Simulation of Mobile Networks using Discrete Event System Specification Theory

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Abstract

The fourth generation (4G) of mobile telecommunication technology provides ultra-band internet access for mobile devices such as smartphones, tablets, and laptops. One of the challenges in the Long Term Evolution (LTE) 4G networks is the low data rate for cell-edge users as well as coverage gaps. In this paper, we define and evaluate models for analysis of performance of mobile networks architectures defined by 3GPP. We used the Discrete-Event System Specification (DEVS) formalism to model the mobile networks and implement the framework. The proposed model implements the deployment layout of the Base Station (BS) cellular antennas, and it manages the distribution and movement of the User Equipment (UE) devices. The model calculates the Propagation for each BS, as well as the path-loss in the links between BSs and the UEs in the range. It also computes the power received by the BS and the UE in each link. These results will be used in the design of models for Coordinated Multipoint approach in delivering faster data.

1. INTRODUCTION

With the increasing availability of affordable mobile devices, today's mobile data traffic is facing a rapid growth, demanding for more efficient wireless technology and advanced communication techniques to address the required capacity. So far, the third-generation (3G) networks [1] could support the traffic growth, however, these networks are quickly reaching their capacity. The Long-Term Evolution-Advanced (LTE) [2] has become the most promising standard for the upcoming fourth-generation (4G) of mobile wireless communication systems. By incorporating high speed radio interfaces, the LTE technology provides a self-configuring, self-optimizing, and self-healing network allowing higher density network deployments yielding a significant increase in system capacity, while reducing the operational expenditure of mobile network operators. Moreover, 4G-LTE, as the next-generation mobile technology, provides much higher rates of data of 10 to 100's of Mbps to mobile users, highly improving the peak performance from the networks compared to current mobile networks.

LTE is a relatively new standard and is becoming increasingly popular. LTE is commonly referred to in the commercial communications world as 4G. The LTE standard aims at providing much faster speeds and improved reliability than what is currently available. An LTE network operates in a similar fashion to the commercial carriers' 3G cellular communications network. It is projected that approximately 90% of the estimated 5 billion cellular subscribers worldwide (who are using 3G technology) will switch to LTE [3].

With LTE, the network operators from the Radio Frequency side act in the same manner as with a regular cellular phone network: there is a main switch, a backhaul network connecting the cells, cell sites, and subscriber devices. On the other hand, from the network side it is an Internet Protocol (IP) solution with no more circuit switched "voice" channels (unlike Land Mobile Radio or the 2G and 3G cellular systems). The ultimate goal of the LTE technology is achieving 100 MB/s data transfer rates between a subscriber device and the user's target application [4]. As of today, the 4G LTE supports data rates of over 100 Mbps in a single 20 MHz carrier and up to 1 Gbps with carrier aggregation, while the 3G mobile rate is barely 3 MB/s. Besides the speed factors, since LTE technology includes a Self-Organizing Networks (SON) feature, it provides automatic coordination of capacity and coverage between macro, micro, pico, and in-building networks.

One of the challenges in providing high-speed data in mobile networks is the low data rate for cell-edge users as well as coverage gaps. Coordinated Multi-Point (CoMP) [1] is a distributed processing approach in solving these issues. CoMP transmission and reception techniques utilize multiple transmit and receive antennas from multiple antenna site locations, to send/receive data as well as reducing the signal interference to the User Equipment (UE). In general, CoMP approaches focus on distributed coordination of Base Station (BS) antennas in providing more effective service to the cell-edge UEs.

In this research, we modeled a mobile network based on the 3GPP LTE specifications of such networks, in order to build a basis for our ongoing research on CoMP processing in LTE networks. The preliminary results of the simulation are presented here which are in compliance with the 3GPP specifications [13].

2. RELATED WORK

While there has been a lot of effort in Modeling and Simulation (M&S) of mobile ad-hoc networks and mobile sensor networks in academia, there is also a number of researches on M&S of LTE mobile networks which are proprietary or available to public. Nevertheless there are a variety of LTE networks simulator tools that try to measure the performance of each layer based on different metrics and goals. Starting from physical layer (PHY), [5] and [6] propose limited simulator tools associated with this layer only, and the focus is on analyzing a single transmitter-receiver pair. System Level simulators accommodate MAC layer on top of the PHY layer and consider an abstract representation of the upper layers, which are usually used for Radio Resource Management (RRM) algorithms, and cannot provide inclusive performance measurements for the network as a whole. Examples of these simulators can be found in [7] and [8]. Therefore, the need for a generic LTE mobile network simulator that considers all the protocols in estimation of the network metrics is inevitable. An open source LTE network simulator is proposed in [9], which supports single and multi-cell environments, QoS management, a multi user environment, user mobility, handover procedures, scheduling, and frequency reuse technology. In [10] the authors presented an NS-3 based module for simulating LTE networks that provides a fully-fledged TCP/IP protocol stack in the simulation, as well as the support for other wireless technologies such as WiFi and WiMAX. Its focus is on the radio interface of LTE, the Evolved Universal Terrestrial Radio Access (E-UTRA). The module can estimate the propagation model and path loss, as well as testing scheduling techniques and link adaptation. Another version of this module was later presented in [11]. This tool allows for manufacturer testing of LTE equipment before deployment in the actual environment. Due to large number of features in LTE networks, these simulation modules only cover a part of the network structure and focus on a few major metrics.

Our approach focuses on a real simulation of LTE networks using the Discrete Event System Specification (DEVS) [12] formal M&S theory, providing measurements of the performance metrics based on radio engineering methods described in the latest 3rd Generation Partnership Project (3GPP) technical report [13].

3. DEVS

As discussed in the previous section, we use formal M&S methodology to model LTE networks. Discrete Event System Specification (DEVS) [12] formalism has been chosen for this purpose, since the M&S aspects of a DEVS system are separated in order to modularize and formulate the design of a model, based on the requirements of the source system. To this end, DEVS has been proposed as a sound formal framework for modeling generic dynamic systems and includes hierarchical, modular and component-oriented structure and formal specifications for defining structure and behavior of a discrete event model. A DEVS model is comprised of structural (Coupled) and behavioral (Atomic) components, in which the coupled component maintains the hierarchical structure of the system, while each atomic component represents a behavior of a part of the system. The atomic component is the basic building block of the system which is composed of I/O ports and a finite state timed automaton representing the behavior of the model. An input to the atomic component via an input port triggers a state transition (referred to as "external transition"), and in contrast the state transition (referred to as "internal transition") at the end of the time-delay of each state leads to an output generation through an output port.

Figure 1 illustrates the state transition of an atomic component. An atomic component is in state s for a specified time ta(s). If the atomic component passes this time without interruption it will produce an output y at the end of this time and change state based on its δ_{int} function (internal transition) and continues the same behavior. However, if it receives an input x during its ta(s) time, it changes its state which is determined by its δ_{ext} function and does not produce an output (external transition).

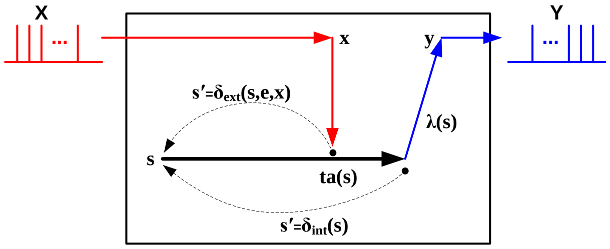


Figure 1. DEVS Atomic Model [14]

A coupled model connects the basic models together in order to form a new model. This model can itself be employed as a component in a larger coupled model, thereby allowing the hierarchical construction of complex models.

4. DEVS MODEL ARCHITECTURE

The model is designed to represent the properties of BS antennas, and UEs as well as the area, movement of UEs and BS antenna deployment layout. These specifications have been extracted from 3GPP technical report release of June 2012 [13].

4.1. Model Specifications

Figure 2 illustrates the DEVS block diagram of the mobile network model. The model is composed of three major components: *UE Manager*, *BS Manager*, and *Stats*. The *UE Manager* is a coupled component composed of three atomic components: *UE Registry* takes care of generating and deactivating the UEs as well as controlling the location, movement, speed, and links between the UEs and the BSs in their range. *UE Generator and UE Deq* atomic components notify *UE Registry* regarding generation or deactivation of UEs. Figure 3 shows the DEVS-Graph [15] state diagram of the *UE Registry* atomic component. The *UE Registry* is initially in *idle* state for 10 ms then it updates the UE positions and links and generates the number of UEs and links as output to *Stats* and goes back to *idle* state. While it is in idle state it can also be notified by *UE Generator and UE Deq* atomic components to produce a UE or deactivate a UE.

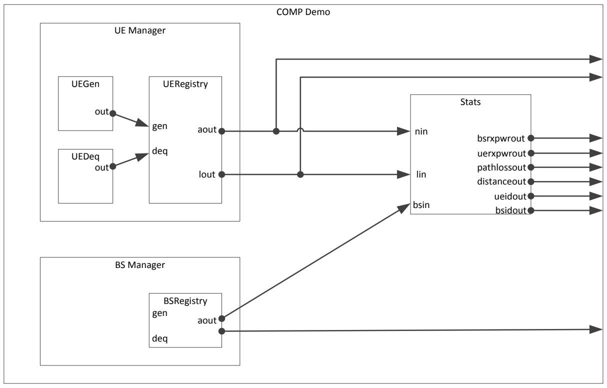


Figure 2. DEVS Model Architecture

The *BS Manager* is in charge of generating BS antennas, at the beginning of the simulation, based on the parameters defined in the model file. It contains the *BS Registry* atomic component which deploys the BS antennas based on the coordinated macro cellular deployment method defined in [13]. In coordinated cellular deployment, identical cell layouts for each cell are considered. Figure 4 shows a coordinated cellular deployment layout in which each BS antenna has fixed distance of 3R (R is the cell radius) from the neighboring BS antenna, while each antenna covers three different directions.

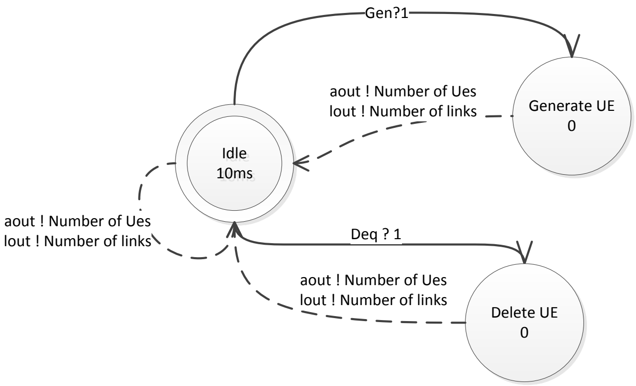


Figure 3. UE Registry State Diagram

The third major component in this model is the *Stats* atomic model which is in charge of recording the statistics of the model during the simulation. *Stats* periodically calculates the propagation model (L) for each BS-UE link based on Equation 1 (for urban areas) and Equation 2 (for rural areas), where:

- *R* is the BS-UE separation in kilometers
- *f* is the carrier frequency in MHz
- *Dhb* is the base station antenna height in meters, measured from the average rooftop level
- *Hb* is the base station antenna height above ground in meters

$$L = 40 \cdot (1 - 4 \cdot 10^{-3} \cdot \mathrm{Dhb}) \cdot \log_{10}(R) - 18 \cdot \log_{10}(\mathrm{Dhb}) + 21 \cdot \log_{10}(f) + 80\mathrm{dB}$$

Equation 1. propagation model – Urban Area [13]

$$L = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(Hb) + [44.9 - 6.55\log_{10}(Hb)]\log(R) - 4.78(\mathrm{Log}_{10}(f))^2 + 18.33\log_{10}(f) - 40.94$$

Equation 2. propagation model – Rural Area [13]

After that, the pathloss for each link is calculated based on Equation 3 in which:

- Log-normally distributed shadowing (LogF) is set to a standard deviation of 10dB

$$\mathrm{Pathloss} = L + \mathrm{LogF}$$

Equation 3. Pathloss Calculation Formula [13]

Finally, the received power from BS in a UE and vice versa is calculated based on Equation 4, where:

- *RX_PWR* is the received signal power
- *TX_PWR* is the transmitted signal power
- *G_TX* is the transmitter antenna gain
- *G_RX* is the receiver antenna gain
- *MCL* is the minimum coupling loss which is 70dB in urban areas and 80dB in rural areas

$$RX\_PWR = TX\_PWR - \mathrm{Max}\,(\mathrm{pathloss} - G\_TX - G\_RX, MCL)$$

Equation 4. Received Power Calculation Formula [13]

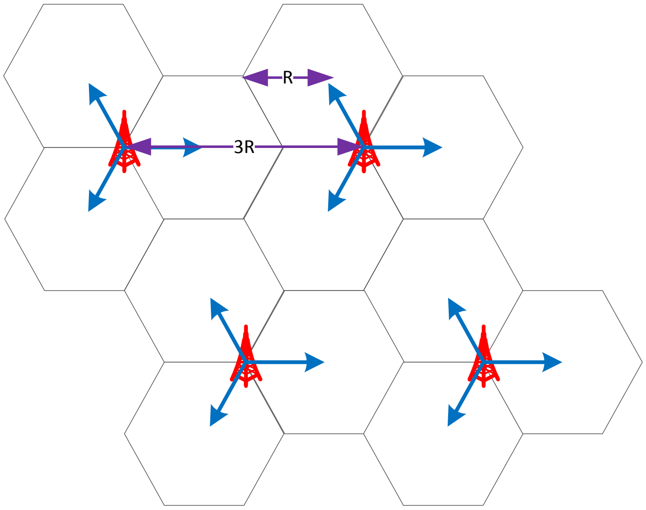


Figure 4. Coordinated Cellular Deployment

4.2. Software Structure

The model was implemented in CD++ [14] DEVS simulation software. CD++ is an open-source simulation software written in C++ that implements the DEVS abstract simulation technique [1][12]. In CD++, simulators and coordinators progress through the simulation by exchanging messages as described by the DEVS abstract simulation mechanism. CD++ benefits from object-oriented design, allowing the developer to make use of powerful object-oriented techniques in integrating the simulation entity with the modeling entities developed by the modeler. CD++ is designed as an object-oriented simulation engine, modularized as a group of components that have well-defined behaviors and have relatively independent functionalities. In CD++ model components are merged with simulator components and are compiled together to generate the executable program. The model objects extend the simulator classes to perform the abstract simulation mechanism.

To implement the proposed model on CD++, aside from the atomic model components mentioned in 4.1, other objects have been added to the model that are used to represent BS antennas, UEs and the BS-UE links (see Figure 5). A UE is represented by an id, status, current coordinates, destination coordinates, speed, transmission power, antenna gain, and list of all connections with BS antennas in range which are embedded in a Node class. The BS class characterizes a BS antenna with the following properties: id, status, type, coordinates, height from ground, height from average roof top, frequency, transmission power, antenna gain, and list of all connections with UEs in range. The *BSLink* class is a linked list held by every UE containing the uplink information from the UE to the BS antennas in its range. This class contains a pointer to the BS antenna, the UE-BS separation distance, received power from BS, and pathloss measurement associated with the link. Respectively the *UELink* class is a linked list belonging to each BS and contains the downlink information (such as a pointer to the UE object, the BS-UE separation distance, received power from UE, etc) to each UE in the BS antenna range. These two respective objects have methods to calculate metrics such as propagation model, pathloss, and the received power in both urban and rural settings [13].

The *Nodes* class holds a pointer to the head of the linked list of UEs. It has methods to update the position of the UEs based on the predefined destination coordinates and the elapsed time since the last position update, as well as the uplink and downlink parameters by using the *BSLink* and *UELink* class methods.

The UE and BS parameters such as Transmission power, gain, UE speed of movement, BS antenna height and range, operation frequency, etc that are defined in [13] can be initialized in a model file to construct the simulation scenario. These parameters can also be automatically set by choosing rural or urban simulation scenarios in the model file. This allows for rapid simulation scenario update for different simulation executions. Other specific simulation properties such as maximum BS power, maximum power per downlink traffic channel, noise Figure, and noise power are automatically set by choosing one of the following simulation settings defined in [13]: UTRA FDD, UTRA 1.28Mcps TDD, UTRA 3.84Mcps TDD, and E-UTRA FDD and E-UTRA TDD. Other general simulation parameters such as the length and width of the area as well as maximum number of BSs and UEs, link update and statistics update time periods can also be specified in the model file.

The *UE Registry* atomic component periodically updates the position of the UEs based on calculation of the movement of the UE to a predefined random destination with certain speed (shown in Figure 6). As soon as the UE reaches the destination, a new destination is randomly generated for it. It also updates the links between the UEs and the BSs in their range. The *Stats* component periodically generates statistics and records them in output files.

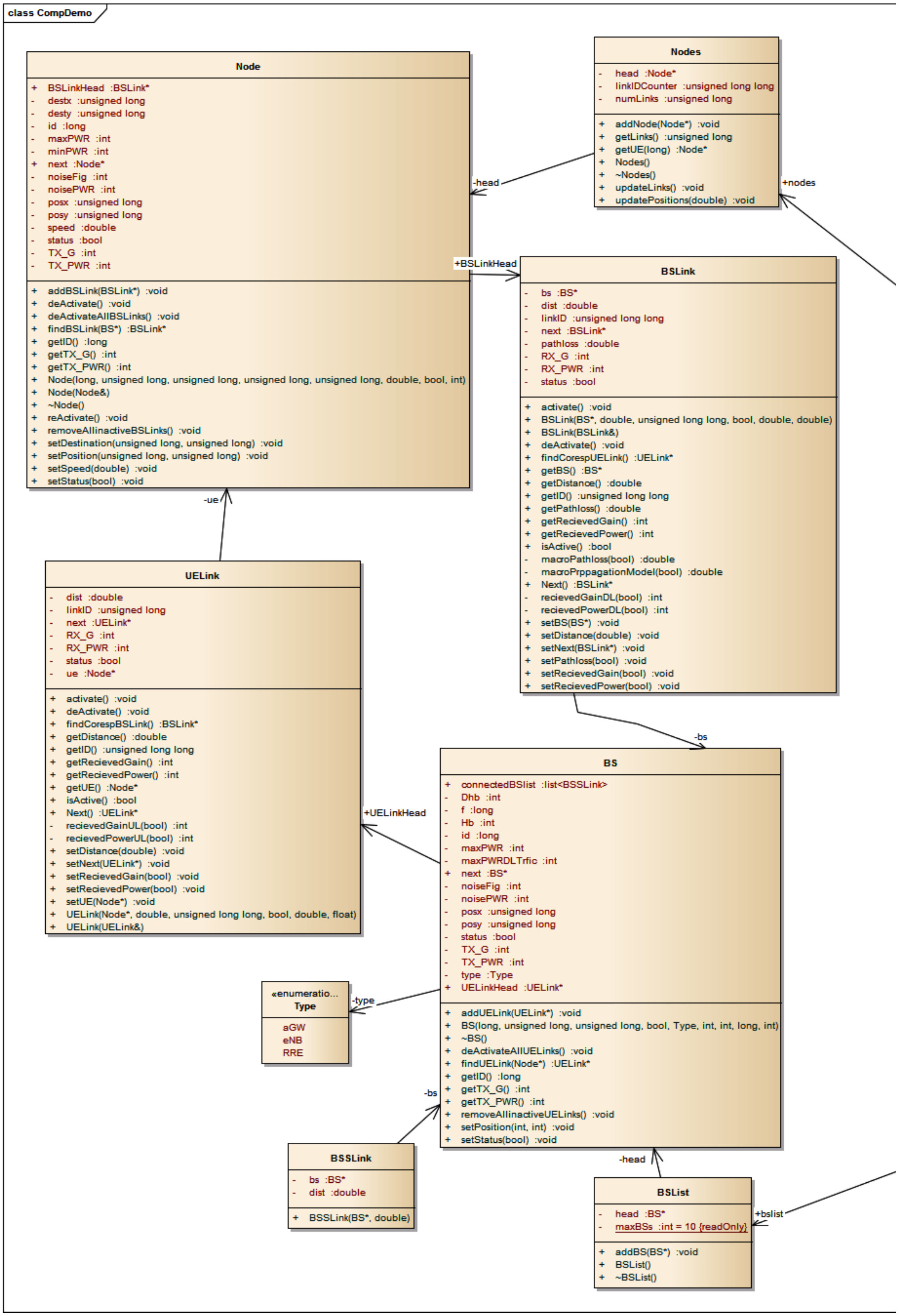


Figure 5. Network Components in the Class Diagram

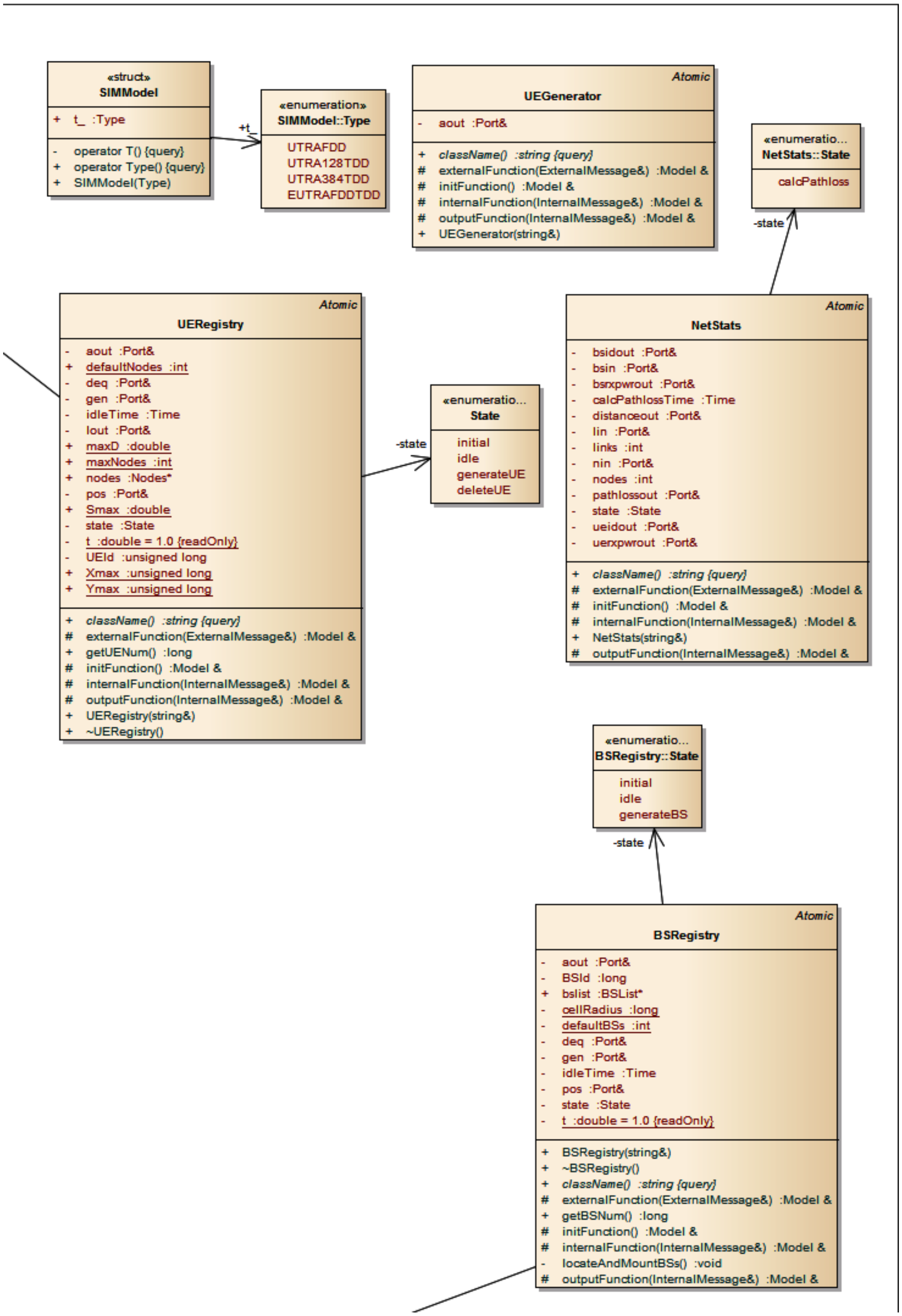


Figure 6. Model Components in the Class Diagram

5. SIMULATION RESULTS

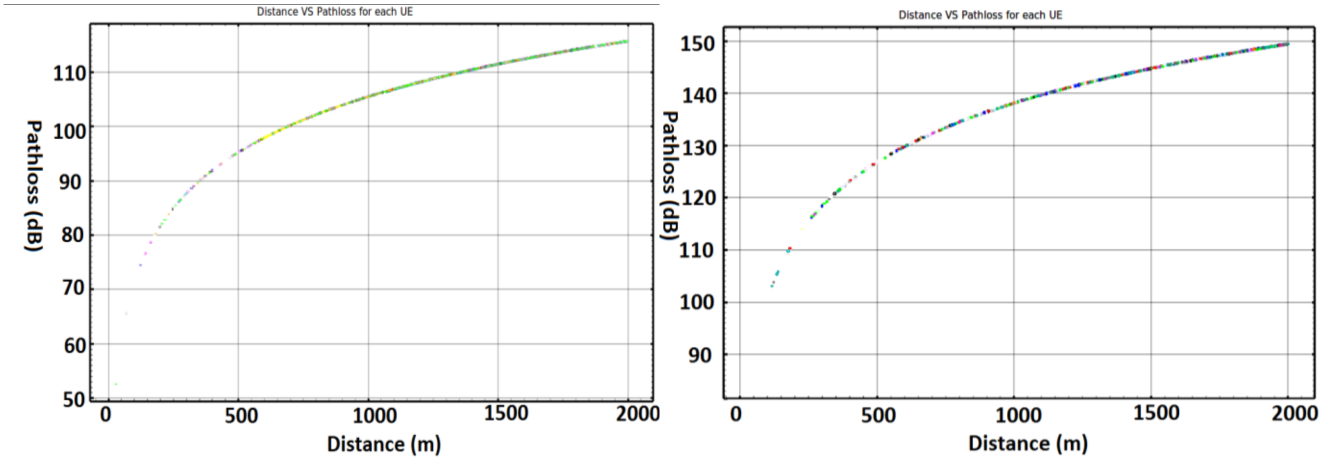
So far, we have extracted some preliminary results from the model that can be used to verify the validity of the model and its implementation. The results of the current model will be used to design and implement CoMP techniques by using the information provided in the current model. For example the switching between the serving BS antennas can be done based on the calculated received power strength from the nearby antennas.

We ran the model in both rural and urban settings with an operating area of 10 km by 10 km, with 60 number of UEs and 20 BSs and maximum speed of 120 km/h for the UEs. The BS properties are set as follows: 45 meters height from ground in rural setting and 30 meters in urban areas, 15 meters height from average roof top in urban setting, frequency of 2000 mhz in urban areas and 900 mhz in rural areas, BS antenna gain of 15 dBi, and transmission power of 43 dBm in both urban and rural settings. We assumed a transmission power of 21 dBm for UE and antenna gain of 0 dBi. All these values were extracted from 3GPP technical report release of June 2012 [13]. The simulation was executed for one hour simulation time and the statistics were collected. Some of the chosen extracted results of the simulation are visualized in the following charts.

Figure 7 shows the BS-UE distance versus pathloss in each link in both urban and rural settings. Note that different colors of the dots represent different UEs in each link. As can be seen from both charts the pathloss increases logarithmically versus the distance, complying with the formulas provided in [13]. Another observation is that the pathloss is greater in urban settings (Figure 7.a) due to lower antenna height and urban hazards.

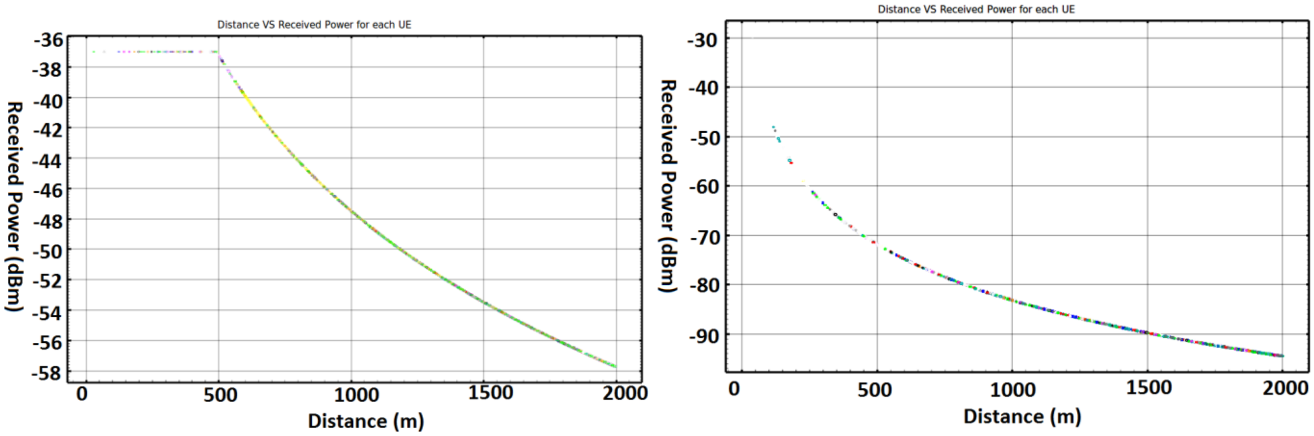
Figure 8 illustrates the BS-UE distance versus the received power in the downlink (received power by UE from BS). The received power decreases logarithmically with the increase of the distance between UE and BS. Again in the rural settings (Figure 8.a) due to higher antenna height and lower frequency, the received power is higher.

Figure 9 depicts the received power in downlink versus pathloss. The charts show a linear relationship between received power in UE and the pathloss which is in conformity with the 3GPP technical report.



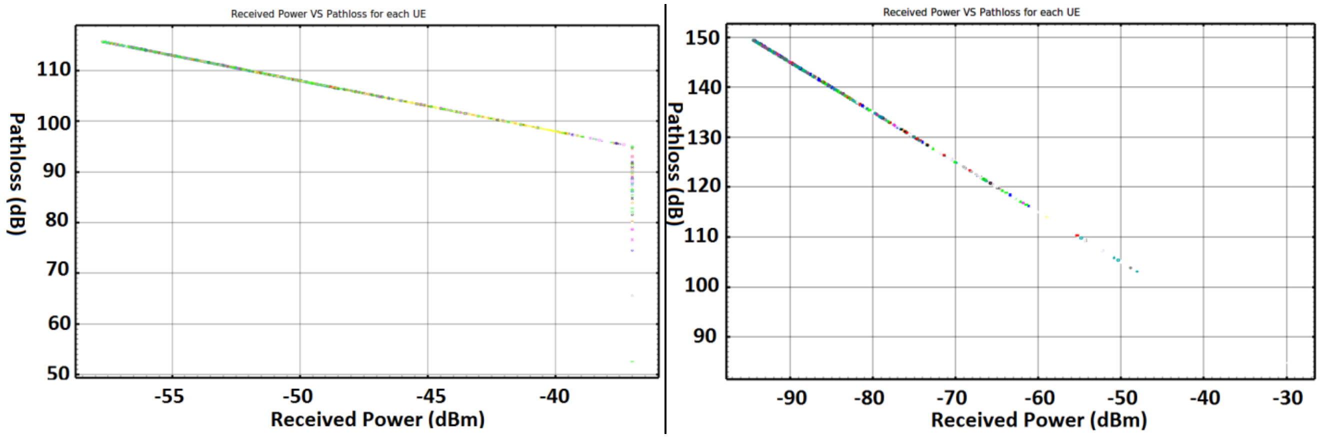
a) Rural Settings **b) Urban Settings**

Figure 7. BS-UE Distance VS Pathloss



a) Rural Settings **b) Urban Settings**

Figure 8. BS-UE Distance VS DL Received Power



a) Rural Settings **b) Urban Settings**

Figure 9. DL Received Power VS Pathloss

6. CONCLUSIONS AND FUTURE WORK

The paper provided an overview of the current status of the LTE advanced technologies and the approaches in modeling and simulation of these networks. We proposed a model of 4G LTE networks based on a formal theoretical approach that can be used for M&S applications, which uses mathematical techniques for discrete-event M&S. In this research, we used the Discrete-Event Systems specification formalism (DEVS), and the CD++ software to implement the model. A few chosen simulation results have been presented graphically using charts and the observed facts have been discussed. The charts were in compliance with the latest 3GPP Technical Report [13]. This work is in the early stages and the long term goal is to use the current simulation platform as the basis for modeling distributed approaches of CoMP processing in 3G and 4G LTE networks.

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