Beam Hopping in DVB –S2X

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1. Context and requirements for Beam-Hopping
DVB-S2 to S2X

- DVB-S2: March 2005, EN302307
- DVB-S2X: October 2014, EN… part 2
- Main improvements were
  - More MODCODs -> Higher dynamic range (VLSNR, 256APSK), smaller gaps between MODCODs
  - Time slicing (new header) -> manageable complexity
  - Lower roll off -> more efficient BW use
  - Scrambling -> Tighter beams (spot beams)
  - Channel bonding -> statistical mux
New requirements

• The S2X standard was all very well but:
  • The standard did not easily allow for dynamic reallocation of resources.
  • Satellite capacity tended to be fixed at launch
    • Satellite throughput limited by amplifiers and TWTs
  • Some areas (cells) required much more capacity than others.
  • More flexibility in throughput allocation was required.

Some cells require more capacity
New Technologies

• Satellite technology moved on.
  ▪ Ferrite switches, regenerative payloads, electronically steerable antennas…
  ▪ Bandwidth could now be allocated to each cell as a function of time.
• -> BEAM-HOPPING
  ▪ Studies showed that 20% improvement in unmet demand
• In order to exploit the potential the DVB-S2 standard had to be upgraded again.
DVB-CM-S and Beam-Hopping

- In October 2017 the CM agreed that CM-S should work on commercial requirements
  - amending the DVB-S2X specification to include optimisations for beam-hopping.
  - chairmanship of Thomas Wrede.
- In October 2018, the DVB-S-CM published a set of commercial requirements for Beam-Hopping (DVB-S CM-S0050).

- The main requirements were:
  - Enable a wider range of applications
    - IOT, flight connectivity, Consumer broadband, maritime, IP trunking.
  - Evolution, not revolution
  - Technical requirements:
    - high illumination ratios (period on vs off), single or multiple carriers per beam, low power, low latency, GEO, MEO, LEO…
  - Interoperability between equipment providers and service providers
  - Holistic approach
    - updating linked standards where appropriate: SI, GSE, RCS
DVB-TM-S and Beam-Hopping

- In June 2018 DVB-TM-S, under the chairmanship of Alberto Morello, was mandated to work on the new standard
- Over to Nader…
2. Beam Hopping Definitions
Basic Definitions

- A **Beam** is a directional Radio Signal Transmitted from a Satellite **Transmission Channel** towards a **Cell**

- At any given time only one **Cell** within a **Cluster** is illuminated.

- A **Transmission Channel** is serving one **Cluster**

- The **Beam Hopping Time Plan** determines cell **dwell times** and the **BH Cycle** within a cluster.
Beam Hopping Concept

- Satellite Gateway to User Terminal Forward Link:
  - **Time-multiplexing** data traffic of multiple cells within each Cluster
  - Typically a **Wideband Transmission**
  - A satellite beam switching (hopping) to different Cells

- Reconfigure according to changing traffic demands and user locations

- Applicable also to the Return Link
R&D Activities

Proof of Concept:
- Beam Hopping Emulator for Satellite Systems:
  https://artes.esa.int/projects/behop

System Studies:
- Beam Hopping Techniques in Multi-Beam Satellite Systems
  https://artes.esa.int/projectsbeam-hopping-techniques-muti-beam-satellite-systems-eads-astrium
  https://artes.esa.int/projectsbeam-hopping-techniques-multibeam-satellite-systems-indra-espacio
Expected Benefits

- Capacity increase by up to +15%
- Reduction of the unmet and excess capacity by 20%
- Better flexibility in allocating capacity to the beams with variable traffic demand
- Lower DC power consumption
Air Interface Technical Overview

A sketch of the Physical Layer Changes:

1. Before each burst, introduce a **TRAINING SEQUENCE** (Preamble) to allow receiver synchronization:

2. Between bursts, introduce a **IDLE-SEQUENCE** to allow satellite beam switching: Postamble
A Generic Beam Hopping Model

A beam hopping transmission channel may switch:

- the carrier frequency,
- carrier bandwidth and
- number of carriers (per cell)
3. Beam Hopping System Scenarios
Satellite systems:
- Multi-beam GEO satellites (HTS, VHTS)
- Medium Earth Orbit Satellites
- Low Earth Orbit constellations

Potential applications:
- Broadband bi-directional traffic (B2B, B2C)
- Maritime, Airborne In-Flight Communications
- VoIP (low delay and jitter),
- IoT (low power consumption of user terminal)
Beam Hopping Operation Strategies

Prescheduled BH cycles:
Regular and periodic illumination pattern

Traffic Driven BH:
Non-periodic illumination pattern (Beam Hopping Time Plan), driven by traffic profile.
Traffic Driven Beam Hopping

Point and Shoot
Every packet to a user is directly transmitted

Quality of Service
More Flexibility to minimize Scheduling Delay (higher QoS)

Fixed Container Strategy
Fixed size transmission packet. Transmitted when filled up.

Non-Periodic Beam Hopping
Beam Hopping Channel Model

Performance Evaluation:
- Acquisition Mode
- Tracking Mode

Performance Metrics:

**Acquisition Modes**
- Mean Acquisition Time
- Estimation Statistics of Sync. Parameters

**Tracking Mode**
- Frame Error Ratio
- Header Decoding Ratio

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Acquisition</th>
<th>Tracking</th>
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<tbody>
<tr>
<td>Carrier Frequency Offset</td>
<td>340 kHz</td>
<td>[1 kHz +1kHz]</td>
</tr>
<tr>
<td>Carrier Symbol Rates</td>
<td>57.526 MBaud</td>
<td>57.526 MBaud</td>
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<tr>
<td>Symbol Rate Offset</td>
<td>15 ppm</td>
<td>1 ppm</td>
</tr>
<tr>
<td>Timing Offset</td>
<td>Uniformly distributed in [-Ts/4 +Ts/4]</td>
<td>Uniformly distributed in [-Ts/4 +Ts/4]</td>
</tr>
<tr>
<td>Initial Phase Offset</td>
<td>Uniformly distributed in [-π +π] interval</td>
<td>Uniformly distributed in [-π +π] interval</td>
</tr>
<tr>
<td>SNIR</td>
<td>-9.5 dB</td>
<td>-9.5 dB, 0 dB, 10 dB</td>
</tr>
</tbody>
</table>
4. General description of new Formats for Beam hopping
DVB-S2X Waveforms for Beam Hopping Support

• Based on Annex E superframes
  ▪ Supports multibeam operation and future waveforms
  ▪ Variable superframe length to provide required granularity for beam-hopping operation
• Format 5: Periodic BH and VLSNR
  ▪ Strong preamble and header protection for cold acquisition and operation at SNR>-10dB
  ▪ Enable fragmentation of frames
• Format 6: Traffic Driven BH and VLSNR
  ▪ Long preamble to strengthen acquisition
  ▪ Protection Level Indicator (PLI) to enable VLSNR support
  ▪ No Fragmentation
• Format 7: Traffic driven, SNR>-3dB
  ▪ Reduced overhead for higher SNR scenarios

Approved by DVB
October 2019
Annex E Superframe - Concept

- WH coded SOSF and Pilots – Ref Scrambler
  - Identify and estimate adjacent cell interference
- Fragmentation enabled by SFH pointer
- VLSNR Support by
  - VLSNR modcods
  - variable header Protection Level by an Indicator (PLI)

Superframe Length = 612540 symbols

Payload (90 symbols)
Pilot group (36 symbols)

SOSF: Start of Super-Frame
SFFI: Super-Frame Format Indication
SFH: Superframe Header
PLH: Physical Layer frame Header
DVB-S2X Waveforms for Beam Hopping Support
New Annex E Superframe Formats

**Format 5**
Periodic BH
VLSNR

**Format 6**
Traffic Driven BH
VLSNR

**Format 7**
Traffic Driven

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SOSF: Start of Super-Frame
SFFI: Super-Frame Format Indication
SFH: Superframe Header
EHF: Extended Header Field
PLI: Protection Level Indication
PA-Seq: Postamble sequence

Beam Switching time

Superframe Length = SFL symbols

Payload CU (90 symbols)
Pilot group (36 symbols)
Superframe Format 5 – Operation Cases
Full Flexibility to the System Designer

Single superframe
All terminals on a similar SNR level

Multiple Superframes
Terminals of different SNR levels

Very short dwells
Frame carried among hops

Multi Carrier operation
Variable superframe length per carrier
Grid Operation

- Hops take place only at an integer multiple of a basic time unit (the grid points)
- Advantages:
  - Ensure alignment of SF among beams
  - Reduces burst acquisition and time and increases acquisition reliability
- Disadvantages
  - Reduces flexibility in the choice of dwell time per cell
5. Simulation and Analysis
Purpose of Analysis and Simulation

Burst Reception Performance

• Robust cold acquisition
  ▪ Detection of the signal at SNR > -10dB
  ▪ Short acquisition time
  ▪ Essential estimation of timing, frequency, phase and SNR

• Robust cycle time learning (for the case of periodic beam hopping)

• Correct header decoding at SNR > -10dB

• Minimal degradation in performance
  ▪ FER at tracking mode
Burst Acquisition - Results

- False Alarm and detection rates < $10^{-6}$
- Acquisition within a single hop time
- Parameter Estimation:
  - Time: 0.06 symbol time
  - Frequency: $10^{-5}$ symbol rate
  - SNR: 0.7 dB
Information Detection- Results

SFH Detection (Format 5): WER<10^{-7}

SNR degradation 0.07dB at VLSNR
Reference to continuous case

PLI Detection (Format 6): WER<10^{-7}

SNR degradation 0.02dB at High SNR
Reference to continuous case
6. Maintenance, further work and closing remarks
The DVB-TM-S also took the opportunity to solve some problems which had been observed in the DVB-S2X:

- Co-existence of VLSNR frames with standard S2X frames.
  - Problem: Instability in transition zone between VLSNR and S2X MODCODs
  - Solution: Dummy Synchronisation Frame
    - Same correlation structure as per new annex-E format 6.
  - VLSNR frames can now coexist in the same carrier as S2X frames thanks to DSF.
Continuity

- Alberto Morello retired from DVB-TM-S in December 2019
- Replaced by Vittoria Mignone (welcome).
  - The work continues
Further work

- Updating linked standards.
  - RCS, GSE, SI tables
  - To support Beam-Hopping
- V&V: Verification and Validation
  - Test patterns
  - Common models
  - File exchange
    - Text based
    - Human and machine readable
Concluding remarks

• The DVB-S standard now includes Beam-Hopping

  ▪ **All of the commercial requirements for Beam-Hopping have been met.**

• This has been an excellent cooperation between multiple companies and institutions. We can be confident that we have a standard that is robust, forward looking and well maintained.
Questions and Answers