Modeling Cellular Network Planning Using Discrete Event System Specification

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***Abstract*— This paper presents an effort to integrate a Cell-DEVS model with agent model using dynamic structure DEVS for planning and redeployment of the cellular network that uses the concept of neighboring cells to build networks with variable topology. The design of this cellular network is a complex problem which turns around a big impact: The quality of the service, the cost of the network and the development time which is a very important criterion. With the continuous and rapid growth of communications traffic, the planning of the cellular network becomes more and more difficult. For such reasons we propose an approach that integrates models defined in other formalisms into a multi-model including components that can be defined as cell spaces by using DEVS, Cell-DEVS and DS-DEVS and we show how these techniques can be used to model cellular mobile networks, improving the performances of the network and allowing to reduce the development time.**

***Keywords*— Cellular networks, DEVS, Cell-DEVS, DS-DEVS, multi-model**

I. INTRODUCTION

Cellular communications has experienced explosive growth in the past two decades. Today millions of people around the world use cellular phones. Cellular phones allow a person to make or receive a call from almost anywhere. Likewise, a person is allowed to continue the phone conversation while on the move. Cellular communications is supported by an infrastructure called a cellular network [1]. The planning of cellular mobile networks faces three major challenges: First, due to the tremendous increase in the number of users, the networks operators have to redesign optimize their systems in order to be able to handle the higher traffic [2]. Second, deploying a complete new network or installing additional hardware in an operating system is highly risky. There are significant costs associated with setting up a new facility; therefore an efficient network design has to minimize the hardware cost. And third, the telecommunication regulators are forcing new network operators to set up their cellular system in a very short time.

In previous works, we have proposed an approach based on spatial ontology and multi-agent systems to planning and redeployment of the cellular network. The contribution reflects an in-depth study of the geographical space, to achieve a cellular network that will meet the needs of coverage and quality, this process aims to develop an optimal cellular network adapted to any geographical area and ensure an automatic redevelopment which reacts to failures and uncertainties, capable of dealing with problems whose data are only partially known, and for which the information arrives over time[3], but simulating the behavior of all units forming multi-agent systems is extremely gourmand in computer resource and hence in time, to solve this problem we used new techniques that conserve the optimization of cost, coverage and quality and that will reduce the time development, these techniques are DEVS (Discrete EVent System specification), Cell-DEVS (Cellular DEVS) and DS-DEVS (Dynamic Structure DEVS).

One of these techniques that gained a lot of attention in recent years is called DEVS (Discrete Event Systems Specifications) [4] which establishes a Framework for modeling and simulation of discrete event systems. DEVS relies on dividing the system under study into atomic models; each of which can exist in specific state at any point of time and has input/output ports to interact with other models and with the external world. This allows for building very complex models by connecting different atomic models in a hierarchical manner. Different extensions were introduced to extend DEVS capabilities. In our work we use two extensions: The first one called Cell-DEVS [5], allows executing cellular models with different time delays associated with each cell and it improves their definition by making the timing specification more expressive, as we have said before that the approach proposed in previous works optimizes the performances of the network during its evolution and to reduce the costs of its reorganization, but simulation time is rather long to simulate the behavior of all units constituting the multi-agent system Thus, we decided to use the Cell-DEVS approach to gain important simulation time and have to make easy the definition of the model. The second called DS-DEVS [6], a formalism to represent discrete event systems that can change their structures dynamically, during the simulation coupling between agents and cellular network (which is modeled here by a Cell-DEVS model) can be added or removed when the interaction between them is started or finished and new agents can be created or destroyed to/from the global model.

The rest of this paper is organized as follow; the second section represents a state of art study, the third is a technical background about fundamental concepts of cellular networks and an overview of DEVS, Cell-DEVS and DS-DEVS formalisms is provided. In section three, we present a general architecture of the proposed approach which is composed of three submodels each one of them is modeled by a different technique. Conclusion and perspectives are given in the last section.

II. STATE OF ART :

In this section we represent a state of art in the field of designing cellular networks. Different techniques have been proposed for planning of the cellular networks.

An approach based on spatial ontology and multi-agent systems is proposed for planning and redeployment of the cellular network. This approach is composed of two phases: The first is " The initial planning of the cellular network" which involves the study of geographical space in order to obtain an initial cell planning, the process simulation of the cellular network is composed of initial phases, each has a key role in fulfilling the ultimate goal, and uses a model of description and spatial ontology to reach an initial cellular network [3]. The second is "Deployment process ", which allows the exploitation of the resource BTS in reliable and intelligent way, ensuring an automatic rearrangement of the cellular network, where each cell reaches the overload is requesting assistance from other neighboring BTS with no load and to be seen as candidate cells [3], the objective of this process is to provide from the beginning an expansion plan of cellular network extending over several periods, according to perceived changes. The system receive as input an initial configuration of the network and developing an optimized network. Maintain a collection of solutions (Historic) allow better and faster adaptation of the network to changes recorded during the next phases[12]. The general architecture of the optimization system is composed of different types of agents, each agent is responsible of solving a problem or performing a particular task :

- *Cell Agent:* a 'reactive agent', it is responsible for monitoring the status of the cell that is responsible. Each cell can be "requested" or "Candidate", and has a degree of participation in the event that it is "candidate".
- *Evaluator Agent:* It is responsible for calculations of parameters needed in terms of: Azimuth, tilt and power drivers, depending on the location of the area.
- *Historic Agent:* a 'cognitive agent', who preserves the solutions of the problems encountered in screen, to provide means for rapid response and less communication.
- *Ontology Agent:* Able to capture and manage geographic information, which focuses on the design specification for a spatial representation of the geographical region of the cellular network (line, point, and polygon).
- *Supervisor Agent:* a 'deliberative agent', the role of this agent is to identify on each time what are the cells of type: "requested" and "Candidate". After working with the ontology agent, Supervisor Agent will decide what is the neighboring cell (closest to the location of the subscriber) to cover the area of overload. Then he delegated to the Evaluator Agent the task of calculating the necessary parameters (azimuth, tilt, power drivers), they will be sent back to the Supervisor Agent to ensure customization away from the BTS (setting antennas) of the cell concerned, and asked the Historic agent to save the configuration of the network (solution) according to the recorded environment(problem) for a similar future condition.[3]

This process is periodically launched during the points of decision, for objective the preparation of the system for the adaptation to the changes of the current period, while trying to take into account later periods, by predicting the zones where the increase of capacities is required and by realizing the necessary intelligent changes: (example: period of the holidays or the fairs, to strengthen BTS "basic station receiving the calls going and outgoing ", of concerned zones). Because often, these changes lead an additional cost (new installations, hand of work), what prevents the system from adapting itself to the environment. Therefore, the integration of intelligent systems is important, to conceive methods auto mobile adaptive which can react to the shape of the problem and which will allow to resolve the problem in its entirety [11], the idea is to make the *Cell agent* as an intelligent agent, so *Cell Agent* takes the initiative to choose the optimal cell among six nearby cells then calculate the necessary parameters and sends these parameters to Supervisor Agent. At the end, it stores the history of the previous solutions, according to the arisen events. For more details see [11].

III. TECHNICAL BACKGROUND :

In this section we present a technical background about some fundamental concepts of cellular network, DEVS & Cell-DEVS formalisms, DS-DEVS formalism and agents in dynamic structure formalization.

A. *Cellular concept :*

The cellular concept [7] was a major breakthrough in solving the problem of spectral congestion and user capacity. It offered high capacity with a limited spectrum allocation without any major technological changes. In cellular network a service coverage area is divided into smaller areas of hexagonal shape, called cells, each of which is served by a base station (BS) and uses a specific band frequency different from those used by all the adjacent cells. The base station is fixed, every (BS) is located at a strategically selected place and covers a given area, and it is able to communicate with mobile station (MS) such as cellular phone using its radio transceiver. A number of adjacent cells grouped together from an area and the corresponding (BS) communicate through a so called Mobile Switching Center (MSC). The MSC is the heart of a cellular radio system. It is responsible for routing or switching calls from the originator to the destinator. It can be thought of managing the cell, being responsible for set-up, routing control and termination of the call, for management of inter-MSC hand over and supplementary services, and for collecting charging and accounting information. The MSC may be connected to other (MSCs) on the same network or to the Public Switched Telephone Network (PSTN) [8]. Figure 1 illustrates a typical cellular network, in which a cell is represented by a hexagon and a (BS) is represented by a triangle.

Dividing the network into cells have several advantages: The use of the same frequencies in multiples cells i.e., channels used in one cell can be reused in another cell with some distance away, variable power level allow cells to be sized according to the subscriber density and demand within a particular region, conversation can be handed off from cell to cell to maintain constant phone service as the user moves between cells and cells can be add to accommodate growth, creating new cells in unserved areas or overlaying cells in existing areas (Small cells in areas with high traffic density and large cells for remote areas).

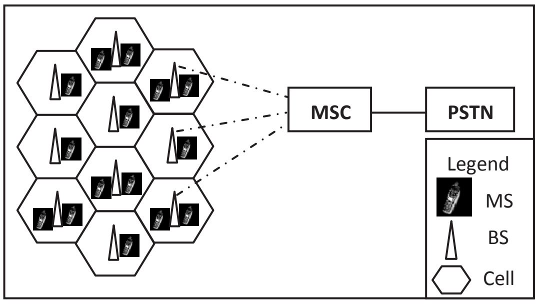

Fig .1 A typical cellular network

B. *DEVS and Cell-DEVS formalisms :*

The DEVS formalism [4] provides a framework for the construction of hierarchical modular models, allowing for model reuse, enhancing reliability, and reducing testing times. A DEVS model can be described as composed of several submodels, each being behavioral (atomic) or structural (coupled), hence multiple DEVS models can be integrated together to form hierarchical structural models. A DEVS atomic model is specified as:

$$\mathbf{< X, S, Y, \delta int, \delta ext, \lambda, ta >}$$

We can summarize the functioning of an atomic model as follows: Each atomic model has an interface consisting of input (X) and output (Y) ports to communicate with other models. External input events in **X** (events received from other models) are collected through the input ports. When the event arrives, the model executes the external transition function **(δext)** to produce a state change. Each state has an associated lifetime **(ta)**. When this time is consumed the internal transition function **(δint)** is activated to produce internal state changes. The internal state **(S)** can be used to provide model outputs **(Y)**, which are sent through the output ports. They are sent by the output function **(λ)**, which executes before the internal transition. Figure 2 illustrates the functioning of an atomic model.

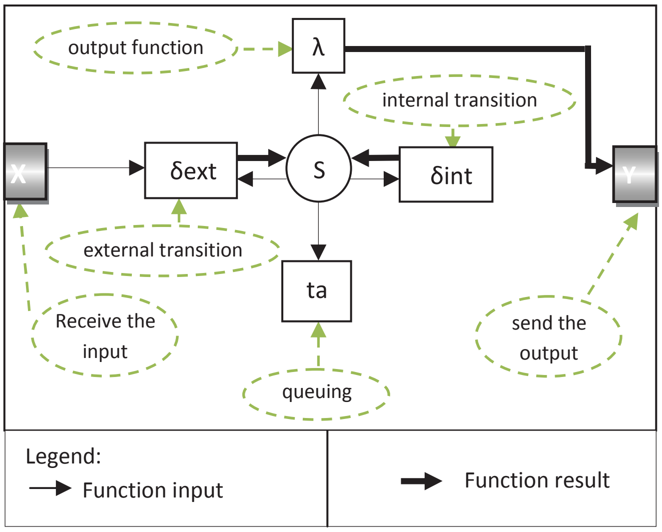

Fig.2 Functioning of atomic DEVS model

A DEVS coupled model is composed of several atomic or coupled sub-models, as shown in Figure 3.

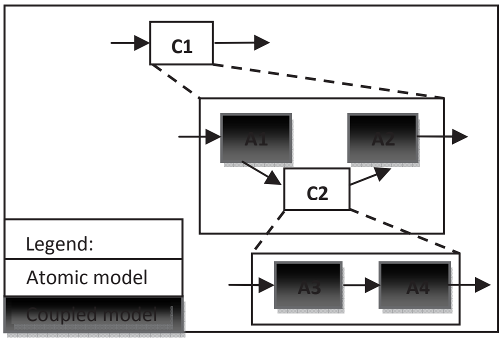

Fig.3 Description of coupled model

This coupled model tells how to connect several component models together to form a new model. This latter model can itself be employed as a component in a larger coupled model, thus given rise to hierarchical construction.

Cell-DEVS [5] was defined as a combination of DEVS and cellular automata with timing delays. This approach allows describing cell spaces as discrete events models, where each cell is seen as a DEVS atomic model that can be integrated to a coupled model representing the cell space. Cell-DEVS atomic models can be specified as:

$$\mathbf{TDC} = < X, Y, S, N, \mathit{delay}, d, \tau, \delta\mathbf{int}, \delta\mathbf{ext}, \lambda, D >$$

Where, **X** defines external input events and **Y** external output events. **S** is the set of states for the cell, and **N** is a set of input events. **Delay** defines the kind of delay for the cell, and **d** its duration. Finally, there are several functions: ***δ*int** for internal transitions, ***δ*ext** for external transitions, ***τ*** for local computations, **λ** for outputs and **D** for the state's duration function. Each cell uses N inputs (from the neighborhood cells) to compute its next state. Each input is received through the model's interface, and is used to activate the local function. A delay can be associated with each cell and the state **(s)** changes can be transmitted to other models, but only after the consumption of this delay**.** Two kinds of delays can be defined: transport delays which have anticipatory semantics (every output event is transmitted after a delay) and inertial delays, which have preemptive semantics (scheduled events can be discarded if the computed value is different than the future state).

When the behavior of a single cell is defined, they can be combined into a coupled model composed of an array of atomic cells with given size and dimensions. A Cell-DEVS coupled model is illustrated in Figure 4. Each cell is connected to its neighborhood through standard DEVS input/output ports; this model's coupling permit connecting these models with other external submodels (can be defined in other formalisms).

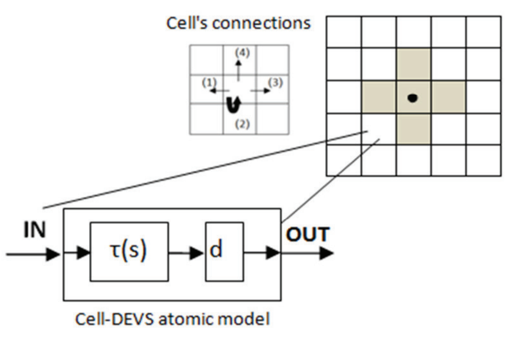

Fig.4 Cell-DEVS coupled model

CD++ [9] is a modeling tool that implements the DEVS and Cell-DEVS formalism. DEVS atomic models can be written using C++ and DEVS Coupled models can be defined using a built-in specification language that follow DEVS formal specification for coupled models. Cell-DEVS models are also defined using a specialized language, the model specification include the size, dimension of the cell space, the shape of the neighborhood and the borders. The cell's local computing function is defined using a set of rules with a specific syntax.

C. DS-DEVS formalism and agents in dynamic structure formalization :

The Dynamic Structure Discrete Event System Specification formalism (DS-DEVS) [6] is a formalism to specify systems that can change their structure dynamically. A change of structure refers to adding or removing components, or modifying component links. There are two types of model in (DS-DEVS), basic models and network models, the first one is a (DEVS) model and the second is a combination of (DS-DEVS) basic models. The network structure can be change when the “executive” performs an internal or external transition since all structural information is kept in the network executive state, any such change will be accompanied by executive transition.

Recently, Duboz and al [10] proposed a formalization of multi agent system (MAS) using (DS-DEVS) through this approach, relation between agents and the environment are changed dynamically (coupling between them can be added or removed) and messages are exchanged between them using discrete event.

IV. GENERAL PRESENTATION OF THE ARCHITECTURE :

Figure 5 shows an architecture of our model that integrates Cell-DEVS DEVS, and DS-DEVS models for modeling cellular network planning. This architecture is composed from three models: Cellular network model, agent model and coupling executive model, each one of them is defined in different modeling techniques that are mentioned previously.

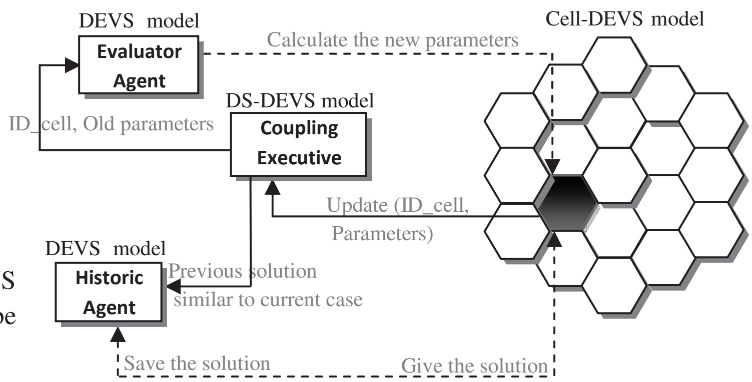

Fig.5 General architecture of deployment process

A. Cellular network model:

The Cell-DEVS model is used here to model the cellular network, this model uses two planes, one for the initial planning and the second for the optimization process of cellular network. The first plane contains information about the geographical area(e.g., number of population, surface of areas...) and the rules to be applied to get an initial planning of the network (We focus our work on the second plane, the optimization process of cellular network and let the first plane for future research). Before talking about the rules applied for the optimization process, we explain this process which permits the exploitation of BS in a reliable and intelligent way to allow an automatic redevelopment of the network [3]. When the volume of traffic in a cell exceeds the capacity of a BS, so this cell is seen as *"requesting"* and ask help from other neighboring without charge which will be seen as *"candidate"*. Instead of installing a new BS or adding TRX cards to cover the overloaded area, the candidate cell will be extended to reduce the charge of requesting cells (as shown in figure 6)

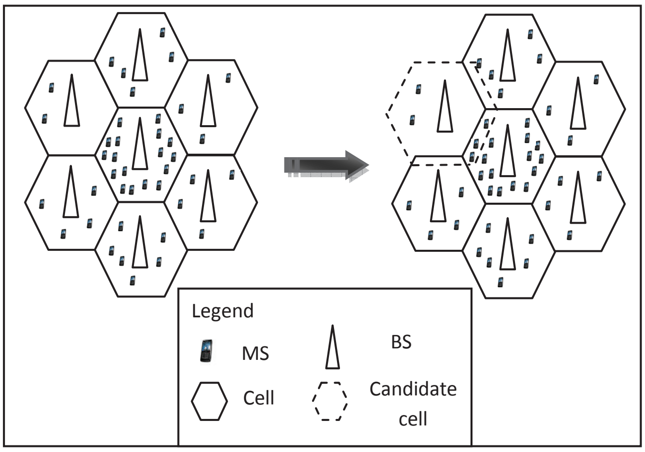

Fig6.Optimization process of cellular network

Each cell has a degree of surcharge and the *candidate* cell has another degree which is of participation. Cells with a relative load approaching 90% see themselves as *requesting* cells and need help from the *candidate* that has the highest degree of participation. The cellular network is representing as a Cell-DEVS coupled model using value **"0"** to represent *requesting* cell, value **"1"** to define the *candidate* one and value **"2"** to *covering* cell. This cellular network is solved using the following rules for updating the cell's states : The first define the case when the cell its neighbors are in surcharge (value 0) in this case, the cell must remain *requesting*, the second is used when the cell is requesting and two or more neighbors without charge (value 1) in this case the cell becomes *candidate*, after being supported by the neighbor cell which has the maximum degree of participation and the third rule is specific to frequency allocation where each cell is assigned a certain number of channels that must be different from those assigned to its neighboring cells in order to avoid radio interference between them. This model can be formally defined using Cell-DEVS specification as follows:

CN = < $X, Y, S, N, d, \tau, \delta$int, δext, λ, D >, X=∅, Y=∅,
S= **requesting**, **candidate**, and **covering**
$N = \{(-1, 1), (-1, 0), (-1, 1), (0, -1), (0, 0),$
$(0, 1)(1, -1), (1, 0), (1, 1)\}$, d=100ms
$\boldsymbol{\tau}$: N → S, is defined by the rule just described, and δint, δext, λ, D are defined according to the definition of Cell-DEVS atomic models. This specification can be implemented in CD++ as shown in figure 7.

```
[CellularNetwork]
type : cell
dim : (15, 45)
delay : transport
defaultdelayTime = 100
border : wrapped
neighbors : (-1, -1) (-1, 0) (-1, 1) (0, -1) (0, 0) (0, 1)
            (1, -1) (1, 0) (1, 1)
localtransition : Cellular-rule

[Cellular-rule]
rule :  0   100  {  [ 0 ] = 0 and [ 1 ] = 0 and [ 2 ] = 0
            and [ 3 ] =0 and [ 4 ] = 0 and [ 5 ] = 0
            and [ 6 ]  = 0 }
rule :  1   100  { [ 0 ] = 0 and truecount ≥ 2 }
rule :  0   100  { t }

[Frequence-rule]
rule :  2   100  {  [ 0 ] = 2 and [ 1 ] != 2 and [ 2 ] != 2
            and [ 3 ] != 2 and [ 4 ] != 2 and [ 5 ] != 2
            and [ 6 ]  != 2 }
```

Fig. 7 Cell-DEVS specification of the cellular network model using CD++

The model in the figure is defined by its size (15 * 45 cells), its border (wrapped, meaning that the cell in one border communicate its results to neighbors in the opposite border), the shape of neighborhood (hexagonal), and the type of delay (transport, meaning that every output event is transmitted after a certain delay). The rules defined by [Cellular-rule] represent the behavior of each cell in the model. In this case, a *requesting* cell ([0] = 0) remain requesting when all its neighbors is overloaded. If the cell is *requesting* and two or more neighbors without overload, the cell becomes *candidate* (truecount indicates the number of candidate neighbors) using a transport delay of 100ms, *" t "* indicates that whenever the rule is evaluated, a true value is returned.

B. Agent Model:

According to the architecture presented above (Figure 5), we have two agents; each one of them is responsible for performing a specific task. ***Evaluator Agent*** is responsible for calculation of the necessary parameters in term of : Azimuth (orientation of the main lobe of the antenna in horizontal plan), Tilt (angle of inclination of an antenna in vertical plan) and Power of pilots (indicate to the mobile the cell with which he has to be connected) and ***Historic Agent*** that saves the solutions of the encountered problems in previous cases, in order to provide the means that allow a quickly response and at lowest cost to similar problems which have been already occurred.

Evaluator agent and *Historic agent* are represented here as a DEVS model so we model both of them as a DEVS atomic model where the functionality of each of these models must be described using the formal specification for DEVS. For example, the ***Historic Agent*** model can be formally described as:

Historic = < X, S, Y, δint, δext, λ, ta >

Fig. 8 Input/output of Historic Agent model

The model presented in figure 9 uses three input ports and one output port. Solution identifiers are stored in the *Historic* as they are received through the input port '*inSol*' (an event that arrives in this port represents a new solution value, which has to be saved). When the *Historic* receive an input in the port ' *doneSol*', we know that the last solution sent has been processed, and hence it has to be erased from the *Historic*, if there are more solution to be transmitted, the first solution in the *Historic* is transmitted through the port ' *outSol*' (calling the output function **λ (s)**) and we schedule the internal event after *'preparationTime'* (invoke the internal transition function **δint (s)**). The input port '*stopSol*' serves to regulate the flow, if we receive a message on the input port '*stopSol*', we temporarily disable the *Historic* (i.e., if the *Historic* was in *active* state and the message value is not zero, Here the time remaining to process the next state change is calculated and then the *Historic* changes its state to *passive* by calling the passivate method). Only input received through the '*inSol*' ports will be stored, but no output will be sent until the *Historic* is enabled again by another message (i.e., if the *Historic* was in *passive* state and the message value is zero, then the *Historic* restarts, and the next state change is scheduled after the remaining processing time). The parameter *'preparationTime'* is used to model the delay of queuing and *'timeLeft'* is used to store the time remaining if the model is interrupted.

Historic = < X, S, Y, δint, δext, λ, ta >

```
X = {(inSol, N); (stopSol, N); (doneSol, N)};
S = { state ∈{active, passive}, preparationTime ∈ R,
 timeLeft ∈ R, historic ∈{solid ∈N}};
Y = {(outSol,N)};
δext (s, e, x) {
    if ( x.port == inSol ) {
      add (x.value, s.historic); }
    if( x.port == doneSol ) {
      delete_first (s.historic);
      if( !empty(s.historic) )
        state = active; ta(state) = preparationTime; }
    if(x.port == stopSol )
      if( state == active && x.value != 0) {
        timeLeft = preparationTime – e ;
        state = passive; ta(state) = infinity; }
      else
        if( state == passive && x.value == 0)
          state = active; ta(state) = timeLeft ; }
λ ( s ) {
sendOutput(time, outSol, first (historic)); }
δint ( s ) {  passivate(); }
```

Fig. 9 DEVS formal specification of Historic Agent model

C. The coupling executive model :

The *Coupling Executive* model manages the coupling changes (as shown in figure 5); this characteristic of dynamic coupling change can be modeled by DS-DEVS. The *Cell-DEVS* model make an initial planning for the cellular network and it is responsible for finding on every time the *candidate* cell which can help the *requesting* one to reduce its overload, First the *Coupling Executive* receives message that contain the cell's (ID-Cell, Degree of participation and Parameters which are azimuth, Tilt and power of pilots) from the *candidate* cell, then asks the *Historic Agent* if there is a previous solution similar to the current case : If *yes(this agent will be enabled)*, coupling between this agent and the concerned cell will be added and the network applies the solution*(this solution is transmitted through the port 'outSol')*. If *no(the agent is disabled by sending a message in the input port 'stopSol')* the *Coupling Executive* send the ID and the old parameters of the cell to the *Evaluator Agent* who calculates the new parameters and a coupling between this agent and the cell will be added to receive the solution and this cell will help the *requesting* one, Finally a coupling between this cell and the *Historic Agent* will be added to save the new solution *(which is received through the port 'inSol')* according to the problem for a similar future condition.

Remark : The coupling that are added will be removed when the interaction finishes, these couplings that are dynamically added/removed are presented in dashes lines in FIGURE 5.

V. CONCLUSION

In this paper we presented how to model cellular network planning by using different techniques (DEVS, Cell-DEVS and DS-DEVS). As compared to the approach proposed in previous work [3] that is based on spatial ontology and multi agent systems for planning and redevelopment of cellular network through effective cooperation of different agents, this approach can improve the cost and the quality of network but simulating the behavior of all units forming multi agent system is very greedy in computer resources and therefore in time, for such reasons we used techniques completely different that maintain the improvement of cost and quality and that reduce the development time (only the active cells perform their local computing function and the execution results are spread out after a predefined delay). A new architecture is presented and composed of three submodels each one of them is developed by a different technique and the integration between them could enable optimizing the performances of the network and reducing development time and cost of it reorganization.

As a future work, the model can be easily improved by adding new components, such as agents or connections. Calendar agent model aims to prevent changes that may occur during the evolution of cellular network, such as expanding the coverage area or introduction of new services or features, to achieve control of the new requirements.

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