Comparison 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. The aim of this paper is to study the most common Simulators regarding the deployment of 5G networks, provide a detailed comparison featuring their main advantages and showcasing potential defects and support the academic community, offering the required data to help choose the necessary one.**

Keywords–Simulator; Comparison; 4G; 5G.

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 that the industry faces during the 4th Generation mobile networks (4G) era, advancements in mobile networks to accommodate such demand has become necessary. Considering that the mobile data traffic flow is expected to increase a thousand percent by the end of this decade, the current research on this generation of mobile networks and the next (5G) is actively moving with a high pace. 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 as well and, accompanied by expansion of network scale, have made it extremely hard to analyse networks. 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 behaviour 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 behaviour under different circumstances and allows the comparison between alternatives to optimize network performance. These developments make network simulators an important requirement 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 behaviour with greater convenience, compared to practical networks. As a consequence, there have been attempts to create diverse softwares for network simulation to test new algorithms and simulate network behaviour. But choosing the most suitable simulator for each occasion is not always an easy decision.

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 5G in consideration of the new needs and tachnologies that emerge are discussed in [1]. One example is the work presented in [2] and [3], 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 [4]. There are researches testing different routing protocols [5] 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 [6].

In this paper, we analyse 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. In [7], 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 manifests importance and difficulties of simulation. In Section III, the simulation tools are presented while the cumulative comparison follows in Section IV where the simulators' features and advantages are discussed. Finally in Section V, we draw up our conclusions.

 ISBN: 978-1-61208-719-1

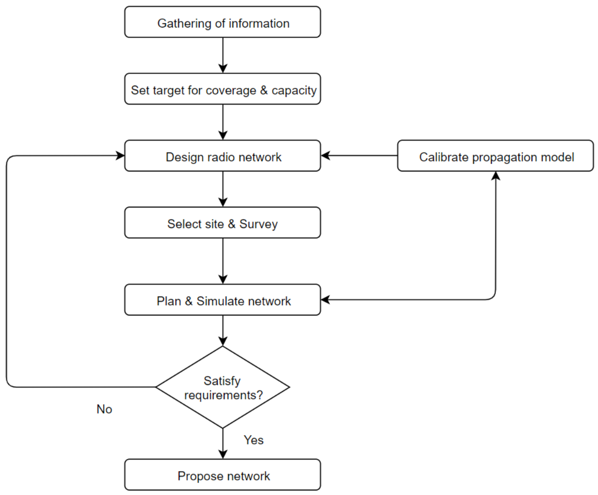

Figure 1. Network Simulation

II. 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 softwares that can be used in every case. In any case, one feature is certain and non-negotiable, all of the simulation softwares have 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 customising or with graphical applications capable of granting users an easy and fast way to visualization of the 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 wireless network simulation can be found in Figure 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.

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 are general information as well as properties of the softwares. They can be found gathered in Table 1 in Section IV.

III. 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 softwares 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 NS2, 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 NS2. 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 NS2 include:

1) Different software core: ns-3 has its core written entirely in C++ and with Python scripting interface [8].
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 softwares.
- 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.

However, it also has some weaknesses:

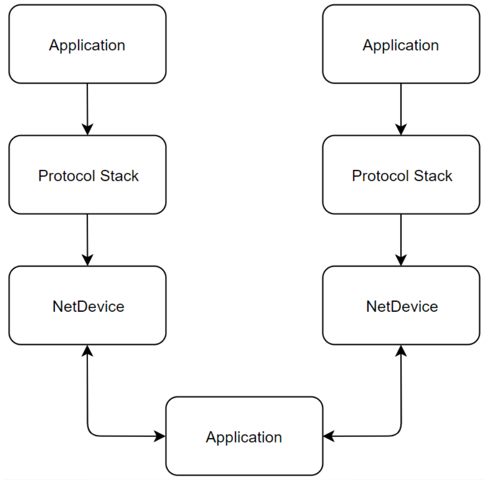

Figure 2. Architecture of ns-3

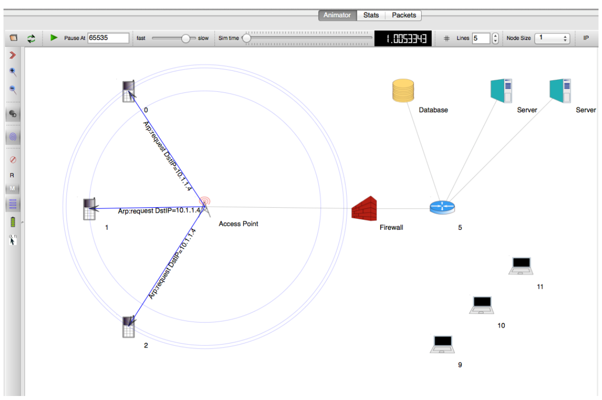

Figure 3. An example of NetAnim [8]

- ns-3 still suffers from lack of credibility.
- ns-3 attempts to replicate the successful approach of NS2 but the latter was used by many organizations that contributed by adding to models and components [6].
- 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 architecture layers is shown in Figure 2. In Figure 3, an example of NetAnim interface is shown, a software exetutable that allows display of topology and animation of packet flow [8].

B. OMNeT++

Publicly available since 1997, OMNeT++ [9] is an extensible, modular, discrete event simulation software [10]. 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.

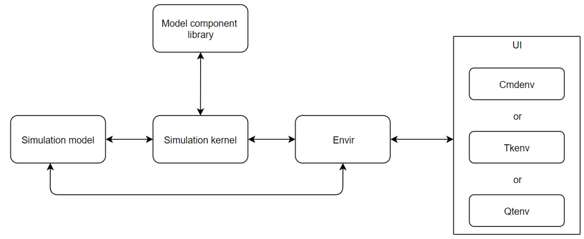

Figure 4. Structure of OMNeT++ simulator

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) [9] [11].

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:

- 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 Figure 4 and an example of simulation in Figure 5.

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

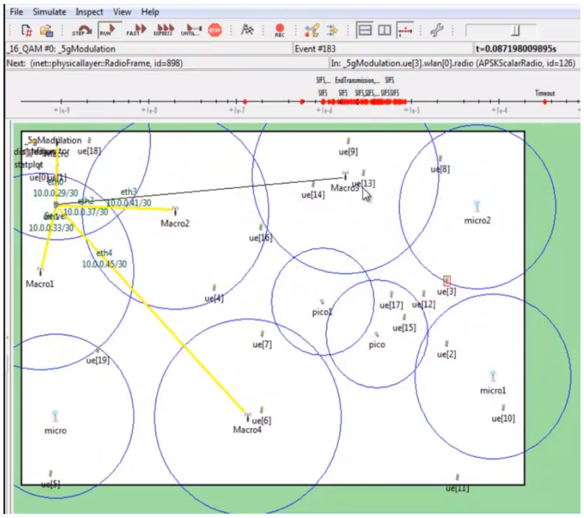

Figure 5. Example of simulation on OMNeT++

one of the most popular commercial simulation softwares 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 [11]. Riverbed is based on a mechanism called discrete event system.

According to the authors of [7], 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 analysed using the simulators tools, such as user friendly charts, animations or statistics.

Important features of the Riverbed system is that the organisation 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 [6].
- Reduces simulation runtime by utilizing parallel and distributed capabilities [12].
- Allows quick correlation of graphical result with network behavior and easy interpretation.

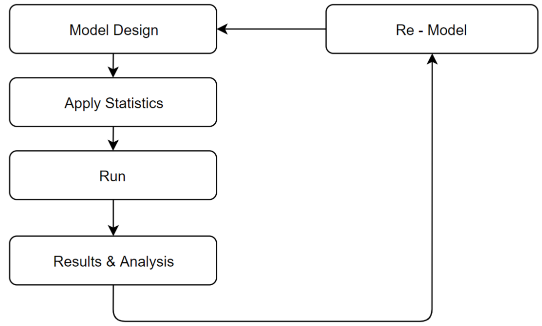

Figure 6. Simulation Workflow of Riverbed Modeler

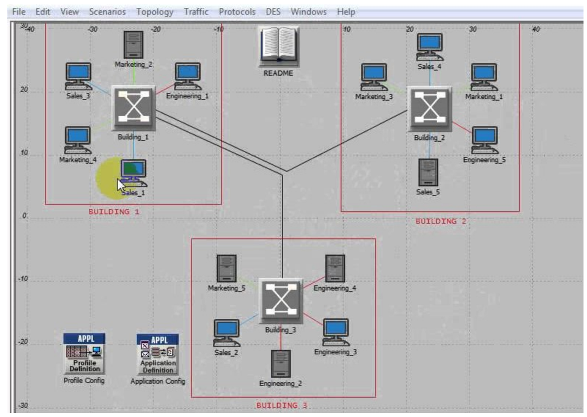

Figure 7. GUI of Riverbed Modeler

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 Figure 6 and the Graphical Interface in Figure 7.

D. NetSim

NetSim is a stochastic discrete event simulator targeted for experimentation and research on networks. Its a leading network simulation software for protocol modelling and simulation, allowing us to analyze computer networks with unmatched depth, power and flexibility [13]. It is developed in 1997 by Tetcos . Its native development environment, acts as the interface between Users code and NetSims protocol libraries and simulation kernel [14]. 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 softwares 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

TABLE I. TABLE FOR 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
5G native support	Yes	No	No	No

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 Figure 8 .

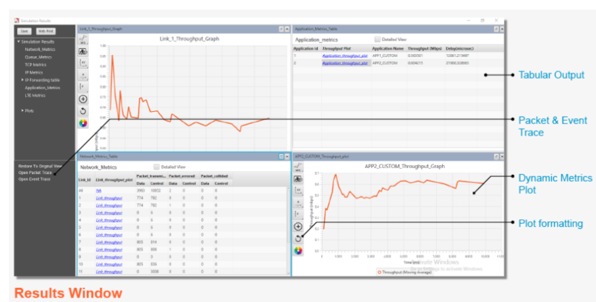

Figure 8. GUI of Netsim [13]

IV. CUMULATIVE COMPARISON

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

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 softwares 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 non commercial 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 softwares, 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. Riverbed on the other hand, 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 is being used by so many students, scientists and academics that the on-line community can help and offer great support for most issues.

More specifically, according to [15] 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. 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. 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 softwares. This seems logical based on the fact that both ns-3 and OMNet++ can be obtained at no cost.

If we discuss about 5G Networks simulations native support, only ns-3 simulator supports 5G Networks simulations and OMNET++, Riverbed, NetSim do not provide native support for 5G Networks simulations. ns-3 supports 5G Networks simulations through ‘mmWave Cellular Network Simulator module’ [16]. 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.

Especially for 5G Networks simulations there are specialized simulators, such as NYUSIM [17]. NYUSIM is a novel channel simulation software, which can be used to generate realistic temporal and spatial channel responses to support realistic physical-layer and link-layer simulations and design for fifth generation (5G) cellular communications. NYUSIM has been built upon the statistical spatial channel model for broadband millimeter wave (mmWave) wireless communication systems.

V. 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 behaviour 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.

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