

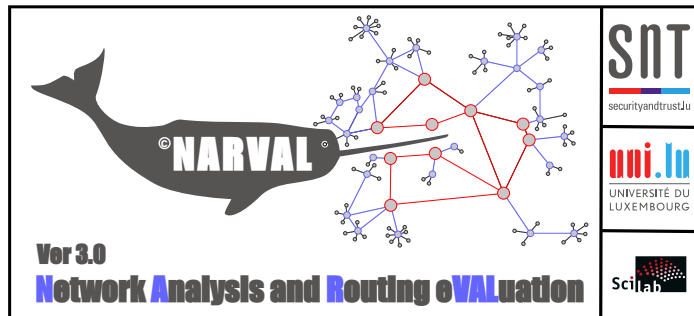
## Network Analysis and Routing EVALuation: The NARVAL Toolbox

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Compatibility: Scilab >=5.3.3



### Introduction and Motivation

Network Analysis and Routing eVALuation, referenced as NARVAL has been designed on top of the Scilab environment. It has been created at the University of Luxembourg within the Interdisciplinary Centre for Security, Reliability and Trust (SnT). The Centre carries out interdisciplinary research and graduate education in secure, reliable, and trustworthy ICT systems and services. This Scilab External Module [1] is focusing on the analysis of network protocols and algorithms. Each network of communicating devices such as computers, phones or sensors, needs to follow specific rules in order to organize and control the data exchange between source and destination nodes. Communication protocols enable to discover the network topology, and to propagate the data traffic between network entities. The main goal of our toolbox is to provide a complete software environment enabling the understanding of available communication algorithms, but also the design of new schemes in order to evaluate and improve the traffic behavior and distribution on network topologies defined by the user. NARVAL permits to generate random topologies according to various algorithms such as Locality, Waxman, Barabasi-Albert and hierarchical models. The user can also design his own topology by providing nodes' coordinates, visualization parameters, and also links' information that are necessary for path calculation. The combination of these functions enables to build a large range of topologies with distinct routing properties. The NARVAL module permits to study the impact of routing algorithms on the effectiveness of transmission protocols used by data communications on a defined network topology. We provide a set of basic functions in order to create network graphs, compute routing algorithms (AODV, BFS, DFS, Bellman-Ford, Dijkstra, Flood, Floyd-Warshall, Multiple Paths, RPL [2], ARC [3], etc.) on them and finally make statistical analysis on the efficiency of data communications. The mobility of nodes (Mobile/Vehicular Ad hoc NETWORK MANET/ VANET) is also supported according to models such as Random Direction, Random Walk, Random Way Point, etc. The target audience of this external module includes academics, students, engineers and scientists. We put some efforts to build detailed help files. The description of each function has been carefully done in order to facilitate the end users' comprehension. It is often accompanied with explicit diagrams. Our simulations and results obtained with NARVAL have been published in several IEEE international conferences and journals [4-6]. This research contribution was partially supported by the following European FP7 projects: U2010 (<http://www.u2010.eu>), EFIPSANS (<http://www.efipsans.org>), IoT6 (<http://www.iot6.eu>) and BUTLER (<http://www.iot-butler.eu>).

### Network and Routing Modeling

We describe in this section our network model (see Figure 1).  $n$  nodes that are connected together in respect with  $l$  links compose the network  $g$ . Each node is defined with a unique identifier  $N_i$  and its coordinates  $(x_i, y_i)$  with  $i \in [1, n]$ . The user is also free to add specific parameters such as a buffer occupancy per node or an energy level for nodes equipped with batteries. By definition, if two nodes  $N_a$  and  $N_b$  are connected together with the direct link  $L_j$  with  $j \in [1, l]$ , they can exchange data and also propagate routing information. Each link  $L_j$  is defined with a metric  $W_j$  that is generally based on the propagation delay related to the Euclidian distance between the connected nodes, the link bandwidth, the hop count, the traffic load, the quality of the radio communication, the data throughput, etc. Its value is used during the path

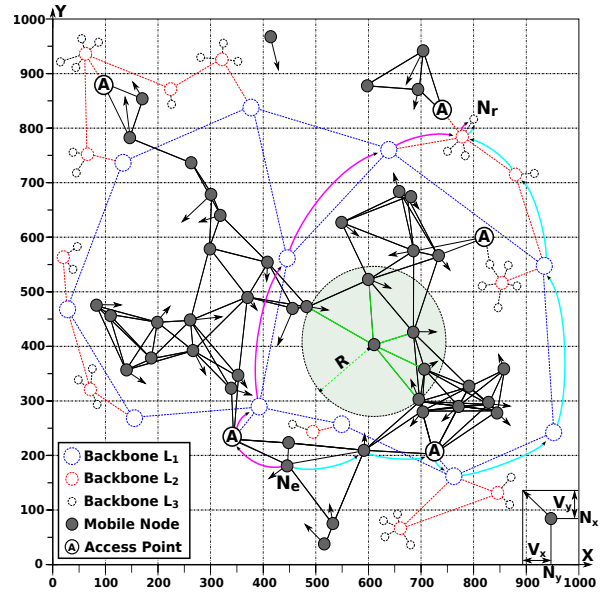


Figure 1 Network model

performance between two nodes. NARVAL permits to select the best paths in respect with a defined routing metric between the two nodes  $N_e$  and  $N_r$ . For instance, we highlight in Figure 1 the result of a routing algorithm composed by two paths  $P_1$  and  $P_2$  displayed in blue and purple. Each path is composed by a list of successive nodes  $(N_e R_1 R_2 \dots R_k N_r)$  that are carefully chosen in order to optimize a selected routing metric. Thereafter the flow of data can be forwarded along the best path (such as  $P_1$ ), but also alternative paths (such as  $P_2$ ) that is generally used in case of network issues. We consider fixed and mobile topologies. A fixed topology is based on nodes whose coordinates remain static during the duration time of a simulation. In practice, this kind of topology can represent a real deployment of stationary network routers connected with either wired or wireless links. In that case, if the two nodes  $N_a$  and  $N_b$  are connected together with the edge  $L_j$ ,  $L_j$  will always be available during the simulation lifetime to store and forward data information between  $N_a$  and  $N_b$ . This assumption facilitates the computation of routes even if the path performance can depend on dynamic metrics. We are also considering mobile graphs where nodes form a network through wireless connections. In that case, the topology can change. In fact the wireless radio communication is intrinsically limited by the medium physical properties. Thus a link between two neighbor nodes can appear (respectively disappear) if their distance gets smaller (respectively larger) than the radio communication range. Then mobility models will play an important role on the topology modification along each simulation and will impact directly on the path computed by routing algorithms.

The path calculation process is usually based on routing tables, which maintain a record of the routes to various network destinations. The routing algorithms aim to build and update these tables stored locally in each network node. The NARVAL module considers the main scheme named unicast (node to node), but also broadcast (node to network) and multicast schemes (node to nodes). In practice, adaptive routing based on the current network configuration generates accurate paths. We can distinguish two kinds of algorithms. The first ones are called distance vector algorithms and are based on the Bellman-Ford algorithm. In that case, a weight is assigned to each network link connecting two neighbor nodes. Thus each node is aware of its local neighborhood. Its routing table is composed by the list of neighbors, the total cost to reach them (i.e. the link weight), and the next hop where to send the data (the neighbor node itself). Each node regularly sends update of its connectivity to its neighbors and also the cost of the destinations it is aware of. The neighboring nodes compare this information to their knowledge. If a better path is discovered, then the neighboring nodes update their routing tables accordingly. After a certain time for the routing algorithm completion, all the nodes in the network will discover the best next hop for all destinations, and the best total cost.

The second ones are called the link-state algorithms. In that case, each node sends its local connectivity knowledge to all network nodes (broadcast/flood). Thus each node can reconstruct the global network topology and thereafter compute the path to any other nodes in respect a shortest path algorithm such as the Dijkstra's algorithm.

New features have been included during the NARVAL implementation and development. We describe in the following section the NARVAL module.

## Toolbox Description

The last version of our toolbox has been developed and tested on top of the latest release Scilab 5.5.0. NARVAL has been updated into the Scilab ATOMS module manager. The toolbox is currently composed by 330 functions that are classified into 8 distinct sets.

### NL\_F: Function (29 functions)

This set gathers all general mathematical functions, such as specific random generators used to compute nodes' coordinates, select emission and destination nodes of data connections, plot histogram, etc.

### NL\_G: Graph (82 functions)

This class is the basis of the NARVAL module. It permits to generate various types of graphs defined by interconnected nodes. The user can easily modify (addition/deletion of nodes/edges, merging of graphs, etc.), retrieve the neighborhood of a node, and highlight specific parts of a graph. A force-based algorithm also permits to place graph nodes in an aesthetically pleasing way. The generic graph statistics can be computed (average distance, average node degree, average neighbor connectivity, betweenness, diameter, eccentricity, center, degree distribution, radius, k-Core, local clustering, periphery, rich club connect, spectrum, etc). We also include functions that enable the extraction of a weakly connected dominating set from a graph.

### NL\_I: Internet (30 functions)

This group of functions enables to simulate random data communications on a network graph and study the traffic variability of a selected connection. New connections can be generated and managed during the simulation. Data packets are described by a list of fields such as source, destination, connection length, index, acknowledgement, arrival time and used transport protocol. A buffer that can store a fixed quantity of packets is defined in each network node. The service is done in respect with the FIFO method. As soon as a packet is emitted on the network, each node where the packet is propagated, selects the best candidate amongst its neighbors where the packet will be forwarded. Routing algorithms permits to achieve this task. This store and forward process is repeated until the packet reaches its destination. The injection of packets in the network is controlled by a transport protocol defined for each source node (UDP, TCP or MPTCP). The user can finally analyze the interaction between the network topology, the network traffic demand and the routing algorithms.

### NL\_M: Mobility (20 functions)

The user can simulate the nodes' connectivity of a MANET and its evolution according to different mobility models such as random direction, random walk, random way point, etc. The user can study the stability of a defined connection, and the impact of the mobility model on the path calculation between a source and a destination.

### NL\_R: Routing (93 functions)

This part is the central component of NARVAL. It provides a list of routing algorithms that can be applied on a network graph, i.e. AODV, ARC, Bellman-Ford, BFS, DFS, Dijkstra, Flood, Floyd-Warshall, Prim, RPL, etc. The user can also build new schemes and test them on various topologies.

### NL\_S: Security (34 functions)

This set of functions is focusing on the network security. It permits for instance to operate the AES or RSA encryption/decryption algorithms on a data payload. We also provide a security approach named

information slicing that is used for anonymous communications. In that case, data emitted from a source are divided into packets that are sent along disjoint paths. As a consequence, a malicious node that tries to capture packets will not be able to reconstruct the complete payload as the data traffic is spread on disjoint routes.

#### NL\_T: Topology (13 functions)

This component is related to NL\_G. It permits to create a variety of distinct topologies with different statistical properties. For instance, the Waxman algorithm provides an accurate representation of real networks, at least at the geographic level. The user can build hierarchic topologies, grids, and topologies based on the Barabasi-Albert algorithm. For wireless networks, the locality algorithm defines the connectivity in respect with a selected radio communication range.

#### NL\_V: Vision (29 functions)

The last set is focusing on computer vision. It is related NL\_M because it was originally designed to compute the path of mobile nodes in non-free space where obstacles are present. After the definition of obstacles, the user can determine the path that a node needs to follow in order to move from an original position to a specific destination. Calculations are done in respect with computer vision algorithms (Moravec, Potential Field and Visibility graph). This realistic mobility model is currently under studies and new models will be released in the next update of the NARVAL module.

## Conclusion

We presented in this paper our toolbox, Network Analysis and Routing eVALuation, referenced as NARVAL. Its main objective is to provide a complete software environment enabling the understanding of available communication algorithms, but also the design of new schemes in order to evaluate and improve the traffic behavior and distribution on network topologies defined by the user. New functions are under studies and will increase the NARVAL functionality (DNS, DHCP, new topology generators, routing algorithms and mobility models, analysis of fault tolerance with global and local repair, data aggregation in wireless sensor networks, etc.).

## Acknowledgements

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