Generic Wireless Network System Modeler:

Fostering the Analysis of Complex LTE Deployments

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Abstract. Despite the huge research effort in the field of LTE networks, there is not a widely accepted methodology to conduct the corresponding analysis. Various approaches and tools are used, each of them having several advantages, but showing some drawbacks as well. One of the most limiting aspects is that they are not usually able to cope with network deployments having a large number of elements, as it would be in dense Heterogeneous Networks (HetNets). In other cases, they do not usually pay too much attention to the requirements that different types of services might have, overusing the so-called *full-buffer* approach. In this paper we introduce the Generic Wireless Network System Modeler (GWNSyM), a flexible framework that allows the deployment of rather complex networks, which can be exploited to analyze a wide range of resource management techniques, solutions and, even, novel architectural approaches. The tool is validated over a high-dense network deployment, embracing different types of cells, users and services. Over such scenario, we assess the performance of CoMP techniques and we leverage the Network Virtualization Function paradigm.

Keywords: Network modeling · Simulation · LTE/LTE-A

1 Introduction and Motivation

Current forecasts expect a remarkable increase on the traffic demand for mobile wireless systems [1]. One of the main reasons behind this unseen growth is the consolidation of novel services, such as video streaming, gaming applications, etc., which would need to share the corresponding resources with more traditional data services, such as web browsing or file download.

Although we have not yet seen the consolidation of the 4G technology, several works and research initiatives are already anticipating the arrival of 5G. However, it is believed that both technologies will coexist and seamlessly deployed and used. For instance, it is expected a prominent role of the so-called small-cell densification strategy [2], since it will yield a remarkable capacity increase. Other elements that have been recently included in the corresponding 3GPP specifications are the cooperation between access elements (Cooperative Multi-Point

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(CoMP) techniques) or the decoupling of downlink and uplink connections [3], among others.

On top of that, there is another key ingredient of the forthcoming wireless communications landscape, which is the exploitation of virtualization techniques and Software Defined Networks (SDN) elements for this type of network deployments [4], leading to the Network Function Virtualization (NFV) paradigm [5]. This would, for instance, facilitate cooperation strategies between base stations, if some of their core functions are moved to the cloud.

Despite the clear advantages of all the previous aspects, it goes without saying that new challenges will certainly arise. In this sense, the scientific community is working on this dynamic and complex playground, advocating new techniques and solutions, assessing their performance for certain scenarios and use cases.

One of the first issues that need to be addressed is the tool, or set of tools, which can be used in order to carry out an accurate analysis at different abstraction levels. We can basically distinguish three possibilities, each of them with their own advantages and disadvantages: (1) utilization of link-level simulators, (2) use a system-level approach, or (3) exploit a network simulation platform to carry out a more detailed analysis. The first approach focuses on the last hop of the communication and allows the investigation of link related topics such as channel estimation, Multiple-Input Multiple-Output (MIMO) techniques or Adaptive Modulation and Coding (AMC) solutions; Vienna LTE simulator [6] appears as one of the most widely accepted solution. The second alternative usually gives a larger degree of flexibility, although some assumptions or simplifications are usually required; furthermore, there are works that are based on proprietary developments (in this case the use of Matlab is quite popular), while others use some of the few tools that have been made available, highlighting again the Vienna LTE Simulators [6]. On the third group, the choice that has gathered more attention is the `ns-3` platform [7], and the LTE-EPC Network Simulator (LENA) extension [8], which is in almost constant evolution. In this case, the most stringent limitation is the long simulation times, which are caused by the high level of detail that is added in the corresponding models. Table 1 provides a detailed analysis of some important characteristics to be considered. One of the limitations of the existing approaches is that they are not usually able to support relatively large and complex scenarios and if they were anyway used, the required simulation time would be unacceptable. Besides, existing solutions do not generally allow studying services evolution, nor the impact that different network techniques and solutions have on them.

Hence, the question is: what should a researcher do if he/she is interested in assessing the performance of a novel technique over a high-dense network deployment, comprising hundreds of access elements and users? According to our best knowledge there is not an answer to such question, and it is unlikely to find a one-fits-all solution. The Vienna LTE Simulator [6] is implemented in Matlab and it is rather focused on the lower layers, so it cannot appropriately model different service types (saturation or full-buffer scenarios are usually assumed) and the simulation is rather time-consuming, so the analysis do not usually

Table 1. Coverage of different parameters by analysis alternatives for wireless networks (LTE). A subjective ranking is established per parameter, filled circles mean good fitness while empty circles represent poor fitness

	Parameter	Link level simulation	System level simulation	Network simulation
	Description of the simulation characteristic that needs to be supported	*Detailed modeling of the lower layers, making it difficult to analyze solutions involving more than one source/destination pair*	*Most of the related literature use Matlab to carry out the analysis. Vienna LTE Simulator is one of the most relevant examples*	*ns-3, along with the LENA extension is one of the most relevant alternatives*
SCENARIO CHARACTERISTICS	*Scenario complexity: # of users and base stations*	◔ Due to the great level of detail within this type of tools, the number of elements is usually low; typically one access element and a number of users [9]	◕ Some simplifications are usually considered, so that the number of elements that can be included in the experiments is usually larger	◑ Simulation time required to analyze large network deployments is usually unacceptable [10], without the use of parallelization techniques [11]
	Time dimension: time that can be simulated, and possibility to keep track of services evolution	◔ Due to the computational load [12],simulated time is usually rather short, no need to keep track of services history	◔ The use of heavy development environments (Matlab) usually prevents from long simulated times	◕ Service evolution is usually considered; however, rather large computational time is required for long experiments
	Accuracy: degree of precision of the models that are used in the different experiments	● The detailed modeling of the lower layer mechanisms is the main goal of link level simulators, which ensures a rather accurate outcome	◕ Some simplifications are usually taken, although existing works follow the recommendations of the 3GPP	◕ Although some simplifications are assumed, precise implementation of the protocols is used

(Continued)

Table 1. *(Continued)*

	Parameter	Link level simulation	System level simulation	Network simulation
TECHNOLOGICAL LANDSCAPE	*Architecture shift: possibility to add support to new networking paradigms: SDN and NFV*	◔ As link-level solutions, they do not usually consider architectural issues, focusing on lower layers mechanisms and techniques	◕ Some of the possibilities brought by novel networking functionalities (tighter cooperation schemes) can be usually modeled	● Although it would require a large implementation effort, the integration of novel architectural approaches is usually possible
	Support for different technologies and solutions/techniques	◑ They are rather limited to the functionalities that were included from the beginning. The integration of different technologies is quite complex	◕ They usually have the flexibility to incorporate novel techniques and solutions due to some simplifications in the modeling of the physical layer	◕ Broad network simulation platforms, such as `ns-3`, are rather flexible, and allow the integration of different technologies and novel techniques and solutions
	Services modeling. Saturation conditions and/or constant load is assumed	◔ Very little attention is paid to the services modeling; the solutions usually focus on how the packets arrive at the lower layers	◑ Basic services characteristics can be included, although it is more frequent to see constant load and/or full-buffer [13]	● In network simulators real applications and services can be even used to generate the corresponding traffic
ADDITIONAL ISSUES	*Specific Vs. Generic purpose and learning curve*	◕ Since their scope is usually very focused, link-level frameworks require a shorter learning curve	◑ They are much more focused than network simulators, but not all its components might always be relevant	◔ They are usually rather heavy frameworks, and it takes a long time before being able to analyze the required scenarios
	Use of complementary methodologies. Use of optimization techniques?	◔ The usual goal is to analyze the performance of particular techniques, and the do not usually seek optimum performances	◑ Although this is not within the objectives of this type of tools, optimization techniques could be integrated	◑ The simulator architecture can be exploited to get an overall vision from which global optimization strategies might be executed

cover long time periods. The consequence is thus that several researches develop their own tools. This has some drawbacks, since most of the time put into the development is worthless from the point of view of the analysis that needs to be done and in addition, being quite ad-hoc solutions, the obtained results are not easily reproducible and integrated in other solutions.

In order to provide a better answer for such question, in this paper we introduce Generic Wireless Network System Modeler (GWNSyM), a flexible platform that allows easy-configuration and easy-analysis of rather large and complex system deployments, and that is specially focused on the evaluation of service performance when applying different network techniques. It has been designed and built with the main goal of being easily extended, with either new functionalities or strategies. We discuss its main design guidelines and some of its most relevant implementation features and we assess its feasibility, by carrying out an analysis comprising a highly dense access network and a large number of users.

The rest of this paper is structured as follows: Sect. 2 describes the main functionality of the developed tool, highlighting its most relevant implementation aspects. Then, Sect. 3 presents the overarching view of the scenario to be evaluated and the implemented network models; afterwards, the assessment of the proposed scenario will be discussed in Sect. 4. Finally Sect. 5 concludes the paper, providing and outlook of the future research lines we will pursue, exploiting the possibilities brought by the platform presented herewith.

2 Simulation Methodology

This section depicts the main principles of the methodology used by GWNSyM, which, in short, carries out the scenario assessment in a step-wise manner. It evaluates consecutive snapshots (i.e., discrete time moments), by applying the models implemented over the corresponding network elements, so that the outcome of one snapshot feeds the following one. This allows capturing the system memory, which is specially relevant for analyzing the quality of services. We start by describing the overall simulation work-flow, to afterwards depict the implementation principles that have been added to the tool to facilitate its extensibility.

2.1 General Approach

The overall methodology can be seen as a single experiment, which represents the analysis of a particular scenario according to some specific settings. An experiment comprises two main loops: (1) the outer one iterates over a number of snapshots, in each of them the network state is updated, considering, among other aspects, the outcome of the previous snapshot; (2) the inner loop deals with enforcing the adequate network behavior, according to the implemented models.

This methodology is generic enough and it is therefore not constrained by a particular technology or access policy. To this end, the following two concepts have been introduced to ensure this abstraction level.

- Type: it establishes an archetype of the elements in the network. A *Type* defines a particular network element, ranging from operators to user devices, as well as its particular configuration. The instantiation of elements belonging to the same *Type*, according to the current configuration, defines the set of elements of such *Type* for the experiment. A *Type* can be configured to aggregate other *Types*, and all of them together are treated as an independent set. For instance, we can define a *Type* for an LTE cell, C, which is then aggregated to macro (M) or pico (P) eNodeBs. This would result in two sets of C type: the first one comprising macro eNodeBs cells, $M \leftarrow C$, and the second one having the cells aggregated to pico eNodeBs, $P \leftarrow C$.
- Action: it represents a particular model to be used over the scenario; they range from propagation models of a specific technology to operator access policies. Each action takes one or more sets of elements and they are sequentially executed during the evaluation of every snapshot. On the other hand, there might be actions that do not need to be applied at every snapshot, but they are only meaningful at the beginning/end of the experiment. We have thus defined two specific action categories: *Pre-Action* and *Post-Action*.

Algorithm 1. Overall work-flow

```
Types definition
Configuration load
Elements instantiation and aggregation
$T \leftarrow \mathit{All\ set\ types}$
$A_{pre} \leftarrow \mathit{Pre\text{-}Actions}$
$A \leftarrow \mathit{Actions}$
$A_{post} \leftarrow \mathit{Post\text{-}Actions}$
$i = 0$
$n \leftarrow \#\ \mathit{Snapshots}$
for $b \in A_{pre}$ do
    Apply pre-action $b(M_b \subseteq T)$
end for
while $i < n$ do
    for $a \in A$ do
        Apply action $s(M_s \subseteq T)$
    end for
end while
for $e \in A_{post}$ do
    Apply post-action $e(M_e \subseteq T)$
end for
```

Algorithm 1 illustrates the overall methodology. First, we define and instantiate the corresponding types, according to the current configuration. As was discussed before, the configuration may define the aggregation of some types, resulting in sets that are independently treated within the scenario. Once all the network elements have been instantiated, the *Pre-actions* are applied over the corresponding type; this is particular useful for network deployments, since they are just performed at the beginning of the experiment. Afterwards, the main loop, line 13, iterates over the sequence of snapshots, and the inner loop, line 14, sequentially applies the appropriate actions. Finally, the experiment finalizes by executing the post-actions over the corresponding types, for instance, to generate experiment traces and statistics. It is worth highlighting that actions are assumed to be stateless and, hence, the network state is kept within the network elements.

2.2 Implementation Principles

Once the overall methodology has been introduced, we discuss some implementation details, by illustrating the definition of a scenario. The framework implementation comprises a set of `C++` libraries, leveraging generic and template-meta-programing (TMP) techniques, which have proved fundamental to provide the required abstraction level.

```
gnsm::System net_;
...
net_.AddType<User, UserConf>("USER");
net_.AddType<LteUe, LteUeConf>("LTE_UE", {Params});

net_.AddType<LteCell, LteCellConf>("CELL", {Params});
net_.AddType<LteEnb, LteEnbConf>("MACRO", {Params});
...
```

(a) Types definition

```
UserConf::ReadInnerConf(void) const
{
    return{{"LTE_UE", 1}}; // read from configuration
}
```

(b) Aggregation

Fig. 1. Example of element instantiations

The first step during the scenario description is the definition of *Types*. Figure 1 shows how different *Types* are defined and aggregated in an illustrative example. As can be seen in Fig. 1a, a name is given to a type, which is then defined with the `C++` classes that implement the network element functionality and its configuration. Furthermore, we can pass a number of arguments to the configuration class, for example, the path to where the configuration file is located. Finally, the libraries also allow the aggregation of types, as defined by the current configuration. In the example shown in Fig. 1b, the *USER* type will keep one element belonging to the *LTE_UE* type.

Once the types are defined, the different actions that establish the network behavior are registered, identifying the elements that have to be passed around during the execution; Fig. 2 shows different ways of using the actions. It is worth noting that aggregated elements can be also passed around, by indicating the

```
net_.PreAction<MacroDeploymentr>({"MACRO"}, {Params.});
...
net_.Action<LteScan>({"USER", "MACRO"}, {Params.});
...
net_.PostAction<MacroLoad>({"MACRO::*::CELL"}, {Params.});
...
net_.Run();
```

Fig. 2. Example of action registrations

set where they have been inserted; for instance, `MACRO::*::CELL` would indicate that cells belonging to all macro base stations set will be passed to the `MacroLoad` action.

Besides the aforementioned details, the tool libraries have been implemented with the idea of fostering their re-usability. To this end, two main decision were taken: first, the tool libraries do not impose any inheritance constraint to the `C++` classes for both types and actions, but minimal interface checking is performed at compilation time; on the other hand, a wrapping functionality has been added, enabling that some types can be passed to specific classes with a customized interface. These two aspects facilitate reusing legacy code of network models, in particular the implementation of actions.

3 Scenario of Interest

This section describes the main characteristics of the scenario that will be used to assess the feasibility of GWNSyM, as well as the different modules that have been implemented to appropriately model it.

The evaluation comprises a large dense urban LTE environment, where both macro and small cells are deployed, and different types of end users generate the corresponding traffic demand. The analysis that will be discussed in the Sect. 4 focuses on the downlink.

In order to show the capabilities of the GWNSyM framework, we have incorporated two different aspects, affecting both the system architecture and the access selection procedure, over the corresponding access network.

- **Cell clustering.** This feature is related to the use of NFV techniques in the so-called Cloud Radio Access Network (C-RAN) concept, where the eNodeB functionalities are moved to the cloud, to leverage a more centralized management of the corresponding resources.
- **CoMP - Joint Transmission.** We assume that access elements can exploit cooperation capabilities, so that a group of cells can use the same resources for a particular user. Note that the two aspects are related, since the NFV approach would facilitate these cooperation techniques.

In order to include the aforementioned functionalities, we can exploit the aggregation capabilities of the proposed framework. In this sense, access elements are grouped in clusters, so that each of them comprises one macro eNodeB and a configurable number of small cells. Furthermore, we assume that each cluster is managed by one Baseband Unit (BBU), and we impose computational constraints, so that we effectively limit the number of bearers each cluster is able to manage.

Concerning traffic, the service model does not assume saturation (full-buffer) conditions, and resources just need to be granted when a user has an active service, according to the defined access policy; both aspects are detailed below.

3.1 Services Modeling

As was already said, and for a particular time (snapshot), users just require connectivity if they have an active service. During a single experiment, a user can initiate a number of sessions of a service; if any of them are rejected (or dropped), we assume that it is not recovered. Hence, if a service is not satisfied at a particular snapshot, such particular service session is not considered until a new one is started; this feature, which allows keeping the history of the simulation, can be exploited to reproduce the very same traffic patterns in different experiments. In order to model this behavior, we have implemented a state-machine with the states described below.

- **Idle**: this is the initial state of a service, corresponding to a situation in which connectivity is not required.
- **Active**: the service has an ongoing active session and it is connected.
- **Rejected**: the service reaches this state when the network cannot allocate resources to satisfy its demand when it is initially started. This state will be kept throughout the session (its duration is known a-priori), to move to *Idle* state afterwards (until a new session is started again).
- **Dropped**: a service is considered as *Dropped* once it has already started but it cannot finish successfully. As in the previous case, this state is maintained until the current session finishes.

It is worth noting that *Dropped* and *Rejected* states, despite modeling similar circumstances, have a different impact on the perceived Quality of Experience (QoE), since it is usually considered that dropping a service has a much more negative impact on the QoE.

3.2 Access Selection and Resource Allocation

When a user has a specific traffic demand for a particular service, the access selection action is executed to satisfy such demand. In the scenario that we have assumed for this work, we are analyzing the benefits of CoMP techniques, and therefore a set of different cells are selected to provide connectivity for a particular user/service request.

The process basically works as follows: we sort the cells according to the received power, Reference Signal Received Power (RSRP), which is established using the propagation model that was previously configured (we are exploiting the ones established by the 3GPP specifications). Afterwards, according to the number of cells a user is able to connect to (configuration parameter of the CoMP functionality), those with the highest RSRP are selected, and the number of required resources is calculated. If one of the previously selected cells is not able to allocate such number of resources, it is discarded, and the next in the list is then selected.

Access elements manage a number of resources, corresponding to the system bandwidth that is configured during the scenario setup, following the characteristics of the LTE-OFDMA scheme. In this sense, assuming that user i selects a set of cells $\mathfrak{J}$ for a given demand D_i, the number of resource blocks that need to be allocated is given by: $N_{\mathrm{RB}i|\mathfrak{J}} = \frac{D_i}{b_{\mathrm{RB}} \cdot S_{i|\mathfrak{J}}}$; where b_{RB} corresponds to the bandwidth of each resource block, and $S_{i|\mathfrak{J}}$ represents the link spectral efficiency, which is calculated as shown in Eq. 1 where both b_{eff} and $\mathrm{SINR}_{\mathrm{eff}}$ are system parameters, as indicated in [14]. Finally, the Signal to Interference plus Noise Ratio (SINR) is calculated with Eq. 2, where γ_{mk} is the power received by user m from cell k.

$$S_{i|\mathfrak{J}} = b_{\mathrm{eff}} \eta \log_2 \left[1 + \frac{\mathrm{SINR}_{i|\mathfrak{J}}}{\mathrm{SINR}_{\mathrm{eff}}} \right] \tag{1}$$

$$SINR_{i|\mathfrak{J}} = \frac{\sum\limits_{j \in \mathfrak{J}} \gamma_{ij}}{N_0 + \sum\limits_{k \notin \mathfrak{J}} \gamma_{ik}} \tag{2}$$

4 Scenario Assessment

Once the general components and functionalities of the scenario have been presented, this section discusses the results that were obtained with GWNSyM, paying special attention to network load and Quality of Service (QoS) levels.

The scenario consists of a two-tier LTE network. The first layer corresponds to tri-sector macro eNodeBs, deployed following an hexagonal pattern, while the second layer comprises small eNodeBs, characterized by a lower transmission power. The main scenario settings can be found in Table 2. Besides, from an architectural point of view, we assume that a BBU manages one cluster, which contains one macro and a number of small cells. We furthermore consider that the front-haul connection (from the LTE cells to the BBU) has un-limited capacity (i.e. fiber connection) but processing capacity constraints are imposed in the BBU, so that only a number of cells can be processed at the same time. Concerning propagation models and antenna patterns, we have implemented those defined by the 3GPP for urban areas and different cell sizes [15,16]. As shown in Table 2 the scenario considers the possibility of having non-line-of-sight between the users and the corresponding cells.

Users are running two different types of services: a light one, which could resemble an application such as web browsing; and a heavier one, which requires 1 `Mbps`, that would mimic a video service. Both types of services follow an

Table 2. Simulation setting

LTE layout FDD 2x20MHz @2.1 GHz			
Macro layer	ISD 500 m, 7 tri-sector sites		
	Max. tx. power 46 dBm		
	Antenna GAin 15dBi, 15 down-tilt		
Pico layer	Random Location		
	Max. tx. power 37 dBm		
	Omni-antenna		
UE	DL NF 7 dB		
	Rx. Gain 7 dB		
LTE layer	L (dB) as a function of the distance $d[m]$		
Macro$_{\mathbf{NLOS}}$	$139.1033 + 39.0864 * (log_{10}(d) - 3)$		
Macro$_{\mathrm{LOS}}$	$36.2995 + 22 * log_{10}(d)$if $d < 328.42$		
	$40 * log_{10}(d) - 10.7953 \quad$ if $d > 328.42$		
Small$_{\mathbf{NLOS}}$	$145.48 + 37.5 * (log_{10}(d) - 3)$		
Small$_{\mathbf{LOS}}$	$103.8 + 20.9 * (log_{10}(d) - 3)$		
	LOS probability as a function of the distance d $[m]$		
Macro	$P_{LOS} = \min(\frac{18}{d}, 1) \cdot (1 - e^{\frac{-d}{36}}) + e^{\frac{-d}{36}}$		
Small	$P_{LOS} = 0.5 - \min(0.5, 5 \cdot e^{\frac{-156}{d}}) + \min(0.5, 5 \cdot e^{(\frac{-d}{30}}))$		
Service	Traffic (Kbps)	ON/OFF (s)	% users
Heavy	1000	300/600	60
Light	128	120/60	40

ON-OFF model whose parameters are indicated in Table 2. Furthermore, 500 users are deployed, and they follow random way-point mobility pattern, with a speed that is randomly selected within $(1, 3)$ $\frac{m}{s}$; hence, the position in one snapshot is not independent from the previous ones. It is worth noting that in order to ease the evaluation, we have restricted it to those cells within the central cluster, while the rest of cells in the scenario are considered as interfering ones. It is worth noting that, although the scenario includes two different services, only one of them is active at each user, according to the statistics shown in Table 2.

In the following, we will discuss a number of illustrative results that can be obtained with GWNSyM, for different configurations, in terms of network load and service performance. In order to ensure the statistical validity of the results, 10 independent runs have been executed per configuration, each of them lasting one hour (3600 s.), with a step of 10 s. Hence, 360 snapshots are evaluated in each experiment.

First, we study the impact that different CoMP configurations (i.e. maximum number of cells a user can be simultaneously connected to) have over the cells

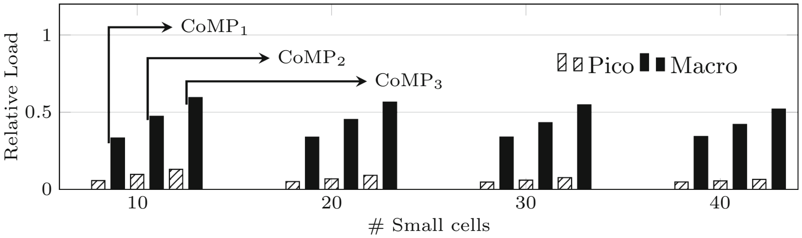


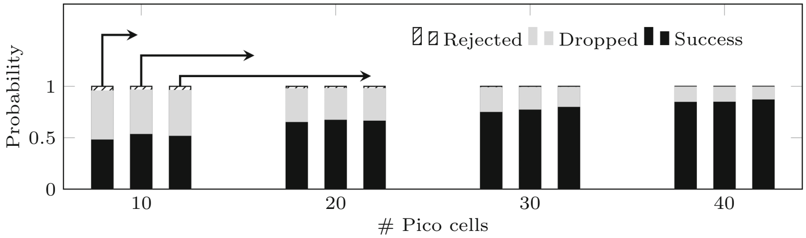
Fig. 3. Cell load for different number of deployed pico-cells

load, increasing as well the small cell density; in all cases, we assume that the BBU has unlimited processing capacities. In the different figures, the CoMP configuration is indicated by a sub-index, so that $CoMP_n$ would actually mean that users connect to n cells.

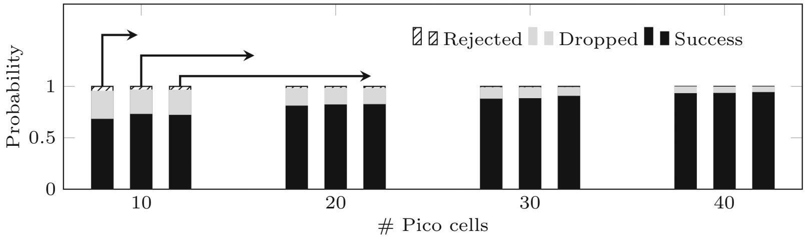
Figure 1 shows the average relative load of the cells for the two base station types. As can be seen, most of the traffic is carried by the macro layer. On the other hand, we can observe that the deployment of more small-cells does not yield a strong impact, since we do not see a remarkable difference when either 10 or 40 small-cells are deployed.

In order to assess the influence that CoMP configurations and network density have on the service QoS, Fig. 4 shows the probability of a service to be successful, dropped or rejected. If we compare the results for both types of service, we can conclude that light connections (with less stringent capacity requirements) are more likely to finish successfully, in particular for smaller network densities. Furthermore, we can also see that it is more likely for a service to be dropped than rejected; this would correspond to a situation in which the service started with a pico-cell and then, if the user moved out of its coverage, there were not available resources at the macro base station to keep the service active. Finally, if we look at the influence of CoMP configurations, the results show that they does not have a relevant impact on the service performance.

In our last result, we are interested in assessing the impact of having limited processing capabilities on the BBU. For that, we start from the scenario with the highest density (40 small cells) and Fig. 5 shows the QoS when some of those small cells are switched off. In particular, we incorporate a smart switching-off policy, discarding those with the lowest accumulated RSRP (values measured at the end-users). This rule is applied for every snapshot during the experiment. If we compare the performance obtained when switching off those cells with the one achieved earlier (that would actually mimic the case where the cells to be switched off are randomly selected), we can observe that the service performance is improved, more notably for the heavy services. For instance, if we compare the values when switching-off 10 small-cells (30 are still available) with the ones that were previously see for 30 cells, we can see a gain of around 5%.

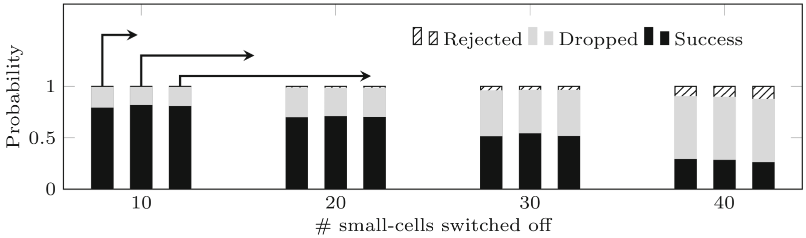


(a) Heavy services

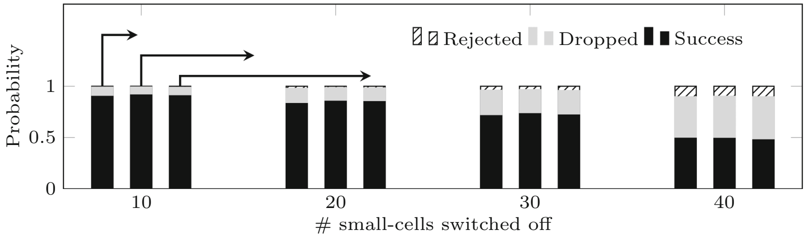


(b) Light services

Fig. 4. Service performance vs. number of small cells



(a) Heavy services



(b) Light services

Fig. 5. Service performance vs. number of switched-off small cells, when 40 small-cells are initially deployed

5 Conclusion

The advent of the 5G is broadening the research landscape of cellular networks. The scientific community does not just address novel technologies, or techniques to improve the quality of service experienced by the end users, but new axis, such as novel topological approaches and/or architectural paradigms, have been added to the already complex playground. One of the consequences is that there is not a *de-facto* methodology/tool/framework widely accepted to analyze such complex scenarios.

Although there exist some alternatives that have reached more momentum than others, they still show several limitations, especially if we aim at analyzing complex and large network deployments and/or we want to leverage a more detailed modeling of the services, as was seen in the survey-type analysis that we carried out. In order to overcome such limitations we have presented the design and implementation of the Generic Wireless Network System Modeler (GWNSyM), a novel approach that enables a flexible and quick analysis of complex cellular network deployments. We have used an illustrative use case, over a large HetNet scenario, to challenge GWNSyM, assessing the performance of CoMP techniques and leveraging a NFV solution.

We have seen that the type of service clearly influences the performance results, while they are not strongly impacted by the use of CoMP techniques. Furthermore, we also assessed that a selective cell switching-off technique would actually be beneficial from the point of view of the performance.

The GWNSyM framework opens a broad range of possibilities and we are planning to exploit it in our near-term research. We are in particular interested in fostering the use of optimization techniques to set a reference level to compare the performance of different access selection policies, and resource management techniques and solutions. In addition, we are also planning to make the whole framework available to the scientific community as open source. The idea is to allow other researchers to use GWNSyM and, at the same time, benefit from their feedback to continuously improve and broaden it.

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