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MobileOnRealEnvironment-GIS: a federated mobile network simulator of mobile nodes on real geographic data

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***Abstract*—In this paper we introduce MORE-GIS, a simulator for the simulation of mobile nodes connected to wired and wireless network for the study of Critical Infrastructures interdependencies. MORE-GIS is based on agent based simulation approach and HLA architecture. Every node is an agent that represents a person. Agents are connected to Internet generating a certain amount of traffic and can move to a new geographic position. Movements are simulated using GIS data of roads and junctions. Every person selects the path using the Dijkstra's algorithm. Actually we use Repast Symphony framework for the agent based simulation and the Mobility Framework of OMNeT++ for the simulation of the wireless and wired communication network. They are synchronized and exchange information using the HLA architecture.**

***Keywords*-critical infrastructure; distributed simulation; agent based simulation; mobility network simulation; GIS**

I. Introduction

Due to complexity of Critical Infrastructure, simulation plays a fundamental role in the study of interdependency as well as infrastructures and individuals protection. Much more infrastructures use communication network to exchange services and information each other. More and more people are constantly connected together thanks to wireless network and new portable devices like Smartphones, PDAs and Netbooks, generating an increasing traffic on the telecommunication network. Even though the design of telecommunication has been built on some invariants like traffic characteristic, call arrival processes, session durations and so on [4] , there are many unpredictable area that are really hard to model and becomes much harder to define in case of a natural disaster, a terroristic attack or during any dangerous situation.

We therefore present MORE-GIS, a federated simulator that consents to simulate a big population of individuals that travels inside a limited realistic geographic area (like a simple neighborhood as well as a city). MORE-GIS is a branch of a general project that has the goal to build a framework to study critical infrastructure interdependencies. In particular, MORE-GIS is the branch for the simulation of wireless and wired communication network. Humans are simulated using the agent based simulation approach. Individuals choose a destination according to their next activity to perform (like going to do shopping in a particular store) and at the same time can communicate each other. The physical simulation of sending/receiving messages or calls is simulated in OMNeT++. Every time a person wants to communicate to someone, he calls the "send" method of the CommunicationNetworkAgent that successively will contact the OMNeT++ simulator using the HLA-RTI interface to calculate delivery time of a packet. HLA-RTI will be responsible to synchronize the time of both simulators in addition to the status of every shared object. The paper is organized as in the following. The model of MORE-GIS is introduced in section 2 . Section 3 describes the architecture of the software. Finally conclusions and remarks are in section 4 .

II. Critical Infrastructure model

The goal of critical infrastructure model is to study their interdependency so that we can prevent both direct and cascade effects. Taking account of the proposed categorization of Dudenhoeffer, Permann and Boring (2006), dependencies can be classified in terms of:

- *Physical*: describes direct relation between infrastructure in terms of supply/consumption/production;
- *Geospatial*: relation between an infrastructure and its geographical position;
- *Policy*: connections between infrastructure component and super-visor decisions;
- *Informational*: dependencies of an infrastructure on information flows between each others.

As illustrated in figure 2, MORE-GIS framework is the composition of *FedABM&S model* with a geography and individuals model to offer a layer for the study of information interdependencies. We will provide more details of every model below.

A. FedABM&S Model

The FedABM&S model [3] is based on concepts derived from agent based simulation model and from federated simulation. An agent is an entity with a location, a behavior,a memory and can interact with other entities. So this concept can be easily exported to the representation of critical infrastructure since they can be seen as a blackbox that performs

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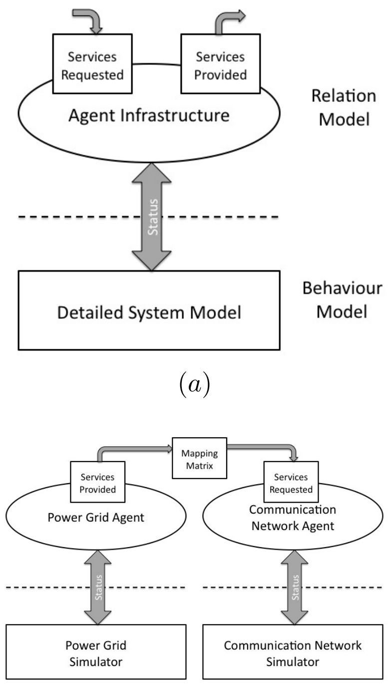
some services. Services are offered to other infrastructures. Every service has an own behavior and the behavior is influenced by the current state. Every infrastructure-agent hides the physical layer to other agents. Considering the communication network agent, it offers services to send and receive messages or calls from other agents. Provided services can be used by other infrastructure as well as simulated individuals (figure 1 b).

The physical layer is simulated by a specific sector model (figure 1 a), so , for example, the delivery time of a message is performed by a specific network simulator. The agent-



(a)

(b)

Figure 1. The federated agent based model (a) and (b) the federated agent model of a complex interdependent system composed of the power grid (left) and the communication network (right)

infrastructure and the sector simulator are connected together using the architecture described by *High Level Architecture*. HLA has the goal to support the interoperability and reuse of simulations. A distributed simulation is called a *federation* while every simulator is referred to as *federate*. HLA includes a non–runtime and a runtime component. The non–runtime specifies objects used by the federation. Objects are any entity with an identity, attributes that are accessible by other objects and associations with other objects. The runtime is called RTI. It provides services for allowing federates to interact with each other plus a means to control and manage the execution.

B. Geography and policy dependency model

Geography dependency is simulated using GIS data. As explained previously, GIS data allows mapping an object to real geospatial coordinates. So, in case we have a catastrophic event in a specific zone, we can evaluate if such object is partially or completely destroyed.

In particular we consider four elements that are earth, water, wind and fire. Every element is associated to an event type: earthquake, flood, storm and conflagration. Every event is associated to a particular characteristic that describes the event. So we have the Richter scale, high of water, speed of wind and temperature. Every characteristic itself is associated to a function that takes a geographical position and a time and returns the current value of such characteristic.

Similarly, policy dependency is modeled as a function that takes a zone and a level of emergency for the zone. The function is associated to every infrastructure. A zone is a delimited polygon geographic area. Every time there is an anomalous event, we set a level of emergency for every affected zone. Using a fuzzy logic model, the function evaluates if an infrastructure must be completely or partially closed/switched off. For example in case of an earthquake, the policy function could close all the roads that go inside the hit zones, while it allows traffic to go outside from such zones.

C. Individuals model

In the study of critical infrastructure is necessary to consider that they are used by individual as well as business people. So aside the demand that is from every single infrastructure, the principal request of service is from humans. Every individual is modeled as an agent with an own behavior, memory and a geographic position. Basic behavior is to select activities to perform during the day, select the location for every activity and move to the new location. Memory evolves with the experience for the selection of the best path as well as updating the list of locations where it is possible to perform an activity.

The current model offers two kinds of individuals: general and technician. Both of them have an energy value to evaluate if they are alive, injured or dead. The general agent moves to a new destination in compliance with the next activity. Every person has a list of destinations in relation to each activity types. Selection of a destination can be random or based on other different models like simple distance model or attraction model (it depends on distance as well as attraction for a particular place). The selection of an activity type is based on preset model, but we are moving on dynamic models (partially already implemented at LANL [1]) that take into consideration current position, needs, utility, personality types . Instead, technicians are specific agents that have a limited set of actions to select. They are used to repair a damage of an infrastructure component or, like in the case of rescuers, to help/safe other people. For the technicians, we have used a fuzzy logic model to select next activity. For example, the rescuer has only four states: 1) stay in waiting for a call; 2) move to an injured person;

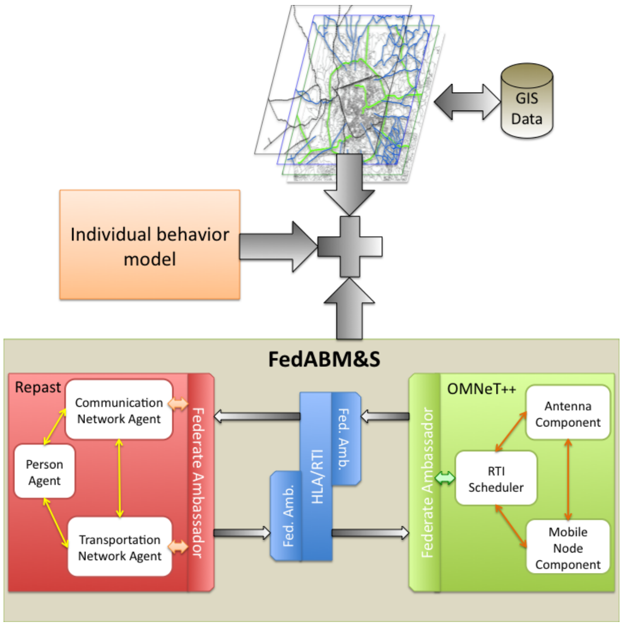


Figure 2. MORE-GIS Model

3) back to the base; 4) take a rest. In addition to energy value, the technician has a stress value that decreases with number of actions performed every time to safe a person.

D. Scenario Model

The scenario model permits to set static data and events that occurs in a predefined simulation time. In our model we consider roads (highways and streets), buildings (at the moment we are using 2D data), railways, antennas and wired link for the communication network. Population as well as their starting position can be generated randomly or using statistical data. Static events are failures of a component or a natural event that occurs at time t in the position (x,y).

III. MORE-GIS ARCHITECTURE

MORE-GIS architecture is composed of a GIS database, the HLA-Repast Symphony simulator with the agents for communication and transportation infrastructure plus population agents, an HLA-RTI implementation called poRTIco for the synchronization and sharing objects and, lastly, the HLA-OMNeT++ simulator with the Mobility Framework for the simulation of mobile nodes and wireless networks. Static data of the scenario are read by Repast to build and initialize the simulation. More details will be provided below.

A. GIS database

In our architecture Repast interacts with map files in shape format; a shape file is a popular geospatial vector data format for GIS software. We use such type of files to represent different kinds of geographical data:

- *points*: to represent the population and wireless antennas;
- *polylines*: to represent roads, highways and railways;
- *polygons*: to represent buildings and administrative areas.

These files can contain other information besides geospatial one; we can see a set of shape files as a database with a geographic reference; every file can be assumed as a database table.

Each line/point/polygon appearing in the shape file corresponds to a database table's row, each row holds some attributes. Attributes represent georefenced information handled by the GIS software.

B. HLA and poRTIco overview

poRTIco is an open-source Java implementation of IEEE-1516 HLA and it offers libraries to implement the own federate ambassador, that is the simulator interface for the RTI. Not all services defined in IEEE-1516 standard are implemented and, currently, only the Java language is supported. Every federate communicates to the RTI through the RTI ambassador. Every time the federate schedule wants to advance in the time, it calls the methods `timeAdvanceRequest` of the RTI ambassador. Request of a service from/to federate to/from any other federate is done through interactions. An interaction is the basic way to exchange messages between federates. The other way is done though the publication of objects that are shared between federates. Every federate can register to an object. Every time the object changes status, the federate is advised.

C. HLA-Repast Symphony

HLA-Repast Symphony is modified version of Repast Symphony with the support of HLA that allows communicating with other sector simulator like OMNeT++.

Repast S is one of many tools to develop proto-agents. A proto-agent is a simple entity without learning behaviors. Every proto-agent lives in a context in which they can interact. A *Context* is a Repast S data structure that provides the basic structure to define a population and interactions inside such population. Anyhow the context does not offer any implementation to support relational model between agents. The Context allows defining an hierarchy of contexts that allows to represent the hierarchy between agents. Vice versa, *Projection* is the structure that defines relations between the population and the context where they live. Examples of projections are network model or grid model. Lastly, Repast S implements the concept of *Context-Sensitive behavior* that allows the model designer to declare in which circumstances a certain behavior has to be executed. This concept can be modeled in Repast S using watchers or triggers for proto-agents. Repast S supports the Terracotta technology for the parallel simulation that permits considerably to increase the performance in case of the simulation of huge population.

HLA-Repast S is a software totally written in Java that uses Repast S to build the environment where every agent lives and uses poRTIco libraries to implement the own federate ambassador to provide the communication with the RTI. The class for the initialization and the building of simulation is the `MoreContextCreator`. It derives from the `ContextBuilder` class of Repast S that is the interface to create an own context.

For the infrastructures and humans we have created separated context on which they lives. In general we have defined follow contexts:

- *Environment context*: environment where every agent lives. It is the lower layer and owns the only environment maps. Environment model, like earthquake or fire model, should use such layer.
- *Infrastructure context*: layer for every infrastructure. It can be subsequently divided for every single infrastructure. It owns data about roads, line power, communication network lines, wireless antenna, etc..
- *Human context*: layer for the representation of individuals that can use services offered by every infrastructure.

As we have described previously, the context is not enough to define relationships inside the space where agents live, so we have to define a projection. In Repast S we have the `Geography` projection class to locate objects in a geographic gis-type space. For every context instantiated, we have to define a Geography projection. The Geography projection will read the correct shape file associated to the agents that are on such context.

Besides creating contexts and agents, the MoreContextCreator class initializes the RTI federate ambassador as well as the Repast federate ambassador. The objects that are published by HLA-Repast S are individuals with their status and geographic positions respect to their spatial reference. It is left up to every federate to transform geographic positions in their appropriate coordinates (in case they need). Lastly, for every specific domain simulator, it publishes the interactions. In the case of OMNeT++, it publishes interactions to: i) request simulation of a message; ii) send a failure; iii) recovery of a failure; iv) set a basic traffic inside the network.

D. *HLA-MobNeT++ architecture*

HLA-MobNeT++ architecture, which we are going to present, is an upgrade of the already present HLA-OMNeT++ [2] which allows to use existing OMNeT++ network simulation model with poRTIco. HLA-OMNeT++ publishes interactions to send and receive messages between network nodes plus to modify nodes properties and the network topologies. The new version has the goal to enable the simulation of mobile nodes and to map it to GIS data as well. We have decided to use the Mobility Framework (MF) of OMNeT++. MF is an extension of OMNeT++ for the simulation of wireless network of static and mobile nodes. It was developed with the idea that it can easily extend with own network layer and mobility model. MF has four principal modules:

- *CahnnelControl Module*: controls all potential connection between hosts;
- *Blackboard Module*: keeps data about energy status, display appearance, hosts status that can be accessed by any other module in the simulation.
- *Mobility Module*: provides a geographical position of the host and handles its movement. Movement can be only inside a fixed geographic area defined before starting a simulation. It can be extended with own mobility module (circle movement, linear movement, rectangle movement and so on);

Every host derives from the Basic Module and itself is derived from cSimpleModule of OMNeT++ plus the BlackBoardAccess. The BlackBoardAcces provides methods to subscribe and publish on the blackboard.

We have reused the same architecture of HLA-OMNeT++ and principally we have kept the already implemented events scheduler (rtiScheduler). At the same time in HLA-MobNeT++ we have a new class derived from Mobility class of MF that permits:

1) to map a GIS position in the OMNeT++'s geographic representation.
2) to move a node in a new position according to the information get from Repast.

IV. Concluding remarks

Simulation of Critical Infrastructure and their interdependencies is still a big challenge due to complex structures and different kinds of dependencies that are involved. This paper has introduced an architecture that uses both FedABM&S approach as well as GIS data to take into consideration physical and geographical interdependency in addition to the traffic generated by a big population to study principally the informational dependencies. The implementation of such architecture and model is an ongoing.Scalability and validating testing will be next steps before releasing the software.

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