The Satellite Communications Network of Excellence "SatNEx"

Erich Lutz, Anton Donner
German Aerospace Center, DLR
Institute of Communications and Navigation
Oberpfaffenhofen, Germany
Erich.Lutz@DLR.de, Anton.Donner@DLR.de

***Abstract*— SatNEx aims to overcome the fragmentation in Europe's satellite communications research by bringing together Europe's leading academic institutions and research organisations in a cohesive and durable way. This paper gives an overview over the first two phases of the SatNEx Network of Excellence project, as well as an outlook to the extension, SatNEx-III, planned for the years 2009 – 2012.**

***Keywords*—Satellite communications, physical layer, networking, protocols, system architectures, visions**

I. INTRODUCTION

Despite of strong international competition European space industry, satellite operators and space organisations are major players in their respective fields.

Over the years, European R&D in satellite communications has encompassed a large number of activities spanning many programmes and organisations, however, such initiatives have been restricted in their strategic value, with limited collaboration and coordination and often lack the critical mass required to make an impact on the world stage.

As an approach to integrate European research in satellite communications, the Satellite Communications Network of Excellence "SatNEx" was established [1] (due to space limitations we do not provide a partner list here).

Removing Barriers, Integrating Research and Spreading Excellence are the primary objectives of this project which is supported under EU Framework Programme 6 (FP6) with the overall goal of rectifying the fragmentation in satellite communications research by bringing together Europe's leading academic institutions and research organisations in a durable way. The creation of the Network aims to establish critical mass and allows access to a range of expertise currently distributed across Europe.

The origins of the SatNEx project can be traced back to the early 1990s, with the establishment of several COST actions [2]. These satellite specific actions brought together a number of the partner institutions that now comprise the SatNEx consortium. Well-known examples are COST 272 (Packet-oriented Service Delivery via Satellite) and COST 280 (Channel Modelling and Propagation Impairment Mitigation for Millimetre Wave Radio Systems). These COST actions can be seen as the parents of SatNEx.

The first phase of the SatNEx project started in January 2004 and ended in March 2006; the second phase started subsequent to the first phase and will end in 2009. Preparations to continue the project without EU support are ongoing.

All satellite communications activities in SatNEx are placed in the context of related ESA efforts, mainly the ARTES R&D programmes, and are carried out in coordination with the activities in the thematic priority on "aeronautics and space". ESA/ESTEC plays as a partner an active role in SatNEx and many project partners are also participating in ESA projects concerning fixed and mobile satellite communications.

Furthermore almost all SatNEx partners are involved in the Integral Satcom Initiative ISI [3], which is a European Technology Platform (ETP) included in the seventh Framework Programme (FP7) of the European Commission. More specifically, several SatNEx partners are members of the ISI Steering Council and contribute to the R&D and Future Internet working groups.

II. IMPLEMENTATION OF THE NOE

A. The Joint Programme of Activities

The overall JPA is described and broken down into activity streams (WPs x000) and work packages, see Figure 1.
The Integrating Activities (WP 1000), led by DLR, support the jointly executed research (JER) (WP 2000) by

- organising the exchange of personnel between SatNEx partners (WP 1100);
- performing integrated management of knowledge and intellectual property (WP 1200);
- providing a communication and collaboration platform based on satellite communications technology (WP 1300);
- providing multi-purpose web-services (WP 1400).

The Jointly Executed Research (JER) activities (WP 2000), led by University of Bologna, support WPs 1000 and 3000 by

- providing new knowledge and expertise;
- producing scientific papers, along with papers of a tutorial nature;
- developing common research tools and testbeds;
- proposing suitable cases for personnel exchange.

Finally, WP 3000, led by University of Bradford, primarily aims at the spreading of excellence to Europe and beyond.

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This activity

- provides training opportunities for students and researchers from organisations that are not members of the Network and for practicing engineers (WP 3100);
- disseminates information and transfers knowledge through the generation of publications and supporting literature and media, including the webpage (WP 3200);
- influences standardisation and regulation, and enhances public awareness of the benefits of satellite communications (WP 3300).

The Management of the Network (WP 4000) is the responsibility of the Network Coordinator, DLR, with input from the leaders of WPs 2000 and 3000.

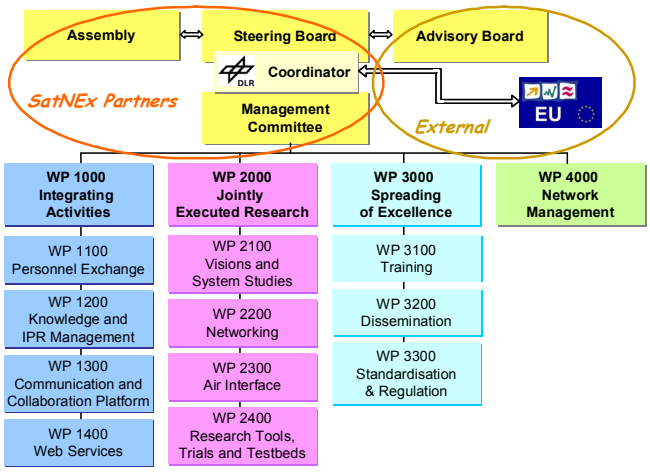

Figure 1. SatNEx Joint Programme of Activities.

B. *The SatNEx NoE Philosophy*

The philosophy underlying the SatNEx approach revolves around the selection of focused actions within the WP 2x00 work packages in order to capitalise on the expertise present within the Network. These focused actions, named "Joint Activities" (JAs) are carried out jointly by the partners and include research, integration and dissemination activities. The research programme, in particular, focuses on addressing knowledge gaps that may be present within the network and on extending the existing knowledge base. The emphasis is on the challenge to existing concepts and ideas, in the never-ending search for improvements and break-throughs. Thus, in addition to work packages, the overall joint programme of activities (JPA) is described by Joint Activities (JAs), a flexible and powerful element for organising the SatNEx research work.

Concerning the implementation of JAs, it is important to note that they can be flexibly set up and closed during the project phase. This flexible work organisation structure, replacing classical fixed sub-work-packages, has shown to be well adapted to the specific needs and objectives of the project. At time of writing the following JAs are active in the network:

- JA-2110 Research Strategy and Visions
- JA-2120 Satellites in 3G and Beyond
- JA-2130 Broadband Access Networks
- JA-2220 Integrated Multi-Platform Systems (IMPS)
- JA-2230 Cross-Layer Protocol Design
- JA-2240 Network Security
- JA-2250 IP-Networking Optimization
- JA-2310 Channel Modelling and Propagation Impairments Simulation
- JA-2320 Physical Layer
- JA-2330 Radio Resource Allocation and Adaptation
- JA-2410 Access, Network and Transport Layer Trials
- JA-2420 Application Layer Trials.

These JAs have been grouped into four work packages:

- Visions and System Studies (JA-2110, JA-2120, JA-2130),
- Networking (JA-2220, JA-2230, JA-2240, JA-2250),
- Air Interface (JA-2310, JA-2320, JA-2330),
- Trials (JA-2410, JA-2420).

The activities and results of these work packages (without WP 2400) are described in the following sections [5][6][7].

III. VISIONS AND SYSTEM STUDIES

The visions and systems studies work area adopts a top down approach to complement and provide new research drives for the satellite communications research agenda for the remainder of SatNEx-II and beyond. It consists of three JAs; JA-2110 is the visions and research agenda activity which horizon scans and continuously updates the SatNEx vision and compares it with other visions. In addition, it produces a research agenda which is tested against others in the European Union (EU) and the European Space Agency (ESA) to identify gaps in research or areas which are not being adequately covered by other research programmes. These are then fed into the systems studies and enabling JAs where more detailed work is performed. JA-2120 and 2130 are JAs which take the key new sectors identified in JA-2110 and develop systems architectures and research issues at a top level. These architectures are then used as reference for enabling research JA activities (typically within WP 2200 and WP 2300) where more detailed research is conducted. The rationale is to firmly base the detailed research into systems requirements, and future architectures.

A. *JA-2110 Visions and Strategic Research Agenda*

1) Satellite Systems for Public Protection and Disaster Relief (PPDR) and Integration with Equivalent Terrestrial Systems

Work in this Focus Topic continued to review and keep abreast of the work in other projects, in particular the EU project WISECOM and the Public Safety Communications Europe (PSCE) group. The main work has concentrated on the TETRA system in PPDR environments where initial system architectures have been established in relation to various satellite scenarios.

SatNEx participated in two successful fire-fighting and flood relief exercises in 2008, which were carried out in close cooperation with first-responders, fire brigades and air force. Satellite communications facilities have proven to be an extreme valuable asset in delivering high resolution images,

situation maps and geo-coded images from an emergency site to decision makers. Furthermore, VoIP services and intranet/internet access via satellite provided full access to the telecommunications infrastructure even in situations where conventional communication services were not available.

SatNEx was also represented in a demonstration within the WISECOM project of the interoperability of terrestrial and satellite communications system for applications in disaster situations. The WISECOM Access Terminal (WAT) features a fast and easy setup, and has multiple functionalities useful in the disaster area. Wifi and GSM over BGAN and Wifi and WiMax over DVB-RCS were demonstrated in a live emergency situation.

2) Spectrum

In the spectrum usage work area two scenarios were investigated. The first was the coexistence of satellite and fixed broadband wireless access systems where interference results have been produced. The second is the spectrum management in the uplink between adjacent broadband satellite networks using DVB-RCS and again interference analysis has been completed.

B. JA-2130 Broadband Access Networks

1) DVB-S2/RCS Adaptation to Mobile Environments

In this JA, as the DVB-TM RCS standardization is ongoing, the work for the gateway /satellite handover management has been contributed to the implementation guide for the new version of EN301 790. The handover management for gateway and satellite handover is considered to be hierarchical, in terms of the handover level, starting from beam handover, gateway handover, and satellite handover.

2) Future Applications, Services and Related Systems Architectures

The major part of the work in this Focus Topic dealt with multicast web caching.

Multicast web caching applied to satellite links provides an improvement of the average connection time as well as bandwidth savings compared with non-caching systems and conventional hierarchical caching architectures. Hence, it allows satellite operators to support more users with the same capacity.

The efficiency of multicast web caching heavily depends on the locality in the access patterns across the client proxies. As this locality is both, spatial and temporal and varies for each client proxy, analytical results are hard to obtain. The tradeoffs of multicast web caching were investigated in terms of the higher system complexity and load as well as the larger cache sizes required.

3) DVB-S2/RCS for Latin America (Tabatinga)

This Focus Topic links SatNEx with another FP6 project BRASIL and is aimed at the use of satellite for broadband access in South America. Common partners exist between the projects as well as in a related ESA ARTES project in the area. The Focus Topic enables other SatNEx partners to collaborate and in specific areas value to be added by joint work. Architecture work resulted in two new reference models being proposed for DVBS2-RCS with Wifi and DVBS2-RCS with WiMAX extensions.

A review of rural applications was conducted and the major market sectors defined as; tele-centres for broadband access, rural telephony, broadband education to schools and remote healthcare. In addition, an evaluation of equipment and costs was conducted for the South American markets.

Work in three areas on improved system design for the South American market was conducted. In respect of the hybrid architectures work is reported on radio resource management in the return channel, cross layer networking and mobility issues in tropical area using gap fillers with mobility management. The latter were all aimed at a more cost effective system for the rural environment. In another work area propagation data has been collected across the Brazilian region and analysed in conjunction with the models produced in the SatNEx propagation team. This is now being used in conjunction with the systems design.

4) FIRST-Future Internet: Role of Satellite Technology

At the end of March 2008, the Future Internet Assembly met in Bled, Slovenia. The assembly comprised working groups, each focusing on different issues related to projects in the Future Internet within the EC FP7 programme. There was an intentional emphasis on cross-fertilisation of concepts and ideas beyond the traditional constraints. SatNEx presented a vision of the satellite component (on behalf of the ISI platform). A booth helped to promote the visibility of satellite technology among the Future Internet community, European Commission and the other ETPs, including a live demo using an ASTRA2connect terminal (0.8 m antenna).

The ETPs have jointly written a document called the "Future Internet, the Cross-ETP Vision Document" that was published in December 2008. This proposes a coordinated European approach to the Future Internet, to address the multiple technological challenges that are ahead. It asserts that turning these challenges into opportunities requires bold steps to be taken at European level to meet the societal needs ahead in terms of economic growth, sustainable environment and quality of life. SatNEx partners contributed text on the Internet architectural evolution and also on satellite-related topics.

IV. NETWORKING

WP2200 addresses networking issues from the system, protocol, security and networking perspectives.

A. JA-2220: IMPS - Integrated Multi-Platform Systems

The aim of this JA has been to define new concepts and networking techniques for an all IP-based integrated system consisting of satellite, terrestrial and high altitude platforms (HAPs). The following research activities have been carried out:

- networking in IMPS, where five different research activities are included:
    - reliable multicast transmission in a hybrid-satellite scenario,
    - optical networking in IMPS,
    - mobility in IP-based IMPS,

    - load balancing in IMPS,
    - metrics for store and forward routing.
- satcom technologies adaptation for HAP networks, where adaptation of various satcom technologies for use in HAP networks were investigated. Two research activities were included:
    - DVB-S2 for HAP based systems,
    - spectrum management techniques.

B. JA-2230: Cross-Layer Protocol Design

The aim of this JA has been to investigate techniques to improve the satellite network performance through cross-layer design concept. Two focus topics have been included; each is sub-divided into different research activities:

- IPQoS - Network Optimisation of IP-based Traffic, where the mapping of IP QoS to Layer 2 and cross-layer mobility have been studied. Two research activities have been considered:
    - X-MOS: Cross-Layer Mobility for BSM Systems
    - Eff_IPDVB: Encapsulation Issues for DVB-S2
- JOPT - Joint Optimisation of Transport and Lower Layers, where interactions between the transport layer and lower layers have been studied in order to improve the performance of the transport layer through optimisation of the MAC and PHY layer. Two research activities have been defined:
    - CROSS-SAT: CROSS-layer Optimization of Transport Layer in SATellite Networks
    - NewQoS: TCP Optimisation over Satellite Links Through Joint FEC and Power Management

C. JA-2240: Network Security

The aim of this JA has been to define security mechanisms for satellite networks from the link layer to the application layer and to investigate VPN techniques over satellite networks. Four Focus Topics have been identified:

- FT1: Unidirectional Link Encapsulation (ULE) security, where ULE security requirements are defined and the security extension for ULE protocol has been preliminary defined.
- FT2: P2P Security over Satellite, where security enhancement to the synchronisation protocol within the satellite footprint has been investigated.
- FT3: Secure Reliable Multicast, where cross-layer IP-Sec and a cross-layer reliable multicast framework have been investigated.
- FT4: Video Streaming Authentication in Satellite Communications, where authentication techniques for video streaming using cryptographic watermarking was studied in order to ensure secure transmission of video streams over satellite.

D. JA-2250: IP Networking

The aim of this JA has been to define optimisation techniques for IP networking over satellite. Three Focus Topics have been carried out during the reference period:

- FT1: Transport Protocols & Performance Enhancing Proxies (PEPs), where transport layer protocols and PEP enhancements well suited for satellite environments have been studied and developed.
- FT2: Higher Layer Coding, where transport and application layers coding techniques for satellite environment has been defined.
- FT5: Mobility and Multicasting, where various multicasting mechanisms and mobility management techniques for satellite systems and mobility for multicast services over satellites are studied.

V. AIR INTERFACE

Work package 2300 (Air Interface) aimed at developing know-how and expertise in all facets involved in the optimised design of the satellite link. The goal was to maximise capacity of the system and to guarantee the QoS requirements, while preserving flexibility to cope with evolution of services and users expectations.

The various issues that have been investigated in the definition of the air interface and the management of the satellite resource were addressed in the following three JAs.

A. JA-2310: Channel Modelling and Propagation Impairments Simulation

Optimization of satellite systems requires taking into account propagation information thanks to relevant channel models that are necessary to assess by simulation the end-to-end quality of service and the satellite system performances.

JA-2310 aimed at improving, developing, and validating channel models to be integrated in system simulation tools and the JA took into account the specific characteristics of the various environments [8]:

- mobile/indoor multi-path,
- atmospheric effects,
- wireless optics,
- satellite navigation channel.

B. JA-2320: Physical Layer

JA-2320 was dedicated to the investigations of all issues related to the physical layer of satellite communications and navigation. The physical layer shall be adapted in an optimal way to the specific satellite peculiarities.

JA-2320 was structured along eight Focus Topics dealing with macro areas of the physical layer field:

- FT-01 DVB-S2/RCS adaptation to mobile environment,
- FT-02 Modulation and coding,
- FT-03 Synchronization and parameter estimation,
- FT-04 Distortion countermeasures,
- FT-05 Diversity and MIMO,
- FT-06 Multi-user satellite communications,
- FT-07 Cognitive radio,
- FT-08 Fade Mitigation Techniques.

C. JA-2330: Radio Resource Allocation and Adaptation

This JA was dealing with the definition of dynamic Layer 2 radio resource management techniques to increase resource utilization while guaranteeing multidimensional QoS support and adaptation to physical layer conditions, traffic loads and traffic types, considering both fixed and mobile users. The interest of JA-2330 was in defining resource management schemes considering the interaction of layer 2 and layer 1, i.e., the satellite-dependent layers. The air interfaces under consideration were: (i) S-UMTS and the satellite HSDPA proposal; and (ii) DVB-S/-S2/-RCS.

Various issues have been investigated in this JA in order to define novel Layer 2 protocols able to manage different traffic classes with distinct QoS levels in satellite networks. Important topics have been identified: efficient radio resource management schemes; adaptation of bandwidth, bit and coding rate for connections experiencing differentiated fading levels; call admission control; bandwidth-on-demand techniques; handover management schemes; resource management strategies supporting user mobility.

Two major research areas were identified (techniques for the efficient allocation of satellite radio resources, resource management schemes for the mobile extension of DVB-S2/DVB-RCS), and were tackled in the following Focus Topics, each subdivided in Specific Research Activities:

- FT-01 Radio Resource Management Techniques
- FT-02 Layer-2 Techniques for DVB-S2/DVB-RCS Extension for Mobile Usage

VI. Major Achievements

The SatNEx project has brought together 24 European organisations working on satellite communications. By bundling the expertise of these partners it was possible to obtain new results which were made available by publications and input to standardisation. In fact, the first phase of SatNEx ("open book phase") was dedicated to "show what other partners do" and to identify gap areas which were covered subsequently.

Typical outputs of the project include:

- articles to journals, conference papers, tutorials;
- three books;
- special issues in journals such as International Journal of Satellite Communications & Networking;
- contributions to standardisation bodies and in particular contributions to ITU-R Study Group 3, ETSI SES BSM and SatEC, DVB, and IETF,
- organisation of a yearly Summer School on satellite communications,
- support of various conferences and events.

Phase 2 was mainly devoted to make use of the common knowledge. Many results were successfully transferred into standards, and the established co-operations will continue after the end of the funding by the European Commission.

New European projects have been initiated partly thanks to SatNEx, such as the new COST action IC-0802: propagation tools and data for integrated telecommunication, navigation and earth observation systems, or a clustering activity with the FP6 BRASIL [4] project, called "Tabatinga".

At the time of writing, discussions with ESA/ESTEC are going on, how to carry on SatNEx. ESA has recently allocated funding for SatNEx-III for another 3 years. Thus we are confident that the SatNEx network of Excellence can be maintained at a reasonable level of activity, ensuring the further close co-operation of the SatNEx partner group.

VII. Acknowledgement

With this paper the authors summarise the achievements of 24 partners active in satellite communications over more than 5 years. Unfortunately a complete listing of names cannot be provided here because of space limitations; nevertheless the authors want to thank all the JA leaders, work package leaders, Steering Board members, Advisory Board members, organisers of SatNEx events, and all partners for the continuous effort and high motivation they have brought into the network. Without their contributions the network would not have achieved its critical mass and impact on European research on satellite communications.

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