Comparison of ATSC 3.0 and 5G Broadcast: Performance and Network Expense

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Why ATSC 3.0 for Terrestrial Broadcast?

- ATSC 3.0 PHY is purpose-built for broadcast
- Superior over current 3GPP MBMS solutions for downlink broadcast/multicast
- Significant network expense (CAPEX and OPEX) savings
- Very compelling case to add to a future 3GPP release
- This presentation includes a performance comparison with 5G-Broadcast (3GPP Rel-16/17), a.k.a FeMBMS

ATSC 3.0 Status in S. Korea

- ATSC 3.0 delivering 4K-UHD started in Seoul metro area (May 2017), extended to major cities (Dec. 2017), and will be nationwide by 2025
- New frequency bands in 700 MHz were assigned for ATSC 3.0 (Simulcasting: ~ 2027)

- Successfully demonstrated high quality mobile broadcast + 4K-UHD in a single RF channel for 2018 Winter Olympics (PyeongChang)

ATSC 3.0 mobile receiver installed in a shuttle bus over Olympic village

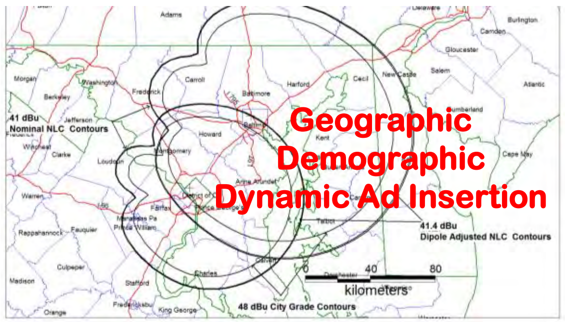
Inside the bus introduced by WRAL-TV (U.S.)

ATSC 3.0 Status in S. Korea

Enhanced TV

Mobility

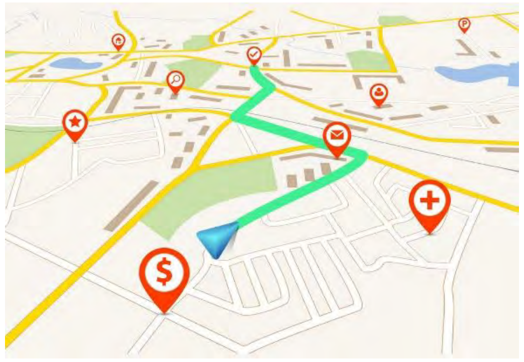
Quality



Targeting

Datacasting

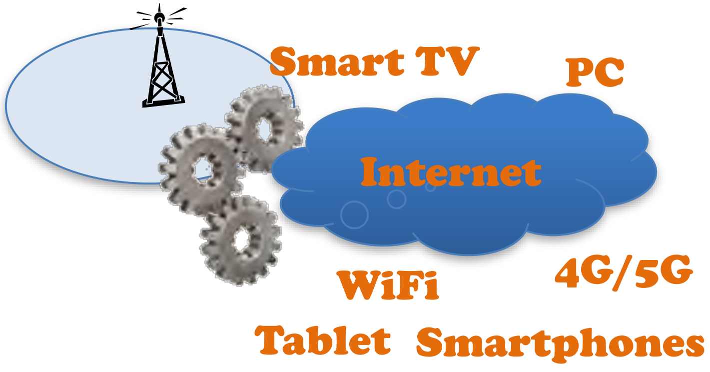
Navigation Updates



Multimedia Files

Apps and Data

Convergence



ATSC 3.0 Status in S. Korea - Consumer Devices

TV

In Korea, all Samsung and LG UHDTV (manufactured after 2017) are ATSC 3.0 ready!!

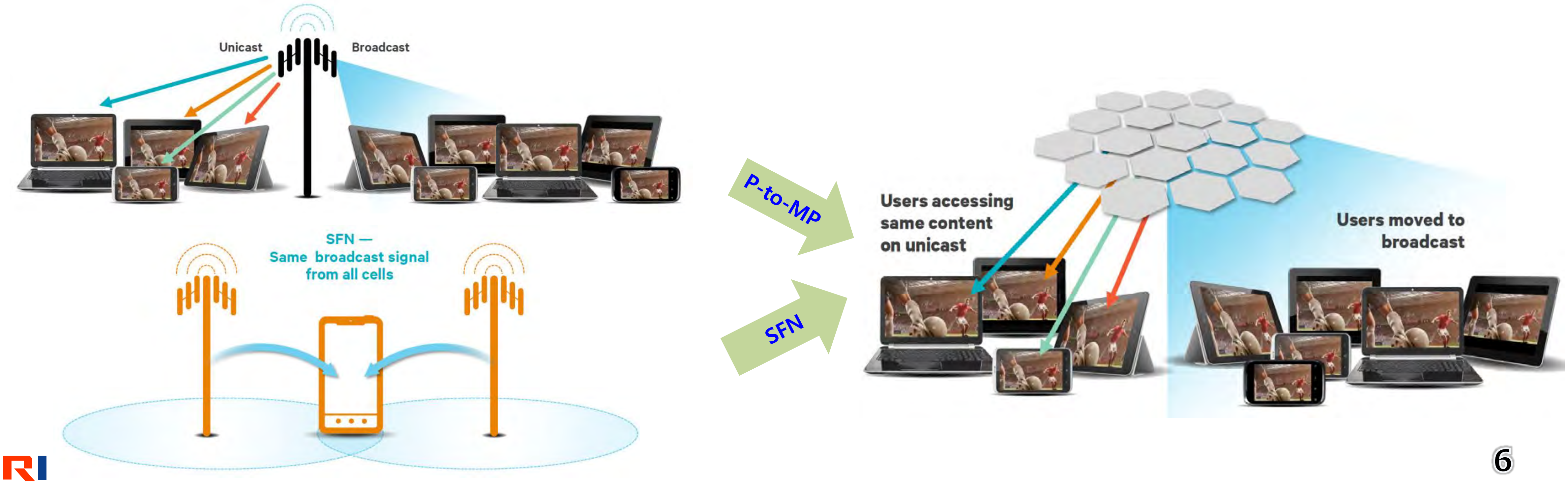
STB

Others

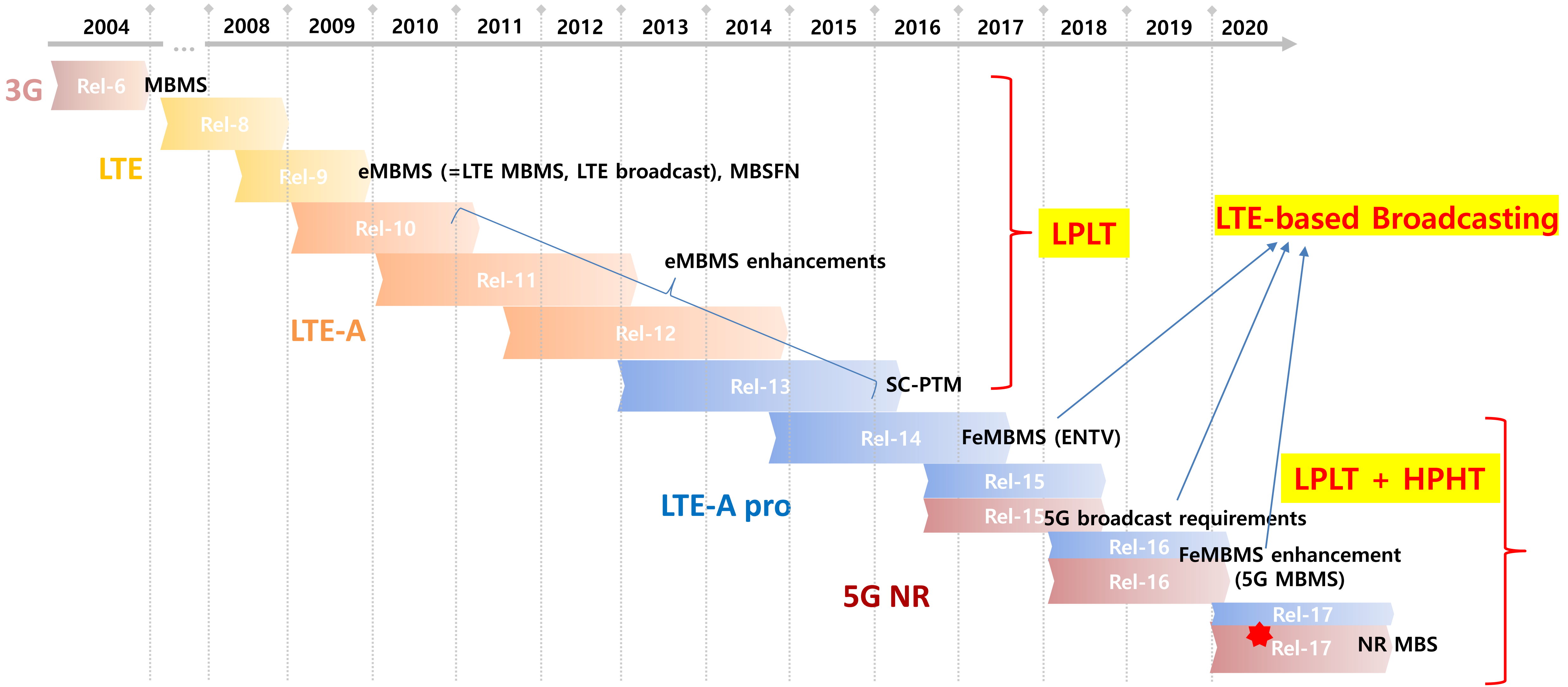
- Dongle receiver for existing device
- Home gateway for WiFi re-distribution

MBMS: Broadcasting Services in 3GPP

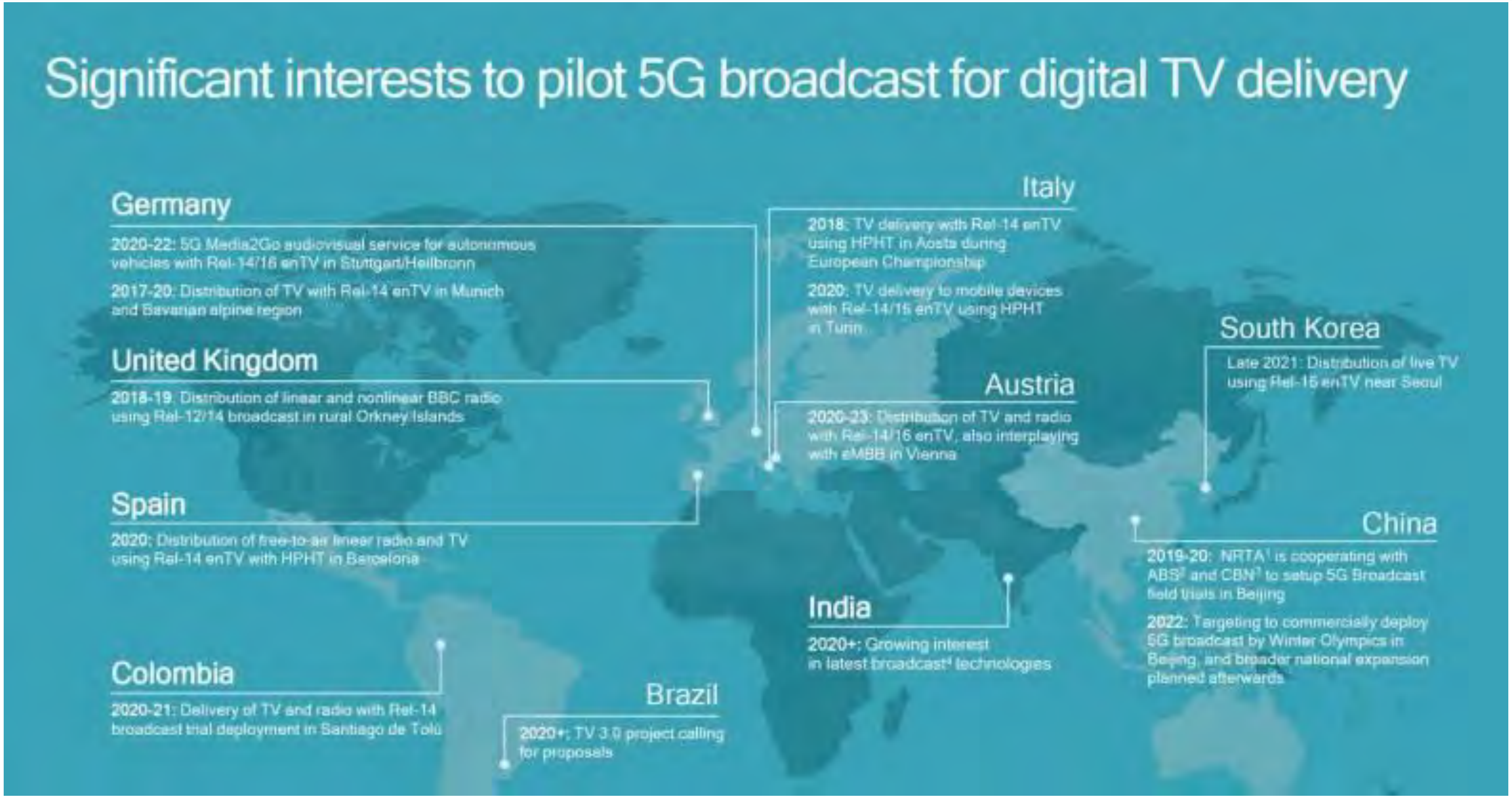
- Broadcasting technologies in cellular-based mobile broadband (3GPP)
  - Starting from LPLT-based point-to-point service
  - Extended to HPHT-based infrastructure for a larger coverage
- MBMS (Multimedia Broadcast and Multicast Service) features
  - Possible to efficiently deliver the same contents (i.e., popular contents: live news and sports) to massive subscribers based Point-to-multipoint (P-to-MP) versus Unicast
  - Possible to deliver the same contents to wider coverage due to SFN



MBMS: History from 3G to 5G



MBMS: 5G-Broadcast Trials



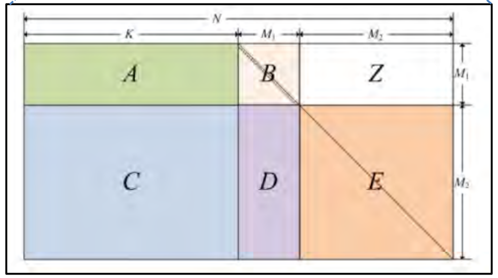
https://www.thebroadcastbridge.com/content/entry/18980/5g-broadcast-gains-momentum-with-field-trials

BICM (Bit-Interleaved Coded Modulation)

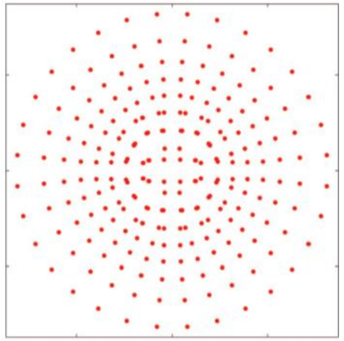
ATSC 3.0

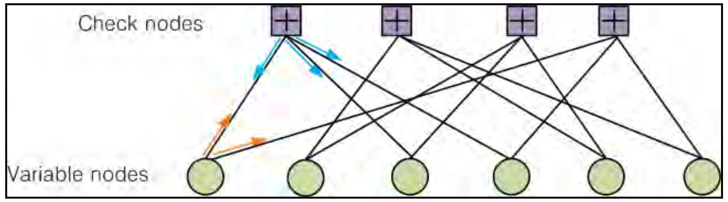
LDPC Code + NUC

LDPC codes → Bit-interleaver → NUC



[LDPC encoding]



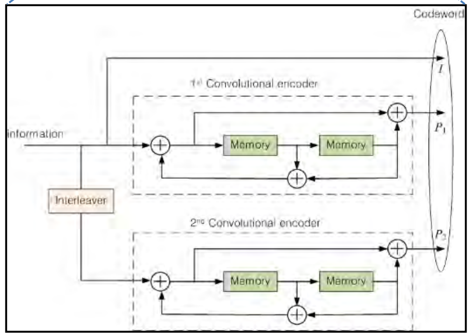


[LDPC decoding]

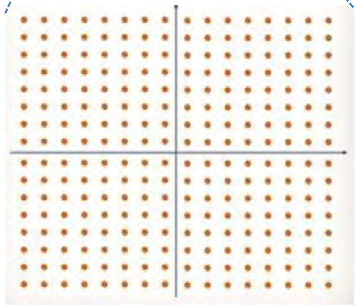
FeMBMS

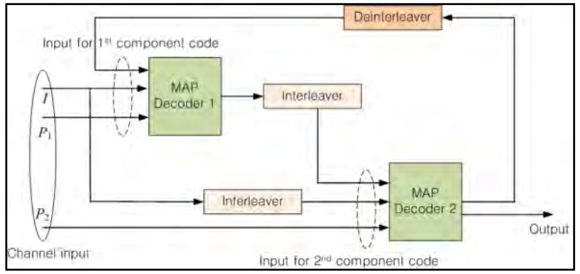
Turbo Code + QAM

Turbo codes → Bit-interleaver → QAM

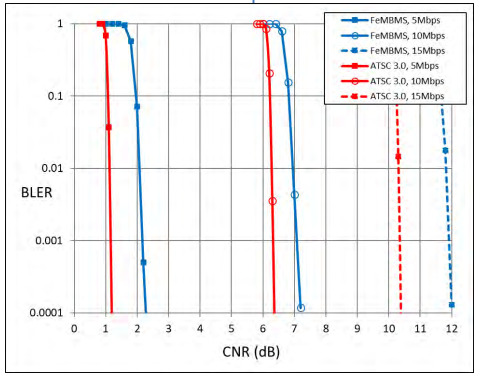


[Turbo encoding]





[Turbo decoding]

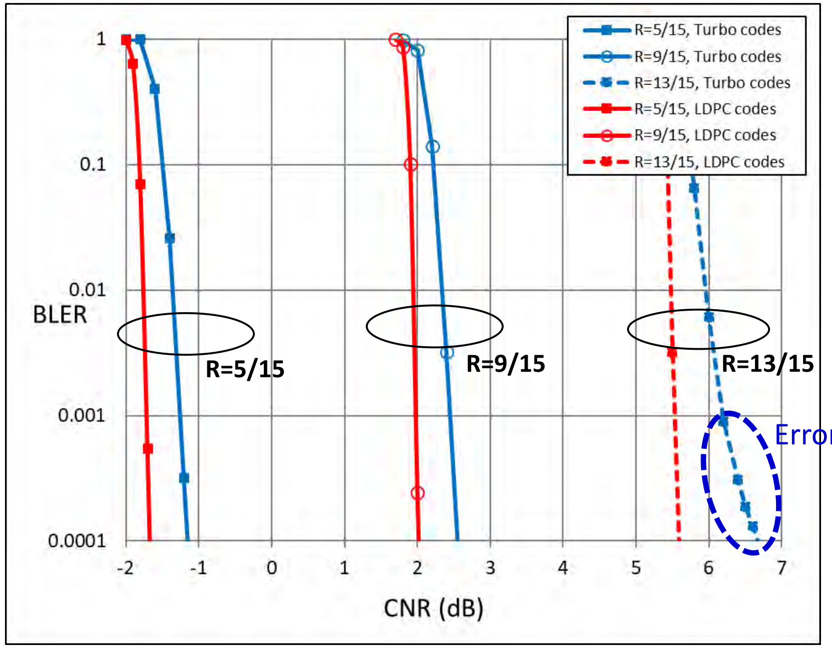


[BICM Performance]

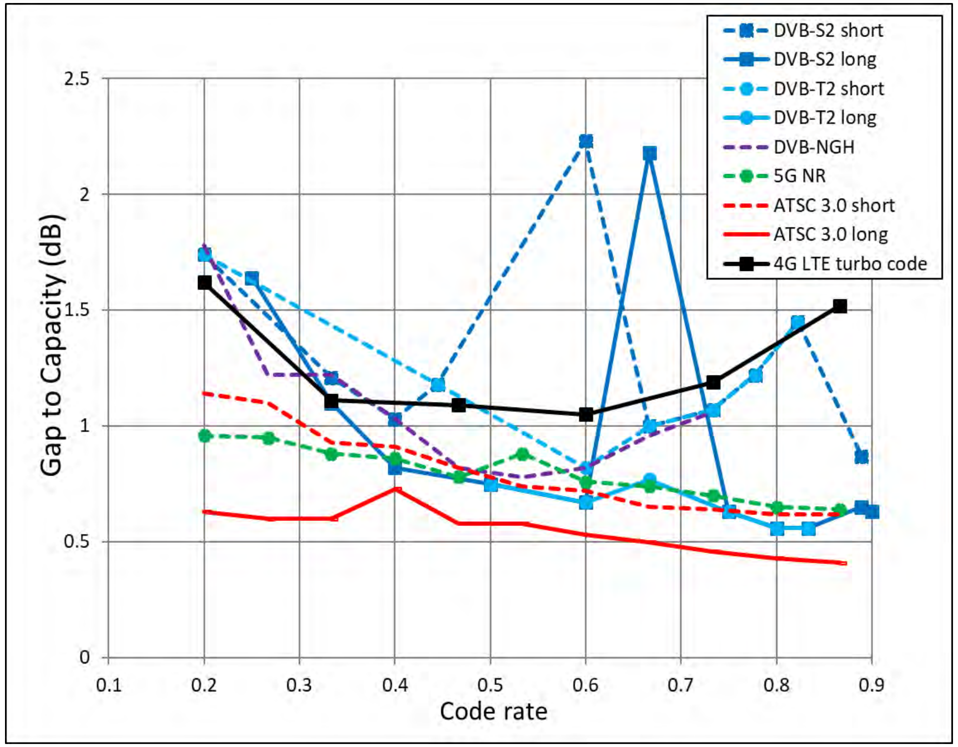
BICM (Bit-Interleaved Coded Modulation)

LDPC code vs Turbo code

	ATSC 3.0 LDPC codes	FeMBMS Turbo codes
Optimized	Delicately optimized for each code rate	Originally for 1/3, Puncturing is used for variable code rates
Codeword length	Up to code bits 64,800	Up to information bits 6144
Error floor	Free	Sometimes, it happens



[Performance: FeMBMS Turbo codes vs ATSC 3.0 LDPC codes]



[Performance: ATSC 3.0 LDPC codes vs other DTT standards]

- ATSC 3.0 LDPC codes outperform other wireless broadcasting/communication standards
- ATSC 3.0 LDPC codes are less than 1 dB away from Shannon Capacity

K.-J. Kim *et al.*, "Low-Density Parity-Check Codes for ATSC 3.0." in *IEEE Trans. on Broadcasting*, vol. 62, no. 1, pp. 189-196, March 2016.

S.-K. Ahn *et al.*, "Comparison of Low-Density Parity-Check Codes in ATSC 3.0 and 5G Standards." in *IEEE Trans. on Broadcasting*, vol. 65, no. 3, pp. 489-495, Sept. 2019.

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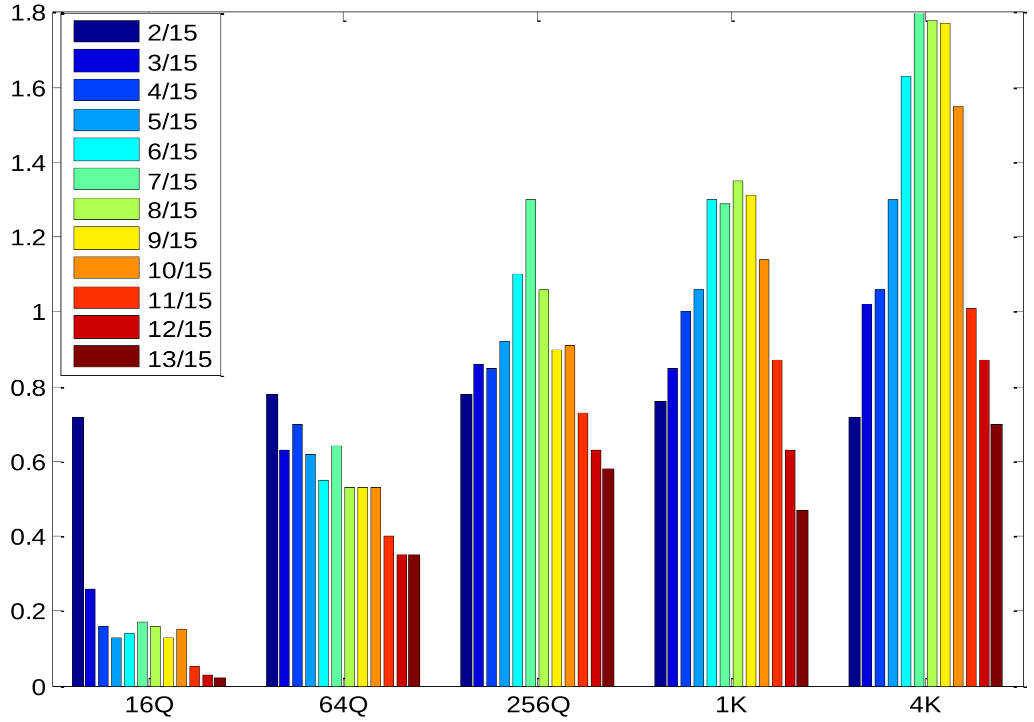
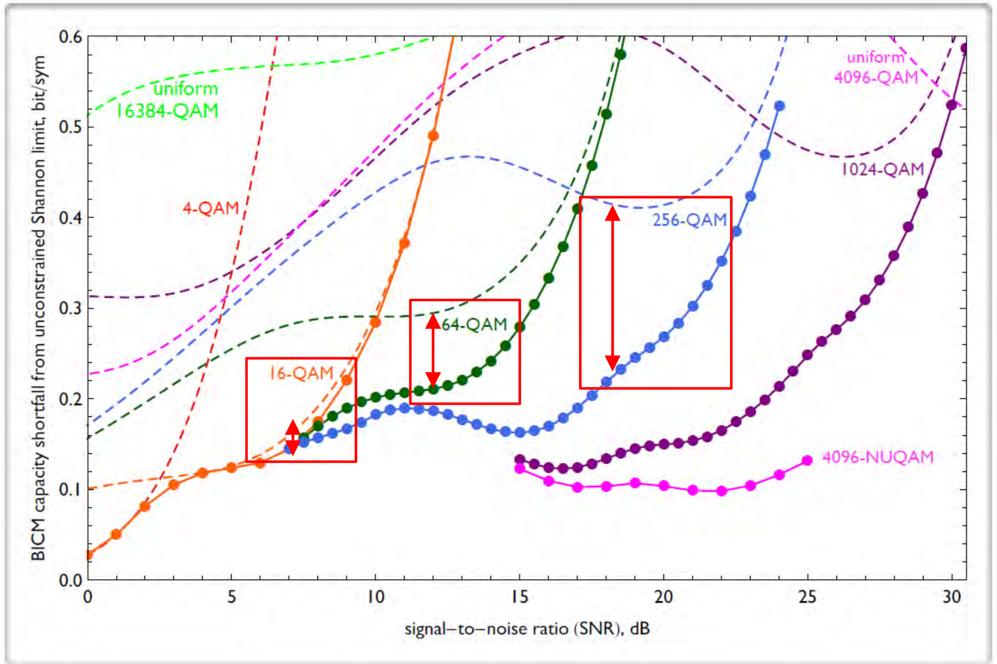
BICM (Bit-Interleaved Coded Modulation)

NUC vs QAM



[Performance: gain of ATSC 3.0 NUC over rectangular QAM]

- ATSC 3.0 NUCs outperform rectangular QAMs
- NUC gain increases when modulation order increases



[Shortfall of the BICM capacity from the Shannon capacity, NUC and QAM][1]

Performance of BICM chain is bounded by its BICM capacity.

➔ NUC is closer to BICM capacity than rectangular QAM

➔ NUC gain increases when modulation order increases

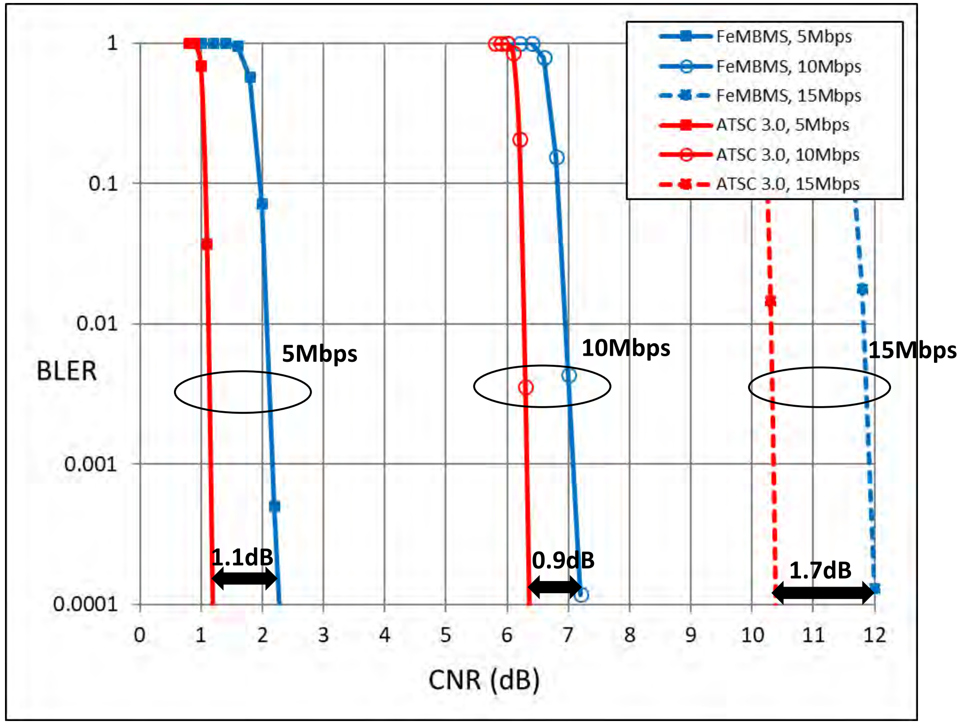
N. S. Loghin *et al*., "Non-Uniform Constellations for ATSC 3.0." in *IEEE Trans. on Broadcasting*, vol. 62, no. 1, pp. 197-203, March 2016.

[1] CM and BICM limits for rectangular constellations, Research & Development White Paper, BBC, 2013.

Performance Comparison over AWGN channel

- **Evaluation over AWGN channel**

	Required CNR (5Mbps)	Required CNR (10Mbps)	Required CNR (15Mbps)
ATSC 3.0	1.2dB	6.4dB	10.4dB
FeMBMS (Rel-16/17)	2.3dB	7.3dB	12.1dB
ATSC 3.0 gain over FeMBMS	**1.1dB**	**0.9dB**	**1.7dB**



[AWGN channel]

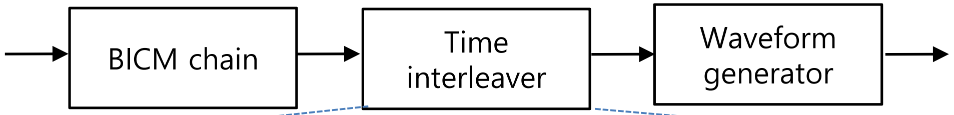
ATSC 3.0 has a better BICM (bit-interleaved coded modulation) efficiency than FeMBMS. In the AWGN channel, ATSC 3.0's latest LDPC codes and NUC (non-uniform constellation) combination provides around 1 – 2 dB gain compared to turbo codes and rectangular QAM of FeMBMS.

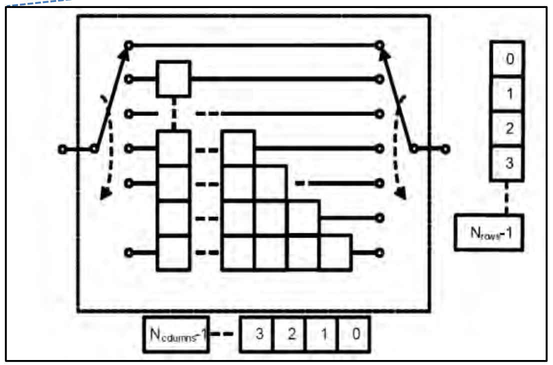
In terms of BICM, ATSC 3.0 is less than 1 dB away from Shannon Capacity.

Time Interleaver

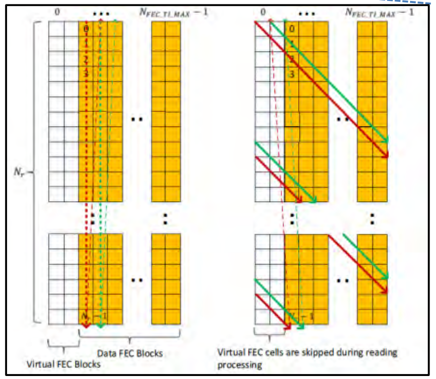
ATSC 3.0 w. Time Interleaver

ATSC 3.0 PHY is designed to provide uniform performance under harsh mobile fading channels. → Time interleaver is an appropriate solution.





[Convolutional Time Interleaver]

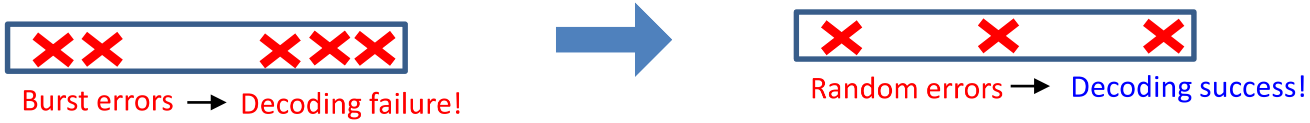


[Hybrid Time Interleaver]

ATSC 3.0's well-designed and optimized time-interleaver provides significant performance benefit over harsh fading environments.

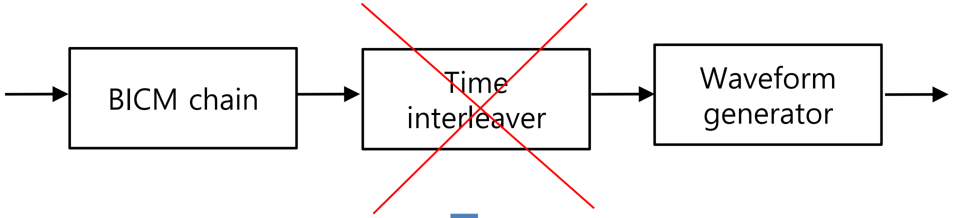
Time Interleaver

Time interleaver spreads burst errors, caused by harsh fading channel, to random errors so that a receiver can make it decode successfully.

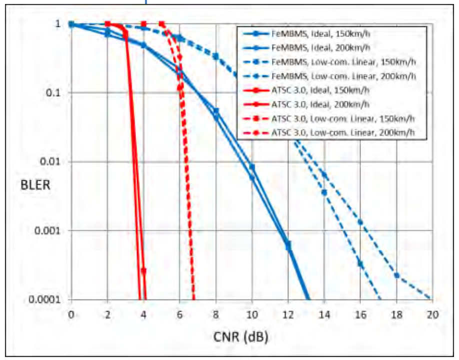


FeMBMS w.o. Time Interleaver

LTE PHY (FeMBMS) is designed to minimize latency for supporting latency requirements of unicast transmission. → Time interleaver is not allowed in LTE PHY layer.



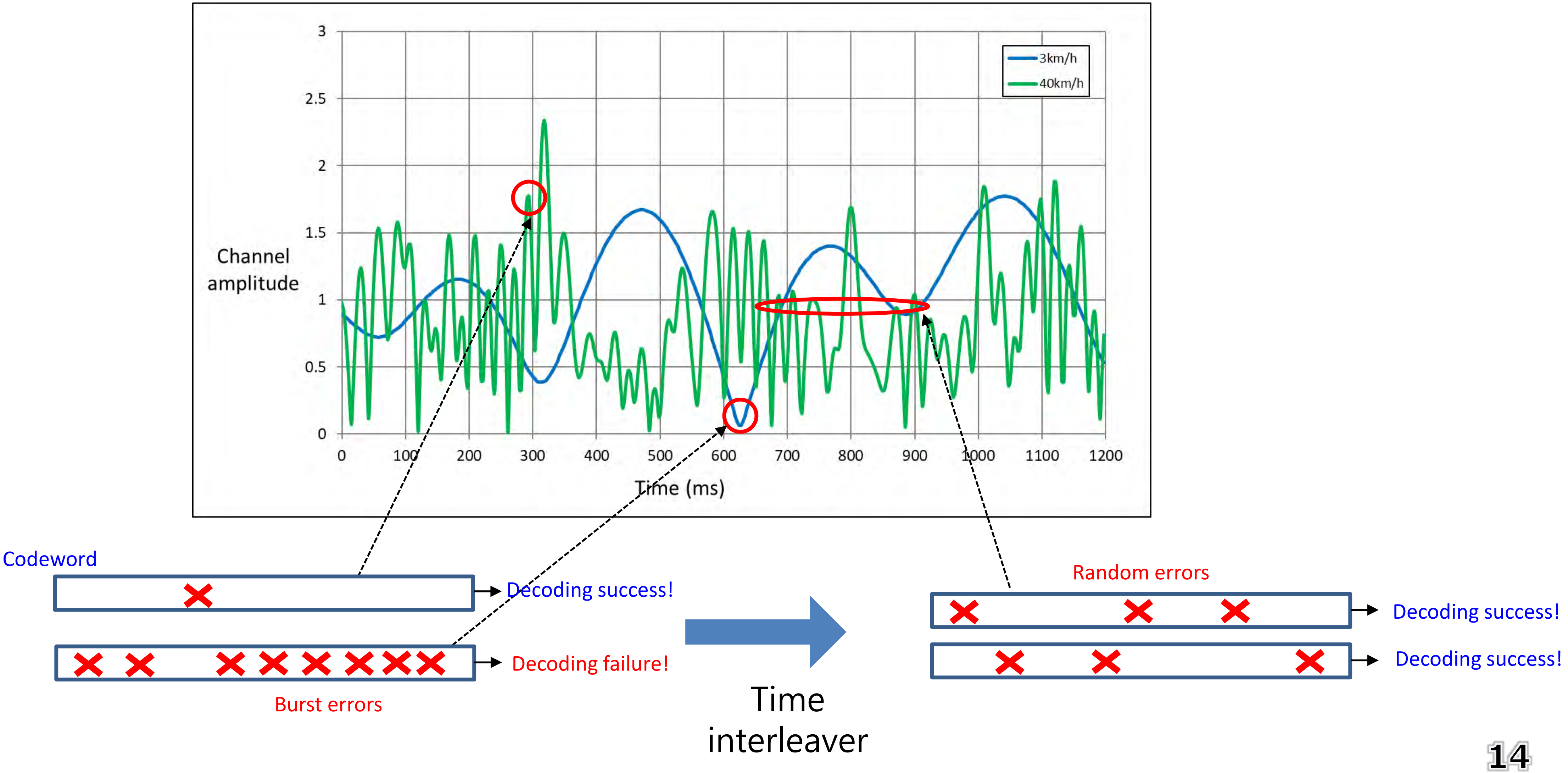
FeMBMS doesn't have a time interleaver function to handle harsh channel fading.



[Fading Performance]

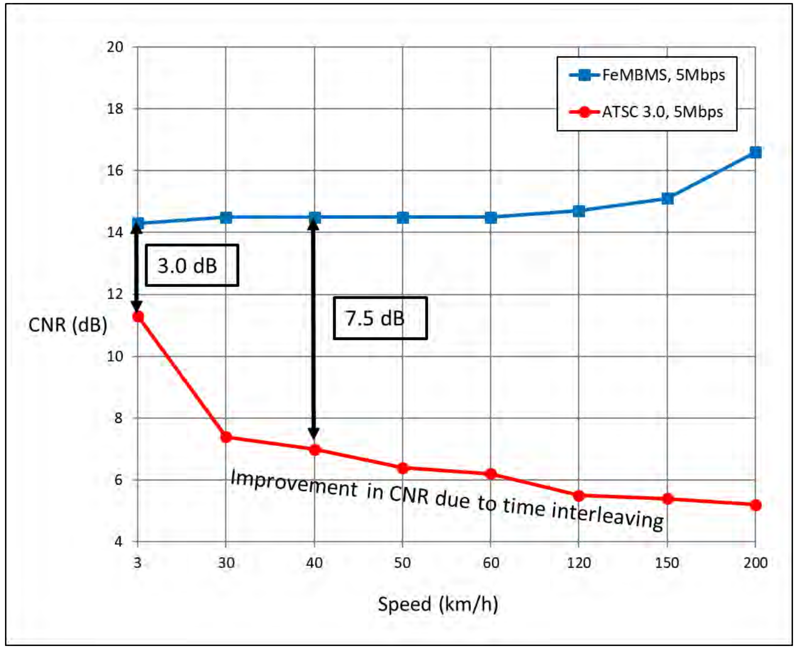
Time Interleaver

[Fading channel realization]

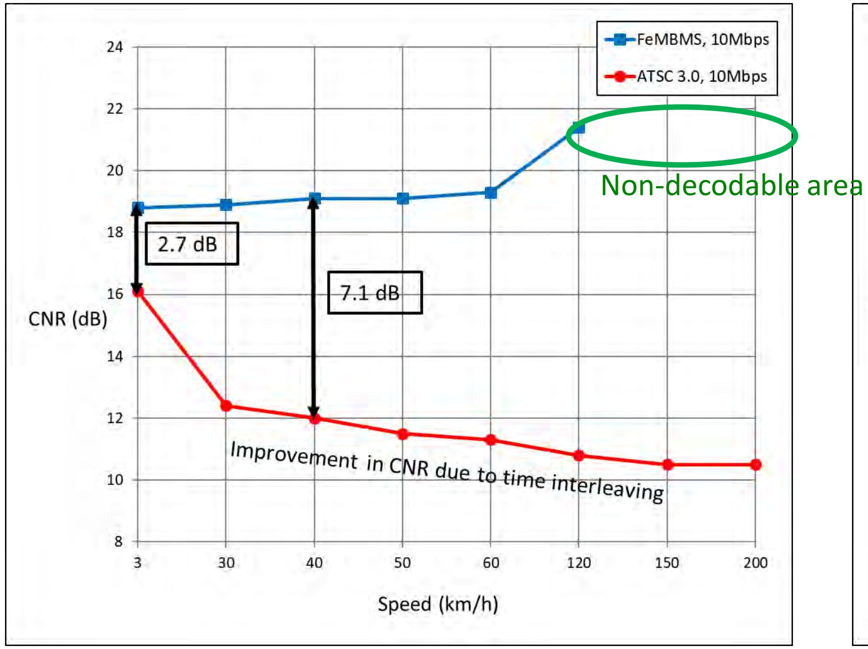


Time Interleaver Effect over India-Urban channel

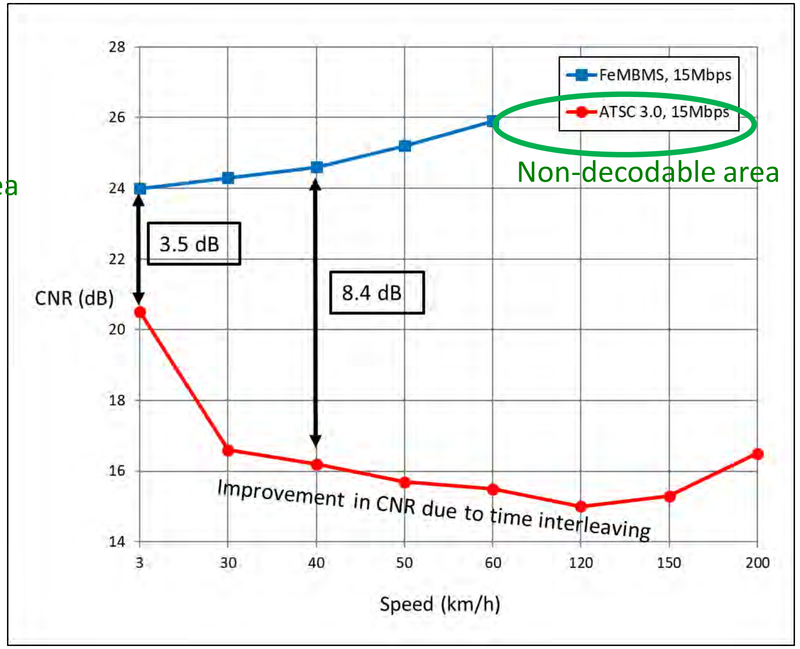
- **Advantage for ATSC 3.0 compared to FeMBMS (Rel-16/17)**



[5Mbps – From 3km/h to 200km/h]



[10Mbps – From 3km/h to 200km/h]



[15Mbps – From 3km/h to 200km/h]

Data rate / Mobility	ATSC 3.0 gain over FeMBMS (Rel-16/17)							
	3km/h	30km/h	40km/h	50km/h	60km/h	120km/h	150km/h	200km/h
5Mbps	3.0 dB	7.1 dB	7.5 dB	8.2 dB	8.3 dB	9.2 dB	9.7 dB	11.4 dB
10Mbps	2.7 dB	6.6 dB	7.1 dB	7.6 dB	8.0 dB	10.7 dB	FeMBMS non-decodable	
15Mbps	3.5 dB	7.7 dB	8.4 dB	9.5 dB	10.4 dB	FeMBMS non-decodable		

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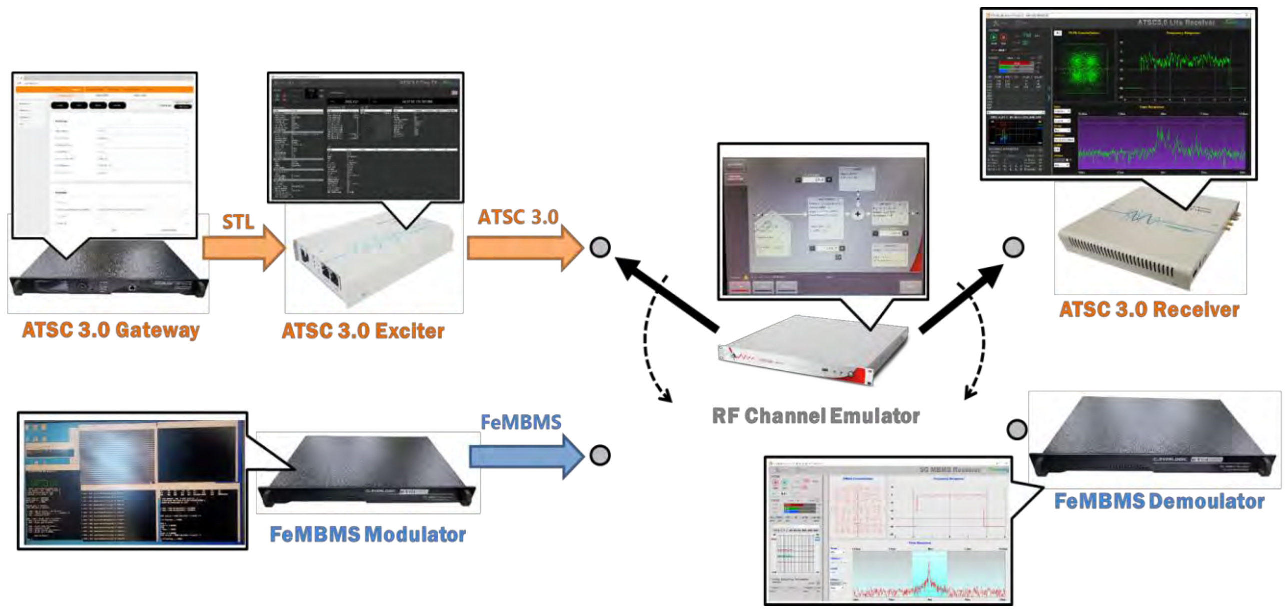
Comparison of ATSC 3.0 vs. 5G Broadcast (Rel-16/17)

[HW-based Laboratory Test] ATSC 3.0 Subframe vs. 5G Broadcast PMCH ➔ 6MHz BW, 768MHz CF, India-Urban/TU-6 channel



[HW-based Laboratory Environment]

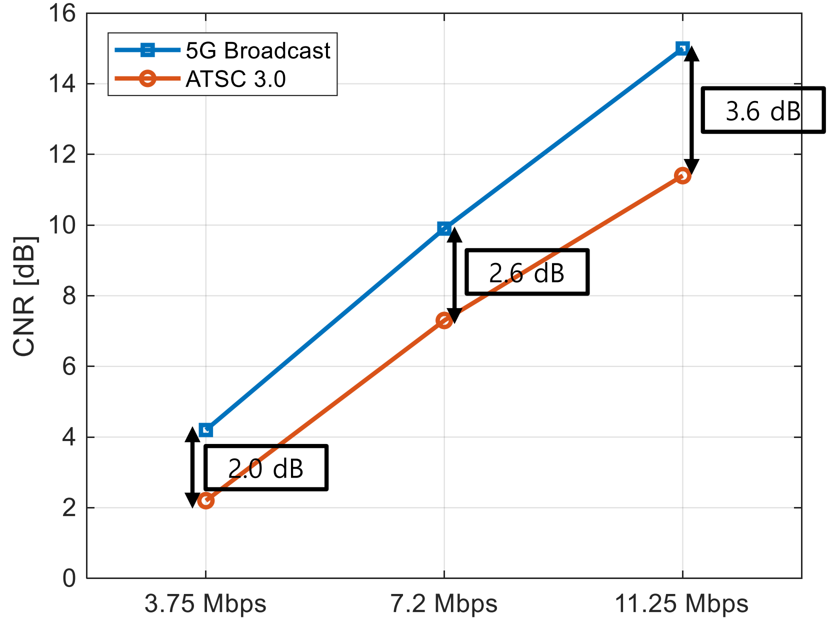
Configuration / Mobility		ATSC 3.0 gain over 5G Broadcast (Rel-16/17)		
		3.75 Mbps	7.5 Mbps	11.25 Mbps
India-Urban	3km/h	8.0 dB	5G Broadcast non-decodable	5G Broadcast non-decodable
	40km/h	9.8 dB	9.5 dB	5G Broadcast non-decodable
TU-6	3km/h	4.5 dB	6.3 dB	5G Broadcast non-decodable
	40km/h	10.3 dB	9.7 dB	5G Broadcast non-decodable

[Performance Comparison between ATSC 3.0 and 5G Broadcast]

Comparison of ATSC 3.0 vs. 5G Broadcast (Rel-16/17)

[HW-based Laboratory Test] ATSC 3.0 Subframe vs. 5G Broadcast PMCH ➔ 6MHz BW, 768MHz CF, AWGN/India-Urban/TU-6 channel

[AWGN]



[India-Urban/TU-6]

Configuration / Mobility	ATSC 3.0 gain over 5G Broadcast (Rel-16/17)			
	India-Urban		TU-6	
	3km/h	40km/h	3km/h	40km/h
3.75 Mbps	8.0 dB	9.8 dB	4.5 dB	10.3 dB
7.5 Mbps	5G Broadcast non-decodable	9.5 dB	6.3 dB	9.7 dB
11.25 Mbps	5G Broadcast non-decodable	5G Broadcast non-decodable	5G Broadcast non-decodable	5G Broadcast non-decodable

Comparison of ATSC 3.0 vs. 5G Broadcast (Rel-16/17)

➢ Transmitter Facilities for ATSC 3.0 and 5G-MBMS Field Trial in 2022

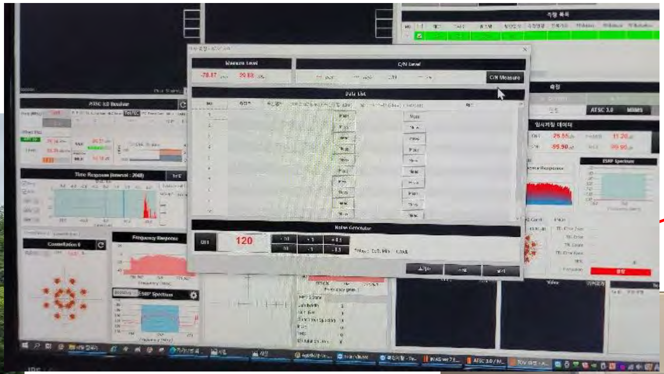
<Building & Tower >

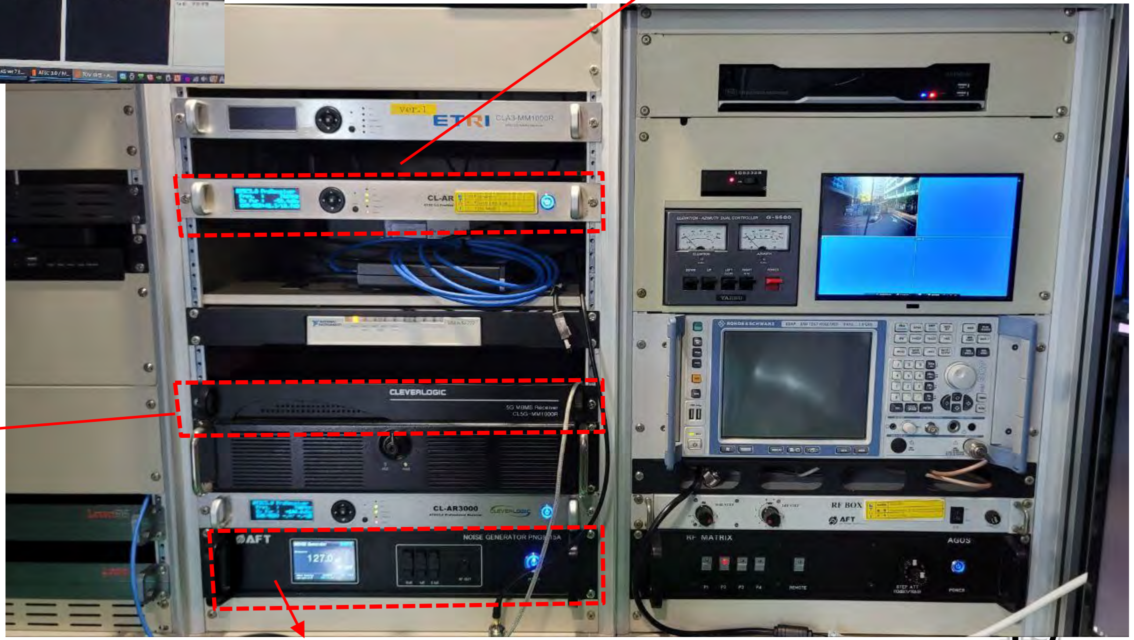
<Gateway & Tx Controller>

< 5G MBMS and ATSC 3.0 Transmitter >
Center Frequency : 768MHz (BW:6MHz)
Transmission power : 100W

Comparison of ATSC 3.0 vs. 5G Broadcast (Rel-16/17)

- Receiver (Test Vehicle) Facilities for ATSC 3.0 and 5G-MBMS Field Trial in 2022
  - For both fixed and mobile reception





Comparison of ATSC 3.0 vs. 5G Broadcast (Rel-16/17)

6MHz is used (instead of 8MHz)

ATSC 3.0

Common Configuration (ATSC 3.0)		
Center frequency		768 MHz
Bandwidth		6MHz
Common parameters	FFT size	8192
	Guard interval	GI7_2048 (222.22 us)
Preamble parameters	Pilot Pattern	SP_Dx = 3
	Signaling Protection	L1-Basic/Detail mode 1
Payload OFDM parameters	Pilot pattern	SP3_2
	# of payload symbols	222
	Time interleaver	CTI with a depth of 1024
	Frequency interleaver	On
Frame length		250.8889 ms

	Configuration 1	Configuration 2	Configuration 3
Outer code	8/15-LDPC (64800)	8/15-LDPC (64800)	8/15-LDPC (64800)
Constellation	QPSK	16-NUC	64-NUC
Data rate	4.03 Mbps	8.06 Mbps	12.09 Mbps

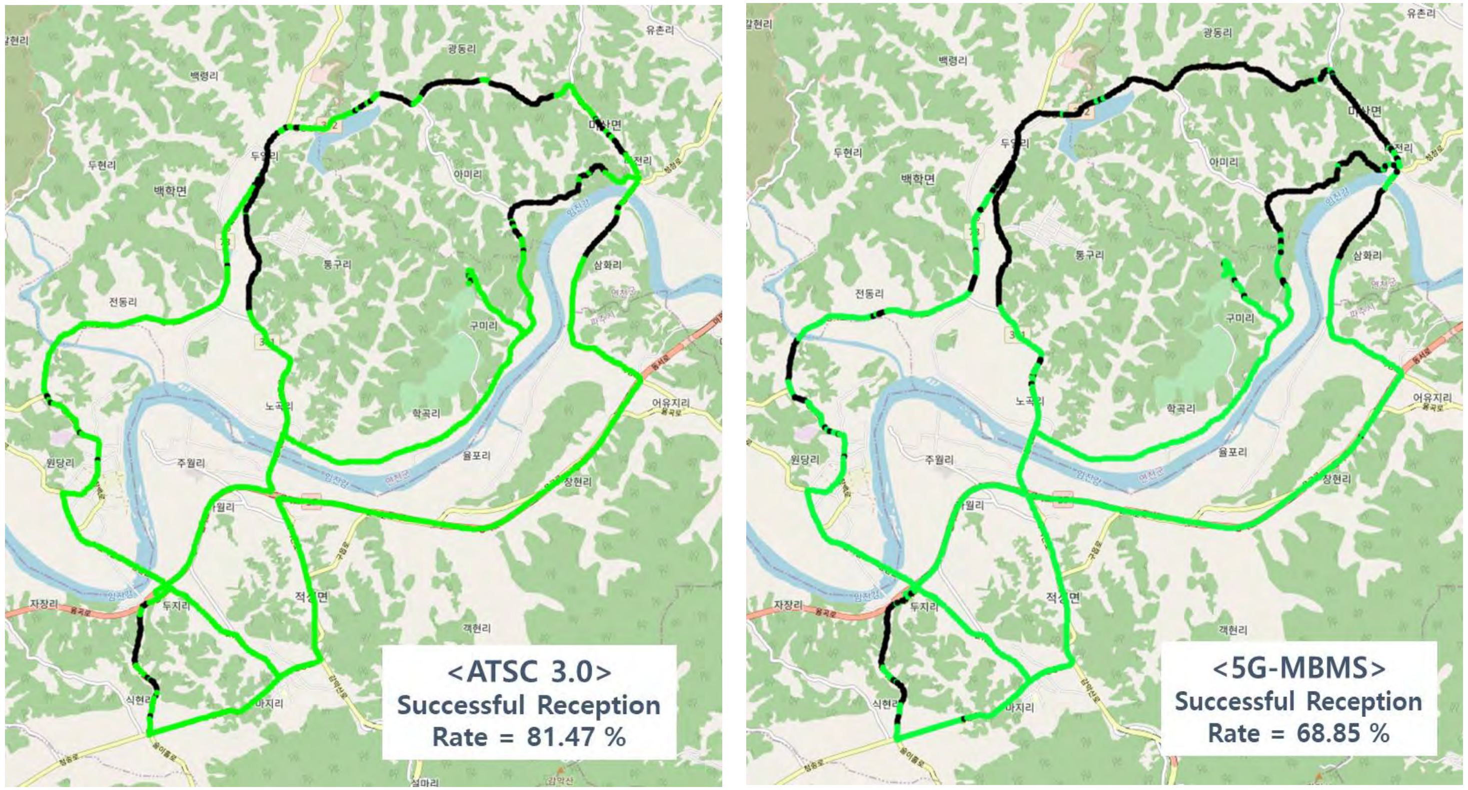
5G-MBMS

Common Configuration (5G-MBMS)	
Center frequency	768 MHz
Bandwidth	6MHz (30RBs)
FFT size	12288
Guard interval	200us
Pilot pattern	SP3_2
Subcarrier spacing	1.25KHz
MCS table	Table 7.1.7.1-1 (TS 36.213) Max 64-QAM table

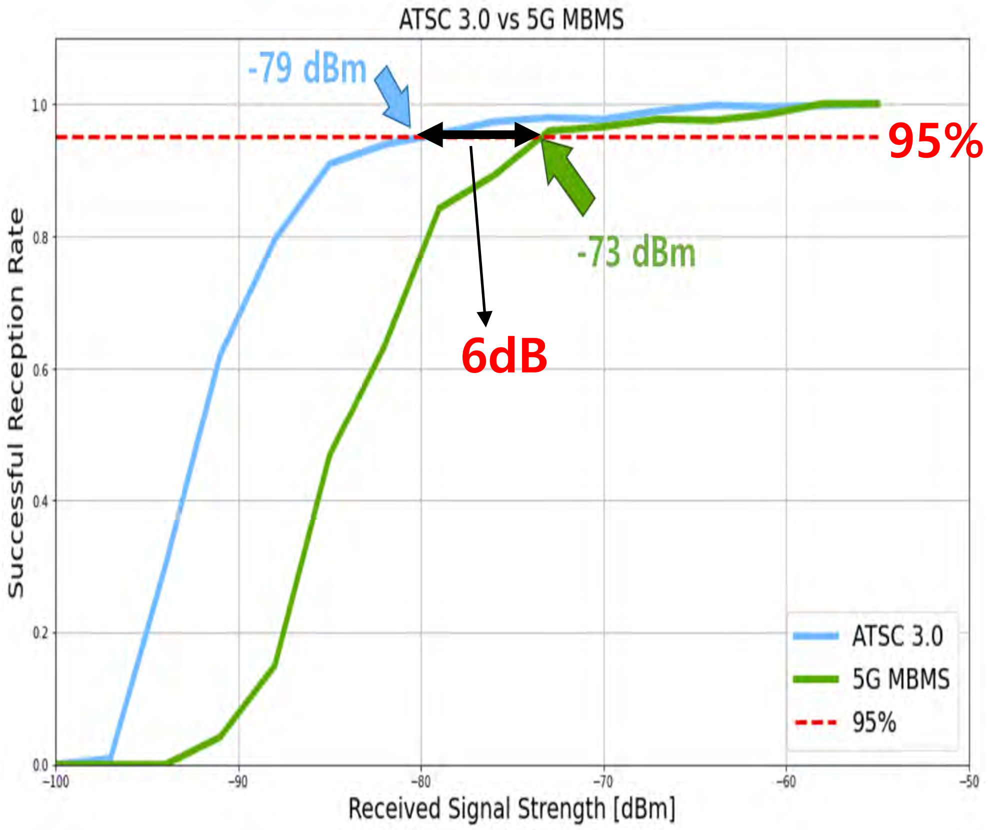
	Configuration 1	Configuration 2	Configuration 3
MCS index	8	14	20
TBS	4264	7736	11832
Code rate	0.58	0.54	0.553
Constellation	QPSK	16-QAM	64-QAM
Data rate	4.16 Mbps	7.54 Mbps	11.54 Mbps

Comparison of ATSC 3.0 vs. 5G Broadcast (Rel-16/17)

[Field Test] ATSC 3.0 Subframe vs. 5G Broadcast PMCH ➔ 6MHz BW, 768MHz CF, 5Mbps



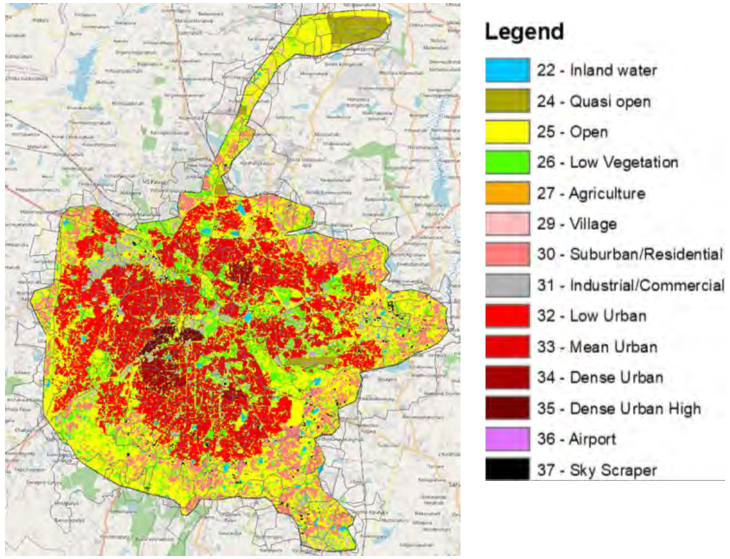
[Reception Success or Failure @ 5Mbps]



[ESR5 @ 5Mbps]

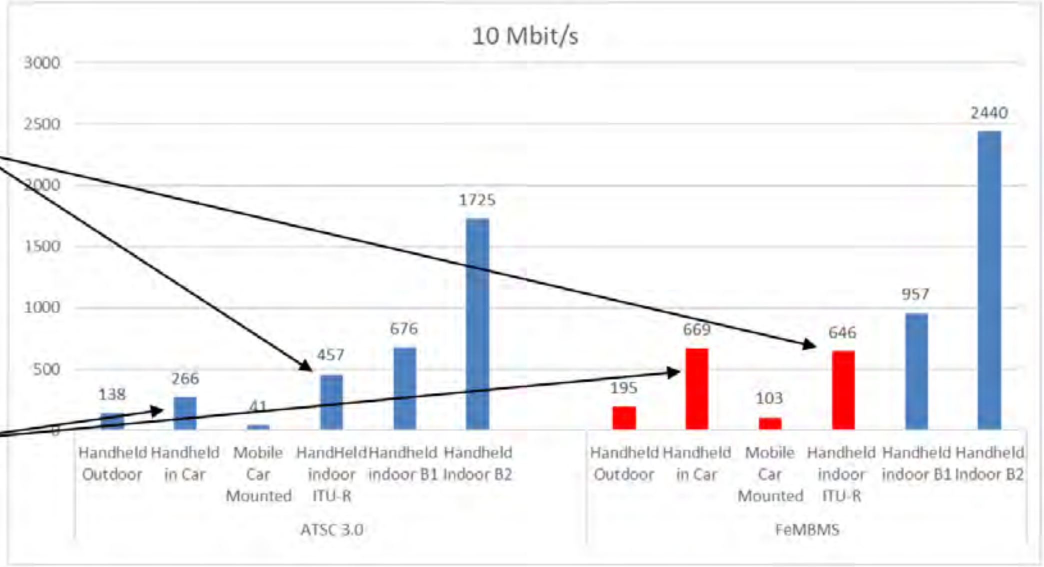
Network Cost Comparison

- **System eligibility – Network cost**
  - ✓ ATSC 3.0 and FeMBMS physical-layers are compared in terms of network cost.
  - ✓ Network expense (CAPEX & OPEX) can be abstracted in terms of the number of operational towers.



[Considered service area in Bangalore, India]

- Results for 10 Mbit/s presented here
- For Handheld indoor (ITU-R) the number of requited sites increase from 457 to 646 (40% increase) ATSC 3.0 vs FeMBMS
- For Handheld in Car reception the increase is about 150 % (266 to 669 sites)



[Theoretical Study: Bangalore, Results]

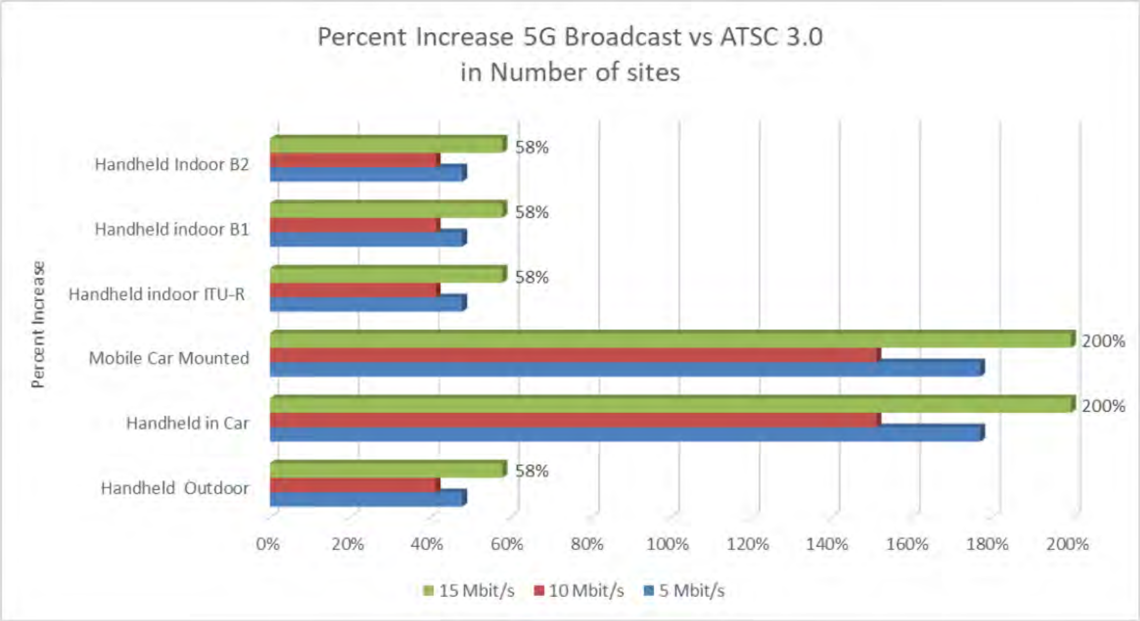
PROGIRA

These results are from Progira's network simulation

Network Cost Comparison

- **System eligibility – Network cost**
  - ✓ Given the target service area and QoS, ATSC 3.0 is more efficient solution in terms of network operation than FeMBMS.

- For handheld indoor reception the FeMBMS (5G Broadcast) will require 40-60% more sites
- For mobile reception the increase in number of sites required for FeMBMS is 140-200%. The reason for the large difference is lack of that time interleaving in 5G Broadcast Release 16/17
- In General 5 dB difference in required C/N will double number of required sites!



[Theoretical Study: Considerations, Summary]

PROGIRA

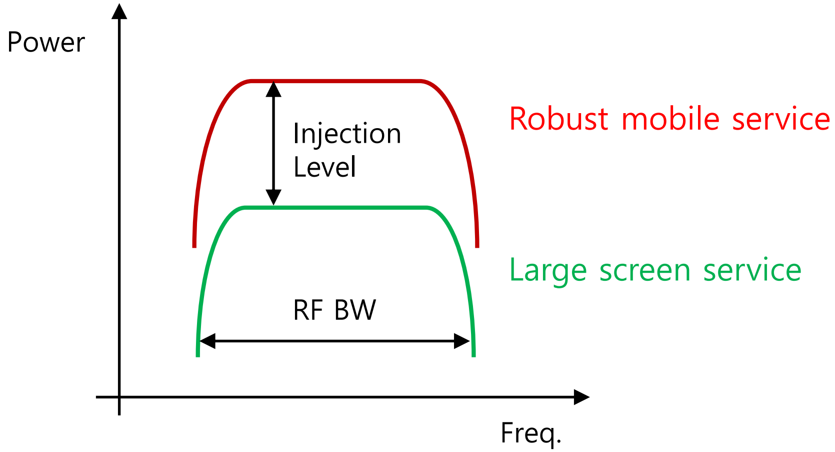
These results are from Progira's network simulation

Layered Division Multiplexing (LDM)

Conventional transport vehicle: single-decker bus.

LDM is like a double-decker bus, more capacity with the same foot print (bandwidth)

Possible for future extension!!



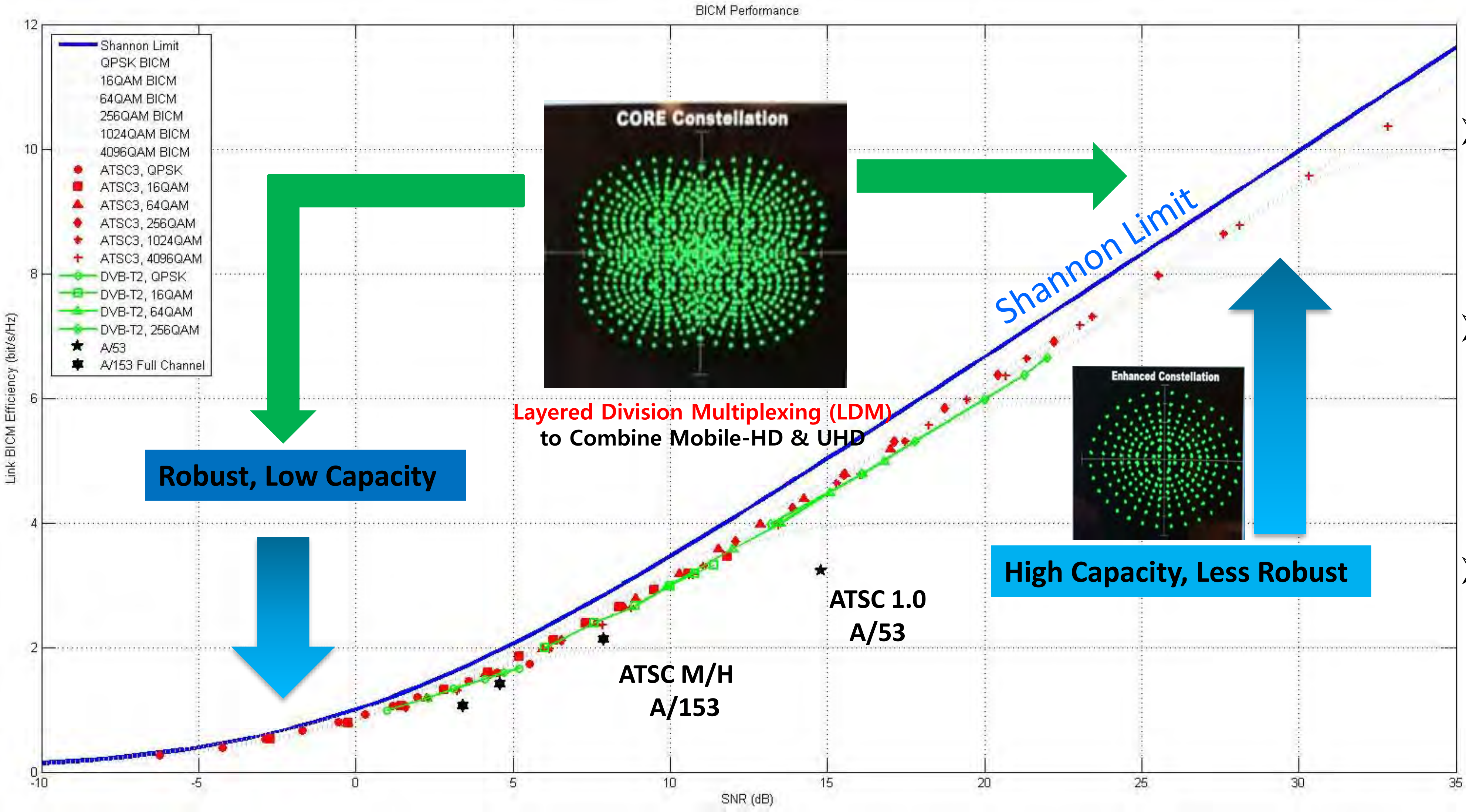
< LDM signal configuration >

LDM key features

- Different services with different robustness are superimposed with different power
- 100% of RF bandwidth & 100% of time are fully used for both robust mobile service & large screen service
- LDM has significant performance gain (3 to 9 dB) over a traditional TDM/FDM schemes [ref]
- Commercialized ATSC 3.0 TVs support LDM technology

[ref#1] S-I. Park *et al.*, "Low Complexity Layered Division Multiplexing for ATSC 3.0," in *IEEE Trans. on Broadcasting*, vol. 62, no. 1, pp. 233-243, March 2016.
[ref#2] S-I. Park *et al.*, "Field Comparison Tests of LDM and TDM in ATSC 3.0," in *IEEE Trans. on Broadcasting*, vol. 64, no. 3, pp. 637-647, Sept. 2018.

Shannon Capacity

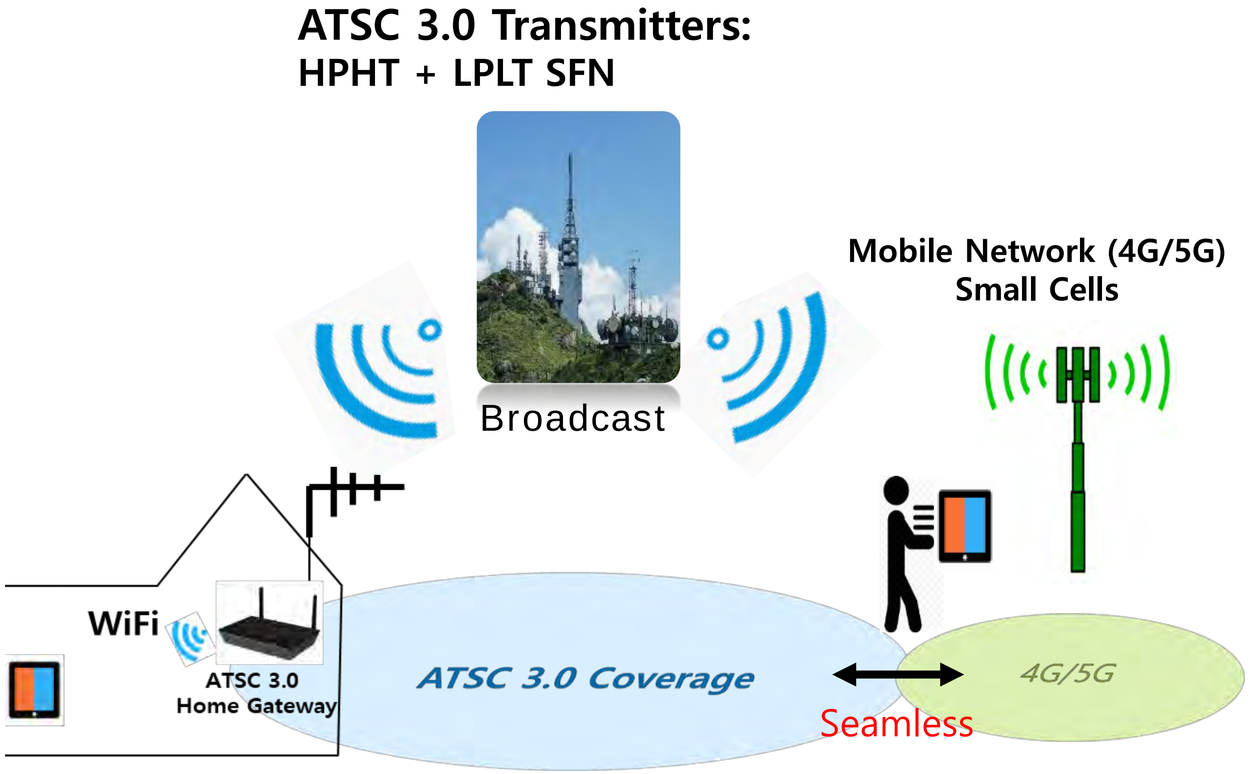


- **Flexibility**: provide large range of operating modes
- **Robustness**: for mobile or deep indoor reception (~ -6 dB SNR)
- **Spectral efficiency:** better efficiency when services are multiplexed ➔ LDM, SHVC

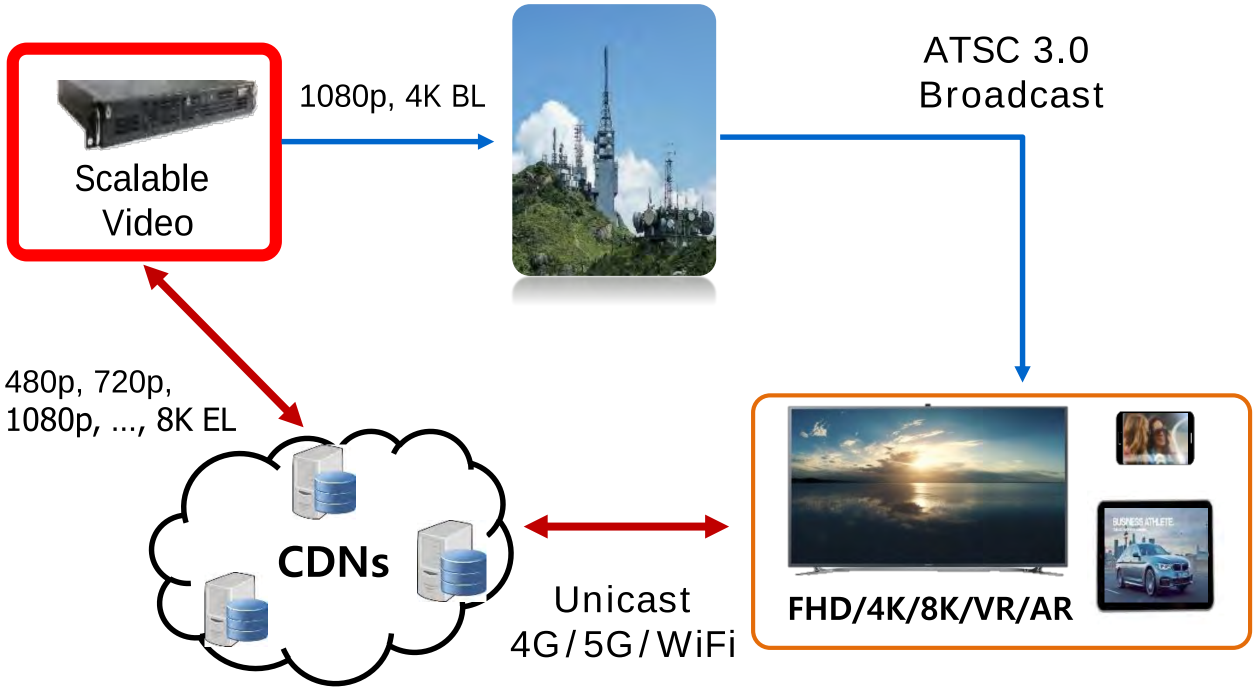
ATSC 3.0 Broadcast Convergence with Broadband

- **ATSC 3.0 IP-Based Broadcast ➔ feasible to cooperate/converge with Broadband (4G/5G/WiFi and others)**

Seamless Experience between BC and BB



Better Quality through BC + BB



- ✓ ATSC 3.0 Broadcast (HPHT or HPHT/LPLT) takes dominant consumption of A/V traffic
  - ✓ Broadband can be supplemented (interactivity, hybrid, coverage extension) thru Unicast
- ✓ Seamless Experience & Better Quality ➔ Viewers don't care about network technology and prefer low-cost (or free) network

Direct-to-Mobile in Korea

Smart-phone demonstration

- **DTM live demonstration** in South Korea on March 2022
  - Public and official demos driven by **KBS**
  - Technical support by ETRI and SBG
- Smartphone with built-in chipset on-board, "**MarkONE**"
  - Supervised by **SBG**, chipset manufactured by **Saankhya Labs**

Commercialized vehicle receiver

Commercialized vehicle antenna

Commercialized vehicle receiver

Korea's major car manufacture will launch ATSC 3.0-ready vehicles in the US and Korea in 2024.

Summary of the Benefits of ATSC 3.0

1. **Convergence with Broadband**
   - ✓ ATSC 3.0 IP-based broadcast makes it possible to cooperate/converge with Broadband (4G/5G/Wi-Fi and others)
   - ✓ 'Seamless Experience' & 'Better Quality' are the commercialized examples of BC/BB convergence
2. **BICM chain**
   - ✓ Well-designed and-optimized structure provides superior performance than any other DTT standard thanks to the superiority of the latest LDPC code and NUC.
   - ✓ ATSC 3.0 is less than 1 dB away from Shannon Capacity in terms of BICM.
3. **Time interleaver**
   - ✓ Time diversity makes ATSC 3.0 have stable performance in various fast fading channels.
   - ✓ Comparing FeMBMS not having time-interleaver, ATSC 3.0 has a 3 dB to 11 dB performance advantage depending on vehicle speeds.
4. **Flexibility in terms of numerology**
   - ✓ ATSC 3.0 provides excellent flexibility for selecting various combinations of guard interval, FFT size, and pilot patterns, depending on the geographical size of the broadcasting network and service requirements.
   - ✓ However, in FeMBMS, guard interval, FFT size, and pilot pattern are fixed for given OFDM numerology.
5. **Layered Division Multiplexing**
   - ✓ Unique & differentiated technology (world 1st commercialized non-orthogonal multiplexing technology, a.k.a NOMA in 3GPP)
   - ✓ LDM provides significant performance gain (3 to 9 dB) over a traditional TDM/FDM schemes.