SatNEx Phase III – Satellite Communication Network of Experts

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Abstract. SatNEx is a European Network of Experts for satellite communications, coordinated by the German Aerospace Center DLR. The first two phases of SatNEx were funded by the EU from 2004 to 2009. The third phase, SatNEx-III, comprises 17 partners and is funded by ESA from 2010 to 2013. A core team consisting of DLR, University of Surrey, and University of Bologna is coordinating the SatNEx-III research activities. Specific research tasks are contracted to partners in the frame of annual "Call-off Orders".

Keywords: Satellite communications, satellite systems, satellite technology.

1 Introduction

The primary goal of SatNEx under European Union (EU) sponsorship was to achieve long-lasting integration of the European research in satellite communications and to develop a common base of knowledge. SatNEx was formed in 2004 by 22 partner research organisations and universities with the support of the EU FP6 programme as one of several new Networks of Excellence (NoE). In 2006, funding was renewed by the EU to continue with SatNEx-II up to 2009.

Apart from establishing a critical mass of research effort in satellite communications in Europe, SatNex has established a series of annual summer schools for new researchers, providing a comprehensive programme of advanced technical and scientific lectures which cover specific areas in satellite communications. Also, SatNEx has sponsored and coordinated several satellite conferences, has produced many journal and conference papers as well as four books, and has provided inputs to standards bodies and participated in forming standards.

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Now, the third stage of SatNEx, SatNEx-III, continues with the support of ESA with a more focused approach. SatNEx III is comprised of 17 European research organisations and universities. The German Aerospace Center DLR with its Institute of Communications and Navigation leads the team with close support by the core team partners University of Surrey, Centre for Communication Systems Research, and University of Bologna.

1.1 Network Partners

The SatNEx-III network comprises the following partners:

- DLR, Institute of Communications and Navigation (Co-ordinator)
- University of Surrey, Centre for Communication Systems Research (UniS)
- University of Bologna, Department of Electronics, Computer Science, and Systems (UoB)
- Aristotle University of Thessaloniki, Department of Electrical and Computer Engineering (Auth)
- University of Bradford, Communication Systems Engineering Research Group (BRU)
- Consorzio Nazionale Interuniversitario per le Telecomunicazioni (CNIT)
- Italian National Research Council CNR, Istit. di Scienza e Tecnologie dell`Inform. "A. Faedo" (CNR-ISTI)
- Centre Tecnologic de Telecomunicacions de Catalunya (CTTC)
- National Observatory of Athens Institute for Space Applications and Remote Sensing (ISARS)
- Office National d`Études et de Recherches Aérospatiales (ONERA)
- University of Salzburg, Department of Computer Sciences (SBG)
- TéSA Association, Institut Supérieur de l`Aéronautique et de l`Espace (TeSA)
- Graz University of Technology, Institute of Communication Networks and SatComs (TUG)
- Universitat Autonoma de Barcelona, Dept. Telecomunicació i Enginyeria de Sistemes (UAB)
- University of Aberdeen, King`s College, Department of Engineering (UoA)
- Universita Degli Studi di Roma "Tor Vergata", Department of Electronics (UROMA2)
- Universidade de Vigo, Department of Signal Theory and Communications (UVI).

Fig. 1 shows the geographical distribution of the SatNEx-III partners.

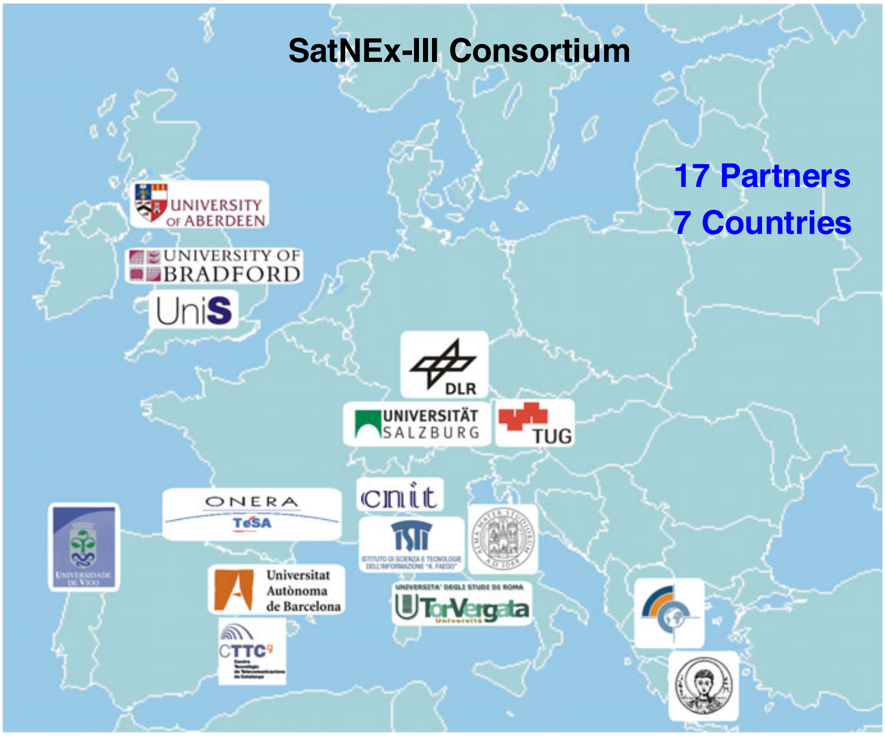

Fig. 1. Geographical distribution of SatNEx-III partners

1.2 General Tasks of SatNEx-III

In general, SatNEx-III will:

- play an important role in exploring new satcom techniques supporting ESA in selecting the right avenues for R&D work plans (TRP, ARTES 1, ARTES 5)
- support ESA in ad-hoc technical actions related to satcom standards
- identify promising terrestrial technology spin-in into space
- play a pivotal role in forming young professionals for satcom.

Throughout the three-years duration of SatNEx-III, **horizontal activities** will be pursued in the following areas:

- Long-term development of satcom visions and systems
- Development of physical and access layer technologies
- Development of networking technologies and protocols
- Satcom training activities and dissemination of SatNEx-III results.

In addition, ESA will activate each year a number of **specific advanced research areas**. In the first project year, SatNEx-III has been charged with the following tasks:

- Concept development for a Terabit/s satellite system
- Exploration of hybrid space/ground signal processing techniques

- Investigation of new protocols for disruption tolerant satellite communications.

Fig. 2 shows the structure of the SatNEx-III tasks.

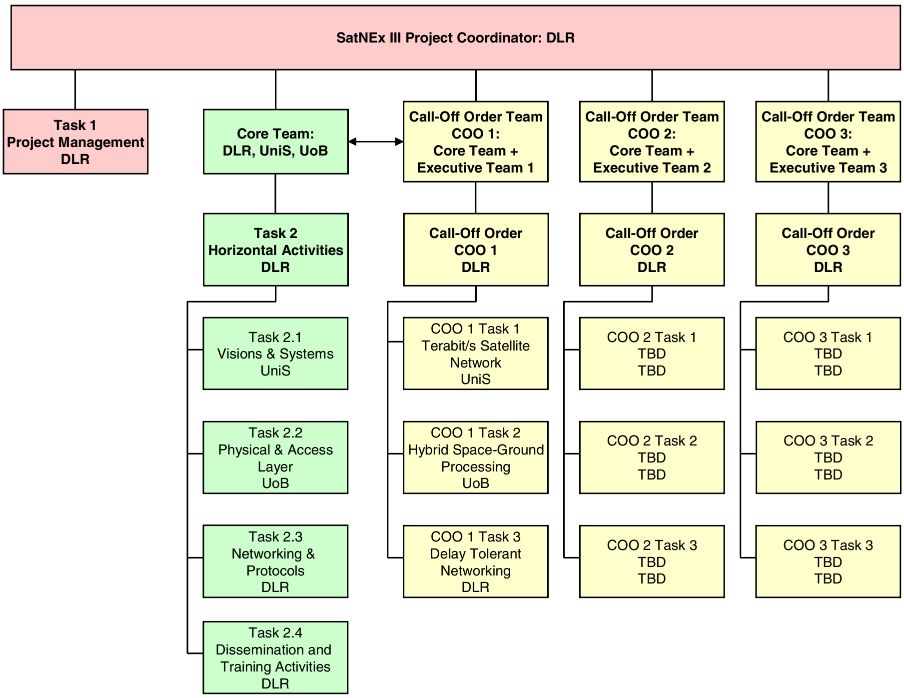

Fig. 2. Structure of SatNEx-III tasks

2 SatNEx-III Horizontal Activities

The horizontal activities last throughout the three-years duration of SatNEx-III, and are performed by the core team consisting of the German Aerospace Center DLR / Institute of Communications and Navigation, University of Surrey / Centre for Communication Systems Research, and University of Bologna. A brief description of the horizontal activities is as follows:

2.1 Long-Term Development of Satcom Visions and Systems (lead: University of Surrey)

- Identify new satcom applications and related requirements
- Devise new system architectures which can satisfy the new applications and requirements
- Investigate the best options for integrating satellite networks with terrestrial systems

- Identify new research areas in view of the identified satcom applications and requirements
- Exchange and consolidate the results with ESA and other key players (e.g. satellite operators and industry).

First Results

The future vision of communications is one of 7 Trillion wireless devices serving 7 Billion people with pervasive machine to machine communications as part of an Internet of Things. As well as connections of large numbers of devices users will expect ubiquitous service delivery with consistent user experience. Data is doubling every year and video content is becoming pervasive in all services which is leading to demands for massive increases in bit rates and hence bandwidth. Current estimates for domestic users indicate downloads of around 20Mb/s by 2016 (Analysys Mason Report 2010) which would easily transform to the EU target of 30Mb/s by 2020. Other users such as SME's and institutional users will be higher. The increase in video content will also increase the return link rates and this is likely to move towards more symmetry with new services. By 2020 services such as social TV involving multiview, HDTV and 3DTV are likely to be wide spread and business users will be using immersive presence systems for virtual meetings requiring 100's of Mb/s. Even today we see the first remote holographic experiences of art galleries and museums and we can envisage this moving to shared experiences between social groups which will increase the bandwidth demands in both directions. Hence the future is a mixed environment between large numbers of low rate M2M traffic and video dominated high bit rate broadband services.

For satellite systems as with any radio system, spectrum is a major issue and its constraints are already forcing us to be smarter in the use of this resource. Sharing of spectrum between systems and mitigation of interference as well as the use of cognitive radio for more opportunistic use are already investigated. Energy conservation (Green Systems) is another major driver on an end to end basis, which will dictate future systems design with systems becoming always available rather than always on.

Future networks will no longer be designed on a vertical service basis but with virtualisation will be flexible and enable separate virtual networks to be set up from a common infrastructure for different services. They will also be self organising from a system level based on power, spectrum, energy, QoS and cost. Such scenarios bring with challenges of resilience, security and network management. One of the key features for satellite is the movement to internet down load replacing traditional broadcasting.

From the above we see key issues for satellites as;

- Higher capacities either in one large GEO or smaller clusters
- Smarter Payloads to provide connectivity
- Smarter use of the spectrum-sharing and interference mitigation
- Dealing with very large numbers of sensors
- Integrated and hybrid systems to be part of flexible networks
- Delivering video content in non broadcast modes.

2.2 Development of Physical and Access Layer Technologies (lead: University of Bologna)

- Report on terrestrial trends and possible reuse of emerging terrestrial wireless physical and access layers standards and solutions in satellite networks
- Identify new research areas and assess their suitability to the satellite scenarios identified in the visions and systems task
- Identify physical and access layers standardisation areas of interest to satcoms.

2.3 Development of Networking Technologies and Protocols (lead: DLR)

- Report on terrestrial trends and possible reuse of emerging terrestrial networking and standard solutions in satellite networks
- Identify new research areas and assess their suitability to the satellite scenarios identified in the visions and systems task.
- Identify networking and protocol standardisation areas of interest for satcoms.

First Results

The study has been primarily concentrated on the standardisation efforts made by IETF (Internet Engineering Task Force), IRTF (Internet Research Task Force), and CCSDS (Consultative Committee for Space Data Systems) about transport layer enhancement and in general networking issues. In particular, the aim of this investigation has been to explore some new areas of research that could be of some applicability in satellite networks, though being conceived for wireless or terrestrial communications.

What has been observed is that transport layer issues cannot be limited to the design of new transport protocols, but also and more importantly to transport layer solutions supporting QoS in multimedia applications. This could be the case of RSVP (Resource reSerVation Protocol) extensions for supporting triple-play applications as to concerns the resource allocation along the routing path. Other aspects related to the QoS management are linked to the assignment of dedicated DSCP codes for admitted capacity over Differv-enabled networks. All these elements are of some importance in integrated terrestrial-satellite networks, when QoS requirements have to be targeted by the service provider to offer the user a satisfactory QoS level.

Another topic being addressed concerns the interconnecting issues between satellite and terrestrial domains, in case NATs, firewalls or in general security countermeasures are applied to filter and shape the incoming/outgoing traffic. In this perspective, the findings of the midcom working group within IETF are certainly of some interest, as they draw the challenges and the possible solutions that can be deployed to allow middlebox communication even in presence of filtering and shaping traffic policies.

Finally, an additional topic considered for a possible application in satellite network regards the synchronisation in IP-based networks. It was noted that this aspect is quite important in environments where disruptions or delay spikes may alter the behaviour of applications. In this respect, the activities of the tictoc working group part of IETF have been considered for possible application to mobile satellite networks. In particular, the expected extensions to the Network Time Protocol (NTP) could result helpful to ensure a more robust synchronisation even in presence of link interruption.

As far as deep space communications are concerned, some investigations about interoperability issues with terrestrial links have been carried out, by taking as reference the standardisation work carried out within the Consultative Committee for Space Data Systems (CCSDS).

2.4 Satcom Training Activities and Dissemination of SatNEx-III Results (lead: DLR)

The purpose of this task is to support the networking of people within SatNEx. In particular, the tasks are to

- Support exchanges of researchers between partners
- Ensure dissemination of results to ESA, delegations, industry and satellite operators
- Maintain the SatNEx web site
- Secure representation of SatNEx-III in major satellite conferences
- Raise funds for maintaining the current SatNEx summer school initiative for PhD students
- Give annual lectures at ESTEC on subjects of common interest to ESA and SatNEx.

One of the main activities in this area will be the organisation of the next SatNEx summer school which is scheduled for Sep. 5 – 9, 2011 in Siena. For more information see the announcement to be published in the Internet. This summer school will maintain the series of summer schools organised in the frame of the SatNEx project.

3 SatNEx-III Specific Research 2010 (Call-off Order 1)

Three specific advanced research topics, activated by ESA, are investigated every year by specific task teams. In the first project year, SatNEx-III has been charged with the following tasks:

3.1 Concept Development for a Terabit/s Satellite System

lead: University of Surrey; partners: ISARS, ONERA, TeSA, UAB
In this task, the team investigates a number of critical technical system aspects related to the development of a Terabit/s satellite system. More specifically, we will:

- define a reference system architecture and related system assumptions, with particular emphasis on frequency bands for the user and feeder links, and number of beams required
- investigate approaches to achieve flexible resource allocation over the coverage region

- investigate physical and access layer techniques able to efficiently cope with unbalanced traffic distribution
- investigate countermeasures at system/network/user terminal level to cope with the residual ground beams displacement
- assess the fading impact for both the feeder link and the user link and define fading countermeasures
- investigate smart feeder link concepts.

First Results

A baseline European system for a generation after next satellite has been determined for the Terabit/s satellite driven by the capability to accommodate a Terabit/s of traffic. The constraints of spectrum at Ka band (2.5GHz up and 3.4GHz down) and Q/V (4GHz up and 5GHz down) as well as the cost of the user terminal have resulted in a system of 19 gateways operating at Q/V plus 175 (or 88 dual polarisation) beams using 3 colour reuse for the user coverage. The system uses DVB-S2-RCS(NG) air interface and ACM on the Ka band links to combat rain fading. On the gateway links in order to achieve a 99.99% availability a smart gateway system is used connecting all the gateways via an optical network and switching the traffic and load balancing between the gateways to achieve performance.

Assuming that the ACM and smart GES system provide the availabilities a baseline link budget has indicated that the capacity can be achieved providing that the satellite antenna C/I exceeds circa 20dB. Current work concentrates on more realistic modelling of the latter with real traffic within the region. The return link is the limiting performance and several configurations of polarisation reuse have been investigated in an attempt to optimise the C/I which is still marginal. Improvements in the latter using managed return link transmissions are being investigated. The smart GES scheme has been modelled for various numbers of GES and shown to provide the necessary availabilities and we are now investigating the payload routing complexity and the practical switching issues between the GES.

The large numbers of beams required to meet the capacity, result in severe requirements on the payload in terms of the numbers of amplifiers required. Payload power estimates for satellites around 2020 are around 20kW and are limited by the solar panels packaging into the limited launcher fairing. Assuming a single feed per beam around 200 amplifiers rapidly exceeds these limits. The use of dual polarisation halves the number of amplifiers and has been adopted and we are investigating the use of Beam Hopping on the forward link to reduce the numbers still further but there is clearly a trade off in the user terminal complexity and in modifications to the air interface. Another implication of large numbers of smaller beams is the stability of the satellite and the resultant beam movements. This is being modelled and mitigation schemes being proposed.

The final issue being investigated is the performance of the ACM in the Ka band. Here with larger fading, a wider Mod/cod range is desirable and extension to 64 APSK with improvements in the SNR estimation and demodulation as well as improvements in the signalling of the mod/cod changes. See reference 1 for further details.

3.2 Exploration of Hybrid Space/Ground Signal Processing Techniques

lead: University of Bologna; partners: CTTC, TUG, UniS, UVI

In this task the team investigates the potential applicability of hybrid space ground processing techniques with signal digitalisation on-board the satellite. In particular, the following tasks are being performed:

- define a reference system architecture and related system assumptions
- review of literature in the field of data compression, beam forming, Multi User (MU) Multiple Input Multiple Output (MIMO) algorithms with apportionment of tasks between the space and the ground segment
- pre-select candidate architectures and algorithms for hybrid space ground processing relevant to the selected reference system
- perform a detailed trade-off among different options for the hybrid space ground processing in terms of performance and complexity
- make recommendations for further R&D activities in this field.

First Results

In the frame of this task different issues related to signal processing have been investigated.

As a consequence of the increase in the number of spot beams in modern satellite systems, more and more flexible beam management systems are required, leading to more complex beamforming networks on board the satellite. As an alternative, ground-based beamforming (GBBF) techniques are based on the exchange of radiating element signals between satellite and gateway. At the cost of a high feeder link bandwidth demand, more sophisticated and power consuming techniques can be implemented. Flexibility is preserved, and changes in shape, traffic and pointing direction can be accommodated. Finally, hybrid schemes consist in partitioning the beamforming process between the satellite (Coarse Beamforming) and the gateway, with the objective of reducing the feed signal space to a subspace, thus decreasing the required feeder link bandwidth.

The deployment of larger number of beams with high frequency reuse increases the total system throughput, however, increasing the interference among users at the same frequency. Multi user interference mitigation techniques can be considered for controlling the corresponding performance degradation.

Multi user interference mitigation techniques can be fully implemented at the gateway (GW), so that the impact on the complexity of the user terminals (UT) is limited. In the forward link (FL), it consists in the use of *precoding* techniques. The general idea is to combine at the GW (i.e. the transmitter side) the different input signals associated with each user in such a way that the interference levels as seen at each UT (i.e. the receiver side) are controlled and minimized. In the return link (RL), the interference between users can be mitigated by considering *multi user detection* (MUD) techniques at the GW (i.e. at the receiver side). In the sense of information theory, these scenarios are respectively referred to as the multiple input multiple output (MIMO) broadcast channel (BC) and multiple-access channel (MAC).

3.3 Investigation of New Protocols for Delay Tolerant Satellite Communications

lead: DLR; partners: CNIT, CNR-ISTI, SBG, UniS, UoA, UoB, UROMA2

In this task the team investigates the applicability of new DTN protocols to satellite communication systems. In particular, the following tasks are being performed:

- review the state-of-the-art in Delay and Disruption Tolerant Networks (DTN) and current level of definitions, standardisation, and demonstration achieved
- investigate the potential applicability and advantages/drawbacks of DTN to:
    - mobile satellite telecom networks to efficiently cope with possible link interruptions
    - broadband satellite telecom networks to efficiently cope with transmission delays, avoiding the use of Proximity Enhancement Proxies (PEP)
    - deep space communications

  and consider aspect such as the impact on applications support, overall data transfer data
- efficiency and reliability, as well as delay
- collect DTN emulation software modules able to demonstrate the performance in selected application cases
- make recommendations for further R&D activities in this field.

First Results

The study being performed within this task aimed at showing the usefulness of the Delay/Disruption Tolerant Network architecture concepts for satellite and space communications. As to the latter, it has been intensively demonstrated that DTN will be of primary importance in the future deep-space missions, to support manned missions and scientific experimentations, even in case of sporadic network infrastructure interruptions and in presence of very large propagation delays, in the order of several minutes. On the other hand, the use of DTN idea for satellite communication has been only partially applied to satellite communications, since this environment experiences only in part the challenges that have actually fostered the research in the DTN scientific community. In fact, satellite communications show limited propagation delays (wrt to deep space environments) and link interruptions stem from user mobility in harsh environments or from adverse weather conditions, both challenges usually counteracted with solutions implemented at the physical layer. However, this study pointed out that the availability of a DTN-enabled architecture shows important benefits also in this environment, owing to the recovery and storage capabilities, which allow achieving high system performance (e.g., throughput and data delivery delay). In particular, it was observed that the DTN concept turn out to be helpful in case of fixed geostationary satellite scenarios, where the DAMA access scheme or weather adverse conditions (playing some role especially in Ka and EHF frequency bands) may introduce additional delays or unexpected link interruptions. Besides, an even greater advantage is registered in LEO satellite scenarios, where the satellite acts as data-mule. In this case, the storage capabilities of the DTN architecture along with the proactive fragmentation option implemented within the Bundle Protocol (the protocol defined for the DTN architecture) allow optimising the contact durations, thus resulting in the maximum resource usage.

Finally, the benefits of DTN architecture in the aforementioned scenarios is also being investigated from an implementation point of view, by means of dedicated testbeds implementing the Bundle Protocols and reproducing the peculiarities of fixed/mobile satellite scenarios or deep-space environment. This study is the last part of this task and is still ongoing.

4 Conclusions

At the time of writing, work on the call-off order 1 is going on, and possible subjects for the next call-off order are being discussed. The SatNEx-III project will continue to work on timely research topics related to future satellite communications and will bring together European research organisations in this important field.

Reference

1. Evans, B.G., Thompson, P.T.: Key issues and technologies for a Terabit/s satellite. In: 28th AIAA International Communications Satellite Systems Conference (ICSSC 2010), Anaheim USA, paper number AIAA-2010-8713 (2010)