Feasibility of 5G Services Over Ka-band Athena-Fidus Satellite
A Study on Ka-band Frequency Use for 5G based Applications Over Satellite

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Abstract: 5G is rapidly approaching: companies and public institutions are significantly investing to design, develop and deploy the next generation telecommunication systems which will be based on flexible network management and new services definition. In this forthcoming scenario, the satellite can play a meaningful role to allow meeting all the claimed requirements, i.e., to support/complement terrestrial networks for a large set of applications. The Athena Fidus system has been realized to support civil and governmental services. The assessment of the overall capacity provided this platform and, in particular, the nominal IP-based bandwidth per terminal is important for the definition of the services and to efficiently plan future its integration with terrestrial networks, in compliance with 5G scenarios. In this paper, the real characteristics of Athena Fidus DVB-S2/DVB-RCS links are considered to identify the set of services that will be possible to offer. The objective is to draw the operational context to be considered for the potential involvement of Athena Fidus in the next communication systems.

1 INTRODUCTION

The design, development and deployment of 5G telecommunication networks (5G-PPP, 2016) is the present objective of the major players of the sector (network operators, service operators and content providers). Many resources are invested in research activities and trials by public institutions (e.g., European Commission) or private companies. The race among far East, Europe and USA has started and soon the winner, the first commercial 5G operational service operator, will be known.

The specifications of these new systems concern mainly the network management, fully based on Software Defined Networking – SDN, Network Functions Virtualisation – NFV, Mobile Edge Computing – MEC, and on other innovative concepts above the physical layer and networking legacy assumptions, as described in (5G-PPP, 2016).

In this new very challenging scenario, the satellite could be fruitfully included in hybrid terrestrial-satellite communication architectures, to ensure the full respect of all the requirements and capabilities associated to the 5G deployment (Luglio et al., 2009b), (Luglio et al., 2009a), (Bacco et al., 2014). In particular, satellite data services can be useful for (and not limited to):

Ubiquitous Coverage for IP Multimedia Communications. Satellite can allow to extend the broadband coverage in scarcely populated areas where investments for terrestrial infrastructures are not economically viable. Furthermore, satellite could help terrestrial providers in responding to users' capacity requirements in densely populated areas where capacity demand outstrips the ability of existing terrestrial infrastructures, and to compensate as well the intrinsic asymmetry of some terrestrial services and networks (i.e., asymmetry of ADSL services, with a very low upload compared to download).

Global Content Distribution. Satellite can improve efficiency in broadcasting contents on large areas, taking advantage of satellite intrinsic coverage that put the satellite in a predominant position in addressing on demand streaming and live broadcasting services. Currently high definition (HD), but also 4K and 8K Ultra HD contents, are consumed by eager mobile users requiring an efficient content distribution on distributed edge caches in order to reduce the latency experienced. Satellite can deliver the contents right to the edges of the 5G networks, avoiding overload the ISP terrestrial networks.

Contribution Services. Thanks to the availabil-

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ity of significant amount of capacity, the satellite is (and has been) often utilized as live contribution link for TV content creation and delivery, from the remote place to collection centers and then re-distributed in broadcast (also on satellite, as described in previous bullet point). Large scale video surveillance, transmission of event-driven high-bandwidth videos, and other multimedia IP based services require an agile communication system not constrained by a fixed infrastructure and/or reserved capacity. Satellite with its global coverage does not need of ad-hoc deployment of an infrastructure and it can manage on-demand uplink bandwidth as a dynamic and flexible IP broadband contribution service.

Specific Mission Services. Satellite architecture envisages a limited number of nodes and presents a relatively short deployment time. These characteristics make satellite suitable for the support of specific services associated to disaster-recovery, tactical operations, search and rescue missions, with requirements drastically different from those associated to consumer-grade fixed services (e.g., home internet access for web browsing, email, etc.).

Connection of a Large Number of Devices. Satellites are tailored to support connectivity for a large number of devices distributed on a large geographical scale because of their wide coverage and inherently efficient broadcast/multicast capabilities, complementing local terrestrial data distribution through the already existing possibility to receive downlink satellite information. IoT/M2M communications Machine-to-Machine (M2M) indicates a set of technologies (sensors or actuators) tailored to exchange data without an explicit human intervention. Internet of Things (IoT) concept extends M2M by introducing IP connectivity to allow interoperability among different-vendor-systems. Among IoT/M2M requirements, it is possible to mention: device multitude, scalability, intrusiveness, security, burst transmission. Satellite characteristics can efficiently satisfy or at least help to match such requirements.

The paper investigates the potentiality of using IP-based bearer services offered by Athena Fidus, showing in details its characteristics, configuration and, by means of simulations, link budget margins and achievable bitrates, suitable to support 5G applications. The results presented will allow to confirm the possibility to utilize an operational satellite in Ka-band frequencies, to provide a subset of the above listed services, with a determined quality of service and availability.

The rest of the paper is organized as follows: section 2 includes the description of the Athena Fidus platform; section 3 describes the detailed radio-frequency channels specification in relation with system availability; in section 4 simulations are run to show link-budget results and relative resulting bearer channel, and in section 5 conclusions are drawn and possible future works are described.

2 ATHENA FIDUS CHARACTERISTICS AND ARCHITECTURE

The Athena Fidus (Access on THeaters for European allied forces Nations-French Italian Dual Use Satellite) system (Iorio et al., 2012), (Sacco, 2016) has been jointly developed by ASI (the Italian Space Agency) and CNES (Centre National dEtudes Spatiales). The aim was to build a telecommunication infrastructure able to support/complement terrestrial networks for a large set of civil and governmental applications. Athena Fidus is based on a single geostationary satellite operating in the Ka-band and EHF band, of which Ka allotment is assigned for civil use and considered in the rest of the paper. The system is designed to provide in general:

- Star and transparent mesh communication services over national coverage in the civilian Ka-band;
- Star and transparent mesh communication services in EHF and Ka-bands over national coverage, and steerable spot beams for military use.

As concerns the civil payload, Italy is the geographical reference area considered for this paper; the overall expected data rate is over 1 Gbit/s (and possibly up to 3 Gbit/s). Athena-Fidus uses DVB-RCS (ETSI, 2005a) for return link communications on a shared channel, and point to point links (for mesh communications) or DVB-S2 (ETSI, 2005b) broadcasting for forward links, to enhance transmission capacity and service availability.

Athena Fidus current utilization allows to consider it a potential resource for the launch of new services, provided that it can assure a suitable amount of net bandwidth to the target applications. In fact, its raw capacity is suitable to the transport of IP packets, using proper encapsulation methods (such as Generic Stream Encapsulation, GSE), for a wide set of applications. The capacity available to the 5G/IP based service depends on the physical characteristics of the defined satellite channels, taking into account the ground antenna parameters in terms of EIRP (Equivalent Isotropic Radiated Power, by transmitter) and G/T (Antenna gain-to-noise-temperature, the specific figure of merit of the antenna in use = G_R/T).

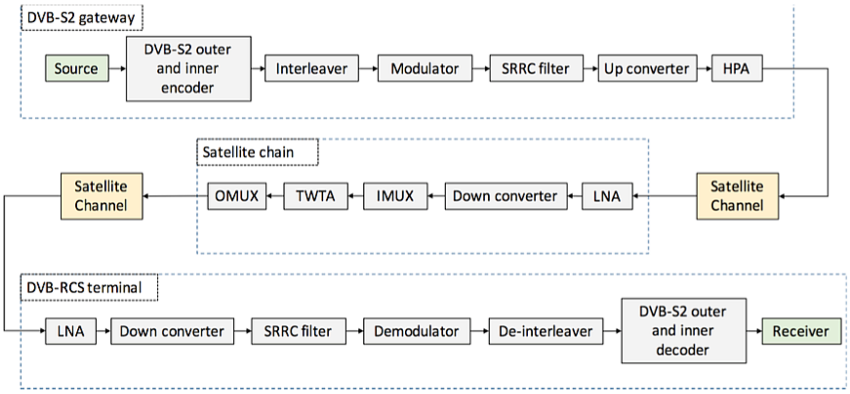

Figure 1: Communication Model for the forward link.

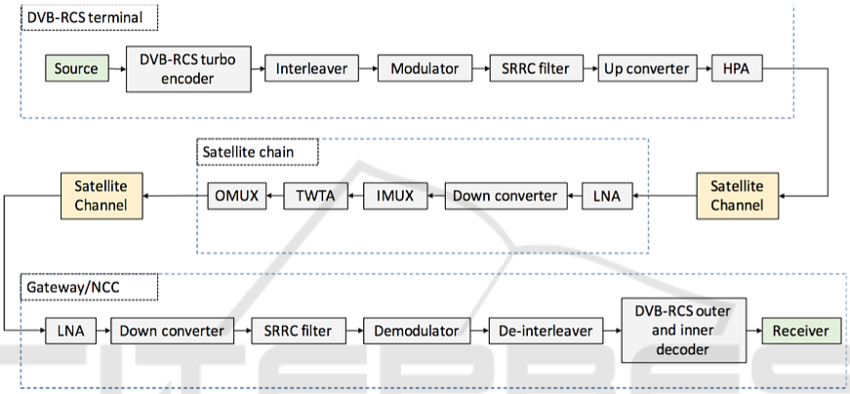

Figure 2: Communication Model for the return link.

A representative block diagram of the general system architecture is provided for both DVB-S2 (used in forward link) and DVB-RCS links in (ETSI, 2005b) and (ETSI, 2005a) (used in return link) and shown in Figure 1 and Figure 2 respectively. All the functional blocks impact on the overall performance and contribute to the determination of the Signal to Noise Ratio (SNR) thresholds for the link budget.

3 SERVICE OVERVIEW AND CHANNEL DESIGN

In order to perform an exhaustive analysis, we consider a distribution of 2200 terminals, distributed randomly in Italy with the aim to cover all possible territory specific characteristic. For instance, rain models and other parameters considered hereafter, may depend on geographical location of the terminal. Each terminal location will be used in all the next calculations and simulations for the service evaluation. As a baseline reference, the typical values for the current commercial Ka-band terminals were used: G_R=42 dB and EIRP = 48 dBW (EUTELSAT, 2016). The nominal IP bandwidth that can be exploited by a Ka-band terminal by these characteristics can be evaluated taking into account three main parameters:

- Link availability (%);
- Carrier Symbol Rate (kbit/s);
- Selected Modulation and Coding scheme (MODCOD).

Link availability indicates the link uptime over the year, and it is usually fixed to a target value agreed with users in the Service Level Agreement (SLA). The dimensioning of the system envisages first the determination of a reference link availability %, and then the tuning of the best combination of other parameters (such as transmitter power, antenna gain, etc.). Satellite commercial systems typically provide connectivity based services with 99.7% of availability. Of course, most critical services could require higher values. For these reasons, in the analysis presented hereinafter, values either equal or higher than 99.7% will be considered. Table 1 summarizes the channel breakdown (bandwidth allotment) on the Athena Fidus transponder. For each channel the main parameters impacting the link budget computation are reported. In the present study, the star-based network architecture is considered as a baseline, where Athena Fidus makes use of a common broadband forward link, whereas a shared return link is used by many remote peers along the territory in time division.

The single carrier (broadcast) forward channels are number 16 and 18, with 75 and 125 MHz bandwidths respectively, making use of DVB-S2 standard. Then, Athena Fidus offers many carriers to be used in time division (DVB-RCS) or as exclusive access: the combination of channel 15 and 17, is in fact further divided into three classes ((1), (2) and (3) in table 1). Depending on the supported symbol rate/bandwidth per channel, this allows to create many narrowband links, with an overall bandwidth of about 200 MHz. For each channel class, in fact, a different number of carriers is defined (last column) and, as reported in Table 2, a different respective bandwidth in MHz. Definitively, the Athena Fidus terminals will be associated to only one of such carriers for the return link, and each single carrier can be associated to multiple terminals competing for the carrier bandwidth as defined by multiple access techniques required by DVB-RCS standard. Multiple access (TDMA) is normally enforced on channel 15+17(1), while the other 2 classes can be used also without contention (one carrier per terminal).

Once the channels are defined, the Ka-band propagation models (ITU-R, 2007a), (Rytir, 2009), (ITU-R, 2007b), (ITU-R, 2005), (ITU-R, 1999) can be applied to assess the attenuation margin as a function of the terminal coordinates/altitude above the sea level and of the target availability. Taking as a reference the Athena Fidus coverage, the two frequencies f_1=19.8 GHz and f_2=29.4 GHz are considered as reference for downlink and uplinks, respectively.

Table 1: Athena Fidus channel repartition.

Channel #	Connectivity	F_{UP} (MHz)	F_{DOWN} (MHz)	Carrier
15+17(1)	Star return (DVB-RCS)	29600	19520	10
15+17(2)	Star return (DVB-RCS)	29600	19520	144
15+17(3)	Star return (DVB-RCS)	29600	19520	116
16	Star forward (DVB-S2)	29427.5	19887.5	1
18	Star forward (DVB-S2)	29302.5	19762.5	1

Table 2: Athena Fidus channel characteristics.

Channel #	Symbol Rate (MSym/s)	Roll-Off	BW per carrier (MHz)	EIRP density (dBW/MHz)	G/T (dB/K)
15+17(1)	1.9	0.35	2.565	28	9
15+17(2)	0.64	0.35	0.864	28	9
15+17(3)	0.32	0.35	0.432	28	9
16	60	0.25	75	32.5	10
18	100	0.25	125	32.5	10

Figure 3 shows the attenuation due to propagation effects in the downlink as a function of the terminal number (1-2200). For a severe availability requirement of 99.9%, the attenuation varies in the range 6-10 dB. It is reminded that the x-axis represent the terminal id, from 1 to 2200, randomly positioned in the Italian territory. Through the simulations it was noted that the higher attenuation values are encountered for terminal installations in North-East of Italy. With a lower availability requirement (i.e. 99.5%), the attenuation value drops below 5 dB.

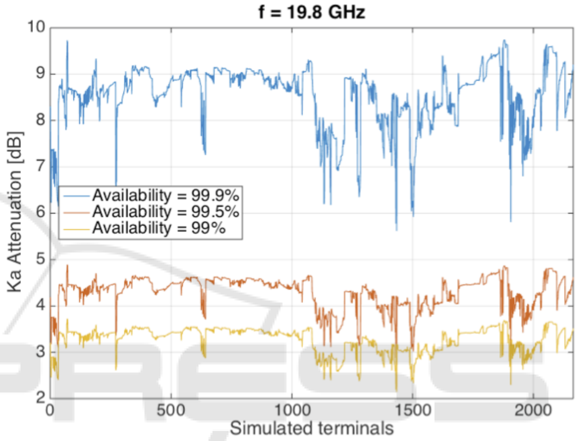

Figure 3: Ka-band attenuation for $f = f_1$ = 19.8 GHz.

Figure 4 shows the attenuation margin for the uplink at f_2=29.4 GHz. Overall values are significantly higher than those obtained for f_1. This is due to the greater dependence on rain fading within this frequency range.

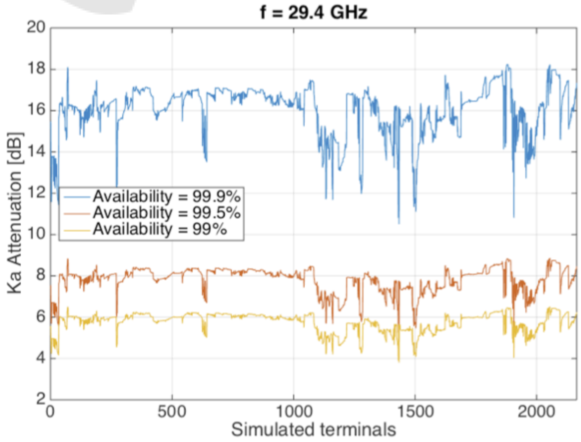

Figure 4: Ka-band attenuation for $f = f_2$ = 29.4 GHz.

To conlcude, a detailed analysis of “non-linear losses” in Athena Fidus is provided in (Iorio et al., 2012). The main loss contributions are due to High Power Amplifiers (HPA) distortions, up-conversion and down-conversion, Input-Multiplexed (IMUX) and Output-Multiplexer (OMUX) filters. The main degradation contributions are summarized in Table 3 and are used for the simulations: they can be combined in Root Sum Square in order to achieve the overall attenuation value due to non-linear effects.

Table 3: Summary of Athena Fidus non-linear degradations.

			Impact of Degradations [dB]			
Channel	**ModCod**	**Carrier BW (MHz)**	**AM/AM AM/PM**	**Phase noise**	**Group delay variation**	**Amplitude variation**
Fwd link Ka-band	QPSK 1/2	75	0.3	0.01	0.34	0.1
	8PSK 3/4		0.49	0.05	0.93	0.34

4 LINK BUDGET RESULTS

All the parameters discussed in Section 3 have been modelled and integrated in a MATLAB simulator aimed to compute link budget for both return and forward link of the target system, at all possible satellite links configurations. Relevant propagation models and ITU standards have been considered, specifically considering the attenuation margins achieved by previous simulations. The goal of the proposed analysis is to determine, given a certain degree of availability associated to a specific service, the useful channel capacity (in terms of available bit/s), which is indicated as C_{IP}.

Before computing link budget, the target signal-to-noise ratio (ideal SNR_0), to be used as lower-bound threshold for the link budget, were determined as a function of the eligible coding and modulation schemes and real channel choices. This in turns allows to determine the associated value of capacity exploitable at the IP level (C_{IP}) to support 5G services. In particular, the link budget requirements for a specific carrier are described in the next sections by means of:

- Mode - MODCOD reference for possible choice of "*Modulation scheme*" and "*coding rate*";
- Target (ideal) E_b/N_0 - (as obtained from standards and test results found in literature, i.e. (ETSI, 2009));
- Spectral Efficiency (η) - transmitted bits per Hertz computed as ratio between IF capacity and channel bandwidth ($C = SR \times R_c \times log_2(M)$, SR =Symbol Rate, R_c =overall coding rate, M=number of modulation symbols);
- Target (ideal) SNR_0 - signal to noise ratio computed as $E_b/N_0 + \eta[dB] + SR[dB]$;

The simulations will allow to identify the MODCOD to use according to the required availability, for each of the channel identified, and then derive the associated C_{IP} (Mbit/s), which is the capacity available at the IP layer (excluding IP encapsulation overhead with Generic Stream Encapsulation – GSE). The required SNR_0 for decoding and attenuation are evaluated for each of the 2200 terminals for all possible channel configurations.

4.1 Return Link

4.1.1 Link Budget Requirements and Calculation of the Nominal Capacity

Considering the channel pool characterized by a symbol rate of 320 kSym/s (carrier 15+17(3)), the maximum throughput allowed at the IP level is below 400 kbit/s, as summarized in Table 4. This rate is sufficient to set up low data rate services such as messaging, Voice over IP (VoIP), small file transfer, small data M2M and sensor networks data exchange. Anyway, this configuration has not been considered for the link budget computation because the paper is focused more in detail for higher data rate capabilities, which are the most critical to be achieved as well as the most attractive for upcoming 5G services. If adopting bandwidth on demand (BoD) techniques, as described in DVB-RCS standard, the broader channels (such as, 15+17(1)) can be used to provide these narrowband services in a sharing mode, more efficiently.

Table 4: DVB-RCS link budget requirements for 320 ksym/s channels.

Mode	Ideal E_b/N_0 [dB]	Spectral efficiency (η)	Ideal SNR_0 [dB]	C_{IP} (kbit/s)
QPSK 1/2	4.5	0.57	**57.14**	**213**
QPSK 2/3	5	0.76	**58.89**	**284**
QPSK 3/4	5.5	0.86	**59.9**	**320**
QPSK 5/6	6	0.95	**60.86**	**356**
QPSK 7/8	6.4	1.0	**61.47**	**373**

Table 5 summarizes requirements and associated maximum capacity available at the IP layer over channels with symbol rate equal to 640 ksym/s (15+17(2)). The allowed IP capacity ranges from 427 to 747 kbit/s depending on the selected MODCOD. Such values are compliant with application requirements of medium data rate such as real time video streaming, file transfer, web browsing, distributed monitoring (Carniato et al., 2013). In fact, the obtained data rates are comparable with the ones experienced in the common ADSL return link, allowing satellite either to offload traffic coming from congested terrestrial networks or to backup terrestrial links during failures or outages.

Table 5: DVB-RCS link budget requirements for 640 kSym/s channels.

Mode	Ideal E_b/N_0 [dB]	Spectral efficiency (η)	Ideal SNR_0 [dB]	C_{IP} (kbit/s)
QPSK 1/2	4.5	0.57	**60.1**	**427**
QPSK 2/3	5	0.76	**61.9**	**569**
QPSK 3/4	5.5	0.86	**62.9**	**641**
QPSK 5/6	6	0.95	**63.8**	**712**
QPSK 7/8	6.4	1.0	**64.4**	**747**

Finally, Table 6 concerns requirements for connectivity over 1.9 MSym/s channels (15-17(1)). Of course, requirements in terms of C/N_0 are more severe, while the allowed IP capacity is much higher: from 1.2 Mbit/s up to more than 2 Mbit/s. With data rates in this range even wideband services such as HD TV can be provided. Also this configuration is considered for link budgets.

Table 6: DVB-RCS Link Budget Requirements for 1.9 MSym/s Channels.

Mode	Ideal E_b/N_0 [dB]	Spectral efficiency (η)	Ideal SNR_0 [dB]	C_{IP} (kbit/s)
QPSK 1/2	4.5	0.57	**64.87**	**1268**
QPSK 2/3	5	0.76	**66.62**	**1691**
QPSK 3/4	5.5	0.86	**67.63**	**1903**
QPSK 5/6	6	0.95	**68.59**	**2114**
QPSK 7/8	6.4	1.0	**69.2**	**2220**

4.1.2 Link Budget Analysis

Figure 5 shows results of link budget calculations for the whole set of terminals in terms of SNR_0, obtained by setting the transmitting antenna gain at 42 dB. Note that the results for different gain values of the antenna (in dB) can be immediately obtained by linearly up or down shifting the curves. The terminals on the abscissa are ordered from the lowest to the highest SNR_0 and the curves are obtained accordingly. Furthermore, the coloured curves are associated with different values of link availability selected for the link budget spanning from 99.3% (yellow curve) up to 99.9% (blue curve).

Finally, SNR_0 thresholds for the different coding schemes supported in the DVB-RCS standard, according to Table 5, are represented by dashed lines. Therefore curves, or portions of a curve, below the lowest threshold (related to QPSK 1/2 scheme) indicate that the corresponding terminals do not respect the target availability requirement. On the other hand, every terminal can efficiently work, respecting the target availability requirement when the relevant curve is above at least one threshold. Of course, each terminal will use the most efficient MODCOD in case overcoming more than one threshold. For presentation convenience, simulated terminals indicated in the x-axis are ordered from the one with the lowest SNR_0 to that with the highest one. In this way, the number of terminals below or above a given threshold can be easily inferred.

With an availability of 99.9% (blue curve), almost all terminals are not able to comply with the link budget. A similar situation occurs with 99.8%, where only about 20% of terminals are above the QPSK 1/2 threshold. Setting availability to 99.7% (typical value exhibited for commercial services), all the terminals satisfy link budget requirements. Almost 25% of terminals can even use more efficient MODCODs, thus working at rates up to 747 kbit/s. Finally, results improve even more when decreasing availability requirements. For instance, with 99.3% all terminals can work at a maximum rate higher than 700 kbit/s.

Figure 6 shows results when considering the highest capacity channels of 1.9 MSym/s. In order to guarantee that all the terminals satisfy link budget requirement, the target availability must go down to 99%. For higher values (i.e. 99.5%) only a small subset of terminals complies. On the other hand, while link budget respects the requirements, the amount of capacity available at the IP layer is much higher than the one allowed with the 640 ksym/s channel (in any configuration). In fact, with availability of 99% all the terminals can transmit at a maximum rate of at least 1.26 Mbit/s, while about 200 (10% of the total) terminals can achieve up to 1.69 Mbit/s. As a general conclusion, these broad channels can be used for broadband applications that do not require commercial-like availability.

4.2 Forward Link - Channel #16

In this section, communication on the forward link over channel #16, characterized by parameters resumed in the Table 1 and Table 2, is specifically addressed. DVB-S2 standard is adopted, enabling a large number of combinations among modulation and coding schemes.

4.2.1 Link Budget Requirements and Calculation of the Nominal Capacity

For each MODCOD, the link budged requires a different SNR to be achieved to guarantee target performance as shown in Table 7.

4.2.2 Link Budget Analysis

Target SNR_0 values are taken as thresholds to be compared to values achieved through link budget compu-

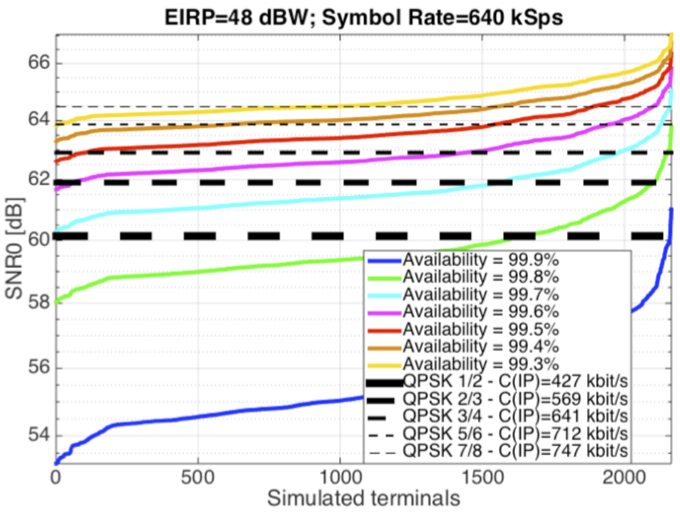

Figure 5: Link budgets for 640 kSym/s carriers.

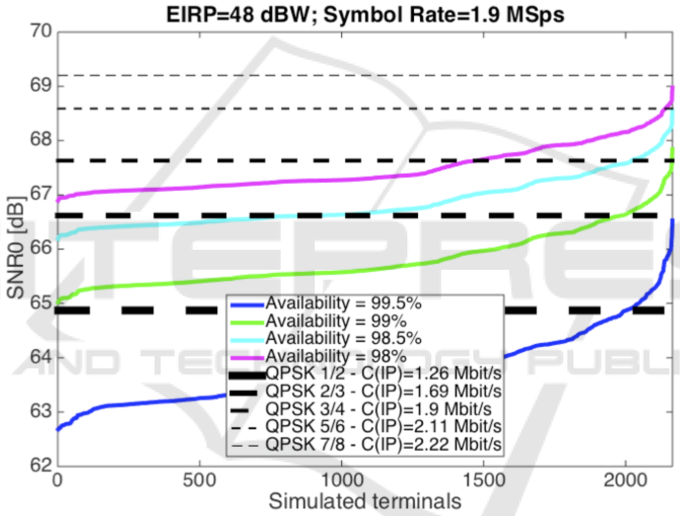

Figure 6: Link budgets for 1.9 MSym/s carriers.

tations related to all the terminals. Results are shown in Figure 7. With a high availability of 99.9%, the totality of terminals closes the link budget above the lower threshold (related to QPSK 1/4) so that connectivity requirement is always respected, giving at IP layer a capacity of at least 28 Mbit/s. In fact, most of the terminals are in conditions to work with QPSK 1/2, thus with a net IP capacity of 38 Mbit/s. Setting a slightly lower availability requirement (i.e. 99.5%), terminals can use a MODCOD much more efficient such as the QPSK 5/6 and then exploiting a capacity of about 95 Mbit/s. In conclusion, the forward link does not present any particular issue in the considered scenario. The receiving gain can be reduced of about 8-9 dB (with respect to the reference value), saving target performance.

4.3 Forward Link - Channel #18

The analysis carried out for channel #16 has been replicated considering the Channel #18 configuration, shown in Table 1 and Table 2.

4.3.1 Link Budget Requirements and Calculation of the Nominal Capacity

Table 8 presents the summary of the link budget requirements and the available capacity at the different protocol layers for all the allowed MODCODs.

4.3.2 Link Budget Analysis

Results, shown in Figure 8, are very similar to those experienced in the previous forward link configura-

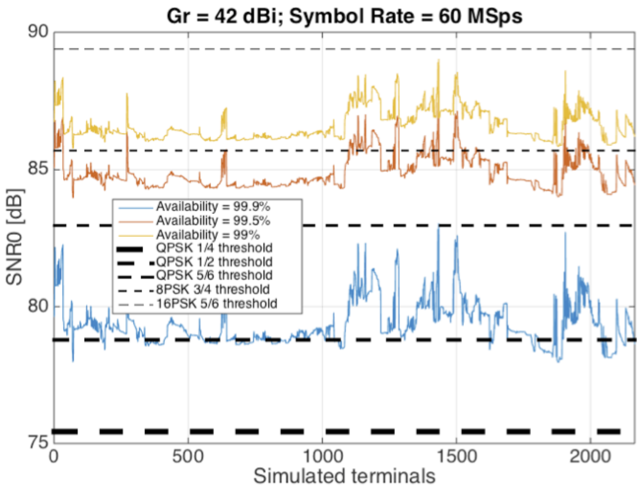

Figure 7: Link budgets on forward link with Channel #16.

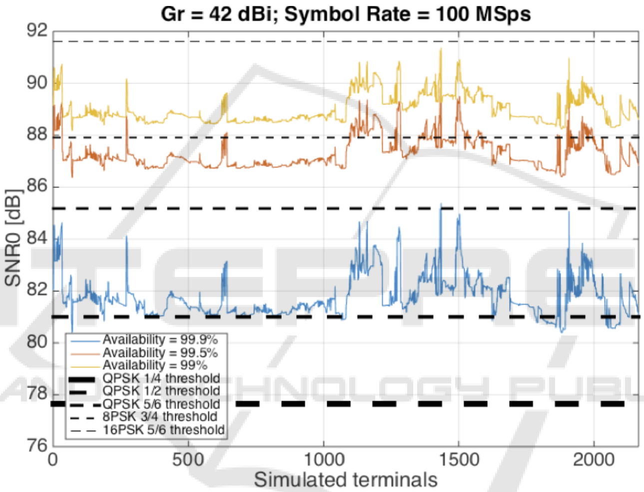

Figure 8: Link budgets on forward link with Channel #18.

tion, in terms of SNR_0. Of course, Channel #18 allows the achievement of much higher overall rates, once fixed the SNR.

5 CONCLUSION

This paper highlights the Athena Fidus potentialities to play an important role in the provision of the upcoming 5G services. The current configuration of Athena Fidus and its peculiar characteristics, can allow the simultaneous support to a number of services with difference performance requirements. Two parameters must properly analyzed in order to fully satisfy 5G application requirements: the maximum eligible capacity and the link availability. After an extensive simulation campaign using the actual configuration and parameters of Athena Fidus, which is already operational, achievable IP throughput have been evaluated for both forward and return links. Results confirmed Athena Fidus flexibility on tuning link characteristics and then achieve the most suitable configuration to support state-of-the art 5G applications. This work represents a first theoretical and thorough analysis of the Athena Fidus channels available today, for which complete details on the service specifications are lacking in literature. The satellite has been launched and it is fully activated: the commercial services are becoming operational in the current days. The authors are willing to compare the results achieved in this paper by measures resulting by real installations, using some test modems distributed on the national territory in areas identified through simulations by peculiar propagation conditions. Furthermore, it will be important to test new transmission protocols and innovative approaches oriented to

Table 7: DVB-S2 Link Budget Requirements for Channel #16.

Mode	Ideal E_b/N_0 [dB]	Spectral efficiency (η)	Ideal SNR_0 [dB]	C_{IP} (Mbit/s)
QPSK 1/4	-2.35	0.49	**75.43**	**28.53**
QPSK 1/3	-1.24	0.65	**76.54**	**38.04**
QPSK 2/5	-0.3	0.78	**77.48**	**45.64**
QPSK 1/2	1	0.98	**78.78**	**57.06**
QPSK 3/5	2.23	1.18	**80.01**	**68.47**
QPSK 2/3	3.1	1.32	**80.88**	**76.08**
QPSK 3/4	4.03	1.48	**81.81**	**85.59**
QPSK 4/5	4.68	1.58	**82.46**	**91.29**
QPSK 5/6	5.18	1.65	**82.96**	**95.1**
QPSK 8/9	6.2	1.76	**83.98**	**101.44**
QPSK 9/10	6.42	1.78	**84.2**	**102.7**
8PSK 3/5	5.5	1.77	**83.28**	**102.7**
8PSK 2/3	6.62	1.98	**84.4**	**114.12**
8PSK 3/4	7.91	2.22	**85.69**	**128.38**
8PSK 5/6	9.35	2.47	**87.13**	**142.65**
8PSK 8/9	10.69	2.64	**88.47**	**152.16**
8PSK 9/10	10.98	2.67	**88.76**	**154.06**
16APSK 2/3	8.97	2.63	**86.75**	**152.16**
16APSK 3/4	10.21	2.96	**87.99**	**171.18**
16APSK 4/5	11.03	3.16	**88.81**	**182.59**
16APSK 5/6	11.61	3.3	**89.39**	**190.2**
16APSK 8/9	12.89	3.52	**90.67**	**202.88**
16APSK 9/10	13.13	3.56	**90.91**	**205.41**
32APSK 3/4	12.73	3.7	**90.51**	**213.97**
32APSK 4/5	13.64	3.95	**91.42**	**228.24**
32APSK 5/6	14.28	4.11	**92.06**	**237.75**
32APSK 8/9	15.69	4.39	**93.47**	**253.6**
32APSK 9/10	16.05	4.45	**93.83**	**256.77**

Table 8: DVB-S2 Link Budget Requirements for Channel #18.

Mode	Ideal E_b/N_0 [dB]	Spectral efficiency (η)	Ideal SNR_0 [dB]	C_{IP} (Mbit/s)
QPSK 1/4	-2.35	0.49	**77.65**	**47.55**
QPSK 1/3	-1.24	0.65	**78.76**	**63.4**
QPSK 2/5	-0.3	0.78	**79.7**	**76.08**
QPSK 1/2	1	0.98	**81**	**95.1**
QPSK 3/5	2.23	1.18	**82.23**	**114.12**
QPSK 2/3	3.1	1.32	**83.1**	**126.8**
QPSK 3/4	4.03	1.48	**84.03**	**142.65**
QPSK 4/5	4.68	1.58	**84.68**	**152.16**
QPSK 5/6	5.18	1.65	**85.18**	**158.5**
QPSK 8/9	6.2	1.76	**86.2**	**169.07**
QPSK 9/10	6.42	1.78	**86.42**	**171.18**
8PSK 3/5	5.5	1.77	**85.5**	**171.18**
8PSK 2/3	6.62	1.98	**86.62**	**190.2**
8PSK 3/4	7.91	2.22	**87.91**	**213.97**
8PSK 5/6	9.35	2.47	**89.35**	**237.75**
8PSK 8/9	10.69	2.64	**90.69**	**253.6**
8PSK 9/10	10.98	2.67	**90.98**	**256.77**
16APSK 2/3	8.97	2.63	**88.97**	**253.6**
16APSK 3/4	10.21	2.96	**90.21**	**285.3**
16APSK 4/5	11.03	3.16	**91.03**	**304.32**
16APSK 5/6	11.61	3.3	**91.61**	**317**
16APSK 8/9	12.89	3.52	**92.89**	**338.13**
16APSK 9/10	13.13	3.56	**93.13**	**342.36**
32APSK 3/4	12.73	3.7	**92.73**	**356.62**
32APSK 4/5	13.64	3.95	**93.64**	**380.4**
32APSK 5/6	14.28	4.11	**94.28**	**396.25**
32APSK 8/9	15.69	4.39	**95.69**	**422.67**
32APSK 9/10	16.05	4.45	**96.05**	**427.95**

5G communications on the real satellite links, as in (Luglio et al., 2009a), (Cataldi et al., 2009) and (Abdelsalam et al., 2015),(Abdelsalam et al., 2017).

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