A System Simulator for 5G Non-Terrestrial Networks Evaluations

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***Abstract*—3rd Generation Partnership Project (3GPP) is working on the specifications related to the 5G satellite component, i.e., 5G Non-Terrestrial Networks (NTN). 5G NTN specifications can be used to build different spaceborne or airborne 5G systems. This article presents a 5G NTN extension to an open-source Network Simulator 3 (ns-3) and its 5G extension (5G LENA). The objective is to use the resulting System Level Simulator (SLS) in 3GPP standardization to evaluate different system concepts and parameterizations.**

Keywords— Ns-3, Network Simulator 3, 5G, New Radio, NTN, Non-Terrestrial Networks, Radio Access Network, RAN, Simulator, System Simulator, SLS, Simulation Services, Magister SimLab

I. Introduction

Fifth generation (5G) telecommunication systems are expected to meet the world market demands of accessing and delivering services anywhere and anytime. [1] Ericsson Mobility Report 2020 [2] predicts that global total mobile data traffic is estimated to reach around 51EB per month by the end of 2020 and is projected to grow by a factor of around 4.5 to reach 226EB per month in 2026. In 2026, 5G is expected to account for an estimated 54 percent of total mobile data.

Satellite based connectivity becomes indispensable where there absolutely cannot be terrestrial coverage or where building such is not economically feasible. Secondarily, satellite systems can provide increased security, resilience, as well as support for connectivity in crisis situations. Instead of competition, satellite systems should be considered to complement the terrestrial networks in providing services over uncovered or under-served geographical areas.

3rd Generation Partnership Project (3GPP) has been working on the 5G Non-Terrestrial Networks (NTN) from 2016 onwards. First with a study item, and currently, with a “Solutions for NR to support non-terrestrial networks (NTN)” work item (WI) targeting at 3GPP Release 17. [7] [8] WI targets at developing technical specifications to support especially transparent payload-based spaceborne systems, i.e., LEO (Low Earth Orbit) and GEO (Geostationary Earth Orbit) scenarios. But the specifications would support also different airborne scenarios, such as Unmanned Aerial Systems (UAS) and High-Altitude Platform Station (HAPS) systems. The 5G NTN challenges, opportunities, key features, architecture and standardization has been discussed in numerous articles, e.g. [3] [4] [5] [6].

5G has the unique possibility of becoming the first global standardized system for both terrestrial and satellite connectivity. The standardization of the satellite component itself shall offer several benefits, e.g., lower barrier for new players to enter the satellite market, interoperability between different manufacturers, and resulting lower pricing. In addition, NTN shall offer service continuity for devices benefiting from both terrestrial and satellite based 5G coverage.

System Level Simulators (SLS) have an important role in the 3GPP standardization process, e.g., to study the system performance and need for new system concepts, but also to evaluate different implementation options and parameterization. Most major players in 3GPP have their in-house developed confidential system simulators to support the standardization process. However, there are no open source 5G system simulators with Non-Terrestrial Networks (NTN) support nor impartial actors providing simulation support for the 3GPP standardization.

This article presents the NTN support for Network Simulator 3 (ns-3) and 5G LENA based open-source SLS. The SLS can be used in 3GPP RAN (1-4) standardization as well as to evaluate different Radio Resource Management (RRM) algorithms and related performances. We shall also integrate the NTN SLS to the Magister SimLab simulation service, which provides easy-to-use workflow, readymade analytics as well as utilize the power of cloud computing [9].

In section II we briefly review existing open source 5G system simulators. In section III we describe the modifications and extensions done on top of the 5G LENA system simulator to support the NTN system and scenarios. In section IV we present the verification results of the simulator within the 3GPP NTN calibration scenarios and finally in section V we provide the conclusions.

II. 5G System Simulators

There exist a few open-source system simulators for 5G research purposes, e.g. “5G K-Simulator” developed in Korea Advanced Institute of Science and Technology [10], a Matlab based 5G system simulator developed in Technical University of Vienna (TU Wien) [11] [12], “5G-air-simulator” developed in Politechnico di Bari [13], Simu5G Omnet++ simulator 5G extensions by University of Pisa [14] and 5G LENA [15] ns-3 5G extensions by Centre Tecnològic Telecomunicacions Catalunya (CTTC).

“5G K-Simulator” [10] is an interesting option since it is claimed to support execution in a cloud computing environment. However, the source code was not available at the time of writing restricting further evaluation. Vienna 5G system simulator [7] requires commercial Matlab and some add-on toolbox licenses, and, in addition, it is licensed under an academic license making it challenging for a commercial usage. Similarly, Simu5G [10] is free for academic usage but requires a commercial license for industrial usage. “5G-air-simulator” [13] is an extension of the LTE-Sim simulator for LTE air interface. It seems an attractive solution, even though it focuses only on the air interface technology.

Ns-3 is a discrete-event network simulator targeted primarily for research and educational use [16]. 5G-LENA is a 5G New Radio (NR) implementation, that is designed as a pluggable module to ns-3 [15]. 5G LENA development is open to the community to foster early adoption, contributions by industrial and academic partners, collaborative development, and results reproducibility.

5G LENA simulator development started from the mmWave module [17] and it is a natural evolution of the previous generation LTE/EPC Network Simulator [18]. It incorporates fundamental physical and Medium Access Control (MAC) layer NR features aligned with New Radio (NR) Release 15 TS 38.300 and compatibility with 3GPP channel model in TR 38.901. The first public release 1.0 of NR module was released in September 2020 [19]. 5G LENA simulator and its features has been previously presented in several publications e.g., in [20] [21] [22] [23].

From the available open-source simulation platforms we have selected ns-3 and 5G LENA as a baseline for the 5G NTN extensions due to e.g., its fully open-source and free nature, active maintenance / development, community support, higher layer protocol support, and our previous experience and competence.

III. 5G NTN Simulator features

A. Assumptions

The 3GPP NTN simulation assumptions are listed in [7]. A transparent satellite payload has been assumed, where gNB is on the ground and satellite acts as an analogue Radio Frequency (RF) repeater. The feeder link is assumed to be ideal and only increases the propagation delay. The satellite beams have been modelled as separate gNBs such that there is one-to-one mapping between a satellite beam and a gNB.

B. Satellite scenario

Frequency Division Duplexing (FDD) is the baseline for 3GPP Release 17 NTN. The satellite can have a configurable number of beams, their target positions being either moving or fixed with respect the Earth surface.

There are two User Equipment (UE) antenna models implemented in NTN simulator: handheld and Very Small Aperture Terminal (VSAT). Handheld antenna has 0 dBi omnidirectional gain while VSAT antenna is modelled as a first order Bessel function with peak gain of 39.7 dBi gain with perfect tracking. Direct to handheld (e.g., smartphone, IoT device) is considered as one of the potential use cases for 5G NTN.

There are three frequency reuse schemes specified in [7]:

- Option 1: Re-use 1, i.e., all beams reuse the same configured system bandwidth.
- Option 2: Re-use 3, i.e., system bandwidth is divided into three parts in classical hexagonal layout fashion where all six neighbors for any beam are using different frequency band.
- Option 3: Re-use 2+2, i.e., frequency reuse 2 and circular polarization re-use 2.

Currently NTN simulator has the support for options 1 and 2 assuming ideal frequency band separation. Option 3 is modelled without interference between different polarizations, effectively corresponding frequency re-use 4.

System simulators usually focus on an isolated set of gNBs/beams, which result in non-uniform interference conditions between the scenario center and edge. We have created the support for *interfering* beams/UEs to configure 2- and 4-tier wrap-around interfering mechanism defined in [7]. The signal from interfering nodes is only used for interference calculation so the impact to simulation run time is minimized.

One major difference between terrestrial and satellite 5G scenarios is the magnitude and effect of the propagation delay between gNB and UE. A constant propagation delay model has been implemented to NTN simulator. The delay is the same for all UEs in both UL and DL and it does not change during the simulation time. A UE specific propagation delay shall be considered in the future on a need basis.

C. Channel model

3GPP TR 38.811 extends the more traditional terrestrial channel model with new user environments, geographical coordinate system, satellite and HAPS antenna models, and fast fading parameters [8]. The main motivation behind the extensions is to support new geometry for performance evaluations to accommodate large distance between satellite and UE and to support user mobility speeds up to 1000 km/h for satellite and up to 500 km/h for HAPS. 5G LENA together with baseline ns-3 implement a terrestrial channel model based on 3GPP TR 38.901 in a Cartesian 3D coordinate system, which we have extended accordingly to the NTN simulator.

The satellite and optionally HAPS antenna pattern model is based on first order Bessel function. HAPS is also allowed to use flat-panel element array used for terrestrial cells. By default, 5G LENA implements a single flat-panel antenna element array per simulated node with either omnidirectional elements or directional elements described in [24] along with ideal beamforming algorithm. We have further inherited our own, antenna class out of ns-3 classes one which implements the Bessel function and use it with single antenna element to model the satellite and UE VSAT antennas, ignoring the beamforming effect.

The large-scale model as well as the fast-fading model are based on user environment, frequency bands of interest, channel condition between the satellite and UE and elevation angle from horizon level up to satellite. To correctly model the NTN scenarios, a global coordinate system was implemented in the simulator. The main frequency bands under study are S-band at 2 GHz center frequency and Ka-band with 20 GHz and 30 GHz center frequencies for DL and UL, respectively. The new user environment options are Rural, Suburban, Urban and Dense Urban, each affecting Line-Of-Sight (LOS) probability for different elevation angles and cluster departure and arrival angle generation.

As new components to large scale path loss model, atmospheric absorption, clutter loss for NLOS link and scintillation model are introduced. Additionally, time-varying Doppler shift is used since both base stations and UE movement speed and direction may change over time.

Faraday rotation is introduced as additional component affecting the cluster factor generation and its amount dependent on carrier frequency; for higher carrier frequencies the Faraday rotation has a smaller effect.

D. Satellite mobility

For satellite mobility, several approaches are considered, each with their own advantages and disadvantages. Firstly we have modelled a stationary satellite for GEO scenarios and short LEO simulations: while simple, due to lack of velocity it lacks the changes to the signal strength caused by Doppler effect in fast fading model. To have the Doppler effect in place, we implemented an additional virtual mobility model not changing position but having constant velocity based on circular orbit to get Doppler effect. However, since the satellite does not actually move the antenna gain will not change, thus making it unrealistic for longer simulations.

An ideal circular orbit between two coordinates on given altitude at realistic speed can be used to model a passing satellite easily, but the more fine-tuned effects of mobility or for other reference ellipsoid model besides perfect sphere might cause inaccuracies. Finally, for longer and more realistic scenarios Two-line element set (TLE) format based mobility model has been implemented. The TLE format can be used to describe an orbit for an Earth-orbitting object and to estimate the position of the object at given time. The TLE mobility model we implemented in the simulator is based on [25] to create the orbit and calculate the positions per time instance. The downsides of TLE are being difficult to configure properly and requiring careful planning to have the satellite at expected position for the terrestrial nodes to be reachable by the satellite during the simulation. However, it provides opportunities for studying larger satellite constellation coverages easily.

E. RRM enhancements

Blind HARQ retransmission refers to a methodology where HARQ retransmissions are sent without receiving any HARQ feedback from the receiver. NTN simulator implements blind HARQ retransmission by disabling regular HARQ feedbacks and generating artificial HARQ feedbacks at the scheduler at consecutive slots after initial data transmission.

Other HARQ changes required by NTN are longer HARQ timer values, support for more HARQ channels and option to disable HARQ feedbacks and these were mostly achieved by changing values of existing attributes.

5G LENA supports a simple Time-Division Multiple Access (TDMA) MAC scheduler but it lacks several required features and therefore a new Frequency Division (FD) scheduler has been implemented. The essential features of the FD scheduler are

- Resource efficient scheduling of new data and HARQ retransmissions into same slot.
- Flexibility to control how many UEs per slot are scheduled.
- Fair scheduling between UEs according to Round Robin (RR) and Proportional Fair (PF) scheduling algorithms assuming previous flexibilities.
- Guaranteeing minimum allocation size according to UE requirement.
- Taking Uplink Power Control (UL PC) limitations into account, so called Power Headroom (PHR) constraint.
- RB shuffling to provide fair interference situation.

F. Power control

Power control functionality is essential in the UL direction to first use enough transmission power for successful reception, but also not to cause excessive amount of interference to others. Pathloss based PC algorithm according to [27], PHR messages and scheduler power limitation constraints have been implemented to the SLS.

G. Initial beam selection and handover

The initial beam selection procedure is based on averaged Reference Signal Received Power (RSRP). Note, that modeling (beam and/or satellite) handover is important, esp. in LEO scenarios, where frequent handovers are expected due to satellite movement, even though UEs would not be moving at all. The beam handover is mostly using ns-3 LTE module (LENA) [18] approach with following features:

- UE (intra-frequency) measurements: RSRP and RSRQ
- Averaging: L1 and L3 filtering.
- Measurement events: A1 – A5 with Hysteresis (Hys) and Time-to-Trigger (TTT).
- Signaling: measurement report, HO command, HO complete.
- Handover algorithm: A2-A4-RSRQ handover algorithm, A3 based strongest cell algorithm.

Note, that some extensions to the handover procedure in NTN system may be required. E.g., 3GPP is considering at least Conditional HO (CHO) and location-based triggers of some kind to complement the Ax events.

H. Traffic models

Definition of the traffic models is essential for system level evaluations. Usually, the traffic models are kept pretty simple, e.g. so called “full buffer” traffic model is often used to evaluate the capacity of the system. Full buffer traffic model models a situation where each UE would have always traffic to send in both directions. Ns-3 LTE module implements a full buffer traffic model in the Radio Link Control (RLC) protocol layer, such that the simulator would not have Evolved Packet Core (EPC) (5GC in 5G terminology) nor the higher protocol layers at all (IP and above). Such RLC mode is called Sparse Mode (SM), which does not implement encapsulation nor retransmission logic.

In addition, the NTN simulator supports other traffic models located in the application layer, e.g. Constant Bit Rate (CBR) and burstly on-off traffic models, through the usage of EPC model

I. Statistics

5G LENA module provides a set of traces and statistic calculators, but we have decided use an own statistics framework which provides flexible way of both adding and collecting different types of new statistics, e.g. scalars, traces, logs and distributions.

By default, we collect coupling loss, delay, SINR, C, I, call throughput, load and allocation statistics, but adding new statisics is straightforward, and shall be done on a need basis.

IV. VERIFICATION RESULTS

The 3GPP TR 38.821 defines a set of parameterization and calibration scenarios to verify the system simulators of different companies. [7] The calibration cases are also presented in Table 2. The calibration cases differ by means of:

- Satellite orbit: GEO, LEO600, LEO1200.
- Satellite parameter set: Set 1, Set 2 (See [7], Table 6.1.1.1-1, Table 6.1.1.1-2).
- Central beam elevation: 45, 90 deg.
- Terminal: Handheld, VSAT.
- Frequency band: S-, Ka-band.
- Frequency reuse: FR 1, FR 3, and FR 2+2.

Calibration cases 1, 2, 6, 7, 9, 10, 14 and 15 are prioritized by 3GPP, and thus, we also present their results in this article. Other SLS parameters are presented in Table 1. Calibration simulation results are summarized in Table 2.

Table 1. Simulation parameters.

Parameter	Value
Direction	DL
System bandwidth	30 MHz
Satellite	One stationary satellite
Beams	7 active beams
Mobility	Stationary UEs
Traffic	Full buffer
HARQ	GEO: enabled LEO: disabled
Scheduler	Round Robin
Max # scheduled UEs	S-band: 6 Ka-band: 1
UEs per cell	10
Simulation duration	5 seconds
# drops	10

It can be observed that

- GEO configuration results in a long lower end SINR tail causing somewhat less than 10% of UEs to be out-of-service. This is caused by the UEs being in NLOS condition. Thus, GEO configurations shall require both directive VSAT antennas and fixed LOS conditions.
- GEO scenarios suffer from the lack of HARQ retransmissions, which could be compensated with slot aggregation or blind retransmissions.
- Frequency reuse 1 shall result in higher peak data rates than reuse 3, but with the expense of lower cell edge data rate. Thus, frequency reuse of 3 colors may be preferred solution to provide more fair service and better service coverage.
- LEO S-band handheld provides quite acceptable performance both at 600 km and 1200 km altitudes. LEO1200 provides slightly better SINR than LEO600 due to 6 dB higher EIRP and relatively slightly smaller beam diameter.

Note, that the presented results consider only DL direction (gNB to UE). The SLS has UL capability as well with e.g., PC and PHR based schedulers. However, the related results were not included due to limited verification time. The final article is planned to be updated with all calibration scenarios, as well as UL statistics.

Note, that the simulations have been performed without any specific enhancements, e.g., at RRM level. However, several issues can be further studied, e.g., slot aggregation and blind retransmissions to improve the reliability (esp. in GEO scenarios), and NTN handover optimizations.

V. CONCLUSIONS

This article presents the 5G Non-Terrestrial Network (NTN) extensions to an open-source Network Simulator 3 (ns-3). The SLS shall be used in the 3GPP RAN standardization to evaluate different system concepts, parameterizations, as well as specification change needs to produce high quality 3GPP specifications for 5G NTN. The SLS is targeted to evolve to be compliant with 3GPP Release 17, but after that also evolving towards later releases, e.g., Release 18.

In short term, the SLS shall be extended with NB-IoT/eMTC over satellite to be used in the 3GPP Release 17 Study Item (SI) "Study on NB-IoT/eMTC support for Non-Terrestrial Network".

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REFERENCES

[1] Helka-Liina Määttänen, Björn Hofström, Sebastian Euler, Jonas Sedin, Xingqin Lin, Olof Liberg, Gino Masini and Martin Israelsson, "5G NR Communication over GEO or LEO Satellite Systems: 3GPP RAN Higher Layer Standardization Aspects", IEEE Global Communications Conference (GLOBECOM), Dec 2019.

[2] Ericsson Mobility Report 2020, https://www.ericsson.com/4adc87/assets/local/mobility-report/documents/2020/november-2020-ericsson-mobility-report.pdf.

[3] Federica Rinaldi, Helka-Liina Määttänen, Johan Torsner, Sara Pizzi, Sergey Andreev, Antonio Iera, Yevgeni Koucheryavey and Giuseppe Araniti, "Non-Terrestrial Networks in 5G & Beyond: A Survey", IEEE Access, Vol: 8, 2020.

[4] Marco Giordani and Michele Zorzi, IEEE "Non-Terrestrial Networks in the 6G Era: Challenges and Opportunities", IEEE Network, Dec 2020.

[5] A. Guidotti, A. Vanelli-Coralli, M. Conti, S. Andrenacci, S. Chatzinotas, N. Maturo, B. Evans, A. Awoseyila, A. Ugolini,

T. Foggi, L. Gaudio, N. Alagha, S. Cioni, "Architectures and Key Technical Challenges for 5G Systems Incorporating Satellites", IEEE Transactions on Vehicular Technology, Vol: 68, Issue: 3, March 2019.

[6] A. Guidotti, S. Cioni, G. Colavolpe, M. Conti, T. Foggi, A. Mengali, G. Montorsi, A. Piemontese, A. Vanelli-Coralli, "Architectures, standardisation, and procedures for 5G Satellite Communications: A survey", Elsevier Computer Networks, Vol: 183, Dec 2020.

[7] 3GPP TR 38.821, "Solutions for NR to support non-terrestrial networks (NTN)", V16.0.0 (2019-12).

[8] 3GPP TR 38.811 "Study on New Radio (NR) to support non-terrestrial networks", V15.4.0 (2020-09).

[9] J. Puttonen, T. Nihtilä, M. Innanen, R. Järvinen, J. Kurjenniemi, V. Hytönen and T. Flink, "Cloud Simulation Platform for Satellite and Terrestrial Network Simulations", Ka and Broadband Communications Conference, Sorrento, Italy, September 30 – October 2, 2019.

[10] Yongjae Kim, Jimin Bae, Jinteak Lim, Eunhye Park, Jaeuk Baek, Sang Ik Han, Chol Chu, Youngnam Han, "5G K-Simulator: 5G System Simulator for Performance Evaluation", IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), 2018.

[11] Martin Klaus Müller, Fjolla Ademaj, Thomas Dittrich, Agnes Fastenbauer, Blanca Ramos Elbal, Armand Nabavi, Lukas Nagel, Stefan Schwarz and Markus Rupp, "Flexible multi-node simulation of cellular mobile communications: the Vienna 5G System Level Simulator", EURASIP Journal on Wireless Communications and Networking, 2018.

[12] Stefan Pratschner, Martin Klaus Müller, Fjolla Ademaj, Armand Nabaviy, Bashar Tahir, Stefan Schwarz and Markus Rupp, "Verification of the Vienna 5G Link and System Level Simulators and Their Interaction", IEEE Annual Consumer Communications & Networking Conference (CCNC), 2019.

[13] Sergio Martiradonna, Alessandro Grassi, Giuseppe Piro, Gennaro Boggia, "5G-air-simulator: An open-source tool modeling the 5G air interface", Elsevier Computer Networks, Vol: 173, 2020.

[14] Giovanni Nardini, Giovanni Stea, Antonio Virdis, Dario Sabella, "Simu5G: A System-level Simulator for 5G Networks", International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH 2020), pp. 68-80, 2020.

[15] ns-3 module to simulate 3GPP 5G networks, Centre Tecnològic Telecomunicacions Catalunya, https://5g-lena.cttc.es/

[16] Network Simulator 3 (ns-3), https://www.nsnam.org/

[17] M. Mezzavilla, M. Zhang, M. Polese, R. Ford, S. Dutta, S. Rangan, M. Zorzi, "End-to-End Simulation of 5G mmWave Networks," in IEEE Communications Surveys & Tutorials, vol. 20, no. 3, pp. 2237-2263, third quarter 2018.

[18] LENA LTE-EPC Network Simulator, http://networks.cttc.es/mobile-networks/software-tools/lena/.

[19] 5G LENA blog, https://5g-lena.cttc.es/blog/12/

[20] N. Patriciello, S. Lagen, B. Bojovic, L. Giupponi, An E2E Simulator for 5G NR Networks, Elsevier Simulation Modelling Practice and Theory (SIMPAT), vol. 96, 101933, Nov. 2019, DOI. Available from http://arxiv.org/abs/1911.05534.

[21] S. Lagen, K. Wanuga, H. Elkotby, S. Goyal, N. Patriciello, L. Giupponi, New Radio Physical Layer Abstraction for System-Level Simulations of 5G Networks, in Proceedings of IEEE International Conference on Communications (IEEE ICC), 7-11 June 2020, Dublin (Ireland). Available from http://arxiv.org/abs/2001.10309.

[22] N. Patriciello, S. Lagen, L. Giupponi, B. Bojovic, An Improved MAC Layer for the 5G NR ns-3 module, in Workshop on ns-3, 19-20 June 2019, Florence (Italy). Available from https://zenodo.org/record/3359064#.Xcvd2NV7m70.

[23] N. Patriciello, S. Lagen, L. Giupponi, B. Bojovic, 5G New Radio Numerologies and their Impact on the End-To-End Latency, in Proceedings of IEEE International Workshop on Computer-Aided Modeling Analysis and Design of Communication Links and Networks (IEEE CAMAD), 17-19 September 2018, Barcelona (Spain). Available from https://zenodo.org/record/2525744#.XcvdwdV7m70.

[24] 3GPP TR 38.901 "Study on channel model for frequencies from 0.5 to 100 GHz"

[25] C++ SGP4 Satellite Library, https://www.danrw.com/sgp4/.

[26] GeographicLib, https://geographiclib.sourceforge.io/.

[27] 3GPP TS 38.213, "Physical layer procedures for control", V16.4.0 (2020-12).

Table 2. Verification results in prioritized calibration scenarios.

		Calibration scenario							
Statistics	**%-ile**	**1 GEO**	**2 GEO**	**6 LEO 600**	**7 LEO 600**	**9 LEO 600**	**10 LEO 600**	**14 LEO 1200**	**15 LEO 1200**
Coupling Loss [dBm]	**5**	110.3	110.4	97.4	97.5	125.1	125.1	130.8	130.6
	50	115.3	115.0	99.6	99.5	129.4	129.6	135.0	134.8
	95	168.9	158.3	101.9	101.6	138.3	137.6	144.0	142.3
C [dBm]	**5**	-155.5	-143.5	-104.5	-103.5	-113.5	-111.5	-111.5	-109.5
	50	-101.5	-101.0	-102.0	-101.5	-102.5	-102.5	-102.0	-102.0
	95	-96.5	-96.5	-100.0	-99.5	-98.0	-98.0	-97.5	-97.5

I [dBm]	**5**	-111.5	-113.0	-111.5	-113.0	-111.0	-114.0	-111.0	-114.0
	50	-106.5	-111.5	-105.0	-111.5	-104.0	-112.5	-105.0	-112.5
	95	-101.0	-109.5	-101.5	-110.5	-99.5	-108.0	-100.5	-108.0
SINR [dB]	**5**	-46.4	-31.7	-2.3	8.1	-8.5	0.5	-6.4	1.5
	50	4.7	10.7	3.7	10.2	1.5	9.6	2.8	10.2
	95	11.9	15.4	10.0	12.3	9.9	14.6	11.1	15.2
UE Tput [kpbs]	**5**	0.0	0.1	296.0	900.5	70.5	217.8	120.0	293.8
	50	1693.2	1098.6	1300.5	1236.8	829.2	1258.9	1175.2	1357.9
	95	4707.0	1923.4	4100.5	1561.7	3742.0	2027.7	4409.8	2265.0

Table 3. 3GPP calibration scenarios [7].

Case	Satellite orbit	Satellite parameter set	Central beam elevation	Terminal	Frequency Band	Frequency/ Polarization Reuse
1	GEO	Set 1	45 deg	VSAT	Ka-band	Option 1
2	GEO	Set 1	45 deg	VSAT	Ka-band	Option 2
3*	GEO	Set 1	45 deg	VSAT	Ka-band	Option 3
4*	GEO	Set 1	45 deg	Handheld	S-band	Option 1
5*	GEO	Set 1	45 deg	Handheld	S-band	Option 2
6	LEO-600	Set 1	90 deg	VSAT	Ka-band	Option 1
7	LEO-600	Set 1	90 deg	VSAT	Ka-band	Option 2
8*	LEO-600	Set 1	90 deg	VSAT	Ka-band	Option 3
9	LEO-600	Set 1	90 deg	Handheld	S-band	Option 1
10	LEO-600	Set 1	90 deg	Handheld	S-band	Option 2
11*	LEO-1200	Set 1	90 deg	VSAT	Ka-band	Option 1
12*	LEO-1200	Set 1	90 deg	VSAT	Ka-band	Option 2
13*	LEO-1200	Set 1	90 deg	VSAT	Ka-band	Option 3
14	LEO-1200	Set 1	90 deg	Handheld	S-band	Option 1
15	LEO-1200	Set 1	90 deg	Handheld	S-band	Option 2
16**	GEO	Set 2	45 deg	VSAT	Ka-band	Option 1
17**	GEO	Set 2	45 deg	VSAT	Ka-band	Option 2
18**	GEO	Set 2	45 deg	VSAT	Ka-band	Option 3
19**	GEO	Set 2	45 deg	Handheld	S-band	Option 1
20**	GEO	Set 2	45 deg	Handheld	S-band	Option 2
21**	LEO-600	Set 2	90 deg	VSAT	Ka-band	Option 1
22**	LEO-600	Set 2	90 deg	VSAT	Ka-band	Option 2
23**	LEO-600	Set 2	90 deg	VSAT	Ka-band	Option 3
24**	LEO-600	Set 2	90 deg	Handheld	S-band	Option 1
25**	LEO-600	Set 2	90 deg	Handheld	S-band	Option 2
26**	LEO-1200	Set 2	90 deg	VSAT	Ka-band	Option 1
27**	LEO-1200	Set 2	90 deg	VSAT	Ka-band	Option 2
28**	LEO-1200	Set 2	90 deg	VSAT	Ka-band	Option 3
29**	LEO-1200	Set 2	90 deg	Handheld	S-band	Option 1
30**	LEO-1200	Set 2	90 deg	Handheld	S-band	Option 2
NOTE 1: no star = 1st priority, * = second priority scenario, ** = third priority scenario NOTE 2: Only 1st priority cases will be considered for calibration phase 1						