Design and implementation of a new manet simulator model for aodv simulation

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Abstract

Distributed systems, such as Ad Hoc networks, are composed of nodes communicating each other using underlying wireless technologies. Communication protocols, connection technologies, traffic flows and routing algorithms are very complex in the design process of the Ad Hoc networks. Due to the challenges in current network simulators such as complexity, mobility and scalability, studies on Ad Hoc networks are far beyond from the real life. For the purpose of overcoming the problems above, the modeling and simulation tools take a great importance in Ad Hoc research. In this study, for studying complexity, scalability, adaptability aspect problems of the mobile systems, a MANET model and its simulator have been developed and called MANET-DEVS simulator. For the purpose of showing the model's superiority and performance, various networks in different size and configurations have been created and simulated under various traffic loads. Furthermore performance of AODV routing protocol as the most common MANET routing protocol have been investigated in developed simulator. The developed model's validation and verification tests have been carried out to depict model's confidence. Result show that MANET-DEVS simulator provides robust and easy simulations for MANETs' characteristics and facilitates education of AODV routing protocol.

Keywords: Modeling, Simulation, MANET, Ad Hoc, AODV, DEVS

1. Introduction

The mobile systems, compared to the conventional wired communication, are advantageous due to lower infrastructure requirements and mobile communication support [1]. Because of these advantages, studies on "Mobile Ad Hoc Networks - MANETs" without prior infrastructure have increased [2]. The studies to be carried out on MANETs are expected to be an important part of 4G architecture [1].

The design process of communication protocols, connection technologies, traffic flows and routing algorithms of Ad Hoc networks are very complex. A typical solution to overcome above challenges should use modeling and simulation techniques [3].

It is clear that almost all the network simulation tools work in similar ways [3]. Current network simulation tools are inadequate for solving all the problems of a network [4]. Aside from software which can be used to directly model the communication networks; there are tools which can be used to model the hardware components as well. When modeling and simulating large scale complex systems, it is hard to use these simulators. Additionally they haven't ability to model systems incorporating various technologies [5]. Because of the number and size of the network systems increasing exponentially, current simulators become insufficient [6]. Although there are simulators which are able to simulate thousands of nodes such as GloMoSim, PDNS etc., none of these can carry out modeling of a dynamic complex and adaptive network [5, 7]. Though state of the art simulators have some or several properties from modularity, hierarchical structure, reusability, adaptation, object orientation, extendibility and deployment, all properties are not included in a single simulator. For example, Omnet ++ is well object-oriented and has modular and hierarchical structure, but is difficult to deploy due for its highly platform dependent programming language. OPNET has very good interfaces and inherits advantages from C++ language but its extendibility is far beyond from a researchers needs. The developed simulator in this study is tried to merge such properties in a single platform and exploits Java advantages.

From the examination of simulators regarding to their different features, it is obvious that there is no excellent simulator tool [6]. In the study carried out by Begg et al it is mentioned that disregarding cost and time, the simulators prepared for special purpose may meet user requirements [8]. Based on this fact, a new simulator is designed and simulation application has been carried out to solve the mobility, complexity, scalability etc. problems of the MANET systems and to design and test advanced routing systems.

In the study, the components making up the MANET network system have been developed on top of the DEVS-Suite [9] modeling and simulation environment. The behaviors of the defined components have been modeled. With the resulting model, experiments have been carried out for several experiments. The developed simulator is called ‘MANET-DEVS'. MANET-DEVS simulator has established an example framework for modeling of sizable, adaptive and powerful mobile network applications on MANETs' specifications.

2. Related Work

The studies carried out related to MANETs focuses on the specifications of MANETs. Due to a direct effect on efficiency and energy consumption, the studies carried out on routing protocols have emerged to the forefront. Making use of simulators holds an important place in the studies carried out. Below, some of the studies in the literature on MANET and simulators are listed and summarized:

In the report prepared by B. P. Zeigler and S. Mittal, the simulators have been examined in terms of the future of ultra wide networks and for development of these networks, modeling and simulation cycles have been examined [4]. M.A. Rahman et al carried out a study on 100 ea. modeling and simulation tools for allowing the researchers to choose the correct tool in their experiments and the tools included to this study have been classified according to their characteristics. In the study, they included the network discovery tools and topology generators to the analysis and examination [3].

In a study carried out by L. Hogie and P. Bouvry, the situations and similar simulation techniques used by simulators capable of carrying out MANETs' modeling and simulation tasks have been examined. Specifying the outstanding aspects of each simulator, making use of it in simulator selection have been aimed and the foremost problems in MANET's simulators have been summarized [10]. With simple topology control algorithm, D. Orfanus et al have made comparison of wireless network simulators [11]. In a comprehensive technical report prepared by L. Begg et al, it have been indicated that discrete event simulation will be an important method in the service availability and flexibility studies in the next generation network simulators [8]. In the studies carried out by R. Ben-El-Kezadri and F. Kamoun, a framework prepared for the analysis, comparison and validation of the MANET simulators. [12]. N. Saquib at al, developed a new simulation tool with Visual basic programing language due to the challenges of working with Ns-2 [13].

Taekyu Kim et al have aimed to make a better simulation study using the relative advantages of DEVS and Ns-2 with respect to each other [14]. M. Malowidzki have put Ns-2, J-Sim, OPNET simulators under examination in terms of simulation mode and programming interface [15]. U. Farooq et al modelled the mobility and routing functionality in wireless Ad Hoc networks and as an example, applied AODV protocol successfully [16].

C. R. Dow et al, based on the articles they gathered from IEEE / IEE Electronic Library, summarized the studies carried out related to MANET putting them 15 categories. The fields on which studying is required have been emphasized, mention have been made to simulation criteria [17]. Stuart Kurkowski have focused on the reliability of the simulation studies in studies carried out related to MANETs. Errors and omissions in simulation studies have been identified and discussed and for improvements, results have been extracted [18]. Wolfgang Kiess, in his research on the real world applications of MANETs, presented the difference of the behaviors of Ad Hoc networks compared to the simulation studies [19].

Another field of study is mobility. Camp has examined the mobility models used in simulations to be helpful in model choise. The effect of changing mobility models in protocol success have been highlighted [20].

2.1 Discrete event system specification and DEVS-Suite

Many of the methods in the modeling and simulation theory are developed based on the system theory [21]. The systems in which the time axis is continuous, but only in limited time period, limited number of events occur; they are taken at hand in a level of abstraction named "discrete event" [22].

DEVS-Suite [23] modeling and simulation environment is based on parallel DEVS [5, 24] formalism and the modular, hierarchical, discrete event system environment is implemented using object oriented Java programming language [25, 26, 27]. MANET-DEVS simulation environment modeling and simulation have been prepared using the advantages of Java in DEVS-Suite environment. It is preferred by modelers for its simplicity, 100% object-orientation, speed, discrete operation, mobility, and so on [28].

2.2 Ad Hoc On-Demand Distance Vector Routing Protocol (AODV)

MANETs are made up of arbitrary and random movable platforms called "node". Data, as opposed to cable networks, is directing transmitted from node to node [2, 29]. The main purpose of routing protocol in Ad Hoc networks is to establish accurate and effective path in between nodes and to provide timely delivery of messages [30]. Due to limited resources in MANETs, the protocols adapt the changes in network status (network size, traffic density etc.) on the same time, the limited resources shall be used effectively [31].

AODV (Ad Hoc On-Demand Distance Vector Routing) routing algorithm is used for management of Ad Hoc networks in between dynamic, self-starting, multi-hopping mobile nodes [32]. AODV fastly establishes path for new destinations for mobile nodes and it is not required to have an active communication infrastructure for management of the route. AODV allows the nodes to respond to the changes and disconnections in the network topology. One of the distinguishing features of AODV is that it uses a destination sequence number for each of the paths. The destination sequence number is issued by the destination for the node which sent the request. Using of destination sequence number can overcome loop-free problem and the Bellmand-Ford counting to infinity problem that may occur when there is change in the Ad Hoc network topology. When a node makes a request, the largest destination sequence number at hand on the node is used [32].

AODV routing algorithm have message types with which 3 basic control messages and data packages are sent which are RREQ (Route Request), RREP (Route Replay) and RRER (route error) (see Figure 1).

3. MANET Modeling Approach and Design

The nodes created for the purpose of modeling the MANET system and the other objects (IP packages etc.) providing communication of these nodes are defined as "basic network components" [33]. One network model composed of a combination of these components is named "DEVS unified network model" [5, 34]. Here, the atomic and composite models are defined using "Parallel DEVS approach" and it is designed in "DEVS-Suite" modeling and simulation environment. In this method, nodes and other network components can be used to determine the behavior of the network model (such as the time out).

The conceptual model of the developed MANET-DEVS simulator is shown in Figure 2 in its most basic form. The basic network components are depicted in Figure 2 in the form of interacting elements composing a network and its experimental frame. They represent modular design allows integration of the new models easily. Models designed based on DEVS atomic and coupled model specification are flexible to add enhancements. As it is seen in the Figure 2 the components in the MANET-DEVS simulator works together with the DEVS core. The class diagrams prepared for MANET-DEVS environment is shown in Figure 3.

3.1 Node atomic model

Each node in the network is modeled as a switching unit that has the capacity of processing a package and routing the packages to appropriate destinations. The nodes modeled are DEVS atomic models which are connected to each other with two or more network connection (link). Behavioral characteristics of nodes, bandwidth for traffic processing, processing speed and buffer size with enough capacity to process the traffic. By altering the defined characteristics, network units with various capacities can be established and varying network scenarios may be developed.

The nodes created have a network interface unit. The network interface unit applies a simple MAC protocol which carries out taking the incoming and outgoing messages in a drop tail process in a simple way. The conceptual model of a node is shown in Figure 4.

3.2. Topography atomic model

The topography atomic model established in MANET network environment locates the nodes into their new coordinates in the determined intervals periodically taking into account the speed and direction information and controls whether if the nodes changing location are within the range of other nodes or not and establishes / removes its connections and allows visual updating of the connections on the screen (Figure 5). The fading which may affect the communication in between nodes, the conditions of the physical environment and the time which the message lost on its way have been ignored.

Establishing and removing of connections in between nodes under varying topology is possible with the variable structure of DEVS-Suite environment (Figure 6) [35, 36].

In the MANET-DEVS environment, on the two-dimensional space which is defined with atomic model named "topography" with the boundaries of the nodes are specified, one of the important mobility models used on the Ad Hoc networks used on this two dimensional space is the "Random Walk Mobility Model" which operates according to Brownian motion principle [20].

3.3. Routing tables

The nodes comprise of a routing table which contains the access information belonging to every possible destination node in the network. Each of the lines in the modeled routing table belongs to a potential destination. The columns contain the information related to that destination. The size of the routing table varies in proportion with the number of nodes for which information is kept (Figure 7).

3.4. Coupled model

Using the DEVS coupled model approach, with the help of coupled models created by connecting atomic models to each other networks of varying structures can be created with varying topologies. In Figure 7, the coupled model created in MANE-DEVS environment and the connections of nodes with each other is shown.

3.5 MANET-DEVS experimental frame and network traffic model

In order to carry out testing of the system/model established in the experimental frame the experimental frame concept in DEVS shall be established /identified. It comprises of experimental environment, an event generator connected for adaptation of system / model on the input terminals of the system / model, an event transducer connected to the output terminals of the system for evaluation of the results coming from the system / model, and an acceptor comparing, together with the input / output variables within the experimental frame, the generator inputs and converter outputs. The acceptor determines whether the system (real or model) experimental environment is in compliance with the objectives of the person carrying out the experiment [22].

In Figure 7, in the study carried out, the DEVS experimental frame components, in order to carry out the success measurement of a mobile network, and adaptation of it to the network are shown. Event converter is used to evaluate the results of the simulation study.

3.6. Topology Generator and Visualization

In network communication, effective protocol designing, solving problems, establishment of correct model for simulation and in error tolerance studies, topology is of great importance [37]. The ideal topology generators generate correct representation of internet topologies and present them to the use of researchers researching on the accuracy of the protocol and algorithms and working on new generation powerful models [38].

The topology to be used in the tests to be carried out in the MANET-DEVS environment which will be prepared by integrating BRITE topology generator to DEVS-Suite simulation environment (Figure 8) will be obtained from the BRITE topology generator. In order to determine the location, coverage area, movement direction and visual tracking of the movements of the nodes on the network for which simulation is being carried out in MANET-DEVS environment, a module called "MANET Viewer" have been designed and whether or not to run the interface is left as an option with a button placed on the BRITE topology generator (Figure 8).

3.7. Modeling of AODV routing algorithm

As an example application in the developed MANET-DEVS environment, AODV algorithm modeling study has been carried out. With this modeling study, it is shown that MANET-DEVS environment is capable of modeling and simulating Ad Hoc routing algorithms. Error control mechanism has been neglected in the MANET-DEVS environment.

MANET - Viewer is accepted as 1m = 1 pixel on its screen. In Figure 9, in a 500 X 500 area, the screen display of a topology consisting of 10 nodes and the meanings of the figures on it are shown with bubbles.

3.8. The behavior and parameters of node atomic model

In the developed sample application (in the experiment carried out), for the purpose of implementing real world conditions and to apply different scenarios; it is provided for the simulation parameters to be adjustable before simulation study or during the simulation which can affect the behavior of the network.

In order to be able to apply/observe scenarios to different IP addresses, input/output ports; all the nodes have event input / event output ports, routing tables and various parameters (packet processing speed, path discovery duration, HELLO message interval etc.). In Figure 10 is shown a simplified version of the state diagram which is used in modeling the dynamic (variable) structure of a node.

3.9. Network model

In this study, the simplest network modeled is a 7 node network. Our basic aim, during the studies carried out while the 7 node "simple network" was created, is to examine the operation of the network in MANET-DEVS environment and the operation of applied algorithms, modeling of them and to observe their behaviors. In the simple network, each of the nodes is connected to a geographically neighboring node. The connection of the simple network during the studies together with an experimental framework and the screen printout under DEVS-Suite are shown in Figure 7.

When the topology was being established and the scenario related to the network was being prepared, the parameters and formulas to be used in the simulator are taken into account as shown in Table 1 [18].

3.10. Create scenarios and the assumptions made

The event generator which is used to program the events occurring during the simulation beforehand is a component of the experimental frame. All elements making up the network evaluate the messages coming from ‘>>einput’ port differently from other ports. All control packets making up the traffic in the network are generated by the nodes while the data packets are prepared by the traffic generator. In the application, the data packets are generated together with the randomly selected source / destination addresses and the data packets are sent to the ‘>>einput’ port of the source node. Then the path to be taken by the packet is determined by the current routing tables and the packet continues on its way to its destination. When the packet arrives its destination, it is sent to the converter from the destination node's ‘>>eoutput’ port. The event converter compares the data it takes from the event generator and the data of the packet and records the results in a file.

4. Simulation Parameters

In the simulation process, the parameters belonging to the created simulation environment (Table 2) (statistics, memory usage, time passed, etc.), the data gathered and the data related to the messages sent in the network are interpreted by the converter and recorded into the produced CSV (comma separated values) are stored in their files.

In the process of testing the routing algorithm, the number of packets passing through the network (throughput) is an important criterion. Under different scenarios, the throughput capability graph belonging to a network on which AODV routing protocol is applied is shown in Figure 11 (a). In the Figure, as the number of nodes increase, it is seen that the work throughput capability also increases gradually. The reason of this is that the traffic used in different topologies are different as well. The increase in the processing capacity (throughput) of the network results in increase in the ability to have work throughput.

Average packet delay is another criterion which is observed in networks allowing us to have information regarding to the general status of the network. When the number of nodes increase, because the packet will need to pass through more number of packets on its path to its destination, and increasing number of messages being transmitted in the network increases the accumulations occurring at the buffers /queues, the duration for a packet to take for reaching its destination becomes longer. The results obtained resulting from the experiments carried out is shown in Figure 11 (b). The increase has been normal up to 200 nodes and from 200 to 500 nodes, it has been high. The reason for this is that the large scale activity and traffic conditions emerging after 500 nodes have an important level of negative effect on AODV performance. However, the delay is at an acceptable value of 1 s level.

Keeping the number of nodes generated in 1s constant, the increase on the number of messages traffic per node as the number of nodes increase is shown in Figure 11 (c). The increase in the number of message traffic can be explained with the increase in the required hopping for a message to reach to its destination and with the broadcasting of the control messages used by the routing protocol.

Another data showing the increase in the network traffic with the increase of the number of nodes is the ratio of the data packets to all messages. The characteristic feature of AODV routing protocol is to carry out path discovery prior to data sending and this leads to increase in the network traffic. In Figure 11 (d), this is shown in a graph. However, the total size of the control messages is way below the total size of the data packets. Effective use of the computer in which simulation is carried out is very important for the scalability in the experiments. In the experiments carried out, for 10 seconds, a traffic of 10 messages per node have been established. Keeping the number of messages generated by each node constant, the change in the network traffic with the increase in number of nodes is shown above. The reflection of this traffic in terms of wall clock time is seen in Figure 11 (e).

Another factor that affects the scalability is the use of memory. Due to random topology, the number of connections and change in the data traffic results in instant changes in the amount of memory used. In the experiments carried out, the memory used by MANET-DEVS environment is shown in Figure 11 (f).

As a result, in the implementation of AODV routing algorithm during the simulation it is observed that the resources are used in a balanced way and the routing tables are consistent. From the above graphs, it is understood that the use of capacity and resources is very stable. The graphs show that MANET-DEVS environment performs all the functions of a network simulator. For this reason, the results are a part of the validation and verification processes of the MANET-DEVS modeling and simulation environment which is designed as a network simulator. However, in the below section, the validation and verification process of MANET-DEVS is taken separately.

4.1 MANET-DEVS verification and validation experiments

Simulation model is a tool to reach to any specific object (design, analysis, control, optimization etc.). For this reason, the essential / pre-condition is to be able to take the results and indications of modeling and simulation tools under assurance. In order to establish this assurance, two separate studies are required: D&G / Verification and Validation [22].

Verification is the process in which control of whether the model design, which is converted into the computer environment, is at the level desired is carried out. Validation is the process in which control of the sufficiency of the model for the purposes at hand is carried out. It is unlikely for any model to be 100% true and there are valid reasons for this situation. However, the objective of D & G is to take the sufficient accuracy of the target model under warranty [39]. There is a strong relationship between the objectives of the experiment and the requirements of the validating. Validation is always related to targets / requirements / plans [40].

4.2. MANET-DEVS conceptual model validation

Conceptual model validation; is to determine whether if the created conceptual model's theory and assumptions are compatible with the system theory or not and to determine whether if the system model displayed is reasonable for accomplishing the objectives determined initially or not.

It is expected for the developed simulator to the real world behavior or theoretic definition of a MANET. It is targeted for the simulator to work according to OSI standard which comprise of 7 layers. In Figure 12, the 3 layer summary of OSI reference model and the corresponding units in the simulator are shown.

4.3. Model behavior validation

For model behavior validation, because of the difficulties in using real-world data, the widely used Ns-2 simulation tool has been used. For MANET-DEVS and Ns-2 simulator, simulator and parameters which are similar as much as possible are used.

Resulting from the simulation experiments carried out in both of the simulators, the throughput ability graph obtained is shown in Figure 13. Taking the random number generators used by both of the simulators into account, it is seen that the throughput of both simulators are very close to each other.

5. Discussions

In this study, a simulator providing modeling and simulation studies on MANET systems have been developed which is created with Parallel DEVS architecture in DEVS-Suite modeling and simulation environment using Java programming language. The developed modeling and simulation environment is called "MANET-DEVS".

The contribution of MANET-DEVS simulator into the community can be listed as follows;

- A system theory based modular and hierarchical simulator required for distributed, complex and highly dynamic systems such as MANET is developed.
- It allows developing of models with reusable components with its object oriented structure.
- It has been made easier to observe the simulation outcomes, and to evaluate / interpret the results providing information on the characteristics of MANET systems.
- MANET-DEVS simulator has a simulator infrastructure with completely object oriented programming language therefore it inherits the advantageous of the technology.
- "Java webstart" technology, MANET-DEVS allows its broadcasting / usage online via Internet; for remote training, it contributes to applied learning and understanding of simulation science.
- MANET-DEVS modeling environment is not a domain specific software, it can be converted into a simulation environment in which modeling and simulation of different distributed systems.
- MANET-DEVS environment allows the structural and behavioral state of the system together with time based curves, message animations, hierarchical component structures which are tracked step by step on the screen.
- The simulation results can be stored in both 'log' (daily) files and 'csv' files. 'Time view' option allows the tracking of the behavior of models on time domain.

- With BRITE topology generator integrated into MANET-DEVS environment can generate large scale topologies without requiring to write any code and allows easy establishment and analysis of large scale networks.

6. Conclusion and future works

In order to measure performance of MANET-DEVS simulator, different scale network models have been established and AODV routing algorithms have been tested. As a result; MANET-DEVS simulator allows healthy and easy simulations to be carried out for MANETs' characteristics in a MANET system. For modeling / design of scalable, adaptive and powerful mobile network applications, an example frame has been established and the wide scale applicability of DEVS methodology has been supported. For modeling of very large scale MANETs, a High Level Architecture - HLA simulator which will carry out parallel and distributed modeling and simulation can be used. The developed MANET-DEVS environment can be moved to DEVS-Suite$_{WS}$ (DEVS-Suite web start) and therefore it is possible to use MANET-DEVS on popular browsers for distant learning purposes.

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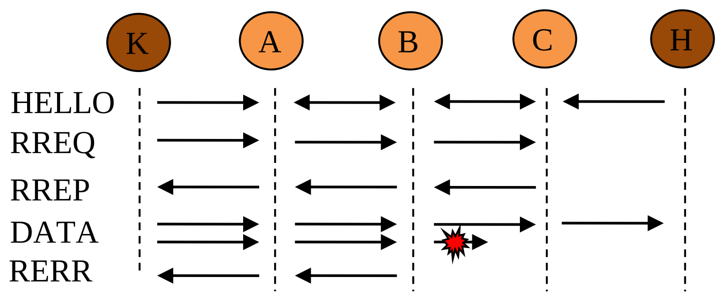


Figure 1. AODV routing protocol messages

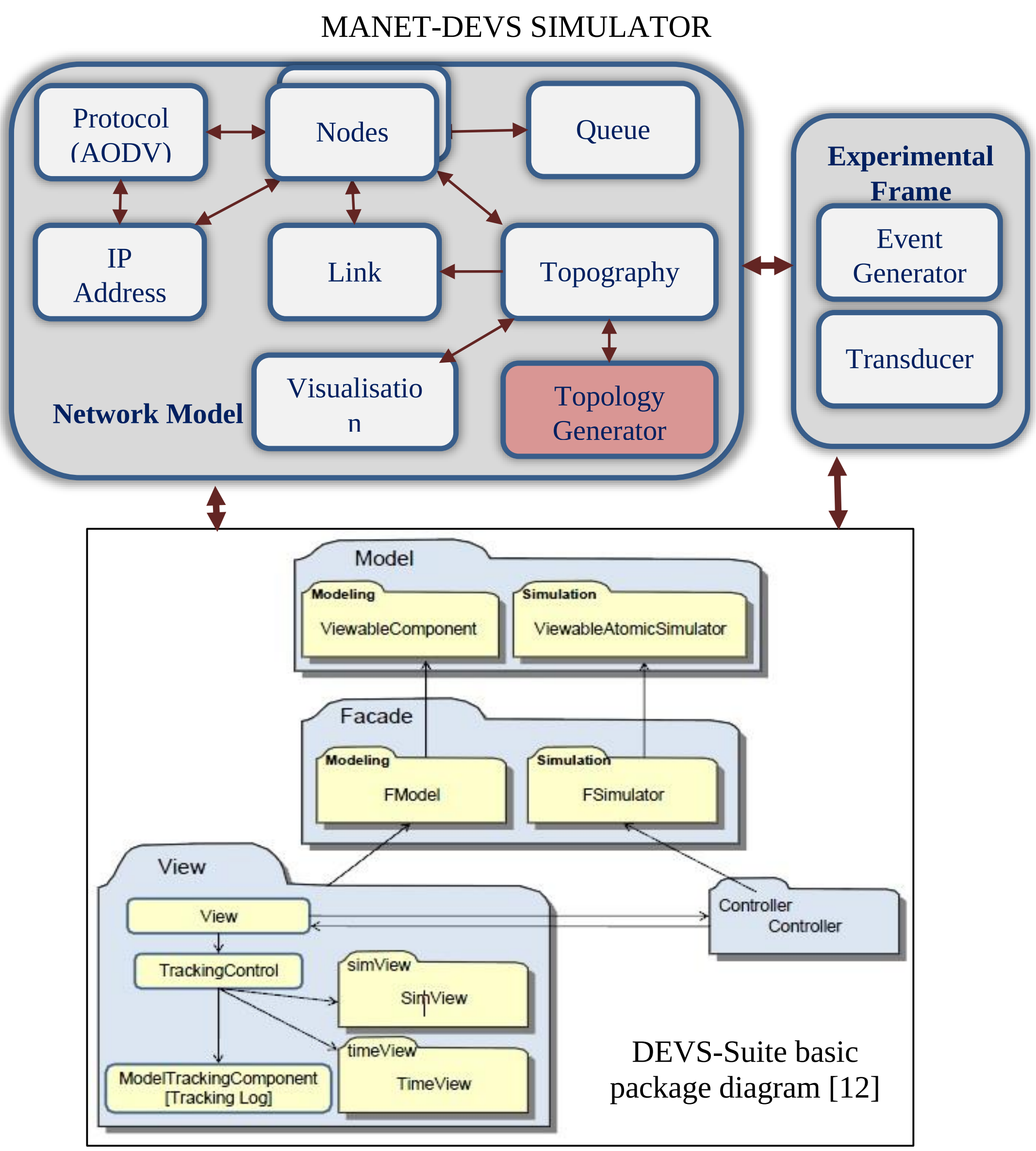


Figure 2. DEVS-Suite and MANET-DEVS conceptual model

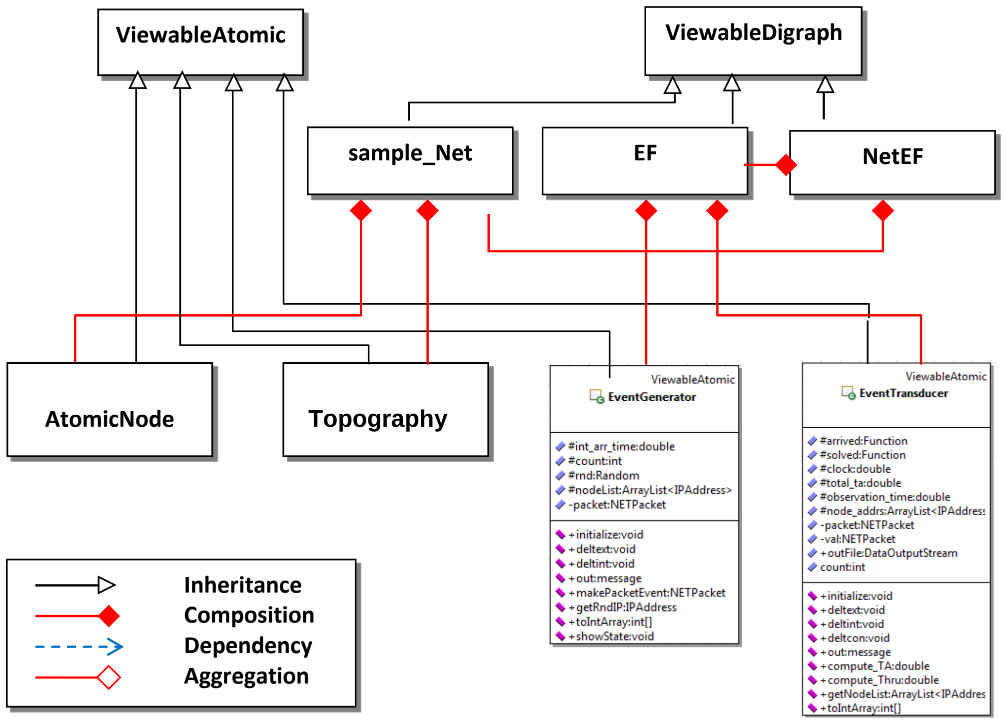


Figure 3. MANET-DEVS simulator class diagram

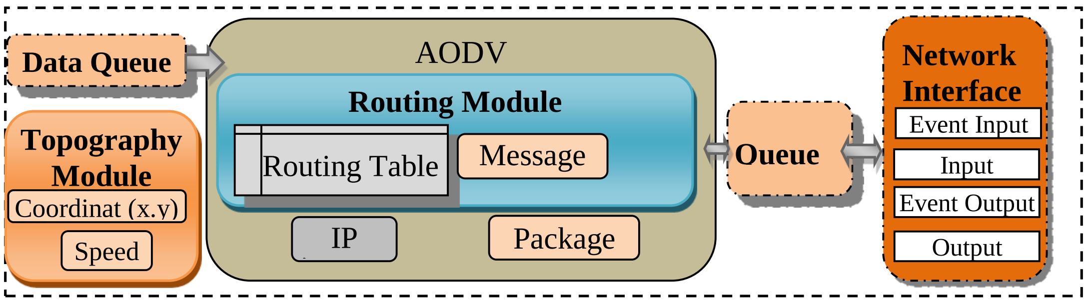


Figure 4. Developed a conceptual model of the node

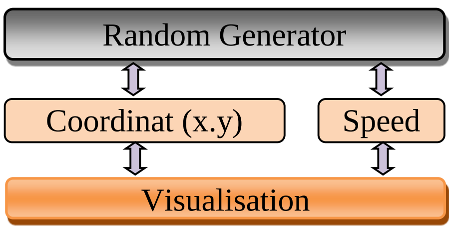
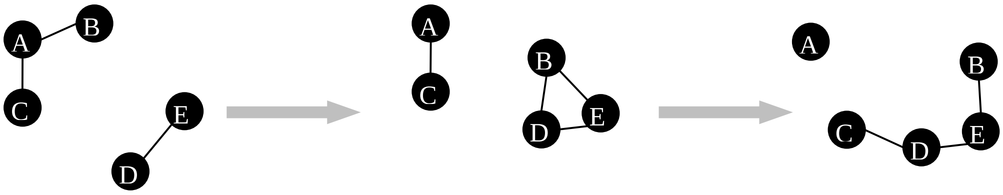


Figure 5. Conceptual model of the atomic model of the topography.



removeCoupling("node name", "port name", “node name”, " port name ");
addCoupling("node name ", "port name ", “node name”, " port name ");

Figure 6. The links between nodes in the add / remove.

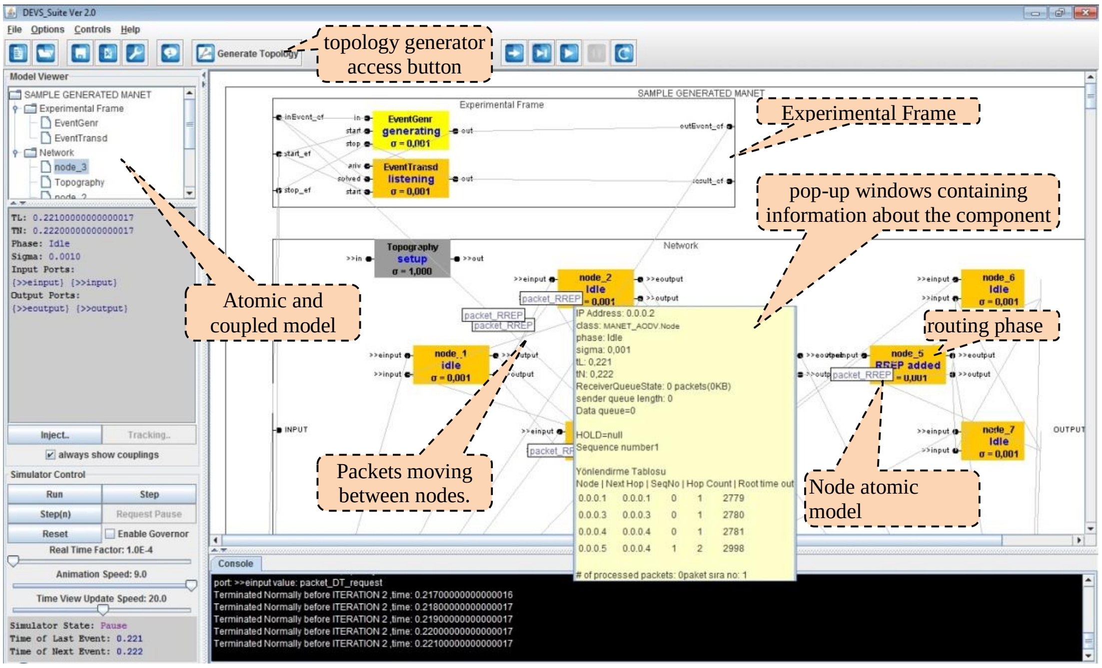


Figure 7. DEVS-Suite is a simple screen view of the network

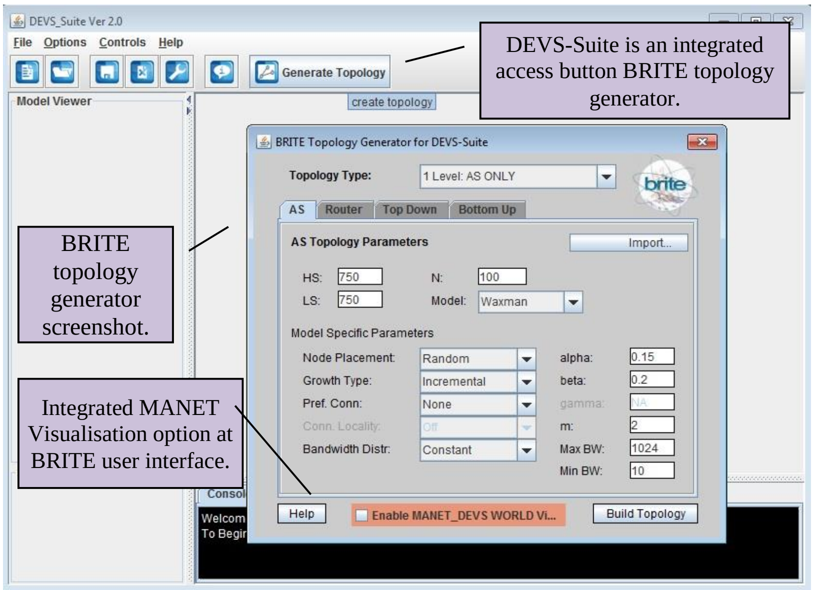


Figure 8. DEVS-Suite BRITE topology generator screenshot

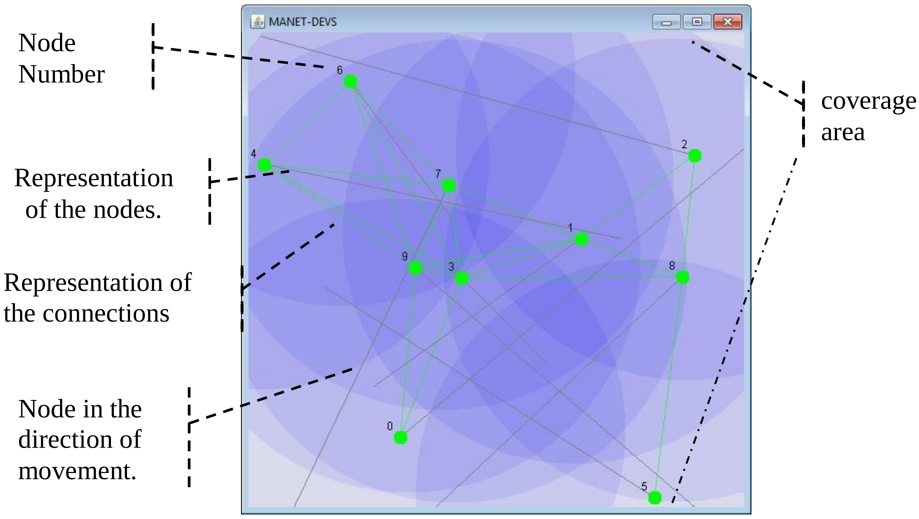


Figure 9. MANET-viewer distribution topology in an area of 500 X 500

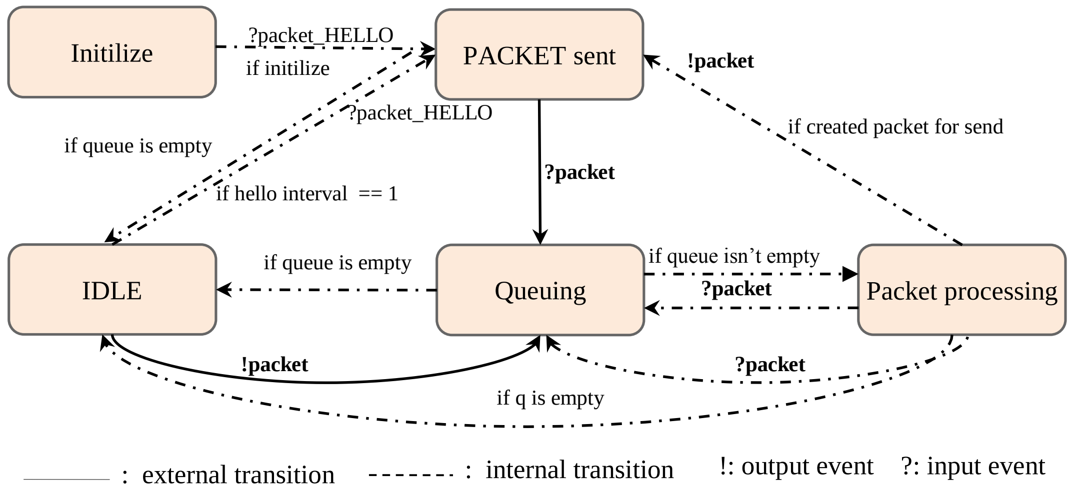


Figure 10. Simplified state diagram of a node

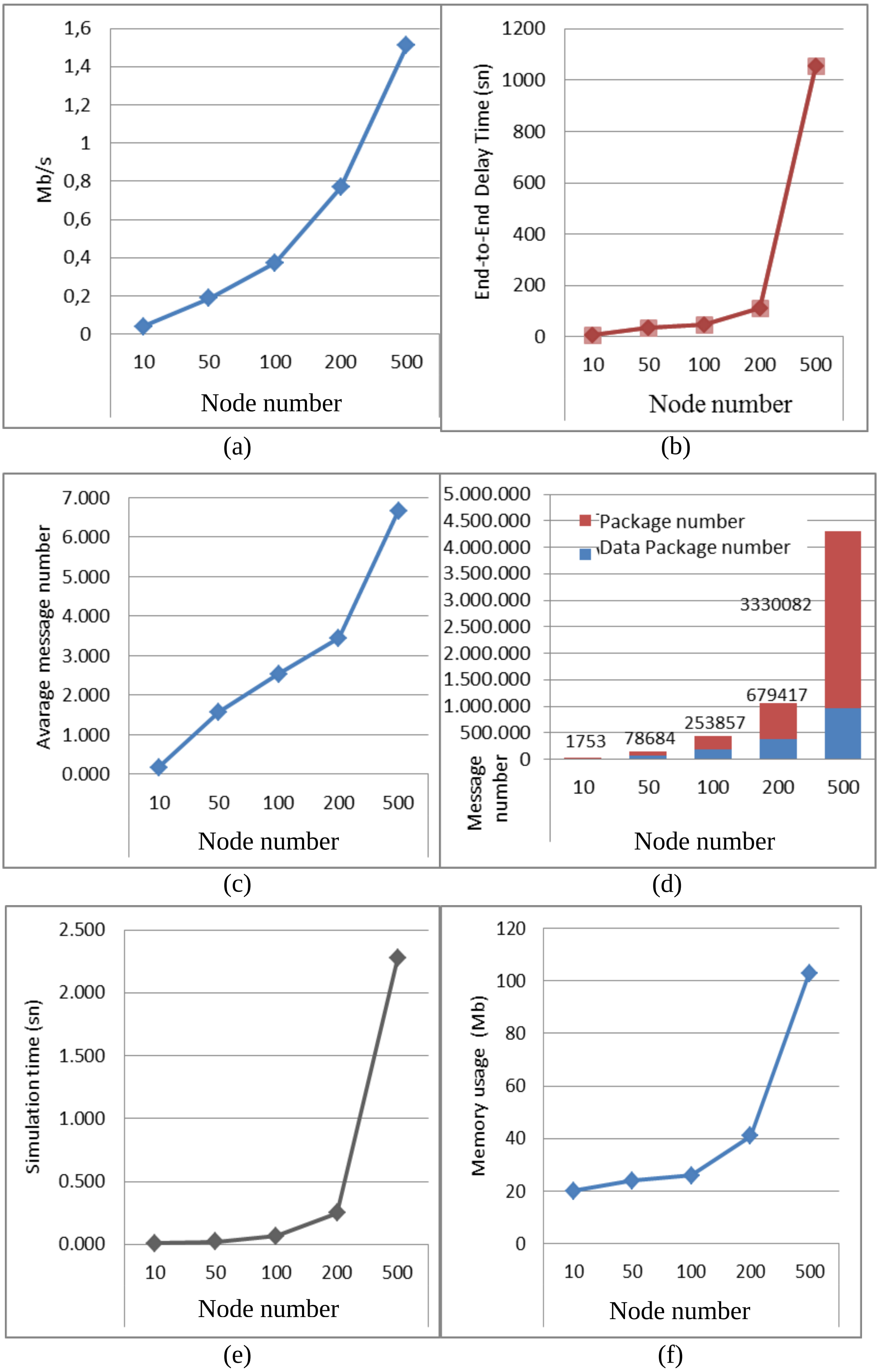


Figure 11. Relation with number of node and simulation results.

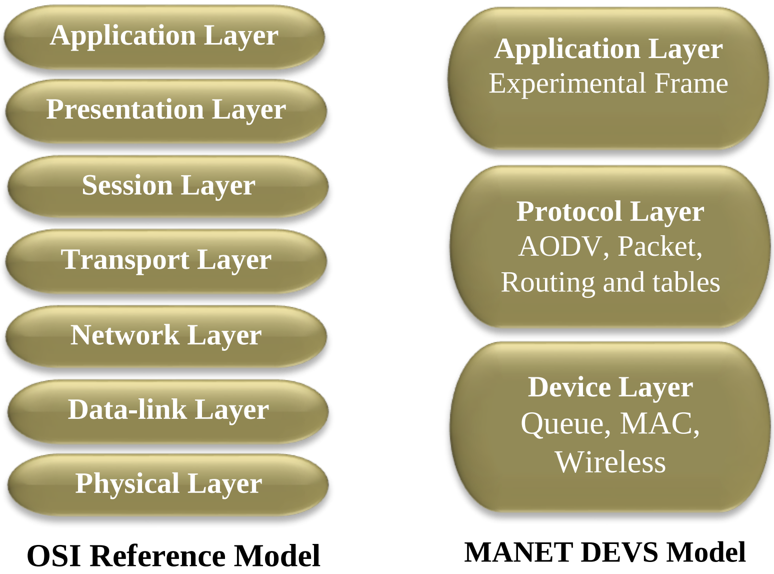


Figure 12. OSI reference model and MANET-DEVS network layers structure

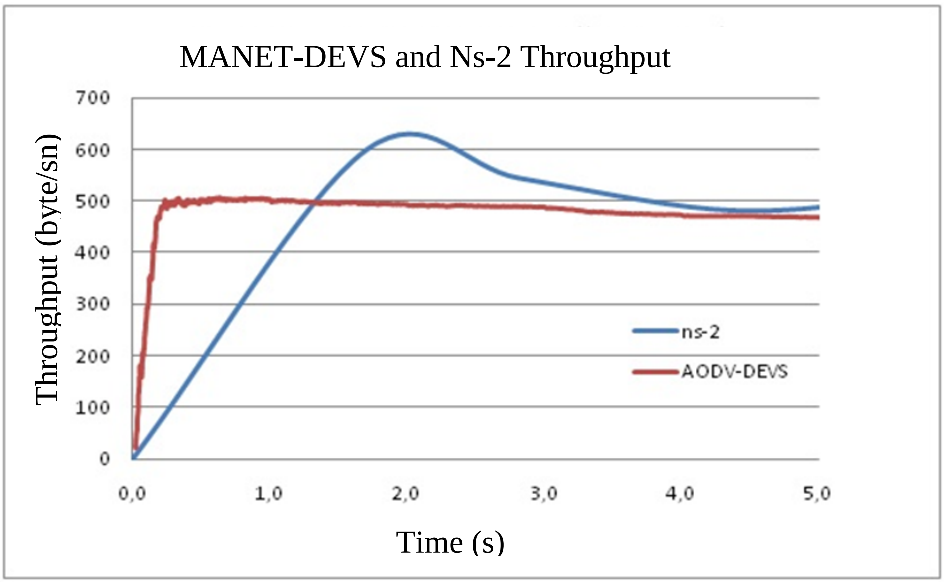


Figure 13. MANET-DEVS and Ns-2 throughput capabilities comparison chart.

Table 1. Parameters and formulas needed for the simulation scenarios.

Parameter	Description	Formula
Simulation area	Topology area	$w * h$
node density	Node density in the simulation.	$\frac{n}{w * h}$
Node coverage area	Coverage of the nodes in diameter	$\pi * r^2$
Footprint	The percentage of the area covered by the nodes in the simulation.	$\frac{(\pi * r^2)}{w * h} * 100$

Maximum route	Maximum distance from the source to the destination package linearly.	$\sqrt{w^2 + h^2}$
network diameter	The minimum number of hops between any two points away from each other.	$\frac{\sqrt{w^2 + h^2}}{r}$
Number of neighbor	Number of neighbor-based simulation and transmission.	$\frac{\pi * r^2}{\left(\frac{w * h}{n}\right)}$
w = width, h = height, r = coverage area, n = Node number		

Table 2. Scenario parameters used for the experiments.

Parameter	Node Number				
	10	50	100	200	500
Area (m)	500 x 500	1000 x 1000	1500 x 1500	2000 x 2000	3500 x 3500
Coverage area (m)	250				
Simulation time (s)	10				
Generated message number / Node	100				
Speed (m/s)	0-10				
Direction	Random				
Topology model	WAXMAN				
Computer	Intel Core 2 Duo 2,93 Ghz 3GB RAM				
Platform	Windows 7 64 bit + 64 bit Java Runtime Environment				