Status of Telecommunication in W-band and possible applications: satellite broadband connection and networks of mobile phones

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Satellite Broadband Connection

- Motivation
- Challenges
- SoA and on-going activities
Motivation

The new generation of High Throughput Satellite is based on the use of Ka-band and multi-beam coverage (in 500MHz of bandwidth for the user terminal, the total throughput can go beyond 70Gbps in case of KA-SAT.)

The demand for more capacity per home will continue to increase

For satellite systems to remain attractive and keep up with the expectations of consumers, next generation HTS will be designed:

- to deliver higher and higher capacity (terabit?)
- with a quality comparable to FTTH and
- at the current consumer price.

Need to go towards higher frequency bands to increase the available bandwidth
Which frequencies bands we are talking about?

**KA-BAND**

![Diagram of Ka-band Frequency Spectrum in ITU Region 1]

*Illustration of Ka-band Frequency Spectrum in ITU Region 1*

*2.5 GHz uplink and 2.5 GHz downlink*
Which frequencies bands we are talking about?

**Q/V-BAND**

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Illustration of **Q/V-band** Frequency Spectrum in ITU Region 1

5GHz in uplink and 5GHz in downlink with some restrictions...
Currently, the use of beyond Ka-band frequencies ONLY for the feeder links, is an interesting option as it would overcome the problems related to the still high costs for user terminal at such high frequencies and it would allow a maximization of both the terminal spectrum (with a consequent increase of the system capacity) and the gateway spectrum (with a consequent minimisation of the number of gateways and the associated costs).

In Q/V band there are already ASI/ESA on-going experimental missions (Alphasat TDP#5 ‘Aldo Payload’).

The next step is W-band!
Motivation

Specific Attenuation for Atmospheric Oxygen and Water Vapour

W-band 70-110 GHz

5GHz in uplink and 5GHz in downlink can be made available
Well known challenges when going to such high frequency bands are:

- Channel propagation impairments (in particular rain and clouds attenuation);
- Need for Propagation Impairments Mitigation Techniques (PIMT);
- Power generation, in particular broadband high power amplifiers;
- Non linear behaviour of HPA;
- Phase Noise;
- Unavailability on energy-efficient high resolution A/D converters for bandwidth of several GHz.
The main objective of the telecommunication experiments of TDP5 mission is to demonstrate the feasibility of broadband satellite communications in Q/V band, optimizing and assessing, over-the-air, the performance of the indispensable adaptive access techniques.

- Alphasat was successfully launched on July 25, 2013, from the European Spaceport in Kourou (French Guiana) via the Ariane 5 rocket;
- IOT phase completed at the end of 2013;
- Scientific experiments started at the beginning of 2014
Status of the Art and on-going Activities

TDP5 System Architecture

Ground Network

- Tito Tx/Rx Station
- Spino D’Adda Tx/Rx Station
- Graz, Tx/Rx Station

Experimental Control Centre of Propagation Exp. (Politecnico of Milan)
Experimental Control Centre of Communication Exp. (University of Rome Tor Vergata)
Mission Control Centre
ESA TECO Interface
Inmarsat Satellite Control Centre
Status of the Art and on-going Activities

Communication Experiment Payload
DAVID (Data and Video DAAta and Video Interactive Distribution) Project

“Small Missions for Science and Technology” Programme of the Italian Space Agency

Pioneering the use of W-band for an experimental collection of high data volume

Phase B completed (2003)
Status of the Art and on-going Activities

WAVE (W-band Analysis and VErification) Project (2008)

Feasibility Study for Telecommunication Payloads operating in the W band (Phase A & A2).
Together with the design of the GEO Mission the following studies have been carried out:

- **HAP** (High Altitude Platform) **demonstrative payload** aiming to provide a first atmospheric channel characterisation in W band → Aero-WAVE Project;

- **small LEO payload** aiming to perform the first in-orbit test of W band hardware → IKNOW (In-orbit Key test and validation Of W-band) Project;

- LEO payload, a pre-operative mission with the same objectives of the GEO payload with a Ground-LEO-Ground link type → WAVE-LEO Mission;

The feasibility study provided a complete W band P/L development line.
Main Goals:

- **To provide a first atmospheric channel characterisation** by transmitting a beacon at ~95 GHz and data at ~94 GHz;

- **Hardware payload designed using COTS components**, already existing and employed for terrestrial applications (e.g. radar); development time will be short and costs relatively low.
Main Goals:
• To gather a measurements dataset related to the signal propagation in W band, in order to develop a significant statistics on additional attenuation contributions (like rain and clouds); testing of W-band communication links.

• To test W band hardware and space qualification methodologies, so getting first results to be used for future missions (LEO and GEO payload).
Status of the Art and on-going Activities

WAVE – IKNOW Payload full configuration
WAVE – IKNOW Payload full configuration

The full payload configuration foresees for the receiving section the reception of a W band modulated signal to be used both to derive BER measurements and to carry out RF power measurements in uplink.

Moreover, the addition of an on-board radiometer for data-gathering is foreseen as optional.

The transmitter chain is basically composed of a frequency generator which generates a modulated signal with Split-Phase (SP) Manchester-coded BPSK modulation, an up-conversion stage, a SSPA and finally a beacon generator.
The future beyond Ka-band satellite telecommunication applications will exploit the large bandwidth availability, that turns into a high system capacity, and the antenna reduced dimension (both on-board the satellite and on the user terminal).

The following future applications have been identified:

- **Fixed Services:**
  - Broadband Multimedia Satellite Systems (BMSS), feeder link in Q/V/W band, service/user link in Ka band
  - Backbone Connectivity Network (BCN);

- **Mobile Services**, in particular aeronautical ones (including UAV and HAPs);

- **Space Services**, in particular inter-satellite link for data relay;
Network for Mobile Applications

- Past activity on W-band for terrestrial links
- Why W-band for terrestrial links?
- State-of-the-Art
- Overview of the research activity for its application to mobile communications
Multi-gigabit LOS secure communication system in W band

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<td>UWB RADIO INTERFACE</td>
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<td>• Use of “imperfect” ADC</td>
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<td>• Low “sensibility” to hostile jamming signals</td>
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W-band Transportable User Terminal (used for operation and soldiers health/status data gathering)

High data-rate bidirectional W-band Pencil-beam (few kms)

Short-range soldiers health/status data

Theatre of Operation

W-band Pencil-beam (few kms)

Jamming signals do not affect UWB radio link

Hostile jamming signal generator
Propagation experiment for terrestrial links
WHY W-band in terrestrial links?

Potential to offer bandwidth delivery comparable to that of fiber optics, but without the financial and logistic challenges of deploying fiber.

Currently the bandwidth available to each major wireless provider 200 MHz across all of the different cellular bands of spectrum available to them.

The band between 70 GHz and 90 GHz (also referred to as E-Band) have been allocated (since 2003) for the purpose of wireless communication in the public domain (in US and Europe).
Ultra high capacity (1-3Gbps) wireless point-to-point (LOS) communications are commercially available in US on the E-band.

**Examples of available products**

Full Duplex providing 1000Mbps upstream and downstream

Adaptive Modulation QPSK/8PSK/16/32/64QAM

Link distances up to 8km at 99.995% availability

**Applications**

- 4G/LTE/WiMAX macro-cell backhaul for access and aggregation
- “Last Mile” fiber extension for enterprises
- Temporary high capacity links for disaster recovery
- LAN/WAN extensions for private/enterprise networks
Overview on mobile communications

From 4G to...

**LTE** radio access technology has been developed by the 3GPP to offer a fully 4G-capable mobile broadband platform

**LTE main characteristics:**
- OFDM-based
- Scalable transmission bandwidth up to **20 MHz**
- Exploitation of advanced multi-antenna transmission
- Peak mobile data rates: **100 Mbps**

**LTE-Advanced:** theoretically 1Gbps peak data rate
Main foreseen features:
- peak data rates higher than 10 Gbps
- cell edge data rates higher than 100 Mbps
- latency less than 1 ms for local area networks
- wide scale small cell (heterogeneous) deployments
- fast interference coordination and cancellation
- Cognitive Radio Networks (CRNs)
- Self Organizing Networks (SONs)
- mmw
- high-gain steerable antennas (both a mobile and BS).
Overview on mobile communications

...5G

Mm-wave frequencies, due to the much smaller wavelength, may exploit polarization and new spatial processing techniques, such as massive MIMO and adaptive beamforming.

Antenna arrays with a few hundred antennas, simultaneously serving many tens of terminals in the same time-frequency resource.

Possible BS antenna configurations
For Massive MIMO
Overview on mobile communications

…5G

Challenges related to the exploitation of MMV bands

➢ Atmospheric attenuation?

➢ Building penetration?

➢ Reflections? (and hence, possibility to effectively use multipath reception for spatial multiplexing/diversity)

Channel characterization is fundamental
we are in the early phase of the channel characterization
Overview on mobile communications

...5G

Some preliminary study on the following mmw frequency bands:
The 28 GHz and 38 GHz bands are currently available with spectrum allocations
of over 1 GHz of bandwidth.
Originally intended for Local Multipoint Distribution Service (LMDS) use in the
late 1990's, these licensees could be used for mobile cellular as well as
backhaul.

Rain attenuation?
Over 200m (typical cell size)
Only 7 dB/km of attenuation is expected
due to heavy rainfall rates of 1 inch/hr for cellular propagation at 28 GHz, which
translates to only 1.4 dB of attenuation over 200 m distance.

No additional losses

THEODORE S. RAPPAPORT, SHU SUN, RIMMA MAYZUS, HANG ZHAO, YANIV AZAR, KEVIN
WANG, GEORGE N. WONG, JOCELYN K. SCHULZ, MATHEW SAMIMI, AND FELIX GUTIERREZ
“Millimeter Wave Mobile Communications for 5G
Cellular: It Will Work!” IEEE Access, Feb. 2013
Overview on mobile communications

...5G

Some preliminary study on the following mmw frequency bands:

Rain attenuation at **70GHz**
Heavy rain (25mm/hr): 10dB/km

Cell size: 200 meters

- Heavy Rainfall @ 73 GHz
  2 dB attenuation @ 200m
- Heavy Rainfall @ 28 GHz
  1.2 dB attenuation @ 200m

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building penetration of mm-waves will be difficult for outdoor transmitters, thus providing high isolation between outdoor and indoor networks.

Outage in urban environment:
- At 28 GHz in cellular measurements the estimated outage probability is 14% for all RX locations within 200 meters.
- At 73 GHz the outage probabilities are 16% and 17% within 216 meters cell size for backhaul and cellular access scenarios, respectively.

Not always rich-scattering environment but this is not a limit for massive MIMO (the tiny wavelengths allow for dozens to hundreds of antenna elements to be placed in an array on a relatively small physical platform at the base station).