the state $\{1, 3\}$ where the node 4 will learn a new route that is not the best one.

The effects of the implicit withdraw can be see in Figure 4.2b the transition from $\{1, 4\}$ to $\{1, 3\}$ thanks to the reception of the announcement $a3$ from the node 4.

As written in [7], I would like to underline the fact that, given the 52 unique possible outputs of the node 5 it would be very difficult to infer the initial signal that provoke all the transitions.

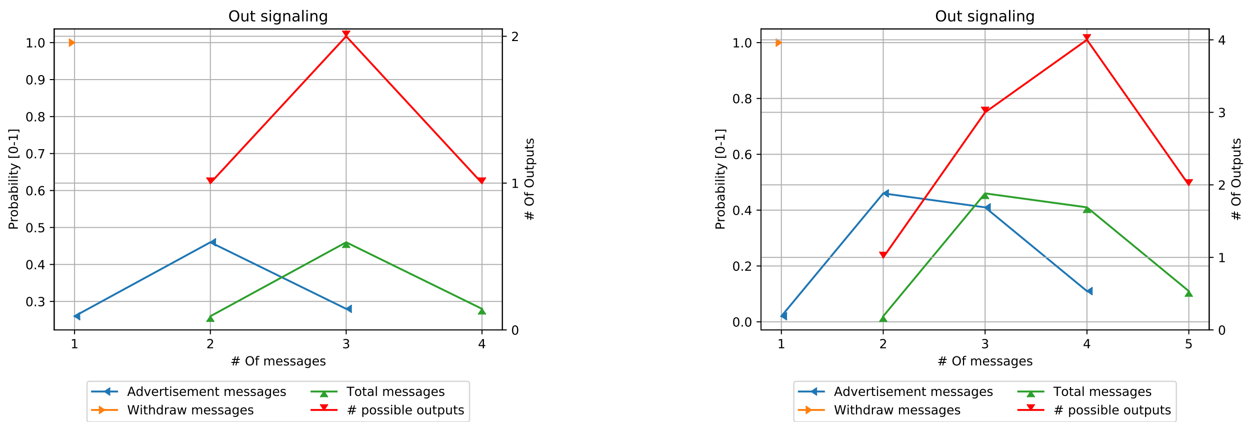


(a) Node 4 CFSM from the environment of Table 4.1

(b) Node 5 CFSM from the environment of Table 4.1

Figure 4.2: CFSM of nodes 4 and 5 of the graph Figure 4.1 with an input signal of "AW"

We can also analyze those output signals, having all the events for each single run we can infer which were the most common output signals that a single node experienced. Is sufficient to take all the transmitted messages of a node and look the sequence of advertisement and withdraws.



(a) Node 4 output signals study

(b) Node 5 output signals study

Figure 4.3: Output signal study of nodes 4 and 5 of the graph Figure 4.1 with an input signal of "AW" at node 1

The plots in Figure 4.3 represents the probability of an output signal of a certain length to appear and the number of unique output signals of a unique length has been found. The x axis represent the number of messages in the output signal, a message is a single announcement or withdraw. The first y axis represent the probability to see a certain number of messages taking a random output signal from the output. For this axis there are three lines that refers to it, the blue one represent the number of advertisement messages in the output signal correlated with the respective probability. For example in Figure 4.3a there is a probability around 0.45 to have exactly two advertisement messages per output signal. And respectively a probability slightly larger than 0.25 to have only one advertisement or three. We can also notice that we didn't see more than three advertisements or less than one. The green line instead represent the total number of messages in the signal, without distinguishing between advertisement and withdraws. By the fact that we will always have one withdraw (the orange line) this line is simply shifted by one unit in respect of the advertisement line. The second y axis refers to the number of unique output signals encountered and their length. For example, in Figure 4.3b we will have 1 unique output signal of length 2, 3 signals of length 3 and 4 of length 4 and 2 of length 5.

Those plots does not give a complete prospective of all the possible outputs that can be generated but only the ones encountered during the runs. In fact, during the 100 runs we encountered only the output signals listed in Table 4.3.

Signal	Frequency
$a1a2a1w1$	28
$a2a1w1$	23
$a2w2$	26
$a1a2w2$	23

(a) Node 4 output signals encountered

Signal	Frequency
$a1a2a3w3$	15
$a1a3w3$	16
$a2a1a2w2$	19
$a1a2w2$	28
$a1w1$	2
$a2a1a3w3$	6
$a2a1a2a3w3$	8
$a3a1a2a3w3$	3
$a2a1w1$	2
$a3a1a3w3$	1

(b) Node 5 output signals encountered

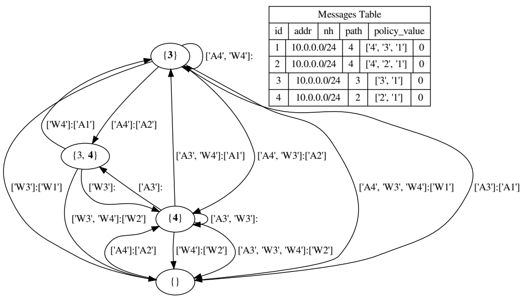
Table 4.3: Node 4 and 5 different output signals encountered during the runs

4.2.1 MRAI and BGP FSM

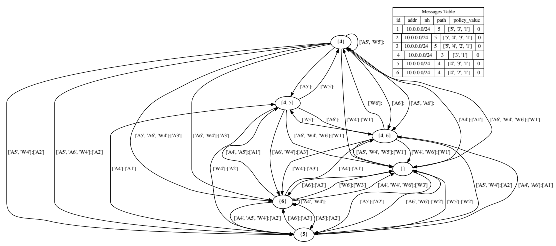
How would MRAI affect the study of the signals produced by Figure 4.1? The answer is that the number of states will be the same but the number of possible transitions will explode, because there will be a lot more possible input signals that will be compressed and evaluated by the nodes.

We can see the effects of MRAI on the CFSMs in Figure 4.4.

FiXme: Figure 4.4b is not readable at all, move the two figure one after the other



(a) Node 4 CFSM from the environment of Table 4.1 with MRAI=30 s



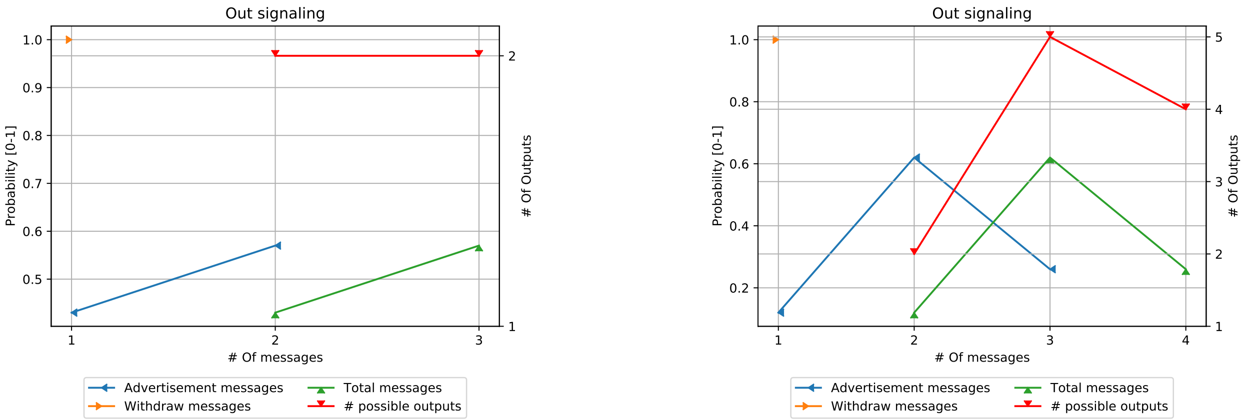
(b) Node 5 CFSM from the environment of Table 4.1 with MRAI=30 s

Figure 4.4: CFSM of nodes 4 and 5 of the graph Figure 4.1 with an input signal of "AW" with MRAI=30 s

Figure 4.2a and Figure 4.4a permits us to compare the two CFSMs of node 4 and is possible to nice a big difference in terms of edges between one figure and the other, the first one has 8 transitions, the second one 15. For the node 5 we pass from 16 transitions to 36.

But the positive effects of MRAI can be found in the output signals, showed in Figure 4.5.

Comparing Figures 4.3b and 4.5b is possible to notice that there is a different distribution of output signals. The x axis never reach the value of 5, this means that the output signals of the node 5 never used more than 4 messages. And we can also notice that the majority of the signals this time have a length of 3 messages, instead of the previous 4. This is a hint that MRAI can have positive effects on the number of output messages produced by single nodes, having, however, more possible transitions to consider.



(a) Node 4 output signals study with MRAI=30 s

(b) Node 5 output signals study with MRAI=30 s

Figure 4.5: Output signal study of nodes 4 and 5 of the graph Figure 4.1 with an input signal of "AW" at node 1 with MRAI=30 s for every link

4.3 BGP FSM explosion

We know that MRAI is not an easy parameter, the incorrect setting of it can lead to an explosion of messages and an exponential convergence time. This problem has been studied by Fabrikant et al. [5] and the origin of the problem has been attributed to the *path exploration* problem. This is a well known problem in the BGP community and it is experienced by a node when it enters in a transitory phase where it accept and publish not optimal paths towards the destination before reaching a stable state. *Path exploration* can lead to an enormous amount of messages even with a small set of nodes [9].

As we saw in Section 4.2.1 that MRAI can influence the CFSMs of the nodes and their output signals, which impact could it have if it is not set correctly?

I have then created an environment that resemble the study conducted by [5] using a topology like the one described in Section 3.1.2 with 3 rings. with different MRAI settings. The environment properties are presented in Table 4.4.

Property	Value
Seeds	$[1, 30]$
Signaling	"A", "AW", "AWA", "AWAW"
Withdraws delay	Uniform distribution between 5 s and 10 s, Uniform distribution between 10 s and 15 s
Announcement delay	Uniform distribution between 5 s and 10 s, Uniform distribution between 10 s and 15 s
Link delay	Uniform distribution between 0.5 s adn 3 s, uniform distribution between 2 s and 4 s

Table 4.4: Fabrikant experiments environment

In total for each signaling experiment this environment produces 240 runs. I have then introduced 4 different MRAI strategies for each different signal. The different MRAI strategies are the following one:

- ***Fixed* 30 s**: MRAI is fixed for each link to 30 s;
- ***No MRAI***: MRAI is fixed for each link to 0.0 s;
- ***Ascendant***: MRAI will be doubled at each leach $(1 - 2 - 4 - 8 - ...)$;
- ***Descendent***: Reverse of the ascendant case, MRAI will be divided by two at each leach.

Another important factor to consider during those experiments is the Implicit Withdraw (IW) capability of BGP. This parameter will influence the number of messages that will be transmitted.

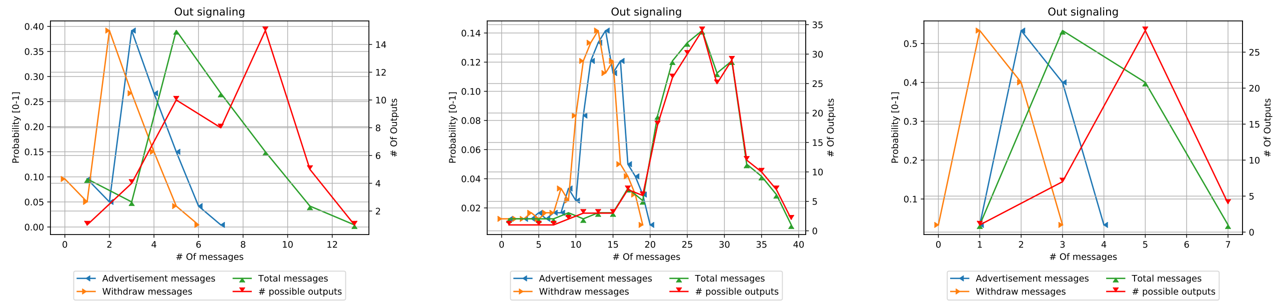
The results of all those different experiments, in terms of CFSM are exposed in Table 4.5

Signaling	IW	No MRAI		Fixed 30s		Ascendent		Descendent	
		$\lvert S\rvert$	$\lvert T\rvert$	$\lvert S\rvert$	$\lvert T\rvert$	$\lvert S\rvert$	$\lvert T\rvert$	$\lvert S\rvert$	$\lvert T\rvert$
"A"	Yes	12	19	15	26	7	12	16	24
	No	30	100	30	125	9	21	30	132
"AW"	Yes	52	181	37	103	24	71	40	80
	No	51	221	57	263	22	90	58	274
"AWA"	Yes	51	170	25	50	33	148	50	137
	No	69	364	37	180	30	203	66	419
"AWAW"	Yes	77	461	38	132	54	300	53	148
	No	78	500	62	429	48	350	66	441

Table 4.5: Fabrikant CFSMs results, $|S|$ is the dimension of the states set $|T|$ is the dimension of the transitions set, The worst results for each category are colored in gray, the topology contains 3 rings, as Figure 3.3

As is possible to see from the gray squares in Table 4.5 the more complex CFSMs are the ones without MRAI and with a descendent MRAI timing. The second case is the same described in [5] and the extremely high number of transitions is caused by the *Path Exploration* problem. Is also noticeable that the IW has a huge effect on both the number of states and the number of transitions. This because there are less possible combination of input signals for the nodes. The opposite case in respect of the *Descendent* strategy obtain great results, even better than the actual standard of 30 s for each link. This performance improvement is caused by the fact that each leach will wait enough time to have more information from its predecessor in order to have more information to take the best decision.

The *Path Exploration* problem is also noticeable evaluating the output signals of the last node of the chain. Results about the output signal of the node 8 (the last node of the gadget) are presented in Figure 4.6.



(a) Node 8 output signals study with ***Fixed* 30 s** strategy

(b) Node 9 output signals study with ***Descendent*** strategy

(c) Node 9 output signals study with ***Ascendant*** strategy

Figure 4.6: Output signal study of nodes 8 of the graph Figure 3.3 with an input signal of "AWA" at node d with the ***Fixed* 30 s**, ***Descendent*** and ***Ascendant*** strategies, without the help of the IW

The first signal study, Figure 4.6a is the one that represent the actual standard of the protocol [10]. We can notice in that particular output study that the maximum detected length of a signal is 13 and it's the last probable output, while the most probable output length is 5. While we can notice the *Path Exploration* problem by the spike of unique output signals with a length of 9, this mean that the node experienced some changes in its decisions. The worst case scenario is the one represented by Fig. 4.6b where the maximum length of output signal reaches almost 40 messages, but the most probable output signal have a length between 20 and 30. This is the marker of a lot of decision changes in the best path for the node 8. Opposite to that case we found the *Ascendent* strategy in Figure 4.6c where the number of output signals never used more than 7 messages. The node 8 in this last case almost never experienced the *Path Exploration* problem, thanks to the fact that most of the times the information it receives from the neighbourhood are already corrected.

In conclusion of this chapter we can say without doubts that MRAI influences the number of states experienced by a node and, confirming what has been sad in [5], that an incorrect setting of it can lead to an explosion on the number of states and transitions. It is also noticeable that a different setting of MRAI can also lead to a better scenario than the standard one. Alternatives to the standard MRAI has been already presented FiXme: Include citations and maybe find a better end of the chapter

5 BGP MRAI dependency

MRAI is one of the parameters that mostly has caused divergences in the scientific community. And, after the introduction in the protocol since the version 4 [10] FiXme: Check this sentence, is one of the more studied for the possibility to improve the protocol or generate exponential convergence behaviour in small network [5].

The protocol strictly depends on this parameter, because as we saw in Chapter 4, the incorrect use of it can lead to tremendous consequences, even worst of not having it at all. In other cases, with a particular setting of it is possible to improve the network performances. Recent studies about centrality metrics on routing protocols introduce, through the distributed computation of the metric, to a timer trade off improvement [11, 12]. This kind of approach has been also applied on BGP with positive results on network failures [13, 14].

All those study points out how we can set MRAI to improve network performances, but what about how MRAI reacts on different problems? Is it possible that MRAI reacts differently based on where the signal occurs? In fact, our hypothesis is that is not enough just look to the MRAI setting because also other factors can be relevant. For example, a change near the central clique of T nodes could provoke a large storm of messages because MRAI doesn't affect in time the spreading of information. While, a change in the periphery could be cushioned without it reaching the center of the network.

5.1 Clique graph

The clique topology is one of the worst case scenario as specified in Labovitz et al. [15] I used two approaches in this Environment, the first one keeps the IW active the second one avoid the use of this property. To emphasize the effects of this parameter with the effects also of different MRAI settings.

The Environment properties are listed in Table 5.1

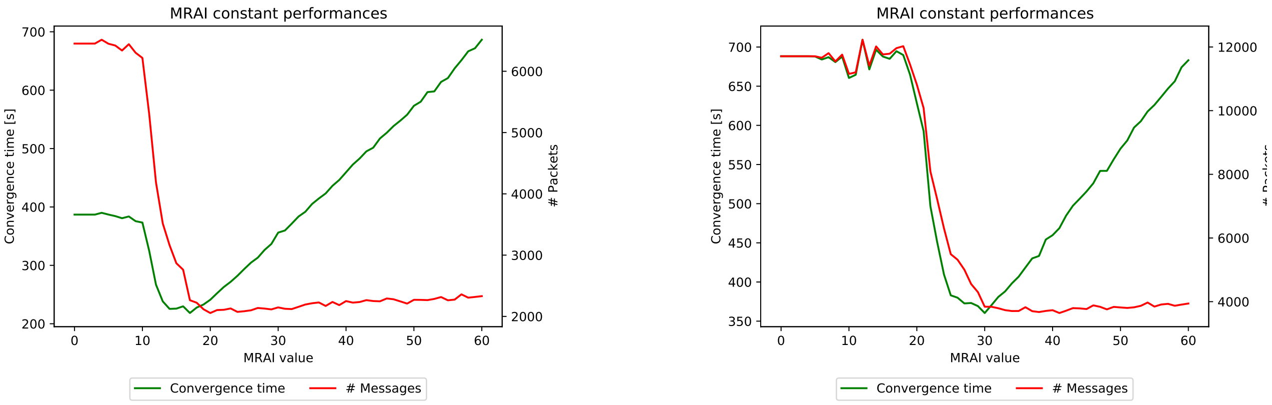
Property	Value
Seeds	$[1, 10]$
Signaling	"AW"
Withdraws delay	Uniform distribution between 1 s and 5 s
Announcement delay	constant distribution of 5 s
MRAI	$[0, 60]$
Link delay	Uniform distribution between 0.0001 s and 0.5 s

Table 5.1: Clique environment properties

As described in Table 5.1, for each MRAI value has been executed 10 different runs of the environment. The clique graph used in this experiments is composed by 15 nodes. The MRAI strategy used is the *fixed*, so every link will have the same MRAI value. The results are presented in Figure 5.1

Is possible to notice in Figure 5.1 both the effect of MRAI and IW. Those plots represent the network performances in terms of convergence time and number of messages transmitted to reach the convergence after the transmission of the signal "AW". The convergence time is represented by the average time from all the nodes in the network. Each point in the plots is the average of the 10 runs with the *fixed* MRAI value on the x axis. The left y axis should be used with the convergence time, the green line, while the second y axis represent the number of messages transmitted, the red line.

The effects of the first one are present in both the plots but in two different moments. In Figure 5.1a MRAI affects both the convergence time and the number of messages around 20 s up to 30 s. After the threshold of 30 s the effects of MRAI are counterproductive, the convergence time is negatively



(a) Network performances **with IW**

(b) Network performances **without IW**

Figure 5.1: Evolution of the network performances on the clique graph of 15 nodes using a fixed MRAI from 0 to 60 seconds. FiXme: use the same interval in the y-axis?

affected because the nodes starts to wait more time without obtaining more useful information. This can be see also in the number of messages that reaches a constant value.

In Figure 5.1b we can see the same effect but with a higher MRAI value. The number of transmitted messages reaches the constant value with an MRAI value around 30 s. The effects of IW can be saw also in the number of messages and the convergence time with a low MRAI, is possible to reach even 12 000 messages while with IW the maximum value is around 6500 messages.

5.2 Internet like graph

The internet like environment is more complex than the clique one, but it permits to have a more close vision of what can really happen on the Internet. During my studies I used different topologies with 1000 nodes resembling the Elmokashfi properties [6] already described in Section 3.1.3.

Using this graph I will look for possible correlation between MRAI and other factor that can influence the network. First of all MRAI has a dependence on how it is set, I'm going to compare different MRAI strategies that can be used on an Internet like graph. Another influence factor could be the signal used as input, or even the position of the node that provoke the change.

5.3 Strategy dependence

Like I mentioned before, the network performances depends on the MRAI strategies chosen. For this reason the first point of my study is to point out this differences. In order to do that, the first study that I would like to present is the one that study how the standard protocol evolves on an Internet environment.

The property of the environment chosen are described in Table 5.2

Property	Value
Seeds	$[1, 10]$
Signaling	"AW"
Withdraws delay	Uniform distribution between 1 s and 60 s
Implicit withdraw	Active
MRAI	$[0, 60]$
Link delay	Uniform distribution between 0.012 s and 3 s

Table 5.2: Internet like environment properties

The graph is an *Internet like* graph with 1000 nodes. The node that will execute the signal has been chosen randomly between all the nodes of type "C". This graph will be the same for all the experiments in this section.

For each MRAI strategy, that I'm going to present, has been executed 61 experiments, one for each possible value of MRAI, for each experiments thanks to the environment variable has been executed 10 runs. In total for each MRAI strategy has been run 610 different runs

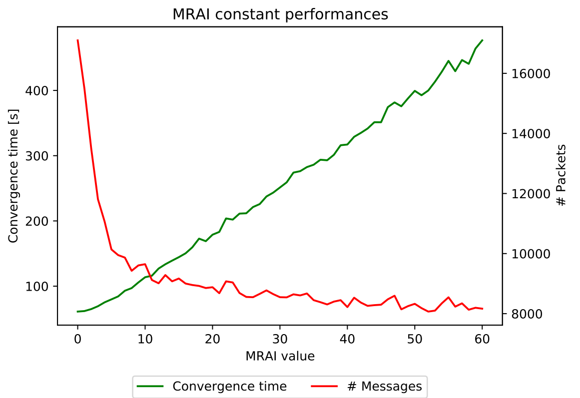
As MRAI strategies I decided to use the following two:

- ***Fixed***; Every link will have the same MRAI value;
- ***DPC***; This strategy assign a different MRAI value to each link depending on the centrality of the node [14]

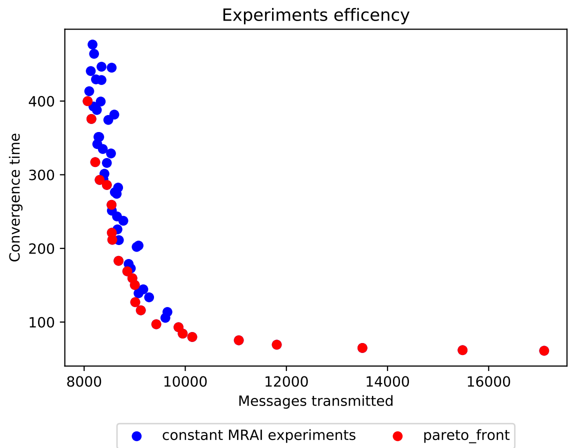
The centrality metric used is called Destination Partial Centrality (DPC) and thanks to the fact that has been already demonstrated that is possible to calculate it in a distributed way [13] I will assume that it is calculated in advance and that every node knows it's own centrality to set the timers.

To permit a comparison between those two different strategies a constraint on the MRAI assignment has been introduced, the *mean* of all the timers in the network must be equal between the two strategies. For the *Fixed* strategy this is constraint intrinsically respected. For the *DPC* strategy the timers are multiplied by a factor k that permits to keep the average equal.

The results of the first strategy are showed in Figure 5.2.



(a) Network performances, messages VS convergence time with different MRAI values



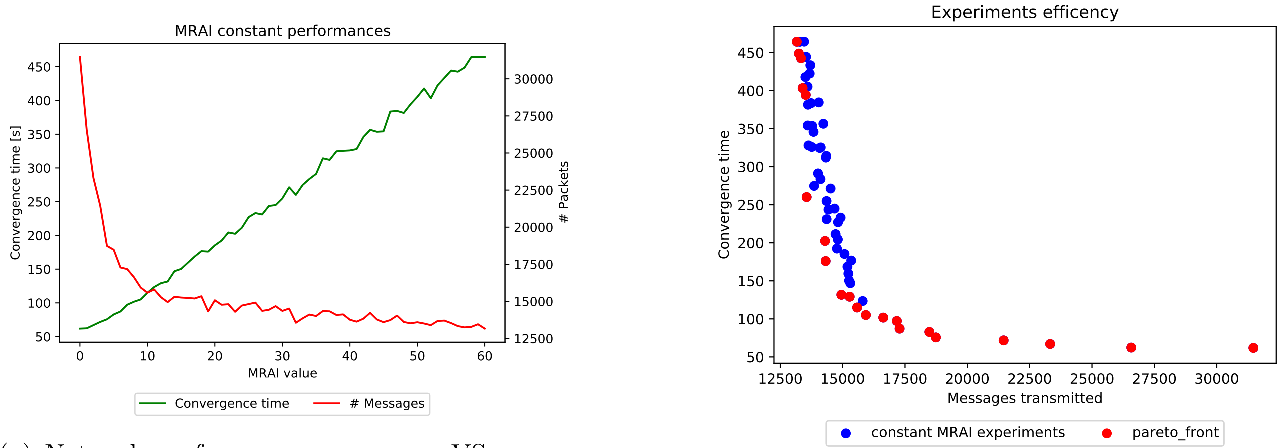
(b) Pareto front of Messages VS Convergence time

Figure 5.2: Evolution of the network performances on the **Internet Like** graph of 1000 nodes using a fixed MRAI from 0 to 60 seconds.

As is possible to see in Figure 5.2a without MRAI we would have a low convergence time, dictated mostly by network delays and processing time. With, on the other hand an enormous amount of messages. Slightly increasing the MRAI value, the number of messages will fell down reaching a constant value around 8000, while the convergence time continuously grows linearly, as it happened for the clique graph in Figure 5.1. This continuous linear grow is dictated by the fact that nodes keep meaningful information for more time before sharing them with their neighbourhood. Figure 5.2b represent the Pareto front of those experiments. The Pareto frontier is the set of values that are Pareto efficient, this concept has been already used in engineering to define the set of best outcomes from the trade-off of two different parameters [16]. We can clearly see that the majority of the points is concentrated to the left of the chart, this means that few MRAI values would give as result a high number of messages and a small convergence time. While, multiple MRAI values would concentrate around the same value of messages transmitted. This can confirm the fact that MRAI would not influence messages after a certain threshold but only the convergence time.

The results of the same environment without IW are showed in Figure 5.3.

Also in this case, comparing Figures 5.2 and 5.3, is possible to notice that IW helps to reduce the number of messages and the convergence time without impacting the network performances trend.

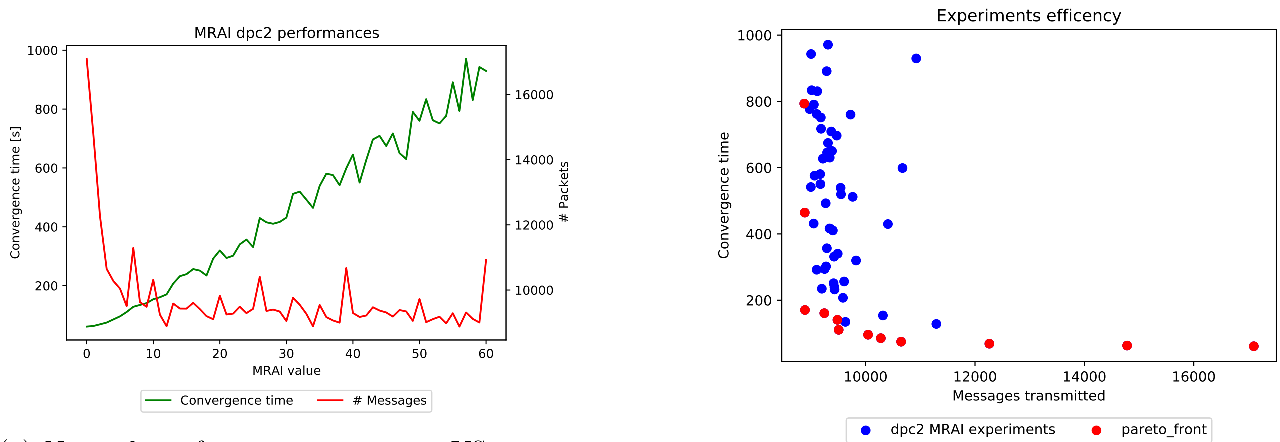


(a) Network performances, messages VS convergence time with different MRAI values

(b) Pareto front of Messages VS Convergence time

Figure 5.3: Evolution of the network performances on the **Internet Like** graph of 1000 nodes using a fixed MRAI from 0 to 60 seconds. **Without IW**

The second strategy, the one dependant on the DPC, produced the results in Figure 5.4 As mentioned before, all the timers are adjusted to respect the same mean as in the *fixed* MRAI experiments. For this reason points with the same MRAI value are comparable one another.



(a) Network performances, messages VS convergence time with different MRAI values

(b) Pareto front of Messages VS Convergence time

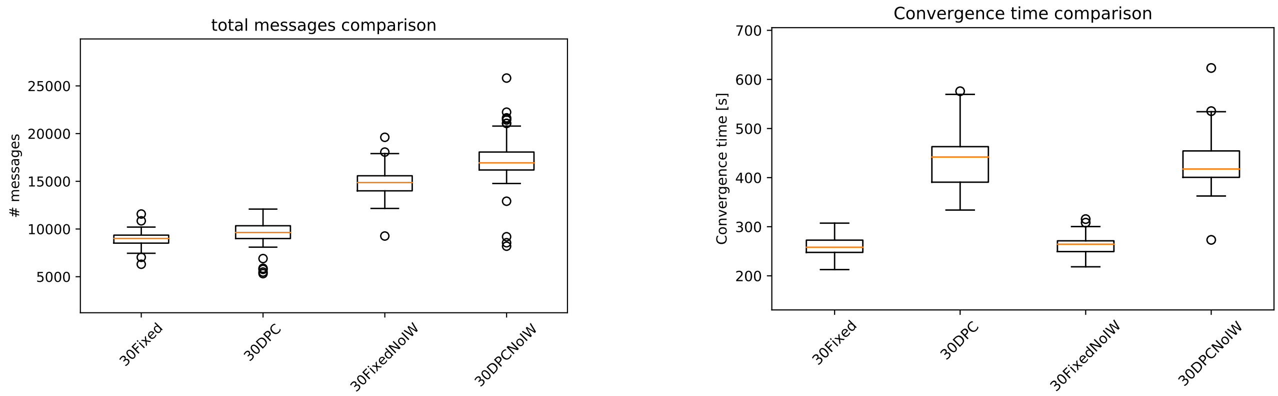
Figure 5.4: Evolution of the network performances on the **Internet Like** graph of 1000 nodes using a *DPC* MRAI strategy with an $MRAI_{mean}$ from 0 to 60 seconds.

FiXme: Cumbersome, reading again it's not very clear what I'm explaining This second strategy leads to the performances showed in Figure 5.4, is possible to notice that the number of messages transmitted fell down very quickly and it reaches the convergence value around an MRAI value of 10. But, it is also noticeable that there are a lot more spikes in this trend, that deviate more from the constant value around 9000 messages. Also the convergence time is affected by this behaviour.

FiXme: Consider introducing a figure to show both trend in the same plot Comparing Figures 5.2 and 5.4.

is possible to notice that the two strategies leads to a different trend. Both are equal at the beginning with MRAI equal 0 but after a while both the number of transmitted messages and the convergence time diverge. The number of messages with the DPC strategy variate more and it converge around 9000 messages, while the *fixed* strategy reaches 8000 messages. And the convergence time with the second strategy grows more quickly. This is caused by the central clique of tier one nodes that have a high MRAI value. The high MRAI value is caused by the fact that all the leafs has 0.0 as centrality that cause an MRAI value of 0 and to respect the $MRAI_{mean}$ value the central nodes needs a huge MRAI. For example, with an $MRAI_{mean}$ of 30 s the node 1 (that is one of the central clique nodes) has an MRAI value of 79.35 for all its neighbours.

The standard value of MRAI is 30 s as described in [10] so I compared those strategies performances in a box-plot in Figure 5.5. I decided to run 100 different runs for each strategy with the $MRAI_{mean}$ fixed to 30 s.



(a) Network performances, messages necessary to reach convergence with different MRAI strategies

(b) Network performances, time required to reach convergence with different MRAI strategies

Figure 5.5: Network performances comparison with different MRAI strategies, Graph internet like with 1000 nodes, MRAI value 30 s, number of runs for each strategy 100

In Figure 5.5 we can compare those two strategies, the first figure, Figure 5.5a represent the number of messages transmitted by the 100 runs, we can see that the two strategies, without IW, are really close one another. While in the time required for convergence, Figure 5.5b there are some huge difference between the two strategies, is not negligible that with the DPC strategy the time required is almost the double of the standard time.

In conclusion we can say that the MRAI strategy is one of the factor that can influence the Network performances.

FiXme: Maybe I can introduce more strategies to expand this section

5.4 Pareto Efficiency Front

The strategies exposed in Section 5.3 are just few of the possibilities that are available. For this reason I would like to explore the set of possibilities looking for MRAI configuration randomly generated.

I would then study the space of possibilities that are generated through the Pareto efficiency plot and compare the results with the Pareto efficiency graphs. To permit this comparison I would set MRAI randomly but like for the DPC strategy respecting the average required.

FiXme: Insert table with the value of MRAI used and the ranges, and the number of total experiments executed

FiXme: Insert the resulting plot

5.5 Signal dependance

I would like to analyze how much the signal can impact the convergence performances with the two different strategies of Section 5.3.

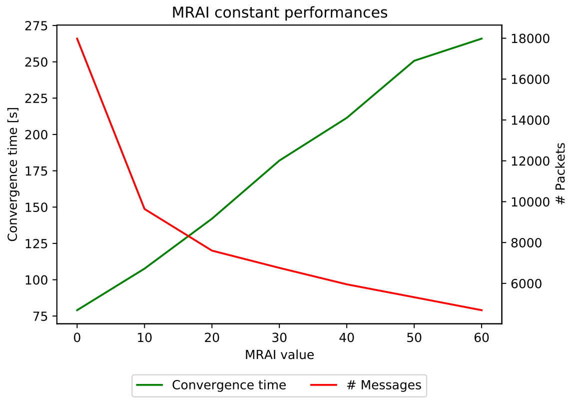
For this reason I used the same environment described before and execute the experiments with different input signals from the same node, "AWA", "AWAW" and "AWAWA".

In those experiments plays a role also the "*re-advertisement distribution*" for the second and third "A", it has been set to a uniform distribution between 1 s and 60 s, like the "*withdraw distribution*".

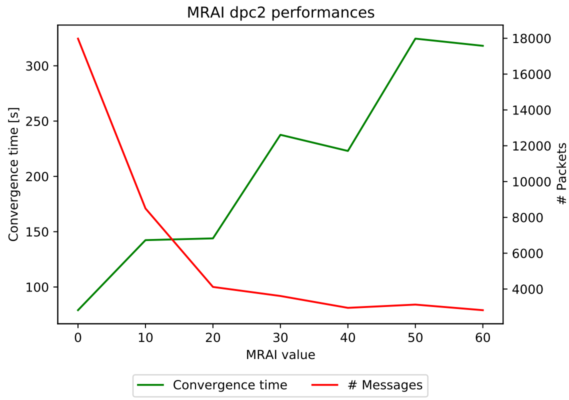
For those experiments I didn't evaluate the case with IW deactivated. FiXme: Explain why

FiXme: all the plots has an MRAI steep of 10 s to give a hint on the trend, redo the plots with a step of 1 s

In Figure 5.6 is possible to see the evolution for the signal "AWA".



(a) Network performances, *fixed* MRAI strategy

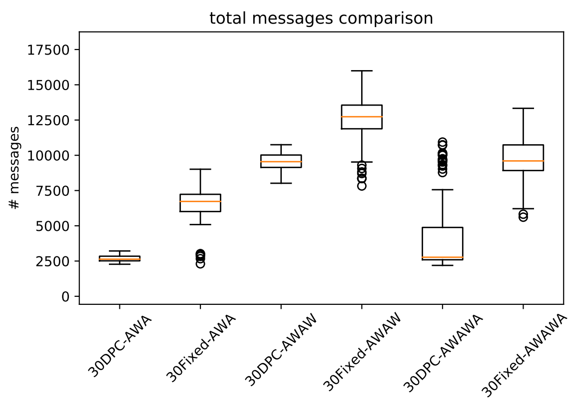


(b) Network performances, DPC MRAI strategy

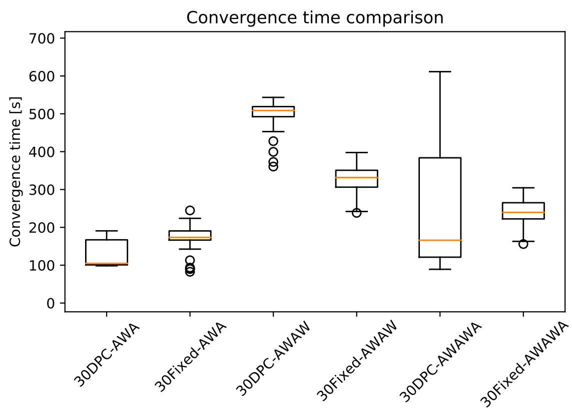
Figure 5.6: Network performances comparison with different MRAI strategies, Graph internet like with 1000 nodes, signal “AWA”

Is possible to notice in Figure 5.6 a huge difference in respect of the plots in Figures 5.2 and 5.4. The DPC strategy was able to outcome the standard *fixed* strategy over multiple prospective. Analyzing Figure 5.6b is possible to notice that the red curve, the one that refers to the number of messages transmitted has a very fast fell, with an MRAI timer *mean* of 30 s the number of messages is less than 1/4 in respect of an MRAI *mean* of 0 s. The convergence time curve has a completely different trend in respect of the previous experiments. We can notice some steps trend. This is caused by the fact that now the timer is able to effectively act on the signal. MRAI doesn’t affect the first message, in this case the first “A” of the signal, but it can affect the next two messages. Infact, some nodes are able to cache both the “WA” part of the signal and completely avoid to send anything at all, because them have already transmitted the first “A”. The complete compression of the signal “AWA” is “A”. The other evolution, for the “AWAW” and “AWAWA” signals, are showed in Figures A.1 and A.2

Like before, comparing the standard 30 s fixed MRAI I executed 100 different runs for each strategy and each different signal, the results are exposed in Figure 5.7b.



(a) Network performances, messages necessary to reach convergence with different MRAI strategies



(b) Network performances, time required to reach convergence with different MRAI strategies

Figure 5.7: Network performances comparison with different MRAI strategies, Graph internet like with 1000 nodes, MRAI value 30 s, number of runs for each strategy 100, signal “allSignals”

Is possible to notice in Figure 5.7 that both the strategies has different performances in respect of the signal produced by the single node source. In particular performances are better when the signal ends up with an “A”. That’s because, after the first “A”, giving the MRAI timer long enough, a node is able to compress a sequence that ends with an other “A” to the empty set and don’t send anything more. While if the sequence ends up with an “W” it has to, at least, send an other message to notify the withdraw.

Other than that is possible to notice that the DPC techniques has better results in terms of messages transmitted, while it could have an higher convergence time. This is caused like before by the high MRAI values used by the most central nodes.

In conclusion there is a correlation between MRAI and the sequence of messages transmitted by the source node. In particular more the timer is able to compress sequence more the performances are good.

FiXme: consider moving figures from the appendix to the chapter

5.6 Position dependance

The last factor of influence for MRAI that I would like to study is how much the position of the signal source can influence the convergence. The main hypothesis is that a node closer to the central clique, that generates a signal would provoke a message storm bigger in respect of a node on the perimeter of the network. This is true only if MRAI is large enough to block the storm near the source of it exporting only the correct information at the end of it.

5.6.1 Different signal sources

As first try I have decided to try 10 different destination chosen randomly on the same graph, this graph is an Internet like topology with 1000 nodes. After that I run the same environment with all the different destination. I also used different MRAI strategies, repeating the experiments for all of them. With this results is possible to analyze how different signal sources provoke different network performances and also study how different MRAI strategies adapt with different nodes that provoke messages storms.

5.6.2 Hierarchical influence

What about the position in the hierarchy? Internet is very strong hierarchical graph, Figure 3.4b is an example with a small set of nodes but its possible to define different levels of the graph. If we take the central clique as the rout of the graph then all the nodes will be at a certain distance (in terms of hops) from it.

Nodes that are on the same hierarchical level reacts on the same way?

- And how much is influencing the position?
- Hierarchically?

6 RFD and MRAI correlation

Route Flap Damping (RFD) is another parameter of BGP used to avoid messages storms. It is used to avoid flapping routes to continuously make the network unstable. When a network flaps a certain value is increased and when it overpass a threshold then the route is suppressed and not advertised anymore until it goes back below the threshold (or after a certain time).

RFD, other than MRAI, is one of the most studied parameters of BGP because of its influence in the convergence time [17, 18]. RFD received different updates from its first implementation, but recent studies showed that most of the providers still use outdated parameters [19].

The use of deprecated values can lead to a to heavy restrictive suppression of small routes delaying the correct spreading of information. Some cases of suppression are caused by faulty interfaces that heavily flaps hundreds of times, while other times is just an update of the node configuration that cause the route to flaps a couple of times and still be suppressed.

In the following chapters I am going to show how legacy RFD can affect small flaps and how would the new version of RFD reacted to it. Finally, I would look forward to understand the correlation between RFD and MRAI. When a suppressed route is shared again it could provoke messages storm that triggers different MRAI session, or the opposite case, a low MRAI that cause the grow of the figure of merit that suppress a route.

6.1 RFD on toy topologies

I firstly studied RFD on toy topologies, to see the effects of it in small networks, like I did in Section 5.1. As graph I used a clique of dimension 10, the source of the signaling is connected to the node 0 while the node 5 act as unique servicer for the node x. The node 5 won't be able to share information to node x because of RFD. Node x would havet to wait until the route fell below the reuse threshold of node 5 to converge.

The parameters used for RFD are the default *CISCO* parameters, showed in table Table 6.1

Parameter	Value
withdrawal penalty	1.0
re-advertisement penalty	0.0
attribute change penalty	1.0
suppress threshold	2.0
half-life (min)	15 (900s)
Reuse Threshold	0.75
Max Suppress Time (min.)	60 (3600s)

Table 6.1: Cisco default RFD parameters

The parameters of the environment are in Table 6.2

Messages in the signal are delayed by 300 s for two reasons:

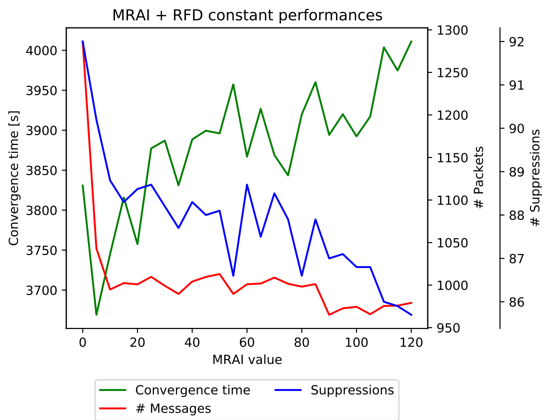
- The main goal of this experiments is to study the correlation from RFD to MRAI and we don't want that MRAI compress parts of the signal.
- I'm trying of simulate one of the possible behaviour tat triggers RFD suppressions, the human faulty reconfiguration of the node.

The signals contains 3 flaps in it, the first one is hipotetically attributed to a configuration that doesn't work properly, the second one is caused by a buggy correction of the configuration and the last one by the introduction of a correct configuration.

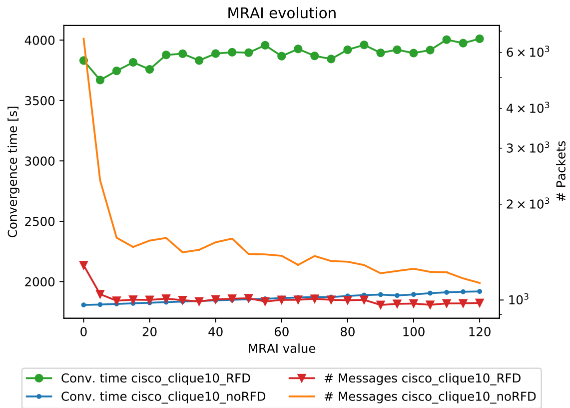
Property	Value
Seeds	$[1, 10]$
Signaling	“AWAWAWA”
Withdraws delay	Constant distribution of 300 s
Announcement delay	constant distribution of 300 s
MRAI	$[0, 120]$
Link delay	Uniform distribution between 0.012 s and 3 s

Table 6.2: Environment parameters used for the experiments on RFD with the clique graph

The MRAI strategy used in all the experiments is the *fixed* one.



(a) Network performances with the standard cisco RFD



(b) Network performances standard RFD vs no RFD

Figure 6.1: Evolution of the performances changing MRAI in the links standard RFD vs no RFD, graph clique of 10 nodes, MRAI strategy fixed, signal “AWAWAWA”

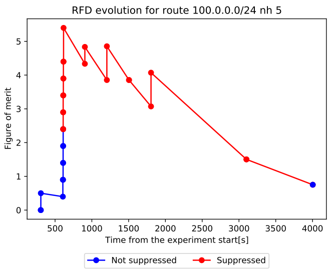
The plot in Figure 6.1a contains a third line that represent the total number of suppressions relevated on the experiment, for each experiment has been executed 10 different runs. The blue line that represent the number of suppressions refers to the third y-axis on the right.

In Fig. 6.1a is possible to see that small changes to MRAI can lead to some differences in the number of suppressions. Also the number of messages decreases rapidly and reaches a constant value around 980, as expected by the passage from an MRAI of 0 s to few seconds. The nodes that doesn’t trigger a suppression seems to affect also the convergence time that grows as expected but with a lot of fluctuations.

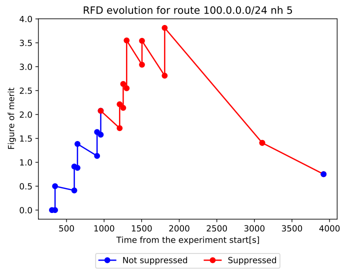
In Figure 6.1b is possible to see the gap between the use of RFD and without it. Notice that the packet axis is in log scale. The difference in the convergence time is due to the fact that with RFD some nodes block the best path that takes a lot of time to become available again. While MRAI grows the set of nodes that suppress routes decreses but the convergence time is highly affected by a restrict subest of them. In our case, for example, the supressions on nodes 0 and 5 plays an important role. The first one for the spreading in the whole network, the second one for the transmission of information to node x.

For this reason we can look more deeply on what happen to the figure of merit of node x and five in Figures 6.2 and 6.3

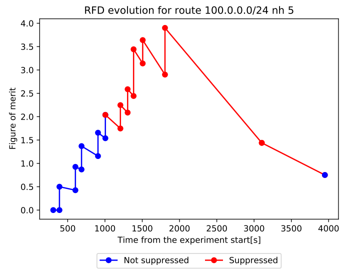
The node x is a leaf of the network that will absorb everthing the node 5 sends to it. In Figure 6.2 is possible to see the evolution of the figure of merit with different MRAI values. In the first case, with an MRAI qual to 0 s we will see a huge spike caused bt a lot of messages and route changes that the node 5 sends to it. while in the other two cases Figures 6.2b and 6.2c the MRAI seems to not be much effective on the route through node 5. In tose cases we can see that the route has been suppressed around 1000 s and is going to become useful again around 4000 s. In this period of time from 1000 s to



(a) MRAI = 0s



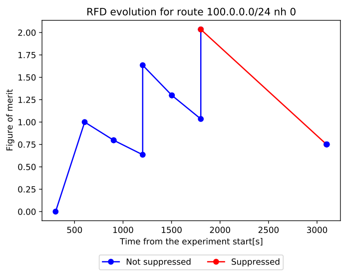
(b) MRAI = 50s



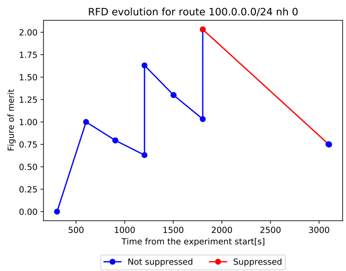
(c) MRAI = 100s

Figure 6.2: Evolution of the figure of merit in the node X with different MRAIs

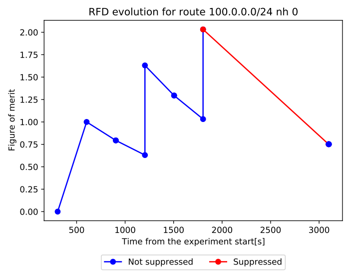
4000 s it still receives some updates from node 5 that changes its own best path, and this makes the figure of merit evolve. The evolution of the figure of merit stops around 2000 s thats because also the node 5 has suppressed the route, Figure 6.3. The point aoround 3000 s represent the moment when the route becomes available again for node 5 that comunicates the change to x.



(a) MRAI = 0s



(b) MRAI = 50s



(c) MRAI = 100s

Figure 6.3: Evolution of the figure of merit in the node X with different MRAIs

The evolution of the figure of merit of the best path of node 5 is a different from the one of node x. In fact, it is not influenced by MRAI as we can see in Figure 6.3. That because the node 5 us directly connected to the node 0 that every 300 s forward the message of d and 300 s is delay too large to be affected by the compression effect of MRAI. Around 2000 s node 5 suppress the route (as any other node in the clique) and stops to forward it to node x until 3000 s when it become available again.

Node x took almost 4000 s to converge because of the big fluctuations of node 5 that suffers of the *Path Exploration* problem, the path changes are considered a bad behaviour in RFD.

In conclusion we can say that RFD can be affected by MRAI and that RFD can prevent a lot of messages at the cost of very high convergence times.

6.2 RFC 2439 VS RFC 7196

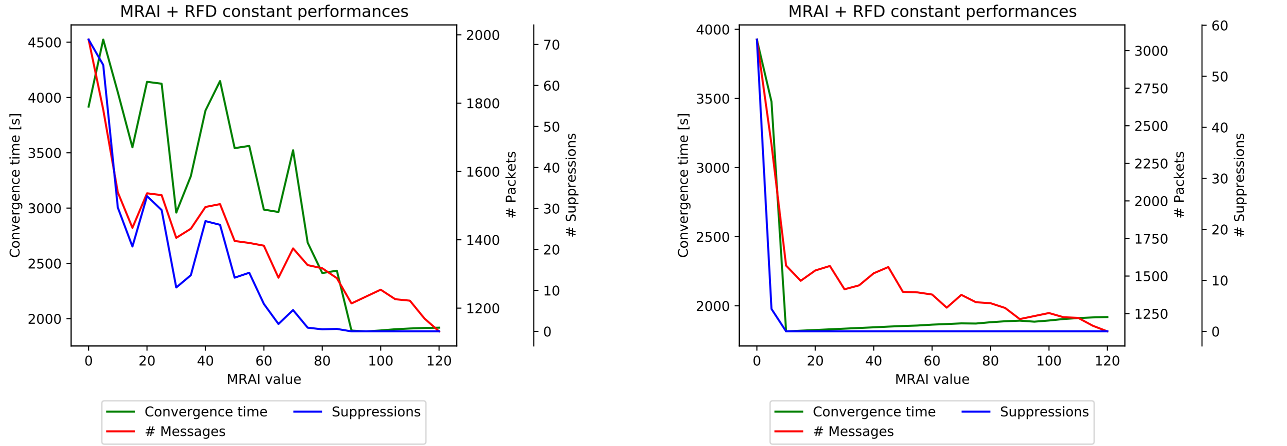
The difference in the two Request For Comment (RFC) that defines RFD [20, 21] is in the parameters used. Infact the last RFC introduced two new set of parameters where the figure of merit threshold is increased up to at least 6.0. The two category are:

- ***Aggressive***, Suppression threshold no less than 6.0;
- ***Conservative***, Suppression threshold no less than 12.0;

Respectively 3 and 6 times the actual standard.

I have then repeated the same experiments of Section 6.1 with the same clique graph, but with the two new RFD strategies, the results are showed in Figure 6.4.

We can see two compleatly different evolutions of the performances in Figure 6.4. On the left plot we can see the evolution with the *Aggressive* strategy. and MRAI is more effective to thisstrategy in respect of the standard one. The number of suppressions fell down to almost 0 with an MRAI near 90 s.



(a) RFD 7196 Aggressive on the clique topology

(b) RFD 7196 Conservative on the clique topology

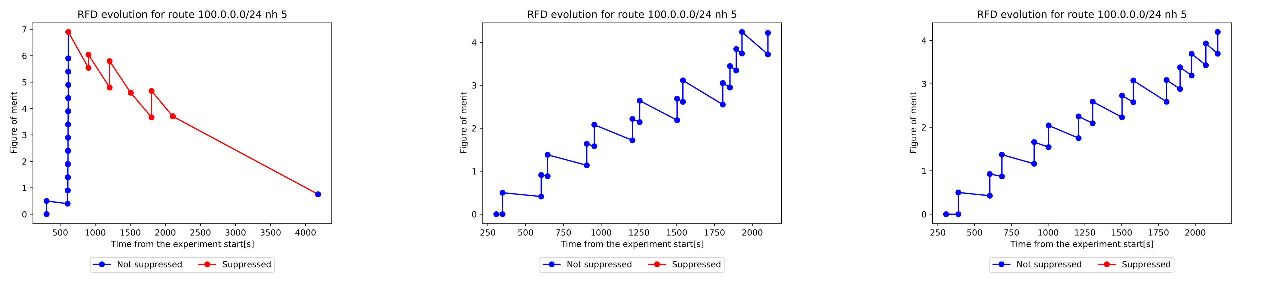
Figure 6.4: MRAI influence with different RFD strategies from [21]

The message trend is similar to the one of the case without RFD but with an important difference in the case of MRAI equal 0 s, the number of average messages is around 2000 in respect of the 6000 without RFD. While with an high MRAI the message trends are similar and equal when the number of suppressions reaches 0.

The convergence time, on the other hand, has the opposite trend in respect of the one that we saw in Figure 6.1a. Here we see a descending trend caused by the fact that MRAI is able to avoid some messages and, as a consequence, avoid th growing of the figure of merit in some nodes permitting to the convergence time to decrease. Once the number of suppressions reaches 0 obvioust the network performances are equal as in the *NoRFD* case.

In Figure 6.4b we can see the evolution of the network with the *Conservative* strategy, the threshold of this strategy is the double of the *Aggressive* strategy. The effects of this difference are huge, is sufficient an MRAI of 10 s to avoid at all suppressions, causing the trend, in terms of messages and convergence time as if there is no RFD at all. Also with an MRAI of 0 s is possible to see a difference in terms of messages and convergence time in respect of the other two strategies. This is the strategy that more likely resemble the *NoRFD* one, having a convergence time increadibly more low, at the cost of few hundreds messages.

We can now take a look more closely to what happens to the figure of merit for the only route that node x receives. Results are exposed in Figure 6.5



(a) MRAI = 0s, RFD 7196 Aggressive, clique topology

(b) MRAI = 50s, RFD 7196 Aggressive, clique topology

(c) MRAI = 100s, RFD 7196 Aggressive, clique topology

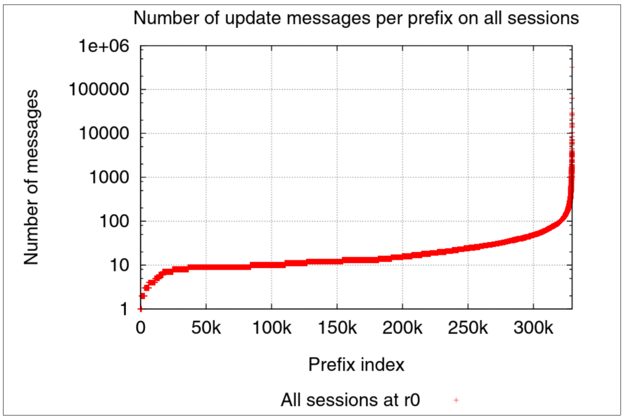
Figure 6.5: Evolution of the figure of merit in the node X with different MRAIs, with RFD 7196 aggressive in a clique topology

We can see in Figures 6.5a and 6.5b that MRAI plays an important role in the figure of merit of node x. In the first case the route would be dalyed up to 4000 s while in the second one the grow never touches the threshold. We can also notice that there is a small difference in the grow with a higher MRAI, in Figure 6.5c we can notice a slower grow, thanks to the fact that node 5 has to send a smaller ammount of messages to correct it knowledge.

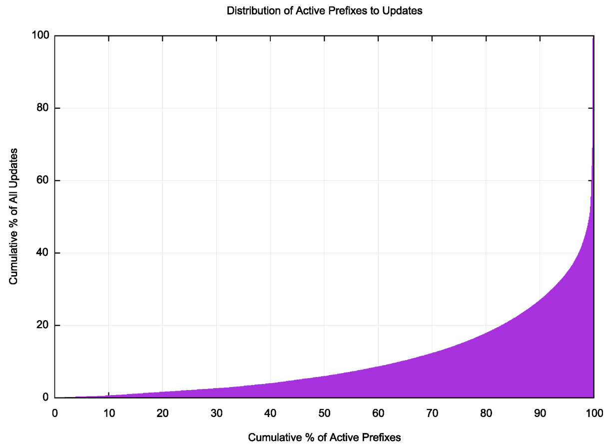
In conclusion, if before MRAI, with the standard RFD was playing a more marginal role because of the restrictive threshold, now, with those strategies it can play a more relevant role and act as key factor between the suppression or not.

6.3 Mice VS Elephants

From the work of R. Bush et al. [18] we know that the majoirty of updates that are transmitted on the Internet are from a small set of AS. Those ASes with their flaps cause update storms almost continuously. I report a figure from [18] for simplicity in Figure 6.6a Thanks to the studies of APNIC FiXme: insert citation of footnode, something we also know that this behaviour is still present nowadays, the Figure 6.6b is taken from one of their annual reports ands shows that the 10% of all the active prefixes produces more or less the 70% of the total updates.



(a) Prefixes and number of updates associated, figure from [18]



(b) Prefixes and number of updates associated, [apnic 2019]

Figure 6.6: Prefixes influence on updates

We can then divide those prefixes in two sets:

- ***Mice***, this set represent the majority of the prefixes, all the prefixes that does not generate more than 100 updates in Figure 6.6a
- ***Elephants***, this set represent the remaining part of the prefixes, those that produces the majority of the messages.

Thanks to a review of a BGP year by APNIC, presented at RIPE 52 [22], we can also have an example of thos elephants prefixes. This example is showed in Figure 6.7, it take in consideration the prefix "202.64.49.0/24" show that in a relative small period of time it has produced thusends of ADV per day. In this case, this particular prefix has produced 198.370 ADV producing in total 96.330 flaps.

I have then used this data to configure two new environments for the simulations. The first one that points to reproduce the *Mice* behaviour, the second one the *Elephants*.

In both this environments I have then compared the four different strategy of RFD, *NoRFD*, standard RFD and the two from [21].

The topology used for those experiments is an *Internet like* topology with 1000 nodes and MRAI is fixed to 30 s for all the links. The source of the signal has been chosen randomly on the graph. For each experiment has been then executed 50 runs.

6.3.1 Mice

The particularity of the *Mice* experiments is in the signal, we have a low number of flaps interlieved by a long timer. I have then used a signal with 5 flaps, "AWAWAWAWAWA" with a delay of 300 s (5 min) between each message. The results are presented in Figure A.8.

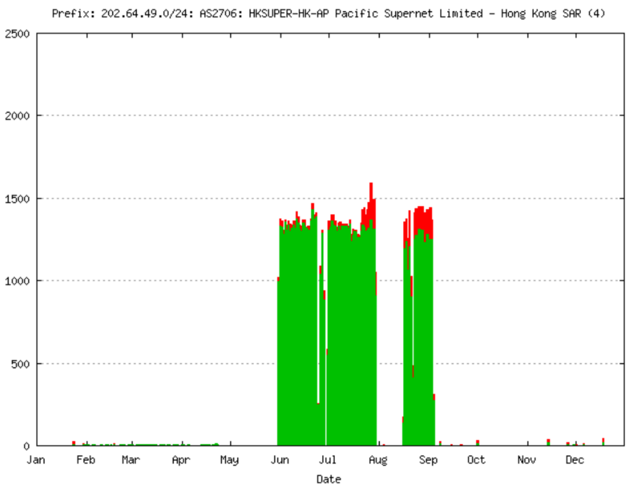
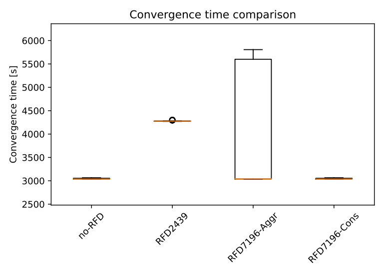
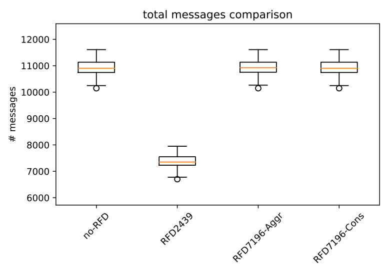


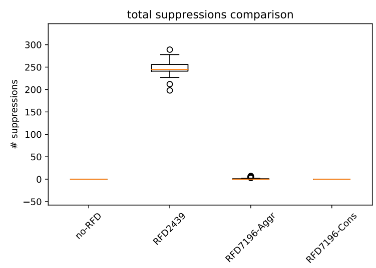
Figure 6.7: 202.64.49.0/24 flaps plot from [22]



(a) Convergence time respect to the RFD strategy



(b) Number of messages respect to the RFD strategy



(c) Number of suppressions respect to the RFD strategy

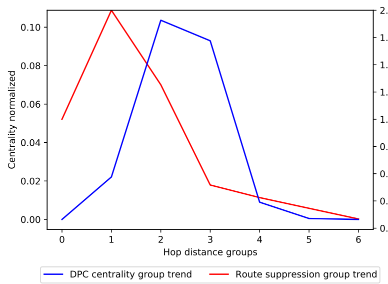
Figure 6.8: Internet like topology 1000 nodes, MRAI=30s, random destination, 5 flaps, 300 s message delay, Network performances

From Figure 6.8c we can see that there is a big difference in terms of suppressions. The standard strategy produces on average 250 suppressions and the effects of those suppressions can be saw in Figure 6.8a because its the only strategy that on average has a convergence time higher than 4500 s The opposite case is represented by the *Conservative* from RFC 7196 [21]. The threshold in this last case is so permissive that it doesn't have any effect different the *NoRFD* strategy. In the middle we find the *Aggressive* strategy, in Figure 6.8c we can see that on average it doesn't suppress anything, but it can happen that it produces few suppressions. The effects of those suppressions are visibile in Figure 6.8a where, with this strategy is possible to have a very huge convergence time, caused by the fact that it takes more time to recover from a route that overpass a threshold of 6.0 in respect of 2.0. In Figure 6.8b we can see that the number of messages transmitted is distribute as expected, the two more permissive strategies have the same behaviour of the *NoRFD* while the standard strategy never produces more than 8000 messages.

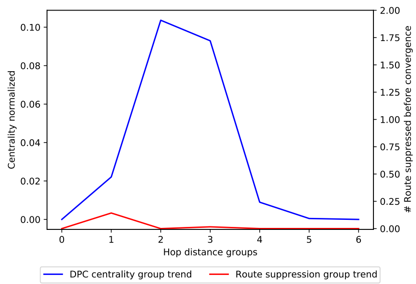
We can then study which are the nodes that produces the suppressions and how far are them from the signal source. We can see the results of this study, for each suppression technique in Figure 6.9.

For the plots in Figure 6.9 the x axis represent the distance from the source node in terms of hops and all the other nodes are grouped by this distance. The blue line represent the average centrality of the groups, for each node of the graph I calculated the centrality using the DPC metric then grouped them and calculated the average value. As expected the central nodes have a higher centrality and them are at few hops of distance from the source node. The centrality trend is equal for each plot in Figure 6.9 because the graph and the source node are the same for each experiment.

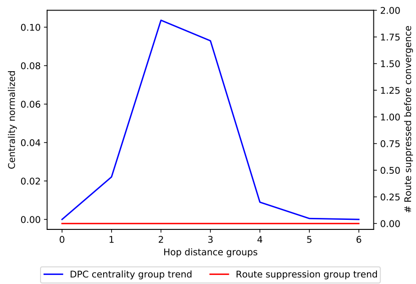
The red line represent the average number of suppressions per group. As we can see with the standard strategy, Figure 6.9a, on average the route is blocked 2 times be the nearest nodes and then, this value, slowly decreases in the following groups but it will be still blocked few times in the farest



(a) RFD 2439 Strategy



(b) RFD 7196 Aggressive Strategy



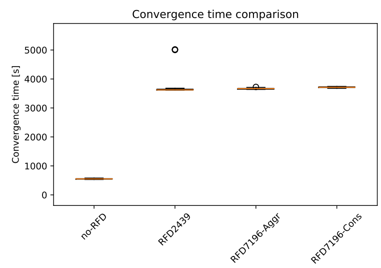
(c) RFD 7196 Conservative Strategy

Figure 6.9: Internet like topology 1000 nodes, MRAI = 30 s, random destination, 5 flaps, 300 s between messages, Suppression trend VS avg hop centrality

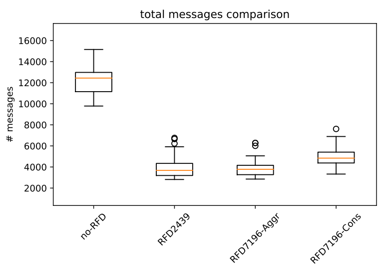
nodes. The *Aggressive* strategy, Figure 6.9b present a compleatly different behaviour, the nearest nodes blocks few times the route, while the most central nodes almost never and the farest nodes never blocks it. This is meaningful because it tells us that the few suppressions in the nearest nodes are enough to not trigger other blocks in the next groups. As expected with the *Conservative* strategy we don't have suppressions at all.

6.3.2 Elephants

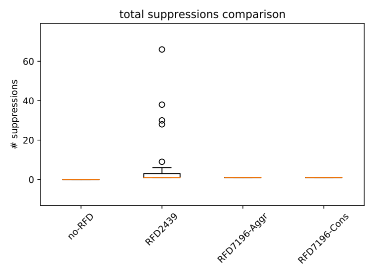
The elephants prefixes, as I mentioned in Section 6.3, are the ones that produces the majoirty of the ADV. And we also know, thanks to [22], that is possible to see over thousands of messages per day. For this reason the *elephants* environment signal is composed by 100 flaps, with a delay between the messages of 3 s. All the other properties of the environment are unchanged. The results are presented in Figures A.10 and A.11.



(a) Convergence time respect to the RFD strategy



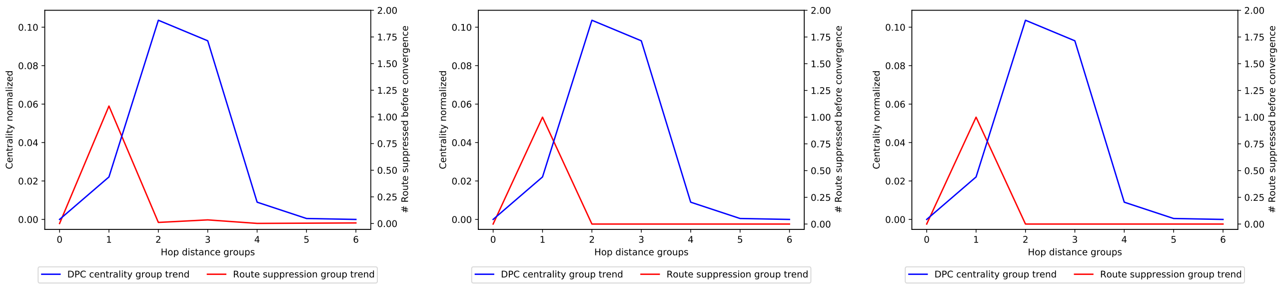
(b) Number of messages respect to the RFD strategy



(c) Number of suppressions respect to the RFD strategy

Figure 6.10: Internet like topology 1000 nodes, MRAI = 30 s, random destination, 100 flaps, 3 s delay, Network performances

Is possible to see in Figure A.10 that this time we have a different behaviour from all the 3 RFD streategies. In Figure A.10o we can see that the standard strategy doesn't have anymore hundreds of suppressions, but on average ti suppress few times the route and this is sufficient. The same behaviour, with less variance, is obtained from the *Aggressive* and the *Conservative* strategies. Also in Figures A.10m and A.10n we can notice a similar trend, the three strategies react at the same way, producing a smaller number of messages (on average 1/3) in respect of the *NoRFD* strategy.



(a) RFD 2439 Strategy (b) RFD 7196 Aggressive Strategy (c) RFD 7196 Conservative Strategy

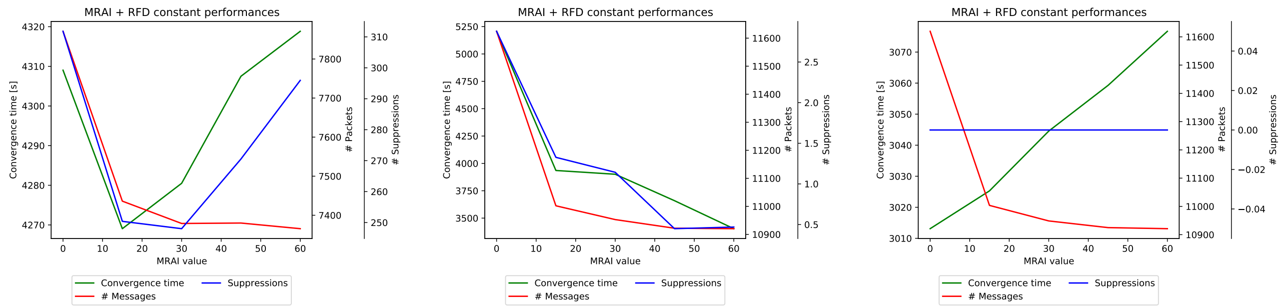
Figure 6.11: Internet like topology 1000 nodes, MRAI = 30 s, random destination, 100 flaps, 3 s delay, Network performances

The same trend can be saw in Figure A.11, were the three strategis produces on average one single suppression in the nearest group.

We can then say that all the strategies catch in time the flap and avoid the propagation of the update storm, increasing the convergence time, but protecting the network from thousands of messages.

6.3.3 MRAI influence on Mice and Elephants

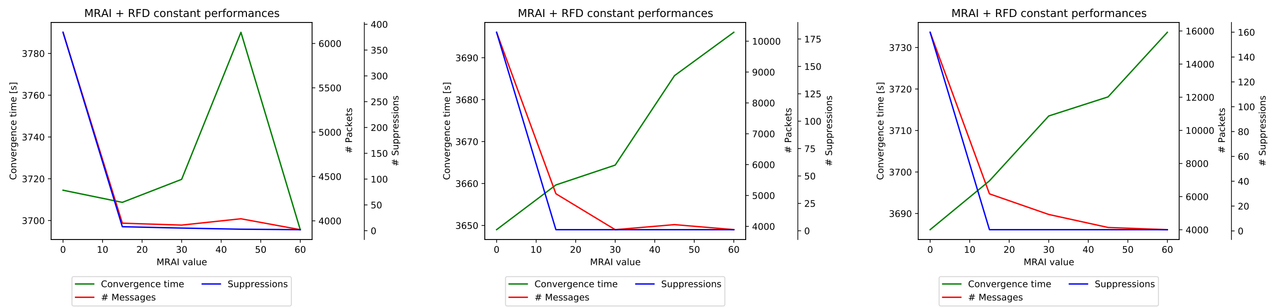
We can now study the influence of MRAI on those two cases. The environments are equal to the previous section. The results of the *Mice* case are exposed in Figure 6.12, while the results of the elephant case are in Figure 6.13.



(a) RFD 2439 Strategy (b) RFD 7196 Aggressive Strategy (c) RFD 7196 Conservative Strategy

Figure 6.12: Internet like topology 1000 nodes, random destination, 100 flaps, 3 s delay, Network performances

FiXme: I don't really know how to explain the rfd courve in Figure 6.12a



(a) RFD 2439 Strategy (b) RFD 7196 Aggressive Strategy (c) RFD 7196 Conservative Strategy

Figure 6.13: Internet like topology 1000 nodes, random destination, 100 flaps, 3 s delay, Network performances

The boxplot that shows the evolution comparing the different strategy are in the Appendix A

7 Conclusion

- Wrap up
- Path exploration explosion of the FSM
- MRAI convergence dependency
- RFD and MRAI co-dependency

7.1 Future Works

:)

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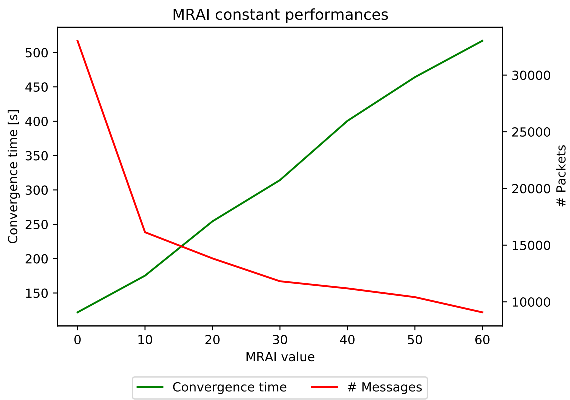
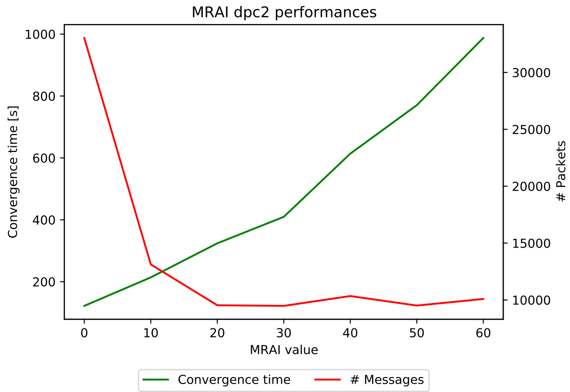
Appendix A Appendix

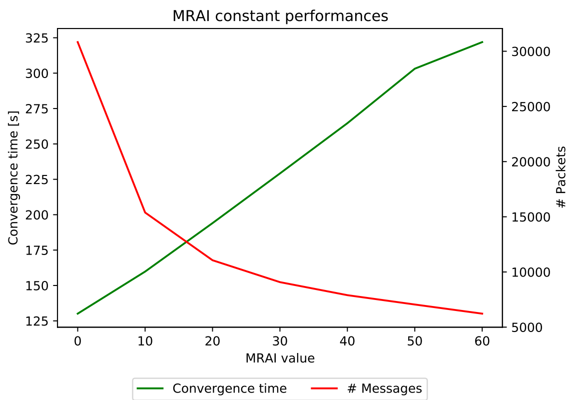


(a) Network perforcances, *fixed* MRAI strategy

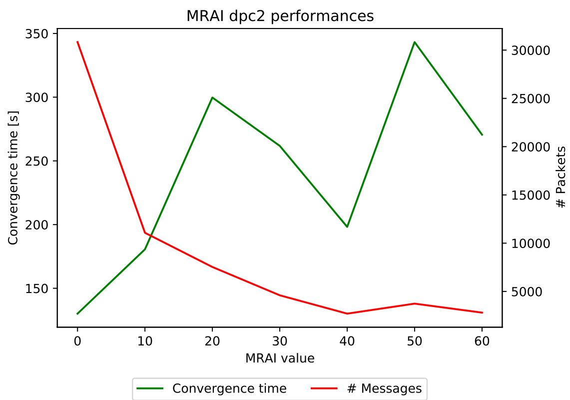


(b) Network perforcances, DPC MRAI strategy

Figure A.1: Network perfomances comparison with different MRAI strategies, Graph internet like with 1000 nodes, signal "AWAW"

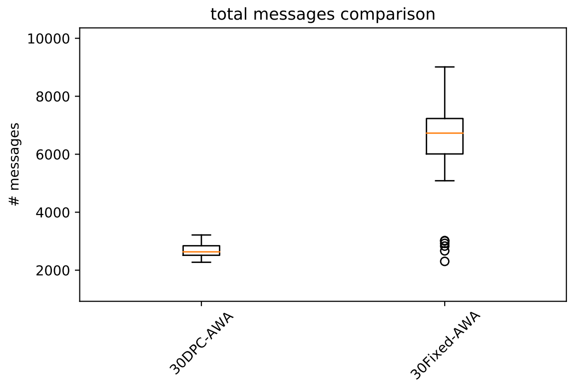


(a) Network perforcances, *fixed* MRAI strategy

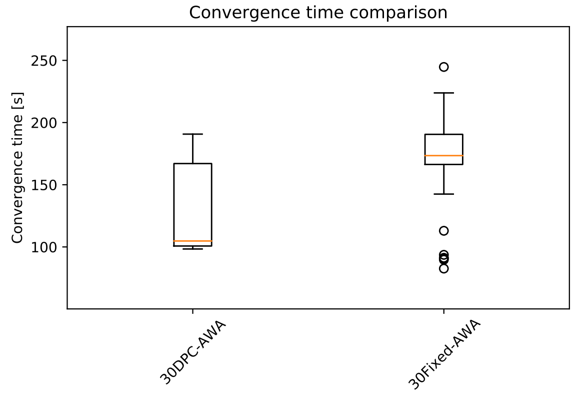


(b) Network perforcances, DPC MRAI strategy

Figure A.2: Network perfomances comparison with different MRAI strategies, Graph internet like with 1000 nodes, signal "AWAWA"

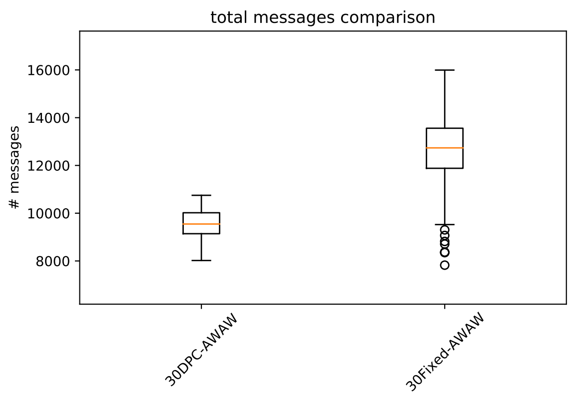


(a) Network perforcances, messages necessary to reach convergence with different MRAI strategies

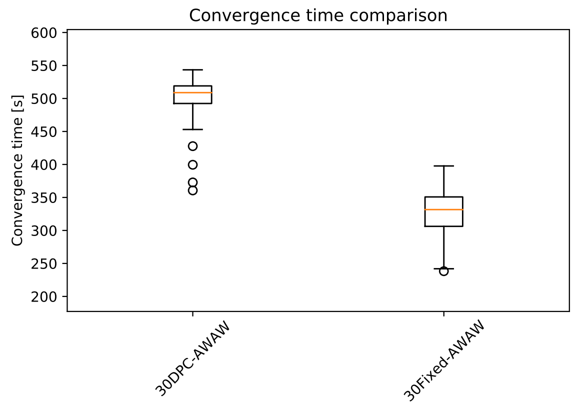


(b) Network perforcances, time required to reach convergence with different MRAI strategies

Figure A.3: Network perfomances comparison with different MRAI strategies, Graph internet like with 1000 nodes, MRAI value 30 s, number of runs for each strategy 100, signal “AWA”

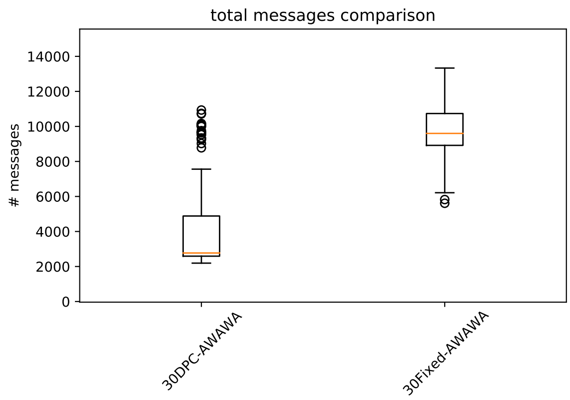


(a) Network perforcances, messages necessary to reach convergence with different MRAI strategies

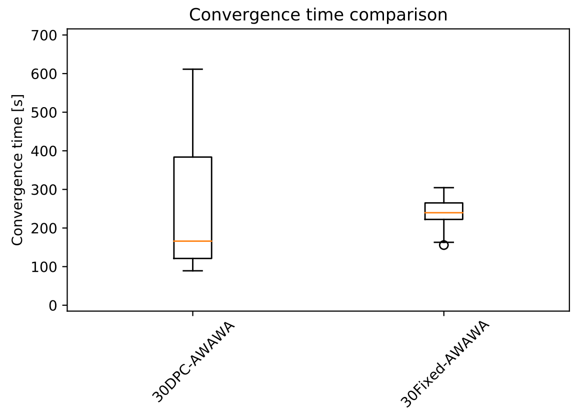


(b) Network perforcances, time required to reach convergence with different MRAI strategies

Figure A.4: Network perfomances comparison with different MRAI strategies, Graph internet like with 1000 nodes, MRAI value 30 s, number of runs for each strategy 100, signal “AWAW”



(a) Network perforcances, messages necessary to reach convergence with different MRAI strategies



(b) Network perforcances, time required to reach convergence with different MRAI strategies

Figure A.5: Network perfomances comparison with different MRAI strategies, Graph internet like with 1000 nodes, MRAI value 30 s, number of runs for each strategy 100, signal “AWAWA”

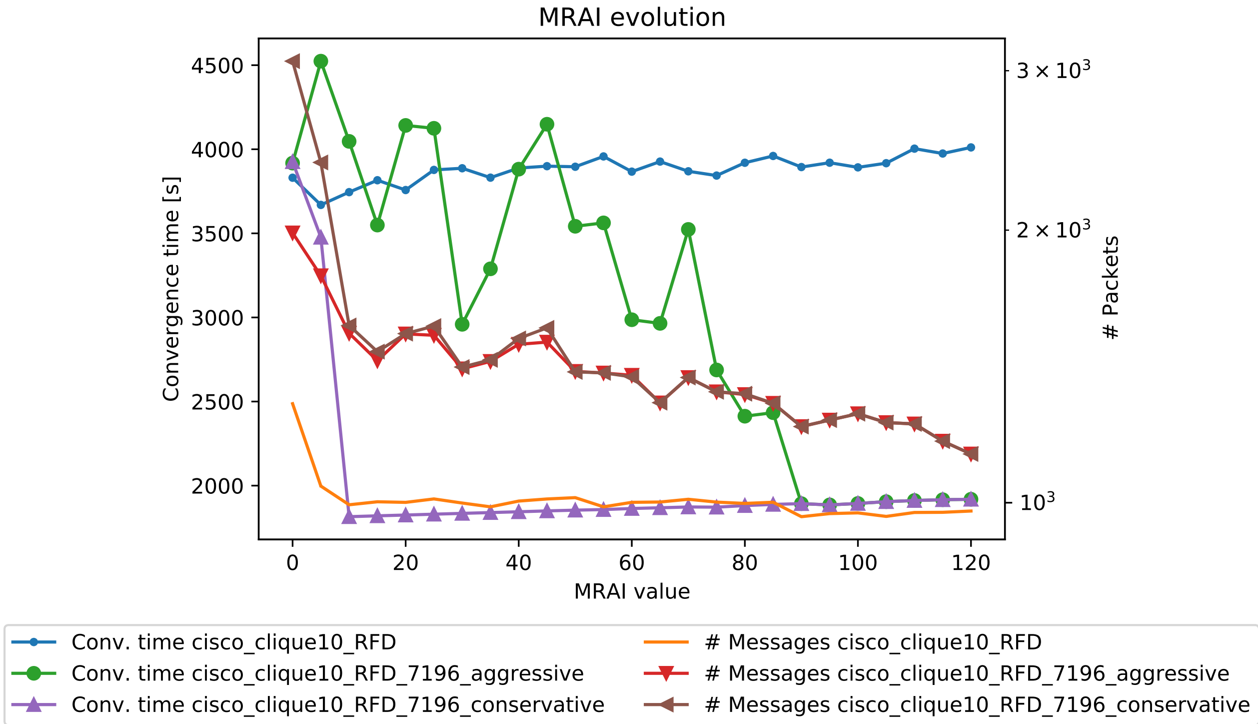
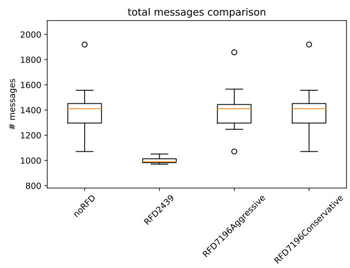
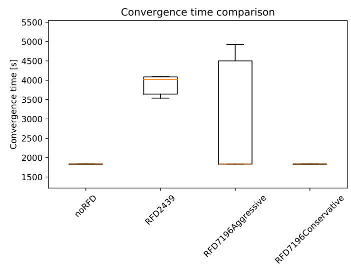


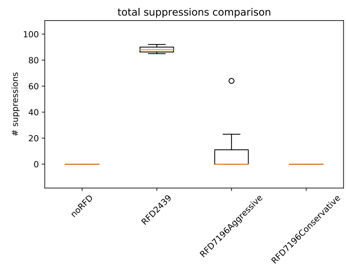
Figure A.6: Comparison of the *clique* topology with RFD 2439 and the with RFD 7196 strategies



(a) clique topology, MRAI=30s, 10 runs, Messages comparison

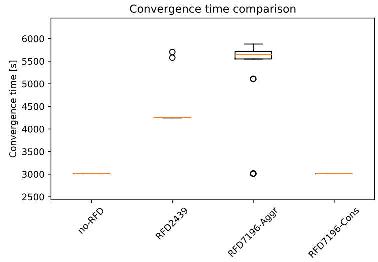


(b) clique topology, MRAI=30s, 10 runs, Convergence time

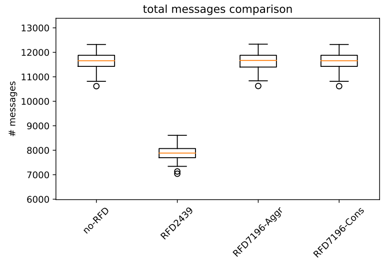


(c) clique topology, MRAI=30s, 10 runs, Number of suppressions

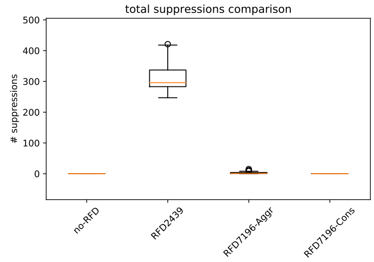
Figure A.7: Clique topology, MRAI=30s, 10 runs, comparison of the network performances



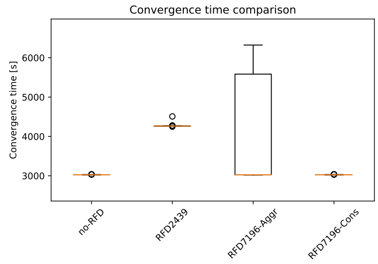
(a) Convergence time respect to the RFD strategy, MRAI=0s



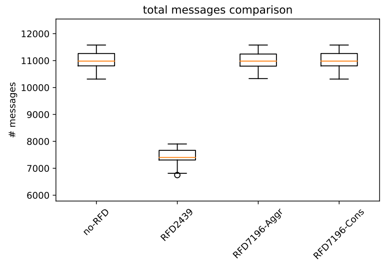
(b) Number of messages respect to the RFD strategy, MRAI=0s



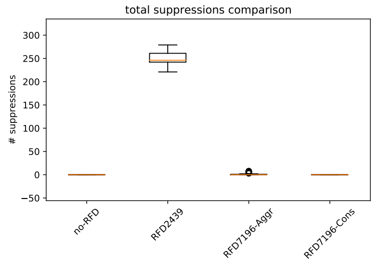
(c) Number of suppressions respect to the RFD strategy, MRAI=0s



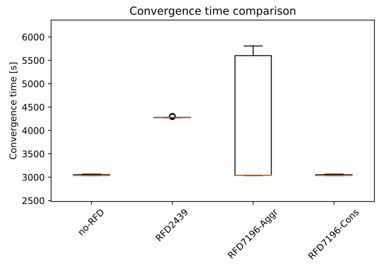
(d) Convergence time respect to the RFD strategy, MRAI=15s



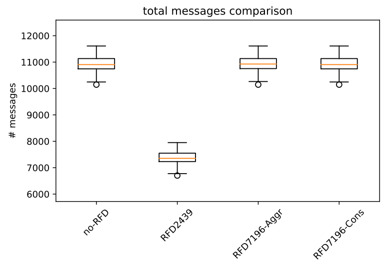
(e) Number of messages respect to the RFD strategy, MRAI=15s



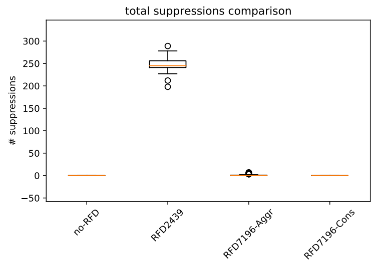
(f) Number of suppressions respect to the RFD strategy, MRAI=15s



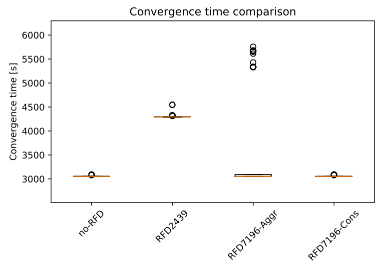
(g) Convergence time respect to the RFD strategy, MRAI=30s



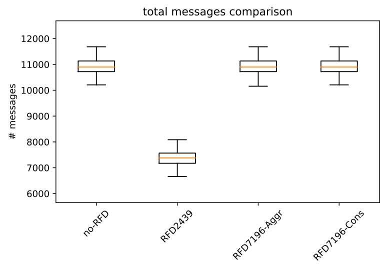
(h) Number of messages respect to the RFD strategy, MRAI=30s



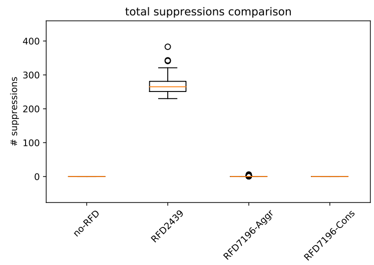
(i) Number of suppressions respect to the RFD strategy, MRAI=30s



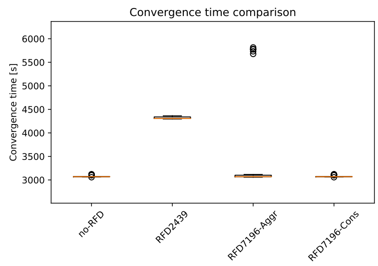
(j) Convergence time respect to the RFD strategy, MRAI=45s



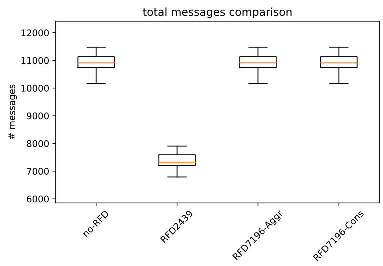
(k) Number of messages respect to the RFD strategy, MRAI=30s



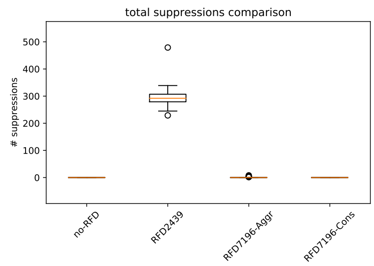
(l) Number of suppressions respect to the RFD strategy, MRAI=45s



(m) Convergence time respect to the RFD strategy, MRAI=60s

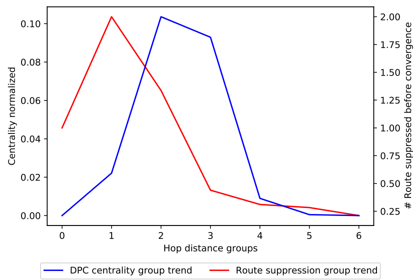


(n) Number of messages respect to the RFD strategy, MRAI=60s

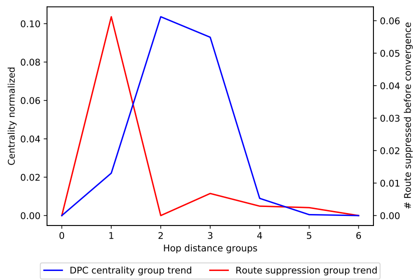


(o) Number of suppressions respect to the RFD strategy, MRAI=60s

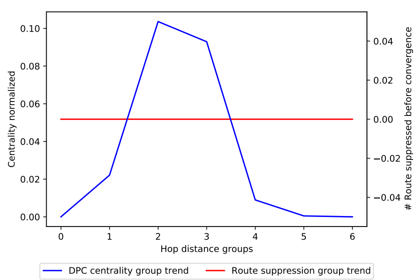
Figure A.8: Internet like topology 1000 nodes, random destination, 100 flaps, 3s delay, Network performances



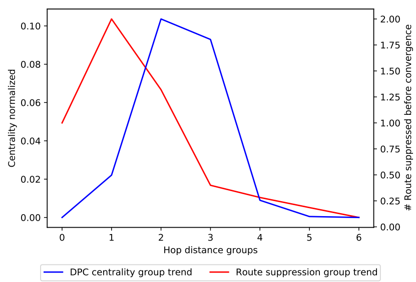
(a) RFD 2439 Strategy, MRAI=0s



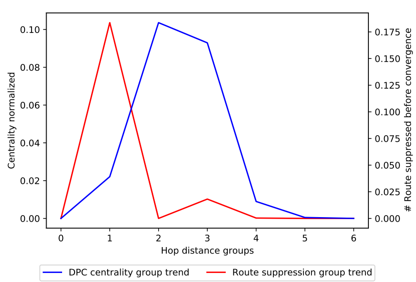
(b) RFD 7196 Aggressive Strategy, MRAI=0s



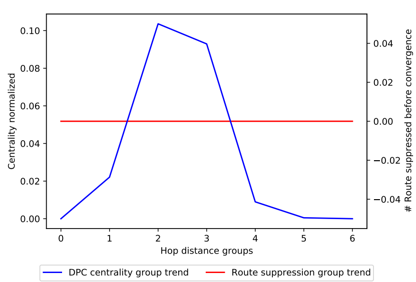
(c) RFD 7196 Conservative Strategy, MRAI=0s



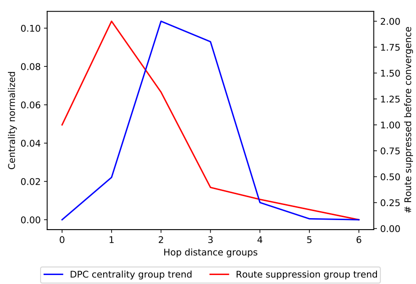
(d) RFD 2439 Strategy, MRAI=15s



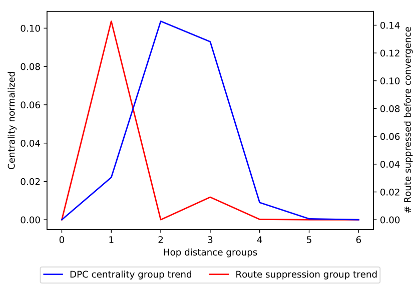
(e) RFD 7196 Aggressive Strategy, MRAI=15s



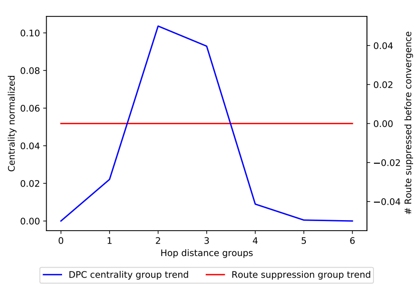
(f) RFD 7196 Conservative Strategy, MRAI=15s



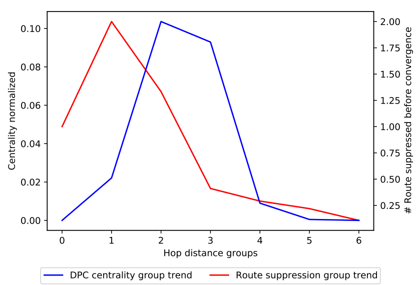
(g) RFD 2439 Strategy, MRAI=30s



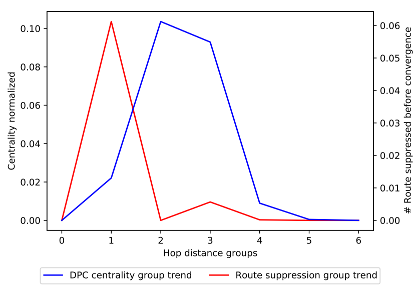
(h) RFD 7196 Aggressive Strategy, MRAI=30s



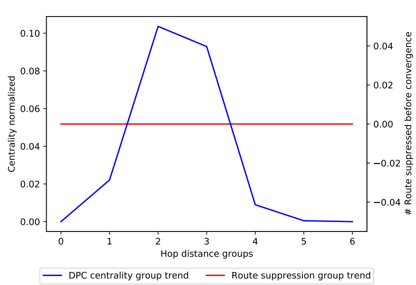
(i) RFD 7196 Conservative Strategy, MRAI=30s



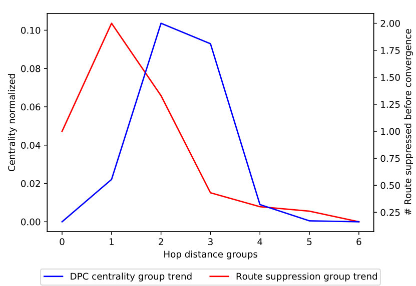
(j) RFD 2439 Strategy, MRAI=45s



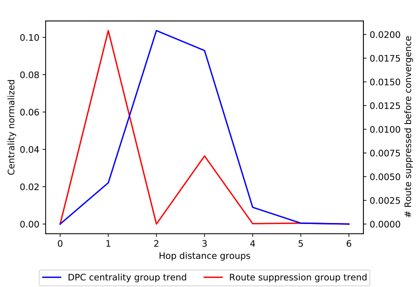
(k) RFD 7196 Aggressive Strategy, MRAI=45s



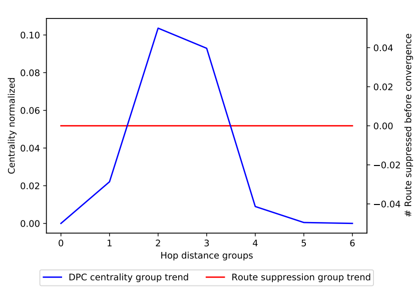
(l) RFD 7196 Conservative Strategy, MRAI=45s



(m) RFD 2439 Strategy, MRAI=60s

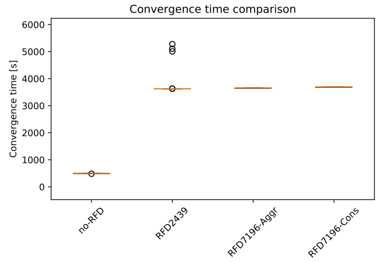


(n) RFD 7196 Aggressive Strategy, MRAI=60s

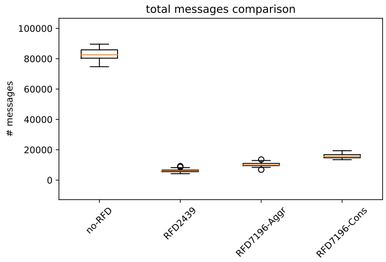


(o) RFD 7196 Conservative Strategy, MRAI=60s

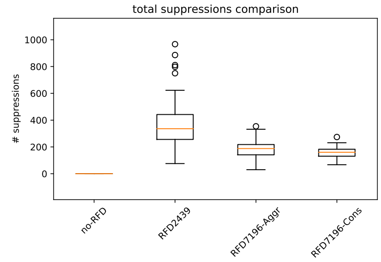
Figure A.9: Internet like topology 1000 nodes, random destination, 100 flaps, 3s delay, Suppression trend VS avg hop centrality



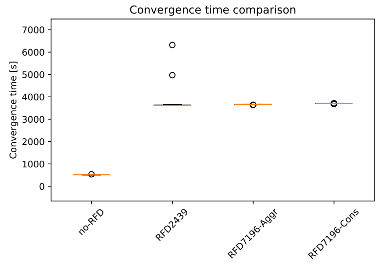
(a) Convergence time respect to the RFD strategy, MRAI=0s



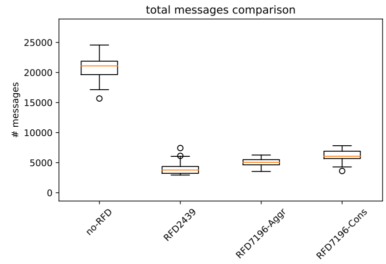
(b) Number of messages respect to the RFD strategy, MRAI=0s



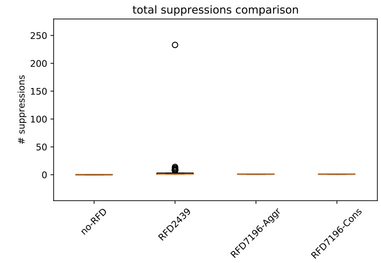
(c) Number of suppressions respect to the RFD strategy, MRAI=0s



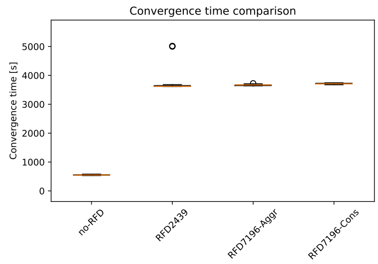
(d) Convergence time respect to the RFD strategy, MRAI=15s



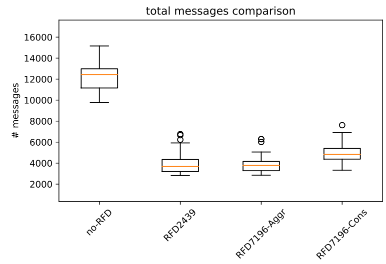
(e) Number of messages respect to the RFD strategy, MRAI=15s



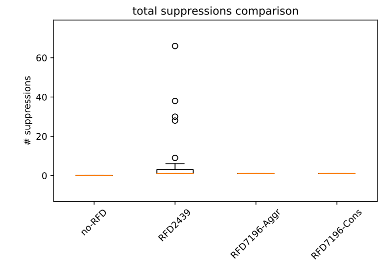
(f) Number of suppressions respect to the RFD strategy, MRAI=15s



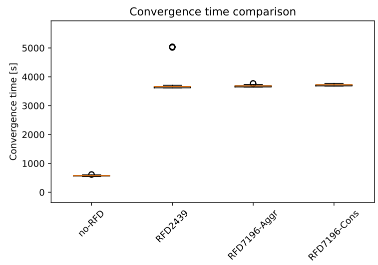
(g) Convergence time respect to the RFD strategy, MRAI=30s



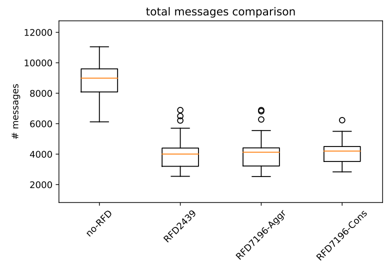
(h) Number of messages respect to the RFD strategy, MRAI=30s



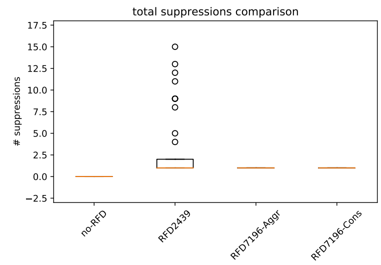
(i) Number of suppressions respect to the RFD strategy, MRAI=30s



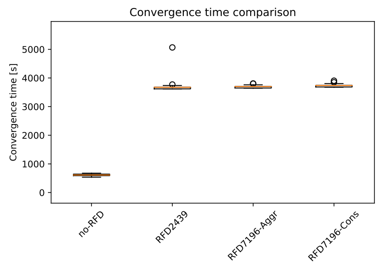
(j) Convergence time respect to the RFD strategy, MRAI=45s



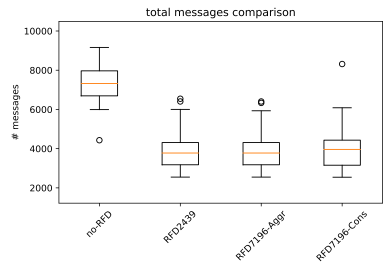
(k) Number of messages respect to the RFD strategy, MRAI=30s



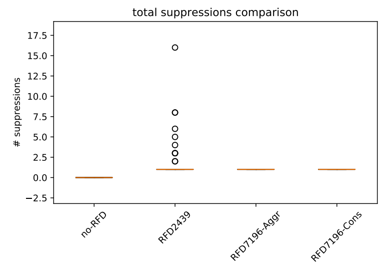
(l) Number of suppressions respect to the RFD strategy, MRAI=45s



(m) Convergence time respect to the RFD strategy, MRAI=60s

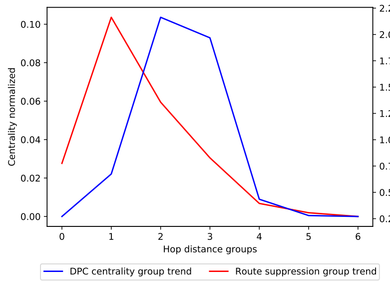


(n) Number of messages respect to the RFD strategy, MRAI=60s

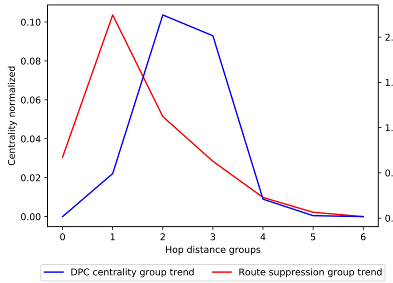


(o) Number of suppressions respect to the RFD strategy, MRAI=60s

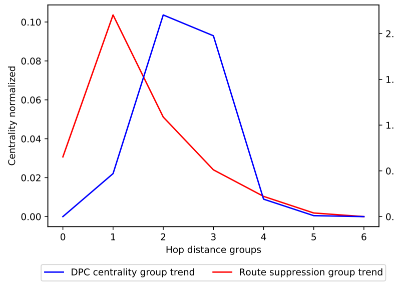
Figure A.10: Internet like topology 1000 nodes, random destination, 100 flaps, 3s delay, Network performances



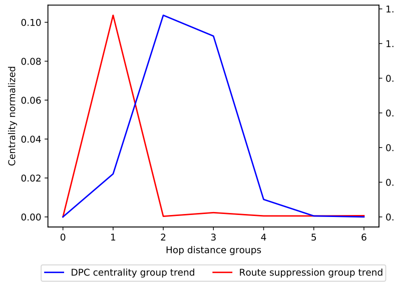
(a) RFD 2439 Strategy, MRAI=0s



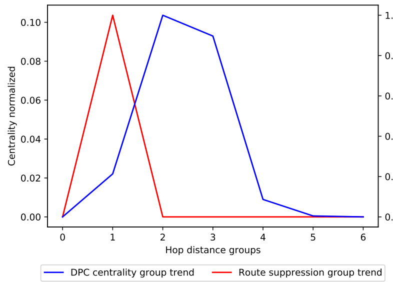
(b) RFD 7196 Aggressive Strategy, MRAI=0s



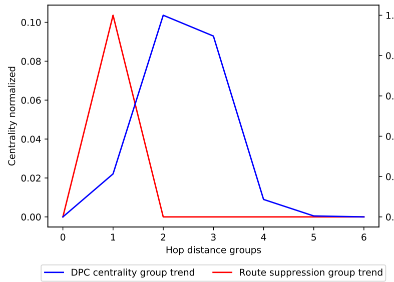
(c) RFD 7196 Conservative Strategy, MRAI=0s



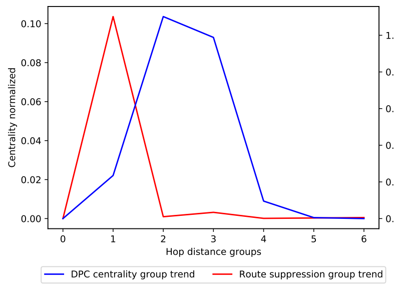
(d) RFD 2439 Strategy, MRAI=15s



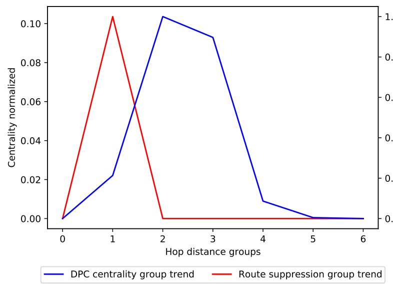
(e) RFD 7196 Aggressive Strategy, MRAI=15s



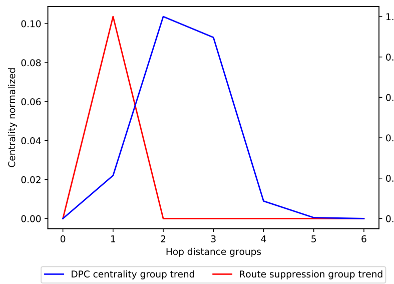
(f) RFD 7196 Conservative Strategy, MRAI=15s



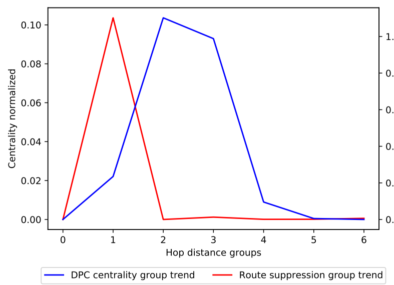
(g) RFD 2439 Strategy, MRAI=30s



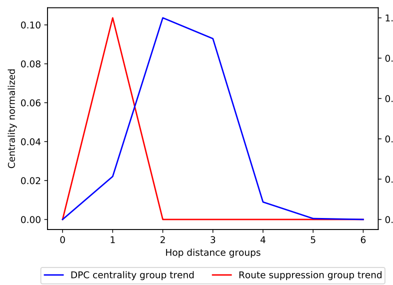
(h) RFD 7196 Aggressive Strategy, MRAI=30s



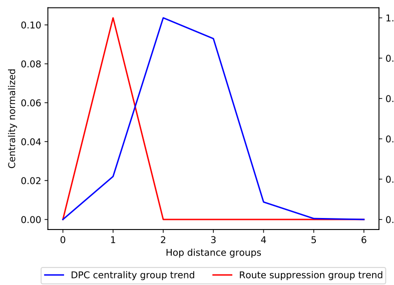
(i) RFD 7196 Conservative Strategy, MRAI=30s



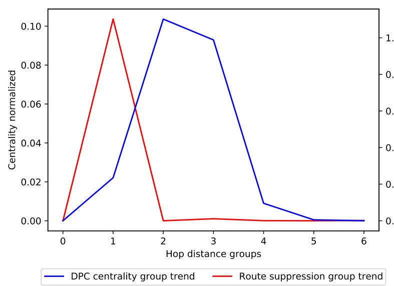
(j) RFD 2439 Strategy, MRAI=45s



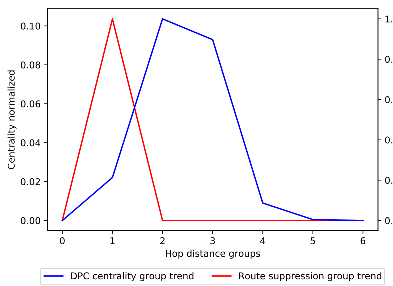
(k) RFD 7196 Aggressive Strategy, MRAI=45s



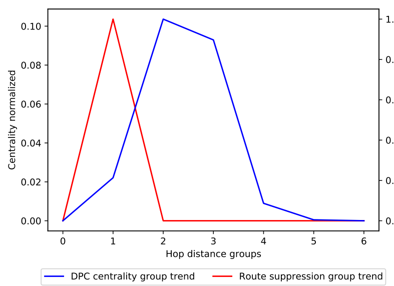
(l) RFD 7196 Conservative Strategy, MRAI=45s



(m) RFD 2439 Strategy, MRAI=60s



(n) RFD 7196 Aggressive Strategy, MRAI=60s



(o) RFD 7196 Conservative Strategy, MRAI=60s

Figure A.11: Internet like topology 1000 nodes, random destination, 100 flaps, 3s delay, Suppression trend VS avg hop centrality

Abbreviations

ADV advertisement

AS Autonomous System

BGP Border Gateway Protocol

CFSM Communicating Finite-State Machine

DES Discrete Event Simulator

DPC Destination Partial Centrality

FSM Finite State Machine

IW Implicit Withdraw

MRAI Minimum Route Advertisement Interval

RFC Request For Comment

RFD Route Flap Damping

RIB Routing Information Base

RNG Random Number Generator

SPP Stable Paths Problem