Satellite-Terrestrial Integration Scenarios for Future Information-Centric Networks[*]

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This paper addresses scenarios of integrated satellite-terrestrial Future Internet networks based on the Information-Centric Networking (ICN) communication paradigm. Focus is given on three integration scenarios: i) Hybrid Broadcast IPTV, paving the way for SatCom integration within the Future Media Internet; ii) Smart M2M Transport, paving the way for SatCom integration within a future Internet of Things; and iii) Extended 4G Backhauling, paving the way for SatCom integration within the 4G mobile Internet.

Nomenclature

AP = Access Provider
CP = Content Provider
DTN = Delay Tolerant Networking
eMBMS = Evolved Multimedia Broadcast Multicast Service
IO = Information Object
LTE = Long-Term Evolution
MPLS = Multi-Protocol Label Switching
PBR = Policy-Based Routing
QoE = Quality of Experience
RV = Rendez-Vous
TM = Topology Management
VANET = Vehicular Ad-hoc NETwork
CDN = Content Delivery Network
DoS = Denial of Service
FI = Future Internet
ICN = Information-Centric Networking
IPTV = Internet Protocol TeleVision
M2M = Machine-to-Machine
MVC = Multi-View Video Coding
PSI = Publish Subscribe Internetworking
QoS = Quality of Service
SVC = Scalable Video Coding
TP = Transit Provider
V2I/V = Vehicle-to-Infrastructure/Vehicle

I. Introduction

IN the last few years there is pressure on the current Internet architecture to meet new and emerging needs of its users. Inefficiencies of the current Internet architecture with regard to, e.g., mobility support, traffic management or content delivery, have been highlighted along with the complexities of proposed work-arounds or patches, which

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have progressively led to the Internet's ossification. The root of these inefficiencies lies in the mismatch between the current Internet's host-centric communication and the Internet's dominant usage, which now involves end-users interested in information and services with no regard to a particular device or location providing the information or the service.

Under this pressure, many research initiatives are investigating Information Centric Networking (ICN) as a new paradigm for the Future Internet (FI) worldwide, both in the US [1-5] and in the EU [6-13]. ICN architectures decouple the data/service from the actual devices storing/providing it by means of the location-independent naming. This decoupling helps tackle problems induced by host mobility much more efficiently, without relying on the communication between end-points (which may change), as now in the standard IP model. The identification of content at the network layer additionally facilitates data caching in network elements (in-network caching) and more efficient content delivery without resorting to add-on, often proprietary and costly overlay solutions (e.g., CDNs). Location-independent naming also facilitates information collection from multiple sources, without individually requesting information from each source. In addition, ICN promotes a *publish/subscribe* information model where receivers will not receive information unless they have explicitly requested for or subscribed to it, thus making the architecture naturally more robust against spamming and DoS attacks to end-systems. ICN's resolution service is responsible for locating the desired content, by matching information requests to publishers where the content is available. After resolution, the routing and forwarding functions transfer information from the publishers to the subscribers (receivers).

Future Internet ICN-related research efforts have thus far focused solely on terrestrial networks, neglecting the opportunity of integrating satellite and terrestrial networks using a common ICN architecture that combines and exploits the advantages of both networks. To the best of our knowledge, φSAT is the first research effort funded worldwide in that direction. The authors' companion paper [14] discusses in detail features of various ICN architectures for the Future Internet and in particular the Publish Subscribe Internetworking (PSI) architecture and their implications and corresponding advantages, disadvantages and trade-offs when they are applied for the integration of satellite and terrestrial networks. The current paper focuses on main relevant satellite/terrestrial FI network integration scenarios matching the ICN-PSI related concepts.

II. ICN over SatCom

ICN identifies individual information objects (content) rather than assigning unique addresses to end-hosts connected by communication links. Based upon the Publish/Subscribe paradigm [6], the network takes up the role of matching subscriptions to publications (information objects, IO); this is commonly referred to as *Rendez-Vous (RV) function*. In addition to name resolution, the other two core functions of ICN include routing (or *Topology Management (TM)*) and *Forwarding*. Node or link identifiers are not eliminated, as they may be needed for lower level topology management mechanisms and for associating nodes with the content they provide.

Figure 1 presents a functional view of a potential targeted ICN-PSI based architecture matching future SatCom requirements. This architecture does not provide any reference layering model; actually, layering is not completely removed but significantly simplified. Except for the application that handles data and subscriptions/publications with associated metadata, the transmission system (i.e. forwarding nodes) is split in only two layers:

- The Forwarding layer, which replaces someway the current IP and integrates transport control (e.g. reliability management, flow/congestion control) in a hop-by-hop or segment-by-segment fashion, rather than end-to-end as in the current Internet.
- The PHY/MAC layer, which is unchanged.

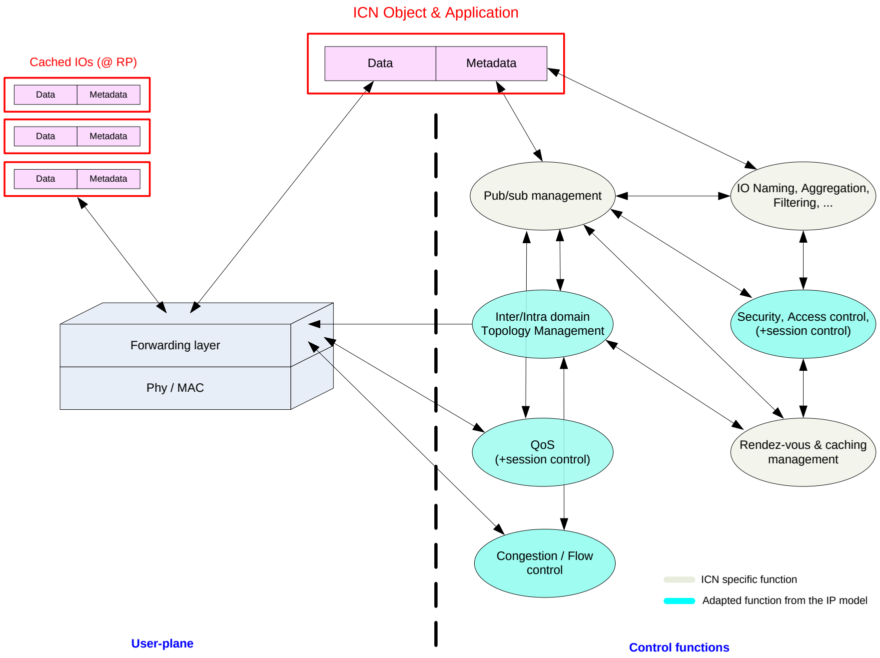

Figure 1: Functional architecture extended from PSIRP/PURSUIT ICN model to match future SatCom requirements

In φSAT, the specific ICN-PSI based architecture chosen as reference baseline refers to PSIRP/PURSUIT architecture [6, 7]. This is mainly because, from the conceptual point of view, PSIRP/PURSUIT implements all the key ICN mechanisms (pub/sub paradigm, caching, IO naming management, routing control…). Moreover, its three core functions (*RV Network, TM, Forwarding*) – that can be found in other ICN approaches sometimes with some minor differences - are conceptually split, which remains a general approach. If required, it does not preclude that some of these functions can be collocated on same nodes. Also, PSIRP/PURSUIT provides support of advanced IO naming: including scoping, aggregation etc. that firstly addresses the scalability issue on the resolution level. In addition, it provides open framework that facilitates the implementation of customized policies such as for core ICN functions but also for side-ICN functions (e.g. QoS support).

To optimise performance of ICN-PSI over SatCom in terms of QoS and resources utilisation, a number of helper/auxiliary functions are included. These are expected to operate either autonomously or integrated with one or more of the key ICN-PSI functions. In this case additional interfaces will be introduced to expose attributes for defining the policies to be enforced in each case. This approach is desired in the longer term as more efficient in terms of routing and traffic management. Moreover, a relay-oriented transport model can be followed so as to synchronise traffic engineering processes between congestion and flow control, Quality of Service (QoS) and resources management for the satellite segment, this being applicable to both GEO and non-GEO based systems.

The key features that characterise the ICN-PSI architecture are *mobility support*, *in-network caching*, *content-aware traffic management*, *decoupling between resolution and* *data transport, decoupling between data routing (topology management) and forwarding*, and *hop-by-hop (or segment-by-segment) congestion control*. Further details on these ICN-PSI architecture features as well as on how the main advantages of satellite networks can be exploited to increase the gain in adopting ICN-PSI architectures for integrating satellite and terrestrial future networks, are reported in [14].

III. φSAT Integration Scenarios

As part of the φSAT project, ten scenarios have been defined and analysed in detail. These scenarios have been ranked based on both technical criteria; such as maximising benefits from adoption of ICN-PSI paradigm and socio-economic gains; such as maximising the incentives for interoperable and integrated satellite/terrestrial future networks.

Important to note that the key features characterising the ICN-PSI architecture are desirable from socio-economic perspective, since it supports clear boundaries between modules and entities implementing different functionalities. Such clear boundaries are important to address tussles [15], i.e. conflicts of interest between different stakeholders in the integrated satellite/terrestrial networks.

The three selected integration scenarios constituting the focus of the paper are *(a) hybrid broadcast IPTV, (b) smart M2M transport, (c) extended 4G backhauling*. For each of these scenarios, the associated issues are presented and the ICN-PSI relevance and benefits are elaborated. For space limitation reasons, the hybrid broadcast IPTV scenario is discussed in detail, while the other two scenarios describe the main differences respect to the first one.

A. Hybrid Broadcast IPTV Scenario

This scenario paves the way of SatCom integration with the Future Media Internet. Typical use case is a GEO SatCom system with classical star topology integrated with terrestrial network. Two or three separate actors are involved in the service provision, namely *Content Provider (CP)*, *Access Providers (AP)* (satellite and terrestrial) and optionally *Transit Providers (TP)* to interconnect content and access providers.

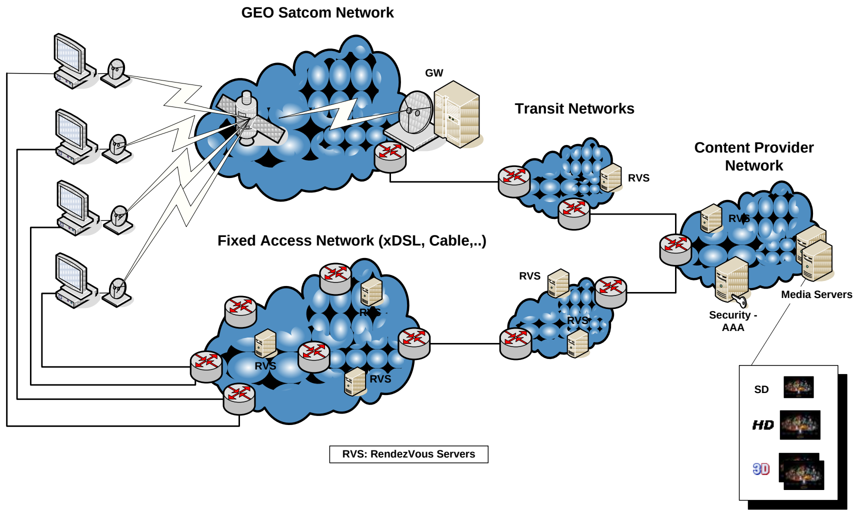

Figure 2: Hybrid broadcast IPTV scenario

ICN-PSI architecture favours *collaborative* service provisioning where the CP(s) polls the access network(s) to determine the optimal forward path using the hierarchical organisation of ICN-PSI functions with the content provider at the top level. CPs manage the core RV network and servers. This network could also host the Inter-Domain Topology Manager or at least one local Topology Manager (i.e. if one manager is allocated to each access domain). A local RV server is also implemented near the satellite gateway for load balancing purposes. This design choice allows CPs to manage dissemination of IOs within their own networks and assist access networks to localize published content as near as possible from the forwarding nodes. Levels of *collaborative* service provisioning depend on both economic (i.e. cost minimisation) as well as technical criteria (i.e. QoS guarantees, required bandwidth, date and time of planned broadcast, number and geographical distribution of subscribers to specific content, popularity of content, etc) and may lead to:

- Leverage routing decision (i.e. towards which network to use),
- Support the implementation of switching from one connection mode to another one in case of link failure,
- Support load-balancing between networks,
- Split service flows in several components sent separately over the two networks (the strategy definition being in that case how the splitting is done). For example, employing layered video coding such as Scalable Video Coding (SVC) / Multi-View Video Coding (MVC) coding send the base layers through satellite and the enhancement layers through terrestrial,
- Send traffic from one network and receive it from the other one, in particular attractive for unidirectional satellite system,
- Share RV servers between different networks,
- Share ICN caches (and increase the virtual storage capacity) of each network (relevant for on demand services as content can be opportunistically cached e.g., near the satellite gateway, the terrestrial access point – DSLAM for xDSL).

QoS–based routing protocols like Multi-Protocol Label Switching (MPLS (-TE)) or their evolutions in the frame of Future Internet, or simpler mechanisms like Policy-Based Routing (PBR) rules (routing rules defined by management, as supported by Cisco IOS-based routers) are possible example of implementations for the QoS-related forward path/network selection.

Other important technical aspects to optimize the performance of ICN over SatCom within the context of on-demand services are *cache management* (which IO to cache and where) and *timing policy* to rule the update and data overwriting. Decision on cache selection may be done jointly with the selection of the access network; in case of simultaneous accesses are possible, each access network designated its own caches.

B. Smart M2M Transport

The scenario paves the way of SatCom integration within future Internet of Things. SatCom can provide an efficient framework for Machine-to-Machine (M2M) smart transport services; in maritime, aeronautical and railway environments, in cases of [16]:

- Terrestrial infrastructure is non-existent or inadequate,
- Collaboration with terrestrial infrastructure providing a coverage extension,
- Enhancement of offered services i.e. with satellite-based GPS units and location-based services, end users benefit from real-time information; e.g., data on vehicle location, driver speeds, traffic peaks and employees work time.

The satellite network itself could comprise a GEO, MEO or LEO topology and it can typically cover V2I (Vehicle-to-Infrastructure) communications and potentially Vehicle-to-

Vehicle (V2V) communications assuming a star-like topology and supporting non-existent Vehicular Ad-hoc NETwork (VANET) links between mobile terminals.

By nature, a LEO-based system can be assimilated as a “network in the sky” due to the multiple Inter-Satellite Links that constitute a fully mesh network. Mesh LEO communications with single satellite hop could lead to an optimal routing. In this case, static strategies within the constellation are possible since the dynamic of topology is purely deterministic, but it can also be expected that actual dynamic routing based on-board processing and taking QoS as well as link loads into account will further be developed in the immediate future. In this way, a good candidate option is based on a pure IP routing, as demonstrated by the recent Cisco IRIS initiative [18]. In a mid-term horizon, their storage capacities are expected to increase and this could be fruitful for a high number of services. More generally, on board capabilities of LEO satellite represent good opportunities to process and/or store user data, as dictated by ICN-PSI features. LEO networks could not only act as (one of the) access networks but also host ICN functions, in particular, some name resolution (RV) and routing functions (TM) could be directly implemented on LEO satellites. A first step in the scenario would be that all ICN metadata are stored on-board which would only require limited storage and processing resources for the satellites. This results in a potential trade-off between ICN performance and processing load in LEO nodes (consequently this could affect applicability from a techno-economical perspective). In case more storage resources were available, but also with large link capacities, on-board caching would bring added QoS in reducing delay and possibly enhancing throughputs. Other data content-oriented functions (filtering, aggregation, etc) could also be advantageously integrated on-board. Last, LEO constellations result in significant decrease in propagation delay, which also directly impacts the global Quality of Experience (QoE).

Important technical aspects to optimize the performance of ICN over SatCom within the context of smart M2M transport services are *(a) hierarchical naming, (b) opportunistic content forwarding and caching and (c) publishers’ mobility.*

M2M data are collected from multiple mobile terminals, falling under different and varying scopes with heterogeneous metadata. The metadata are spatial and temporal with some timestamp/validity period. Efficient naming hierarchy must be used to facilitate the following: IO classification; Content prioritization (e.g. alerts such as safety or vehicle related conditions vs typical measurements); Scoping; etc. Since many M2M applications include transfer of multiple data from remote sources to service servers, handling all such data as a separate publication could pose scalability problems. Naming techniques are being investigated with respect to their ability to support IO aggregation. Typically, this would also involve aggregation in higher layers (e.g. resolution function, TM function, etc).

To maximize the energy efficiency, opportunistic content push-cache management techniques should be used. There are three main aspects of content storing that need to be addressed depending on the case: *(a) caching in the SatCom network nodes* (e.g. satellite gateway or LEO nodes); *(b) opportunistic content forwarding to terrestrial gateways in case of SatCom – terrestrial network co-existence*; *(c) caching in mobile terminals*; the latter perceived as an enhancement to the proposed VANET architectures. Specifically, a vehicle within the context of VANET will store content to relay to another vehicle. However, this function can be expanded to effectively make vehicles ICN-PSI nodes, i.e. nodes that can satisfy requests for content via cached copies.

In M2M scenarios, both subscribers and publishers are mobile. To reduce the convergence time expected for the RV network updated in case of publisher mobility, centralized RV functions are considered. Implications could arise due to publisher mobility between satellite and terrestrial networks.

Finally, on top of the generic ICN-PSI benefits, important additional benefits emerge from the *inherent support of Delay Tolerant Networking (DTN);* content originating from or directed to vehicles may be subject to unexpected delays caused by several parameters such as temporary loss of LOS due to blockage in an urban environment or by the random access scheme employed in the satellite return channel, especially in cases of increased traffic.

C. **Extended 4G Backhauling Scenario**

This scenario provides advantages in SatCom integration within the 4G/mobile Internet context given the aggressive video traffic growth levels in terrestrial mobile networks.

Integrating satellite in a terrestrial 4G infrastructure allows Service Providers to extend their services towards isolated areas and enhance network capabilities for more efficient video content delivery, such as Evolved Multimedia Broadcast Multicast (eMBMS), [17]. The satellite network itself could comprise typically a GEO or MEO topology. In some areas terrestrial repeaters (such as in systems based on DVB-SH and –NGH) could also be used to boost the satellite signal, e.g. for reception in urban areas (Hybrid satellite –LTE system).

Major ICN-PSI integration benefit arises from the *QoS based inter-component handover management.* Inter-component handovers in Long-Term Evolution (LTE), i.e. handovers between LTE Radio Access Network (RAN) nodes with different backhaul technologies, lead to performance degradation due to the high variation in delay [17]. Typically, the ICN-PSI TM function, which would handle a case of inter-component handover, can include QoS mechanisms in the path selection and data forwarding. Moreover, proactive/opportunistic forwarding and content caching support could assist further seamless handovers by forwarding and cashing content in the base stations with the satellite backhaul to prevent any noticeable connection changes in terms of delay lags to the mobile user. Seamless service continuity can be served by transmissions of stored content during the initial period after handover. On the other hand, delays occur also due to the handover signalling preparation delays over the satellite channel. This can also be mitigated in terms of active applications (i.e. on-going data delivery to mobile user) via cached content. Similar benefits of ICN-PSI can be perceived in the case of handovers from a satellite backhauled base station to another base station, again via the use of opportunistic caching. In this case, content delivery is unaffected from the RTT change (decrease) that could cause content to be delivered out of sequence, as the initial phase after handover can be addressed by transmissions of cached content from the base station(s).

As previously stated, joint optimisation of the ICN-PSI core functions with QoS support functions and satellite resources utilisation and Bandwidth-on-Demand mechanisms would further optimise integrated networks performance. For example, with respect to traditional backhauling services, the network operator(s) may here finely control(s) the delivery, caching and management of IO content as desired instead of relying on fixed capacity where some resources are unavoidably lost when the amount of traffic to transport is reduced. Individual access control can be applied, i.e. per object, per user or per user and terminal, billing (i.e. online or offline charging, object cost…), or even decision to route objects via the classical terrestrial LTE UTRAN, if available.

Finally, utilizing the satellite medium as a backhaul link deviates from acceptable security policies regarding core network security in cellular networks. However, within the context of ICN-PSI networking, both the content itself and the subscriber in the publish/subscribe paradigm are authenticated.

IV. Conclusion

In this paper, integration scenarios for satellite terrestrial FI networks based on the ICN paradigms are discussed. The main advantages of the satellite networks, namely wide-area coverage, inherent broadcast/multicast support and services ubiquity and resilience can be exploited to increase the gain in adopting ICN-PSI architectures for integrating satellite and terrestrial future networks. Inversely, capabilities of ICN-PSI architectures can resolve some important issues of satellite networks such as high propagation delay. Functionalities have been exemplified through three promising satellite/terrestrial FI network integration scenarios namely: (a) Hybrid Broadcast IPTV Scenario, which paves the way for SatCom integration within a Future Media Internet; (b) Smart M2M Transport Scenario, which paves the way for SatCom integration within a future Internet of Things; and (c) Extended 4G Backhauling Scenario, which paves the way for SatCom integration within the 4G/mobile Internet context given the aggressive traffic growth levels in terrestrial mobile networks.

Future work is dedicated to the functional validation of the presented scenarios with emphasis on the Hybrid Broadcast IPTV Scenario, where the employed validation tool integrates mainly two available testbeds (a) DVB-RCS/S2 satellite emulator *OpenSAND* [19] and (b) ICN-PSI emulator *Blackadder* based on PSIRP/PURSUIT [6, 7].

References

1. Jacobson V., Mosko M., Smetters D. and Garcia-Luna-Aceves, J. J., “Content-Centric Networking,” *whitepaper 2007*, URL: http://www.bibsonomy.org/bibtex/7f704918cca2b3d07940f216e218f6f4.
2. US PARC project CCN (Content-Centric Networking), URL: http://www.parc.com/work/focus-area/content-centric-networking/.
3. US NSF FIA project NDN (Content-Centric Networking), URL: http://www.named-data.net/.
4. Koponen T., Chawla M., Chun B.G., Ermolinskiy A., Kim K.H. , Shenker S., Stoica I., “A Data-Oriented (and beyond) Network Architecture”, SIGCOMM Comput. Commun. Rev. 37, vol 4, August 2007, pp.181-192, http://doi.acm.org/10.1145/1282427.1282402.
5. US project CNF (Cache-aND-Forward), URL: http://www.winlab.rutgers.edu/docs/focus/CNF.html/.
6. EC FP7 ICT project PSIRP (Publish Subscribe Internet Routing Paradigm), URL: http://www.psirp.org/.
7. EC FP7 ICT project PURSUIT (Publish Subscribe Internet Technology), URL: www.fp7-pursuit.eu/.
8. Fotiou N. , Polyzos G.C. , Trossen D. , “Illustrating a Publish-Subscribe Internet Architecture,” *Telecommunication Systems*, Springer, 2011, URL: http://www.springerlink.com/content/t6m0k022042088t5/fulltext.pdf.
9. EC FP7 ICT project COMET (COntent Mediator architecture for content-aware nETworks), URL: http://www.comet-project.org/ .
10. EC FP7 ICT project CONVERGENCE, URL: http://www.ict-convergence.eu/.
11. EC FP7 ICT project 4WARD, URL: http://www.4ward-project.eu/ .
12. EC FP7 ICT project SAIL (Scalable and Adaptive Internet soLutions), URL: http://www.sail-project.eu/ .
13. French National ANR project CONNECT (Content-Oriented Networking: a New Experience for Content Transfer), URL: http://anr-connect.org/ .
14. V. A. Siris, C. N. Ververidis, G. C. Polyzos, and K.P. Liolis, "Information-Centric Networking (ICN) Architectures for Integration of Satellites into the Future Internet," in Proc. 1st International IEEE-AESS Conference in Europe about Space and Satellite Telecommunications (ESTEL 2012), Rome, Italy, October 2012.
15. Clark D.D., Wroclawski J., Sollins W.R., and Braden R., “Tussles in Cyberspace: Defining Tomorrow’s Internet”, *IEEE/ACM Transactions on Networking*, vol. 13, no. 3, pp. 462-475, June 2005.
16. ESA project “SAMOS” (Satellite Machine-to-Machine Market Observatory Study), URL: http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=31097.
17. ESA project: ‘Benefit Analysis of Integration of MSS with Terrestrial Mobile Networks’, http://telecom.esa.int/telecom/www/object/index.cfm?fobjectid=31577/.
18. CISCO Internet Routing in Space (IRIS), URL: http://www.cisco.com/web/strategy/government/space-routing.html/.
19. URL: http://www.opensand.org/.