ABSTRACTION ON NETWORK MODEL UNDER INTEROPERABLE SIMULATION ENVIRONMENT

Bong Gu Kang, Byeong Soo Kim, and Tag Gon Kim
Department of Electrical Engineering
Korea Advanced Institute of Science and Technology
Daejeon, 305-701, Republic of Korea
E-mail: kbgmode@kaist.ac.kr

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Abstraction of network model, interoperable simulation environment, metamodeling, simulation execution time.

ABSTRACT

This paper proposes a method for abstraction of a network model that enables a reduction of simulation execution time under the interoperable military system simulation environment that consists of two models: the network model and computer-generated forces (CGF) model. This paper illustrates the 1) overall procedure of abstraction and 2) empirical analysis. In the abstraction step, our approach uses the information between the two models and, as well as of the network model, unlike previous research. To show how the procedure can be applied, we first implement the CGF model, network model, and interoperable simulation environment. Then, we apply our method to the simulation environment in a case study by comparing with previous study in terms of accuracy and speed. From the empirical results, we can draw the conclusion that the accuracy of the simulation is significantly enhanced by sacrificing a little execution time within an acceptable range. In closing, we expect that this approach will help people conduct replication simulations that require long execution times in one execution.

INTRODUCTION

In modern warfare, the influence of communication is considered as important as other factors, which is why the word “communication (C)” is considered as one element of Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR). In this respect, many researchers in defense modeling and simulation (M&S) have paid close attention to the effects of communication in defense-system simulations. Nevertheless, until recently, many military models have assumed sufficient communication functions between entities in the military model. To be specific, many models still assumed perfect communication, that is, no delay and loss of communication (Kim et al. 2012; Sung and Kim 2012); others assumed a simple connection model with probability (Yang et al. 2006) or a relatively more complex model (Shin et al. 2013) by designing the model as one sub-model of the entire military model to determine whether messages were transmitted. By extension, others tried to depict the effects of communication by doing integration or interoperation with existing standalone communication, network models developed through various tools suitable for communication modeling and the military model, or the CGF model. (Walsh et al. 2005; Paz and Baer 2008; Kang and Kim 2013).

Although the integration or interoperation approach has an advantage to be able to depict the detailed effects of communication, each requires long execution times to complete the simulation, owing to the complexity of the network model. Thus, these approaches make it difficult to experiment on a large number of scenarios and replications. To overcome this problem, Porche et al. (2004) constructed an abstracted model of the network model and integrated the abstracted model with the CGF model, or war-game model, in order to measure the impact of communication effects on combat power (Porche et al. 2006). In this procedure, the abstracted model unfortunately considered only inputs of the network model, such as specification of communication equipment, not information between the network model and CGF model, thereby reducing the accuracy of the abstracted model.

To face the above challenge, this study presents a method that considers the information between two models: the network model and CGF model, as well as the inputs of the network model. This paper illustrates 1) the overall procedure composed of three phase—data acquisition from simulation, abstracted model construction from the data, and application of the abstracted model in analysis—and 2) empirical simulation results in order to show how the procedure can be applied in defense simulation. In detail, we first construct an infantry-company-level CGF model and a network model including a depiction of the mobile ad-hoc network (MANET) using ad hoc on-demand distance vector routing (AODV) protocols in the battlefield (Kaur and Sharma 2013). Then, we implement an interoperation simulation environment using the above two models based on high-level architecture (HLA), a specification for interoperation of distributed heterogeneous models (IEEE Standards Association 2010). Finally, the network model under the interoperation environment is abstracted according to our proposed procedure, and it is compared with previous studies (Porche et al. 2004, 2006) with regard to the accuracy and simulation execution speed of the model.

This study is organized as follows: In the next section, related works on abstraction of the network model are described. Then, we illustrate our method to overcome

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related work's flaws and its application. Finally, we evaluate our proposed work and draw a conclusion.

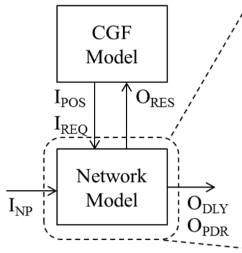
RELATED WORKS

Because M&S has been regarded as an important technique in the communication research fields, various open-source, commercial communication, or network models focusing on a network analysis have been developed (Pan and Jain 2008). Such models usually calculate packet-delivery ratio (PDR) and end-to-end delay as their outputs from simulation. The former means the ratio of the number of delivered packets from the source to the destination node, and the latter indicates the average time taken by packets to arrive at the destination from the source node. For this reason, earlier studies considered the two factors (i.e., PDR and end-to-end delay) as outputs of an abstracted network model (Porche et al. 2004).

As mentioned before, the target-simulation model focusing on communication effects in the battlefield consists of two models, as shown in the left part of Figure 1: the CGF and network model. In detail, the combat entities of the CGF model and nodes (i.e., communication equipment) of the network model share their positions to represent them as deployed under the same battlefield condition. To be more specific, when communicating between two entities in the CGF model, the CGF model first sends a packet to the network model. After that, the communication effects are calculated based on the PDR and end-to-end delay in the network model, and the packet is again delivered to the CGF model. Eventually, packet loss and delay affect the combat power of the CGF model, and thus, the influence of the network parameter, such as the transmission power of the communication equipment, on combat power can be measured and analyzed.

Under this circumstance, the network model requires long execution times due to high complexity. Thus, it causes the necessity of abstraction of the model. The right part of Figure 1 shows how the network model can be abstracted. An earlier study (Porche et al. 2004) only considered the network parameter as its inputs by not considering network information such as node positions. However, this approach has a limitation in showing high accuracy. To be specific, the communication between nodes over long distances is conducted by multi-hops using intermediate nodes in the real world; in spite of that, the earlier study cannot express such a situation. Thus, this paper proposes a method that is able to consider not only the network information from the CGF model but also the network parameters of the network model for enhanced accuracy.

PROBLEM DEFINITION



Type	Index	Implications
Input	I_{NP}	Network model parameter
Input	I_{POS}	Network node position
Input	I_{REQ}	Packet for request
Output	O_{DLY}	End-to-end delay
Output	O_{PDR}	Packet delivery ratio
Output	O_{RES}	Packet for response

Figure 2: Input and Output of Network Model

Figure 2 illustrates more specific inputs and outputs of the target network model for abstraction, which is mentioned in the left part of Figure 1. Input consists of 3 factors: network model parameter, node position, and packet for request. Output also has 3 factors: PDR, end-to-end delay, and packet for response. The packet for response is calculated with the PDR and end-to-end delay of the network model against arrived packets for request. The PDR and end-to-end delay can vary due to the network model parameter and node position. In terms of such a network model, this paper focuses on constructing an abstracted network model, including the same input/output factors, assuming that we can only access input/output, not inner state. When it comes to the packet for response, which is one of the outputs, it is indirectly acquired by the PDR and end-to-end delay against the arrived request packet, not directly calculated. In other words, the packet for response can be calculated only if we know the PDR and end-to-end delay. Thus, our method only focuses on the abovementioned two outputs. Even though the proposed abstracted method explains the two

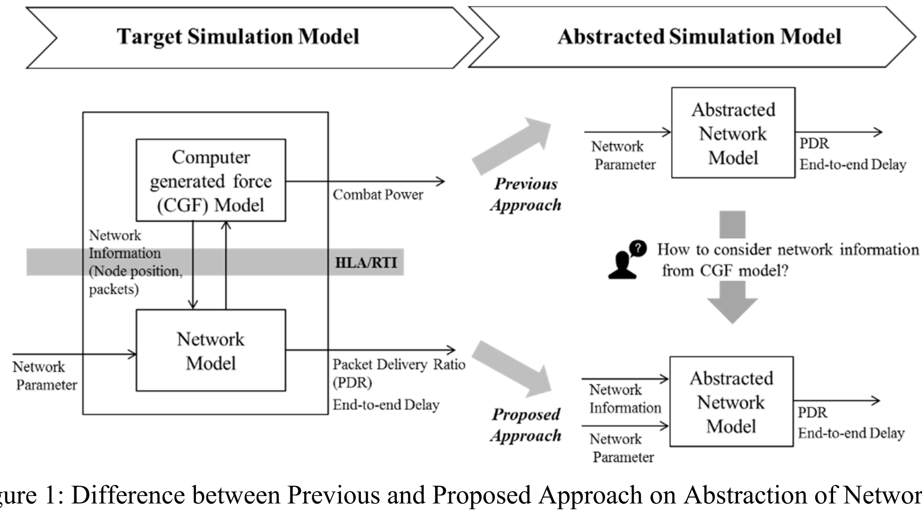


Figure 1: Difference between Previous and Proposed Approach on Abstraction of Network Model

outputs, our abstracted model can be substituted for the existing network model because our model internally includes a function that reflects the PDR and end-to-end delay on the packet for request and transmits the packet for response to the CGF model by implementing the function in the abstracted network model.

PROPOSED WORKS

This section presents an overall procedure to show how the network model can be abstracted and how it can be used with the CGF model for interoperable simulation. Before describing the procedure, we describe prior knowledge to aid understanding the process.

In the previous section, we confirmed that node position is one of the outputs, and it has effects on communication. Thus, the positions of all nodes should be reflected to enhance the accuracy, not only one node position, which receives from the CGF model because the positions of all nodes include other nodes' positions besides a source and destination node. However, to represent all node positions in this way expands the dimension of inputs when the number of nodes is increased, and it needs much more time to execute simulations based on the number of nodes. Also, these absolute positions of nodes cannot give any other insight. To confront this weakness, we condensed the position of all nodes to distance and network density, as shown in Figure 3, which have been considered major factors in the communication research field (Adam et al. 2010). The former represents the distance between the source and destination node, and the latter represents the number of nodes in the rectangular area by the source and destination node. To put it concretely, a long distance requires more hops for communication, and it consequently causes the increased end-to-end delay and the decreased PDR; on the other hand, a larger network density implies the probability of the existence of inter-mediate nodes between the source and destination node, which causes the increased end-to-end delay and PDR. Due to this importance of these facts, we chose the two factors: distance and network density. Whenever I_{POS} from the CGF model occurs, one must save the position and then calculate the two factors whenever I_{REQ} is sent from the CGF model.

Figure 4 illustrates the overall procedure of the network model abstraction, and the process consists of 3 phases: 1) simulation using the target network model, 2) abstraction, (i.e., metamodeling) of the network model, and 3) simulation and analysis on an abstracted network model.

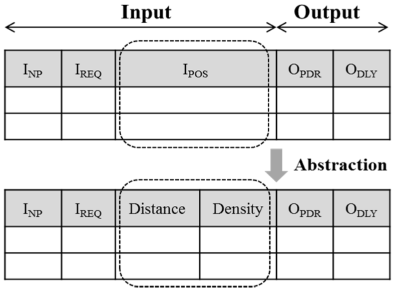


Figure 3: Identify Input for Abstracted Network Model

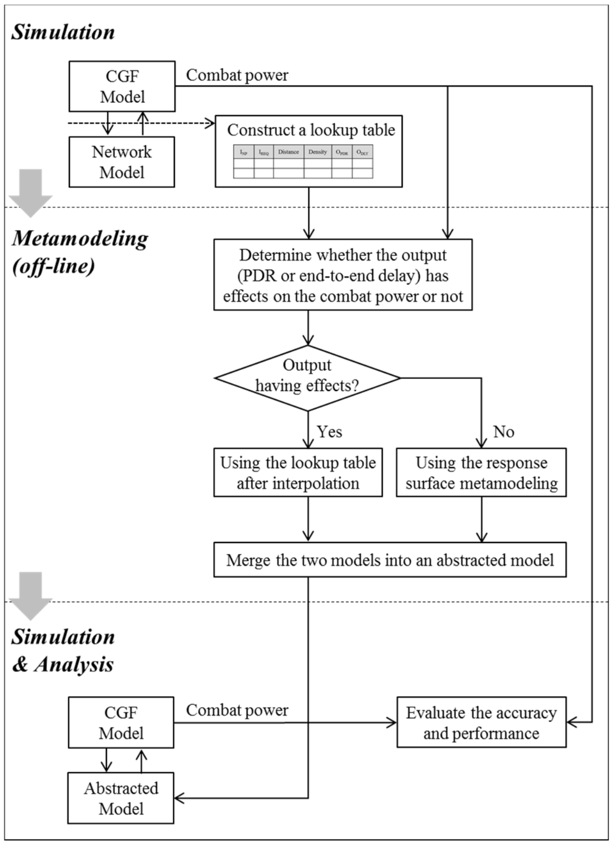


Figure 4: Overall Process of Abstracted Network Model

In the first step, interoperable simulation using the CGF and target network model is executed. During this time, data related to communication is saved, as in the form of Figure 3. Also, combat power is measured as an output of the CGF model.

After finishing the simulation, the abstraction process is conducted with data acquired in the first stage. In this procedure, we first determine whether the output of the network model (O_{PDR}, O_{DLY}) has effects on the combat power. If the output has no impact on the combat power, we don't need to represent the output in detail. Figures 6 and 7 show the decision process, which will be mentioned in the case-study section. In other words, if the output of the network model has an effect on the result of the CGF model, the output should be specifically depicted. Thus, this study uses the tabulation technique including interpolation, which was recently used in defense M&S to abstract one system between two (Bae et al. 2016). On the contrary, if the output of the network model has little effect on the result of the CGF model, it does not need to be described in detail. For this reason, this paper represents it as a simple model using a general regression method, such as response surface metamodeling (RSM; refer to Table 2 in the case-study section). After constructing each model against the output (O_{PDR}, O_{DLY}), we merge the two models into an abstracted model, since the target network model is one model component.

In the last phase, the target network model is substituted for the abstracted model and participates in simulation with the CGF model. From this simulation, the abstracted network model can be evaluated in terms of accuracy and speed. The fundamental objective of using the target network model is to derive the combat power of the CGF model, which reflects effects of communication, not to merely measure its functions or performance (although it goes without saying that it is ideal to depict the functions perfectly). In this regard, the accuracy should be evaluated against the output of the CGF, not the network model. Thus, the combat power of experimental results using the target network model and abstracted network model should be measured and compared. Regarding simulation speed, this paper measures the simulation execution, or run time, since the ultimate goal of using the abstracted model is to shrink the execution time. After acquiring the two performances: accuracy and speed, this paper analyzes the trade-off between the two performances by comparing with the previous method and determining whether the proposed method is valid.

EXPERIMENT

This section illustrates a case study for the proposed method in the following order: simulation model design, experiment design to compare the simulation model and its abstraction, and experiment results.

Simulation Model Design

The simulation model for abstraction consists of two models, the CGF and network model, and conducts the army's ground operations at infantry-company level. Recently, owing to the importance of communication, the equipment for communication is allocated to each solider, which is reflected in the defense M&S (Kuosmanen 2002) domain. In this respect, we first constructed 131 combat entities—108 soldiers, 12 squad command and control (C2)s, 4 platoon C2s, 1 company C2, and 6 mortars—for the CGF model using discrete event systems specification (DEVS) formalism, which has been widely used for defense M&S (Zeigler et al. 2000; Seo et al. 2011). Then, we also constructed 131 network equipment, which corresponded with the above combat entities of the CGF model in the network model. We assumed that the network equipment used AODV protocol for MANET, which has been described as the form of a finite state machine (FSM) (Wagner et al. 2006). Finally, to depict the combat entities and network equipment as under the same battlefield situation, we participate the two models in an HLA-based interoperable simulation through run-time infrastructure (RTI) by using one object and one interaction for each node's position information and packet information between two nodes, respectively.

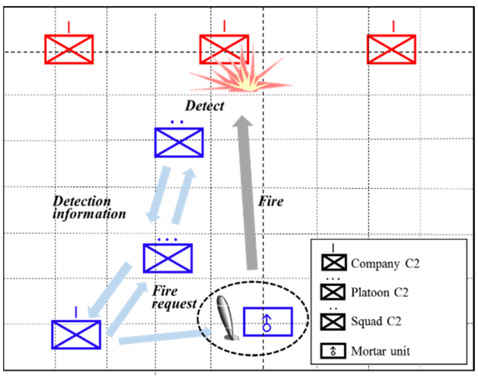


Figure 5: Illustration of Abstracted Combat Scenario

Figure 5 depicts a combat scenario that simplifies the complex hierarchy of the CGF model. Concretely, the blue force's combat entities and equipment were located in a 2 km × 2 km operation area, and one company within the blue force executed defense operations against three companies within the red force. When the red force approached from the upper region of the operation area, a blue solider detected the red one and hierarchically sent the detection information to the top company C2 via squad and platoon C2 in order (Dekker 2002). After that, the company C2 conducted a threat evaluation and weapons, such as mortar allocation, and then transmitted a fire request message to the mortar and solider through a subordinate C2, as shown by the light blue arrows in Figure 5. In such a transmission of the messages, the communication effects are reflected and affect the combat power. For instance, an in-direct attack using a mortar will be smooth if the condition of communication is perfect (i.e., no packet delay and loss), and it can consecutively enable an easier direct attack by soldiers.

Experiment Design

The objective of this experiment is to compare existing and proposed methods for abstraction against two factors: accuracy and simulation speed. This paper chose enemy survivability rate and simulation execution, or run time, as performance indexes against the accuracy and speed, respectively. Also, we considered net diameter in MANET AODV as a parameter of the network model, as shown in Table 1, which shows the maximum possible number of hops between two nodes in the network. Against this parameter, we chose 10 experimental points and ran repeat simulations 30 times per one experiment point.

Finally, the simulation environment for this case study is as follows. For the CGF model, CPU: I5-3550 3.3 GHz, RAM: 4 GB, DEVSim++ v.3.1, and KHLAAdaptor were used (Kim et al. 2011). In the network model, OPNET v.14.5 was used under the same hardware. These models, or simulators, were interoperated by RTI 1.3-NG. The simulation progressed over 2 hours (i.e., when the enemy survivability was sufficiently saturated).

Table 1: Network Model Parameter

Parameter name	Parameter description	Parameter level
Net Diameter	Maximum possible number of hops between two nodes in the network	1, 2, …, 10 (10 cases)

Experiment Result

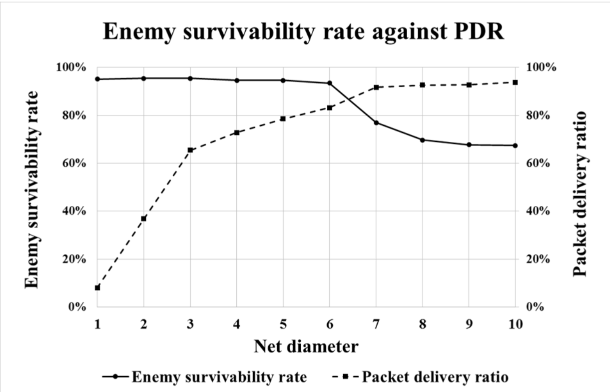


Figure 6: Enemy Survivability Rate against PDR

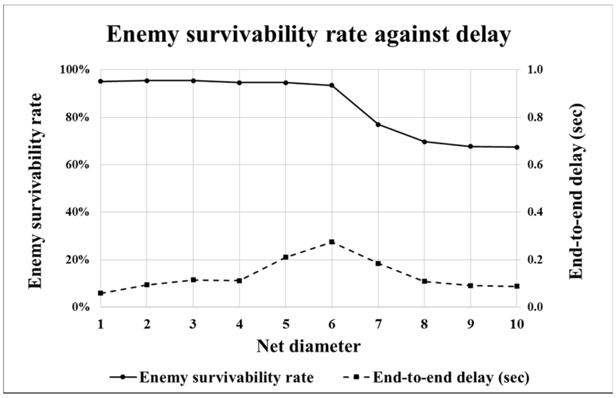


Figure 7: Enemy Survivability Rate according to End-to-end Delay

Figures 6 and 7 show experimental results when using the network model without abstraction. We can identify that the enemy survivability rate has a declining tendency when the net diameter increases from the above two figures. The reason for this is that the increased net diameter enables multi-hop communication. In this circumstance, and by extension, we are able to profoundly analyze the effects of communication performance on the enemy survivability rate by observing the PDR and end-to-end delay in each figure. For example, Figure 6 shows that the PDR has numerous effects on the enemy survivability rate; on the other hand, we can recognize from Figure 7 that the end-to-end delay has little effect on the survivability rate because the delay is too small.

Table 2: Abstraction Model through Previous Method

Abstraction model input/output	Abstraction model identified parameters
PDR =f(x=Net Diameter)	$0.260690x - 0.016206x^2$ -0.094425, $R^2_{adj} = 0.955$
End-to-end delay =g(x=Net Diameter)	$0.077975x - 0.006822x^2$ -0.033217, $R^2_{adj} = 0.509$

On the basis of the data acquired by the network model, we constructed two kinds of abstraction models using a previous (Porche et al. 2004) and a proposed method.

For the former's case, we constructed an abstraction model covering two functions, PDR and end-to-end delay, against the network model parameter using the RSM method, as shown in Table 2.

In the case of the latter, we constructed another abstraction model representing the PDR and end-to-end delay with tabulation technique and RSM, respectively. Since we recognize that the end-to-end delay has little effect on the enemy survivability rate from above the experiment, we chose the RSM because it was relatively simple compared to the tabulation technique. Meanwhile, we made a table consisting of 3 inputs—net diameter, distance, and density, against the PDR—and then we set quantization size as 1, 20, and 1 in each input and used linear interpolation for tabulation.

After constructing two abstracted models as mentioned above, we substituted the network model to the abstracted model and executed the simulation. Figure 8 shows simulation results in terms of accuracy. From Figure 8, we observed that the enemy survivability rate from the previous method deviated far more than the proposed method. For the quantitative analysis, we measured the root mean square error (RMSE) of the survivability rate. The RMSE of the case using the existing method-based model and the network model was measured to be 14.16%; on the other hand, the RMSE was recorded as 4.58% when using the proposed method-based model and the network model. This indicates that the proposed method was 3.09 times more accurate than the earlier study. Regarding speed, we measured a total execution time of about 300 trials (10 experimental points × 30 replications), and the time was recorded as 111,658, 459, and 493 minutes against cases using the network model, previous model, and proposed abstracted network model, respectively. This result shows that 1.07 times more execution time is required when using the proposed method compared with the existing one.

To sum up the experimental results, accuracy is considerably enhanced with the proposed method without exhausting the corresponding execution time.

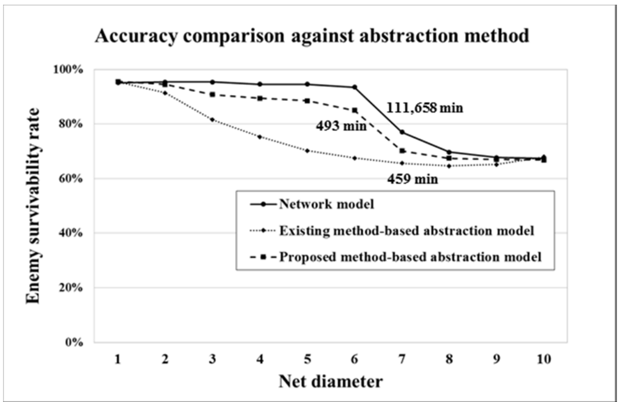


Figure 8: Accuracy Comparison according to the Abstraction Methods

CONCLUSIONS

In modern warfare, the importance of communication has increased. Thus, many M&S researches have used complex network models, such as simulation tools that are dedicated to the network domain, to analyze the influence of communication effects on combat power in the military system. However, to use the complex network models unfortunately causes long execution time problems due to the complexity of the network models.

To overcome this weakness, many studies have tried to use the network model in an abstracted form, and use it with the computer generated forces (CGF) model by integrating/interoperating the two models. Nevertheless, the previous research did not consider the information between the two models during the abstraction process, and it consequently caused an accuracy decrease.

In this study, we presented a method that considers the information between two models, as well as the inputs of the network model, like property of network equipment. For this, we described the overall procedure of the abstraction using various abstraction techniques and showed empirical simulation results acquired through a case study by comparing the proposed method with the previous study.

As a main contribution, the accuracy of the abstracted model was significantly enhanced by sacrificing a little simulation execution time within an acceptable range. Furthermore, this proposed method can help people conduct simulation-based analyses against various scenarios and replications within time constraints.

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AUTHOR BIOGRAPHIES

BONG GU KANG is a PhD. candidate at the Department of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST). His research interests include methodology for M&S of discrete event systems

(DEVS), defense modeling and simulation, and interoperation simulation.

BYEONG SOO KIM is a PhD. candidate at the Department of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST). His research interests include methodology for M&S of discrete event systems (DEVS), distributed simulation, and system design.

TAG GON KIM is a professor at the Department of Electrical Engineering Korea Advanced Institute of Science and Technology (KAIST). He was the editor-in-chief for *Simulation: Transactions for Society for Computer Modeling and Simulation International* (SCS). He is a co-author of the text book, *Theory of Modeling and Simulation*, Academic Press, 2000. He has published about 200 papers on M&S theory and practice in international journals and conference proceedings. He is very active in defense modeling and simulation in Korea.