SATELLITE AND SPACE COMMUNICATIONS **SSC**

http://committees.comsoc.org/ssc/

IEEE COMMUNICATIONS SOCIETY

SSC Newsletter **Vol. 25, No. 1, June 2015**

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The Satellite and Space Communications (SSC) Committee is a volunteer group actively involved in advancing satellite and space communication technologies within the IEEE. This committee is approved by the IEEE Communications Society and is governed by the constitution and bylaws of the IEEE as well as the other twenty-three Technical Committees in the Society. The committee belongs to the Technical Committee Clusters of Communication/Signal Processing (C/SP).

SATELLITE & SPACE

- JOIN US -

All conference attendees are welcome to join us in the SSC Committee meeting.
Location: London Suites 4, Excel Convention Center
Date: Thursday, 11 June 2015
Time: 13:00-14:30

Future SSC Meetings
Dec. 2015, San Diego, USA
June 2016, Kuala Lumpur, Malaysia
Dec. 2016, Washington, USA

ICC 2015 SSC Committee Activities:

Symposium on Selected Areas in Communications:

- *Wednesday, 10 June 2015 • 09:00-10:30*
  Location: ICC Capital Hall 1
  SAC06-SSC-01: Satellite Networking
  Chair: Claudio Sacchi (University of Trento, Italy)
- *Thursday, 11 June 2015 • 09:00-10:30*
  Location: ICC Capital Hall 1
  SAC06-SSC-02 Satellite Communications
  Chair: Giuseppe Cocco (German Aerospace Center, DLR, Germany)
- *Thursday, 11 June 2015 • 15.15-16:00*
  Location: ICC Capital Hall Interactive 4
  SAC06-SSC-I01 Satellite communications and networking
  Chair: Song Guo (The University of Aizu, Japan)

HOW TO JOIN SSC COMMITTEE AND MAILING LIST

If you like to join SSC Technical Committee: Please send your name and e-mail address to the SSC Secretary, optionally include your mail address, telephone and fax numbers.
If you like to join SSC Mailing List: Instructions on how to subscribe/unsubscribe are available at http://lists.scnl.dist.unige.it/listinfo/ssc/.

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MESSAGE FROM THE CHAIR

Prof. Igor Bisio

The Satellite and Space Communications (SSC) Technical Committee (TC) members will meet again during IEEE ICC2015. The SSC TC activities are continuing to maintain excellence level, usual for our TC, and to consolidate the role of out TC that exists since 1962. In more detail, I propose the update of the activities carried on by the SSC TC in the last period.

Participation to TC Meetings. The SSC TC last meetings have a quite satisfactory number of attendees. In Atlanta during IEEE GLOBECOM 2013, we had around 40 attendees, in Sydney during IEEE ICC 2014 we had 23 attendees, and finally, in Austin during IEEE Globecom 2014 we had 29 attendees. It is a satisfactory trend as well as a sort of index representing the interest of the IEEE ComSoc members in the SSC initiatives. Anyway, we have to continue to publicize our meeting and to invite members, past and new, to attend. In this way they will be aware of the numerous TC activities and, why not, be part of them.

Operative Policies and Procedures (OP&P). The SSC TC since December 2013 has new OP&Ps. At the moment, we can confirm that current version seems satisfactory but we will evaluate during the current term if amendments are needed. In particular, it will be discussed if insert in the OP&P the working-groups (or sub-committees) that we want to appoint as described below.

Membership Management. The two-fold approach described in my previous Messages is continuing: we are acquiring new members and, more importantly, we are involving old and new members in the TC activities (as Symposium Chairs, Guest Editors, etc.). The former activity is always proceeding at a slow pace: a few colleagues (around 5) asked to be new members in the last six months. We need more incisive action. For what concerns the second part, we deem it is producing adequate results: we nominate new representatives for IEEE ICC/GC and several members are working on interesting and prestigious editorial initiatives.

Extended Cooperation. It consists of strict cooperation with Industries, research institutes, standardization institutes (e.g., CCSDS, ETSI), and space agencies of several countries (NASA, JAXA, ESA). A first step has been represented by the nomination of a Standardization Liaison coming from industry. We want to continue this activity by appointing working-groups composed of members coming from different institutions/industries/agencies.

Review of the Advisory Committee. The new Officers team has evaluated the involvement of new members for this committee. Considering that the IEEE ComSoc Technical Activity Council (TAC) is revising the TCs portfolio, possible revisions could be asked also to our SSC TC. For this reason, we think that the current officers should be supported by an Advisory Committee composed of experienced members such as the current Advisor, Prof. Des Taylor, and other members that can help with their expertise.

SSC Website and Mailing List. The Vice-Chair and the Secretary have moved the SSC website to the IEEE ComSoc template (please visit http://cms.comsoc.org/eprise/main/SiteGen/TC_SSC/Content/Home.html) and the new mailinglist is working as well. Now all the on-line tools of our TC are on ComSoc premises.

Current Journals/Magazines. As you certainly recall, three editorial initiatives have been recently organized: the IEEE Communications Magazine (COMMAG), the IEEE JSAC, and the IEEE IoT Journal. The first is closed: Prof. Sacchi and his Co-guest Editors team have done an excellent work that Prof. Sacchi will personally introduce during the meeting. Concerning the IEEE JSAC editorial initiative, Prof. Vanelli, the leading Guest Editor on behalf the Guest Editor team, submitted the Special

Issue proposal. The IEEE JSAC Editor in Chief, Prof. Medard, received the proposal and forwarded it to the JSAC Editorial Board. We hope to receive a positive feedback very soon. Finally, the Special Issue on the IEEE Internet of Things Journal, edited by our Past-Chair Prof. Nei Kato and myself. If you look at the *Call for Papers* (CFP), you can note that is not entirely dedicated to satellite and space communications and networking topics but contributions from this research area are really welcome.
Actually from this viewpoint, our TC is really active. Indeed, other initiatives concerning possible Special Issues are ongoing for possible proposals, for example, the IEEE Wireless Communications Magazine and the IEEE Network. Operatively, our Vice-Chair, Dr. Tomaso de Cola, opened a sort of 'Call for Topics', through the TC mailinglist, aimed at finding interesting subjects for the aforementioned possible editorial initiatives. Several answers have been received. The proposals concerns: SmallSats/ Cubesats; Nanosatellites for Network Access in Rural and Isolated Areas; Terabit Satellite Communications; Software-Defined Satellite Payloads and Networks; Reconfigurable Payloads and Mega Constellations networks.
An appropriate selection of the topics and of the Guest Editors team will follow. For this task, specific working-groups, aimed at promoting the Editorial activities, will be appointed as group supporting the officers about this issue.

Conference Activities (ICC/GC and others). In ICC/GC, the SSC Track is consolidated. In the recent years the SSC track has been quite successful. The SSC track of IEEE ICC'15, chaired by our Vice-Chair, received around 30 submissions. Concerning the representatives from our TC, for future ICC/GC, we propose for IEEE ICC 2017 (Paris) the following nominations: Prof. Giovanni Giambene for the Wireless Communications Symposium; Prof. Shaowei Wang for the Wireless Networking Symposium; and myself for the SSC Track of the SAC Symposium that, as usual, is leaded by a member of the Officers' team.
Concerning other conferences, the SSC TC has endorsed SPECTS2015 and APCC2015 (Asia-Pacific Conference on Communications 2015).

Awards and Distinguished Lecturers. The SSC TC works on two kinds of awards: the SSC Awards and the other IEEE/ComSoc Awards. For the first, the submission deadline is September 15th 2015.
Concerning the second kind of award, we have to nominate a working-group. Finally, about the Distinguished Lecturers we have to individuate another working-group to find and convey nominations as well as propose educational activities for our TC under the ComSoc umbrella.

Standardization Activities. our Standard Liaison, Dr. Henry Suthon, Principal Senior Engineer at Boeing (h.suthon@ieee.org) is working and will lead the working-group, that we are planning to appoint, about Standards.

Finally, as described above, to make SSC activities more intense, we propose to appoint the following working-groups:

a. IEEE and IEEE ComSoc Awards and Fellowships;
b. Education and Distinguish Lecturers;
c. Standards:
d. Editorial Initiatives.

Volunteers, suggestions and any other contribution are highly welcome.

Prof. Igor Bisio, Chair

Satellite and Space Communications TC

SCANNING THE WORLD

Dr. Tomaso de Cola

In the past months, the interest towards networking in the sky by means of low earth and elliptical orbits has gained again particular interest from industries. After the missed promised of late 90's with Iridium, Teledesic, and Globalstar, renewed appeal is taking the deployment of large satellite constellations to provide broadband connectivity, especially to those areas that can be hardly connected to terrestrial infrastructures to receive Internet services. A similar initiative has been also started in the past years by Google, by means of a network of balloons mostly experimented over Australia. More recently, Facebook too entered this business, by planning a constellation of satellite network, mostly based on LTE connectivity and laser-optical downlinks. Closer to real service provisioning is certainly the deployment being prepared by O3b or the corresponding done by OneWeb, whose satellite constellation is composed of 700 satellites, which are expected to "wire" the entire globe, in order to ensure connectivity to all users, regardless of their specific position. As pointed out for the O3b solution, the overall network capacity will be in the order of few Gbit/s, still much smaller than what envisioned by High Throughput Satellite (HTS) paradigms, but with smaller costs, supposedly. Different applications are already foreseen, not only in the framework of digital divide but also as support of maritime communications, for instance. This interesting trend was actually started a few years ago with some pioneer plans about nano-satellite or swarms of satellite, wherein the concept of CubeSat was also devised. Unlike CubeSat, which is mostly conceived for experimental purposes or in any case not for broadband communications, the new age of networking in sky seems particularly promising because of the important money investments made by several big players in the field of communication.

Another important topic that is emerging in the satellite domain is the opportunity to reconfigure satellite devices on the fly. This is particularly interesting in the light of the the recent advances of SDR and cognitive radio for satellite applications. Further to this, software re-configurability implicitly bridge satellite domain to SDN-based world, where the possibility of self-networking through centralized or distributed orchestrators is certainly an interesting opportunity for satellite network design, in order to make them more flexible to users' requirements and traffic fluctuations. Particularly attracting seems the implementation of SDN-based schemes on gateways, whereas potentials of SDR should be mostly exploited on the satellite payload, which is typically not IP-enabled and therefore likely not able to support SDN-based schemes (e.g., OpenFlow)

Dr. Tomaso de Cola, Vice Chair
Satellite and Space Communications TC

FORTHCOMING GLOBECOM AND ICC CONFERENCES

ICC 2016

May 23-27, 2016, Kuala Lumpur, Malaysia

https://ieee-collabratec.ieee.org/app/event/34413

The International Conference on Communications (ICC) is one of the two flagship conferences of the IEEE Communications Society, together with IEEE GLOBECOM. Each year the ICC conference attracts about 2-3000 submitted scientific papers, a technical program committee involving about 1500 experts provides more than 10000 reviews, the conference being finally attended by 1500 - 2000 professionals from all around the world. IEEE ICC is therefore one of the most significant scientific events of the networking and communications community, a must-attend forum for both industrials and academics working in this area. We invite you to submit your original technical papers, and industry forum, workshop, and tutorial proposals to this event. Accepted and presented papers will be published in the IEEE ICC 2016 Conference Proceedings and submitted to IEEE Xplore®.

COSPONSORING / RELATED CONFERENCES AND WORKSHOPS

MILCOM 2015

October 26-28 2015, Tampa, FL

http://www.milcom.org/

The MILCOM 2014 - Military Communications Conference is dedicated to military communications networking, services, timing and applications, including:

- *Waveforms and Signal Processing view details*
- *Selected Topics in Communications view details*
- *International Perspectives on Communications*
- *Networking Protocols and Performance view details*
- *Services and Applications view details*
- *Cyber Security and Trusted Computing view details*
- *System Perspectives view details*

The MILCOM 2015 - Military Communications Conference brings together professionals from the industry, academia, and government.

GLOBECOM 2015

December 6-10, 2015, San Diego, CA, USA

http://globecom2015.ieee-globecom.org/

IEEE GLOBECOM is one of two flagship conferences of the IEEE Communications Society, together with IEEE ICC. Each year the conference attracts about 3000 submitted scientific papers. A technical program committee of more than 1,500 experts provides more than 10,000 reviews, and from this a small fraction of the submitted papers are accepted for publication and presentation at the conference. The conference meets once a year in North America and attracts roughly 2000 leading scientists and researchers and industry leaders from all around the world. IEEE GLOBECOM is therefore one of the most significant scientific events of the networking and communications community, a must attend event for scientists and researchers from industry and academia.

CONFERENCES CALENDAR

CONFERENCE	DATE & LOCATION	INFORMATION
SPECTS 2015 International Symposium on Performance Evaluation of Computer and Telecommunication Systems	July 26-29, 2015 Chicago, IL, USA	http://atc.udg.edu/SPECTS2015/
International Conference on Localization and GNSS	June 22-24, 2015 Gothenburg, Sweden	http://www.icl-gnss.org/2015/index.php
PIMRC 2015 IEEE International Symposium on Personal, Indoor and Mobile Radio Communications	Aug 30-Sept. 2, 2015, Hong Kong, China	http://pimrc2015.eee.hku.hk/index.html
20th Ka and Broadband Communications Navigation and Earth Observation Conference 2015	October 12-14, 2015 Bologna, Italy	http://www.kaconf.org/
2015 IEEE 82nd Vehicular Technology Conference (VTC-Fall)	September 6-9, 2015 Boston, MA, USA	http://www.ieeevtc.org/vtc2015fall/

To all SSC members: If your postal address, telephone or fax numbers have changed, please update them with the committee secretary. You can review our current records on our web page at http://committees.comsoc.org/ssc/.

Broadband Access via integrated Terrestrial and Satellite systems

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Abstract — **Satellite broadband systems will play a key role in reducing the Digital Divide by complementing terrestrial networks in the delivery of next generation broadband to users in remote and rural locations. We describe an integrated broadband delivery system to fixed users that makes simultaneous use of different access networks in order to optimise the end-user QoE. The design of the overall network architecture and the key building blocks of the routing entities at both ends of the integrated system are presented. Moreover, we introduce the design of a High Throughput Satellite (HTS) system targeting the 2020 timeframe and envisaging two different configurations for the feeder link using either Q/V or optical gateways, whereas user links are always in Ka-band.**

INTRODUCTION

The research project BATS (Broadband Access via integrated Terrestrial & Satellite systems) [1], co-funded by the European Commission (EC) under the FP7 programme, addresses the delivery of Broadband (BB) future services in Europe according to the EC Digital Agenda [2] objective to reliably deliver >30Mbps to 100% of European households by 2020. Next generation geostationary (GEO) broadband satellite systems will play a key role in achieving such objectives as the accelerated deployment of terrestrial broadband technology will not be able to satisfy this requirement in the most difficult-to-serve locations. The BATS project aims to bridge the potentially widening Broadband divide between urban and rural areas and fulfil the Digital Agenda targets in the underserved areas via an integrated network that combines the flexibility, large coverage and high capacity of future multi-spot beam satellites, the low latency of fixed DSL lines, and the pervasiveness of mobile-wireless access. The integrated broadband service will be delivered to the end-user via an *Intelligent User Gateway (IUG)* and *Intelligent Network Gateway (ING)*, dynamically routing traffic flows according to their service needs through the most appropriate broadband access network, with the goal of optimizing the user´s Quality of Experience (QoE).

In this paper we first present the overall network architecture of the BATS system. We then focus on the building blocks of the two routing entities at both end-points on the network, the IUG and ING. Two different High Throughput Satellite systems are then presented with Q/V-band and Optical feeder link configuration respectively. Finally we conclude the paper with some details on our future work.

NETWORK ARCHITECTURE

As illustrated in Figure 1 the overall network architecture comprises the three broadband access segments, namely xDSL, cellular and satellite, whose connections are terminated at the IUG on the end-user side and at the ING on the central/operator side. The IUG is the routing entity located at the end-user premises serving as the focal point for the integration of the terrestrial and satellite connections. As the counterpart of the IUG on the network side, the ING has the functionalities of both managing a set of associated IUGs and acting as a single connection interface to the public internet. For the downstream traffic, an ING has equivalent building blocks and routing functionalities to the IUG. The main functionality of IUG and ING is to route the outgoing traffic towards the most suitable access network segment considering the QoE requirements of each particular traffic flow and the real-time status of each of the links. Based on this, the ING shall be located closer to the Point of Presence (PoP) of the terrestrial operators involved in the integrated system, in order not to increase the latency of the services routed terrestrially (which are meant to be the most delay sensitive).

In addition, due to TCP performance degradation over satellite links, Performance Enhancement Proxies (PEPs) are currently one of the most commonly adopted solutions to achieve good transport performances whatever the available TCP stack at both ends. For the BATS architecture it has been decided that the best compromise between performance, impact and complexity is to locate a high capacity PEP in a central point of the network near to the PoP or at the ING, alleviating the internal re-routing and synchronization issues compared to a case where the PEP is located at the nominal satellite gateway and traffic needs to be re-routed to a redundant gateway to avoid service interruption due to fading or failure at the nominal one.

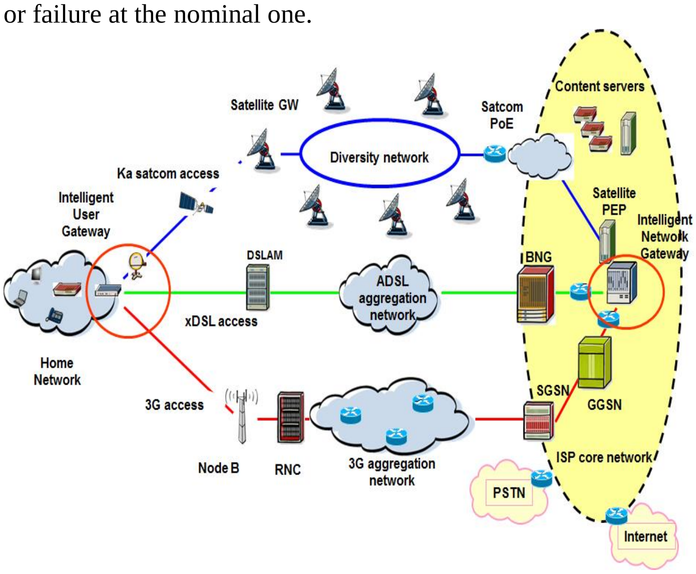

Figure 1. BATS Network Architecture

THE INTELLIGENT USER AND NETWORK GATEWAYS

Due to the heterogeneity of the various technologies (e.g. satellite broadband offers high bandwidth but higher latency as opposed to narrow-band xDSL low latency links) randomly distributing traffic among the different connections despite their different characteristics could in turn affect negatively the service quality. More sophisticated methods are required which allow for a simultaneous use of the different links in a seamless manner fully exploiting their particular benefits. The IUG and ING have been conceived with a modular approach and well-defined connecting interfaces between the different components which allow for specific improvements on individual modules without modifying the entire system. Figure 2 illustrates the key building blocks of both IUG and ING, namely being the Traffic Classifier, QoS-aware Link Selection module and the module for Link Status Estimation.

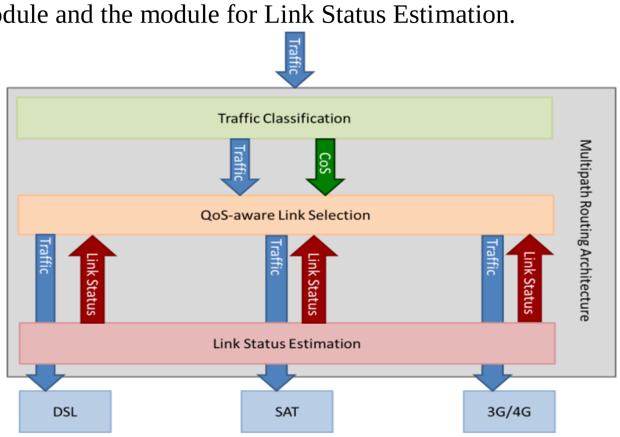

Figure 2. Key building modules in IUG and ING

Since TCP (and HTTP) are now the main protocols dominating the Internet traffic [3], they become a de-facto convergence layer. For this reason, the innovations in the IUG and ING design have focused on optimizing the routing of TCP traffic, managing UDP via Policy Based Routing (e.g., route traffic over terrestrial links when available). MPTCP [4] has been identified as an appropriate instantiation to base the core of the multipath routing architecture, as it aims at using multiple paths between a source and a destination host while providing the same interface to both the application and the network layer as in conventional TCP. As regular TCP, MPTCP is also designed to be an end-to-end transport layer protocol. Hence, in order to exploit the multipath features of MPTCP only between intermediate routers such as IUG and ING, MPTCP proxies need to be used at those routers. In the BATS design, the implementation of MPTCP proxies at both IUG and ING allows the definition of a completely integrated architecture based on a common set of mechanisms independent from the heterogeneity of the access networks.

Link Status Estimation

The link estimation module analyses each path between the IUG and the ING and provides the real-time status of different path characteristics, e.g. latency, bandwidth, loss rate, in order to assist the decision on link selection. Benefiting from the MPTCP architecture in which the IUG and ING become the end-points for the TCP subflows, in BATS the link estimation module is implemented by measuring information from the TCP connections, updating the statistics each time a TCP packet is sent or received. The maximum achievable bandwidth is evaluated by properly low-pass filtering the rate of returning acknowledgment packets from a peer. Each TCP connection is estimated individually and the sum of all estimations provides the bandwidth estimation for a particular path. The latency in each path between an IUG and ING is estimated based on the smooth round trip time (SRTT) available in the TCP kernel.

Traffic Classification and QoS-aware Link Selection

As the reference MPTCP implementation always routes the traffic first towards the sub-flow with lowest latency, which is a limitation for the BATS setup, the IUG and ING are based on a novel QoS-aware Link Selection algorithm named "Path Selection based on Object Length (PSBOL)" that takes account of traffic requirements and the real-time status of each of the links. The link selection is performed by analyzing the so-called TCP object size, where an object is typically an Application Protocol Data Unit (APDU), e.g. an HTML request. In this initial implementation, the link selection algorithm is based on the assumption that for long objects (e.g. greater than a certain threshold, which can be selected dynamically based on the link characteristics and the class of traffic) the priority is to benefit from high bandwidth links to reduce the total transmission time, whereas for short objects is preferable to benefit from low latency and faster delivery times. Thus, for a particular TCP connection, long objects are routed via the highest bandwidth link (e.g. satellite) and short-objects are routed towards the lowest latency link (e.g. terrestrial). The discovery of object boundaries is based on an algorithm that computes packets inter-arrival times and differentiates between the reception of packets from current or new objects.

This method is applicable to any TCP-based application protocol and works on unencrypted as well as encrypted TCP connections. Due to the IxG architecture, optimized link selection decisions can be performed independently for the inbound and outbound traffic.
The work in [5] provides additional details on the implementation of the IUG and ING together with results from in-factory validation tests with prototype models of the gateways. Figure 3 shows the averaged result from a test consisting of loading 35 different websites using the prototype IxGs connected to real networks (i.e., 7Mbps satellite link, 500kbps cellular link, and 1 Mbps DSL link). PSBOL reduces the time of loading all websites as compared with the other test cases (i.e., DSL only, Satellite only, and Weighted Round Robin over the three links).

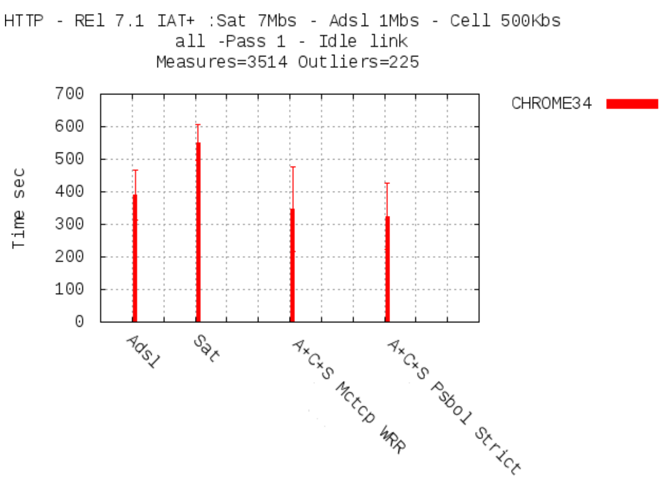

Figure 3. HTTP Acceleration Test Results with real networks

NEXT GENERATION HIGH THROUGHPUT SATELLITES

Recent studies [6] have estimated that 2-3 Tbps of satellite capacity will be required to serve the addressable market for satellite broadband in Europe by 2020. In order to be able to serve this increasing demand, more than one advanced High Throughput Satellite (HTS) will be required. Next generation HTS will need to be able to offer both higher overall throughput and higher end-user data rates, flexibility to adapt to traffic demand across the coverage area, and at the same time decrease the cost per transmitted bit. In order to maximise the overall data throughput, the Ka-band resources dedicated to satellite broadband communications shall be fully allocated to the user links. The occupied spectrum will include shared civil bands ([17.7-19.7] GHz on the downlink and [27.5-29.5] GHz on the uplink) and exclusive civil bands ([17.3-17.7] GHz and [19.7-20.2] GHz on the downlink and [29.5-30] GHz on the uplink). As the Ka-band is dedicated to the user links, the satellite-to gateway (feeder) links need to be moved to higher frequency bands. Two feeder options are considered in the BATS project, a first one based on Q/V-band feeders and a second looking at optical frequencies.

Independently from the feeder link configuration, the mission defined for the BATS project comprises two GEO satellites covering the EU27 countries and Turkey, both co-located at the orbital slot in 13^{0}E and based on the Alphabus Extended platform. The user coverage includes $302 \times 0.21°$ beams, with an East / West coverage sharing between the two satellites, as illustrated on Figure 4. Each satellite involves 2 Ka-band antennas with 4.8m reflectors and multiple feed per beam technology. Each of these antennas is used in both reception (Rx) and transmission (Tx). The air interfaces will be based on the DVB-S2X standard on the F/L and DVB-RCS2 on the R/L.

A major activity related to the satellite component in the BATS research project has been to explore the two feeder link options. The study included satcom system sizing and performance evaluations, and has additionally investigated the subsequent gateway network requirements and the associated operational constraints. In addition to possible evolutions of the air interface, advanced interference management techniques within the multibeam coverage, possibly leading to more aggressive frequency reuse schemes, have been investigated [7][8][9].

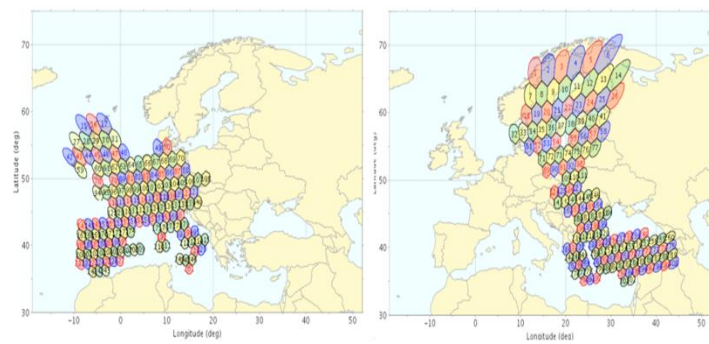

Figure 4. User Beam layout covering EU27 and Turkey for both Q/V-band and Optical configurations

Q/V-band feeder link configuration

In this first configuration the bands of interests are for the feeder uplink the [42.5 – 43.5] GHz, [47.2 – 50.2] GHz and [50.4 – 51.4] GHz bands, allocated in V-band to FSS by the ITU. For the feeder downlink, the considered Q-band spectrum is the [37.5 – 42.5] GHz band. The satellite feeder antenna in Q/V band is based on a single reflector with 2m diameter, fed by a Single Feed per Beam (SFPB) focal array, each feed being in charge of one gateway site, in transmission and reception.

The frequency plan considered for the system allows a gateway to convey the traffic of 6 user beams in Q/V band, with the following bandwidth allocation strategy: in the F/L, 1.5 GHz is allocated to 66% of the beams with the highest expected need for capacity by 2020, whereas the remaining 33% is allocated with 1GHz; in the R/L, 500 MHz is allocated to user beams. The channel allocation to the user beams relies on a conventional four-colour reuse scheme.

Based on the frequency plan defined, the satellite system will be fed by approximately 50 active gateways on ground. We have selected the gateway sites so to maximise the distance between stations while minimising the terrestrial link costs, using where possible existing teleports. We considered single gateways (to only one of the satellites) for WEST and

EAST zones of the coverage, and dual gateways (to both satellites) for the locations in the CENTRAL region. Gateway clustering has been considered, not only in terms of system architecture but also with regards to the backbone cost and the on-board switching matrix complexity in the satellite. As presented in [10], we have evaluated the availabilities that can be achieved for different solutions using the ITU-R P618-10 recommendation for fading statistics. Results show that requirements can be met with 25+1 dual gateways and in the alternative scenario with 12 active and 1 redundant gateway in East and West zones and 13+1 dual gateways in the central region.

As detailed in [11], we have performed an initial assessment of the performances of this system. On the F/L, considering 420 Mbaud carriers, the maximum throughput is 735 Mbps provided by both satellites across the 302 beams in nominal conditions. The average spectral efficiency is 1.87 bit/s/Hz. The average user beam capacity is 2.5 Gbps in the beams with 1.45 GHz allocated to the forward link, and 1.67 Gbps in the beams with 1 GHz on the forward link. On the R/L, considering 20.7 Mbaud carriers, the maximum satellite capacity provided by the two spacecraft is 260 Gbps. The average spectral efficiency is 1.72 bit/s/Hz, and the average beam capacity is 850 Mbps on the return link.

Optical feeder link configuration

An alternative to Q/V-band feeders is free space optical communications. These have already been a hot topic for research in several applications in leading countries such as France, Germany, Japan and USA. In Europe, systems using 0.8μm and 1.06μm technologies have been successively put into orbit for data relay application and LEO-LEO links. Recently the European DRS programme has been specified by ESA for LEO-GEO links at 1.06μm. The 1.55μm technology widely deployed in terrestrial networks could be used also for free space links, subject to its qualification for space applications. Optical links allow the entire spectrum of 225 GHz (uplink) and 75 GHz (downlink) to be transmitted over one site. However important challenges arise when considering this architecture, such as the space qualification of the optical terminal equipment, the transmission of high data rate optical signal through the atmospheric turbulence and the size, operation and cost of a very high data rate on-ground optical network to support site diversity.

The innovative optical feeder link architecture proposed for the BATS project (ground-GEO) is based on the Dense Wavelength Division Multiplexing (DWDM) technology to multiplex channels and high power Erbium Doped Fibre Amplifier (EDFA) booster amplifiers. The optical feeder link must be transparent with respect to the user terminal air interface in order to minimize the on-board hardware. This is possible using either digital or analogue modulation of the optical carrier. Both options are assessed for the BATS mission. The digital option increases the required optical bandwidth due to the quantization of the DVB-S2 and DVB-RCS2 user signals; however it benefits from error correcting codes and framing schemes which are efficient against atmospheric impairments. The digital option needs a high-speed processor on board for the digital-to-analogue and analogue-to-digital conversions. The analogue option implemented with Radio over Fibre (RoF) is more bandwidth efficient and it does not require a high-speed processor. However, with the analogue modulation, the atmospheric turbulence impairments can only be mitigated with complex optics on the ground terminal. Both analog and digital options are feasible in the 2025 timeframe but the digital option is considered more mature, in particular with respect to the implementation of the fade mitigating techniques.

An optical feeder link will obviously be of higher capacity than a Q/V band feeder link. As a consequence, the number of simultaneously active gateways is expected to be limited to one or two per satellite, which is a very significant reduction compared to the Q/V option. On the other hand, it is much more sensitive to the atmospheric events (link blockage by the clouds) and site diversity will be required to maintain the 99.9% availability level. An optimisation process has been performed to locate the Optical Gateways (OGs) by minimising the weather correlation between the OGs over 2 years of cloud mask data files [12]. Results show that 8 to 14 OGs are sufficient to reach 99.9% to 99.7% availability under the assumption that OGs can be anywhere in Europe + Turkey and OGs are constrained to be in a radius of less than 50 km around PoPs selected from the global high data rate carrier network (terrestrial and submarine), By including PoPs in Africa and Middle East, the number of required OGs reduces to 3 to 5 OGs.

An end-to-end performances assessment has been carried out and results show that, considering both satellites combined, a total capacity going above 1Tbps is achieved with the proposed design. On the F/L, considering 420Mbaud carriers, a maximum throughput of circa 800Gbps is obtained with both satellites in nominal conditions (Clear Sky). The average user beam capacity is 2.65 Gbps. On the R/L link, up to 249Gbps are reached with an average user beam capacity of 825Mbps, leading to a design fully compliant with the BATS satellite access network requirements.

CONCLUSIONS AND FUTURE WORK

We have presented a novel broadband delivery system designed in the frame of the ongoing EC FP7 project BATS which integrates satellite with terrestrial communication networks. We have described the design of integrated gateways in both user and central sides of the system intelligently using all available access technologies to provide high speed broadband and improved QoE to users in underserved areas. In addition, we have presented the initial design of a HTS system targeting the delivery of near 1 Tbps of aggregated capacity in order to meet the 2020 demand for satellite broadband in Europe. We have discussed the specific designs for two possible configurations on the feeder link making use of either Q/V or optical gateways.

Our future work will focus on running extensive Laboratory and Field trials with the prototype IUG and ING involving real end-users in both controlled and real-world environments to be able to assess the benefit of the designed system in terms of QoE. Figure 5 shows a picture of the prototype IUG for the field trials which has internal DSL and 3G/4G modems and connects to a satellite router via an Ethernet interface.

Figure 5. Prototype IUG for Field Trials

ACKNOWLEDGMENT

This work has been supported by the BATS research project funded by EU-FP7 under contract n317533.

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