Layered Division Multiplexing (LDM) Summary

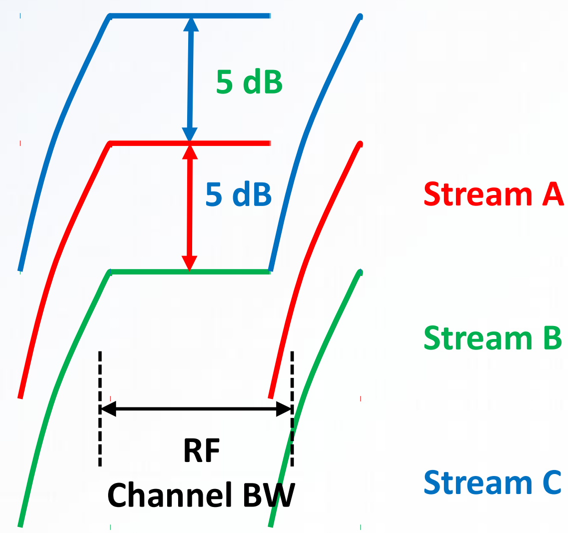
Conventional transport vehicle: single-decker bus.

Layered Division Multiplexing (LDM) is like a double-decker bus, more capacity with the same foot print – in 6 MHz RF channel.

It also provides flexibility for future growth: multi-decker bus, or adaptive-decker bus, with full backward compatibility (no impact to legacy system data rate).

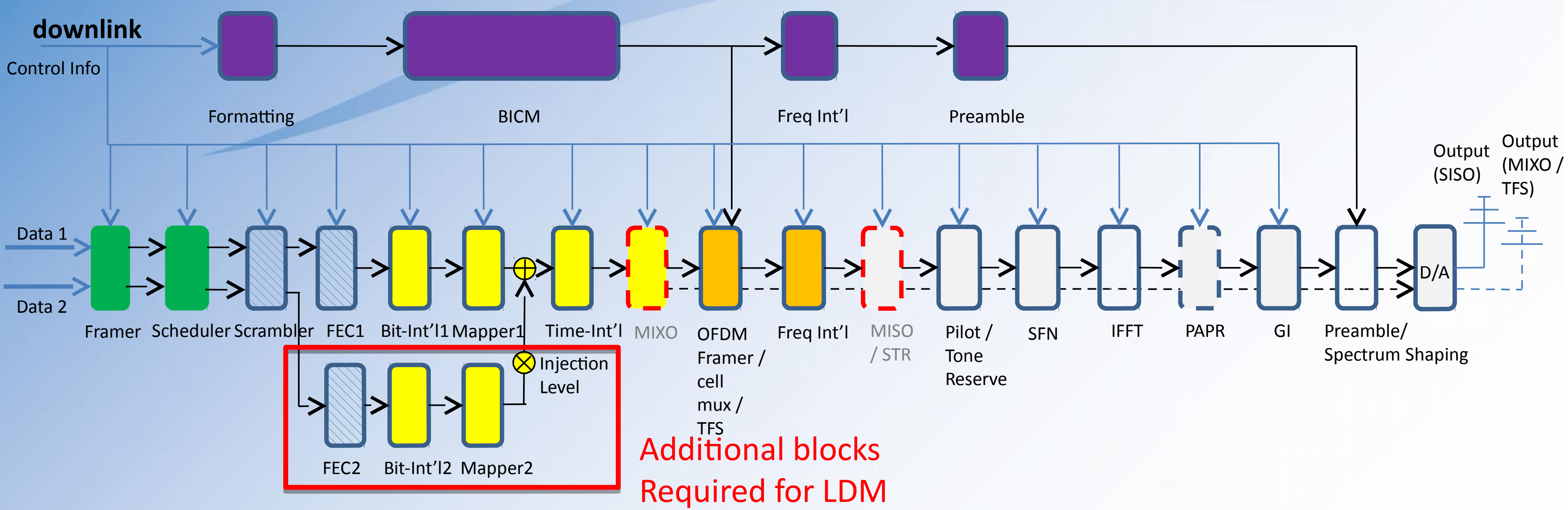
Layered Division Multiplexing

- LDM super-imposes multiple physical layer data streams with different power levels, channel coding and modulation schemes for different services and reception environments;
- It enables more flexible use of spectrum to deliver mobile HDTV and UHDTV simultaneously in one 6 MHz channel to mobile, indoor, and fixed reception terminals;
- 100% of RF bandwidth and 100% of the time are used to transmit the multi-layered signals for better time and frequency diversity, and robust reception;
- A receiver will decode the upper layer most robust signal first, cancel it from the received signal, and start decoding the second layer signal;
- LDM can have 3-6 SNR gain comparing with Traditional TDM system.



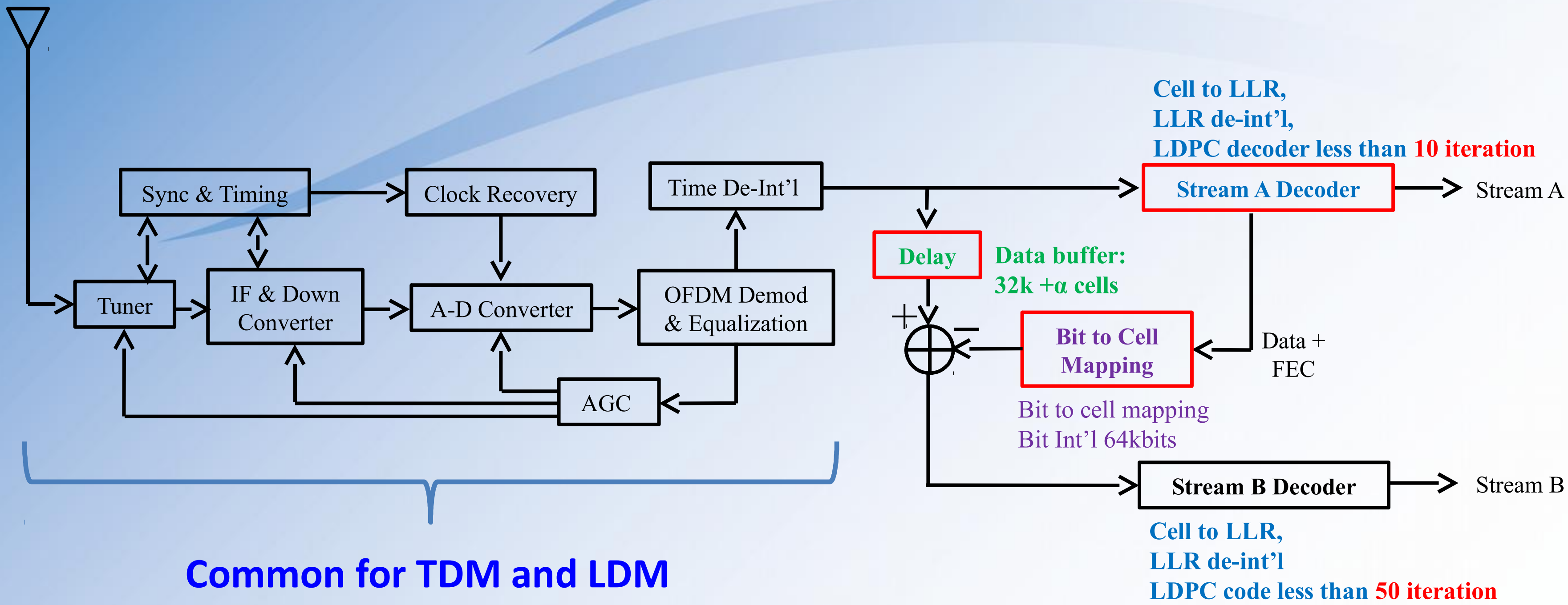
LDM system: hierarchical spectrum re-use to improve reception performance.

LDM Tx Functional Architecture



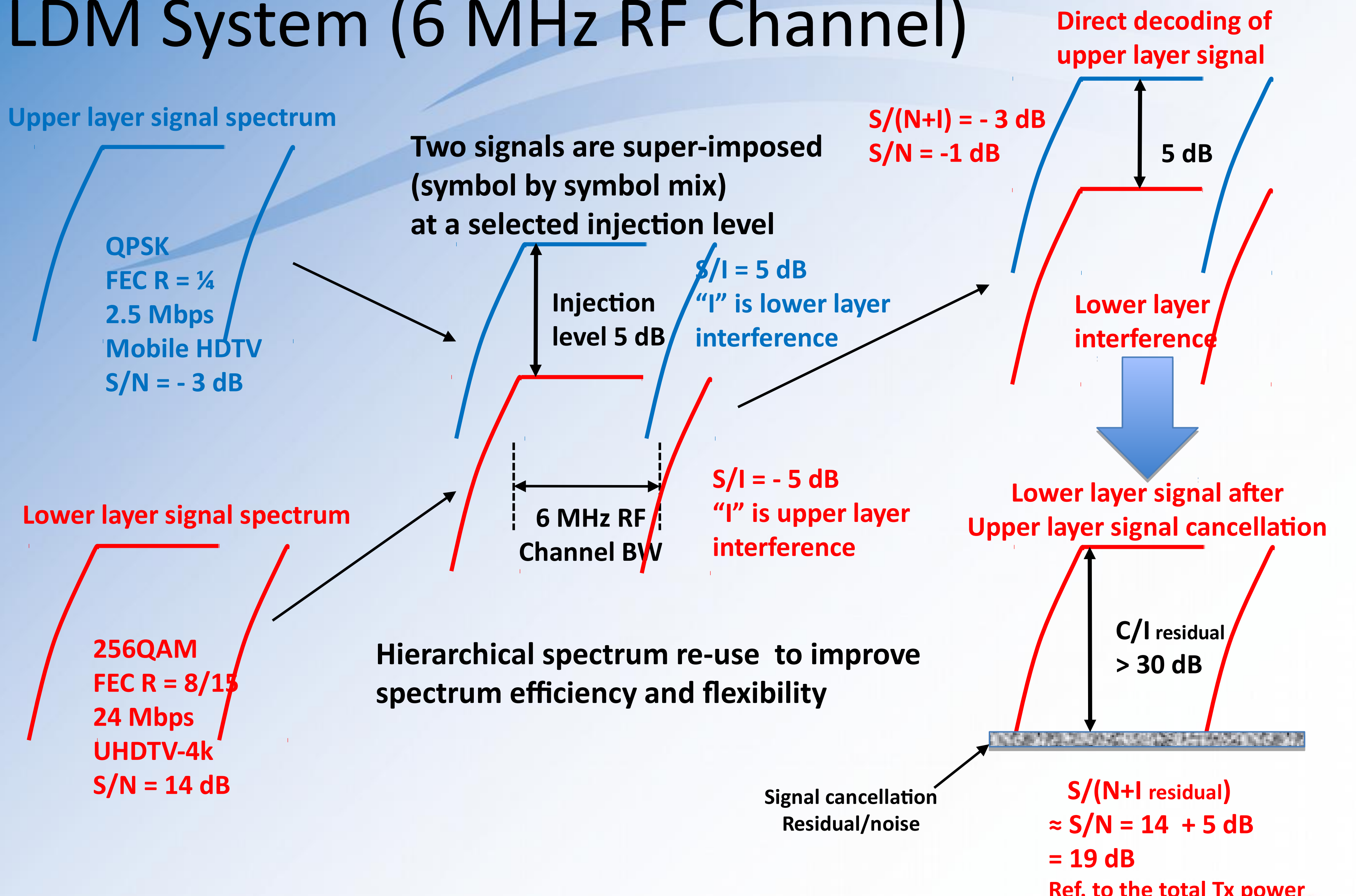
- LDM is independent to MIMO, MISO, PLP, TI, Pilots, GI, pre-amble and PAR;
- LDM receiver complexity increase is less than 10%;
- LDM SNR performance gain is 4-6 dB for AWGN, and even higher SNR gains for mobile and strong multipath channels, due to stronger FEC and modulation used.

Cloud Txn Receiver (two layers) Diagram:



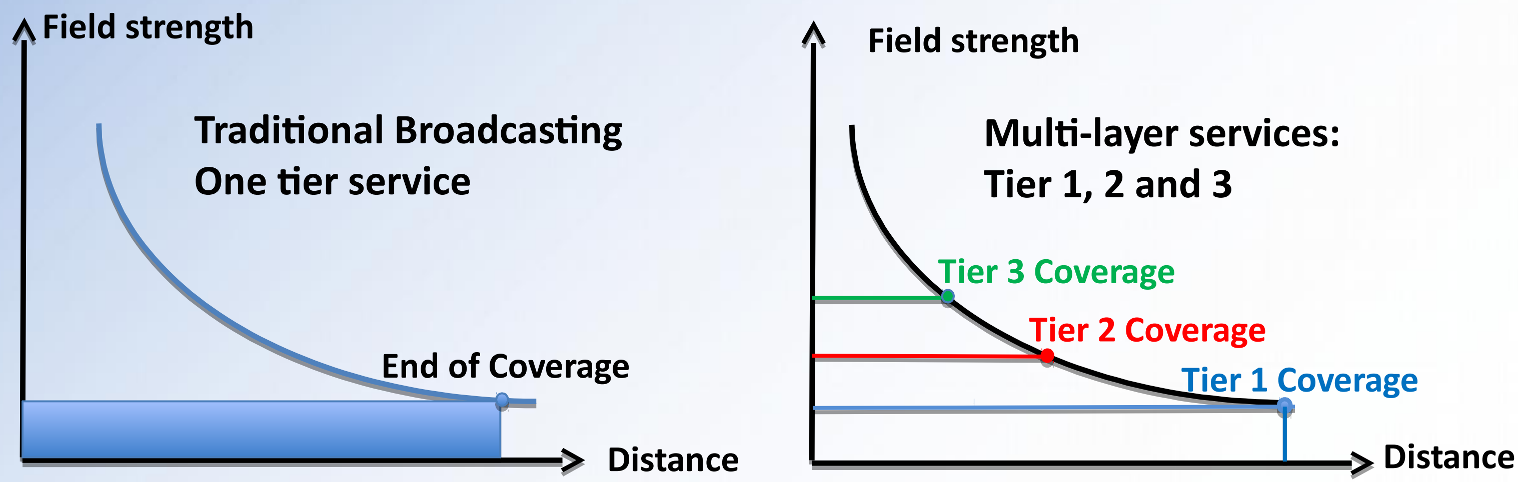
- A multi-layer system does not increase the receiver complexity by much;
- A large part of the circuits can be shared (tuner, sync, IF, ADC, AGC, equalizer, etc.);
- Upper layer needs FEC decoding, bit to symbol mapping, signal cancellation and DELAY data buffer;
- About 8% LDPC computation complexity increase and less than 10% memory increase for a 2-layer system receiver.

LDM System (6 MHz RF Channel)



More Flexible Use of Broadcasting spectrum

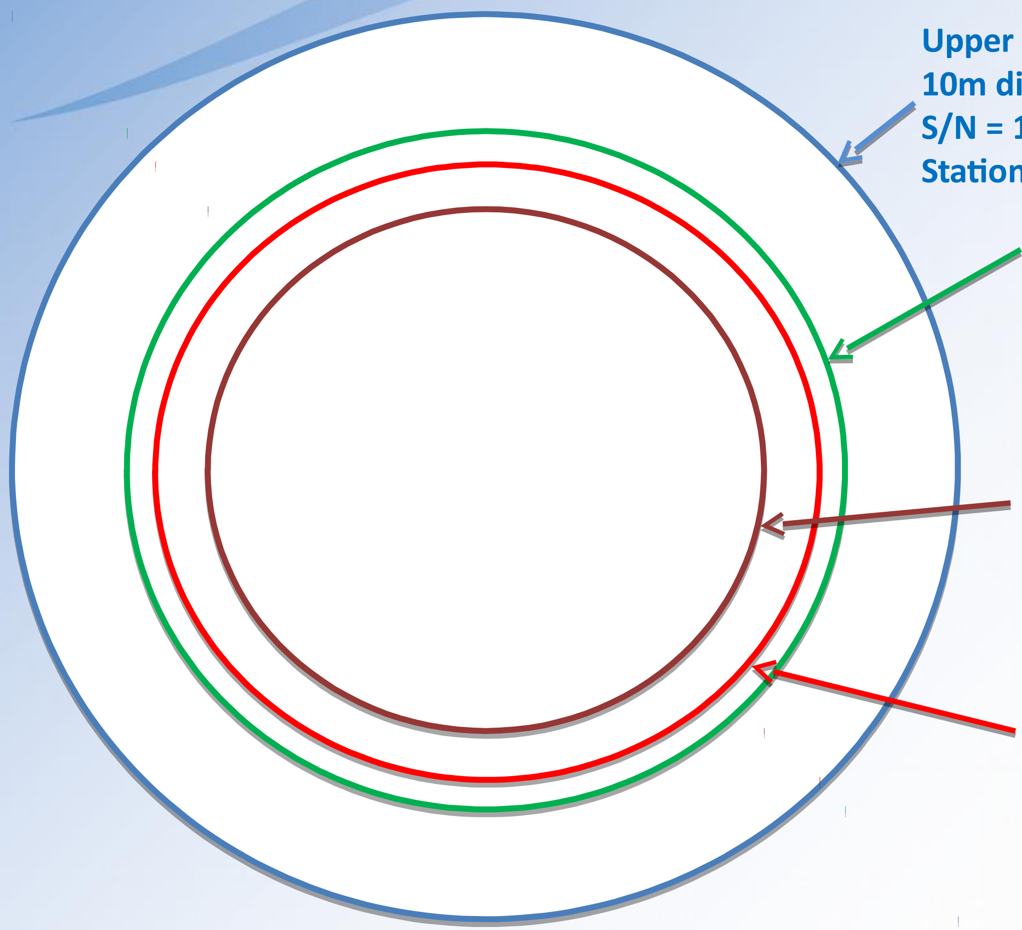
- In *point-to-point communications*, e.g., LTE, adaptive modulation and coding, as well as Tx power adaptation are used to fully explore the channel capacity;
- Broadcasting system is an *one-to-many communication*, the system is really designed to provide satisfactory service to the audiences at the End-of-Coverage;
- For audiences well inside the broadcast coverage area, they have very high field strength. This is not efficient use of channel capacity and those audiences can have better services;
- Solution: combine various services in one RF channel for tiered services.



Tiered coverage is not new, ACATS proposals, DVB-T/T2, ISDB-T, ATSC M/H all can do it. LDM can make it working better, with more robust mobile/handheld HDTV solution.

LDM 2-Layer System Coverage (outdoor)

with one robust mobile upper layer (S/N = 1.5 dB, 4 Mbps, 1080p/60 or 2 x 720p/60) and one high-data rate lower layer (S/N = +19 dB, 20 Mbps, 4k-UHD or multi-HDTV)



Upper layer fix reception:
10m directional antenna, F(50,90),
S/N = 1.5 dB, 4 Mbps, 1080p/60
Stationary HDTV, robust audio

Upper layer portable reception:
1.5m Omni-directional antenna,
S/N = 1.5 dB, 4 Mbps, 1080p
Portable/handheld HDTV (tablets),
Robust audio, F(50,90)

Upper layer mobile reception:
1.5m Omni-directional antenna,
S/N = 4.5 dB, 4 Mbps, 1080p HDTV
Vehicle speed (150+ km/h),
Robust audio, F(90,90)

Lower layer fix reception:
10m directional antenna,
S/N = 19 dB, 20 Mbps, 4k-UHD or multiple HDTV 1080p,
Immersive audio, F(50,90)

LDM Co-existence with other Technologies:

- A 2-layer LDM system, by nature, has one robust mobile/indoor PLP and one high data rate PLP for UHD or multiple HD services;
- LDM with layered transmission is naturally fit for Scalable Video Coding (SVC);
- Audio can be carried by robust mobile layer for extra-robustness;
- LDM can work with the traditional TDM/FDM to form 2-D or 3-D multiplexing;
- Backward compatible "Future Extension Layer (FEL)" can be added later, without impact the legacy services data rate.

LDM Flexibility:

- LDM is an enhanced TDM, which allows multi-layer transmission;
- A LDM system can do TDM, LDM, as well as mixed TDM/LDM;
- The injection level between layers is an important parameter to distribute the total transmitter power between layers;
- For example: A 6 dB injection level difference means 80% of the Tx power are assigned to mobile/indoor service, and 20% for fixed service;
- It gives broadcasters more flexibility!

Transition scenario and Future Extension Layer:

- During the transition period, an one-layer system can be deployed first to provide two 720p/60 HD mobile and indoor service at about 4 Mbps and SNR = -0.5 dB (AWGN);
- A lower layer can be added for 4k UHD or multiple HD fixed services, data rate ranges from 15 to 30 Mbps for high frame rate UHD at SNR = 14 to 24 dB;
- The two 720p/60 upper layer can be changed to one 1080p/60, if desired;
- Adding additional layers later without impact legacy services is one of the benefit on LDM: The legacy receiver will not go dark; the new service can be introduced seamlessly; CE can sell another round of new Rxs;
- The network is scalable and it can grow.

LDM vs. TDM System

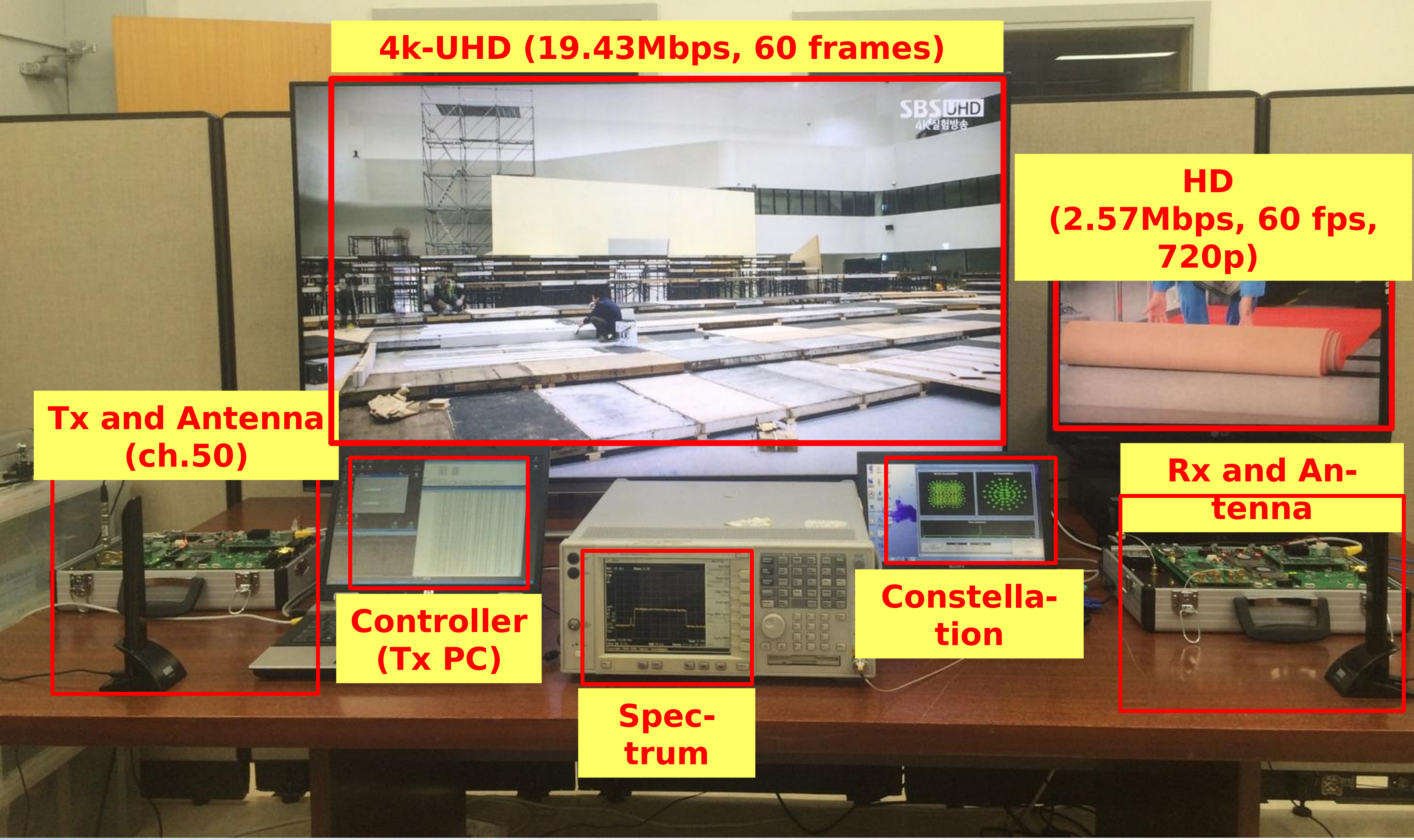
LDM (two layers) vs. DVB-T2+NGH (single layer, baseline code, no pre-amble) 6 MHz RF Channel (-4 dB Lower Layer Injection)								
LDM System			Mobile 55% Capacity		Mobile 40% Capacity		Mobile 30% Capacity	
Upper layer (robust-mod)	Data rate	SNR	Data rate	SNR	Data rate	SNR	Data rate	SNR
	2.0 Mbps QPSK 3/15	-2.0 dB	2.0 Mbps QPSK 6/15	-0.4 dB	2.0 Mbps QPSK 8/15	1.3 dB	2.1 Mbps QPSK11/15	3.7 dB
Upper layer (mid-rate)	2.7 Mbps QPSK 4/15	-0.3 dB	2.7 Mbps QPSK 8/15	1.3 dB	2.7 Mbps QPSK 11/15	3.7 dB	2.6 Mbps 16Q 7/15	5.3 dB
Upper layer (high-rate)	4.1 Mbps QPSK 6/15	2.7 dB	4.1 Mbps 16Q 6/15	4.3 dB	4.0 Mbps 16Q 8/15	6.4 dB	4.1 Mbps 16Q 11/15	9.6 dB
Low layer with -4 dB injection			Fixed(TDM) 45%		Fixed(TDM) 60%		Fixed(TDM) 70%	
Low-rate	14.3 Mbps 64Q 7/15	14.6 dB	14.4 Mbps 256Q 11/15	18.9 dB	14.4 Mbps 64Q 11/15	14.4 dB	15.3 Mbps 64Q 10/15	13.0 dB
Mid-rate1	20.5 Mbps 64Q 10/15	18.5 dB	19.6 Mbps 1kQ 12/15	25.6 dB	21.0 Mbps 256Q 12/15	20.7 dB	20.4 Mbps 256Q 10/15	17.3 dB
Mid-rate2	24.6 Mbps 256Q 9/15	21.2 dB	-	N/A	24.0 Mbps 1kQ 11/15	23.5 dB	24.4 Mbps 256Q 12/15	20.7 dB
High-rate	30.1 Mbps 256Q 11/15	24.4 dB	-	N/A	-	N/A	30.6 Mbps 1kQ 12/15	25.6 dB

Hardware (upper layer mid-rate)

Hardware (low layer mid-rate1)

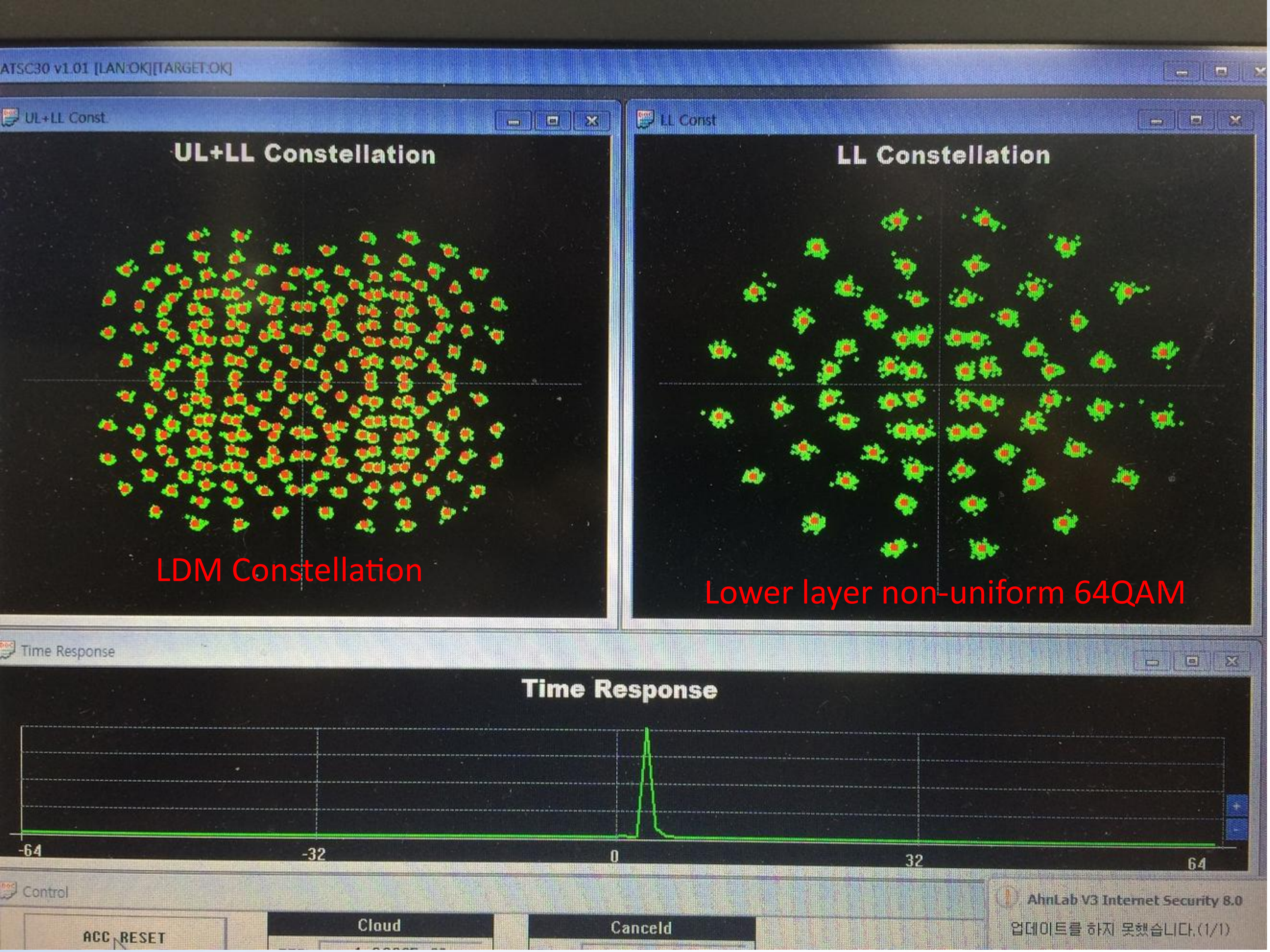
All SNR power levels are referenced to the total RF in-band power (of all layers)

LDM: 16K FFT, GI= 1/16, P12,2.   TDM: Fixed 32K FFT, GI = 1/32, P24,4; Mobile 8K FFT, GI = 1/8, P6,2.



LDM Prototype Hardware & Demo configuration

Mobile/Indoor: 2.6 Mbps 720p SNR = -0.4dB. High data rate: 20Mbps 4kUHD SNR = 18.5 dB.



LDM Constellation on the Prototype Hardware

ETRI Hardware Parameters

Hardware Parameters @ 6MHz		
OFDM Waveform	**FFT Size**	16K (16384)
	CP Size	1024 (6.25%)
	# of guard subcarriers	2751 (16.79%)
	# of used subcarriers	13633 (83.21%)
	# of pilot subcarriers	1197 (7.31%, PP2(12,2)) Scattered/continual/edge pilots (**from T2**)
	# of data subcarriers	12436 (75.9%)
	OFDM sample length	7/48us (~0.1458 us)
	CP length	0.1493 ms
	Useful OFDM symbol length	2.3893 ms
	OFDM symbol length (Ts)	**2.5387 ms**
	Subcarrier spacing (Δf)	418.527 Hz
	Occupied BW	**5.7058 MHz**
	Preamble	Hierarchical (2%) (**from ETRI proposal**)
Modulation and Coding	UL BICM	4/15 LDPC (64k) & QPSK **(from baseline)**
	LL BICM	10/15 LDPC (64k) & 64NUC **(from baseline)**
	Injection level	-4 dB (variable from -3 ~ -10 dB)
	Time Interleaver	[illegible]
	Frame size	[illegible]
	Frame size	97 OFDM symbols **246.25 ms**

Laboratory Test Results

- Required C/N after LDPC decoding
- AWGN, DVB-F1/P1, 0dB echo performance
  - BER = 1 x 10^{-6}
  - Step size = 0.1 dB
- TU-6 performance (UL) @ PER = 0.1%

Injection Level = -4 dB		Gaussian Channel (AWGN)	Ricean Channel (DVB F1)	Rayleigh Channel (DVB P1)	0dB Echo Channel @ 73us	TU-6 @60km & 120km/h
Simulation	UL	-0.5 dB	-0.3 dB	1.3 dB	1.7 dB	3.0, 3.5 dB
	LL	18.2 dB	18.6 dB	20.9 dB	21.8 dB	-
HW test	UL	-0.3 dB	-0.1 dB	1.5 dB	1.8 dB	4.1, 4.6 dB
	LL	18.5 dB	18.9 dB	21.6 dB	22.2 dB	-

Both Hardware and Simulation are using DFT-base channel estimation.
Simulation assumes perfect synchronization. HW performance can be further improved.

LDM vs. ATSC Mobile (mix & 1/4 rates)

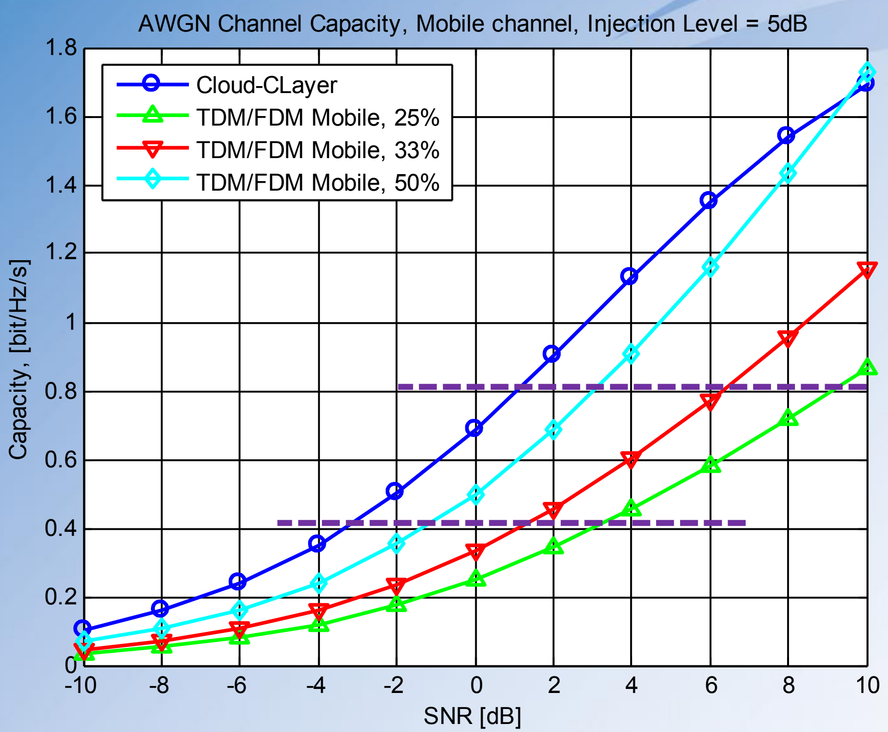
	LDM	ATSC Mobile		LDM vs ATSC Mobile Mixed Rate	LDM vs ATSC Mobile Quarter Rate
Mobile service	2.7 Mbps	2.2 Mbps	1.4 Mbps	23% better	93% better
Coding mode	QPSK, 1/4 code	Mixed Rate	1/4 Rate	-	-
SNR@AWGN	-1 dB	7 dB	3.5 dB	8 dB better	4.5 dB better
SNR@TU-6 (mobile)	+3 dB	17 dB	13 dB	14 dB better	10 dB better
Fixed service	14 Mbps Two 1080p HEVC	11 Mbps One 1080i MPEG-2		3 Mbps higher data rate or 27% better	
Mod & coding	64QAM + 7/15 LDPC	8-VSB, Trellis + R-S		-	
Injection level	5 dB below mobile	TDM with mobile		-	
SNR @AWGN	15 dB	15 dB		Same	
SNR @0 dB echo (SFN)	19 dB	22+ dB		3+ dB improvement	

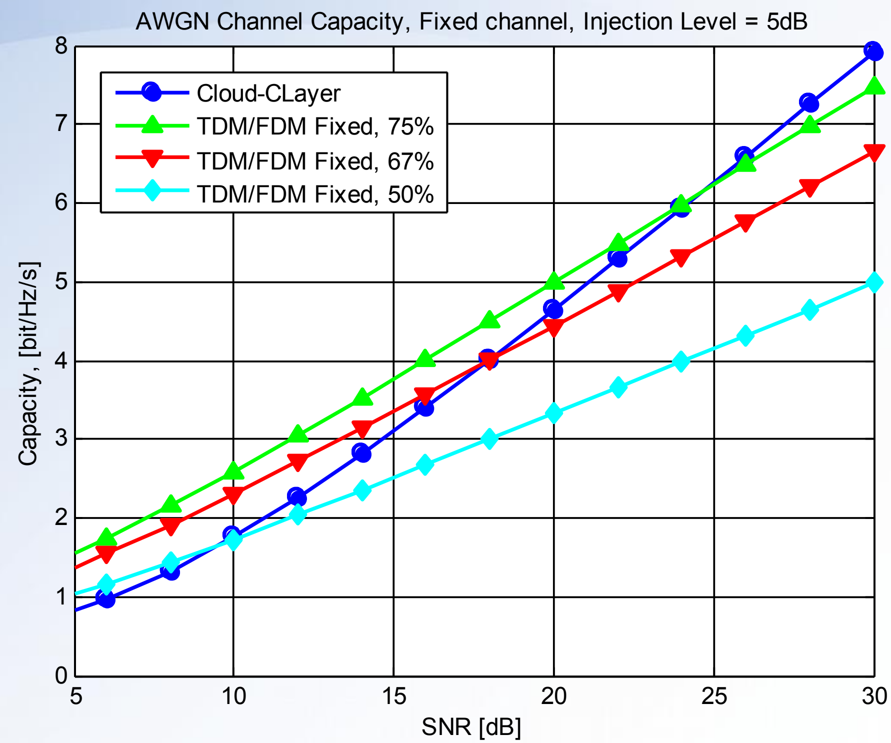
Conclusions and Suggestions:

- LDM can achieve significant performance gains (3 to 6 dB) and can have backward compatible future extension;
- LDM can co-exist with all other proposed new technologies;
- LDM has been tested, cross-checked, hardware built;
- LDM should be accepted as the baseline technology for the ATSC 3.0 PHY standard, expeditiously, so that there is sufficient time to build ATSC 3.0 compliant hardware for laboratory and field tests and to maintain the standardization time table.

Thank You

Channel Capacity: LDM vs. Single Layer TDM





LDM upper layer capacity vs. TDM single layer system with 50%, 33.3% and 25% capacity for mobile services:

At 0.4 b/s/Hz, the LDM upper layer is 1.8, 4.3 and 6.3 dB better, respectively.

At 0.8 b/s/Hz, the LDM upper layer is 1.8, 5.2 and 8.1 dB better, respectively.

LDM lower layer capacity vs. TDM single layer system with 50%, 66.7% and 75% fixed services:

The LDM lower layer curve (dark blue) crossed 50% curve at 8 dB, 66.7% curve at 18 dB, and 75% curve at 24 dB.

It has advantage at high data rate!