A Comparative Study of 4G and 5G Network Simulators

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***Abstract*— Network simulation is a technique of utmost importance to evaluate new network performance, verify new algorithms and analyze various network topologies. It is used to find results to be expected from a hardware setup without the need for actual implementation. For this reason, there is a plethora of network simulation software applied to different scenarios to evaluate theories and hypotheses. A cellular network is an example of an extremely complex system in which different components impact the overall performance in different ways. The aim of this paper is to study the most common simulators regarding the deployment of 4G and 5G networks. In addition, this paper provides a detailed comparison of 4G and 5G simulators in order to support the academic community choose the most appropriate simulator for each project.**

Keywords- Simulator; Comparison; 4G Networks; 5G Networks; Cellular Network.

I. INTRODUCTION

The exponential increase in mobile data traffic has driven current wireless networks towards their limits and as a result, researchers should be highly motivated to create powerful next-generation mobile networks, based on the current networks trends and needs of that era. It is indicative that due to popularization of smart devices and development of Internet services, the mobile data traffic flow is expected to increase a thousand percent by the end of this decade. 4G is the fourth generation of mobile phone technology. It follows on from the existing 3G (third generation) and 2G (second generation) mobile technology. 5G will elevate the mobile network to not only interconnect people, but also interconnect and control machines, objects, and devices. The current research on 5G networks is actively moving with a high pace, meaning vendors and operators are already involved in 5G testing and trials, which is soon expected to lead to a finalized standard.

Network technology is advancing rapidly and, accompanied by expansion of network scale, have made it extremely hard to analyze network. It goes without saying that testing algorithms and protocols is extremely important since their launching in large scale is prohibitive because of uncertainty of its outcome. Network schemes can be tested either by analytical modelling or with the help of simulation tools. Although analytical modelling can indeed have very realistic results, it does not come without drawbacks, most notably the lack of precision regarding energy and memory needs and can be proven to be very expensive.

On the other hand, network simulation is used to imitate over time the operation of a real-world system enabling the observation of services and applications the network could support. It allows the researchers to model a network's behavior given the proposed changes, either with the use of mathematical formulas to calculate the interaction between the various entities of the network, or actually recording and recapping information that emerge from it. It provides the capability to manipulate most of the environment attributes to evaluate the system behavior under different circumstances and allows the comparison between alternatives to optimize network performance.

These developments render network simulators an urgent need for scientific researchers around the globe. It comes with relatively low cost and small to no risk, enabling researchers to decide and predict on network behavior with greater convenience, compared to practical networks. Therefore, there have been attempts to create diverse software for network simulation to test new algorithms and simulate network behavior. But choosing the most suitable simulator for each occasion is not always an easy decision.

In this paper, we analyze both commercial and open source state-of-the-art simulators presenting performance comparison regarding 4G and 5G networks in an attempt to provide reference to the scientific community when there is a need to choose the right software for simulation. Currently, the majority of the state-of-the-art simulation tools follow discrete event simulation methodology. This is the reason why we will only focus on this technique [1]. In [2] researchers discussed current simulators with different characteristics in different aspects. Here we study some of the most popular simulation tools that follow discrete event simulation like NS-3, OMNeT++, Riverbed and NetSim. The motivation behind this paper is to provide comprehensive review of various simulators, available for scientists allowing advanced research on 4G and 5G networks.

The rest of the paper is structured as follows. Section II presents related work and Section III provides and introduction to 4G and 5G networks. Section IV manifests importance and difficulties of simulation and Section V describes the special requirements of cellular network simulation. In Section VI the simulation tools are presented while the cumulative comparison follows in Section VII where the simulators' features and advantages are discussed. Finally, in Section VII we draw up our conclusions and we present our future work.

II. Related Work

Picking the right simulation tool is a subject that has been troubling scientists for many years. Actually, it is not the first attempt to compare simulation software, as there have been a couple published in recent years. Challenges of system-level simulation and performance evaluation and the importance of creating a stable and reliable tool for 4G and 5G in consideration of the new needs and technologies that emerge are discussed in [3]. One example is the work presented in [4] and [5], where the comparison of popular network simulators is shown.

A performance analysis, which includes open source platforms simulating a MANET routing protocol is presented in [6]. There are researches testing different routing protocols [7] in different simulators with different network parameters to evaluate the performance of network protocols. A more detailed comparison, in which in addition to open simulators, commercial platforms are also included, is presented in [8].

The issue of 4G and 5G network simulators has engaged researchers all over the world. Authors in [9] present the analysis of traffic measurements collected from commercial cellular networks in China, and demonstrate that the spatial distribution of the traffic density (the traffic load per unit area) can be approximated by the log-normal or Weibull distribution depending on time and space. After that, the authors propose a spatial traffic model, which generates large-scale spatial traffic variations by a sum of sinusoids that captures the characteristics of log-normally distributed and spatially correlated cellular traffic. The proposed model can be directly used to generate realistic spatial traffic patterns for cellular network simulations, such as performance evaluations of network planning and load balancing.

Paper [10] studies the performance trade-offs between conventional cellular and multi-hop ad-hoc wireless networks. The authors compare through simulations the performance of the two network models in terms of raw network capacity, end-to-end throughput, end-to-end delay, power consumption, per-node fairness (for throughput, delay, and power), and impact of mobility on the network performance. The simulation results show that while adhoc networks perform better in terms of throughput, delay, and power, they suffer from unfairness and poor network performance in the event of mobility. In addition, the authors present a simple hybrid wireless network model that has the combined advantages of cellular and ad-hoc wireless networks but does not suffer from the disadvantages of either.

Authors in [11] describe SimuLTE, a framework within the OMNeT++ ecosystem for simulating Long Term Evolution (LTE) networks. The main focus of SimuLTE lies on developing and testing of communication protocols and resource-allocation algorithms, with an emphasis on the impact at the system level. The paper presents two tutorials on the modeling and performance evaluation of two LTE-related research problems are presented, namely, one concerning interference coordination and one on direct-communication management. Each tutorial provides guidelines for network definition, for configuring the scenario, and their parameters. The tutorials also describe how to modify the code of the available functions. Exemplary result analysis is presented along with each tutorial, to demonstrate the evaluation capabilities of the framework.

Several simulation frameworks and tools exist to deal with these constraints of scalability and time. However, all of them require profound background knowledge for building such a custom scenario. This crucial and necessary procedure is often time consuming and error-prone. Paper [12] presents the RACE framework which aims to solves these problems for the simulation of cellular LTE networks. RACE is intuitive and based upon real life cellular network infrastructure data as well as a realistic vehicular traffic simulation.

Paper [13] presents the Vienna 5G system level simulator, which allows to perform numerical performance evaluation of large-scale multi-tier networks, with numerous types of network nodes. The simulator is based on MATLAB and is implemented in a modular fashion, to conveniently investigate arbitrary network and parameter constellations, which can be enhanced effortlessly.

One of the main strengths of Network Simulator 3 (NS-3) is the availability of modules to simulate cellular networks, including LTE and mmWave/NR deployments. These implementations model the protocol stack with a high level of detail, and, thanks to the integration with the whole NS-3 code base, make it possible to study end-to-end scenarios and identify complex interactions between the different components of a network. Authors in [14] discuss the current limitations of this platform and suggest directions for future work that could improve the accuracy of the simulations.

Carrier aggregation (CA) technology was introduced in 3GPP specification in Release 10, in 2011, as part of Long-Term Evolution Advanced (LTE-A) standardization. Authors in [15] describe the CA extension of the LTE module of NS-

3 network simulator. This paper provides description of example scenarios and the validation of the carrier aggregation feature providing a performance comparison of the LTE system with and without CA capability.

LTE/Wi-Fi Link Aggregation (LWA) and LTE WLAN Radio Level Integration with IPSec Tunnel (LWIP) are two approaches put forward by the 3rd Generation Partnership Project (3GPP) to enable flexible, general, and scalable LTE-WLAN interworking in the context of 5G. These techniques enable operator-controlled access of licensed and unlicensed spectrum and allow transparent access of operator's evolved core. Paper [16] describes the design details of LWA and LWIP protocols and presents the first NS-3 LWA and LWIP implementations in NS-3.

III. 4G Networks and 5G Networks

4G is the fourth generation of mobile phone technology. It follows on from the existing 3G (third generation) and 2G (second generation) mobile technology. 2G technology launched in the 1990s and was capable of making digital phone calls and sending texts. Then 3G came along in 2003 and made it possible to browse web pages, make video calls and download music and video on the move. 4G technology builds upon what 3G offers but does everything at a much faster speed.

The benefits of 4G fall firmly into three categories. These are:

- Improved download/upload speeds.
- Reduced latency.
- Crystal clear voice calls.

Standard 4G (or 4G LTE) is around five to seven times faster than 3G, offering theoretical speeds of up to around 150Mbps. That equates to maximum potential speeds of around 80Mbps in the real world. With standard 4G someone can download a 2GB HD film in 3 minutes 20 seconds on a standard 4G mobile network, while it would take over 25 minutes on a standard 3G network.

Meanwhile, researchers and vendors expressed a growing interest in 4G wireless networks that support global roaming across multiple wireless and mobile networks—for example, from a cellular network to a satellite-based network to a high-bandwidth wireless LAN. With this feature, users have access to different services, increased coverage, the convenience of a single device, one bill with reduced total access cost, and more reliable wireless access even with the failure or loss of one or more networks. 4G networks also feature IP interoperability for seamless mobile Internet access and bit rates of 50 Mbps or more.

5G will elevate the mobile network to not only interconnect people, but also interconnect and control machines, objects, and devices. It will deliver new levels of performance and efficiency that will empower new user experiences and connect new industries. 5G will deliver multi-Gbps peak rates, ultra-low latency, massive capacity, and more uniform user experience.

5G is a new kind of network: a platform for innovations that will not only enhances today's mobile broadband services but will also expand mobile networks to support a vast diversity of devices and services and connect new industries with improved performance, efficiency, and cost. 5G will redefine a broad range of industries with connected services from retail to education, transportation to entertainment, and everything in between. We see 5G as technology as transformative as the automobile and electricity.

In general, 5G use cases can be broadly categorized into three main types of connected services:

- Enhanced Mobile Broadband: 5G will usher in new immersive experiences, such as VR and AR, with faster, more uniform data rates, lower latency, and cost-per-bit.
- Mission-Critical communications: 5G will enable new services that can transform industries with ultra-reliable/available, low latency links—such as remote control of critical infrastructure, vehicles, and medical procedures.
- Massive Internet of Things: 5G will seamlessly connect a massive number of embedded sensors in virtually everything through the ability to scale down in data rates, power and mobility to provide extremely lean/low-cost solutions.
- A defining capability of 5G is also the design for forward compatibility—the ability to flexibly support future services that are unknown today.

IV. Network Simulation

Creating the desirable network in a real time scenario is challenging as researchers' needs and requirements may vary depending on the situation. For that reason, there is a great number of software that can be used in every case. In any case, one feature is certain and non-negotiable, all of the simulation software has to enable a user to represent a network topology, specify the nodes on the network, and of course the links and the traffic between them. Of course, there may be simulators of much higher complexity that permit specification of every detail regarding the protocols they wish to use for handling traffic in a network laying quite solid foundations for future real time implementation. Simulators may come with text-based applications that can provide a not very intuitive interface, which could nevertheless allow evolved tools for customizing or with graphical applications capable of granting users an easy and fast way to visualization of the workings of the environment they wish to examine.

The simulation of wireless networks is even more complicated due to the nature of wireless networks. The basic concept of network simulation can be found in Fig. 1.

Differentiating simulators is most commonly based in terms of speed, accuracy, cost and convenience of use. The majority of the simulators provide a multi-protocol and modularity framework. There are some network simulators in companies that are developed exclusively for business, while others are developed by research institutes and/or universities to be used for researching purposes. In general, commercial software is not open, more expensive but can provide more protocol and model support while the other simulators are free but may not be as applicable.

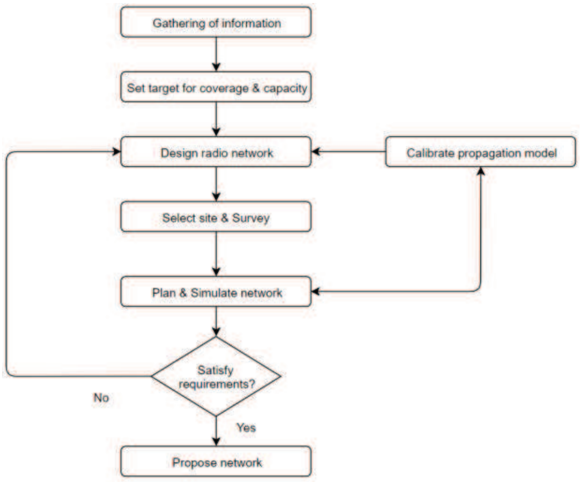

Figure 1. Network simulation

The criteria based on which the different types of simulators will be judged regard system performance, ease of learning and ease of use, the presence of Graphical Interface support, availability of the tool etc. There is general information as well as properties of the software. They can be found gathered in Table I in Section VII.

V. Cellular Network Simulation

A cellular network is an example of an extremely complex system in which different components impact the overall performance in different ways. For example, user mobility, data traffic, and the propagation model can affect the network behavior.

According to [12] cellular network simulator provides multiple simulation modules, each focusing on the modeling of a different modules, which can be interfaced together to obtain a thorough description of the overall system. The simulation of cellular networks involves both the modules implementing the cellular technology, the core network, and other modules, which take into account and influence the system behavior. More specifically these modules include the following:

- Channel Model: General speaking channel model describes the propagation of the signal through the surrounding environment, taking into account different parameters like carrier frequency, the presence of blocking objects, etc. Given that the performance of cellular networks strongly depends on the nature of the wireless channel, proper modeling of its behavior is of primary importance to obtain accurate simulation results.
- Application Model: The application model is utilized to simulate the client traffic. The use of unrealistic traffic models may prompt assessing the simulation under conditions that are not representative of those encountered in real-world scenarios, something that may lead to wrong results.
- Mobility Model: The mobility model characterizes the movements of mobile users in the environment. The usage of proper mobility models is an important aspect to consider in order to obtain accurate results.

VI. Simulators And Their Features

The following section presents the main simulators studied, their main properties, the major strengths and most important weaknesses. As mentioned above, the software in question follow discrete-event simulation. This methodology means that the operation of the system is modeled as a discrete sequence of events in time and its behavior can be simulated by modeling the events in the system where user has to set the scenarios in the right order. Also, they are chosen due to their popularity and widespread use.

A. NS-3

The NS-3 is a discrete-event network simulator developed mainly to be used for research and educational purposes. Based on the development on NS-2, the NS-3 project was launched in 2006 and is licensed under the GNU GPLv2 license and is applicable for development and research for free. It should be noted that although NS-3 was based on NS-2, it is to not be mistaken as an updated version of it, rather than as an attempt to replace it, meaning that NS-3 does not provide backward compatibility with NS-2. It defines a model of working procedure of packet data networks and provides an engine for simulation. Without deviating from its predecessor and base, NS-3 uses two key languages in C++ and Python. While the simulator is developed exclusively in C++ with optional python bindings, this allows the users the freedom to choose between C++ and Python for the scripts of simulation they write. It should be noted that in any case, both languages work very effectively on NS-3. The specified software also provides Graphical Interface for the results' visual presentation, with the use of animators. Finally, NS-3 comes with a powerful library enabling the users to do have the desired outcome, allowing them to edit NS-3 itself.

The main features of Network Simulator 3, which also differentiate it from NS-2 include:

1. Different software core: NS-3 has its core written entirely in C++ and with Python scripting interface [17].
2. Virtualization support: Implements the use of lightweight Virtual Machines.
3. Software integration: allow the inclusion of more open-source networking software, which means that the simulation models do not have to be rewritten.
4. Attention to realism: real computers are emulated in more detail by protocol entities.

Due to its features, NS-3 displays several strengths, such as:

- High modularity.
- A lot more flexibility in comparison to most simulation software.

- Easier and more credible model validation via ported code support.
- Enable simulation for a plethora of protocols.
- Wide range of use for expanding or enhancing existing networks.
- Allows Software integration.

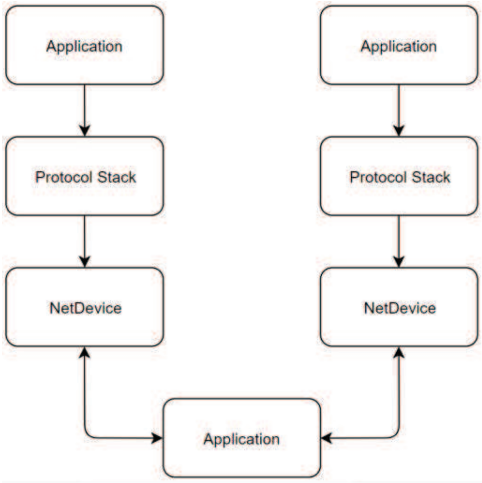

Figure 2. Architecture of NS-3

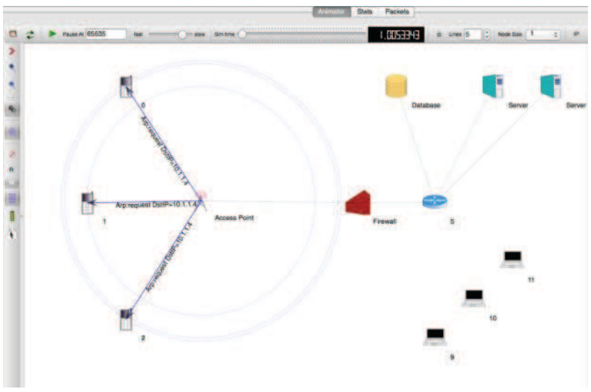

Figure 3. An example of NetAnim

However, it also has some weaknesses:

- NS-3 still suffers from lack of credibility.
- NS-3 attempts to replicate the successful approach of NS-2 but the latter was used by many organizations that contributed by adding to models and components [8].
- There is an imperative need of active maintainers who will respond to the user questions, write adequate documentation, fix reported bugs, and ensure the correct service of the system.
- The aforementioned maintainers are also needed in order to have financial advantage of NS-3 like other commercially released simulators.

The basic structure of NS-3 can be found in Fig. 2. In Fig. 3, an example of NetAnim is shown, a software executable that allows display of topology and animation of packet flow [17].

NS-3 provides support for 4G networks through the LTE module, which consist of two main components:

- The LTE Model. This model includes the LTE Radio Protocol stack.
- The EPC Model. This model includes core network interfaces, protocols and entities.

NS-3 supports 5G networks simulations through "mmWave Cellular Network Simulator module" [18]. This module includes a number of detailed statistical channel models as well as the ability to incorporate real measurements or raytracing data.

B. OMNeT++

Publicly available since 1997, OMNeT++ [19] is an extensible, modular, discrete event simulation software [20]. Although it can successfully model complex IT systems, multiprocessors, distributed hardware architectures, it is more often used for computer networks simulation, both wireless and wired. It is written thoroughly in C++. Using the software under the Academic Public License makes it free for non-benefit or academic use. Its free disposal combined with the tool's extensibility and the amount of available online documentations have made it very popular in the academic community. The motivation behind the development of OMNeT++ is to bridge the gap between research-oriented, free simulators like NS-3 and commercial alternatives like Riverbed that are much more high-priced. It is a component-based architecture and components (called modules) are programmed entirely in C++. They are then assembled into larger components and models with the use of NED, a language of higher level. Its modular architecture allows the simulation kernel to be easily embedded into almost every application.

The software has great GUI support and the simulation environment also offers a compiler for the NED topology description language (NEDC), graphical network editor for NED files (GNED), GUI for simulation execution (Tkenv), command-line user interface for simulation execution (Cmdenv) [19] [21].

The most important feature of the simulator is that the modules are assembled by reusable components to be combined in different ways. Another important feature is that OMNet++ is basically a framework approach, providing the groundwork to develop various simulations models to meet different application areas requirements, which subsequently follow their release cycles. Currently, it is on version 5.4.1.

The simulator's strengths can be summarized as follows:

- Makes it easier to trace and debug.
- Can be used to model most hardware with accuracy.
- It offers wide GUI support via a complete, robust environment.
- Provides Reusable modules that can be combined in different ways.

While its weaknesses include:

- User still have to do a pretty important amount of background work due to the lack of variety of protocols offered and implemented.
- The mobility extension can be found somewhat incomplete.
- It offers poor analysis and management of typical performance.

The structure of OMNeT++ simulation system can be found in Fig. 4 and an example of simulation in Fig. 5.

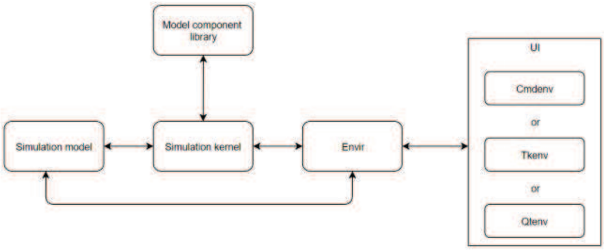

Figure 4. Structure of OMNeT++ simulator

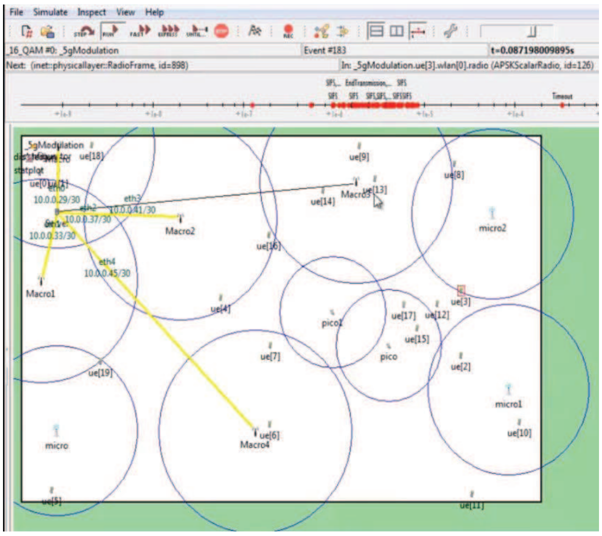

Figure 5. Example of simulation on OMNeT++

OMNet++ provides support for 4G network simulation through SimuLTE module [22]. SimuLTE is an innovative simulation tool enabling complex system level performance-evaluation of LTE and LTE Advanced networks (3GPP Release 8 and beyond) for the OMNeT++ framework. SimuLTE is written in C++ and is fully customizable with a simple pluggable interface. One can also develop new modules implementing new algorithms and protocols. SimuLTE is an open source project building on top of OMNeT++ and INET Framework [23].

C. *Riverbed Modeler*

OPNET (Optimized Network Engineering Tools) Modeler is the development environment of OPNET simulator and is targeted for both research purposes and development. It was one of the most popular commercial simulation software by the end of 2008 and being in the market for such a long period, it managed to occupy a large share of it. Nowadays it is part of Riverbed Modeler. Its flexibility allows it to be highly useful in studying communication applications, protocols and networks. It offers the users vast and impressive visual interface, due to its commercial nature. Using the graphical editor interface, the users are able to build whole network topology and entities from the application layer all the way to the physical layer and the mapping from the graphical design to the implementation of the real systems is created using Object-Oriented programming. All topologies' configuration and simulation results can be presented very intuitively and visually. The users also have the freedom to adjust the parameters and quickly repeat experiments using the graphical interface, performing tests for various scenarios [21]. Riverbed is based on a mechanism called discrete event system.

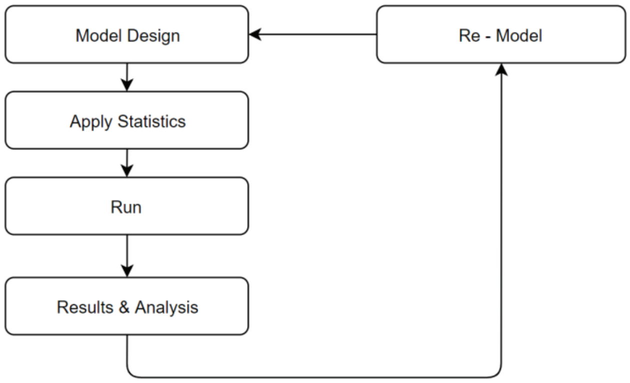

Figure 6. Simulation Workflow of Riverbed Modeler

According to the authors of [2] OPNET can be used to carry through with three functions:

1. modeling: it provides a vary intuitive and visually rich GUI, allowing users to develop a great variety of models.
2. simulating: It uses three different technologies.
3. analysis: the results originating from the simulation process can be presented and analyzed using the simulators tools, such as user-friendly charts, animations or statistics.

Important features of the Riverbed system are that the organization of the networks is accomplished via hierarchical structure plus the fact that graphical interface and programming tools are available to users to define protocols or packet format.

Some strengths of the system include:

- Fast discrete event analytical simulation engine [8].
- Reduces simulation runtime by utilizing parallel and distributed capabilities [24].
- Allows quick correlation of graphical result with network behavior and easy interpretation.

While some weaknesses could be:

- It only supports a small number of nodes within a single device.
- Simulation is inadequate in case there are long periods where nothing happens.
- Provided GUI might be powerful but its use it rather complicated.
- Sampling resolution sets the limit for the result accuracy.

The simulation workflow of Riverbed modeler can be found in Fig. 6 and the Graphical Interface in Fig. 7.

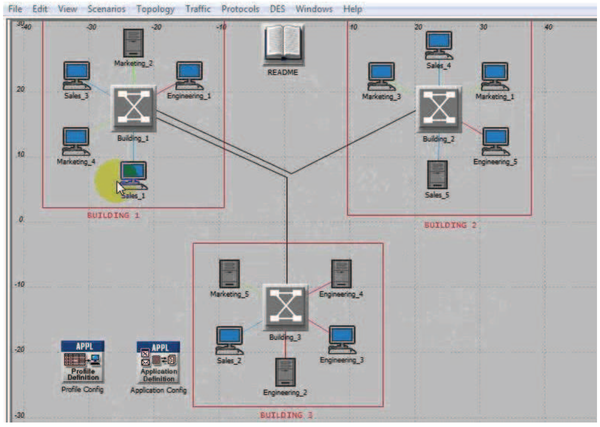

Figure 7. GUI of Riverbed Modeler

OPNET provides native support of LTE network simulation. Authors of [25] introduce modelling, simulation and Electromagnetic Compatibility (EMC) analysis methods based on OPNET for IMT-2020(5G) systems. The models presented on this paper can be used for network planning, design and performance analysis in the following research. This paper shows the new method of EMC analysis and new application of network simulation technology.

D. *NetSim*

NetSim is a stochastic discrete event simulator targeted for experimentation and research on networks. It is a leading network simulation software for protocol modelling and simulation, allowing us to analyze computer networks with unmatched depth, power and flexibility [26]. It is developed in 1997 by Tetcos. Its native development environment acts as the interface between User's code and NetSim's protocol libraries and simulation kernel [27]. NetSim is available as Pro, Standard or Academic versions and is built on a common design framework of high-level architecture and code. Every version has of course different features, supports different options and has a different price. NetSim is more versatile than most of the other software and robust with an excellent and easy to use graphical interface. It should be noted that it is capable to provide performance metrics at abstraction levels from network to node and creates a packet trace with all of the necessary details. Its main limitation is that it is follows a single process discrete event simulation methodology. This means that it uses a single event queue for the needs of the simulation and at any given time, it contains one entry for each station on the network. Currently it is on Version 10.

The major benefits are (a) programmability, (b) architectural accuracy, and (c) flexibility.

NetSim's strengths include:

- It offers a powerful, user friendly GUI that makes its use rather simple.
- Allows data packet flow visualization using its built-in animator.
- Users can extract performance analysis metrics in various levels.
- Its analysis framework offers various graphical options and enables intra and inter-protocol performance comparison.
- Some weaknesses could be identified:
- All of the versions are commercial, meaning there is no free way of usage.
- It is a single process discrete event simulator.

The graphical interface of Netsim can be found in Fig. 8.

NetSim provides support for 4G network simulation through LTE / LTE – Advanced module [28]. NetSim Long-Term Evolution (LTE) Model Library provides high fidelity simulation of 4G / 4.5G cellular networks based on the 3GPP TS 36.xxx standards. It includes models of nodes called MME (Mobility Management Entity), eNodeB (Base Station), Relay and UE (Mobile Station) and each has detailed MAC and PHY models.

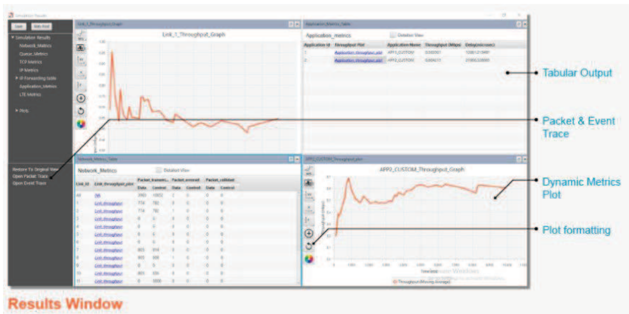

Figure 8. GUI of Netsim

During 2019, NetSim starts to provide support of 5G Network (beta software) through 5G NR mmWave module [29]. This module is in beta stage and provides the following features:

- Edge-to-edge and Edge-to-core simulation covering.
- GUI based with Drag and Drop, Packet Animator and Results Dashboard.
- 5G library interfaces with NetSim's proprietary TCP/IP stack providing simulation capability across all layers of the network stack.
- Discrete Event Simulation (DES) with event level debugging to inspect and control the simulation.
- Application Models - FTP, HTTP, Voice, Video, Email, DB, Custom.
- Packet level simulation with detailed packet trace.

VII. Cumulative Comparison

The simulation comparison is shown in Table I, where the criteria are presented and whether they are fulfilled. The comparison was an overall comparison and it is based on both general information as well as properties of the software.

The general information that can be found on the upper section of the table, e.g., supported language & OS, license type, GUI support and technical properties of the software are compiled under the middle rule, e.g., simulation event type, scalability and network visualization tool.

All the simulators studied in this paper support tools that help the visualization of the network. They also allow scenarios redesign and modification through parameters change and can create trace files. They offer complete documentation and are user friendly, easy to use with NS-3 proving to be the most challenging to learn. The modularity of OMNeT++ is a big advantage, although it leaves the user with quite a big amount of work to done because of the lack of protocols offered.

When it comes to communication with other simulators, Riverbed Modeler supports this feature while Omnet++, NS-3 and NetSim do not. Because of its proprietary nature, it is only natural that Riverbed can afford to simulate networks of much larger scale.

On the other hand, NS-3 is open source, OMNeT++ may not entirely be free but offers academic version for noncommercial use and NetSim offers a cheaper, alternative version for students. This means that for these versions, the simulation scale ability is more limited. Of course, the commercial versions of the latter two software, can support large scale simulations. NS-3 and OMNeT++ can be deployed in all widely used Operating Systems, contrary to Riverbed and NetSim.

As far as GUI support is compared, the graphical environment offered by all of them are found more than adequate. Of course, OMNeT++ and NetSim offer vast and powerful GUI support with many more features and abilities like analysis framework and graphical options. On the other hand, Riverbed does provide an excellent GUI but it can be judged quite complicated and not so user-friendly.

It should be noted that all the simulators are supported by a great community but, NS-3 being open source means that there are less maintainers to respond to questions or fix reported bugs and abnormalities. However, it is extremely widespread and used by many students, scientists and academics that the online community can help and offer great support. More specifically, according to [30] a Google Scholar search of the ‘NS-3 simulator’ results since 2017 (excluding patents and citations) yields over 2000 links (with some false positives). In addition, the IEEE digital library lists 145 NS-3 publications for 2017, and the ACM digital library lists 2579 publications matching the search term ‘NS-3’ in 2017. In addition, there are organized Workshops on NS-3 and the related proceedings are published in the ACM digital library [31]. The above facts ensure the important acceptance of NS-3 simulator as network research tool. In addition to NS-3, also OMNeT++ has an active community, which have organized 5 OMNeT++ Community Summits until 2018 [32]. As result, if we compare the above simulators in terms of research community support seems that NS-3 and OMNeT++ have the most active research community, which organize relative workshops about the evolution of the simulation software. This seems logical based on the fact that both NS-3 and OMNet++ can be obtained at no cost.

If we discuss about 4G networks simulations native support all the simulators in investigation provides support for 4G – LTE network simulation.

If we discuss about 5G networks simulations native support, only NS-3 and NetSim simulators supports 5G networks simulations and OMNET++, Riverbed, do not provide native support for 5G networks simulations.

TABLE I. COMPARISON OF SIMULATORS.

	NS-3	OMNeT++	Riverbed	NetSim
License Type	Open Source	Open Source (study & research)	Commercial	Proprietary
Language Supported	C++ & Python	C++	C & C++	C++ & Java
Supported OS	Linux, Mac OS Windows	Linux, Mac OS Windows	Linux, Windows	Windows
GUI Support	Good	Good	Excellent	Excellent
Document Available	Yes	Yes	Yes	Yes
Ease of Use	Hard	Easy	Easy	Easy
Simulation Event Type	Discrete event	Discrete event	Discrete event	Stochastic Discrete event
Available Module	Wired, Wireless Adhoc,WSN	Wired, Wireless Adhoc,WSN	Wired, Wireless Adhoc,WSN	Wired, Wireless, SN
Scalability	Limited	Enough	Large	Enough
Availability of analysis tool	Yes	Yes	Yes	No
Communication with other modules	No	No	Yes	No
Network visualization tool	Yes	Yes	Yes	Yes
Possibility to design and modify scenarios	Yes	Yes	Yes	Yes
4G native support	Yes	Yes	Yes	Yes
5G native support	Yes	No	No	No

NS-3 supports 5G networks simulations through "mmWave Cellular Network Simulator module" [33]. This module includes a number of detailed statistical channel models as well as the ability to incorporate real measurements or raytracing data. The physical and medium access control layers are modular and highly customizable. The module is interfaced with the core network of the NS-3 Long Term Evolution (LTE) module for full-stack simulations of end-to-end connectivity, and advanced architectural features, such as dual-connectivity, are also available.

During 2019, NetSim starts to provide support of 5G network (beta software) through 5G NR mmWave module [29]. This module is in beta stage and provides the following features:

- Edge-to-edge and Edge-to-core simulation covering.
- GUI based with Drag and Drop, Packet Animator and Results Dashboard.
- 5G library interfaces with NetSim's proprietary TCP/IP stack providing simulation capability across all layers of the network stack.
- Discrete Event Simulation (DES) with event level debugging to inspect and control the simulation.
- Application Models - FTP, HTTP, Voice, Video, Email, DB, Custom.
- Packet level simulation with detailed packet trace.

Especially for 5G networks simulations there are specialized simulators like NYUSIM [33]. NYUSIM is a novel channel simulation software, which can be used to generate realistic temporal and spatial channel responses to support realistic physical- and link-layer simulations and design for fifth-generation (5G) cellular communications. NYUSIM is built upon the statistical spatial channel model for broadband millimeter-wave (mmWave) wireless communication systems.

VIII. Conclusion and Future Work

Network simulation is an effective, low cost and small risk method. However, it is necessary and this why it is extensively performed by scientists in all kinds of fields to validate the research carried out. Network simulation can prove to be an essential mechanism on the hands of researchers for the analysis on network behavior and evaluation on possible network design and will remain increasingly important following the networks' growing complexity and scale. This paper contains a general overview of a number of tools used for standard network simulation, along with a comparison between them with respect to various parameters. The study confirms that picking a suitable, required and efficient simulator for the specific job of a research work can be quite demanding but bears the according results. Each simulator comes with its advantages and disadvantages and can be useful or even necessary in different cases and the choice of a fitting software should be done based on the study motive.

If we discuss about 4G networks simulations native support all the simulators in investigation provides support for 4G – LTE network simulation. If we discuss about 5G networks simulations native support, only NS-3 and NetSim simulators supports 5G networks simulations and OMNET++, Riverbed, do not provide native support for 5G networks simulations.

Our future work includes the evaluation of the investigated simulators based on the simulation of the same cellular network scenarios. The above will allows us to compare the performance of investigated simulators with parameters like time to complete simulation, accuracy of the simulation results etc.

In addition, our future work includes the comparison of the investigated simulators during the simulation of Low Power Wide Area Networks (LPWAN) like LoRA (Long Range) and NB-IoT (Narrow Band – Internet of Things). LPWAN are very important for the implementation of the Internet of Things (IoT) applications something very important because IoT is the extension of Internet connectivity into physical devices and everyday objects.

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