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# Multi-Resolution Entities Aggregation and Disaggregation Method for Train Control System Modeling and Simulation Based on HLA*

Chen-xi Gou, Bai-gen Cai

***Abstract*— Train control system modeling and simulation based on Multi-resolution modeling method could replicate the real system operation precisely and efficiently. During simulation, the resolution level of system model could be switched from high to low or low to high according to real-time simulation needs. In order to realize the resolution switching of system model, based on High Level Architecture (HLA), a new multi-resolution modeling method called multi-resolution entities aggregation and disaggregation method is proposed. By adopting HLA simulation environment, operable external interface could be realized to receive manual resolution switch information. With combination of both traditional multi-resolution modeling methods, which are multi-resolution entity method and aggregation and disaggregation method, could solve the problem of model data resolution mapping and also support concurrent operation of models from different resolution levels. A simulation example of train operation control system was modeled and simulated based on this method and demonstrated advantages.**

## I. Introduction

Train control system played as a very important role in Chinese high speed railway system [1]. To maintain system safety in a certain level, system performance should be evaluated during massive tests, while some of the tests are dangerous or expensive in terms of human and material resources. Thus, simulation system could be constructed with modern system modeling theories to present train control process in an abstract and precise way.

Multi-resolution modeling theory was effectively applied in many fields as key technology in massive complex system simulation modeling [2-6]. Together with various application, multi-resolution modeling methods is always considered as hot spot in multi-resolution modeling theory [7]. There are several traditional and widely used modeling methods, like Selected Viewpoint method, Integrated Hierarchical Variable Resolution Modeling (IHVR), Multi-Resolution Entity method (MRE), Aggregation and Disaggregation method (A/D method), etc. In Selected Viewpoint method, model should be operated in highest resolution level during the whole simulation process and data from lower resolution level model could be obtained according to highest resolution level model [8,9]. In IHVR method, models are organized in hierarchical structure, as outputs from higher resolution level model are considered as inputs to lower resolution level [10]. Basic idea of MRE method is to present the real system with several models of different resolution levels, and to create attribute dependency graphs and interaction resolver to realize inter-operation between the models [11]. As in the name of A/D method, it is used for multi-resolution modeling by running the model from lower resolution model to increase simulation efficiency. When the simulation or user needs more details, model will be disaggregated into higher resolution models. And when it is no longer needs details, the aggregation will start to lead the simulation back to lower resolution again [12].

Since A/D method is easily comprehended and realized, it is popularly used and improved in some ways for different system simulation requirements [13]. When it comes to train control system multi-resolution modeling, there are three major problem to settle, which are interface to receive resolution switch messages, simulation strategy of resolution change and interaction support between models from different resolution levels. In this paper, all of three problems could be solved by combining MRE method and A/D method together under HLA simulation environments. In this way, the multi-resolution model of train control system could gain good reusability and expansibility.

## II. HLA-Based Multi-Resolution Model of Train Control System

### A. Multi-Resolution Model of Train Control System

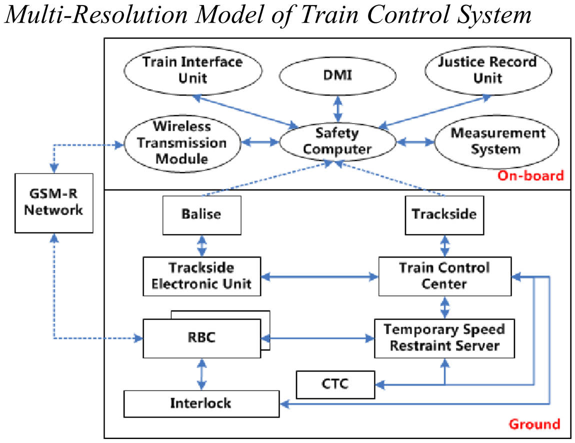


Figure 1. Train Control System Structure

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Chen-xi Gou and Bai-gen Cai are with School of Electronic and Information Engineering, and State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, P. R. China (Post Code: 100044, corresponding author phone: 086-010-51684887; fax: 086-010-51687111; e-mail: gouchenxi@gmail.com ; bgcai@bjtu.edu.cn).

Train control system applied in High Speed Railway system is called CTCS-3 train control system. It has three major parts, as ground subsystem, on-board subsystem and GSM-R. Main structure of this train control system is shown in Fig.1.

According to system simulation and testing requirements, the system simulation model could be divided into several different resolution levels. The model of lowest resolution level is to describe the system activities in a large railway network and to evaluate system efficiency on some certain operation plan by showing the flow feature of a large amount of trains. The model of lower resolution level is to describe the system performance in a certain area like section between two stations by updating and showing the positions and brief informations of all trains in this area during the whole simulation. The model of higher resolution level is to perform how one train follows the control information and carries on operation to run safely and efficiently by updating all the information and data just like in real system and providing user the operation interface for further human factor evaluation. And last not the least, the model of highest resolution level is to show how one equipment receives information and sends information to others after calculation and finally there is the train control message. The multi-resolution model structure of train control system is shown in Fig.2.

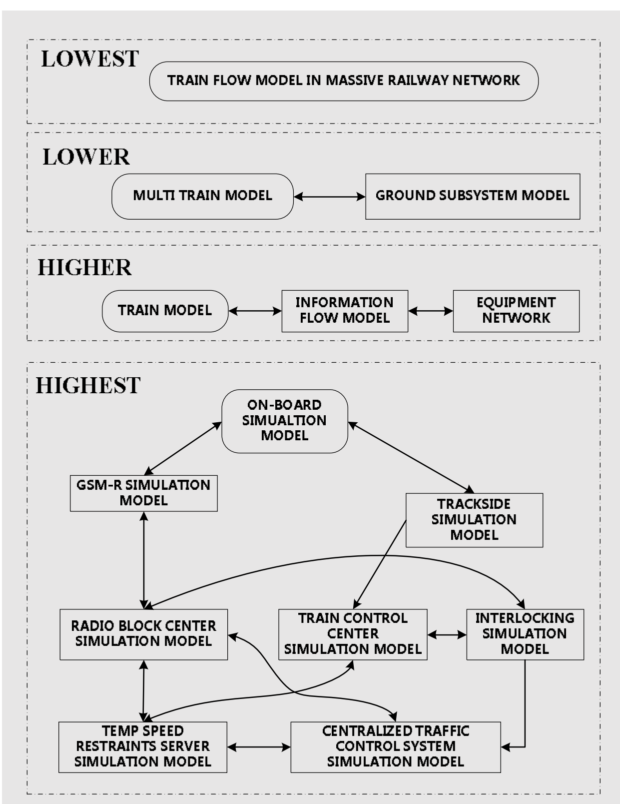


Figure 2. Multi-Resolution Model Structure of Train Control System

## *B. HLA-Based Simulation Structure*

High Level Architecture (HLA) is widely used distributed simulation architecture. Under this architecture, every simulation member could join in or sign out the simulation process during simulation. And also, it could support to create a simulation manager, which could have the authority to give every simulation member simulation orders to control the simulation process. So, by this means, a simulation manager could be created to receive manual resolution switch orders and change the activeness of simulation members to change the simulation resolution during simulation.

For train control system multi-resolution modeling and simulation, every simulation modules or subsystems from every resolution level would have a spot in this HLA structure. The simulation manager, which plays the most important part during simulation, should have many functions, including simulation initialization, simulation member identification, simulation member synchronization, simulation process management, human-machine interface, simulation data recording and analyzing, simulation resolution level switching, etc. The overall process of simulation manager is shown in Fig.3.

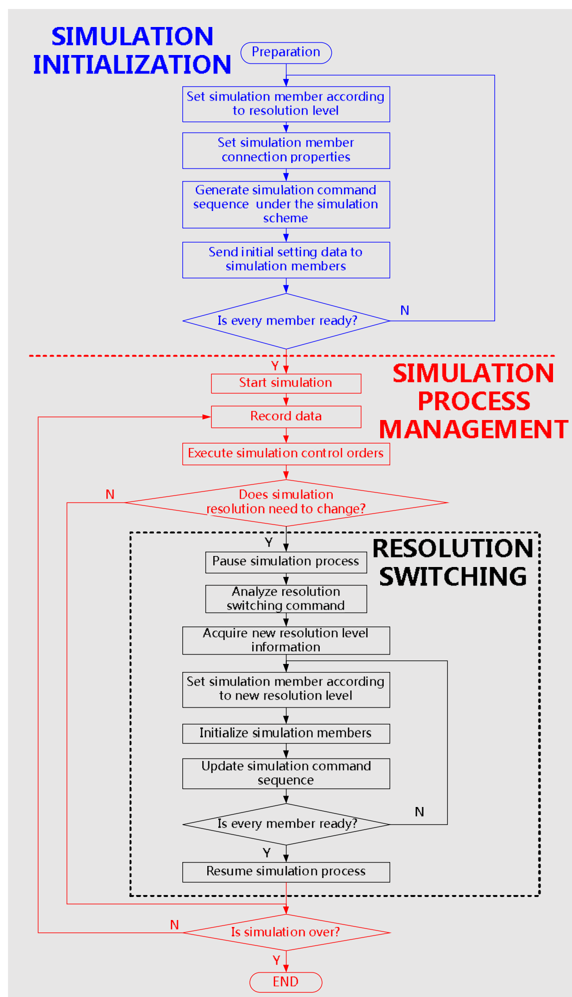


Figure 3. General Process of Simulation Manager

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In Fig.3, as simulation manager starts to work, it connects every simulation members and recognizes them. According to initial resolution setting, simulation manager activates simulation members which are involved in this resolution level. After downloading the simulation scheme, simulation manager generates a chronological list of simulation control commands which is needed during the simulation. At last, simulation manager synchronizes all the members. Then, the simulation could be started. During simulation, simulation manager records all the communication data between the simulation members. As there are needs to change the simulation resolution, no matter it comes from the user or the model space or even the simulation itself, simulation manager would pause the simulation process first and deal with the resolution switch information to gain the target resolution information. Based on the new resolution information, simulation members needed in this new resolution level would be activated and initialized by simulation manager. After all these synchronization and initialization, simulation manager resumes the simulation process.

# III. Multi-Resolution Entity Aggregation and Disaggregation Method

As soon as simulation environment receives resolution switch orders from manual interface or simulation itself, resolution switch action would be performed. To realize resolution switch action, aggregation and disaggregation method could be utilized. After the resolution change, it could be possible that models from various resolution levels all run at the same time. To deal with that, since there is no support definition of that in aggregation and disaggregation method, multi-resolution entity method could be used by consider every model as an entity with equal importance.

## A. Aggregation and Disaggregation Method

According to train control system specifications and standards, we can easily obtain the models of system equipment from highest resolution level. Then based on those models with the most detailed information, aggregation action could be used to obtain system inner network structure model and dynamic information flow model. This two models are in the same resolution level with single train model. To perform system operation process in this resolution level, concept of system steady-state model would be adopted. System steady-state model is for system feature description when system is operated in a normal way, like system structure, logic method, data processing and parameter setting. This steady-state model could contain all the three models involved in this resolution level.

Then, by aggregating the models again, the ground subsystem model from the lower resolution level could be created. Information involved in the information flow model is analyzed and divided into four classes, as connection confirm information, rail line information, train status information and train control information. Since connection confirm information is not as important as other information in train control system, it is not considered and described in this resolution level. Each equipment, performing as a node in the system network structure model, could also be classified according to its contribution to train control process, as transmitting node, processing node or source node. We only take processing node and source node into consideration during aggregation, cause the contribution to the train control process from transmitting node is less than the other two kinds. By taking GSM-R network model as an example, GSM-R network receive train status information from simulation train, process the information and then send to Radio Block Center (RBC). On the other way, GSM-R networks receive train Movement Authority (MA) information from RBC and transfer the information to the train. So, the basic content of information is not changed by GSM-R network model, which could be considered as transmitting node. So GSM-R network model would not appear in the model structure in this resolution level. Based on this idea, it would be easy to abstract the characteristic structure, characteristic node and characteristic I/O information of ground subsystem, which could help to build the ground subsystem model. The general model structure in the lower resolution level is shown in Fig.4.

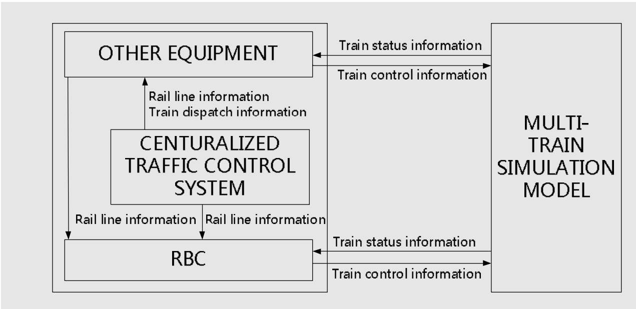


Figure 4. General Model Structure in the Lower Resolution Level

In Fig.4, RBC and centralized traffic control system are remained as key node in ground subsystem model for they are classified as important processing node and important source node, while other equipment are aggregated as others.

After aggregating again and again, we could create models from each resolution level. During the simulation, there is another problem, which is model interaction between models from different resolution level. Since information from different resolution models are not consistent in format or even in content, which makes it impossible to communicate to each other, the resolution switch action like the aggregation or disaggregation would be needed to change some models to make the communication possible. However, some of the resolution switch actions are quite often, which costs a lot of system occupancy. By analyzing this problem and its causes, pseudo A/D method could be adopted for certain circumstances, that is when one model from a certain resolution just needs some of the information from other resolution model without affecting normal simulation process of other resolution model. In pseudo A/D method, we could create a pseudo model which is in the same resolution level with the model requiring information. The simulation information of pseudo model is generated by multi-resolution model space manage model based on other resolution model information. The communication process is shown in Fig.5.

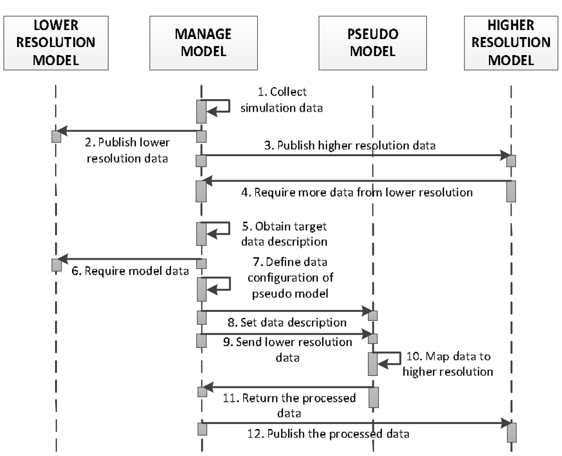


Figure 5. Communication Process between Models from Different Resolution Level based on Pseudo A/D Method

In Fig.5, as model from higher resolution level needs data from lower resolution level in some circumstances, there is no need to disaggregate lower resolution model. By using pseudo model, the data higher resolution model needs could be obtained. It also could be used when the lower model needs higher data. So it could save a lot of work as model aggregation or disaggregation during the simulation.

In train control system simulation, pseudo A/D method could help as train model require more detail information from some particular equipment or detail of information flow process, like train entering station. According to data from train model and information from train schedule, the pseudo model could calculate detail control information of train route, without disaggregating the ground subsystem model.

### *B. Multi-Resolution Entity Method*

Although some of connection problems between models from different resolution levels could be handled by pseudo A/D method, most of them still occurs during simulation involving deeper model connection as model interaction or interoperation, which calls for multi-resolution entity method. Certain interface and module definition in multi-resolution entity method could help to deal with model concurrent interaction problem.

Sometimes in train control system simulation, control operation and running process of a certain train on a certain rail section are interested, as shown in Fig.6.

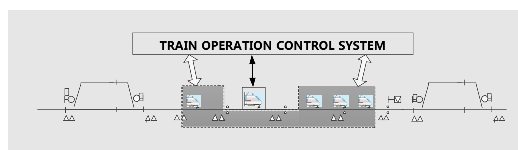


Figure 6. Simulation Program to Focus on Operation of Certain Train

In simulation program shown in Fig.6, operation details of one specific train should be performed by simulation. And to make this operation more real, there should be other trains involved in this simulation. Other trains' status, like position and speed, could affect the control strategy of this specific train. But the operation and control processes of the other train are not interested. For simulation cost saving, multi train model could be used to perform all the other trains.

By taking this into consideration, there would be models from two resolution levels. Some of them would be train model, ground subsystem structure model and information flow model from higher resolution level to describe operation and control process of the certain train, while the others would be multi train model and ground subsystem model from lower resolution level for those of other trains. Operations of each trains are kind of independent of each other no matter which resolution level the model from, while generation processes of control strategies and information from ground subsystem models are related to each other. So the ground subsystem models from different resolution level needs to be considered by adopting some module definitions from multi-resolution entity method. The multi-resolution model concurrent interaction framework of train control system is shown in Fig.7.

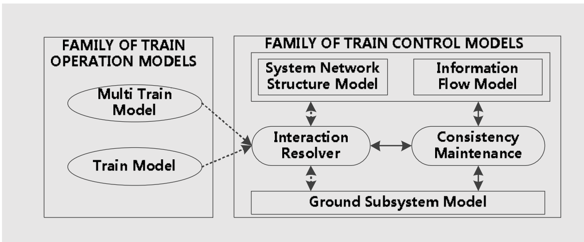


Figure 7. Concurrent Interaction Simulation Framework for Multi-Resolution Train Control System Models

This simulation framework also could be useful when the models from any two or even more resolution levels need to interaction. Interaction resolver could map the information to the right resolution level. The consistency of model family could be adjusted properly by using the consistency maintenance module.

## IV. System Realization

After multi-resolution model of train control system has been completed, the simulation is ready to begin. RTI tools as a communication interface manager could support the separation between simulation function and basic communication, shown in Fig.8.

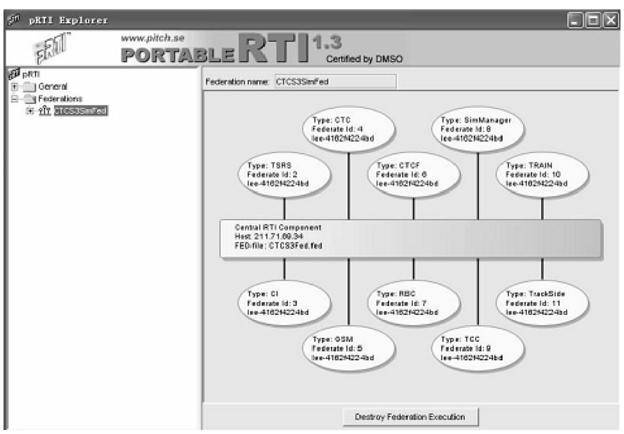


Figure 8. RTI Interface

As it was mentioned before, simulation manager played as an important role during the simulation. The simulation manger is shown in Fig.9.

Figure 9. Simulation Manager Interface

After the prepare work for simulation, the simulation process begins. The multi-resolution simulation view is also shown by simulation manager. In simulation process for this paper, there are trains' operations in a certain section, which perform as lower resolution models, shown in Fig.10. And after one certain train was selected, the view would change into the operation interface of that train and connection between train and other equipment, performing as models from higher resolution level, shown in Fig.11.

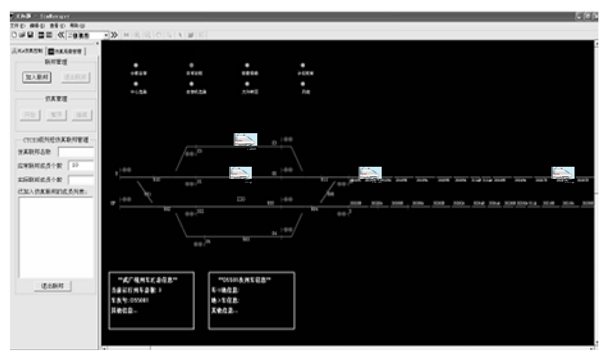

Figure 10. Trains' Operation in Certain Section

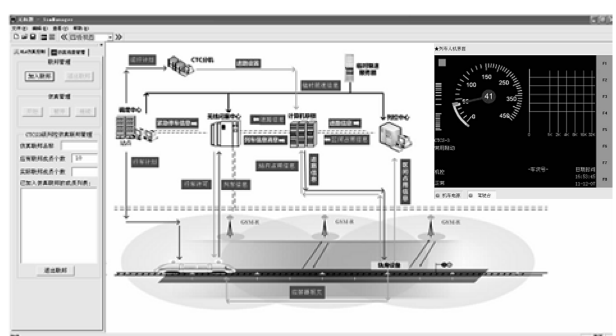

Figure 11. Operation Interface of Selected Train and Equipment Connection in Realtime

This was just an example. There were more options for model resolution change, like to view one or several trains in higher resolution level, or to view the train flow situation on a whole rail net, or to monitor performance of one selected equipment. And also, based on HLA structure, great extensibility of this simulation system could make it easy to change or add lines, which only needs to change or expand the line database, and also easy to update or change equipment according to system specification. With functions like those, multi-resolution simulation modeling demonstrated great advantage.

## V. Conclusion

Realization of simulation system shows feasibility and efficiency of multi-resolution modeling for train control system. With models from various resolution levels of train control system, we could study the system from various aspects together, as energy saving, system safety evaluation, equipment testing, train schedule optimization and so on, which are interrelated. By taking the idea of multi-resolution during whole process, as system analysis, system modeling, system simulation and also system evaluation, established simulation system would have great credibility and consistency with real system to provide services for full life cycle of train control system.

## Acknowledgment

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