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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 with each other using underlying wireless technologies. Communication protocols, connection technologies, traffic flows, and routing algorithms are very complex in the design process of 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 real life. For the purpose of overcoming the problems above, modeling and simulation tools are extremely significant in ad hoc research. In this study, for studying complexity, scalability, and adaptability aspect problems of mobile systems, a MANET model and its simulator have been developed and called the MANET-DEVS simulator. For the purpose of showing the model's superiority and performance, various networks with different sizes and configurations have been created and simulated under various traffic loads. Furthermore, the performance of the AODV routing protocol as the most common MANET routing protocol has been investigated in the developed simulator. The developed model's validation and verification tests have been carried out to depict the model's confidence. The results show that the MANET-DEVS simulator provides robust and easy simulations for MANET characteristics and facilitates the education of the AODV routing protocol.

Key words: Modeling, Simulation, MANET, ad hoc, AODV, DEVS

1. Introduction

Mobile systems, as compared to conventional wired communications, 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 processes of communication protocols, connection technologies, traffic flows, and routing algorithms of ad hoc networks are very complex. A typical solution to overcome the above challenges should use modeling and simulation techniques [3].

It is clear that almost all 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 that 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 do not have the ability to model systems incorporating various technologies [5]. Because of the numbers and sizes of network systems increasing exponentially, current simulators have

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become insufficient [6]. Although there are simulators that are able to simulate thousands of nodes, such as GloMoSim or PDNS, 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 of modularity, hierarchical structures, reusability, adaptation, object orientation, extendibility, and deployment, all properties are not included in a single simulator. For example, Omnet++ is object-oriented and has a modular and hierarchical structure, but is difficult to deploy due to its highly platform-dependent programming language. OPNET has very good interfaces and inherits advantages from the C++ language, but its extendibility is far beyond a researcher's needs. The developed simulator in this study attempts to merge such properties in a single platform and exploits Java advantages.

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

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. The MANET-DEVS simulator has established an example framework for modeling of sizable, adaptive, and powerful mobile network applications on MANET specifications.

2. Related work

The studies related to MANETs focus 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 MANETs and simulators are summarized.

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

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

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

Dow et al., based on articles they gathered from the IEEE/IEE Electronic Library, summarized the studies carried out related to MANETs, putting them into 15 categories. The fields for which study is required were emphasized and mention was made of simulation criteria [17]. Kurkowski et al. focused on the reliability of simulation studies in studies carried out related to MANETs. Errors and omissions in simulation studies were identified and discussed and, for improvements, results were extracted [18]. Kiess and Mauve, in research on the real-world applications of MANETs, presented the difference of the behaviors of ad hoc networks compared to simulation studies [19].

Another field of study is mobility. Camp et al. examined the mobility models used in simulations to be helpful in model choice. The effect of changing mobility models on protocol success was highlighted [20].

2.1. Discrete event system specification and DEVS-Suite

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

The 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 [25–27]. MANET-DEVS simulation environment modeling and simulation have been prepared using the advantages of Java in the 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 nodes. Data, as opposed to cable networks, are transmitted from node to node [2,29]. The main purpose of the routing protocol in ad hoc networks is to establish accurate and effective paths among nodes and provide timely delivery of messages [30]. Due to limited resources in MANETs, the protocols adapt to changes in network status (network size, traffic density, etc.) at the same time and limited resources can be used effectively [31].

The ad hoc on-demand distance vector routing (AODV) routing algorithm is used for management of ad hoc networks among dynamic, self-starting, multihopping mobile nodes [32]. AODV swiftly 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 nodes to respond to 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 that sent the request. Using the destination sequence number can overcome the 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 on hand for the node is used [32].

The AODV routing algorithm has 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) (Figure 1).

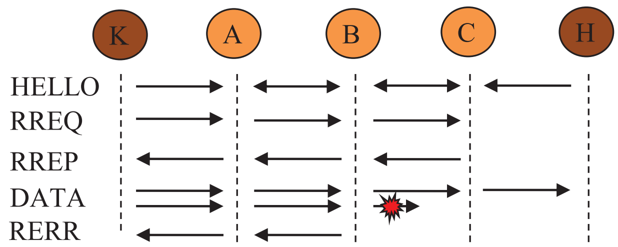

Figure 1. AODV routing protocol messages.

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 the DEVS unified network model [5,34]. Here, the atomic and composite models are defined using the parallel DEVS approach and it is designed in the 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).

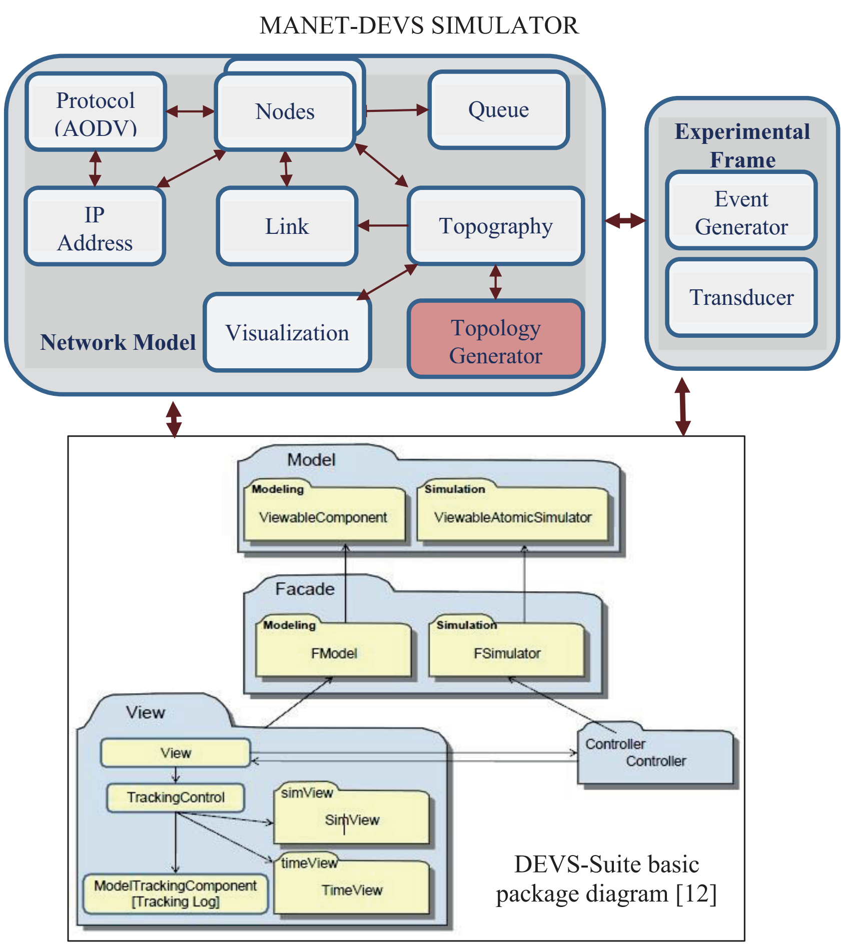

Figure 2. DEVS-Suite and MANET-DEVS conceptual model.

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 a modular design that allows integration of the new models easily. Models designed based on DEVS atomic and coupled model specification are flexible for adding enhancements. As seen in Figure 2, the components in the MANET-DEVS simulator work together with the DEVS core. The class diagrams prepared for the MANET-DEVS environment are shown in Figure 3.

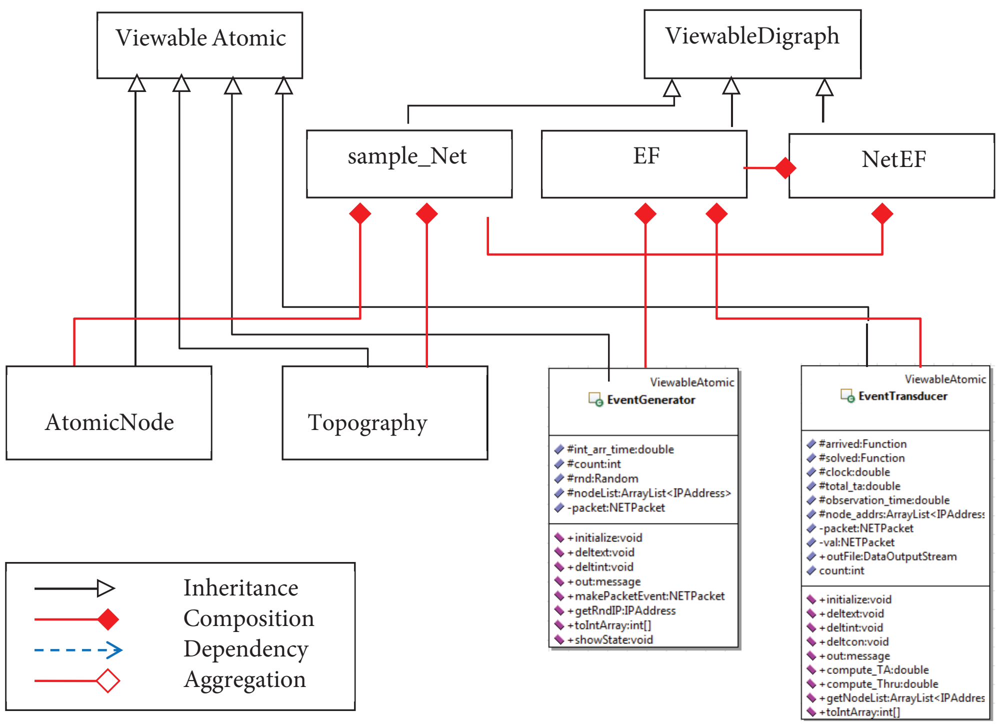

Figure 3. MANET-DEVS simulator class diagram.

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 connections (links). Behavioral characteristics of nodes include 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 the MANET network environment locates the nodes into their new coordinates in the determined intervals, periodically taking into account the speed and direction information; checks whether the nodes changing location are within the range of other nodes or not; establishes/removes its connections; and allows visual updating of the connections on the screen (Figure 5). The fading that may affect the communication among nodes, the conditions of the physical environment, and the time at which the message was lost on its way have been ignored.

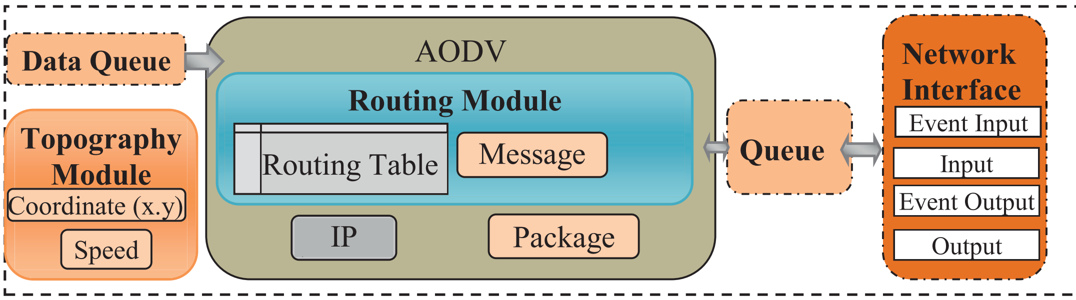

Figure 4. Conceptual model of the node.

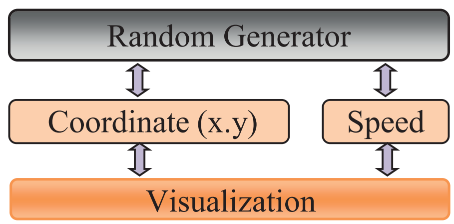

Figure 5. Conceptual model of the atomic model of the topography.

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

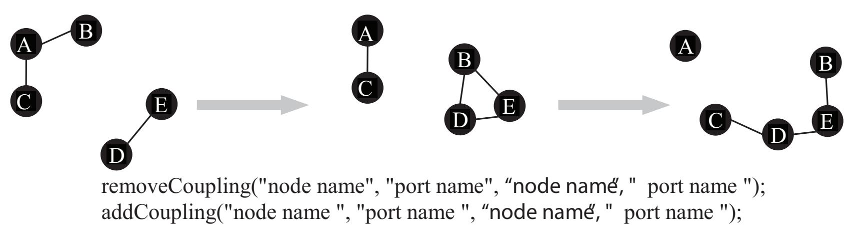

Figure 6. The links between nodes in add/remove.

In the MANET-DEVS environment, in the two-dimensional space defined with the atomic model named ‘topography’ with the boundaries of the nodes specified, one of the important mobility models used for ad hoc networks in this two-dimensional space is the random walk mobility model, which operates according to the Brownian motion principle [20].

3.3. Routing tables

The nodes constitute 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).

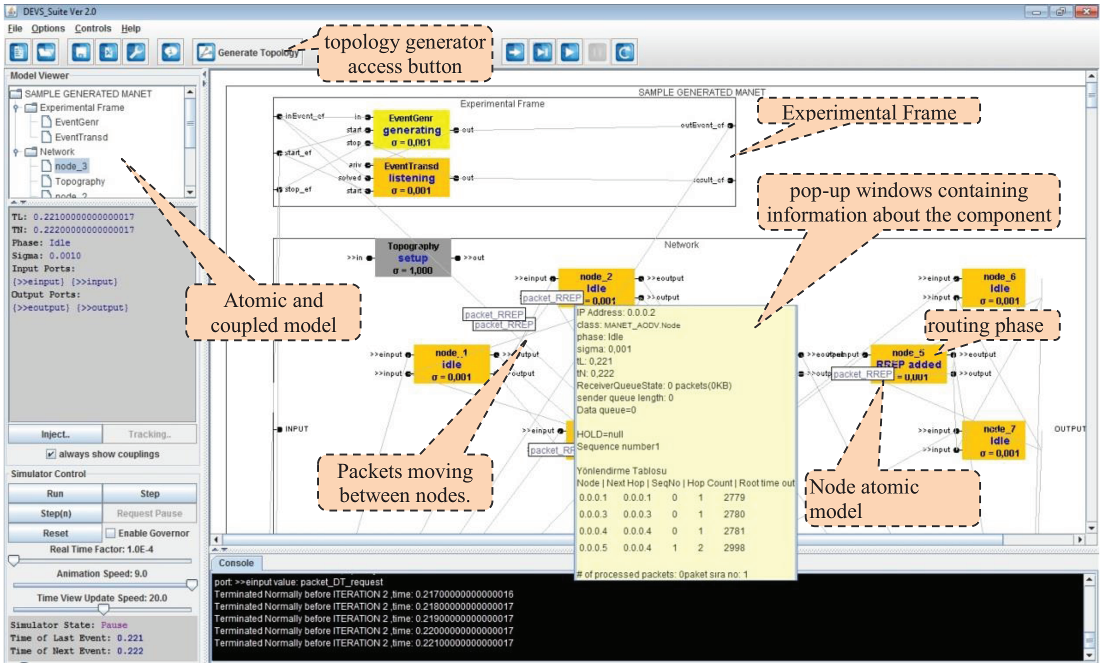

Figure 7. DEVS-Suite is a simple screen view of the network.

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 the MANET-DEVS environment and the connections of nodes with each other are 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 an experimental environment, an event generator connected for adaptation of the 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's (real or model) experimental environment is in compliance with the objectives of the person carrying out the experiment [22].

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

3.6. Topology generator and visualization

In network communication, effective protocol design, problem solving, establishment of a correct model for simulation, and, in error tolerance studies, topology are of great importance [37]. The ideal topology generators generate correct representations of internet topologies and present them for the use of researchers studying 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 the BRITE topology generator into the 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 the MANET-DEVS environment, a module called MANET Viewer has 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).

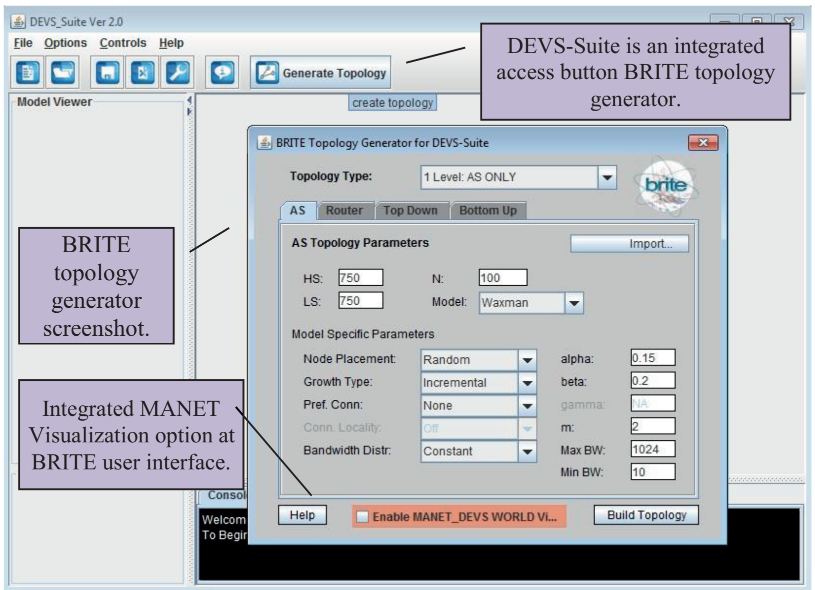

Figure 8. DEVS-Suite BRITE topology generator screenshot.

3.7. Modeling of the AODV routing algorithm

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

MANET Viewer is accepted as 1 m = 1 pixel on its screen. In Figure 9, in a 500 × 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 the 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 a 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 and 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, a simplified version of the state diagram that is used in modeling the dynamic (variable) structure of a node is shown.

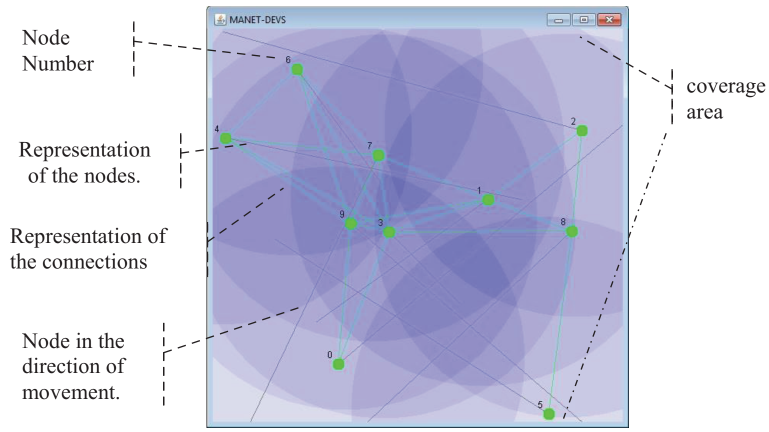

Figure 9. MANET Viewer distribution topology in an area of 500 × 500.

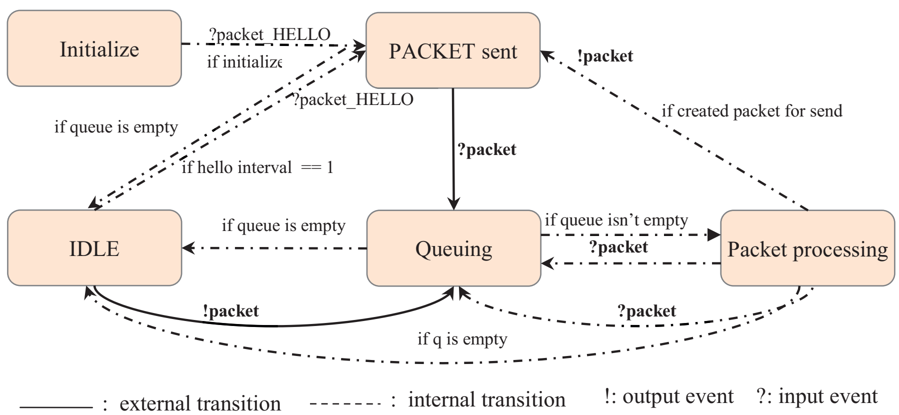

Figure 10. Simplified state diagram of a node.

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 was to examine the operation of the network in the MANET-DEVS environment and the operation of applied algorithms, modeling them and observing 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 were taken into account as shown in Table 1 [18].

3.10. Create scenarios and the assumptions made

The event generator 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 the '>>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. The path to be taken by the packet is then determined by the current routing tables and the packet continues on its way to its destination. When the packet arrives at 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.

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

Parameter	Description	Formula
Simulation area	Topology area	$w \times h$
Node density	Node density in the simulation	$\frac{n}{w \times h}$
Node coverage area	Coverage of the nodes in diameter	$\pi \times r^2$
Footprint	The percentage of the area covered by the nodes in the simulation	$\frac{(\pi \times r^2)}{w \times h} \times 100$
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	$\frac{\pi \times r^2}{\left(\frac{w \times h}{n}\right)}$
w = width, h = height, r = coverage area, n = node number		

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) stored in their files.

Table 2. Scenario parameters used for the experiments.

Parameter	Node number				
	10	50	100	200	500
Area (m)	500 × 500	1000 × 1000	1500 × 1500	2000 × 2000	3500 × 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 3 GB RAM				
Platform	Windows 7 64 bit + 64 bit Java Runtime Environment				

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 the AODV routing protocol is applied is shown in Figure 11a. In the figure, as the number of nodes increase, it is seen that the work throughput capability also increases gradually. The reason for this is that the traffic used in different topologies is different, as well. The increase in the processing capacity (throughput) of the network results in an increase in the ability to have work throughput.

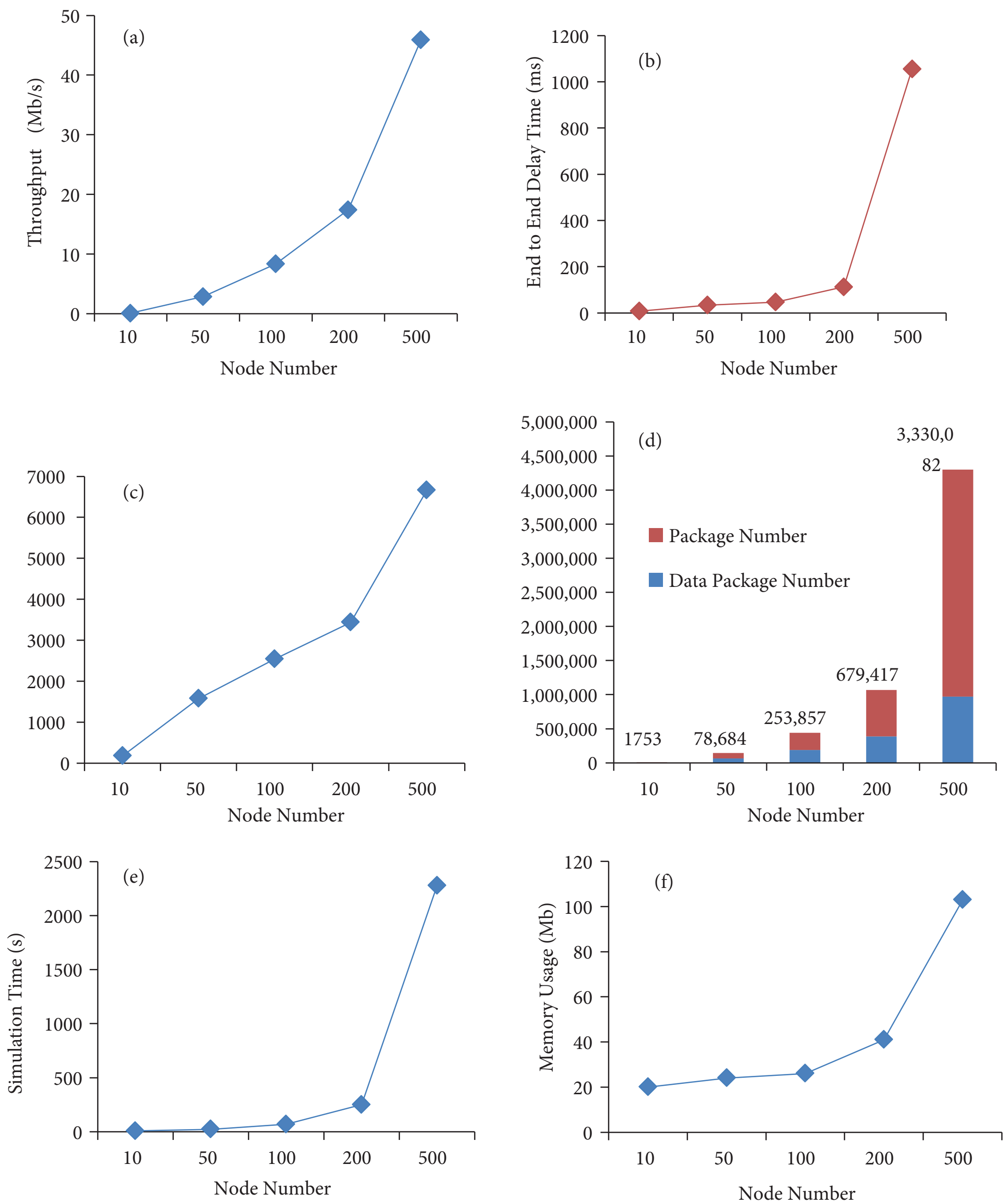

Figure 11. Relation with number of node and simulation results.

Average packet delay is another criterion observed in networks allowing us to have information regarding the general status of the network. When the number of nodes increases, because the packet will need to pass through more packets on its path to its destination, and because the increasing number of messages being transmitted in the network increases the accumulations occurring at the buffers/queues, the duration for a packet to reach its destination becomes longer. The results obtained after the experiments are carried out are shown in Figure 11b. The increase was normal up to 200 nodes, and from 200 to 500 nodes, it was 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.

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

Another parameter 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 the AODV routing protocol is to carry out path discovery prior to data sending and this leads to an increase in the network traffic. In Figure 11d, 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 on which the simulation is carried out is very important for the scalability in the experiments. In the experiments carried out, for 10 s, traffic of 10 messages per node has 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. The reflection of this traffic in terms of wall clock time is seen in Figure 11e.

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 the MANET-DEVS environment is shown in Figure 11f.

As a result, in the implementation of the 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 the MANET-DEVS environment performs all the functions of a network simulator. For this reason, the results are 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 following section, the validation and verification process of MANET-DEVS is taken separately.

4.1. MANET-DEVS verification and validation experiments

A simulation model is a tool to reach to any specific object (design, analysis, control, optimization, etc.). For this reason, an essential precondition 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 and 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. However, the objective of D&G is to confirm the sufficient accuracy of the target model [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 done to determine whether the created conceptual model's theory and assumptions are compatible with the system theory or not and to determine whether the system model displayed is reasonable for accomplishing the objectives determined initially or not.

It is expected for the developed simulator to conform to real-world behavior or the theoretic definition of a MANET. It is targeted for the simulator to work according to OSI standards, which comprise 7 layers. In

Figure 12, the 3-layer summary of the 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 the Ns-2 simulator, simulator and parameters that are as similar as possible are used.

Resulting from the simulation experiments carried out with 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 throughputs of both simulators are very close to each other.

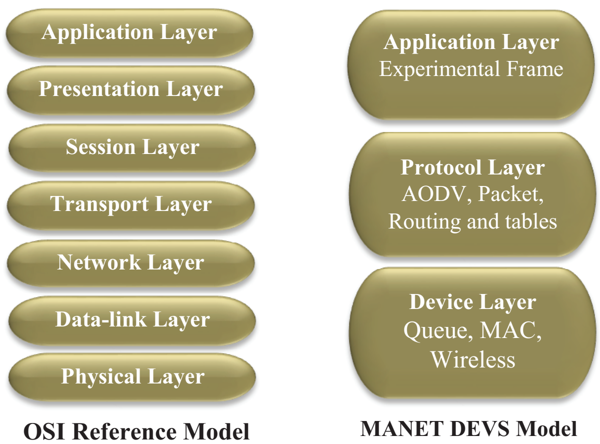

Figure 12. OSI reference model and MANET-DEVS network layers structure.

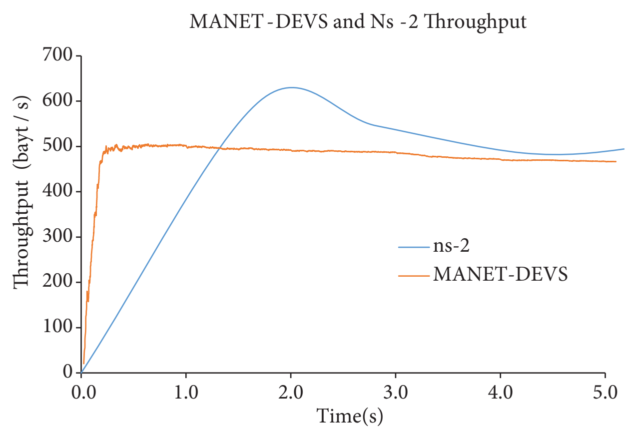

Figure 13. MANET-DEVS and Ns-2 throughput capabilities comparison chart.

5. Discussion

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

The contributions of the MANET-DEVS simulator to 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.
- The MANET-DEVS simulator has a simulator infrastructure with completely object-oriented programming language; therefore, it inherits the advantages of the technology.
- With Java Web Start technology, MANET-DEVS allows its broadcasting/usage online via the Internet; for remote training, it contributes to applied learning and understanding of simulation science.

- The 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 can be done.
- The MANET-DEVS environment allows the structural and behavioral state of the system together with time-based curves, message animations, and 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. The 'time view' option allows the tracking of the behavior of models in the time domain.
- With the BRITE topology generator integrated into the MANET-DEVS environment it 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 the performance of the MANET-DEVS simulator, different scale network models have been established and AODV routing algorithms have been tested. As a result, the MANET-DEVS simulator allows easy simulations to be carried out for MANET 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 simulator that 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 in popular browsers for distance-learning purposes.

References

[1] Jayakumar G, Gopinath G. Ad hoc mobile wireless networks routing protocols – a review. J Comput Sci 2007; 3: 574-582.

[2] Tavli B, Heinzelman W. Mobile Ad Hoc Networks: Energy-Efficient Real-Time Data Communications. New York, NY, USA: Springer, 2006.

[3] Rahman MA, Pakštas A, Wang FZ. Network modelling and simulation tools. Simul Model Pract Th 2009; 17: 1011-1031.

[4] Zeigler BP, Mittal S. Modeling and Simulation of Ultra-large Networks: A Framework for New Research Directions. Tucson, AZ, USA: University of Arizona, 2002.

[5] Zeigler BP, Praehofer H, Kim TG. Theory of Modelling and Simulation: Integrating Discrete Event and Continuous Complex Dynamic Systems. 2nd ed. New York, NY, USA: Academic Press, 2000.

[6] Zengin A. Large-scale integrated network system simulation with DEVS Suite. KSII T Internet Info 2010; 4: 452-474.

[7] Zeng X, Bagrodia R, Gerla M. GloMoSim: a library for parallel large-scale wireless networks. In: Proceedings of the 12th Workshop on Parallel Simulations; 22–29 May 1998; Banff, Canada. New York, NY, USA: IEEE. pp. 154-161.

[8] Begg L, Liu W, Pawlikowski K, Perera S, Sirisena H. Survey of Simulators of Next Generation Networks for Studying Service Availability and Resilience. Technical Report TR-COSC 05/06. Christchurch, New Zealand: University of Canterbury, 2006.

[9] Kim S, Sarjoughian HS, Elamvazhuthi V. DEVS-Suite: A simulator supporting visual experimentation design and behavior monitoring. In: Spring Simulation Multiconference; 22–27 March 2009; San Diego, CA, USA. Article no. 161.

[10] Hogie L, Bouvry P, Guinand F. An overview of MANETs simulation. Electron Notes Theor Comput Sci 2006; 150: 81-101.

[11] Orfanus D, Lessmann J, Janacik P, Lachev L. Performance of wireless network simulators - a case study. In: The 11th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems; 2008. pp. 59-66.

[12] Ben-El-Kezadri R, Kamoun F. Towards MANET simulators massive comparison and validation. In: The 18th Annual IEEE International Symposium on Personal Indoor and Mobile Radio Communications; 3–7 September 2007; Athens, Greece. New York, NY, USA: IEEE. pp. 1-7.

[13] Saquib N, Sakip MSR, Pathan ASK. ViSim: A user-friendly graphical simulation tool for performance analysis of MANET routing protocols. Math Comput Model 2011; 53: 2204-2218.

[14] Kim T, Hwang MH, Kim D. DEVS/NS-2 environment: an integrated tool for efficient networks modeling and simulation. J Def Model Simul 2008; 5: 33-60.

[15] Malowidzki M. Network simulators: a developer's perspective. In: Symposium on Performance Evaluation of Computer and Telecommunication Systems (SPECTS'04); 25–29 July; San Diego, CA, USA. pp. 412-419.

[16] Farooq O, Wainer G, Balya B. DEVS modeling of mobile wireless ad hoc networks. Simul Model Pract Th 2007; 15: 285-314.

[17] Dow CR, Lin PJ, Chen SC, Lin JH, Hwang SF. A study of recent research trends and experimental guidelines in mobile ad-hoc networks. In: Proceedings of the 19th International Conference on Advanced Information Networking and Applications; 28–30 March 2005; Taiwan. New York, NY, USA: IEEE. pp. 72-77.

[18] Kurkowski S, Camp T, Colagrosso M. MANET simulation studies: the incredibles. Mobile Computing and Communications Review 2005; 9: 50-61.

[19] Kiess W, Mauve M. A survey on real-world implementations of mobile ad-hoc networks. Ad Hoc Netw 2007; 5: 324-339.

[20] Camp T, Boleng J, Davies V. A survey of mobility models for ad hoc network research. Wirel Commun Mob Com 2002; 2: 483-502.

[21] Zeigler BP, Praehofer H, Kim TG. Theory of Modelling and Simulation. Malabar, FL, USA: Academic Press, 2000.

[22] Zengin A. A routing algorithm for distributed simulation systems. PhD, Sakarya University, Sakarya, Turkey, 2004.

[23] Zeigler BP. Multifaceted Modelling and Discrete Event Simulation. London, UK: Academic Press, 1984.

[24] Antoine-Santoni T, Santucci JF, De Gentili E, Costa B. Discrete event modeling and simulation of wireless sensor network performance. Simulation 2008; 84: 103-121.

[25] Kuljis J, Paul RJ. An appraisal of web-based simulation: whither we wander? Simulat Pract Theory 2001; 9: 37-54.

[26] Cassel RA, Pidd M. Distributed discrete event simulation using the three-phase approach and Java. Simulat Pract Theory 2001; 8: 491-507.

[27] Pidd M, Cassel RA. Using Java to develop discrete event simulations. J Oper Res Soc 2000; 51: 405-412.

[28] Kilgore RA, Kleindorfer GB. The future of Java-based simulation. In: Winter Simulation Conference; 13–16 December 2008; Washington, USA. pp. 1707-1712.

[29] Corson S, Macker J. Mobile Ad Hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations. Reston, VA, USA: The Internet Society, 1999.

[30] Royer EM. A review of current routing protokols for ad hoc mobile wireless networks. IEEE Pers Commun 1999; 6: 46-55.

[31] Abolhasan M, Wysocki T, Dutkiewicz E. A review of routing protocols for mobile ad hoc networks. Ad Hoc Netw 2004; 2: 1-22.

[32] Perkins C, Belding-Royer E, Das S. Ad hoc On-Demand Distance Vector (AODV) Routing (rfc3561). Reston, VA, USA: The Internet Society, 2003.

[33] Al-Karaki JN, Kamal AE. Routing techniques in wireless sensor networks: a survey. IEEE Wirel Commun 2004; 11: 6-28.

[34] Hild DR. Discrete event system specification (DEVS) distributed object computing (DOC) modeling and simulation. PhD, University of Tucson, Tucson, AZ, USA, 2000.

[35] Mittal S, Mak E. DEVS-based dynamic model reconfiguration and simulation control in the enhanced DoDAF design process. J Def Model Simul 2006; 3: 239-267.

[36] Uhrmacher AM. Dynamic structures in modeling and simulation: a reflective approach. ACM T Model Comput S 2001; 11: 206-232.

[37] Rahman MA, Pakštas A, Wang FZ. Review: network topology generation and discovery tools. Simul Model Pract Th 2009; 17: 1011-1031.

[38] Medina A, Lakhina AI, Matta I, Byers J. BRITE: Universal Topology Generation from a User's Perspective, Technical Report. Boston, MA, USA: Boston University, 2001.

[39] Robinson S. Simulation model verification and validation: increasing the users' confidence. In: Winter Simulation Conference; 7–10 December 1997; Atlanta, GA, USA. pp. 53-59.

[40] Pace DK. Modeling and simulation verification and validation challenges. J Hopkins APL Tech D 2004; 25: 163-172.