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Communication Range Dynamics Using an Energy Saving Self-Adaptive Transmission Power Controller in a Wireless Sensor Network

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Summary

- Introduction
- Description of the Self-Adaptive System
- Description of the Experiment
- Results
- Conclusions
- Future works
- Acknowledgements

Introduction (I)

Wireless Sensor and Actuator Networks (WSAN) reliability is strongly affected by unpredictable changes in the environment.

Using the maximum transmission power to improve the reliability over those changes causes a non-optimized extra energy consumption.

Acting on the transmission power to adapt it to environmental changes seems a good approach to achieve a good trade-off between energy consumption and communication reliability.

Introduction (II)

Kotian *et al.* have worked on the problem of Transmission Power Control (TPC) for WSAN by measuring the Received Signal Strength Indicator (RSSI) [1].

Mahmood *et al.* have studied the reliability of protocols used in WSN concluding, among other things, that cross layer design should be further explored to achieve reliability [2].

Kusy *et al*. proposed a dual radio network architecture to improve communication reliability in WSN with minor increase in energy consumption [3].

Introduction (III)

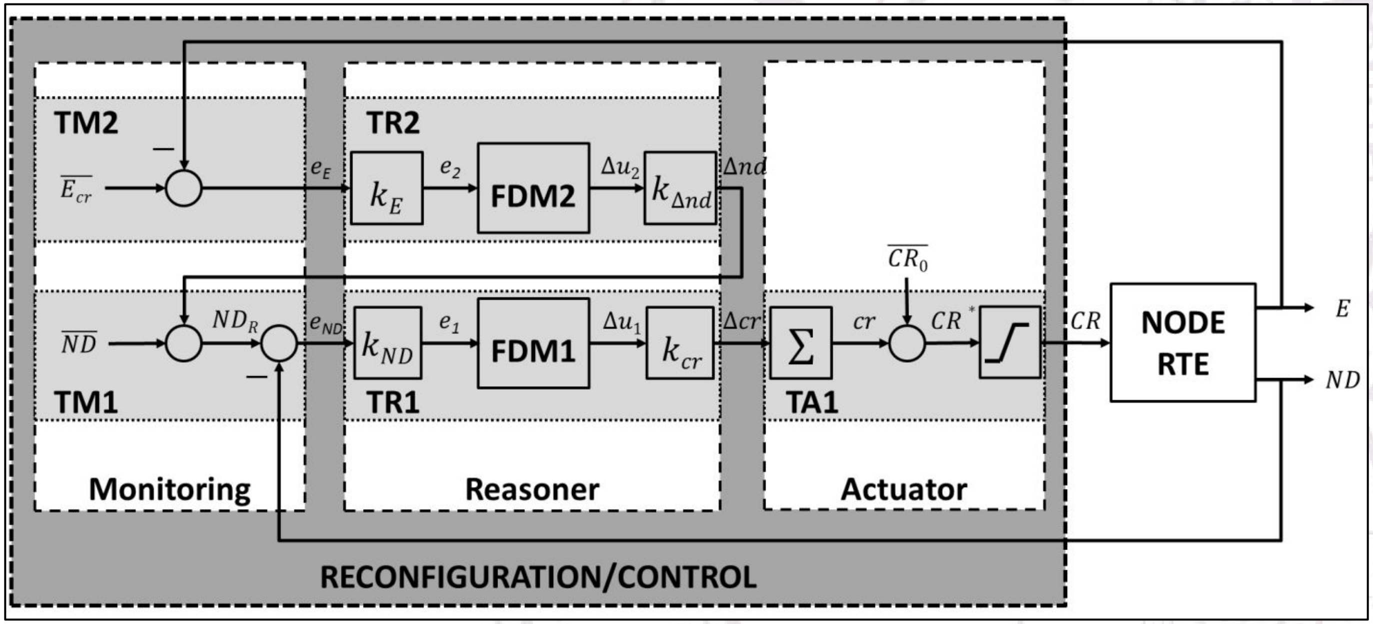
In Huang *et al.* [4] we propose a self-adaptive strategy based on fuzzy control. In this strategy each node transmission power is adapted to achieve an optimal number of neighbors (optimal **node degree**).

In Díaz *et al*. we explored the performance of the proposed self-adaptive system in a real physical deployment from a network perspective [5].

In this work we discuss about the achievements of the same real deployment focusing on each node performance.

Description of the System (DoS)

The system accomplishes a self-adaptive system through two feedback control loops as suggested by Yuriy Brun *et al.* [6]

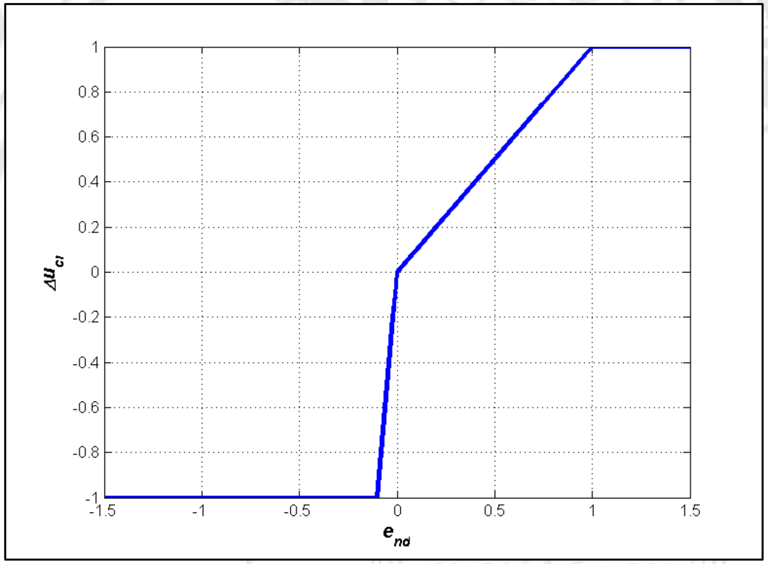


DoS: The primary loop

The primary feedback control loop manages the node transmission power considering both its real (ND) and targeted number of neighbors (ND_R).

The reasoner uses a function of decision making (FDM1) based on fuzzy logic to decide whether to modify the transmission power or not.

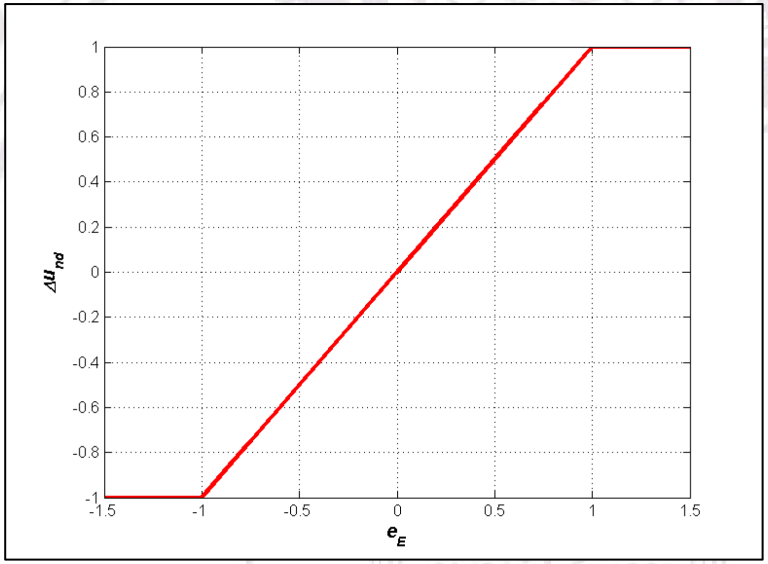
The fuzzy transfer function is the one shown in this slide.



DoS: The secondary loop

The secondary feedback control loop manages the node targeted number of neighbors (ND_R) considering the battery level (E_{CR}).

The reasoner uses a function of decision making (FDM2) based on fuzzy logic to decide whether to modify the targeted number of neighbors or not.



The fuzzy transfer function is the one shown in this slide.

DoS: The configuration parameters

ND_R is the number of neighbors that the node must have.

ξ_{ND} determines when the difference (e_{ND}) between a node ND_R and its real number of neighbors is significant enough to trigger the reasoner.

k_{CR} amplifies FDM1 output, that is, the required change in the node transmission power.

$\overline{E_{CR}}$ is the reference critical level that implies an adjustment on ND_R to reduce energy consumption.

DoS: The trigger rules

A set of rules have been defined to trigger each loop:

1. **Saturation control rule**: To avoid trying to adjust the transmission power over the available limits.

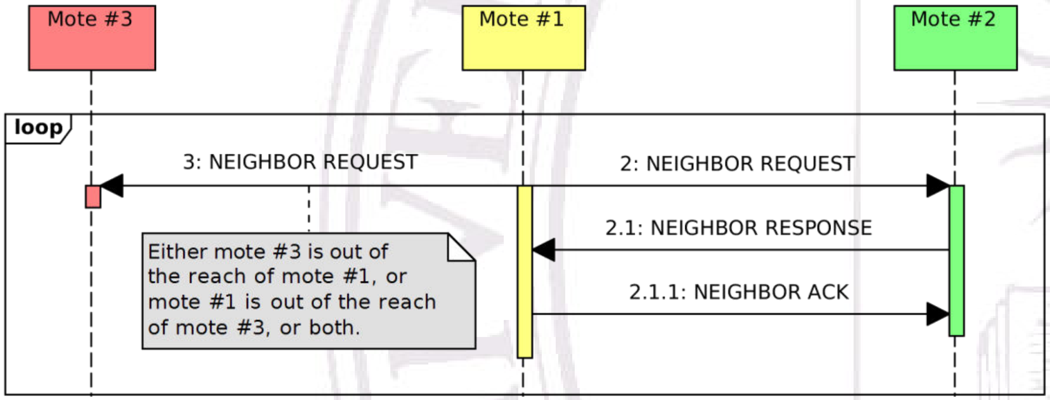
2. ***Debouncing* control rule**: To prevent the motes to oscillate between two communication ranges.

3. **Critical energy control rule**: To redefine the targeted number of neighbors when low energy levels have been reached in a mote.

DoS: The Neighbor Discovery

We use a simple active neighbor discovery protocol:

1. Each node periodically broadcasts a neighbor request.
2. If a node receives a response to its request, it means that there is a neighbor able to receive and send, so it is added to the list.
3. If a node receives an acknowledge to its response, it means that there is a neighbor able to receive and send, so it is added to the list.



Description of the Experiment (DoE)

We have defined a set of eight tests to explore the impact of the configuration parameters in the WSAN performance.

We also run two control test without the self-adaptive system using a fixed maximum and median value for the transmission power.

In the tests with the self-adaptive system the control rules are evaluated periodically with an interval of 20 s. Each node sends a status message addressed to the base station at the end of each iteration.

DoE: Used equipment

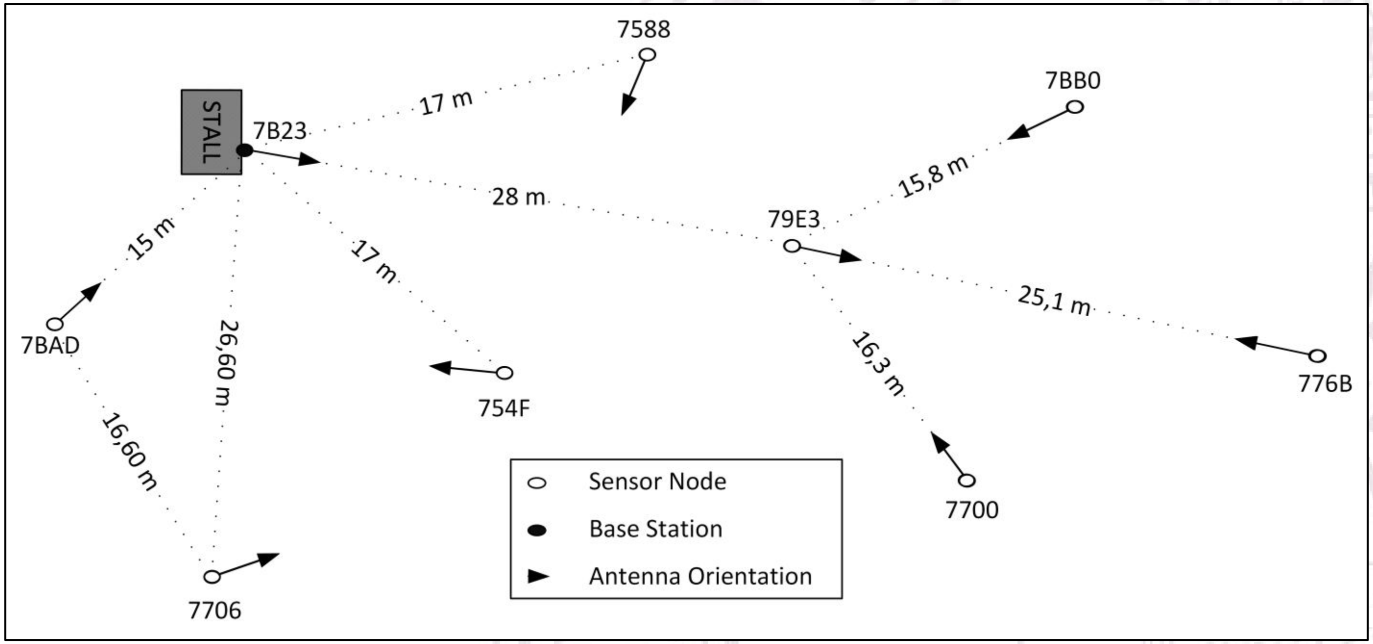
The motes used in the scenario are SunSPOT devices manufactured by Oracle Corporation.

Eight motes were configured to run the control based self-adaptive system and arbitrarily deployed in an outdoor open area.

One extra mote without sensors was used as a sink, and therefore not using the self-adaptive system.

DoE: Deployment

The motes were deployed at the facilities of the Centro de Automática y Robótica in Arganda del Rey using the following scheme:



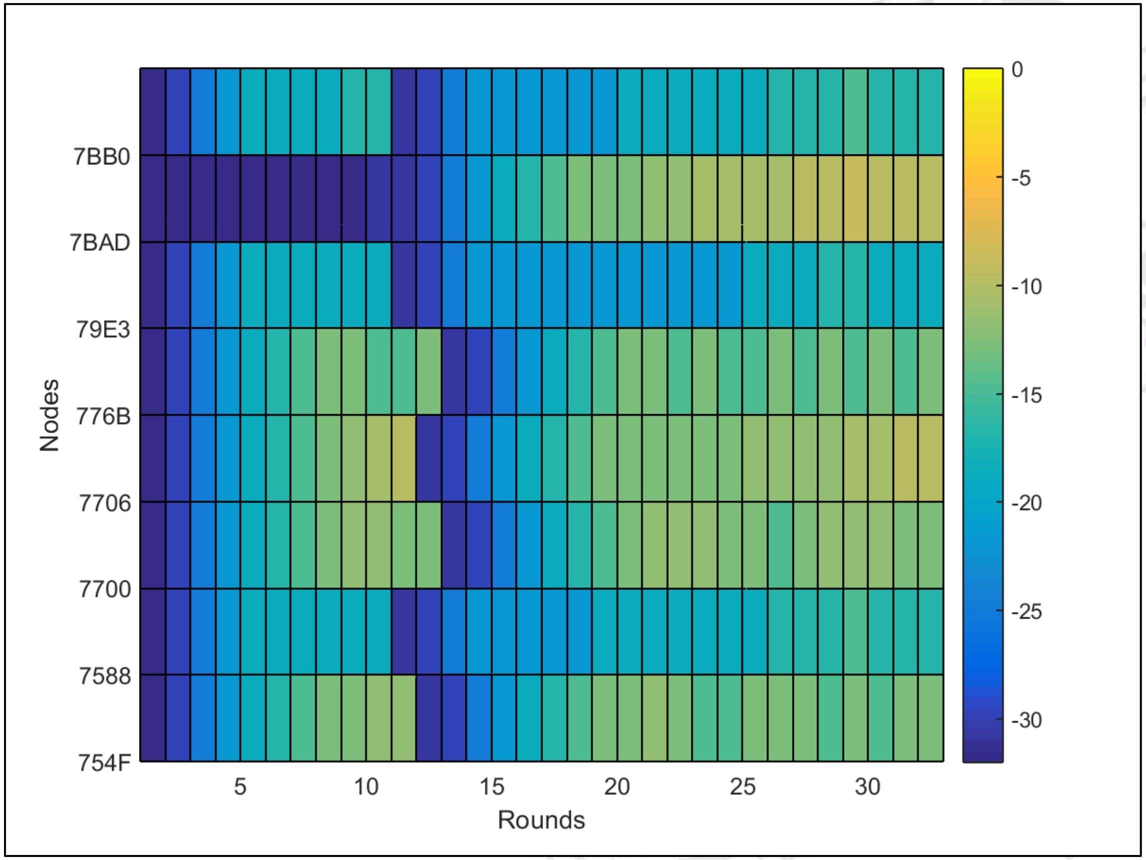
DoE: Description of tests

Configuration parameters and previous analyzed results

Experiment	ND_R	ξ_{ND}	k_{CR}	E_{CR}	P_{TX}	J_e	J_c
Control: e01					-3 dBm	4283.19	2.3734
Control: e02					-15 dBm	3408.00	21.0463
Test: e03	2	0	1	150		3921.53	36.7036
Test: e04	2	0	3	150		3947.76	17.0662
Test: e05	2	1	3	150		3639.89	9.6857
Test: e06	3	1	3	150		3817.46	12.9013
Test: e07	3	0	3	150		3846.54	11.3045
Test: e08	3	0	1	150		3865.22	19.0762
Test: e09	3	1	1	150		3798.83	20.1254
Test: e10	2	1	1	150		3952.63	40.1113

Results: CR Dynamics. (I)

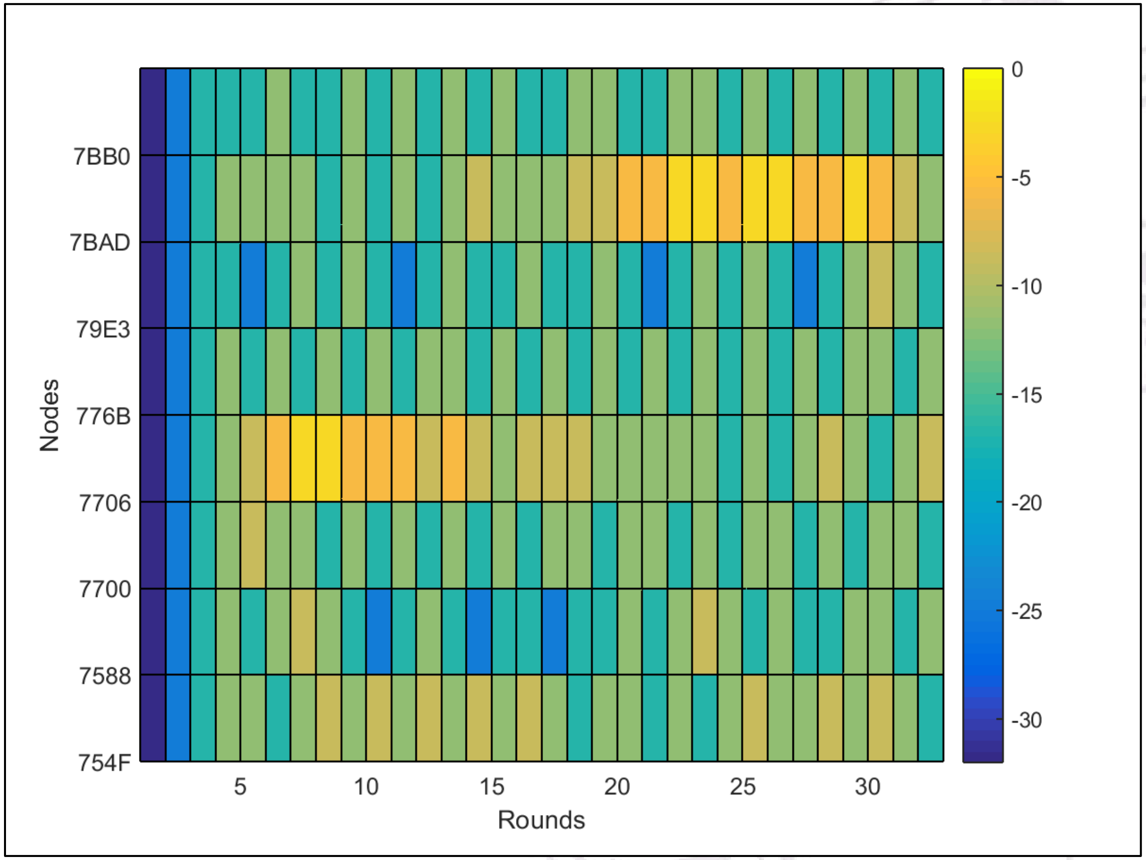
Test e03: Transmission power changes for each node



$$ND_R = 2$$
$$\xi_{ND} = 0$$
$$k_{CR} = 1$$
$$E_{CR} = 150$$

Results: CR Dynamics (II)

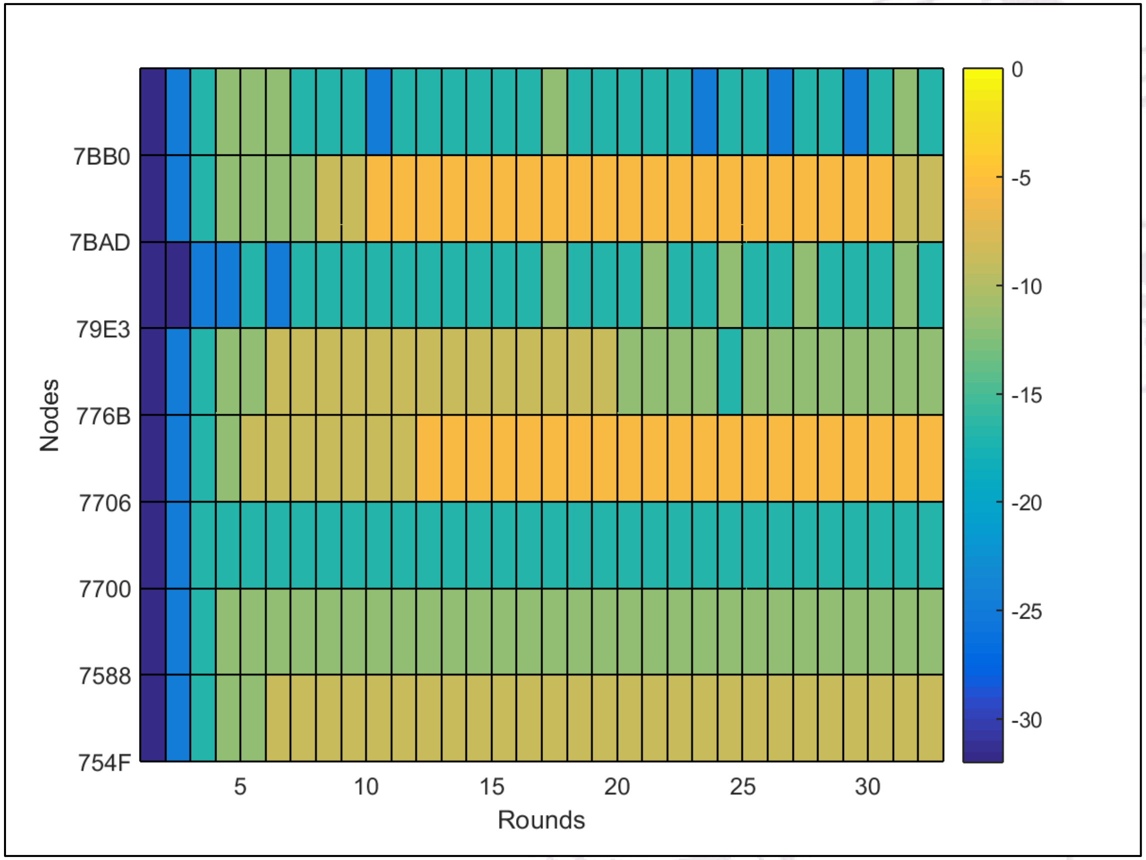
Test e04: Transmission power changes for each node



$$ND_R = 2$$
$$\xi_{ND} = 0$$
$$k_{CR} = 3$$
$$E_{CR} = 150$$

Results: CR Dynamics (III)

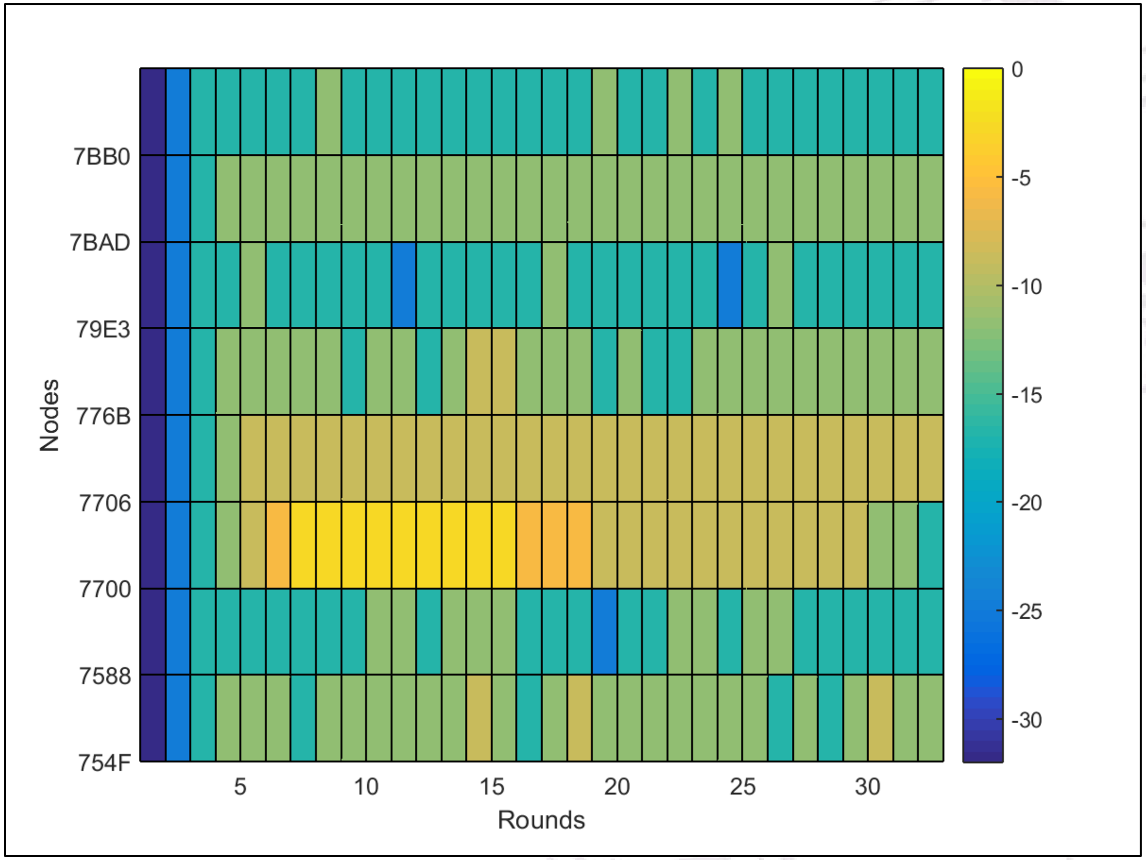
Test e05: Transmission power changes for each node



$ND_R = 2$
$\xi_{ND} = 1$
$k_{CR} = 3$
$E_{CR} = 150$

Results: CR Dynamics (IV)

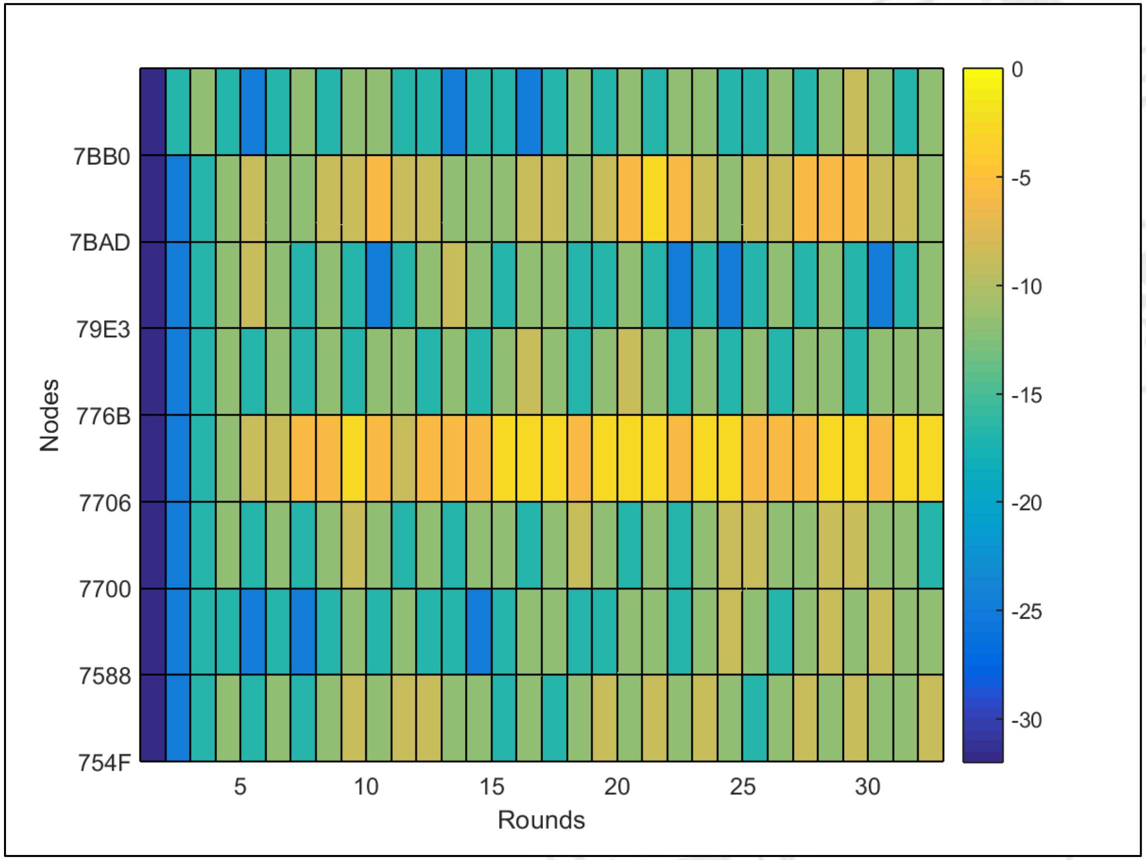
Test e06: Transmission power changes for each node



$$ND_R = 3$$
$$\xi_{ND} = 1$$
$$k_{CR} = 3$$
$$E_{CR} = 150$$

Results: CR Dynamics (V)

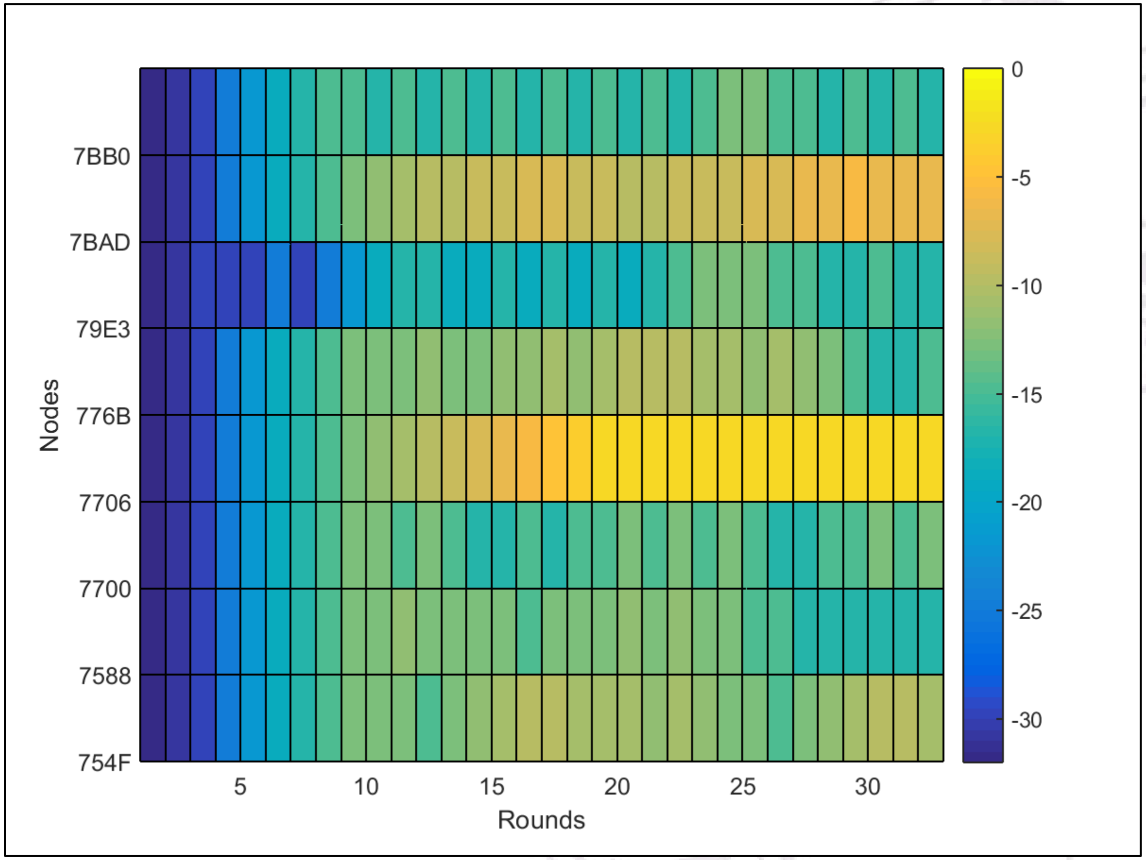
Test e07: Transmission power changes for each node



$ND_R = 3$
$\xi_{ND} = 0$
$k_{CR} = 3$
$E_{CR} = 150$

Results: CR Dynamics (VI)

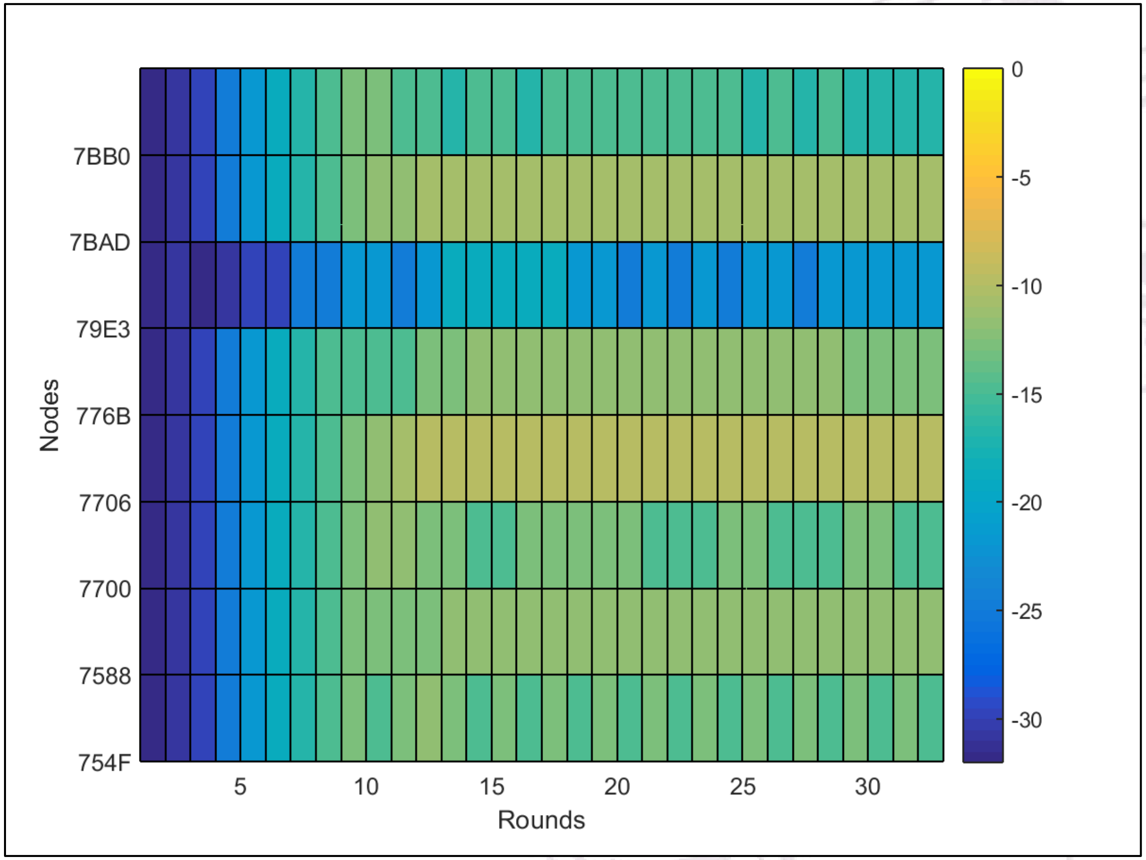
Test e08: Transmission power changes for each node



$$ND_R = 3$$
$$\xi_{ND} = 0$$
$$k_{CR} = 1$$
$$E_{CR} = 150$$

Results: CR Dynamics (VII)

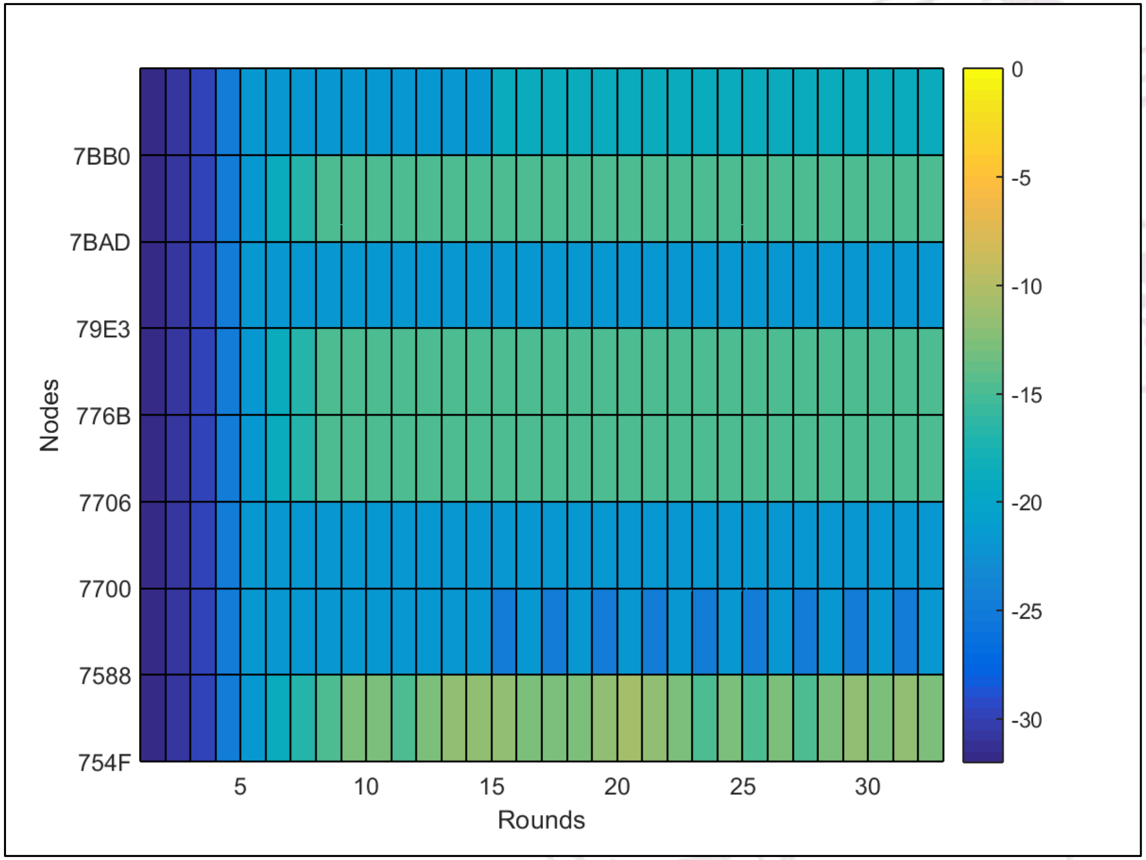
Test e09: Transmission power changes for each node



$ND_R = 3$
$\xi_{ND} = 1$
$k_{CR} = 1$
$E_{CR} = 150$

Results: CR Dynamics (VIII)

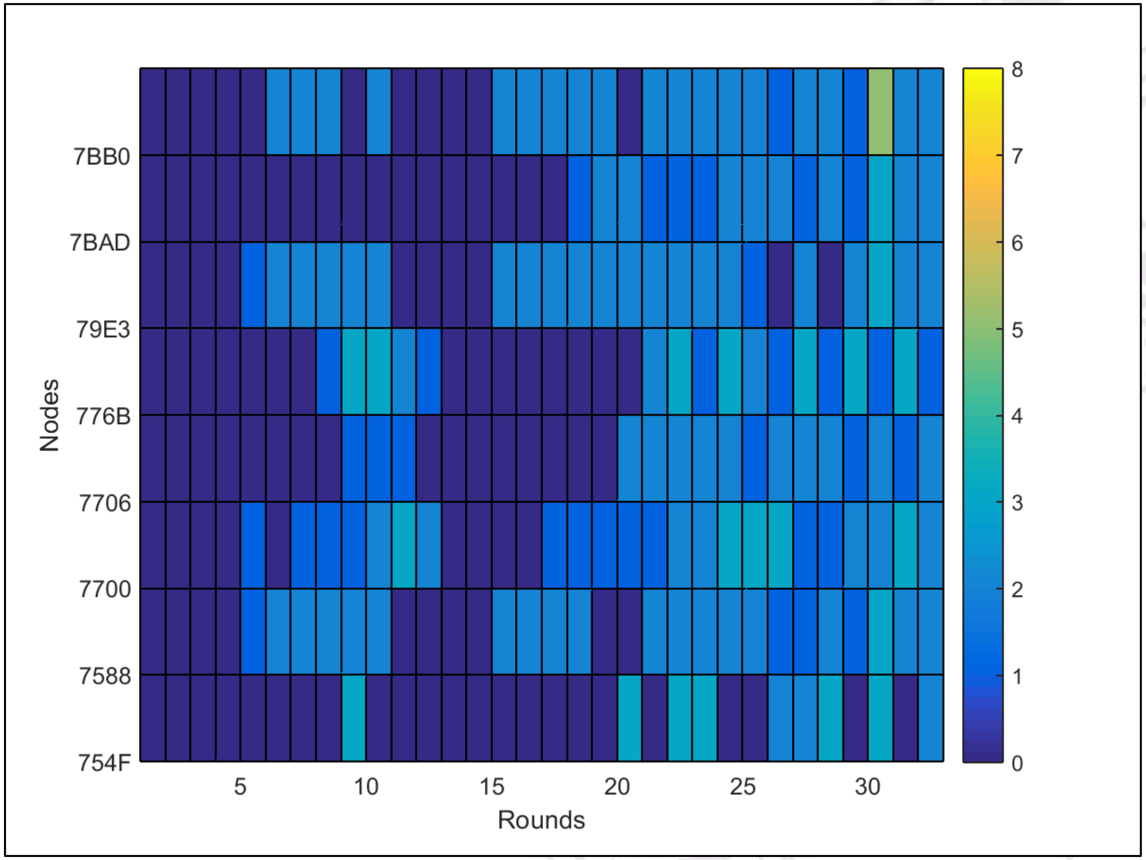
Test e10: Transmission power changes for each node



$ND_R = 2$
$\xi_{ND} = 1$
$k_{CR} = 1$
$E_{CR} = 150$

Results: Node Degree Dynamics (I)

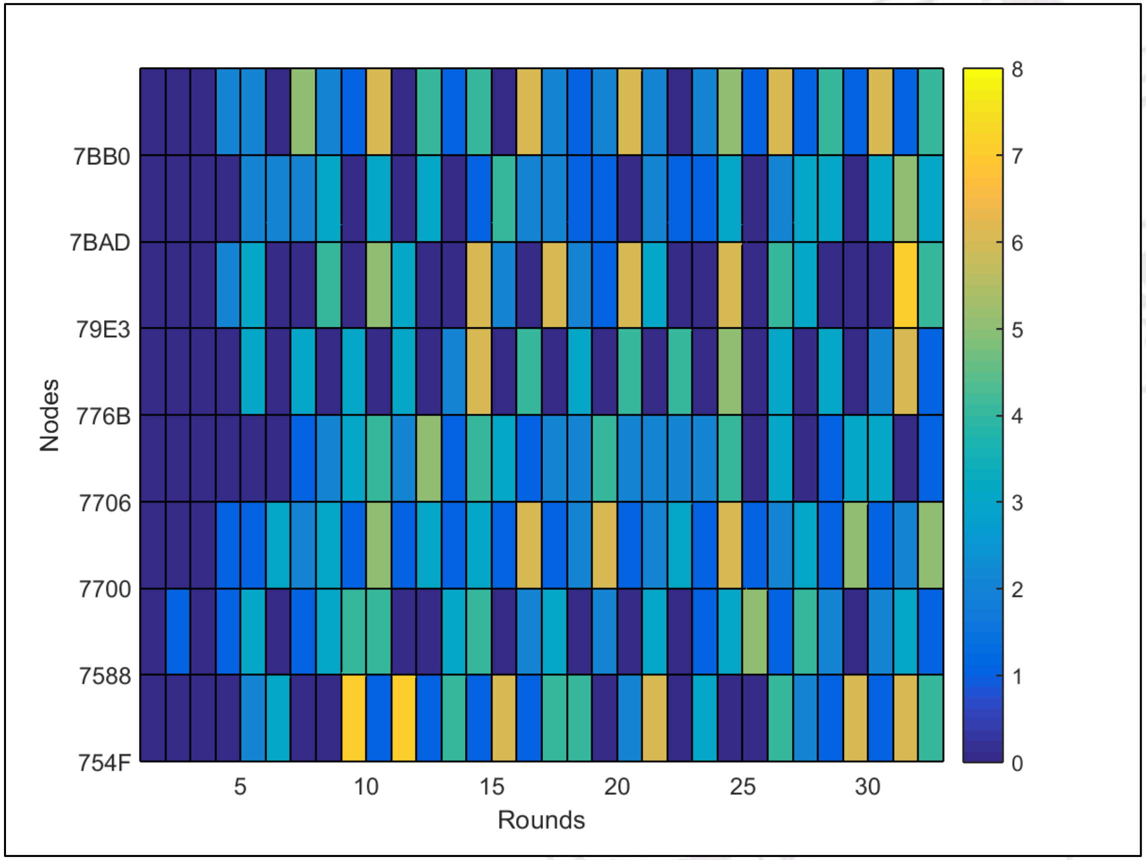
Test e03: Node degree evolution for each node



$$ND_R = 2$$
$$\xi_{ND} = 0$$
$$k_{CR} = 1$$
$$E_{CR} = 150$$

Results: Node Degree Dynamics (II)

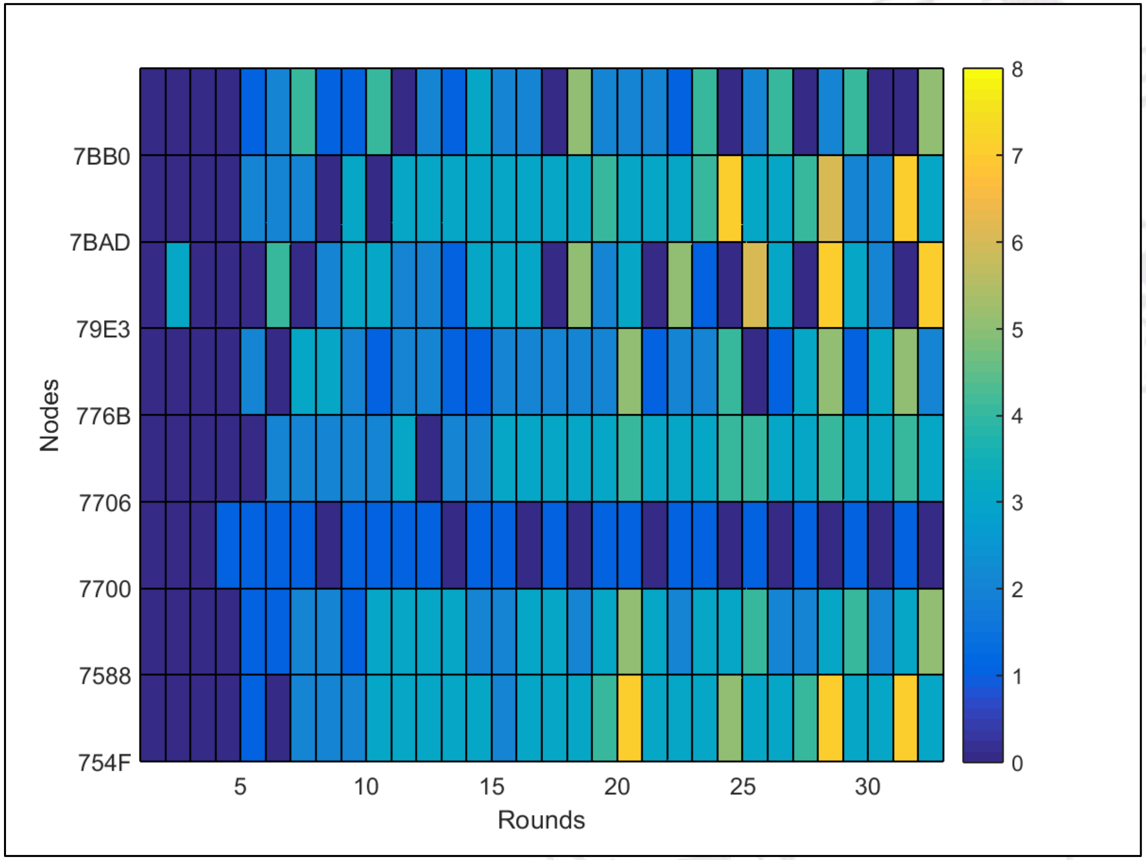
Test e04: Node degree evolution for each node



$$ND_R = 2$$
$$\xi_{ND} = 0$$
$$k_{CR} = 3$$
$$E_{CR} = 150$$

Results: Node Degree Dynamics (III)

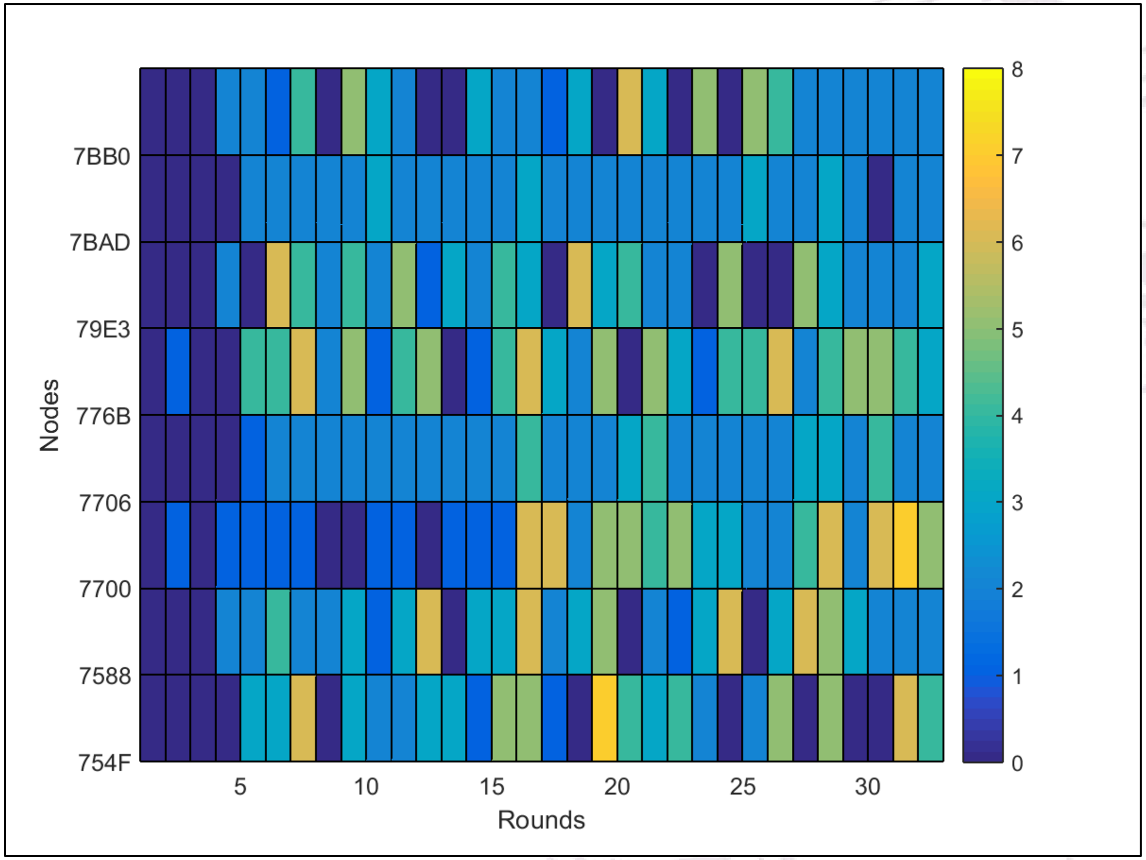
Test e05: Node degree evolution for each node



$ND_R = 2$
$\xi_{ND} = 1$
$k_{CR} = 3$
$E_{CR} = 150$

Results: Node Degree Dynamics (IV)

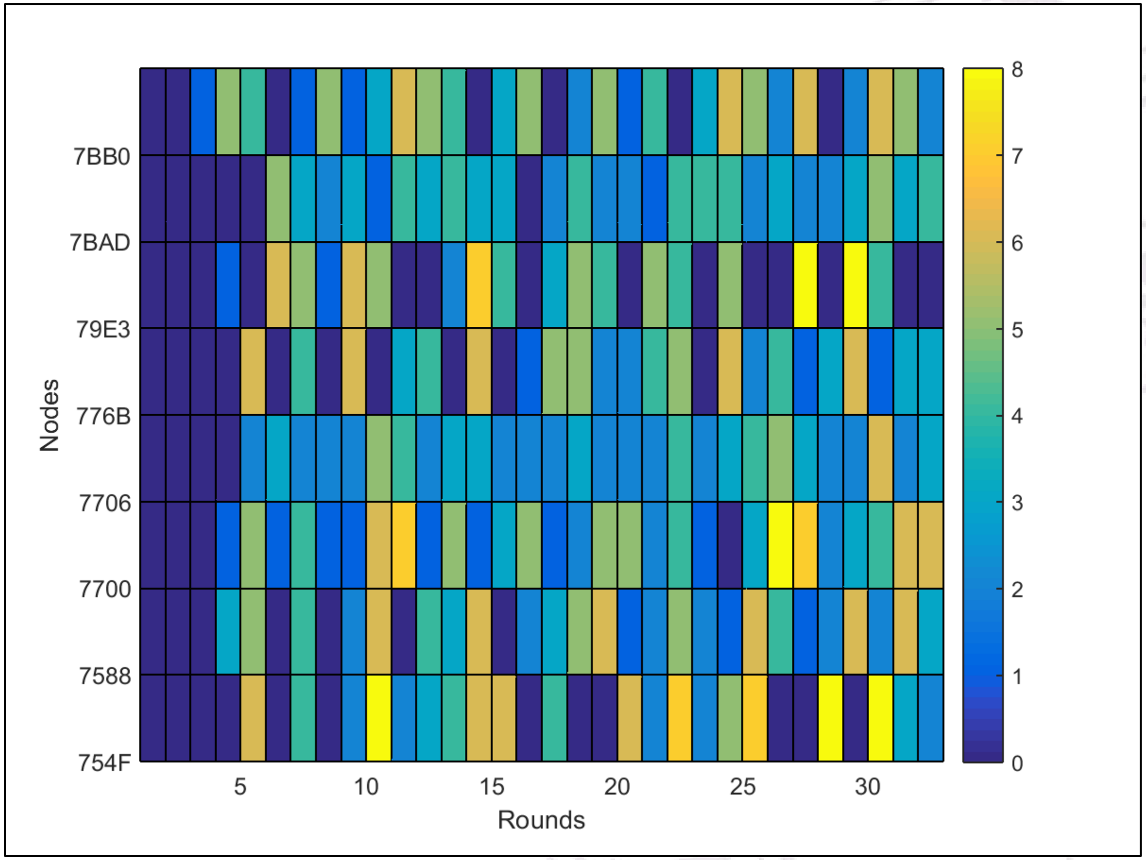
Test e06: Node degree evolution for each node



$ND_R = 3$
$\xi_{ND} = 1$
$k_{CR} = 3$
$E_{CR} = 150$

Results: Node Degree Dynamics (V)

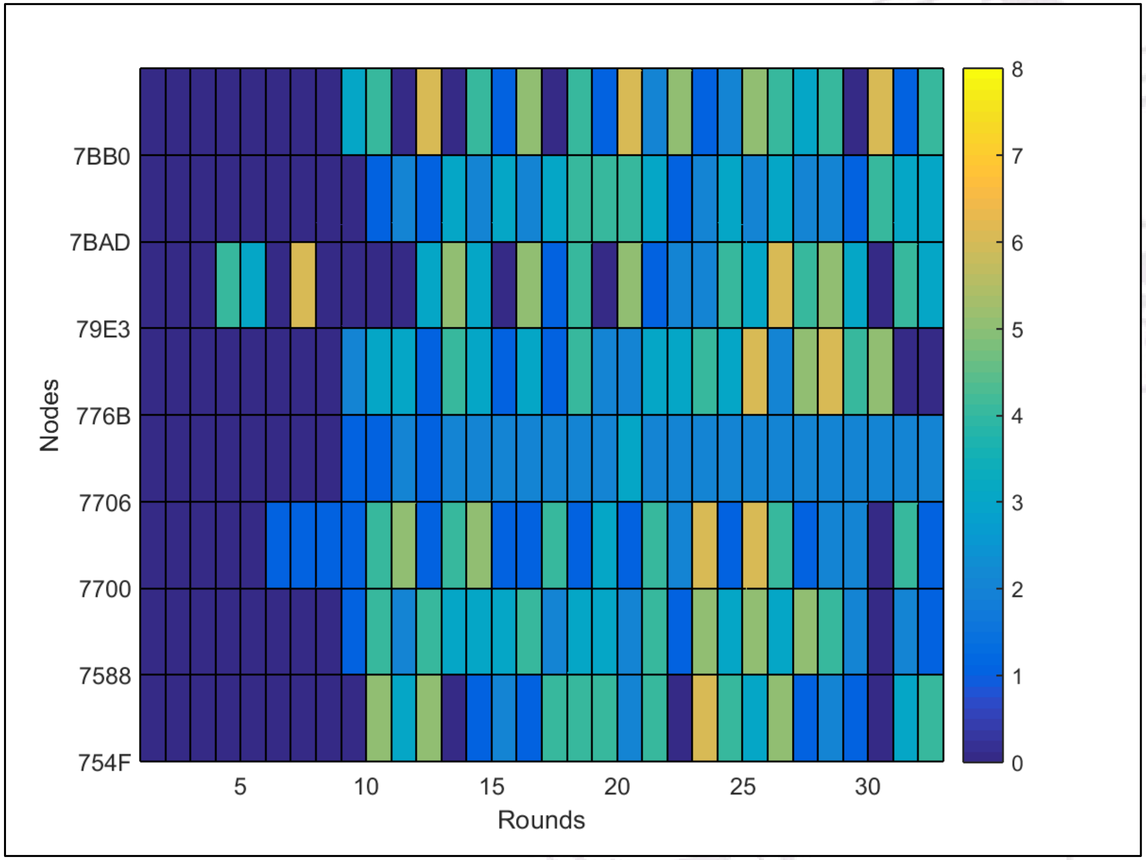
Test e07: Node degree evolution for each node



$$ND_R = 3$$
$$\xi_{ND} = 0$$
$$k_{CR} = 3$$
$$E_{CR} = 150$$

Results: Node Degree Dynamics (VI)

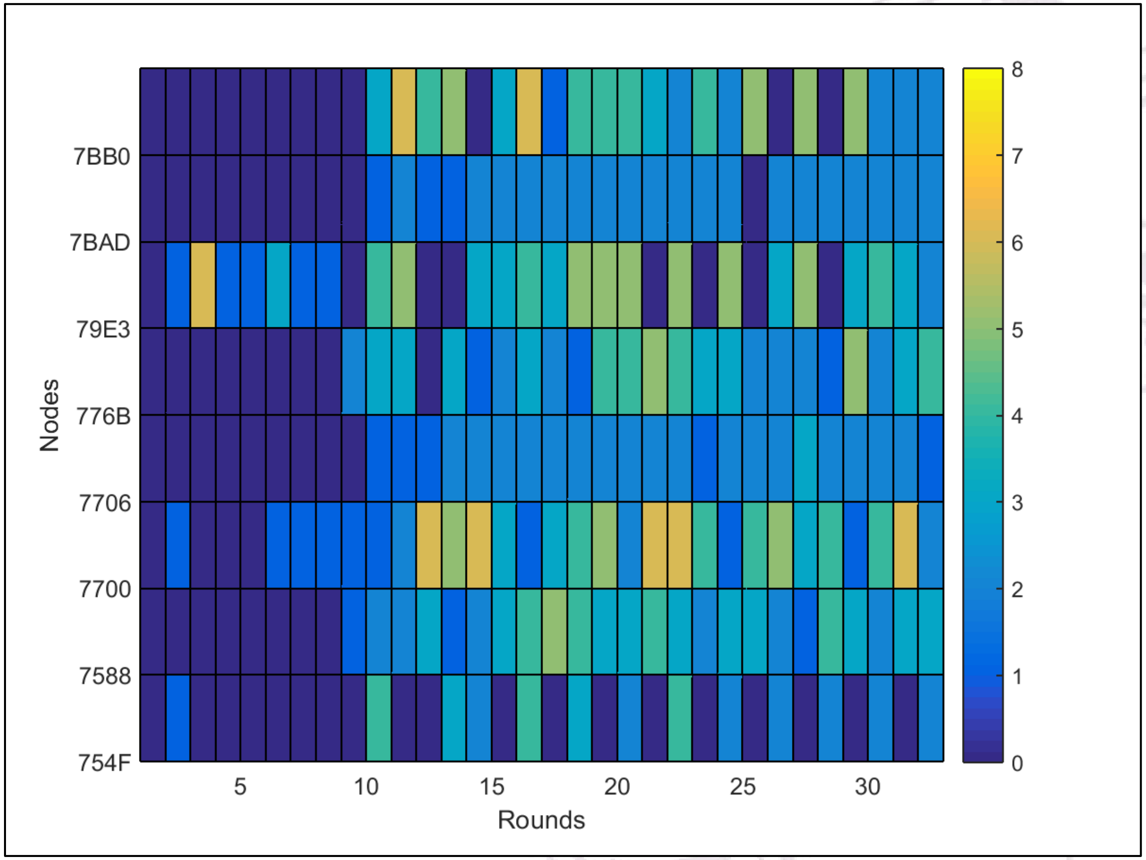
Test e08: Node degree evolution for each node



$ND_R = 3$
$\xi_{ND} = 0$
$k_{CR} = 1$
$E_{CR} = 150$

Results: Node Degree Dynamics (VII)

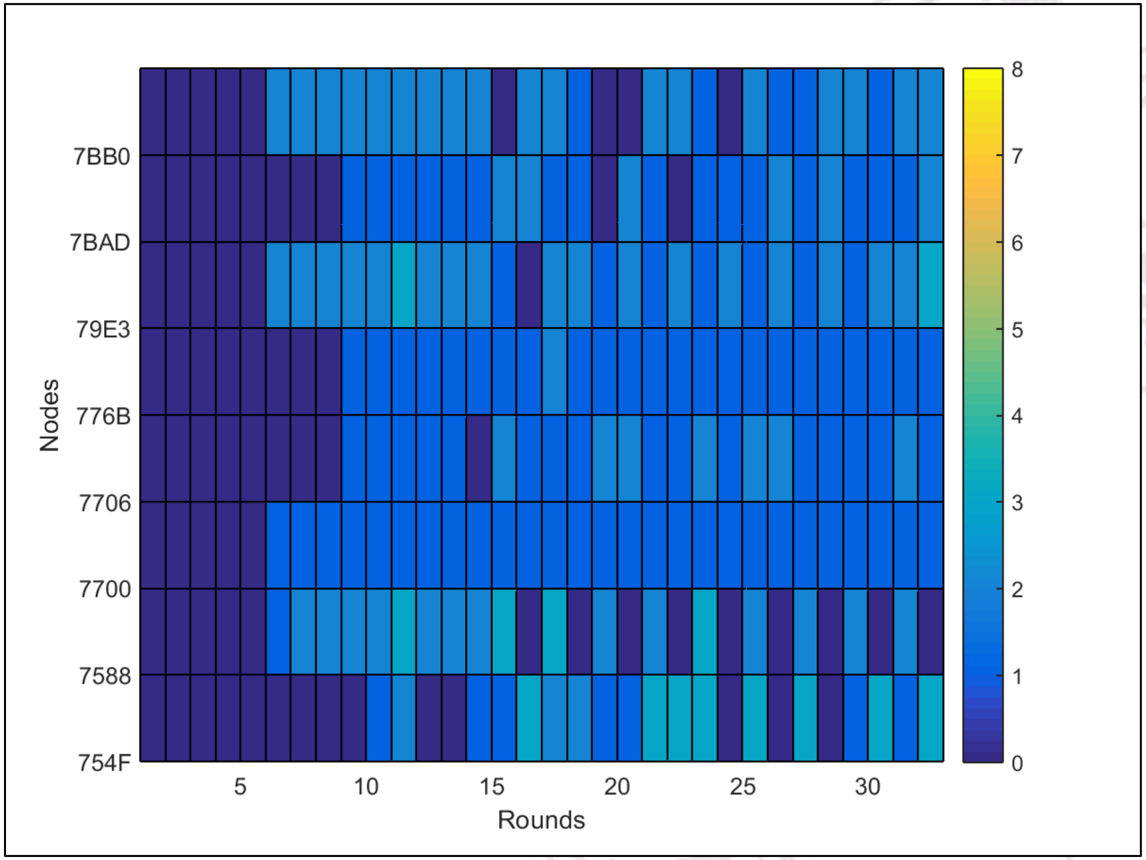
Test e09: Node degree evolution for each node



$ND_R = 3$
$\xi_{ND} = 1$
$k_{CR} = 1$
$E_{CR} = 150$

Results: Node Degree Dynamics (VIII)

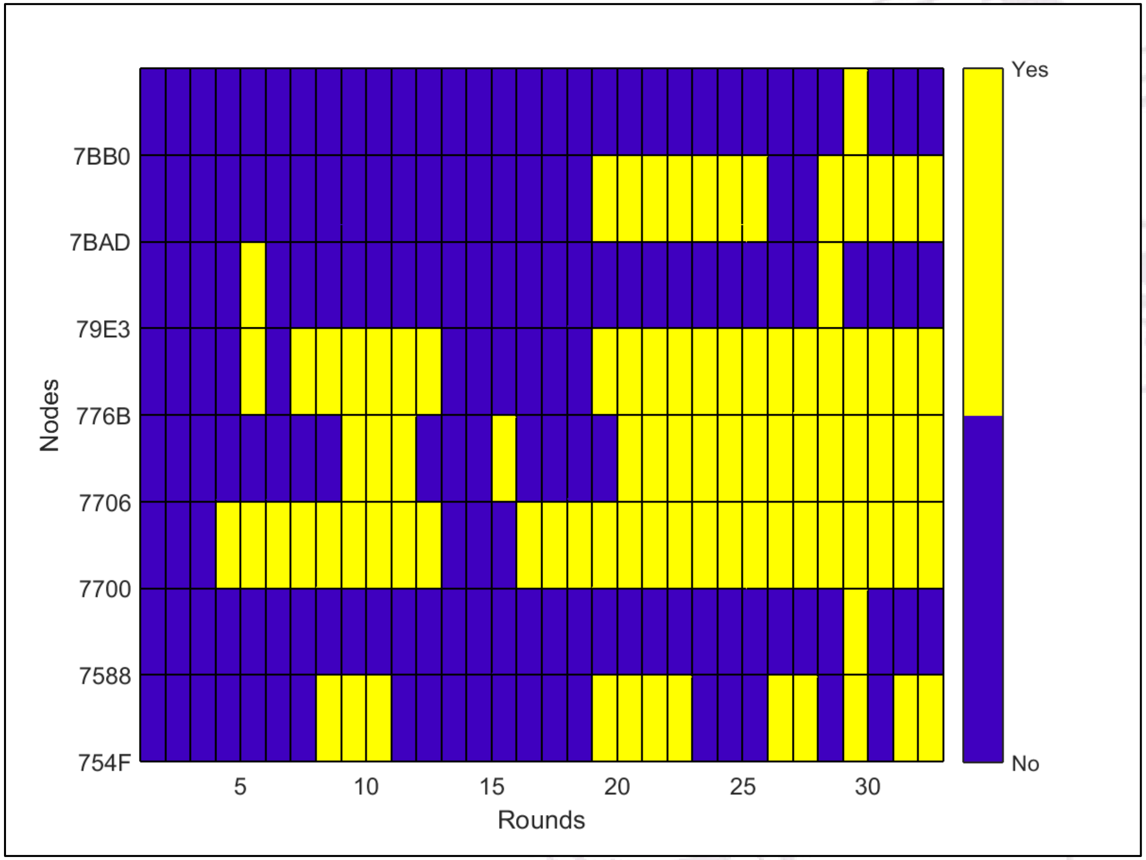
Test e10: Node degree evolution for each node



$ND_R = 2$
$\xi_{ND} = 1$
$k_{CR} = 1$
$E_{CR} = 150$

Results: Packet Delivery Dynamics (I)

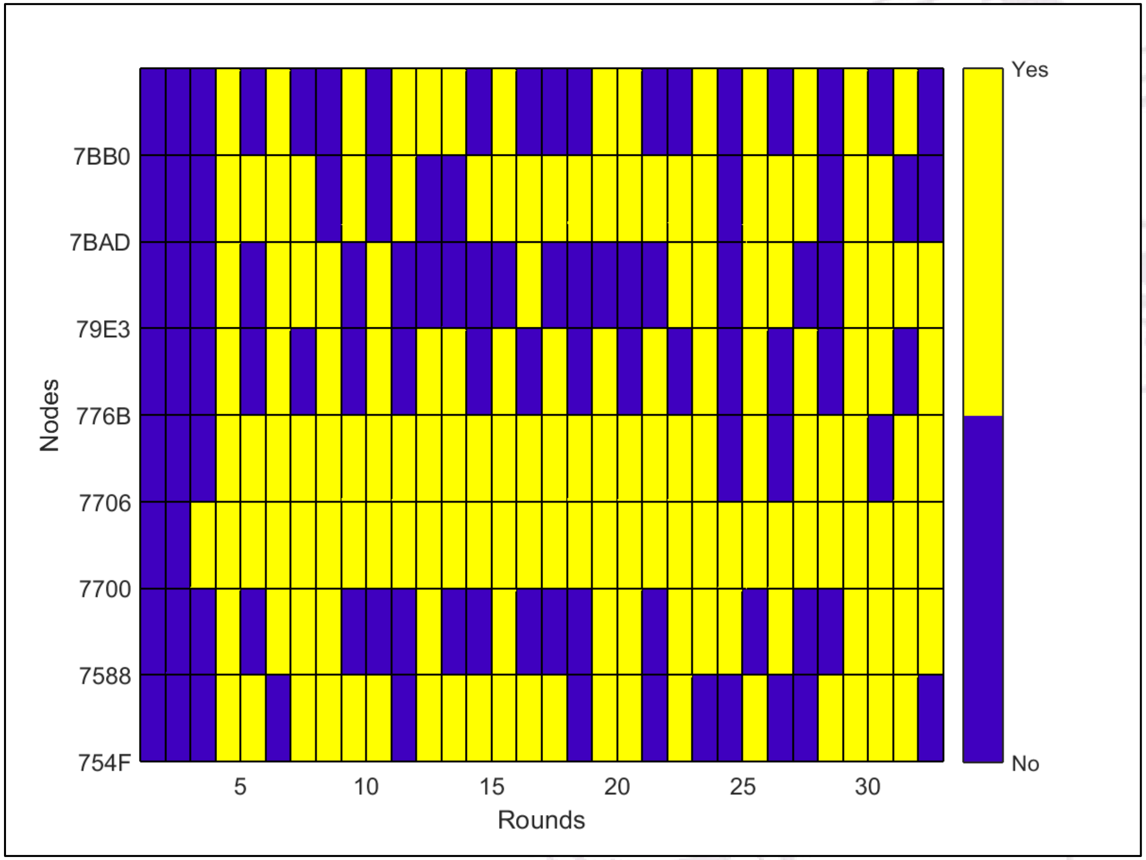
Test e03: Packet delivery evolution for each node



$$ND_R = 2$$
$$\xi_{ND} = 0$$
$$k_{CR} = 1$$
$$E_{CR} = 150$$

Results: Packet Delivery Dynamics (II)

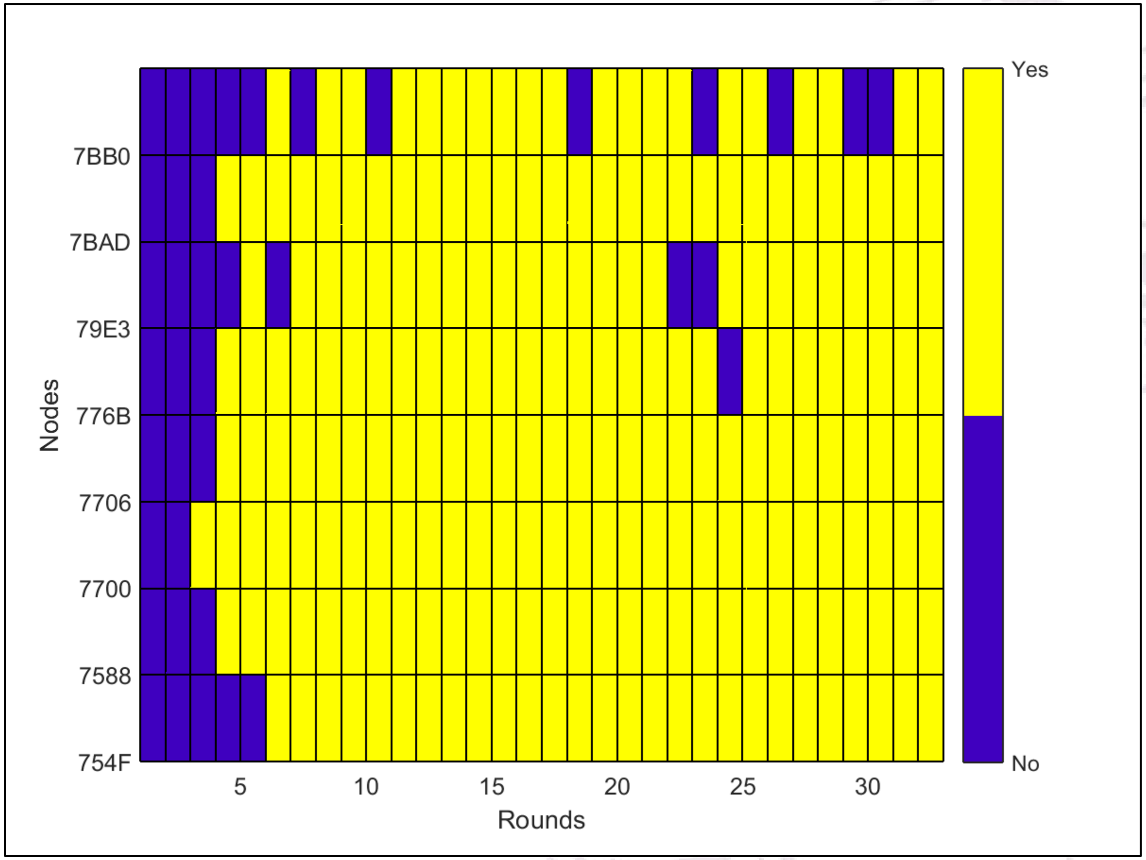
Test e04: Packet delivery evolution for each node



$$ND_R = 2$$
$$\xi_{ND} = 0$$
$$k_{CR} = 3$$
$$E_{CR} = 150$$

Results: Packet Delivery Dynamics (III)

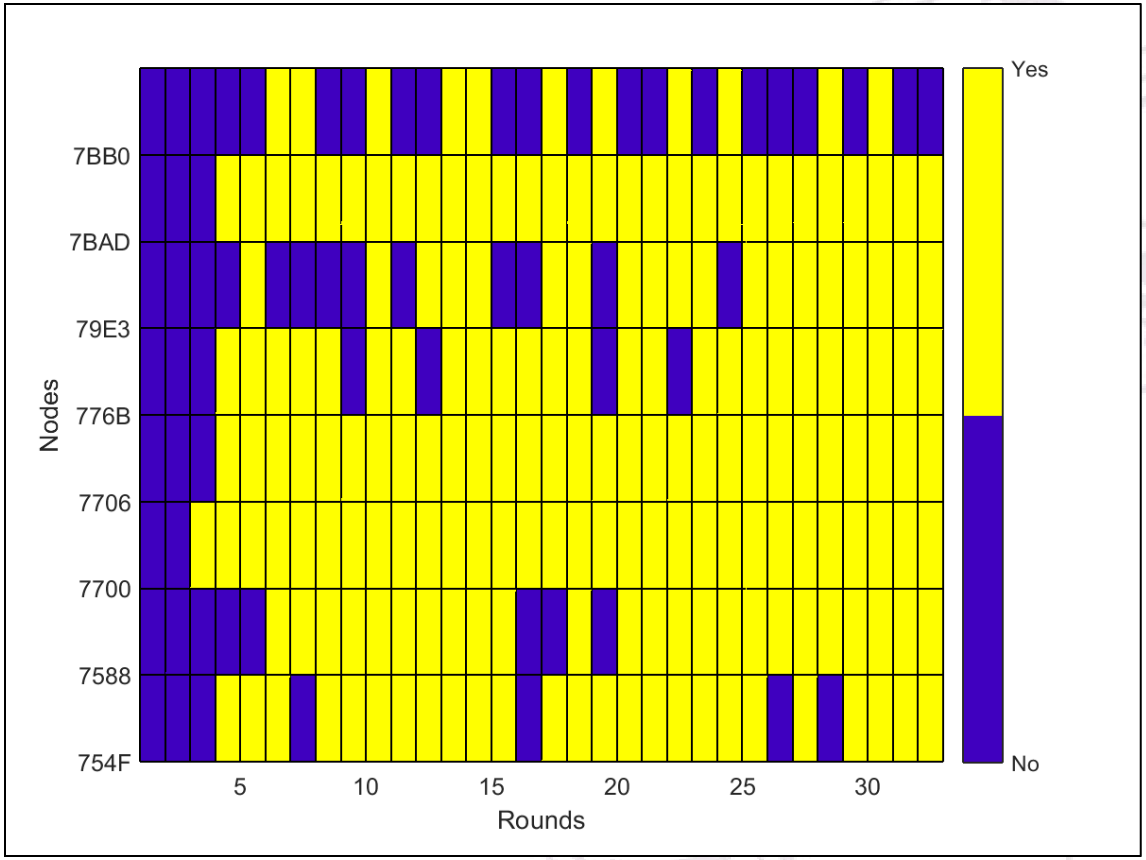
Test e05: Packet delivery evolution for each node



$$ND_R = 2$$
$$\xi_{ND} = 1$$
$$k_{CR} = 3$$
$$E_{CR} = 150$$

Results: Packet Delivery Dynamics (IV)

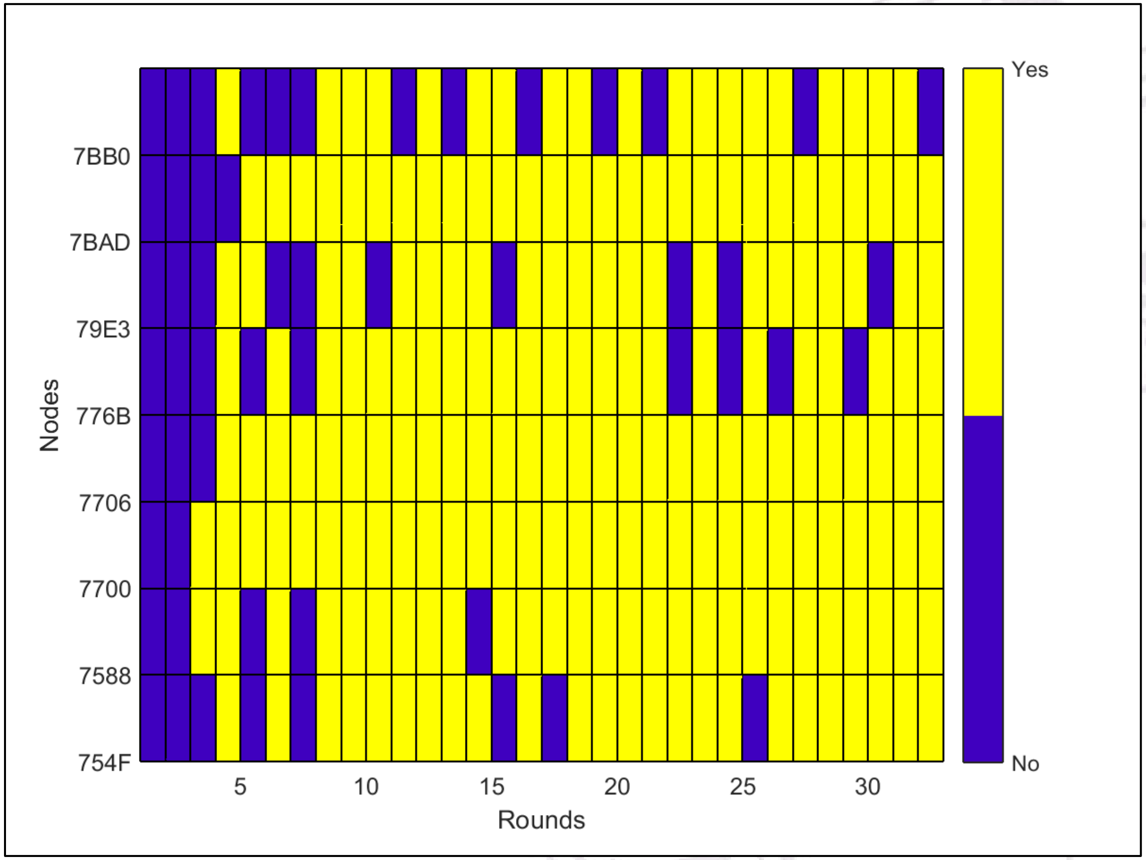
Test e06: Packet delivery evolution for each node



$ND_R = 3$
$\xi_{ND} = 1$
$k_{CR} = 3$
$E_{CR} = 150$

Results: Packet Delivery Dynamics (V)

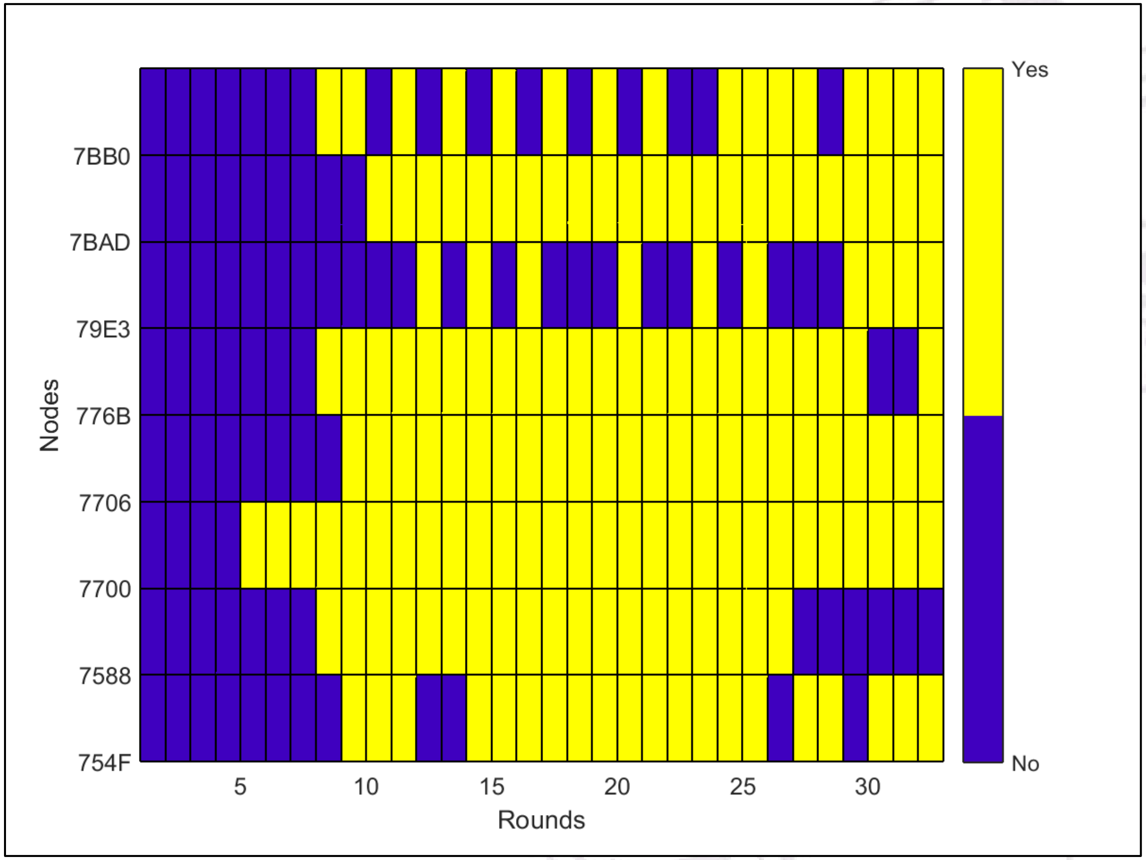
Test e07: Packet delivery evolution for each node



$$ND_R = 3$$
$$\xi_{ND} = 0$$
$$k_{CR} = 3$$
$$E_{CR} = 150$$

Results: Packet Delivery Dynamics (VI)

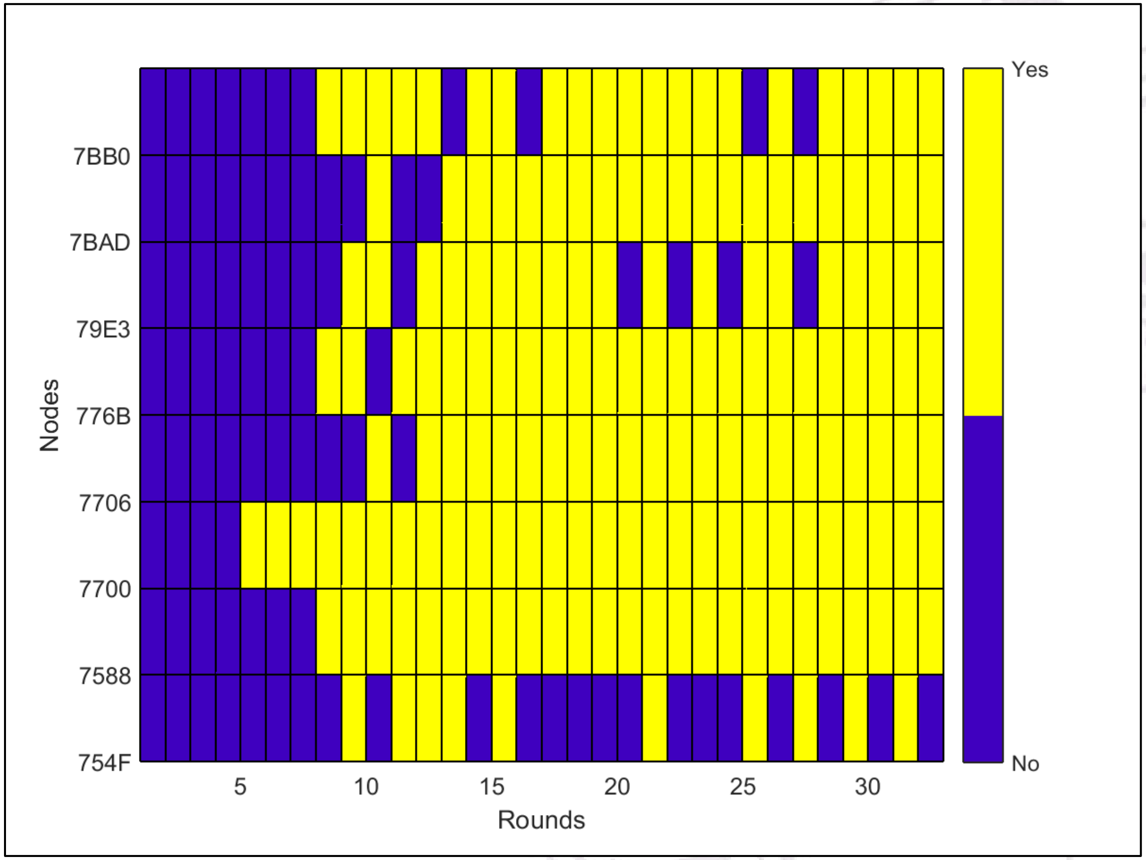
Test e08: Packet delivery evolution for each node



$$ND_R = 3$$
$$\xi_{ND} = 0$$
$$k_{CR} = 1$$
$$E_{CR} = 150$$

Results: Packet Delivery Dynamics (VII)

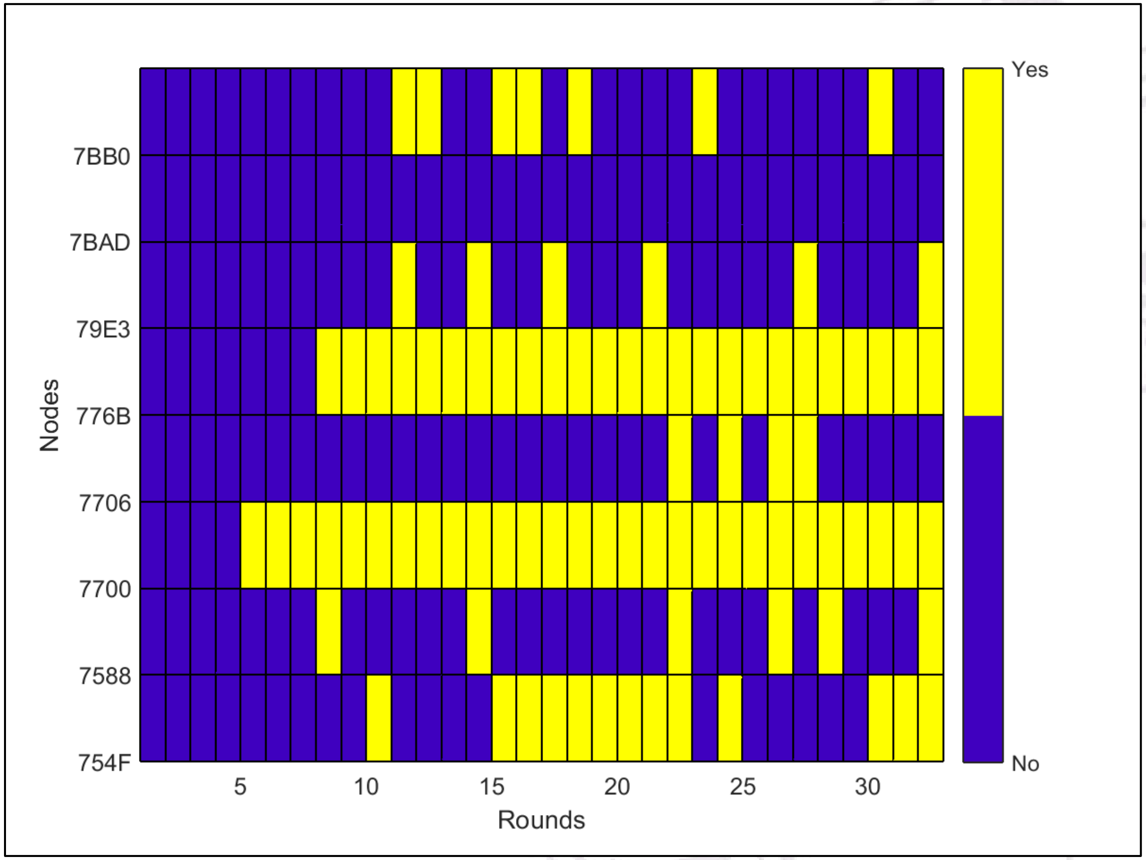
Test e09: Packet delivery evolution for each node



$$ND_R = 3$$
$$\xi_{ND} = 1$$
$$k_{CR} = 1$$
$$E_{CR} = 150$$

Results: Packet Delivery Dynamics (VIII)

Test e10: Packet delivery evolution for each node



$ND_R = 2$
$\xi_{ND} = 1$
$k_{CR} = 1$
$E_{CR} = 150$

Results: Cost of Dynamics (I)

The cost of dynamics due to changes in the communication range by means of adjusting the transmission power can be estimated by the accompanying equation, obtaining the results shown in the table.

$$J_{d_{CR}} = \sum_{i=0}^{n} \chi_{i_{CR}}$$

Experiment	ND_R	ξ_{ND}	k_{CR}	E_{CR}	J_d
Test: e03	2	0	1	150	150
Test: e04	2	0	3	150	211
Test: e05	2	1	3	150	58
Test: e06	3	1	3	150	83
Test: e07	3	0	3	150	205
Test: e08	3	0	1	150	182
Test: e09	3	1	1	150	127
Test: e10	2	1	1	150	84

Results: Cost of Dynamics (II)

Comparison for different values of tolerance (ξ_{ND}):

- Using $\xi_{ND} = 0$ (without tolerance):
  - Average cost: $\mu_{\xi_{ND=0}} = 187$
  - Standar deviation: $\sigma_{\xi_{ND=0}} = 27{,}6526$

- Using $\xi_{ND} = 1$ (with tolerance of 1 neighbor):
  - Average cost: $\mu_{\xi_{ND>0}} = 88$
  - Standar deviation: $\sigma_{\xi_{ND>0}} = 28{,}6473$

Conclusions (I)

We can notice from the results that using a positive tolerance value ($\xi_{ND} > 0$) has better cost results than using no tolerance at all ($\xi_{ND} = 0$).

CONCLUSION 1: Using a positive tolerance value over the reference node degree improves the efficiency of the proposed self-adaptive system.

Conclusions (II)

There are rounds with changes in the nodes current node degree without a previous change in the transmission power. This can be due to interferences and other attenuations out of the control of the system.

Also the neighbor discovery protocol can introduce instability by accepting as a neighbor a mote with high Packet Error Ratio (PER).

CONCLUSION 2: Changing the decision making over the neighbor membership can have also an impact on the system performance.

Future works

From the obtained results it seems worth to further explore the decision making used in the neighbor discovery protocol, either using a fixed trigger over radio quality parameters, or even defining a fuzzy decision making method to assign a membership value to each possible neighbor.

Also it is worth to explore the self-adaptivity of certain configuration parameters. For instance, self-adapting k_{CR} to act on the velocity of the self-adaptive transmission power control system.

References

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