# Performance Evaluation of IMS/NGN Network with SDN-Based Transport Stratum

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**Abstract.** The paper continues research on the use of the Software-Defined Networking (SDN) concept in the IP Multimedia Subsystem/Next Generation Network (IMS/NGN) transport stratum to increase flexibility of transport resource control and management mechanisms and make them independent of hardware solutions. The developed simulation model is used to examine the IMS/NGN network performance expressed by standardized Call Processing Performance (CPP) parameters such as mean Call Set-up Delay and mean Call Disengagement Delay. The research is carried out in a multidomain network, taking into account a wide range of service scenarios as well as parameters of network and generated traffic. As a result, the parameters, which are most important from the point of view of the performance are indicated, along with possible further steps to increase the performance.

**Keywords:** IMS, NGN, SDN, 5G, simulation model, call processing performance.

## 1 Introduction

The IP Multimedia Subsystem (IMS) [1] architecture includes a set of functional units designed to control the process of providing multimedia services to users based on the IP protocol. It is a very important component of the 4G and 5G mobile networks [1]. It also forms the basis for the operation of the Next Generation Network (NGN) [2] service stratum, which is, therefore, also called the IMS/NGN network.

In the NGN architecture, apart from the service stratum (based on IMS), there is also a transport stratum that provides resources for the services requested by users. In the ITU-T standards for NGN [2], there are no assumptions regarding the technologies used in the transport stratum, the only requirement is support for transporting IP packets. Therefore, it is possible to use the Software-Defined Networking (SDN) [3] concept, which provides the ability to control and manage transport resources independently of the technology and hardware manufacturers.

However, the cooperation of the SDN concept with the IMS/NGN network has not yet been standardized and its verification is required. Performed related work review [4] indicated that there are no analytical and simulation models for IMS/NGN network

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with SDN-based transport stratum. Moreover, existing practical solutions (testbeds) do not take into account ITU-T standards for NGN networks (primarily in the field of resource control – RACF unit [2]) and do not have the source code available, which causes problems with their further use. In response to these drawbacks, the authors proposed their own testbed [5] which does not have the above-mentioned limitations. The experience gained from the implementation of this testbed (message exchange procedures, data regarding message lengths and processing times, etc.) was used to propose a simulation model and demonstrate that application of the SDN concept in the transport stratum of the IMS/NGN network is possible [4]. The aim of this paper is to use the simulator [4] to examine the performance of such a solution taking into account multiple network domains and a wide set of service scenarios as well as parameters of network and generated traffic. Mean Call Set-up Delay ($E(CSD)$) and mean Call Disengagement Delay Call ($E(CDD)$) are taken as a performance measure, which are a subset of standardized Call Processing Performance (CPP) parameters [6,7] important for both network users and operators.

The rest of the paper is organized as follows. Section 2 provides a brief description of the performed simulation conditions. Section 3 presents and discusses the obtained research results. Section 4 summarizes the paper and presents further work.

## 2 Simulation Conditions

The simulation model presented in [4] will be used to conduct research in the IMS/NGN network consisting of two domains managed by two operators. Due to space limitations the details regarding the simulator operation (network structure, service scenarios, software structure, exact course of simulation and methods of obtaining final results) are not provided in this paper and can be found in [4]. To understand the results presented in the next section, only a brief description of the simulator input (Table 1) and output variables (Table 2) is given. Apart from the $E(CSD)$ and $E(CDD)$ times presented in Table 2, associated confidence intervals are also obtained as final simulation results.

In the conducted research, relatively high values of maximum simulation duration time (sim-time-limit = 72000 s) and maximum number of generated calls (call_num_max = 1000000000) were assumed. In this way, the end of each simulation was determined by the values of the confidence intervals for mean *CSD* and *CDD* times, which should be less than 5% of these times (conf_interv_max = 5%). The results of the performed experiments are described in the next section.

## 3 Results

The aim of the research presented in this section was to check how the parameters of IMS/NGN network with SDN-based transport stratum and traffic generated to this network (Table 1) affect its performance, described by CPP parameters (Table 2). The input data sets for the conducted experiments are presented in Table 3. For each set, the value of one input variable is changed in a wide range for all related network elements, while the remaining input variables have the default values given in Table 1.

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**Table 1.** The most vital input variables of the simulator.

| Variable name | Description | Default value |
|---|---|---|
| sim-time-limit | Maximum simulation duration time [s]. | 72000 |
| warmup-period | Warm-up period duration time [s]. | 1250 |
| call_num_max | Maximum number of generated calls. | 1000000000 |
| meas_per_num | Number of measurement periods. | 5 |
| conf_level | Confidence level. | 0.95 |
| conf_interv_max | Threshold value for confidence intervals. | 5% |
| delay | Base delay value in [s] defined separately for all modeled network elements. For SUP-FE/SAA-FE servers it applies to all messages. For the remaining elements it concerns a base message, while processing time of other messages is proportional according to the ak variable (more details are available in [4]). The list of base messages for particular network elements is also provided in [4]. | 0.01 SUP-FE/SAA-FE, 0.001 for programmable switches, 0.0005 for other elements |
| link_datarate | Link bandwidth in [bps]. | 50000000 |
| link_length | Link length in [m]. | 200000 |
| res_info_prob | Probability of controller having information about the resource state in programmable switches. | 0.7 |
| res_avail_prob | Probability of resource availability in particular programmable switch. | 1 |
| intrad_call_intensity | Intra-operator call set-up request intensity in [1/s]. | 50 |
| interd_call_intensity | Inter-operator call set-up request intensity in [1/s]. | 50 |
| registr_intensity | Registration request intensity in [1/s]. | 50 |
| multiple_access_areas_ratio | Ratio of intra-operator calls concerning multiple access areas to all generated intra-operator calls. | 0.5 |

**Table 2.** Successful call scenarios and related output simulation variables.

| Scenario name and description | Output variables |
|---|---|
| b1 – successful intra-operator call performed in domain 1 with both UEs connected to the same access areas | $E(CSD)_{b1}$, $E(CDD)_{b1}$ |
| b2 – successful intra-operator call performed in domain 2 with both UEs connected to the same access areas | $E(CSD)_{b2}$, $E(CDD)_{b2}$ |
| d1 – successful intra-operator call performed in domain 1 with both UEs connected to different access areas | $E(CSD)_{d1}$, $E(CDD)_{d1}$ |
| d2 – successful intra-operator call performed in domain 2 with both UEs connected to different access areas | $E(CSD)_{d2}$, $E(CDD)_{d2}$ |
| f1 – successful inter-operator calls originated in domain 1 | $E(CSD)_{f1}$, $E(CDD)_{f1}$ |
| f2 – successful inter-operator calls originated in domain 2 | $E(CSD)_{f2}$, $E(CDD)_{f2}$ |

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**Table 3.** Input data sets for the performed investigations.

| Set | Input variable | Range | Set | Input variable | Range |
|---|---|---|---|---|---|
| 1 | CSCF_delay | 0.1-0.8 [ms] | 8 | res_info_prob | 0-1 |
| 2 | SUP-FE_SAA-FE_delay | 0.1-400 [ms] | 9 | res_avail_prob | 0-1 |
| 3 | GATEAPP_delay | 0.1-1.4 [ms] | 10 | intrad_call_intensity | 1-130 [1/s] |
| 4 | CONTROLLER_delay | 0.1-1 [ms] | 11 | interd_call_intensity | 1-100 [1/s] |
| 5 | SWITCH_delay | 0.1-2.1 [ms] | 12 | registr_intensity | 1-450 [1/s] |
| 6 | link_datarate | 5-200 [Mbps] | 13 | multiple_access_areas_ratio | 0-1 |
| 7 | link_length | 1-1000 [km] | | | |

For example, for input data set no. 6, bandwidths of all links in the network are set equally to values ranging from 5 to 200 Mbps, and the values of the remaining parameters are consistent with Table 1. The names of the input variables in Table 3 are generally the same as in Table 1. The exception is the "delay" parameter representing the base delay of the network elements (Table 1). In the performed investigations (Table 3, input data sets no. 1-5), it is changed for particular groups of network elements: for all CSCF servers (CSCF_delay), SUP-FE/SAA-FE servers (SUP-FE_SAA-FE_delay), GATEAPP units (GATEAPP_delay), SDN controllers (CONTROLLER_delay) and programmable switches (SWITCH_delay).

In the next part of the section, all obtained research results will be discussed (all input data sets from Table 3). Due to space limitations, only the results of the $E(CSD)_{b1}$, $E(CDD)_{b1}$, $E(CSD)_{f1}$, $E(CDD)_{f1}$ times for selected input data sets will be presented (Figs. 1-3). The choice of presented output variables results from identical parameters of elements and traffic in both network domains. Therefore, CPP parameters for the same types of calls generated in domains 1 and 2 are similar and the results for calls generated in domain 2 (scenarios b2, d2, f2; Table 2) are not presented. At the same time, for the examined set of network parameters, the results obtained for scenario d1 are similar to those obtained for scenario b1 and only the latter are presented.

The first analyzed group of IMS/NGN network parameters includes base delays of elements (input data sets no. 1-5 from Table 3). For most network elements (CSCF servers – Fig. 1 (left), GATEAPP units, SDN controllers), increasing their base delay enlarges the number of messages in the queues of their processors. This leads to an increase in all analyzed CPP parameters. At a certain base delay value (dependent on the type of network element, e.g. 0.7 ms for CSCF servers – Fig. 1 (left)), the processor starts having problems with handling incoming messages and the analyzed output variables begin to grow rapidly. Additionally, in Fig. 1 (left) some characteristic relations between mean *CSD* and *CDD* times in IMS/NGN network can be observed. As expected, $E(CSD)$ and $E(CDD)$ times are always higher for inter-operator calls (scenario f1) than for intra-operator calls (scenario b1). Moreover, for particular scenarios, $E(CSD)$ times are always higher than $E(CDD)$ times, which results from more complicated message exchange procedures when establishing a call.

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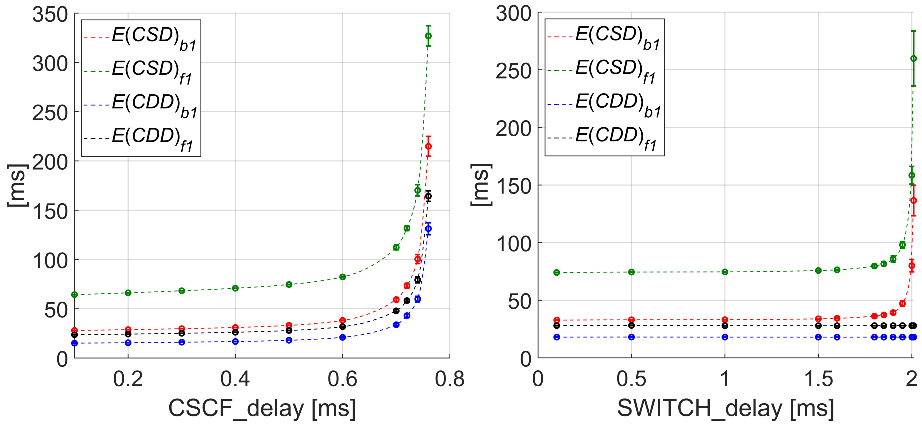


**Fig. 1.** Results for data set 1 (left) and 5 (right) from Table 3.

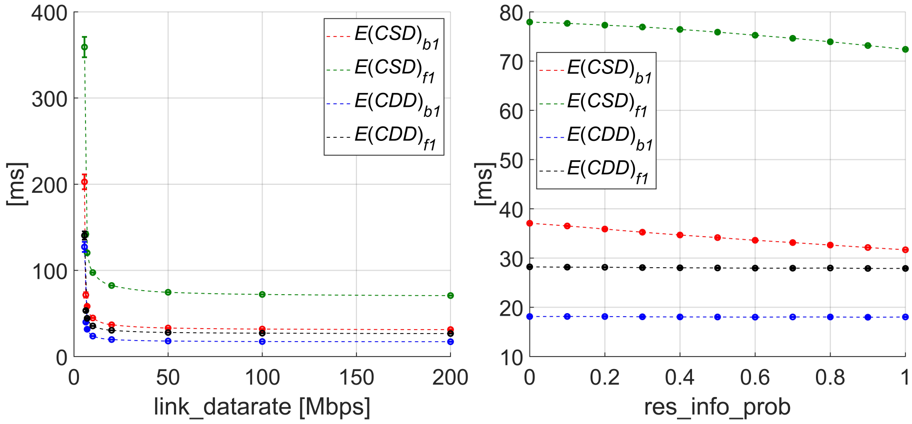


**Fig. 2.** Results for data set 6 (left) and 8 (right) from Table 3.

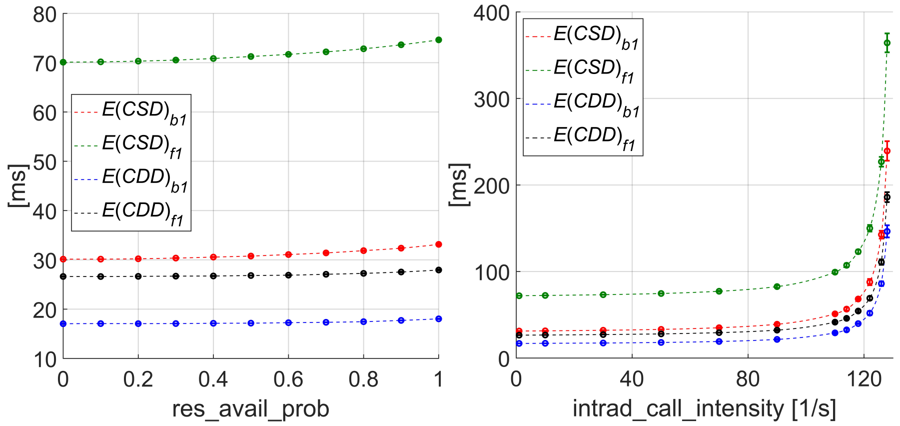


**Fig. 3.** Results for data set 9 (left) and 10 (right) from Table 3.

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For programmable switches (Fig. 1 (right)), a similar increase in $E(CSD)$ times with rising base delay can be observed as in the previously discussed cases (Fig. 1 (left)). However, here there are no changes in $E(CDD)$ times, which results from the fact that during disengaging a call SDN controllers do not wait for the switches' response regarding the release of resources. It is assumed that this operation is always successful [4].

A separate case are the SUP-FE/SAA-FE servers, which do not contain a queue in the simulation model, but respond to each received message after a given base delay. These servers are used only when establishing inter-operator calls. This results in a linear increase in the $E(CSD)_{f1}$ time with the base delay of SUP-FE/SAA-FE servers and no changes in the other presented output variables.

Input data sets no. 6 and 7 allow examining how parameters of the links dedicated for signaling messages affect CPP parameters. It is important to ensure appropriate link bandwidths so that they are not overloaded and do not introduce large delays (10 Mbps is sufficient for the tested sets of network parameters, Fig. 2 (left)). Additionally, link lengths, which proportionally increase propagation delay (5μs/km for optical links), can also have a significant impact on mean *CSD* and *CDD* times. For the most complex process of establishing an inter-operator call, the values of $E(CSD)_{f1}$ times increase by about 200 ms when link length is changed from 1 km to 1000 km.

The res_info_prob parameter determines the probability that the SDN controller knows the status of resources in programmable switches and has information that transport resources are available. Therefore, there is no need to query the switches about the status of resources and fewer messages are exchanged in the network, which results in shorter mean *CSD* and *CDD* times (Fig. 2 (right)). When the controller does not know the status of resources, it queries the programmable switches, which respond positively according to the res_avail_prob probability (Fig. 3 (left)). The lower the value of this probability is, the more call set-up procedures fail, which involve exchange of fewer messages than for the procedures that are successful. This results in a lower load of network elements and lower values of the analyzed output variables. The influence of the res_avail_prob parameter on the analyzed output variables presented in Fig. 3 (left) is relatively small, because for these studies in 70% of cases the controller knows the status of resources and does not have to query the switches about them (res_info_prob = 0.7). For higher number of resource queries sent to switches (lower res_info_prob values) the res_avail_prob parameter will have a stronger impact on the analyzed $E(CSD)$ and $E(CDD)$ times.

Input data sets no. 10-12 show the impact of intra-operator call (Fig. 3 (right)), inter-operator call and terminal registration request intensity on $E(CSD)$ and $E(CDD)$ times. Increasing the above-mentioned intensities results in a larger number of messages in the network and, consequently, causes an increase in the load of network elements. Similarly to the case of base delays, there is a value of each intensity above which the network is overloaded and the analyzed mean *CSD* and *CDD* times increase rapidly. This value is dependent on the request type – the smallest for inter-operator calls (about 90 [1/s]; this is the most complicated message exchange scenario in the network) and the largest for terminal registration (about 400 [1/s]).

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For the input data set no. 13 the influence of the multiple_access_areas_ratio parameter on the output variables of the simulator was examined. This input variable turned out to be insignificant – mean *CSD* and *CDD* times increase by about 1-2 ms when the value of the multiple_access_areas_ratio parameter changes from 0 to 1. Such a slight change in the analyzed output variables was caused by the same parameters of network elements and traffic in both domains. When establishing an intra-operator call with several access areas, resources are reserved simultaneously in the access and core networks, but these processes take a similar amount of time. As a result, the P-CSCF server does not wait significantly longer for the result of resource reservation, which would drastically increase mean *CSD* time. Of course, due to additional resource reservation in the core network, slightly more messages are exchanged, but this does not have a critical impact on the analyzed CPP parameters.

To sum up the obtained results, it can be stated that the performance of the IMS/NGN network with the SDN-based transport stratum is the most influenced by:

- base delays of service stratum elements (CSCF servers) and transport stratum elements (GATEAPP, CONTROLLER, SWITCH),
- link parameters (bandwidths and length),
- intensities of generated requests (intra-operator and inter-operator calls, terminal registration).

The large impact of transport stratum elements base delays, which result from their performance, draws attention. Therefore, these elements should have an appropriate processing power. Another approach is to modify the logic of the SDN-based transport stratum to reduce the number of messages exchanged for the resource reservation and release process, which will decrease its load. This will be the subject of our further research.

## 4 Conclusions

The paper examines the performance of the IMS/NGN network with the SDN-based transport stratum, which is assessed by the $E(CSD)$ and $E(CDD)$ times, a subset of standardized Call Processing Performance parameters important for both network users and operators. The studies use the previously developed and verified simulation model [4]. Several message exchange scenarios (intra-operator and inter-operator calls, terminal registration) are taken into account along with a wide set of parameters of network and generated traffic (including the probability of resource availability, which determines whether a given call request will be successfully handled).

The studies cover 13 input data sets. In each of them, one input variable is modified in a wide range for all related network elements (equally in all domains), and the remaining input variables have default values. As a result of the conducted studies, the parameters that have a significant impact on the performance of the IMS/NGN network with the SDN-based transport stratum are indicated. These are: base delays of selected elements (CSCF servers, GATEAPP, CONTROLLER, SWITCH), link parameters (bandwidth and length), intensities of all types of generated requests. It is demonstrated

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that with appropriate values of these parameters, the network is able to handle even hundreds of call set-up requests per second.

As already indicated, the efficiency of transport stratum is crucial for performance of the whole IMS/NGN network. In addition to using GATEAPP, CONTROLLER, SWITCH elements with low base delay, another approach is to reduce their load by changing the logic of their operation. One of the solutions that will be tested is the quota-based algorithm [8,9]. In this approach, resources are allocated with some reserves and most call set-up requests are only mapped in the SDN controller resource database, without communication with programmable switches. It can limit the number of messages exchanged in the network.

Regardless of this, it is planned to extend the presented research in order to include situations in which the parameters of elements and traffic are different in individual network domains. This will allow checking how particular parameters of one domain affect mean *CSD* and *CDD* times for all types of calls generated in all domains.

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