LEAP AHEAD

INBUILT CONVERGENCE: A Review of Emerging 3GPP and ATSC 3.x Terrestrial Broadcast Offerings

May 13-14, 2020
Agenda

• PHY Layer Convergence
  • Service Objectives
  • OFDM Numerology
• Standards Evolution
• Performance Considerations
• PHY Configurations
• Deployment Scenarios
• System Observations
• Concluding Remarks
Service Objectives
OFDM Numerology

\[ \Delta f = \frac{BW}{N_{FFT}} = \frac{1}{T_{FFT}} \]

\[ v_D \propto c \cdot \frac{\Delta f}{f_c} \]

\[ T_{FFT} = \frac{N_{FFT}}{f_s} = \frac{1}{\Delta f} \]

\[ ISD = c \cdot T_{GI} \]

\[ BW = f_s \]

\[ T_{GI} \]

\[ T_{FFT} \]

\[ \Delta f: \text{subcarrier spacing} \rightarrow \text{Doppler Tolerance} \]

\[ f_c: \text{carrier frequency} \]

\[ \text{throughput} \leftarrow \text{ModCod} \rightarrow 1/\text{range}_{SNR} \]
<table>
<thead>
<tr>
<th>Standard</th>
<th>DVB</th>
<th>DVB</th>
<th>DVB</th>
<th>ATSC</th>
<th>3GPP</th>
<th>3GPP</th>
<th>3GPP</th>
<th>3GPP</th>
<th>3GPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release</td>
<td>T</td>
<td>T2</td>
<td>NGH</td>
<td>3.0</td>
<td>9 - eMBMS</td>
<td>14 - FeMBMS</td>
<td>16 ~ 5G Broadcast</td>
<td>17 ~ 5G-NR (TB)</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Q1 1997</td>
<td>Q3 2009</td>
<td>Q2 2013</td>
<td>Q3 2016</td>
<td>Q1 2010</td>
<td>Q2 2017</td>
<td>Q1 2020</td>
<td>Q1 2021+</td>
<td></td>
</tr>
<tr>
<td>Service Objectives</td>
<td>Fixed reception to rooftop antennas</td>
<td>Increased Capacity, ruggedness, flexibility</td>
<td>Hybrid (terrestrial with satellite) broadcast to handheld terminals</td>
<td>Increased spectral efficiency, added mobility, improved resiliency for indoor rx</td>
<td>Enables Broad-/multicast alongside 4G LTE unicast</td>
<td>4G LTE based. Larger SFN ISDs. Receive-only-mode which enables free-to-air reception, i.e. SIM free</td>
<td>Based on LTE</td>
<td>Added subcarrier spacings for terrestrial broadcast in new bands based on 5G-NR</td>
<td></td>
</tr>
<tr>
<td>Features</td>
<td>Uniform constellations</td>
<td>Rotated constellations</td>
<td>Non-uniform constellations</td>
<td>Uniform constellations</td>
<td>Uniform constellations</td>
<td>Uniform constellations</td>
<td>Uniform constellations</td>
<td>Uniform constellations</td>
<td></td>
</tr>
<tr>
<td>Variable GI duration</td>
<td>New FEC, high order mod</td>
<td>4D rotated constellation</td>
<td>Higher mod order</td>
<td>40/60 unicast/MBMS</td>
<td>Cell Acquisition SF (CAS)</td>
<td>Uniform constellations</td>
<td>Uniform constellations</td>
<td>Uniform constellations</td>
<td></td>
</tr>
<tr>
<td>Multiple (2) subcarrier spacings</td>
<td>Additional subcarrier spacings</td>
<td>Hierarchical modulation for local service insertion</td>
<td>multiplexing arrangement including LDM</td>
<td>Added subcarrier spacings (7.5, 1.25) KHz</td>
<td>Added subcarrier spacings (2.5, 0.37) KHz</td>
<td>Even more subcarrier spacings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FFT Sizes</td>
<td>2K, 8K</td>
<td>1K, 2K, 4K, 8K, 16K</td>
<td>1K, 2K, 4K, 8K (extended)</td>
<td>16K (extended)</td>
<td>8K, 16K, 32K</td>
<td>2K, 4K</td>
<td>2K, 4K, 24.6K</td>
<td>2K, 4K, 12.3K, 24.6K, 41.5K</td>
<td>9.2K, 12.3K, 15K, 30K, 24.6K, 49.2K, 60K, 73.8K, 141.3K, 147.5K, 295K</td>
</tr>
<tr>
<td>Modulation formats</td>
<td>QPSK, 16/64QAM</td>
<td>QPSK, 16/64/256QAM</td>
<td>QPSK 2D/4D rotated, 16/64QAM 2D rotated, NU-64QAM 2D rotated, 256QAM, NU-256QAM</td>
<td>QPSK 16/64/256QAM NUC, 1024/4096QAM</td>
<td>QPSK 16/64/256QAM</td>
<td>QPSK 16/64/256QAM</td>
<td>QPSK 16/64/256QAM</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>Scattered Pilots</td>
<td>8% of total</td>
<td>1%, 2%, 4%, 8% of total</td>
<td>DX = [3, 4, 6, 8, 12, 16, 24, 32]</td>
<td>NY = [2, 4]</td>
<td>DX = [3, 4, 6, 8, 12, 16, 24, 32]</td>
<td>NY = [2, 4]</td>
<td>(DX, DY) = (3, 7), (3, 6), (1, 8), (2, 4), (3, 2)</td>
<td>DMRS</td>
<td></td>
</tr>
<tr>
<td>Continual Pilots</td>
<td>2.6% of total</td>
<td>0.35% of total</td>
<td>CP1, CP2, CP3, CP4, CP5</td>
<td>CP32, CP16, CP8</td>
<td>CP32, CP16, CP8</td>
<td>4.8% of total</td>
<td>7.1% of total</td>
<td>PT-RS</td>
<td></td>
</tr>
<tr>
<td>Error Correction</td>
<td>Convolutional Coding + Reed Solomon</td>
<td>LDPC + BCH</td>
<td>LDPC + BCH</td>
<td>LDPC + [CRC or BCH]</td>
<td>Parallel Concatenated Convolutional Coding</td>
<td>Parallel Concatenated Convolutional Coding</td>
<td>Parallel Concatenated Convolutional Coding</td>
<td>LDPC, Polar</td>
<td></td>
</tr>
<tr>
<td>GI Durations</td>
<td>1/4, 1/8, 1/16, 1/32</td>
<td>1/4, 19/256, 1/16, 1/32, 1/128</td>
<td>1/32, 1/16, 1/8, 1/4, 1/128, 19/256, 19/128</td>
<td>3/152,256, 1/64,32, 19/256, 128, 57/512,256</td>
<td>1/4</td>
<td>7%-25%</td>
<td>7%-25%</td>
<td>2%-25%</td>
<td></td>
</tr>
<tr>
<td>Multiplexing Arrangement</td>
<td>TDM</td>
<td>TDM</td>
<td>TDM + H-LS</td>
<td>TDM, FDM, TFDM, LDM</td>
<td>TFDM</td>
<td>SF containing no unicast Read-only-Mode (ROM)</td>
<td>TDM, FDM</td>
<td>TDM, FDM (CBP)</td>
<td></td>
</tr>
<tr>
<td>Frame Availability</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>60%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>
## Performance Considerations

<table>
<thead>
<tr>
<th></th>
<th>ATSC 3.0</th>
<th>3GPP – Rel 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage – ISD (Km)</td>
<td>8 - 211</td>
<td>1.4 - 90</td>
</tr>
<tr>
<td>Mobility - Doppler Limit (Hz)</td>
<td>46 - 206</td>
<td>42 - 1000</td>
</tr>
<tr>
<td>BICM spectral efficiency (bpc)(^1)</td>
<td>10.36</td>
<td>7.09</td>
</tr>
</tbody>
</table>

\[\text{Doppler Limit} = \frac{1}{2 \times D_t \times T_{sym}}\]

PHY Configurations

System Configurations

- Increasing $T_{GI}$ and/or pilot density
  $\Rightarrow$ increased delay spread tolerance

- Decreasing $N_{FFT}$, increasing $\Delta f$
  $\Rightarrow$ increased Doppler tolerance

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Deployment Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>LPLT</th>
<th>MPMT</th>
<th>HPHT-1</th>
<th>HPHT-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISD</td>
<td>15 km</td>
<td>50 km</td>
<td>125 km</td>
<td>173 km</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Rooftop</th>
<th>Indoor</th>
<th>Car-mounted-1</th>
<th>Car-mounted-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rx Velocity</td>
<td>0 km/h</td>
<td>3 km/h</td>
<td>125 km/h</td>
<td>250 km/h</td>
</tr>
</tbody>
</table>

\(^1\) 3GPP R1-1811728, “Chairman’s notes of AI 6.2.4 Study on LTE-based 5G Terrestrial Broadcast,” 2018.
Scenario 1: Rooftop/HPHT-2

System Carrying Capacity: Rooftop (0 km/h) HPHT-2
(173 km) VHF-HI

Carrying Capacity (Subcarriers/s/Hz)

PHY Configurations

Anticipated

ATSC 3.0
3GPP R14
3GPP R16
3GPP R17+

System Carrying Capacity: Rooftop (0 km/h) HPHT-2
(173 km) UHF

Carrying Capacity (Subcarriers/s/Hz)

PHY Configurations

Anticipated

ATSC 3.0
3GPP R14
3GPP R16
3GPP R17+
Scenario 2: Indoor/HPHT-1

System Carrying Capacity: Indoor (3 km/h) HPHT-1
(125 km) VHF-Hi

System Carrying Capacity: Indoor (3 km/h) HPHT-1
(125 km) UHF
Scenario 3: Car-Mounted-1/MPMT

System Carrying Capacity: Car-mounted 1 (125 km/h)
MPMT (50 km) VHF-Hi

System Carrying Capacity: Car-mounted 1 (125 km/h)
MPMT (50 km) UHF
Scenario 4: Car-Mounted-2/LPLT
System Observations – ATSC 3.0

• Support new system bandwidths of 5, 10, 20 MHz.
  • 20 MHz could be supported via the channel bonding of two adjacent 10 MHz RF channels.

• Carrier spacing might need to be increased in order to maintain sufficient Doppler tolerance at higher carrier frequencies than the typical television broadcast frequencies.

• Support new FFT sizes.
  • Either 4K (to support a wider carrier spacing) or 64K (to support a wider system bandwidth).
Frame structure type 1 for subframes using any subcarrier spacing except $\Delta f = 0.370$ kHz\(^1\)

Frame structure type 1 for subframes using subcarrier spacing $\Delta f = 0.370$ kHz\(^1\)

<table>
<thead>
<tr>
<th>Subcarrier Spacing (KHz)</th>
<th>15</th>
<th>2.5</th>
<th>1.25</th>
<th>0.37</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Bandwidth (MHz)</td>
<td></td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>FFT Size</td>
<td>2048</td>
<td>12288</td>
<td>24576</td>
<td>41472</td>
</tr>
</tbody>
</table>

\(^1\) 3GPP TR 36.276 v0.2.0, “LTE-based 5G terrestrial broadcast; Overall Description,” 2019.
Concluding Remarks

ATSC 3.X

256/512/1K FFTs to enable mobile above 1GHz

16K-256K FFTs to enable mobile below 1GHz

VHF-Lo RF 2-6 54-88

VHF-Hi RF 7-13 174-216

UHF RF 14-36 614 806

DCS 1805-1880

PCS 1930-1990

AWS 2110-2200

IMT 2110-2170

3GPP R17/17+

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Thank You

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For questions and feedback:
Kevin Shelby: shelby@coherentlogix.com
Ahmed Hamza: hamza@coherentlogix.com
Mark Earnshaw: earnshaw@coherentlogix.com
David Starks: starks@coherentlogix.com