Contract no.: 257118

FISI Project - contract n°257118

D1.2.1 Analysis of emerging SatCom architectures - draft

FISI project executive summary

The FISI project aims at supporting the Integral SatCom Initiative (European Technology Platform) in defining a strategic vision on innovation priorities to reinforce the competitiveness of the European SatCom industry and in promoting emerging SatCom architectures in response to EU policy objectives.

Abstract

This deliverable identifies and analyzes various architecture options and undertakes high level technico-economical analysis to highlight the benefits of these architectures in support of the universal service requirements identified in D1.1.1. It also identifies and analyzes various techniques enabling to overcome key issues inherent to SatCom as well as integration scenarios of SatCom with terrestrial networks in the context of Future Internet and in support of relevant requirements identified in D1.1.1

Disclaimer

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1 Introduction

This document aims at identifying trends in SatCom architectures and their added value in the context of the Digital Agenda related objectives.

It undertakes high level techno-economical analysis and identifies enabling techniques to overcome issues inherent to SatCom as well as integration scenarios of SatCom with terrestrial networks:

- Firstly, the SatCom market context is recalled;
- Secondly, the European SatCom industry context is introduced including its market positioning in order to identify the needed evolutions and the related research and innovation priorities;
- Thirdly, the potential contributions of SatCom to the Digital Agenda objectives is highlighted;
- Fourthly, it identifies the emerging SatCom architectures principles and main enablers (technologies, integration scenarios with terrestrial networks) thanks to monitoring of relevant market analysis, standardisation activities, R&D projects;
- Fifthly, it identifies their impact on the performance, features but also economics in order to highlight how future SatCom solutions based on emerging SatCom architectures can support Digital Agenda objectives.

This analysis constitutes an input for the identification of the European SatCom industry research and innovation priorities.

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3 SatCom solutions and markets

3.1 A wide range of solutions

Satellite communications (SatComs) encompass a wide range of solutions providing communication services via satellite(s) from the outer space.

Space component of SatComs are located is the outer space following different orbit types among which Geostationary (GEO), Medium Earth Orbiting (MEO), High Elliptical Orbit (HEO) or Low Earth Orbiting (LEO). The system can operate in low frequency bands (below 3 GHz, such as UHF, L and S band) or in higher frequency bands (above 3 GHz, such as C, X, Ku, Ka, Q and V bands).

They can address a wide range of services broadcast, broadband and narrowband services to fixed, portable and mobile terminals.

It also refers to systems either global or restricted regional coverage in a stand alone or an integrated or hybrid configuration with terrestrial.

SatCom systems may cover all the earth including north and south poles.

3.2 The main European SatCom industry markets

The main markets of the European SatCom industry are listed hereunder in decreasing order of revenues generated. Unless stated, most economical data comes from various SatCom market analysis reports (Northern Sky Research) consolidated with Thales Alenia Space own market analysis.

3.2.1 Direct To Home TV

Undoubtedly the bulk of SatCom markets, it represents a worldwide revenue of 33 B$ retail sales with an expected CAGR of 5-10% over the next 5 years.

According to IDATE, in 2009, terrestrial reception remained the primary television reception mode in Europe, with nearly 35% of equipped households watching television from terrestrial networks. Nevertheless, terrestrial broadcast reception has continued to decline (45.3% of terrestrial TV households in 2006).

Satellite remains the third most popular delivery mechanism behind terrestrial broadcast and cable with 28.4% of equipped households, it is and will remain a key access technology for video distribution in Europe, as shown in the graph below.

IPTV is used as the primary television reception mode by 12.8 million European households (not live broadcast but streaming). It shall be noted the increased adoption of IPTV.

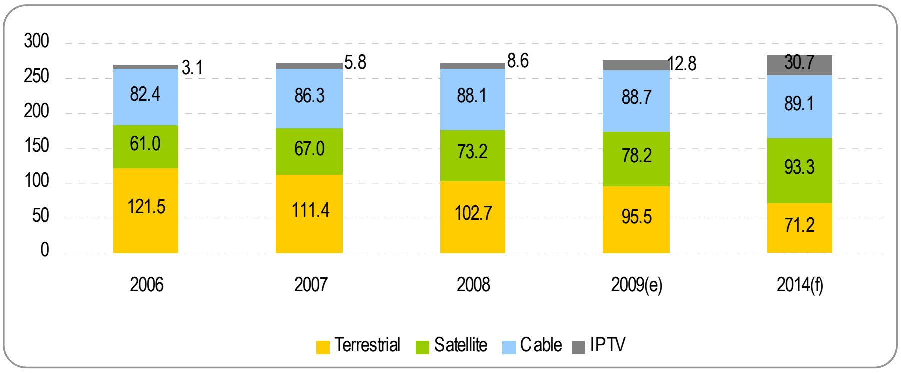


Figure 1: Changes in TV reception modes in Europe, 2006-2014 (Millions of TV households)

(e) estimates – (f) forecasts; Source: IDATE

The market growth is mainly driven by the introduction of HDTV (High Definition TV) but recently 3DTV and has been introduced. In the future, multi-view 3DTV and UHDTV (Ultra High Definition TV) will come on stream.

TV program format	SDTV	HDTV	3DTV	UHDTV
Service introduction	1996	2006	2010	?
Number of TV programs currently broadcasted over Europe	Thousands	Hundreds	Tens	-
Current Satellite TV receivers base (in Households)	78 M	12 M	0.1 M	0 M
Expected Satellite TV receivers base in 2014 (in Households)	93 M	34 M	11 M	?

Tableau 1: Evolution of House holds served by satellite broadcast networks

Let us analyse the trends in terms of bandwidth requirements for the different TV formats over Satellite which targets premium quality:

Video encoder (Estimated bandwidth requirements in Mbps)	MPEG2 (currently)	H.264/MPEG-4 AVC[1] (currently)	MVC[2] (upcoming)	HEVC[3] (in 5 years)
SDTV format (768 pixels x 576 lines)	3.5 Mbps	2 Mbps	-	1.2 Mbps
HDTV format “1080i” (1920 pixels x 1080 lines at 25 frames/s interlaced)	-	Current 10 Mbps Towards 8 Mbps	-	-
HDTV format “1080p” (1920 pixels x 1080 lines at 50 frames/s progressive)	-	10 Mbps	-	5 Mbps
3DTV format (1920 pixels x 1080 lines)	-	10 Mbps	13 Mbps	-
UHDTV format (3840 x pixels x 2160 lines)	-	32 Mbps	-	20 Mbps

The expected trends in SatCom mission requirements are

- Triple play service offer thanks to a service hybridization of broadcast and broadband, for diversified and personalized multimedia offer (TV, push and data-casting) and QoS;

[1] AVC = Advanced Video Coding
[2] MVC = Multi View Video Coding
[3] HEVC = High Efficiency Video Coding

- allow an increase in the number of TV channel in a given transponder with optimized waveforms and scalable source coding techniques and improved space segment performance;
- Environmental impact reduction (visual pollution) thanks to smaller satellite dish;
- Lower installation, cost thanks to self installation antenna.
- Emergence of multiview 3DTV increasing the demand for bandwidth.

3.2.2 Backbone/Backhaul

This refers to SatCom systems supporting Content Delivery Networks (CDN), Virtual Private Networks (VPN) to connect corporate sites, Backhauling of cellular networks, TV Distribution to network head-ends and hence contribute to the overall efficiency of the internet.

They are generally based on multi purpose FSS satellites. However we should also mention that "O3B networks" have recently commissioned a Ka band MEO network to provide back haul services to cellular systems in the equatorial regions and thus accelerate the roll out of the internet to developing countries.

This second SatCom market in size generates a worldwide revenue of ~10 B$ retail sales with an expected CAGR of 5-10% over the next 5 years.

The expected trends in SatCom mission requirements are

- Flexibility in terms of connectivity scenario, Geographical distribution of the capacity, Frequency plan which requires smart payloads;
- Flexibility of coverage footprint and orbital position so that it can be reconfigure for another mission;
- Cost reduction;
- Increased throughput per satellite.driven by broadband and multiview TV.

3.2.3 Broadband access

So far, satellite broadband access service offer has been making use of space assets designed primarily for broadcast or backbone services and operating in FSS Ku band. From this year on, broadband access is going to take advantage of specific Ka band satellites recently launched over Europe enabling enhanced broadband service offer.

So far the market has been generating a revenue of 1 B$ in retail sales mainly in the USA, where Ka band has been in service since 2007, with an expected CAGR of 20-30%, over the next 5 years thanks to numerous projects worldwide.

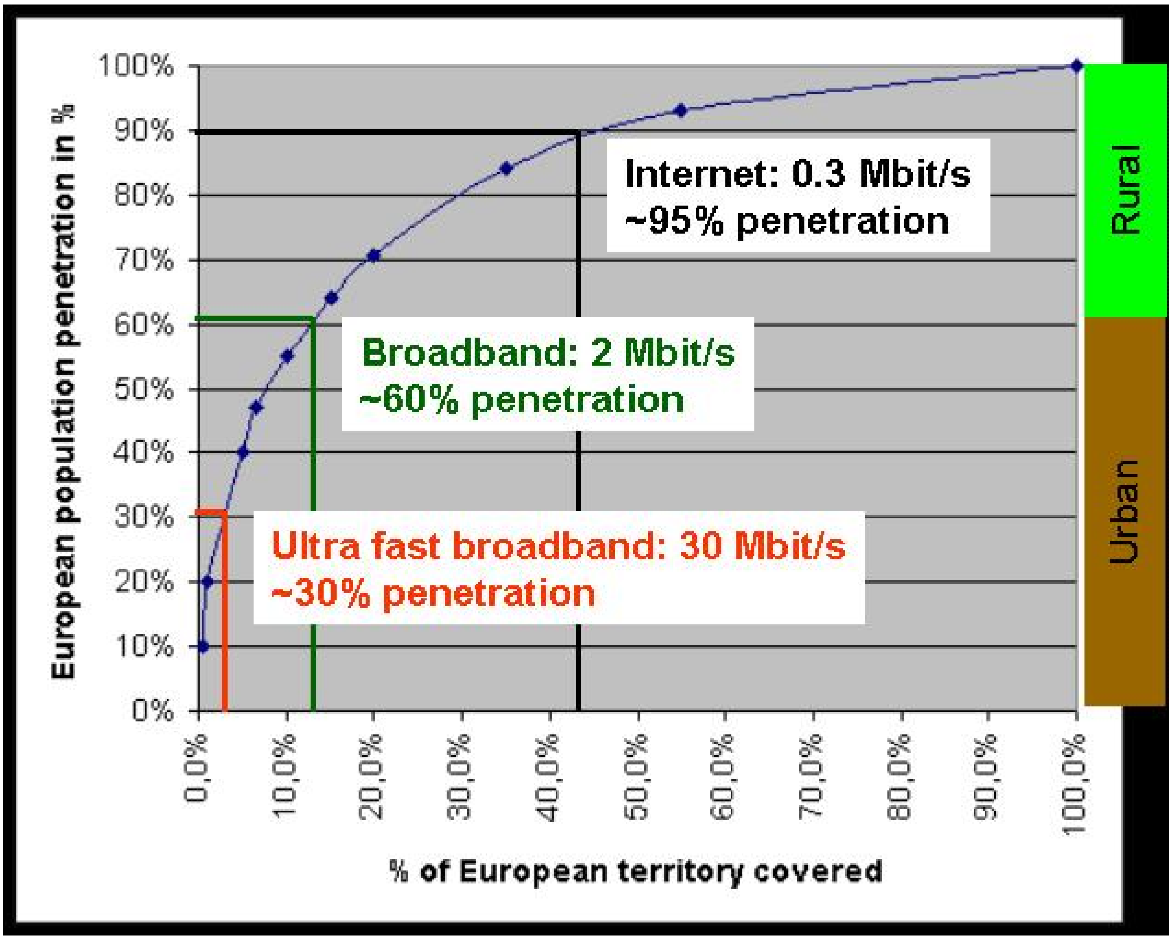


Figure 2: broadband access penetration in Europe

The figure shows the geographical distribution of the European population (Source Thales Alenia Space in 2009). It highlights the service penetration of internet access (0.3 Mbit/s), basic broadband access (2 Mbit/s) and ultra fast broadband access (30 Mbit/s). Source 1st Digital Agenda progress report published by the European Commission, early June 2011.

Terrestrial broadband access network (Optical fibre, cable, xDSL and wireless solutions) are expected to cover at most 97% of the population due to exponential infrastructure deployment cost in the low density populated areas.

Assuming 500 M of inhabitants in the Europe Union (Source Eurostat, European demography, newsletter 110/2010 – 27th July 2010) and an average of 2.4 inhabitants per house holds (Source Eurostat: Households structure in the EU, 2010 edition, ISSN 1977-0375), the SatCom market potential address up to 15 M households in Europe in un served areas and partly in underserved areas and consequently contribute to meet the Digital Agenda policy ([Ref1.]) objective that seeks to ensure that, by 2020, all Europeans have access to higher internet speeds of above 30 Mbps (peak rates).

Timeframe	**Currently**	**2011**	**2015**	**2020**

Timeframe	Currently	2011	2015	2020
Technology	Ku band satellites designed for broadcast or backbone/backhaul services	1st generation multi-beam Ka band satellites	2nd generation multi-beam Ka band satellites	3rd generation multi-beam Ka band satellites
Service capability	Internet broadband	High speed broadband internet	Very high speed broadband internet	Very high speed broadband internet
Max service rate (Downlink)	5 Mbps	10 Mbps	50 Mbps	100 Mbps
Number of House Holds served per satellite	Few 10 K	Several 100 K	> 1 M	> 1 M
Average data per month limitation	Some GBs	Up to 25 GBs	Up to 100 GBs	Hundreds of GBs
Connexion fee (including terminal and installation cost but excluding monthly fee)	< 400 €	< 250 €	< 200 €	< 150 €
Example of service offer or planned projects	Astra2Connect or A2C (SES), Tooway (Eutelsat)	KaSat (Eutelsat), A2C Enhanced SES Ka band capacity (SES), Hylas1 (Avanti)	Very High Speed	Terabits Ultra high speed

Tableau 2: Evolution of satellite broadband access systems

The expected trends in SatCom mission requirements are consequently to

- Reduce cost per bit/s: Increase throughput towards Terabit/s satellites to sustain several hundreds kbps of “busy hour bandwidth” per Households;
- Increase service rate capability beyond 100 Mbps for Next General Access compatibility (Compatible with LTE-A)
- Target a cost effective connectivity cost (terminal + installation) typically < 150 € (incl. Installation which should be quasi self installation) as well as a monthly fee comparable to terrestrial broadband access systems.

3.2.4 Mobile Satellite Systems

Initially Mobile Satellite Systems refer to SatCom systems operating to ships, planes and passenger land vehicles in frequency bands lower than 3 GHz and regulatory framework conditions allowing also personal handheld communications. They typically provide:

- Handheld and vehicular communication services for users roaming beyond cellular coverage (typically journalist, business, rescue teams, defence);
- Narrowband Machine to Machine services (M2M) for asset tracking and monitoring, SCADA applications;
- Narrowband (several hundreds of kbps) communication services for maritime and aeronautical markets;

- Multicast and broadcast services to vehicles and handhelds.

The table below compares the main characteristics of mobile satellite systems and cellular systems in order to highlight the different and complementary market positioning:

Characteristics	Cellular systems	Mobile Satellite Systems
Usage constraints	No user cooperation needed even indoor	Some user cooperation needed. Outdoor conditions only
QoS issues	Non-Availability in case of saturation or disaster	Latency requires special protocols to achieve quality
Main regulatory issues	Increased population concern to radio exposure associated to antenna sites	Spectrum scarcity, landing rights
Dimensioning approach	Trade-off between QoS and site density => Issue in covering low density populated areas	Trade-off between QoS and throughput since terminals always at « cell » edge from the satellite point of view
Main assets	Scalability in Capacity	Ubiquitous coverage, reliability in terrestrial disasters

Tableau 3: MSS versus cellular systems

The MSS market generates an annual retail sales of 1.4 B$ ([Ref10.]) for the industry with an expected CAGR of about 7% over the next 10 years. This growth in revenue is due to an "increased demand for broadband and other MSS services in a number of vertical segments and emerging regions". From 2.4 million terminals in service in 2010, the number of MSS terminal is expected to reach 7.8 million by 2020 mainly driven by Low-data rate machine-to-machine (M2M) devices. According to [Ref11.] , the global MSS market will grow to $10.2 billion in 2020, with mobile broadband via High Throughput Satellite (in Ka band) holding a 22% market share.

MSS market encompasses GEO (Geostationary), MEO (mid earth orbits) and LEO (Low earth orbit) satellite constellation systems. LEO and GEO systems are compared in a qualitative manner in the table below:

	LEO systems	GEO systems
Coverage	++ (global coverage including north and south poles in the case of Iridium only)	+ (Continental or worldwide coverage excluding poles)
Throughput	+	++ (for similar terminal performances)
QoS	+	- (latency)
Service capability	+ (point to point)	++ (point to point/point to multipoint)

Tableau 4: LEO versus GEO mobile satellite systems

The tables below illustrate the positioning of the European SatCom industry in the MSS market:

LEO Systems	Orbcomm	Iridium	Globalstar
Spectrum	1 MHz @ 138 MHz 1 MHz @ 150 MHz	8.7MHz @ 1.6 GHz	8.7 MHz @ 1.6 GHz 16.5 MHz @ 2.5 GHz
Constellation	34 satellites @ ~800 km	66 satellites @ ~780 km	48 satellites @ ~1414 km
Features	Store and Forward	Inter satellite Links	Gateway service area
Service capabilities	Messaging	Voice, Messaging, Narrowband (up to 1 Mbps)	Voice, Messaging, Narrowband (up to 1 Mbps)
Market	Asset tracking	Handheld, maritime, aeronautical, asset tracking	Handheld, asset tracking

LEO Systems	Orbcomm	Iridium	Globalstar
Total throughput	< 10 Mbps	Hundreds of Mbps	Hundreds of Mbps
Radio Interface	FDD / TDMA	TDD / TDMA	FDD / CDMA
Launch 1G / 2G	1999 / 2011-2012	1998 / 2015 - 2017	2000 / 2010-2011

Tableau 5: State of the art in LEO Mobile Satellite Systems

IridiumNext and GlobalStar constellation have been contracted to European SatCom prime manufacturers.

GEO satellites	I-2	I-3	Thuraya	I-4	Lightsquared	*@Sat*	ICO	Terrestar
Spectrum	L band	L band	L band	L band	L band	*L band*	S band	S band
Antenna diameter	2 m	2.25 m	12.25 * 16 m	9 m	22.8 m	*11 m*	12 m	18 m
Nber of beams/beamwidth	1 @ 18°	5 @ 4.5° 1 @ 18°	250 @ 0.5°	200 @ 18° 5 @ 4.5° 1 @ 18°	Up to 500 @ 0.5 – 0.6°	*> 300 @ 1.2°*	Up to 250 @ 0.5°	Up to 500 @ < 0.4°
Aggregated EIRP (dBW)	39	49	74.5	67	79	*70*	74.5	80
G/T (dB/K)	-10	0	17	11	21	*13*	16.5	21
Beam generation	Fixed pattern	Fixed pattern	OBBF[4]	OBBF[5]	GBBF	*OBBF (fixed pattern)*	GBBF	GBBF
Smallest terminals supported	Ø1.2 m	Mini M (A4)	Handheld	Laptop (A5)	Handheld	*Handheld*	Handheld	Handheld
Satellite launch	1990	1996	2000	2005	2010	*2012*	2008	2009

Tableau 6: State of the art in GEO Mobile Satellite Systems

The I-2, I-3, I-4 and @Sat GEO satellites have been contracted to European SatCom prime manufacturers.

The European space industry is in the lead for the supply of most LEO mobile satellite systems and has managed to supply the geostationary Inmarsat satellites; Inmarsat being the leading service provider in the market. However LEO systems represent a small part of the MSS market.
The trends in mobile satellite systems are

- Accommodation of small size devices, handset or battery activated modem integrated in sensors (M2M) for sensor networks applications, thanks to higher radio performance of space assets (EIRP and G/T);
- Increased service rate capability for broadband services (This requires to develop MSS in higher frequency bands than 3 GHz, for example in Ku and Ka band);
- Increased throughput for lower cost per Mbps;
- Interoperability and/or Integration with cellular networks to offer service continuity or complementary service offer. In that respect, one should highlight the great progress MSS have undergone in the last 10 years. Indeed the large majority of MSS systems make use of standards 3GPP core networks and delivery 3G services (e.g. See ETSI standardisation activity in TC-SES on the GMR-1 and SL family radio interfaces; This also applies to the newest generation of Globalstar and Iridium systems);
- Implementation of a Satellite component to off load the network of cellular operators.

[4] OBBF = On Board Beam Forming
[5] GBBF = Ground Based Beam Forming

3.2.5 Governmental SatCom systems

We shall, here, restrict the addressable market by the European industry. This market has been generating an annual revenue of ~0.5 B$ in retail sales corresponding to ~5% orders by national defence agencies in Europe and selected opportunities in exports.
The market encompasses dedicated SatCom systems and capacity for defence and for civilian security purposes. The usage conditions of Satellite resources depends on the SatCom grade of service and the related mission requirements which mainly depend on three types of requirements:

- Satellite control
  - Ownership: full control of the satellite
  - Or Long term leasing of resources
    - pooling with other allied member states
    - access to commercial satellite resources
- Resource management:
  - Exclusive use of the satellite resources
  - Or Access to dedicated resources (distinct transponders or frequency bands within a transponder)
  - Or Shared resources with guaranteed SLA via dynamical resource allocation
- Communication Security with respect to different threats (in decreasing order of complexity). According to [Ref15.] , Communication security (COMSEC) encompasses CRYPTOSEC, TRANSEC and NETSEC)
  - Transmission Security (TRANSEC): It refers to measures designed to protect transmissions from interception and exploitation by means other than cryptanalysis. It refers to anti jamming, Limited Probability of Interception (LPI) and Low Probability of Detection (LPD);
  - And/or Network Security (NETSEC): protects networks and their services from unauthorized modification, destruction, or disclosure, and provides assurance that the network performs its critical functions correctly;
  - And/or Cryptographic Security (CRYPTOSEC) is used to safeguard confidentiality, integrity, availability, and/or accountability of all classified and extremely sensitive information stored or transmitted by electronic means. It relies on Crypto feature to provide data confidentiality and integrity while being transmitted and Keying feature for authentication.

It shall be noted that [Ref2.] proposes a Governmental SatCom typology for Governmental SatCom.
The European industry entails a significant record of end to end SatCom deployment in this market among which the most famous are Syracuse (France), SatCom BW (Germany), Sicral (Italy), Hisdesat (Spain), Skynet (UK). The SatCom systems operate mainly in X band but also in UHF as well as EHF bands and provide mainly broadband services to fixed and vehicular mounted terminals.

In addition, the industry has been contracted

- Export systems for United Arab Emirates (YahSat), Korea etc.
- Governmental systems such as AthenaFidus

Considering a general increase of the Average traffic per users due to increased video content as in the internet as well as the mobility usage, the trends in Governmental SatCom systems are to provide:

- Broadband capability to low profile vehicle, UAV/Aircraft mounted terminals and small size Nomadic or handheld terminals pushing up to Ka band usage.
- Narrowband capability (voice, messaging, PTT, data) to Handheld, Sensor networks / SCADA;
- Service availability: Where and when needed;

- Flexibility: geographical traffic distribution, network topology including mesh connectivity;
- Global coverage;
- Cost effective;
- Security & Protected infrastructure: The level of protection depends on customer requirements see the table above;
- Integration and/or complementary with terrestrial wireless systems.

3.2.6 Synthesis on main trends in the SatCom market segments

The table summarises the main trends in the next 10 years for each of the SatCom market segments:

SatCom Market segment	Main trends
Direct To Home TV	HDTV generalisation, non linear service, hybrid networks, 3DTV, multi view and UHDTV uptake
Backbone/Backhaul	Flexibility/intelligence
Broadband access	Very high speed broadband, resilience, improved QoE
Mobile Satellite Systems	Mobile Broadband in higher frequency bands especially for professional and governmental services (e.g. Ku or Ka band), security systems in lower bands
Governmental systems	Increased throughput, reinforced security, mobility and dual military and institutional systems

In all cases, interoperability with terrestrial systems is important.

4 European SatCom industry context

4.1 Critical infrastructures

SatComs are infrastructures which are in essence

- Global in terms of targeted coverage enabling ubiquitous services once the space segment is launched;
- Resilient with failure independent of terrestrial communication systems subject to natural or man made disasters;
- Solar powered and hence based exclusively on renewable energy in the space segment;
- Strategic for Europe since they constitute essential elements of any global networks and in particular for Universal Service, Security and Defence purposes.
- the basis of services featuring Confidentiality, Integrity, Availability (CIA)

4.2 A highly competitive market

SatCom is a worldwide market, which includes a commercial market open to competition and a governmental restricted market (at least for core Military Satellite Communications[6] missions). Ranked second among the main space industries around the world behind USA, the European industry is increasingly challenged by Russian, Indian and Chinese new entrant industries benefiting from massive institutional support and accessing captive domestic markets..

The SatCom industry is characterised by high capital expenditure in infrastructures and technologies with multi year development programs and generates 2 B€ revenues for the up stream and many times greater for the downstream. Having to rely for 50% on commercial and export sales compared to less than 20% in other countries, the European SatCom manufacturing industry is losing competitiveness and market share even with respect to European Satellite Operators market especially with long lasting $/€ depreciation which penalise manufacturing in Europe. With more than 65% of the industry turnover, SatCom indirectly contributes to the sustainability of other space sectors in terms of innovation and volume of production, it however receives low public financing support compared to highly state aided competing space industry.

4.3 The SatCom industry profile

The European SatCom industry encompasses three main activities:

a) Service provisioning
European satellite operators and retail service providers are very healthy with three of the European operators among the top 5 in the world in terms of revenues and margin.
This also includes hundreds of SMEs providing value-added SatCom downstream services to several private and public sector users in Europe.

b) Manufacturing
The European SatCom manufacturing industry encompasses several types of organisations all working in close interdependence:

[6] Milsatcom

- three Space focused Large Scale Integrators (LSIs) with the critical mass and necessary heritage to compete worldwide in order to prime hundreds of million euros (up to multi-billion) contracts associated to high technical, financial and legal risks;
- tens of space business units within larger industry structures mostly in the aerospace domain;
- hundreds of SMEs providing quick and efficient hardware or software development for flexible and tailor made technologies/components useful to meet the specific requirements of a space program,.

Note that manufacturing represents more than 90% of the jobs created for SatCom with an equivalent of 20 000 skilled employees all located in Europe (65% of 32 000 head count in the Europe space manufacturing industry). It is however ageing with an average age very close to 43.
It shall be noted that although composed of a majority of males, the percentage of female employees is regularly increasing and now accounts for 23% of the space industry employment ([Ref3.]).

c) Research and consultancy
European Researchers and academics in satellite communications are of high quality, and world leading in some areas, located in some tens of leading centres around Europe. Several hundreds of consultancy SMEs are also active in the sector.

4.4 The European SatCom manufacturing industry positioning in the different market segments

Here below is summarised the positioning of the European SatCom industry (service provisioning and manufacturing) in the different SatCom market segments[7] based on a SWOT analysis:

[7] Sources Thales Alenia Space market analysis

European Industry positioning wrt market segments	Strength	Weakness	Threats	Opportunities
Direct To Home TV: Broadcast of TV channels Direct To Home	Strong in orbit heritage	Competitiveness due to €/$ exchange rate; flight heritage required for market acceptance of innovation. Lack of spectrum limits new deployments without terminals upgrades	Evolution of the media environment from Broadcast to Internet/connected TV with the increasing role of terrestrial broadband access in the distribution of TV contents	Demand growth in emerging markets Hybrid systems combining broadcast and broadband assets (including terrestrial) for Triple play/interactivity Moving existing C & Ku band VSAT networks to Ka band with adaptable ground systems can free some capacity on existing C & Ku band for more available broadcasting capabilities.
Backbone/Backhaul for TV distribution to TV head-ends or backhaul for wireless communication, VPN network	Strong in orbit heritage	Competitiveness; flight heritage required for market acceptance of innovation	Massive deployment of optical fibre networks	Satellite overlay networks to improve the overall QoS or resiliency of critical connectivity between selected network nodes of the Future Networks Future Internet trends (e.g., Information Centric Network) being well suited to SatCom due to their multicast nature and supporting content management/distribution services

European Industry positioning wrt market segments	Strength	Weakness	Threats	Opportunities
Broadband access	Ka band multi-beam satellites heritage via Hylas 1, KaSat and Yahsat programs. Established Ku band services.	Need to catch up with US space industry to build next generation multi beam satellites based on high capacity platforms and very wide band payloads; Low heritage of European Ka band ground segments providers requires partnership with main US competitors for systems bids.	User requirement trend towards very high broadband access network based mainly on fibre and cable networks	Digital Agenda Policy: Satellite solutions can connect more than 5% and 10% of the population in low density populated areas of respectively Europe and the rest of the world, in complement to terrestrial solutions more suited to high population density areas. Market perspective enables a virtuous circle leading to low cost terminals.
Mobile Satellite systems	Leading market positioning in LEO systems with IridiumNext and Globalstar Good positioning in GEO narrowband systems with Inmarsat 4/BGAN as well as mobile broadcast systems (e.g. XM radio)	100% dependant from USA for large deployable antenna technology for GEO systems	Risk of spectrum pre-emption for cellular systems	Hybridisation with ad-hoc networks for handheld services in low frequency bands Towards higher frequency bands for broadband services Future Internet trends (e.g., ICN) being well suited to SatCom due to their multicast nature and supporting M2M services

European Industry positioning wrt market segments	Strength	Weakness	Threats	Opportunities
Governmental SatCom	Good heritage via national governmental programs (Syracuse, Skynet, Sicral,…) enabling a leadership in export sales systems	Poor financial perspective to prepare next generation systems featuring flexible connectivity and mobile broadband capability.	Governmental budget crunch post financial crisis reducing opportunities to develop innovative technologies, products and system architectures for Defence but also for commercial markets	Harmonised systems between security (civilian) and defence as well as between European member states Use of SatCom commercial assets for defence/peace time application

Tableau 7: European SatCom Industry positioning with respect to the SatCom market segments

In all SatCom market segments, the main requirement for future solutions is to decrease the cost/ bits with higher throughput.

The European SatCom manufacturing industry remains and is increasingly dependant on the US SatCom industry for key space based component such as on board antenna systems (e.g. based on deployable, un-foldable) as well as chipset including ASICS, FPGA and micro-processors. This leads Europe to compel with the ITAR[8] policy evolving according to US political concerns.

In addition, it shall be noted that new service opportunities will be made available by hybridization of Earth observation, navigation and telecom applications hence creating a new market.

[8] ITAR: International Traffic Arm Regulations

5 Existing and planned SatCom contributing to Digital Agenda objectives

5.1 Relevant Digital Agenda objectives

As detailed in FISI Deliverable D1.1.1, SatCom solutions contributes to all identified Digital Agenda objectives but in priority to the two objectives below:

5.1.1 Fast and ultra fast Internet access

In her speech on 17th May 2011 in Cologne, Commissioner Kroes underlined that “Europe needs growth. And in my view ICT investment is the best way to achieve it and spread it relatively evenly.”.
This is inline with the statement of the Digital Agenda where the need for very fast Internet is recognized for the economy to grow strongly and to create jobs and prosperity, and to ensure citizens can access the content and services they want.
This argument is that the future economy will be a network-based knowledge economy with the internet at its centre. Europe needs widely available and competitively-priced fast and ultra fast Internet access.
In this context, the Europe 2020 Strategy has underlined the importance of broadband deployment to promote social inclusion and competitiveness in the EU and restated the objective to bring basic broadband to all Europeans by 2013 and seeks to ensure that, by 2020,

(i) all Europeans have access to much higher internet speeds of above 30 Mbps
(ii) 50% or more of European households subscribe to internet connections above 100 Mbps.

To reach the 30 Mbps internet access for every European Households it is well acknowledged that SatCom based solutions will be necessary at least to connect those ~10 M House Holds in the low density populated areas that will not be addressed by the terrestrial solutions be they fibre or wireless based.

This requires to develop Satellite broadband access solutions with increased throughput and performance in order to sustain the traffic evolution which is mainly driven by the video consumption and hence feature higher bandwidth per house holds especially during the busy hour.
It also requires to develop low cost Customer Premises Equipment as well as low cost installation.

5.1.2 ICT-enabled benefits for EU society

The Digital Agenda states that “The digital society must be envisioned as a society with better outcomes for all. The deployment of ICT is becoming a critical element for delivering policy objectives like supporting an ageing society, climate change, reducing energy consumption, improving transportation efficiency and mobility, empowering patients and ensuring the inclusion of persons with disabilities.”
Indeed these objectives are related to several EU Grand Societal Challenges as identified in a preliminary manner by the Lund declaration (see [Ref4.]):

In that context, thanks to their dependability/resilience and ubiquitous access properties, SatCom can be profitably exploited in the following application domains and enabled smart infrastructures in support of selected EU Grand Societal Challenges:

- **Transport and mobility**: SatCom can help to alert about events (e.g. accidents, traffic jams, local bad weather conditions) impacting the traffic at regional level and provide guidance to the public and private transport resources, the travellers and decision making tools via fixed or mobile broadcast systems. SatCom can also support asset monitoring anywhere beyond terrestrial reach (low density populated areas, over seas) and hence ensure a permanent status report.

- **Energy**: SatCom are well suited in the Smart Grid eco system to monitor the power grid and contribute to secure the energy supply. In particular, it can optimise the efficiency of the global monitoring and black-out management. Furthermore, telecom satellites can easily back-up high availability links of the communication and control network in critical parts of the smart energy grids.
- **Security:** Thanks to their inherent dependability, and ubiquitous access capability, SatCom are key component of telecom infrastructure for security missions given the strong requirements for availability anywhere anytime, as well as in emergency situations where exact and timely available information content is essential for security related missions such as crisis management with the coordination of first responders, rescue teams and survivors .
- **Content (Culture, knowledge, Digital literacy, skills and inclusion)**: SatCom can assist in a cost effective manner the delivery of high resolution content in areas beyond reach of any terrestrial access system (e.g. efficient Ultra HD and 3D content delivery to low density populated areas but also on board vessels, aircraft, trains, buses or light vehicles). By connecting people around the globe, SatCom also contribute to protect and promote the diversity of cultural expressions.
- **Healthcare**: to assist patients under medical treatment in their homes and interconnect hospitals and medical teams in low density populated areas. Moreover, as the need for improving healthcare in rural and low density populated areas intensifies and the importance of bringing the international medical community together in the years ahead grows, SatCom are ideally positioned to facilitate the flow and sharing of medical expertise and information between medical centres and contribute to empower the patient.
- **Environmental monitoring**: SatCom are ideal to collect in a synchronous and real time manner, data from sensors deployed over a wide area (regional, national or continental), on board observation satellites or on board Unmanned Aerial Vehicles (UAV). They can, also be used to relay the collected measurements from earth observation systems to the relevant users for the early detection of disasters (natural or man-made) and to provide alert and guidance services to rescue teams as well as the population.

5.2 Contributions of SatCom to the DA objectives

The table below attempts to identify the SatCom solutions that will contribute to DA objectives:

Digital Agenda objectives	Broadcast	Backbone (Transport domain)	Broadband access (includes both fixed and mobile)	Mobile Satellite Systems (referring to narrowband services)	Governmental systems (incl. Fixed and Mobile broadband)	Comments
Fast and ultra fast internet access	x		X			Broadcast solution will enable to support Triple play service offer
Transportation efficiency and mobility			x	X		Handheld services are used for asset tracking while mobile broadband access will ensure connectivity on board public transportation vehicles
Smart Energy grid		x	X	X		Broadband access and MSS via M2M services can be used for the surveillance of the grid
Security				X	X	Handheld, nomadic and vehicle mounted broadband connectivity are needed for most security related missions
Climate change,		X	X			Broadband connectivity will be used to convey video and image based traffic. e. g. environmental monitoring
Digital literacy, skills and inclusion (content)	X	X	X			Broadcast as well a broadband in the transport and the access domain are needed for the provisioning of video based services
Healthcare			X			Broadband connectivity are needed for remote diagnostic as well as patient remote surveillance

Tableau 8: Contributions of SatCom architectures to the Digital Agenda objectives

6 Emerging SatCom architectures

For each market segments, new SatCom architectures will be developed referring to new space segment configuration, new radio interface technologies or even new network integration scenario with terrestrial systems.

This chapter highlights the principles underlying the definition of emerging SatCom architectures in the coming decade.

6.1 The main drivers for innovation in SatCom

To maintain the European SatCom industry market share or address the future targeted applications, great effort need to be spent on innovative SatCom systems at both space and ground level in the following areas:

- **Performance**: In order to support multimedia services, the maximum service rate capability, the service availability (in time & space) and service QoS shall be improved in line with terrestrial networks. This also requires an increase in terms of space segment throughput (for instance by increased spectrum efficiency, by more efficient resource usage, …) to accommodate a larger number of users as well as higher sustainable service rate.
- **Quality of Experience** (QoE): New protocols and techniques that address improved quality of experience via satellite need to be developed. The use of terminals shall be simplified especially in its installation, set-up and operation including energy efficiency..
- **Cost**: A decrease of the operational cost (e.g. cost per bit) requires optimised space segment throughput but also simple network management process. Optimisation of SatCom development and deployment cost requires reduction of space and ground equipment production costs as well as installation cost.
- **Network integration** (satellite with terrestrial systems): Further efforts are needed to improve the integration of SatCom systems in Next Generation Networks at core network (e.g. IMS) and access network home or remote local network environment level. In particular SatCom shall support unified service delivery to end-user whatever access network and support mobility between satellite links and terrestrial links. SatComs shall also prepare themselves to the possible ‘revolution’ of the Internet (Future Internet, from the technical point of view)
- **Flexibility**: It enables the reconfiguration of the satellite payload over operational in orbit lifetime in order to best adapt to the evolving market conditions or to support a change of the satellite mission. Flexibility may refer to the reconfiguration of the satellite coverage, frequency plan (with respect to ITU allocations), polarisation, transmit power, capacity allocated to a specific service area, connectivity scenarios between service areas (transponder, carrier or even connection). The purpose of flexibility is to enhance the satellite operators economics by better answering their needs. It provides a way to better mitigate business risks over satellite lifetime, when traffic and user need evolve, and are also a way to generate additional revenues throughout satellite life time thanks to higher transponder load.
- **Integration with navigation and observation systems**: The hybridization of Earth observation, navigation and telecom applications and systems will open the door to new services and applications enlarging the SatCom market.
- **Resilience and Security**: The SatCom service availability originates from the radio link availability but also from the system (payload and ground network) availability and resilience with respect to possible disruption.

In order to achieve these above objectives, the industry shall undertake research and innovation activities in three areas during the next 10 years:

- Innovative spectrum usage: This refers in particular (but not limited) to a further optimisation on the way to use the FSS and MSS frequency spectrum (by further reducing beam size in order to increase frequency reuse factor, as well as by using a wider proportion of the total available spectrum for user links), the use of new frequency bands (Q/V bands in the medium term future, optical band in the longer term), and the evolution of the regulatory frameworks for bands currently exploited. For this later point, techniques allowing spectrum sharing or opportunistic use of the spectrum (e.g. cognitive radio) will be investigated, with however the permanent objective to protect satellite services against any degradation of interference which would come for such sharing schemes with terrestrial networks.
- Innovative techniques, protocols and architectures from physical layer to service and application layers, enabled by disruptive on board technologies like large deployable reflectors, smart antennas, GaN, photonic, 65 nm (or below) CMOS process mode, reconfigurable and hardened FPGA, high capacity micro-processors for data processing and traffic routing, (Open standard) Inter Satellite Links. The future techniques for SatCom may also exploit on going R&D effort in the context of terrestrial fixed and mobile telecommunication systems. In all cases, development of cost competitive solutions shall always be considered as a key driver to consolidate development priorities
- Innovative business models involving public institution to facilitate/fasten the introduction of breakthrough technologies as well as innovative product, architectures, services and applications onto the market. This includes the federation of public and private R&D efforts and the stimulation of the demand for innovative service by aggregation or other incentives. The development of demonstrators and In orbit Validation experiments have also to be considered in that respect.

6.2 Emerging SatCom architectures principles

Emerging SatCom architectures aim at offering (see [Ref5.]) :

- Increased performance in terms of data rate capability;
- Optimized operational cost thanks to increased throughput and optimized operation and maintenance procedures at user terminals, network and space segment level;
- Improved Quality of Experience
- Increased space segment capability to support various
  - terminal profile and usage conditions;
  - service coverage configuration to accommodate temporary geographical service demand;
  - capacity distribution scenarios to best serve the traffic demand everywhere;
  - connectivity scenarios to support direct connectivity between terminals under the same satellite coverage (mesh) or under different satellites (inter satellite links).
- Enrichment of service offer thanks to integration/inter-working with terrestrial systems or other satellite systems

6.2.1 Towards satellite/terrestrial networks

There is an increasing interest to combine satellite and terrestrial components to form a single telecom network. The objective or added value of the resulting network compared to a standalone satellite component. There may be one or several objectives among the following (see [Ref8.] , [Ref16.]):

- to extend service coverage (e.g. rural + urban areas, outdoor + indoor)
- to provide a broader range of services (e.g. broadcast + unicast)
- to maximise the spectrum usage via smart techniques enabling sharing or coexistence
- to optimise operational/investment cost
- to provide path diversity for increased service availability and/or resilience (e.g. doubling of critical communication link)
- to minimise the energy required for conveying an information to recipients
- to off load some traffic between components
- to achieve rapid service deployment

Each stakeholder of such network will mostly be concerned by different aspects:

- Regulators : spectrum optimisation and service typology
- End-Users: seamless service access, device, subscription
- Operators and Service providers: cost optimisation, service differentiation and the control of the subscriber, deployment strategy
- Terminal vendors: hw/sw commonality
- Network vendors: equipment synergy

In order to characterise such network, one should consider

- The role of the satellite component in the resulting network
  - in the access network:
  - in the backbone: e.g. Satellite backhaul service to remote local access network, Satellite service delivery to access point, Doubling of a critical terrestrial link by a satellite link (and fast traffic rerouting), Multicasting in future information centric networks
- The operational dependencies between the terrestrial components with respect to satellite components: independent, dependant
- The service capabilities of the terrestrial components with respect to the involved satellite components: similar, complementary (e.g. unicast + broadcast) or overlapping (partly similar but also providing other services)
- The type of the combination or integration of the components: The integration may take place at management, service, terminal, network (e.g. same core network), technology standard (e.g. same radio interface technology) and/or spectrum level (e.g. operating in same spectrum allocation or even same frequency band).

Note that such network may also refer to several satellite components: e.g. for an integration of broadband and broadcast service.

ITU-R (WP4B) has initiated a document that attempts to clarify the notion of Integrated or hybrid Satellite and terrestrial communication networks widely used but unfortunately referring to blurred concept. ETSI via the Satellite Earth Stations and Systems Technical Committee (TC-SES) is also contributing into the debate see (Work Item DTR/SES-00322: Definitions of hybrid and integrated Mobile Satellite Systems).

If one sticks to the regulatory point of view we can classify of satellite and terrestrial heterogeneous network according to two criteria:

- Service offer delivery by both satellite and terrestrial components
- Spectrum usage

The table below provides some example of systems falling into the different categories:

Spectrum usage	**Concept architecture**[9]	**Same service offer on both components**	**Complementary service offer on both components**
Separate spectrum for each component	Bi mode terminals with possible coupling between both components at higher layers or network management level	*For example, Thuraya terminals offer 2G mobile telephony services via GSM or Thuraya network. It may also refer to broadband access via fibre/cable network in urban areas, wireless systems in sub-urban areas and satellite in rural areas*	*This applies for example to broadcast service via satellite and broadband service via ADSL.*
Allocated spectrum shared between both component but operating in separate frequency bands	CGC system concept with a coordination of the frequency band allocation between both components	*For example L band (LightSquared) and S band (Terrestar) in North America*	*Typically broadcast via satellite and telephony/mobile broadband via the terrestrial component*
Both components operating in the same frequency band of a given allocated spectrum	Specific configuration of a CGC system with the coupling of both components' radio resource management	*This is envisaged to provide mobile broadcast services (e.g. DVB-SH or EDSR technology) and/or data collect (e.g. S-MIM technology on the return link). For example via the S band ICO-G1 or Solaris satellites*	*This could be made possible thanks to MIMO and interference mitigation techniques or operational constraints. For example, an indoor CGC component sharing the same band as the satellite component.*

Tableau 9: Typology of heterogeneous satellite/terrestrial networks

[9] see [Ref7.] for further details

Common and Complementary service offer can also be envisaged on both components. Given link budget constraints, the satellite component may only provide a subset of the service offered by the terrestrial component. For example, this could be achieved with a specific waveform using techniques like hierarchical modulation allowing to offer a basic quality service (e.g. mobile TV) via satellite and enhanced resolution via terrestrial component.

6.2.2 Towards System of Systems

New services opportunities will be made available with a hybridization of SatCom with other satellite applications, namely Earth Observation and NAVigation.

Coupling scenario	**Rational**
SatCom and Global Satellite Navigation Systems	To deliver Location based services To optimise the SatCom radio resources management To use timing for improved synchronisation To improve positioning accuracy: e.g. with Logical assistance channel To improve Navigation service integrity (e.g. EGNOS)
SatCom and Earth Observation Satellite systems	Data relay to overcome the revisit time associated to low earth orbiting earth observation system
SatCom, Global Satellite Navigation System and Earth Observation Satellite system	To increase efficiency in tacking grand societal challenges such as crisis management, environmental monitoring, energy sustainability, transport and mobility

6.3 Enabling technologies for ermerging SatCom architectures

This section details the main technical enablers supporting the characteristics of emerging SatCom systems. It doesn't identify in details the needed technologies and products (see [Ref6.]).

6.3.1 Increased service performance

The achievable **service data rate** depends on the antenna gain and RF power of the transmitter, the figure of merit (G/T) of the receiver and the efficiency of the waveform. To achieve high service rate with affordable terminals in terms of cost and size, leads to maximize the satellite antenna gain and its RF power performance while ensuring very fine pointing accuracy. This favours the use of large reflector, powerful platforms and efficient waveforms. The narrower footprint of these reflectors can be compensated by multi-beam coverage. Interference in such systems becomes and important quality determinant and mechanisms to manage or cancel interference are needed.

Upcoming High frequency SatCom implementing multi-beam technology and operating in higher frequency band to support high service rates.

Low frequency SatCom, targeting handheld devices with omni directional antenna are able to deliver service rates up to 1 Mbps on the forward link and few tens of Kbps on the return link. The service rate can be further increased on the return link using terminal with laptop form factor device and sufficient transmit power.

While high frequency band SatCom are able to scale with the broadband traffic evolution, low frequency band SatCom will best offer broadcast and messaging services to scale with the traffic demand.

6.3.2 Optimized operational cost

The most effective way to reduce Operational cost is to increase satellite throughput beyond the present capabilities. The more the throughput is, the more the addressable end users and revenues become. Other cost reduction factors are faster terminal installation/set-up process, simple network management process similar to the ones used for terrestrial systems and, in general, reduction of space production costs by new technologies and solutions at Payload and Platform level.

The **satellite total throughput** depends on the same performance factors as service rate and also on the total available bandwidth. This available bandwidth can be increased, as in the ground wireless networks, by enlarging the number of beams and re-using the spectrum.

Further enlargement of SatCom throughput can also be achieved thanks to progress with the implementation of

- New Adaptive Coding and Modulation (ACM) and distributed diversity techniques to optimize satellite link performances in extreme weather and mobility conditions;
- Advanced Radio Resource Management (RRM) schemes based on cross layer techniques;
- Interference mitigation techniques to provide robustness/protection over adjacent satellite, co-channel and adjacent channel interference;

Up to recently, broadband access service offers were mainly based on satellite operating in Ku band initially optimized for broadcast services in a single beam usually over a regional area (typically 7° by 4° beamwidth) and typically providing less than 5 Gbps of throughput of broadband traffic. Multi beam satellites operating in Ka band start to be deployed and can increase the throughput by at least an order of magnitude. KaSat from Eutelsat (launched end 2010) provides for example 70 Gbps throughput via 80 spots with <0.5° beam-width. The throughput can be further increased (towards Terabits satellite) with more challenging antennas and payload techniques (<0.3° beam-width), high power platform, smart system design approach and exploiting Q/V frequency bands on the feeder link, where the useful spectrum is about 3 to 4 times greater than in Ka band.

Most recent low frequency SatCom based on Geo-stationary satellites operates in L and S band and use very large deployable reflector (>15 m diameters). These large reflectors provide spot coverage (< 0.5° beam-width) that allow extensive re-use of frequency. Further increase in throughout can be achieved using for example diversity techniques such as MIMO (multiple-input multiple-output) technology together with innovative terminal antenna systems.

The throughput of Broadcast service satellite in Ku band can also be improved with higher power platform and efficient scalable video/audio coding techniques to exploit the best out of varying radio conditions and enable 3D content communications (e.g., 3DTV).

6.3.3 Improved Quality of Experience

While all services can be offered via satellite, satellite communication is inherently associated with long delay and challenging channel conditions that require special considerations.

- For GEO satellites acceleration schemes embedded in PEP's have been produced which in association with caching allow for equivalent QoE to terrestrial systems for all but a small percentage of gaming applications.
- For LEO and MEO systems the latency is less of a problem but the routing protocols around constellations need to be optimised for service provision.

In very high reliability systems error resilience can be achieved by use of Delay Tolerant Networking (DTN) although this needs further investigation.

QoE for satellite delivery is an area that can benefit from further research and will be key in establishing future integrated systems.

6.3.4 Increased space segment capability

6.3.4.1 Terminal profile and usage conditions

Upcoming SatCom by now provide services to wide range of terminal profiles and usage conditions using the same space segment in order to aggregate as many markets as possible. Low frequency SatCom are serving handheld, laptop form factor as well as terminal on vehicle like vessels or aircrafts. Similarly, High frequency SatCom are addressing fixed, nomadic and vessel mounted terminals.

In all cases, further efforts shall be spend to reduce the terminal form factor, set-up time and pricing. Low frequency SatCom should support cellular handheld device with dual ground and satellite connection capability. High frequency SatCom systems should serve low profile vehicle mounted terminals or highly transportable nomadic devices.

This will impact the satellite performance in terms of Effective Isotropic Radiated Power (EIRP) and G/T but also requires implementing reinforced interference mitigation, energy saving schemes as well as coupling with Global Navigation Satellite Systems (GNSS) to fasten and ease the terminal set-up.

6.3.4.2 Capacity distribution scenarios

The wide coverage of existing Satellites can easily aggregate the traffic demand of widely dispersed terminals. In a multi beam SatCom, the traffic is aggregated over a smaller beam area; the smaller the beam-size, the larger the potential traffic congestion in some beams and unused radio resources in other beams. This leads to design new payload and system architectures capable to dynamically allocate capacity according the real needs.

The implementation of this flexibility in capacity allocation between beams may be achieved through

- flexibility in allocated power per beam by flexible high power amplifiers or multi-port amplifier architectures; flexible payloads in the frequency domain or beam hopping in the time domain.
- flexibility in beam bandwidth by use of on board processing with reconfigurable RF filters, flexible wideband converters. RRM schemes exploiting ACM techniques can cope to mitigate interference in some applications..

6.3.4.3 Connectivity scenarios

Most SatCom systems operate on a star network topology with a central hub serving a set of terminals. All the traffic is conveyed to and from the hub interfacing to the public internet. Some SatCom systems can support mesh connectivity with reduced latency in terminal to terminal communications. However, this technique requires specific radio carrier transmission to be set-up between the terminals, lead to sub-optimal use of the satellite transponder resources and force complex RF transceiver implementation in the terminals. More advanced satellites embark digital transparent processor able to switch channels or even carriers with improved flexibility in the connectivity.

On board regenerative processors (AmerHis on the Amazonas satellite, or SkyplexNet on the HotBird satellite) are already capable to switch terminal connections.

The perspective is to increase the digital transparent processor and the on board regenerative processor (router) capabilities to obtain:

- Flexible routing of channels, carriers, connections or packets;
- Processing of a higher number of inputs/outputs and bandwidth;
- Support of direct connectivity between terminals under the same satellite coverage (mesh) or under different satellites (inter satellite links).

Moreover, smart payload design should be developed to support partial mesh connectivity capability. This will allow maximizing the satellite performances while providing the necessary flexibility in connectivity.

6.3.4.4 Service coverage configuration

In some cases, it could be desired to readapt the original satellite radio coverage to new service demands; it is the typical case of humanitarian or rescue missions that require strong capacity in an unpredictable location in the world and for limited amount of time.

This important feature requires techniques to dynamically reconfigure antenna footprint to cover contiguous or non contiguous small areas on a given region.

This can be achieved adopting active or semi-active antennas based on Direct Radiating Array (DRA) or Focal Array Fed Reflector (FAFR) together with digital beam forming networks.

Furthermore advances in Digital Beam-forming Techniques would allow beam forming at packet or burst level so that, ultimately, future satellites will be able to implement Space Diversity Multiple Access scheme (SDMA) where each terminal or co-located terminal is served with a beam concentrating nearly all the available capacity.

6.3.5 Enrichment of service offer

Heterogeneous satellite/terrestrial networks or Hybridization of several satellite application systems requires more or less integration or interoperability between the components.

The coupling may take place at spectrum, service, terminal, network level.

For example, SatCom systems shall evolve to provide an integrated role in the deployment of Next Generation Networks and the associated telecommunications services. In particular, SatCom shall support the unified service delivery to end-user whatever the access network and support mobility between SatCom links and terrestrial communication links (vertical hand-over).

This requires to

- Evolve the SatCom architecture with the Separation into “Access Stratum” (satellite specific) and “Non-Access Stratum” (multi access technology), for the seamless support of IP Multimedia Sub-system (IMS) protocols;
- Adapt the emerging SatCom to Future Internet services and protocol stack;
- Combine satellite and terrestrial component resources to offer service continuity over 100% territory (also in rural areas) and/or an optimized service delivery based on aggregated bandwidth from different access networks.

6.3.6 Research priorities

From a market point of view and taking into account the identified technical enablers, we can already give a tentative priorities for research topics in the next 10 years:

SatCom market segments	Space segment	Ground network and system aspects
Broadcast	++ (e.g. performance enhancement)	++ (e.g. low cost and self installed hybrid terminals, spectrum efficient waveforms)
Backbone	++ (e.g. flexible payloads, multi beam)	+ (redundancy, impacts of space segment configuration on network topologies and connectivity scenarios)
Broadband access	++ (e.g. Ultra wide band spectrum, exploitation of higher frequency band, very small beams)	+++ (e.g. low cost self installed terminals)
Mobile Satellite Systems (frequency band < 3 GHz	+ (e.g. performance enhancement)	++ (e.g. broadband service, vehicle, aircraft mounted low profile antenna)
Governmental SatCom	++ (e.g. flexible payloads, global coverage)	++ (e.g. mobile platforms for broadband services, fast on-demand access to resources, security features)

Tableau 10: Research priorities per SatCom market segments

+: lower priority;

+++: higher priority

Much of the current research is aimed at single large GEO satellites but an alternative approach is to use clusters of smaller GEO's connected in orbit by ISL's. The potential here is for more economic rollout of the coverage area and provision of services as the demand expands. There are also advantages in reducing power and launch requirements for the satellites. More research in this area is needed.

6.4 Non technical enablers

Beyond the technical development, it is important to address the potential market barriers (e.g. regulatory, standardisation, business models, validation) in order to maximise the chances of successful market introduction and remove technical and regulatory risks associated to technical innovations.

6.4.1 Regulatory framework

In case of new service concept or new spectrum usage, the regulatory framework will need to evolve. Ideally, measures should be developed to facilitate the definition of harmonised framework in Europe and beyond. The EU and the CEPT shall play a major role in setting up the appropriate regulatory instruments to enable the authorisation of new services in Europe by National Regulatory Authorities. When frequency allocations are at stake, Europe interests shall be identified, coordinated and defended in the ITU.

The following areas can be identified:

- *Unleashing the full Ka/Q/V band potential:* In the Ka band, the CEPT is currently acting towards making available additional spectrum for use for broadband terminal emissions. This effort is supported by the satellite industry. Due to broadband traffic asymmetry, a large amount of associated downlink spectrum is needed to unleash the full Ka band potential. This downlink spectrum could be accessed only if consistent regulatory and technical measures are in place to enable a robust satellite service, while ensuring the development of the services present in these bands.
- *There are no dedicated satellite bands at Q/V* and these bands will be needed for higher capacity feeder links in the future. Co existence of satellite and terrestrial systems needs to be investigated in more detail here.
- *Preserve critical SatCom bands:* Certain frequency bands used by satellite services are increasing targeted by other applications such as terrestrial mobile. In these bands, critical satellite services are provided (e.g. C band FSS) and their continued development must be ensured.
- *Investigate new sharing mechanisms:* It is a known fact that sharing frequencies between satellite and terrestrial applications can be difficult especially with mobile services. New schemes should be investigated to enable the provision of satellite services in complex and changing interference environments. This may include the recourse to cognitive radio technologies with however the permanent objective to protect satellite services against any degradation of interference which would come for such sharing schemes with terrestrial networks.
- *Identify new bands for SatComs:* New bands must be identified to meet the increasing demand for satellite services. In particular, WRC-12 will decide upon new allocations for MSS. Such allocations must be promoted, in particular in the 13/15 GHz bands. Also, the are proposals for the work of WRC-15/16, to enlarge the allocation in the congested X band for governmental SatComs. This work should be supported, while ensuring the compatibility with existing services (especially Space science).

6.4.2 In Orbit Validation for innovative space segment technologies/payloads

Given the intrinsic nature of satellites, which are deployed far out in space, bringing technology, product or service concept innovation to the Satellite communication market implies to overcome several barriers, linked to risk aversion, which requires significant level of investment. Risks result from the combination of

- Technical risk since the proposed innovation items has never been validated in orbit;
- Commercial risk when opening a new service with a technique that has not been flight qualified;
- Regulatory risks when requiring a new spectrum or a new framework which may not be fully secured at the time the investment on the space craft needs to be made.

"In orbit validation" is therefore of utmost importance since it alleviates most of the above risks and favour market access thanks to the highly appreciated "flight proven/heritage label".

In the past years, the space industry has benefited from higher public support brought by space agencies, to develop and validate new technologies. In Orbit Validation was achieved thanks to technological satellites procured by public agencies. Note that such institutional satellite projects required significant funding levels and are usually associated to long development schedule. This long development cycle originates from the necessity to accommodate schedule slippage due to technical issues, to allow time for fund raising and to aggregate a sufficient number of items to be validated to "fill in" a satellite. This can lead to an excessive delay not really compatible with fast time to market constraints for the introduction of innovative technologies/products/concept.

In times of public financing crunch, alternatives to the technology satellites have started to be successfully implemented. The main idea is to launch a technology piggyback on board a commercial satellite. This enables to optimise both the launch and operational costs shared with the commercial mission and the development cycle constrained by the commercial satellite. It also offers an interesting flexibility with respect to the manufacturer's product roadmap by selecting the most relevant opportunity among commercial flights which outnumbers the institutional (agency and government) ones by at least a factor of 3.

6.4.3 Standards

Standards offer many advantages

- To users: Safe, healthy, secure, high quality, flexible products and services; More likely to be supported by applications or accessories vendors
- To business
    - Opportunity for new vendors
    - a solid foundation upon which to develop new technologies
    - an opportunity to share and enhance existing practices
- To Governments, Administrations, Regulators: a good support throughout the life cycle of the products/services

However the following aspects need to be considered before going to standards:

- Cost/time: Time and cost to develop and maintain the standard versus, Cost/Benefits associated to the offering of a standard product
- Involvement of multiple different players: It gives larger pool of innovation but limits freedoms for individual customisations
- Markets: A trade-off shall be made between the benefits of a larger market but probably with lower margins versus a smaller fragmented proprietary markets with higher margins

The most relevant standard related organisations for SatCom systems are

- European Telecommunication Standards Institute (ETSI) which is responsible via its Technical Committee for Satellite Earth Stations and Systems (TC-SES) for the development of harmonised standards for Broadcast Satellite Services (BSS), Fixed Satellite Services (FSS) and Mobile Satellite Services (MSS) allocated spectrum, for the definition of satellite access networks (e.g. GMR-1, BGAN, S-MIM, S-UMTS mainly for mobile satellite systems) for the interoperability/integration of satellite network with terrestrial networks, the definition of Satellite Emergency Communication solutions as well as for the definition of satellite based navigation systems;
- Digital Video Broadcasting (DVB) industry forum: which has defined the popular DVB-S2 radio interface for broadcast services. It is currently defining the 2nd generation of the Return Channel via Satellite (DVB-RCS2) that combined with DVB-S2 used as forward link will support fixed and

mobile broadband services with increased performance compared to DVB-RCS. A potential DVB-S3 may well be defined in the coming year with increased performances compared to DVB-S2.

The table here below summarizes the current standards adoption in the different SatCom market segments:

SatCom market segments	Worldwide market size in number of terminals	Standard and proprietary systems
Broadcast	Hundreds M	Mostly standards DVB-S progressively replaced by DVB-S2
Backbone	Hundreds k	Point to point systems: mostly standards with IBS-IDR progressively replaced by DVB-S2 Access systems: Mostly proprietary systems
Broadband access	Currently several M	Mostly proprietary systems based on DVB-S/S2 forward link; DVB-RCS market share still limited (<20%)
Mobile Satellite Systems (frequency band < 3 GHz	Several M	GEO systems:ETSI SL family for Inmarsat BGAN (the market leader); ETSI GMR-1 3G for Thuraya, Terestar, ICO; ETSI GMR-2 for AceS LEO systems: Iridium, Globalstar: proprietary systems given the specificities of the constellation's orbit and spectrum
Governmental SatComs	Hundreds k	Point to point broadband systems: mostly standards with IBS-IDR progressively replaced by DVB-S2 Access broadband systems: Mostly DVB-RCS systems

Tableau 11: Standard adoption in SatCom market segments

In the SatCom domain, standards adoption is mainly driven by:

- Significant market size as per broadcast justifying the involvement of different players
- Or markets subject to public procurement having strong interest in interoperability and avoidance of a "lock-in". (see action 22 of [Ref17.])

With the market potential associated to fixed broadband access, a standard could emerge and take over the market share of proprietary systems. However this requires to define a standard favouring very low cost devices (purchase and installation) while supporting the required performances. DVB-RCS2 is one candidate, but alternative options may be envisaged fostering synergies with technologies developed for other ICT markets (e.g. use of LTE on the return link). EC regulations should foster the selection of a unique European standard for broadband access via satellite but let the SatCom industry to define it.

In its EC M/415 EN Programming mandate ([Ref12.]) addressed to CEN, CENELEC and ETSI, the European Commission encourages to establish space industry standards. In particular, this mandate defines a standardization programme that shall concentrate on the scope defined by ten sectorial dossiers set out in the phase 2 final report of Mandate M/415, among which:

- Integration of Navigation and Positioning (NP) Applications with **Telecommunications** (TEL) [Sectorial dossier 2];
- Data Format for Information Exchange in support of applications which are defined in a "System of Systems" environment (in particular inside and between Earth Observation (EO), Navigation and Positioning (NP), and **Telecommunications** (TEL)) [Sectorial dossier 3];
- Interoperability and Integration of **Mobile Satellite Systems** (MSS) and **Fixed Satellite Systems** (FSS) with Terrestrial Systems in particular Next Generation Networks (NGN), and with Global Navigation Satellite Systems (GNSS) in particular Galileo [Sectorial dossier 4];
- **Disaster Management** [Sectorial dossier 9];

This mandate is expected to foster standardisation of Emerging SatCom solutions and contribute to reinforce the leadership of Europe also in the SatCom domain. This is a potential framework to define next generation SatCom standards and promote them for wide market acceptance.

6.4.4 Business model: Financing the innovation

In the context of satellite communications, innovation may take place at different level:

- Spectrum: Exploitation of spectrum unused or accommodating a new regulatory framework and making a continuous more efficient use of the spectrum
- Space segment: Orbit configuration, new concept satellite and payload improving performance, coverage or bandwidth
- Ground segment: terminals concept with improved usage conditions and performances for better market acceptance, Enhanced radio resource management, seamless inter-working with other systems (telecom, navigation, observation, satellite or terrestrial), satisfying the evolving and more stringent user requirements.
- Service & applications: New services/applications able to take advantage of the satellite system characteristics and integration/interoperability with terrestrial communication infrastructures and providing high user quality of experience.

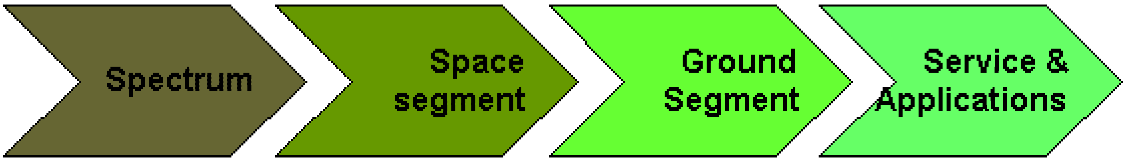


Figure 3 : Innovation at different stages of the SatCom development cycle

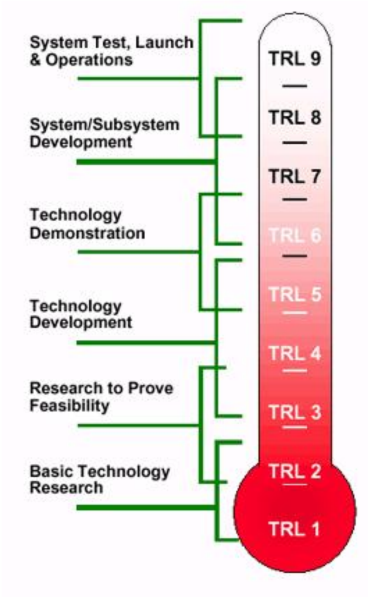
The level of risk associated to the development of an innovation will depend on

- The delay to the market

- The technical maturity of the technologies it is based upon

On one hand, innovations at spectrum level is likely to trigger innovations at all stages with a high time to market and risk level. On the other hand, the time to market of innovations at service & application is very short. Typically, it will take 7 to 10 years to exploit a new band while it will take less than 1-2 years to introduce a new service and/or application on existing/in orbit space segment.

The innovation cycle takes a technology (materials, components, devices, manufacturing process etc) or techniques and bring it to the market. Before a technology can be incorporated into a space based system and sold to a customer, it has to reach a certain maturity measured by its Technology Readiness Level (TRL). The space industry standard define 9 maturity levels from “Basic principles observed and reported” up to “Actual system "Flight proven" through successful mission operations”. This 9 maturity levels can be translated into 6 development phases covering Basic technology research, Research to prove feasibility, Technology development, Technology demonstration, System/sub-system development, System test launch and operations.



Public financial support is needed especially during the initial phases of the SatCom development cycle:

- Exploratory studies on Spectrum usage
- R&D up to in orbit validation of space segment products and technologies and the necessary industrial tools that help to reduce the satellite manufacturing cost and delay

Furthermore, public financial support to the deployment of future SatCom solutions will be needed to address selected Digital Agenda objectives where there are evidence of market failure or no commercial market:

- Broadband access in low density populated areas: This was already in the EU i2010 objective but never fulfilled. As broadband now refers to higher service rate, this objective will not be achievable without significant public financial support. This however would be a unique opportunity to progress the state of the art and the competitiveness of EU manufacturing industry in this SatCom market which will be worldwide according to market analyst (e.g. NSR)
- SatCom for institutional applications such as crisis management, critical infrastructure protection: There aren’t any commercial market. Public financial support is also needed to develop SatCom solutions targeted to the needs.

Given that it takes 7 to 10 years to deploy a new space infrastructure while it will take less than 1-2 years to introduce a new service and/or application on existing/in orbit space segment, most private investment goes into innovative services and /or applications but with limited innovation steps. New business structure should be considered favouring also investment on innovations in space infrastructure enabling much larger innovation steps.

7 Socio-Economical impacts of emerging SatCom architectures

The economics differ between SatCom market segments.

We shall focus our analysis on selected markets:

SatCom systems addressing the consumer market (e.g. broadcast, broadband) have to align in price with other terrestrial systems. .

7.1 Direct To Home TV market

The subscription fee for Direct To Home TV offer via satellite is expected to decrease. This constraints the business case of satellite broadcasters which have to cope with the transport of TV programs with increased resolution and hence bandwidth requirements (see [Ref14.]) at the time horizon 2020:

TV program format	HDTV	UHDTV	Stereoscopic 3DTV
Screen resolution	"1080p", to support all HDTV formats	3840 x 2160	1920 x 1080 Multiview
Expected required bandwidth in Mbps[10]	5 Mbit/s	20 Mbit/s	~ 13 Mbit/s
Nber of TV program broadcasted per 36 MHz transponder[11]	10	2	4
Nber of TV program broadcasted per satellite[12]	400 - 600	80 - 120	160 - 240

Tableau 12 : Evolution of TV programs bandwidth requirements at Time Horizon 2020

Increased throughput will enable to embark additional TV programs and reduce further the transmission cost associated to the broadcast of TV programs via satellite as well as support smaller satellite dish with increased market acceptance.

Hybridisation with an interactive link (terrestrial or satellite) will open up a new set of applications for value added services to sustain the evolution of video consumption towards personalized, non linear and interactive. In other words:

- from linear TV (broadcast) with passive consumption of a video program assembled by a TV channel editor
- to non linear TV (VoD, catch-up TV, OTTV and PVR with internet TV, IPTV).

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[10] Used to compute the number of TV programs in a 36 MHz transponder thanks to statistical multiplexing

[11] Assuming DVB-S3 radio interface with ~1.45 bps/Hz spectral efficiency (10% improvement wrt DVB-S2

[12] Assuming 40 to 60 transponders (36 MHz bandwidth) per satellite

7.2 Backbone market

Also known as telecom satellite, these are used to provide connectivity service. Current geo-stationary satellite communication payloads offer limited and expensive flexibility for reconfiguration before launch or during the satellite lifetime in order to best adapt to the evolving market conditions or to support a change of mission with a new regulatory context.

- Flexibility may refer to the satellite reconfiguration in terms of Resource allocation over the service area and connectivity scenarios between service areas to adapt to the evolutions of the traffic and services (applications), to face various connectivity scenarios;
- Frequency plan to support a change of orbit, regulatory conditions or satellite mission (e.g. broadcast, broadband communications or VSAT communications)
- Service area to address different businesses/business areas

The purpose of flexible payloads is to optimize the satellite revenues throughout satellite life time thanks to higher transponder load and in a mitigation of the operator commercial risks. Business perspective is promising especially for TV distribution to TV head-ends, Content Delivery network, Virtual Private Networks, and Backhaul for cellular and wireless communication. Such payloads can also secure the business of a "fleet operator" with a single adaptive satellite used as a gap filler.

7.3 Broadband access market

Let us compare the evolution of the Gbps transmission cost with the successive generation of broadband satellites:

	Unit	Ku band	1st gen Ka band	2nd gen Ka band	3rd gen Ka band
Capacity per satellite	Gbit/s	5 - 10	50 - 100,0	150 - 200	> 500
Gbps transmission cost over satellite[13]	Euros	30 to 60	4 to 8	~3	< 2

This trends shows the significant cost improvements brought by future satellites in Ka band. It is necessary to accommodate an increase of the busy hour bandwidth required per home (BHBB) is expected to increase from currently 60 kbps to several hundred kbps at the 2020 time horizon ([Ref13.]). Still a satellite could serve ~ 1 million Households.

To achieve a monthly subscription fee for broadband access via satellite comparable to broadband access via terrestrial (~30€ per month), state aid is needed but expected to be overall lower than subsidies to fibre optical network or wireless network in low populated density areas.

[13] This cost takes into account the total system Capital Expenditure costs (Capex) which is the amount of money that needs to be invested to start service. Thus, it includes the spacecraft, launch, its control station, the gateways needed for the service, project management costs and launch insurances.

Given the addressable European market for SatComs in the order of 10 to 15 millions households in low density populated areas, this corresponds to a potential market of up to 10 to 15 satellites.

7.4 Governmental and MSS market

SatCom system for security are essential contributors and therefore the pricing aspects are less important. However, future SatCom systems will outperform existing ones. Currently, the most used satellite resources are

- For mobile broadband services: Inmarsat where the transmitted Mbyte is priced 6 $ for standard IP traffic (best effort) and the transportable terminal devices retail price accounts ~2.5 k$.
- For handheld services: Iridium with voice calls charged ~1 $ per minute and a terminal pricing of ~1300 $.

Exploiting future Ka band satellite will allow to achieve increased throughput and service rate with reduced cost compared to existing MSS service offer.
Here under are compared the cost of MB transmitted over different mobile infrastructure. Future mobile broadband solution in Ka band are expected to be well positioned with respect to the LTE technology.

	UMTS	HSPA	LTE	Current & future MSS in L & S band (several hundred of Mbit/s throughput)	Mobile broadband via Ka band satellite (Several Gbit/s throughput)
Service coverage (territory)	<20% of Europe	<20% of Europe	<20% of Europe	ITU region per satellite	Continental (e.g. Europe)
Cost of Mbyte transmitted (CAPEX[14]/throughput)	0.06€	0.03€	0.01€	>2 €	< 0.2€

With IridiumNext, the terminal pricing is expected to be reduced thanks to lower constraints on the antenna and the RF front-end. In addition, thanks to higher throughput, the cost per MB will also decrease.

[14] Excluding licence fee

8 Conclusion

In this deliverable, we have identified the main drivers for emerging SatCom architectures in the context of the Digital Agenda for Europe and their expected added value.

The main enablers for such promising architectures have been highlighted. Detailed topics for research and development will be described and prioritized in the FISI D2.1 deliverable.

Appendix: FISI internal document control

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END