Network and Protocol Architectures for Future Satellite Systems

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Contents

Abstract

Since their conception, satellite communications have been regarded as a promising tool for all environments where the terrestrial infrastructure is limited in capacity or to take advantage of the multicasting/broadcasting capabilities inherent in satellite technology. Recent advances have seen satellite technology mature to a more prominent role in the telecommunications domain. In particular, the design of novel satellite payload concepts for Geostationary (GEO) satellite platforms, as well as renewed interest in Low Earth Orbit (LEO) satellite constellations have made the integration of satellite and terrestrial networks almost compulsory to ensure new services meet the requirements for high user-rate and quality of experience that could not be achieved using either of the two technologies independently. From this viewpoint, convergence of satellite and terrestrial technologies also requires considering the most recent trends in networking, with special attention being paid to the potential new architectures that have been recently proposed in the framework of Future Internet.

This monograph explores the main components of the scenarios above, putting particular emphasis on the networking aspects. To this end, novel protocols such as Multi Path TCP (MPTCP) and networking trends such as Information Centric Networking (ICN) are explored by demonstrating their applicability in some scenarios that deploy both satellite and terrestrial segments. Particular attention is given to smart gateway diversity schemes which advocate the use of sophisticated multi-path transmission schemes to exploit the multi-homing features offered by present day devices. The second part of the monograph is dedicated to content-based networking, which is becoming increasingly popular driven by the pervasiveness of the Internet in everyday life. In this regard, applications to satellite communications are illustrated and the technical challenges to be further addressed are highlighted.

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List of Abbreviations and Acronyms

ACK Acknowledgment

ACM Adaptive Coding and Modulation

AeNB Aerial eNB

AIDA Agile Integrated Downconverter Assembly

AIMD Additive Increase Multiplicative Decrease

AMR Automatic Meter Reading

AP Access Provider

ARQ Automatic Repeat reQuest

AS Autonomous System

BDP Bandwidth-Delay Product

BER Bit Error Rate

BFN Beam Forming Network

BH Beam Hopping

BIC Binary Increase Congestion control

BSM	Broadband Satellite Multimedia
CCSDS	Consultative Committee for Space Data Systems
CDN	Content Delivery Networks
CP	Content Provider
CR	Content Router
CRA	Contention Resolution ALOHA
CRC	Cyclic Redundancy Check
CRDSA	Contention Resolution Diversity Slotted ALOHA
cwnd	congestion window
DAMA	Demand Assignment Multiple Access
DPI	Deep Packet Inspection
DRA	Direct Radiating Array
DSA	Diversity Slotted ALOHA
DTN	Delay/Disruption Tolerant Network
EIRP	Effective Isotropic Radiated Power
EPC	Evolved Packet Core
ESA	European Space Agency
FAFR	Focal Array Fed Reflector
FCFS	First Come, First Served
FEC	Forward Error Correction
FIFO	First In, First Out
FN	Forwarding Node

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FTP File Transfer Protocol

GEO Geostationary Orbit

GFP Generic Flexible Payload

GW Gateway

HAP High Altitude Platform

HAP High-Altitude Platform

HL-BFN High level BFN

HPA High Power Amplifier

HTS High Throughput Satellite

HTS High Throughput Systems

HTTP Hypertext Transfer Protocol

ICN Information Centric Networking

IMUX Input Multiplexer

IoT Internet of Things

IP Internet Protocol

IRIS IP Routing in Space

IRSA Irregular Repetition Slotted ALOHA

ISL Inter-Satellite Link

ISL Inter-Satellite Links

ISP Internet Service Provider

LEO Low Earth Orbit

LFU Least Frequently Used

LL-BFN Low level BFN

LNA Low Noise Amplifier

LRU Least Recently Used

M2M Machine-to-Machine

MAC Media Access Control

MFPB Multi Feed Per Beam

MPA Multi-Port Amplifier

MPLS Multi-Protocol Label Switching

MSS Maximum Segment Size

NACK Negative Acknowledgment

NASA National Aeronautics and Space Administration

NC No Caching

NCC Network Control Center

NDN Named Data Networking

NFV Network Function Virtualization

NMC Network Management Center

NRS Name Resolution Service

OBP On-Board Processor

PBR Policy-Based Routing

PEP Performance Enhancing Proxy

PER Packet Erasure Rate

PER Packet Error Rate

PLA	Packet Level Authentication
PLMU	Portable Land Mobile Unit
PLR	Packet Loss Rate
PSI	Publish-Subscribe Internetworking
QoE	Quality of Experience
QoS	Quality of Service
RA	Random Access
RASE	Routing and Switching Equipment
RENE	Rendezvous Network
RLNC	Random Linear Network Coding
RN	Rendezvous Nodes
RTT	Round-Trip Time
SA	Slotted ALOHA
SACK	Selective Acknowledgment
SCACE	Single Channel Agile Converter Equipment
SC-ARQ	Selective-Coded ARQ
SCPS-TP	Space Communications Protocol Specifications - Transport Protocol
SDN	Software Defined Networking
SFPB	Single Feed Per Beam
SIC	Successive Interference Cancelation
SNACK	Selective Negative Acknowledgment
SNO	Satellite Network Operator

SR-ARQ Selective-Repeat ARQ

SSPA Solid State Power Amplifier

STP Satellite Transport Protocol

SVNO Satellite Virtual network Operator

TCP Transmission Control Protocol

TCP Transmission Control Protocol

TM Topology Manager

TP Transit Provider

TWTA Travelling Wave Tube

UAV Unmanned Aerial Vehicle

V2I Vehicle-to-Infrastructure

V2V Vehicle-to-Vehicle

VANET Vehicular Ad-Hoc Network

1

Introduction

1.1 Modern Satellite Systems

Ever since the inspirational and visionary article from Arthur L. Clark in 1945[1], satellite communications have become more and more part of our everyday life, as they counted a large number of applications such as TV broadcasting, Earth observation, navigation-assisted vehicle, support to disaster situations, just to cite a few. As a result of the increasing number of applications, the satellite academic and industrial community has put quite some effort in developing new platforms able to offer more capacity, so as to enable richer services. From this standpoint, it also worthwhile to mention the proliferation of communication standards developed to ensure interoperability between different satellite systems, such as those elaborated in DVB and then ETSI standardisation fora.

In the continuous technological progress observed in the last 20 years, a prominent role has been played by the communication paradigm switch from single-beam to multi-beam, in order to provide

[1] "Extra-Terrestrial Relays – Can Rocket Stations Give Worldwide Radio Coverage?", Wireless World, October 1945.

larger data-rates, though at cost of increased interference to be contrasted by suitable mitigation techniques. This revolution has led to rethinking of the overall satellite system, for what concerns both the terrestrial and the space segment. As to the latter, classical bent-pipe satellites have been more often accompanied by on-board processing ones, thus broadening the optimisation space to be considered during the system design. In particular, the advent of satellite payload flexible in power, frequency or time (beam-hopping) introduced a new dimension in the resource allocation problem across the entire satellite system, hence facilitating to more efficiently meet the capacity requests of users.

Another key technological advance has been offered by the introduction of LEO constellations in early 2000's that initially turned out be unsuccessful and eventually becoming again an appealing concept as proven by the recent launch of *mega-constellations*, supposed to be able to better serve users with larger data rates and lower access latency, thus possibly resulting a direct competitor to terrestrial technologies. In this perspective, the advent of free space laser optics too signed an important step in revolutionizing the design of future satellite systems, in that they can offer much larger data rates that those available with radio-frequency counterpart, although the performance of the former can be severely hampered by adverse conditions such as clouds.

In spite of the ever-increasing effort made by the satellite community to evolve the operational concept of satellite communication, it is however immediate to grasp that satellite technology cannot be ultimate vehicle to support telecommunications in all its forms. On the contrary, Internet has been typically transported over terrestrial infrastructures and its predominance will even increase, taking also advantage of the increasing penetration of mobile devices in everyday life. Nevertheless, the ideal compromise between the two competing worlds consists in the convergence in a unique ecosystem therefore able to meet all users' demands on a full anytime-anywhere scale. To make the integration exercise meaningful for both worlds, satellite systems has undergone important enhancements from a communication viewpoint, aimed at increasing the overall offered capacity, as testified by the experimentation of Extra High Frequency (EHF) frequency bands and the related use of diversity techniques to efficiently support gateway handover events and still to attain very high level of system availability. Further to this, new networking paradigms have been explored to let the satellite technology become an appealing candidate for integration with terrestrial network. In the perspective, an important role is also being played by the current reshaping of Internet delivery infrastructures that are more and more tailored around the content rather than the traditional *source-destination* philosophy. From this standpoint, the promotion of Information Centric Networking paradigms represents an important shift in the networking paradigm used so far and also introduces some important features to ease integration between heterogeneous technologies.

All in all, these are the main components that are considered instrumental to develop a more modern vision of satellite systems, which are destined to seamlessly integrate with terrestrial infrastructure in the near future.

1.2 Overall Framework

This monograph surveys the most recent advances in satellite communication technology, putting special emphasis on the networking concepts that are expected to enable seamless integration of satellite and terrestrial segments. In this view, it guides the readers along a path ideally connecting the current trends in satellite payloads design and the related implications in the design of resource allocation schemes with the modern protocol architectures that have emerged during the last years in the terrestrial domain. The logical decomposition of this picture therefore consists in three main elements to which specific sections are reserved, starting from a system view of satellite environments to conclude with an architectural perspective. In this light, the monograph is conveniently structured as follows:

- Section 2 illustrates the main concepts behind the design of flexible and beam hopping payloads, giving also insights into how more efficient resource allocations should be implemented. The overall discussion provides a system view analysis of satellite systems, providing a possible outlook on the design of next generation satellite systems and consequent enabling of new services.

- Section 3 approaches the trend of network convergence for satellite and terrestrial segments, delving the potentials of multi-path communication protocols. In this respect, overview of the Multi Path TCP protocol (MPTCP) is given and its application combined to networking coding in heterogeneous terrestrial-satellite links is illustrated.

- Section 4 is the natural follow-up of the discussion about integrated satellite and terrestrial network given in Section 3, here giving an architectural perspective. In particular, the recently conceived concept of Information Centric Networking (ICN) is applied to illustrate the advantages in terms of seamless network integration offered by some of its features.

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