

**3GPP TSG RAN1#41 Meeting
Athens, Greece, May 9-13 2005**

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Agenda Item: 13.2

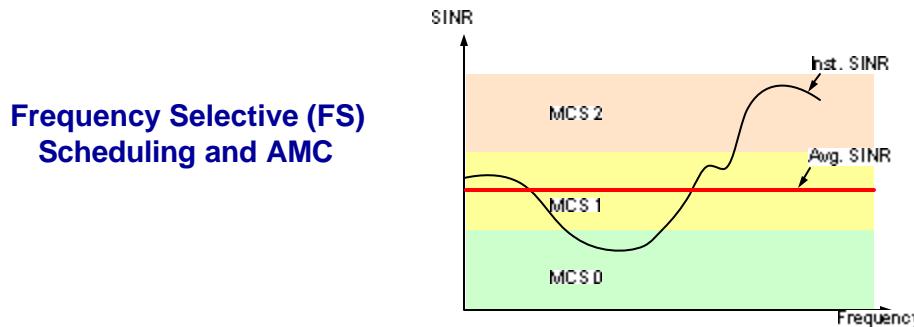
Source: Motorola

Title: EUTRA Downlink Numerology

Document for: Discussion

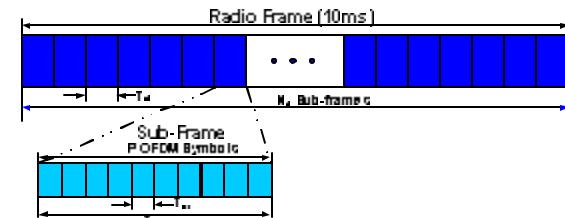
Downlink Transmission Scheme

- OFDM appears to be best long-term DL MA choice for EUTRA LTE SI
- Key OFDM Opportunities
 - *Flexible Time-frequency Scheduling* – supporting efficient system operation over broadband, time- and frequency-dispersive channels
 - *Fully Scalable Bandwidth Modes* – to suit varying spectrum allocations and regulatory regimes
 - *Low UE Complexity* – including low complexity UE receiver designs, especially in high bandwidth modes and with MIMO
 - *System Efficiency* – including one-cell frequency reuse and efficient support of broadcast services
- ‘Classical’ OFDM employing guard interval (cyclic prefix) preferred



Downlink Frame Structure

- **Retain UTRA 10ms core radio frame**
 - $N_{rf} = 16$ to 20 **subframes** per radio frame
 - Subframe candidates 0.5, 0.556, 0.625, 0.667ms
 - **Subframe integer number of OFDM symbols**
- **A frame (TTI) is constructed from integer number of subframes**
 - **More than one frame size beneficial**
 - Provides optimal mapping of QoS traffic classes to frame types as bandwidth mode changes
 - **Short frames: constructed from a single subframe**
 - Efficient support for small packet transmissions with lowest latency requirements
 - **Long frames: constructed from multiple subframes**
 - Low latency
 - Enhanced coverage
 - Reduced control signaling overhead
 - Minimum fragmentation (esp. low BW modes and/or FS scheduling)



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Subcarrier Spacing

Transmitter Distortion – Impact on Achievable SNR

- Primary Sources of Base Station Power Amplifier (PA) Distortion
 - PA nonlinearities and PAR suppression methods (e.g. clipping)
 - Synthesizer phase noise and modulator amplitude and phase imbalance
 - Site engineering effects, including connector non-linearities etc.
- Contemporary Transmitter EVM Specifications

Source	Configuration	EVM (%)	SNR (dB)
3GPP TS 25.104 V6.8.0 (2004-12), Section 6.8.2.1	QPSK	17.5	15.1
	<u>16-QAM</u>	<u>12.5</u>	<u>18.1</u>
IEEE Std 802.16-2004, OFDMA Mode, Section 8.4.12.3 ^{1,2}	QPSK, R=1/2	15.1	16.4
	QPSK, R=3/4	12.3	18.2
	16QAM, R=3/4	5.5	25.2
	64QAM, R=3/4	2.7	31.4

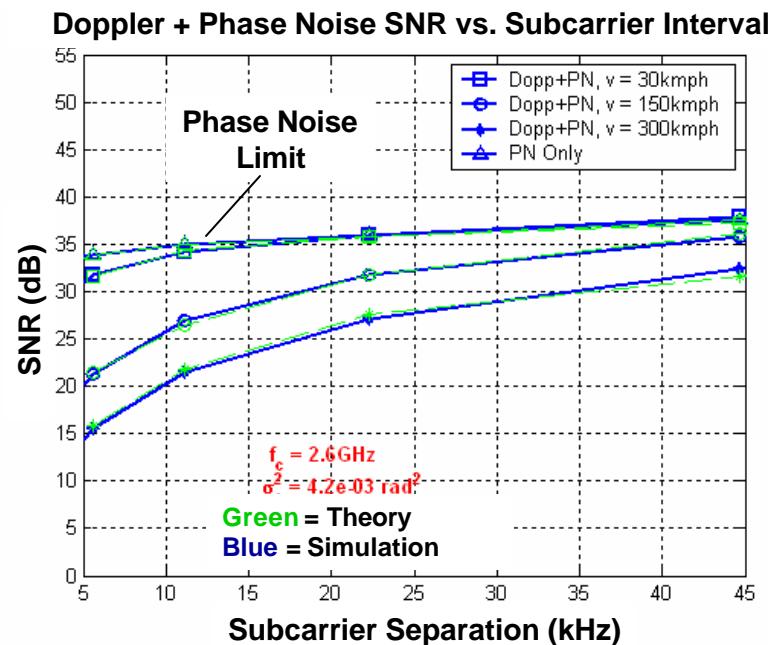
Notes:

1. EVM specified to limit Eb/No increase due to transmitter distortion to 0.5dB.
2. Commercial performance specification subject to further discussion.

- Observation
 - Current HSDPA PA EVM requirement **limits per sub-carrier SNR to 18dB**
 - Assuming ‘white’ error process over occupied sub-carriers at base station
 - EUTRA PA EVM requirement will **need to be tightened** to remove transmitter as limiting element in link achievable SNR – UE phase noise may not be primary source

Asymptotic SNR – Doppler and Phase Noise

- Assumptions
 - Single-ray Rayleigh-faded channel
 - Carrier frequency = 2.6GHz
 - UE velocity = 30-300km/h
 - UE total phase noise standard deviation = 6.5e-2 rads (4.2e-3 rads²)
- Observations
 - Phase noise is SNR-limiting process at less than 30km/h
 - But, phase noise SNR limit could be ~30dB



Subcarrier Spacing

- A single 17-18 kHz subcarrier spacing may be sufficient
 - Total overhead is better for 17-18 kHz than 22.5/11.25 kHz
 - Losses for 17-18 kHz at higher speeds / modulations are reasonable
 - 30 dB SNR limit from Phase Noise + Doppler
 - Achieved with 17-18 kHz spacing at 150 kph
 - 30 dB SNR limit from 3.5% EVM
 - 3.5% EVM already difficult, to get lower may not be practical
 - Target ~18 dB for R=3/4 64 QAM, ~21 dB for R=3/4 256 QAM
 - ~0.5 dB loss for 150 kph and R=3/4 64 QAM
 - $17.5\text{dB} = 10\log_{10}(1/(10^{(-30/10)} + 10^{(-30/10)} + 10^{(-18/10)}))$
 - ~1.0 dB loss for 150 kph and R=3/4 256 QAM
 - $20.0\text{dB} = 10\log_{10}(1/(10^{(-30/10)} + 10^{(-30/10)} + 10^{(-21/10)}))$
- Degradations due to 11-16kHz are under investigation

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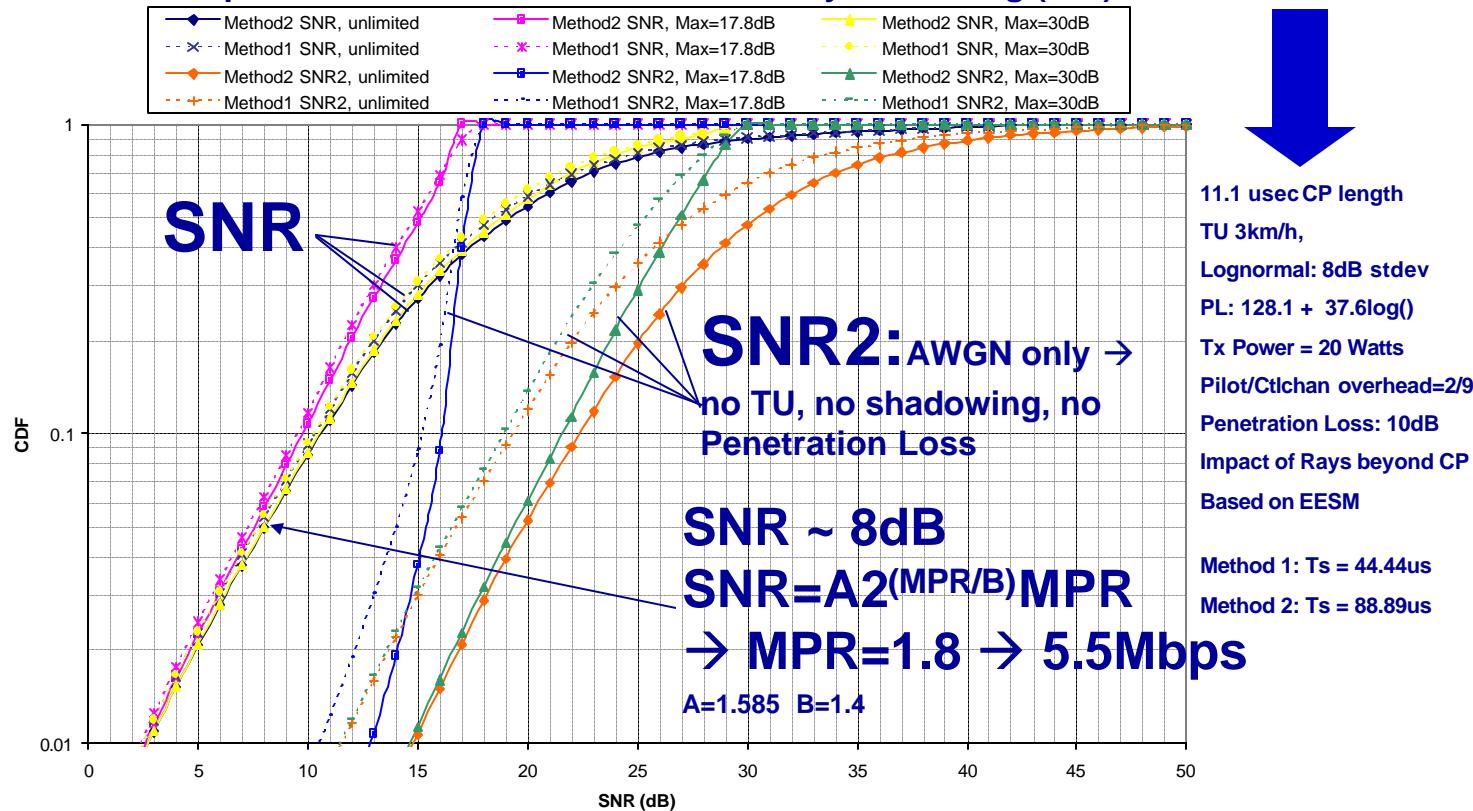
CP Length

Cyclic Prefix Analysis (Unicast)

- **Target 5 us**
 - Requirements [RP-050155] and field data state rms delay spread
 - 3us rms delay spread requirement
 - 2-3us rms observed in Chicago / Schaumburg field data [VTC2004]
 - Some channel energy can exist **beyond the RMS delay spread**
 - Add CP to capture some amount of energy in rays beyond 3us
 - **5us CP includes some margin for implementation issues**
 - Reduces impact of timing estimation noise
 - Helps to reduce UE complexity
- **Danger of choosing too small a value**
 - Making the CP too small is more detrimental to capacity curve than making it too large [VTC2004]

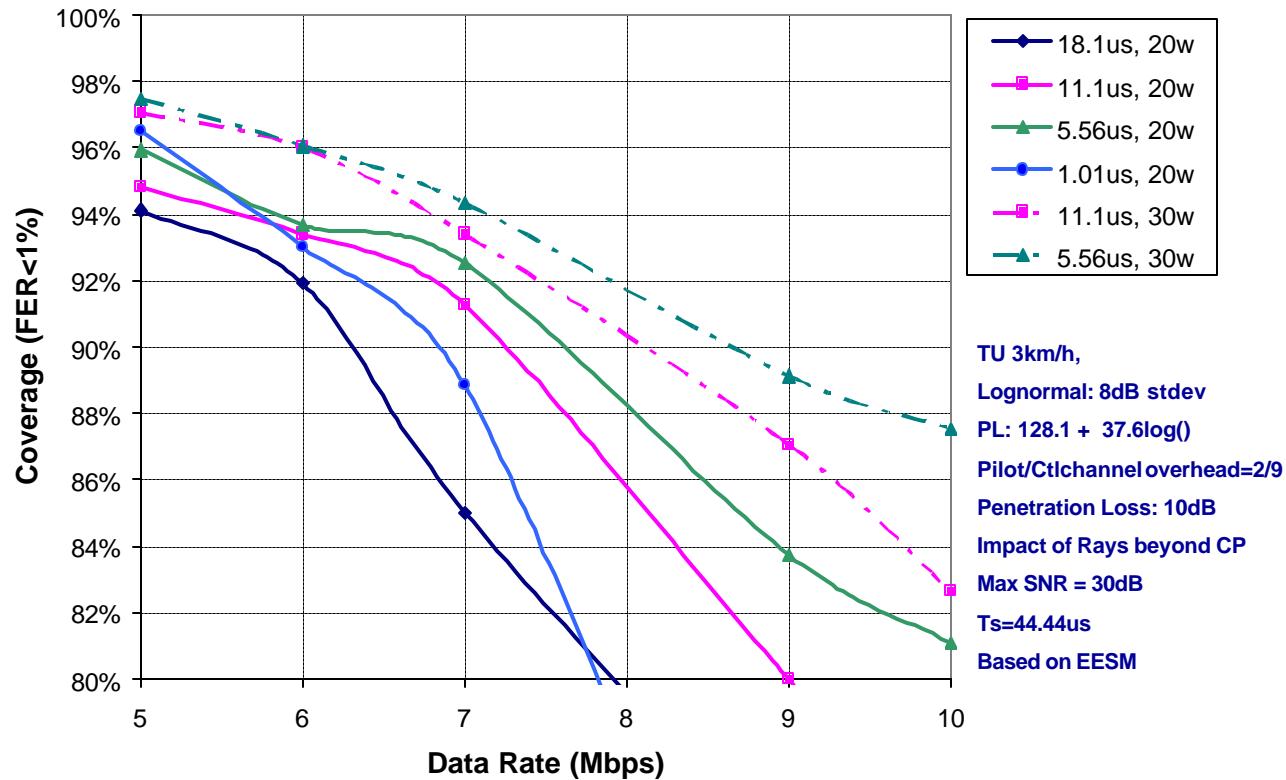
Broadcast SNR/SNR2 CDF for 2.8km site-to-site

- CDF of per-burst SNR after 2-branch diversity combining (2x2) – other ovhd inc.



Simulcast Coverage vs. Data Rate for 2.8km site-to-site

- CP length impact on Coverage for 20W and 30W → <11us OK for 2.8km s-to-s



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Numerology

Numerology Key Drivers

- **Cyclic Prefix Duration (Guard Interval)**
 - ~5 us for unicast subframes, ~12us for broadcast subframes
 - CP should also be integer number of samples (preferred, but not essential)
- **Constant useful symbol duration across all BW modes of a given frame type**
- **Subframe integer number of OFDM symbols**
 - Broadcast subframes have e.g., 1- 2 fewer symbols than unicast
- **Occupied Bandwidth**
 - Target ~18 MHz for 20 MHz channel BW (4.5MHz for 5MHz channel)
- **Subcarrier Spacing**
 - Avoid too small (loss from phase noise, Doppler, etc.) or too large (lose OFDM benefit)
 - **Current target 17-25 kHz**
- **Subchannel Bandwidth (F-Domain Allocable Unit)**
 - Supports efficient frequency-selective resource allocation and scheduling
 - All subchannels for a BW mode should have same number of subcarriers
 - Number of subchannels preferably scales with nominal BW
 - 200kHz channel fine-grain granularity desirable, but need not be *exactly* 200kHz
- **Time-Domain Efficiency**
 - Efficient guard interval (cyclic prefix): suggests longer symbols
 - Efficient TDM pilot & control: suggests shorter symbols and/or longer frame
- **FFT Complexity**
 - Not a *major* concern, power-of-2 FFT core is straightforward
 - 15MHz operation adds some complexity (either use mixed radix for e.g. 768, or 20MHz FFT w/ fewer occupied subcarriers)
 - **Target ~50-75% subcarrier occupancy**

Current Preferred Options (No Preference Order)

- 20-25 kHz subcarrier spacing

Option	Subframe Duration (ms)	Syms / Subframe	Useful Sym Duration (us)	FFT Size (5MHz)	Used Sub-Carriers	Subcarrier Spacing (kHz)	CP Overhead (us)
1	0.5	10, 9	44.44	256	200	22.50	5.55, 11.11
2	0.67	14, 12	42.62	256	192	23.46	5.00, 12.93

- 17-18 kHz subcarrier spacing

Option	Subframe Duration (ms)	Syms / Subframe	Useful Sym Duration (us)	FFT Size (5MHz)	Used Sub-Carriers	Subcarrier Spacing (kHz)	CP Overhead (us)
1a	0.5	8, 7	57.14	512	256	17.5	5.36, 14.29
2b	0.67 ²	11, 10	55.41	512	250	18.05	5.19, 11.26
3	0.625 ¹	10, 9	57.35	512	256	17.44	5.15, 12.10
4	0.556	9, 8	56.44	512	256	17.72	5.30, 13.00

Notes: 1 & 2. Lowest overhead with good time granularity and moderate subcarrier separation

- Broadcast GI
 - Symbol reduction allows different GIs (note no change to sub-carrier spacing)
 - E.g. Option 1: 10sym:5.56usec; 9sym:11.11usec; 8sym:18.06us; 7sym: 26.98us
 - Only two GI shown in table

Overhead Comparison (1 of 2)

- **Cases compared**
 - Option 1 → Fixed $Df = 22.5\text{kHz}$ with sub-frame symbol removal for BC
 - Unicast: $T_{CP} = 5.56 \mu\text{s}$ Broadcast: $T_{CP} = 11.12 \mu\text{s}$ $T_{sub} = 0.5\text{ms}$
 - Option 1a → Fixed $Df = 17.5\text{kHz}$ with sub-frame symbol removal for BC
 - Unicast: $T_{CP} = 5.36 \mu\text{s}$ Broadcast: $T_{CP} = 14.29 \mu\text{s}$ $T_{sub} = 0.5\text{ms}$
 - Option 2b → Fixed $Df = 18.1\text{kHz}$ with sub-frame symbol removal for BC
 - Unicast: $T_{CP} = 5.19 \mu\text{s}$ Broadcast: $T_{CP} = 11.26 \mu\text{s}$ $T_{sub} = 0.667\text{ms}$
 - Option 3 → Fixed $Df = 17.4\text{kHz}$ with sub-frame symbol removal for BC
 - Unicast: $T_{CP} = 5.15 \mu\text{s}$ Broadcast: $T_{CP} = 12.10 \mu\text{s}$ $T_{sub} = 0.625\text{ms}$
 - Option 1* → Divide Df in half for BC with $Df = 22.5\text{kHz}$ for UC
 - Unicast: $T_{CP} = 5.56 \mu\text{s}$ Broadcast: $T_{CP} = 11.12 \mu\text{s}$ $T_{sub} = 0.5\text{ms}$

N_s : Number of symbols per sub-frame

Df : Sub-carrier spacing

T_s : Useful symbol duration

T_{CP} : Length of cyclic prefix or guard interval

n : Number of pilot and control symbols per short or long frame (TDM or FDM or both)

T_{sub} : sub-frame duration

Overhead Comparison (2 of 2)

Option	T_{sub} (ms)	N_s (sym)	D_f (kHz)	T_s (msec)	T_{CP} (msec)	CP overhead	Total overhead (CP + pilot + control)				
							Frame = 1 x T_{sub}		Frame = 4 x T_{sub}		
							$n = 1$	$n = 2$	$n = 3$	$n = 5$	$n = 6$
broadcast unicast											
1	0.5	10	22.5	44.44	5.56	11.1%		30.0%	38.8%	23.4%	25.6%
1a	0.5	8	17.5	57.14	5.36	8.6%		32.0%	43.4%	23.5%	26.4%
2b	0.667	11	18.05	55.41	5.19	8.6%		25.9%	34.1%	19.7%	21.7%
3	0.625	10	17.44	57.35	5.15	8.2%		27.2%	36.3%	20.4%	22.6%
1*	0.5	9	22.5	44.44	11.12	20.0%	33.4%	41.7%		35.4%	37.5%
1a	0.5	7	17.5	57.14	14.29	20.0%	35.7%	46.4%		38.4%	41.1%
2b	0.667	10	18.05	55.41	11.26	16.9%	28.3%	36.3%		30.3%	32.3%
3	0.625	9	17.44	57.35	12.10	17.4%	29.9%	38.6%		32.1%	34.2%
1*	0.5	5	11.25	88.89	11.12	11.1%	30.0%	47.5%		34.4%	38.8%

- Option 2b and 3 with moderate Δf have **lowest unicast CP overhead** and best **overall total overhead efficiency for both unicast and broadcast**
 - FDM of data and control/pilot may help the 1* option (i.e., non-integer n in table)
- Pilot overhead scales with frame size i.e. one pilot symbol per subframe

Summary of Numerology Investigation

- **Unicast**
 - Lowest total overhead with 0.625ms and 0.667 ms subframes
 - 17-18 kHz sub-carrier spacing good Doppler performance at 150KHz
 - **Target GI: ~5 usec**
 - Adequate for delay spread in very large cells
- **Broadcast**
 - A single 17-18 kHz subcarrier spacing may be sufficient
 - **At least two guard intervals needed**
 - Smallest could be primarily for UC
 - Medium could be primarily for BC (<2km R)
 - Largest could be primarily for BC (~5km+ R)
 - **Target GIs: ~5us, 11-14us, 20-28us**
 - Assume 2.8km site-to-site or less covers majority of UTRA/EUTRA sites
 - Large cells also covered but overall EUTRA design not compromised
 - Symbol removal achieves larger GI
- **A joint work item with RAN4 and their agreement / view is also needed for issues like EVM, Phase Noise, Doppler, etc**

UC – unicast; BC – broadcast; GI – guard interval;

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Detailed Numerology Options

Option 1 example

- **0.5ms subframe**
 - Short frame = 1 subframe
 - Long frame = 4 or 6 subframes
- **44.44us useful symbol duration**
 - 22.5kHz sub-carrier separation
- **Multiple GIs supported**
 - 5.56 us (10 sym / subframe)
 - 11.11 us (9 sym / subframe)
 - 18.06 us (8 sym / subframe)
 - 26.98 us (7 sym / subframe)
 - Fully scalable
 - i.e. scalable and integer number of samples over GI and useful symbol for unicast and broadcast modes
- **18 MHz occupied BW (20MHz)**
 - 4.5MHz occupied BW (5MHz)
- **Subchannel (a.k.a. sc group)**
 - 562.5 kHz = 25 subcarriers
 - 32, 24, 16, 8, 4, or 2 subchannels

Normal Subframe

Parameter	Carrier Bandwidth (MHz)					
	20	15	10	5	2.5	1.25
frame duration (ms)	0.5	0.5	0.5	0.5	0.5	0.5
FFT size	1024	768	512	256	128	64
subcarriers (occupied)	800	600	400	200	100	50
symbol duration (us)	50	50	50	50	50	50
useful (us)	44.44	44.44	44.44	44.44	44.44	44.44
guard (us)	5.56	5.56	5.56	5.56	5.56	5.56
CP Efficiency (%)	12.50%	12.50%	12.50%	12.50%	12.50%	12.50%
guard (samples)	128	96	64	32	16	8
subcarrier spacing (kHz)	22.5	22.5	22.5	22.5	22.5	22.5
occupied BW (MHz)	18	13.5	9	4.5	2.25	1.125
BW Efficiency (%)	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%
subchannels	32	24	16	8	4	2
subcarriers/subchannel	25	25	25	25	25	25
subchannel BW (kHz)	562.5	562.5	562.5	562.5	562.5	562.5
symbols per frame	10	10	10	10	10	10
16QAM data rate (Mbps)	51.20	38.40	25.60	12.80	6.40	3.20

Broadcast Subframe

Parameter	Carrier Bandwidth (MHz)					
	20	15	10	5	2.5	1.25
frame duration (ms)	0.5	0.5	0.5	0.5	0.5	0.5
FFT size	1024	768	512	256	128	64
subcarriers (occupied)	800	600	400	200	100	50
symbol duration (us)	55.5556	55.5556	55.5556	55.5556	55.5556	55.5556
useful (us)	44.44	44.44	44.44	44.44	44.44	44.44
guard (us)	11.11	11.11	11.11	11.11	11.11	11.11
CP Efficiency (%)	25.00%	25.00%	25.00%	25.00%	25.00%	25.00%
guard (samples)	256	192	128	64	32	16
subcarrier spacing (kHz)	22.5	22.5	22.5	22.5	22.5	22.5
occupied BW (MHz)	18	13.5	9	4.5	2.25	1.125
BW Efficiency (%)	90.00%	90.00%	90.00%	90.00%	90.00%	90.00%
subchannels	32	24	16	8	4	2
subcarriers/subchannel	25	25	25	25	25	25
subchannel BW (kHz)	562.5	562.5	562.5	562.5	562.5	562.5
symbols per frame	9	9	9	9	9	9
16QAM data rate (Mbps)	44.80	33.60	22.40	11.20	5.60	2.80

Option 2b example

- **0.667ms subframe**
 - Short frame = 1 subframe
 - Long frame = 3 subframes
- **55.41us useful symbol duration**
 - 18.05kHz sub-carrier separation
- **Multiple GIs supported**
 - 5.19 us (11 sym / subframe)
 - 11.26 us (10 sym / subframe)
 - 18.66 us (9 sym / subframe)
 - 27.92 us (8 sym / subframe)
 - Scalable
 - Not always integer number of samples over GI. Useful symbol for unicast and broadcast modes
- **18 MHz occupied BW (20MHz)**
 - 4.51MHz occupied BW (5MHz)
- **Subchannel (a.k.a. sc group)**
 - 451.2 kHz = 25 subcarriers
 - 40, 30, 20, 10, 5, or 2.5 subchannels

Normal Subframe

Parameter	Carrier Bandwidth (MHz)					
	20	15	10	5	2.5	1.25
frame duration (ms)	0.666667	0.666667	0.666667	0.666667	0.666667	0.666667
FFT size	2048	1536	1024	512	256	128
subcarriers (occupied)	1000	750	500	250	125	62.5
symbol duration (us)	60.606	60.606	60.606	60.606	60.606	60.606
useful (us)	55.41	55.41	55.41	55.41	55.41	55.41
guard (us)	5.19	5.19	5.19	5.19	5.19	5.19
CP Efficiency (%)	9.38%	9.38%	9.38%	9.38%	9.38%	9.38%
guard (samples)	192	144	96	48	24	12
subcarrier spacing (kHz)	18.05	18.05	18.05	18.05	18.05	18.05
occupied BW (MHz)	18.05	13.54	9.02	4.51	2.26	1.13
BW Efficiency (%)	90.23%	90.23%	90.23%	90.23%	90.23%	90.23%
subchannels	40	30	20	10	5	2.5
subcarriers/subchannel	25	25	25	25	25	25
subchannel BW (kHz)	451.2	451.2	451.2	451.2	451.2	451.2
symbols per frame	11	11	11	11	11	11
16QAM data rate (Mbps)	54.00	40.50	27.00	13.50	6.75	3.38

Broadcast Subframe

Parameter	Carrier Bandwidth (MHz)					
	20	15	10	5	2.5	1.25
frame duration (ms)	0.666667	0.666667	0.666667	0.666667	0.666667	0.666667
FFT size	2048	1536	1024	512	256	128
subcarriers (occupied)	1000	750	500	250	125	62.5
symbol duration (us)	66.667	66.667	66.667	66.667	66.667	66.667
useful (us)	55.41	55.41	55.41	55.41	55.41	55.41
guard (us)	11.26	11.26	11.26	11.26	11.26	11.26
CP Efficiency (%)	20.31%	20.31%	20.31%	20.31%	20.31%	20.31%
guard (samples)	416	312	208	104	52	26
subcarrier spacing (kHz)	18.05	18.05	18.05	18.05	18.05	18.05
occupied BW (MHz)	18.05	13.54	9.02	4.51	2.26	1.13
BW Efficiency (%)	90.23%	90.23%	90.23%	90.23%	90.23%	90.23%
subchannels	40	30	20	10	5	2.5
subcarriers/subchannel	25	25	25	25	25	25
subchannel BW (kHz)	451.2	451.2	451.2	451.2	451.2	451.2
symbols per frame	10	10	10	10	10	10
16QAM data rate (Mbps)	48.00	36.00	24.00	12.00	6.00	3.00

Option 3 example

- **0.625ms subframe**
 - Short frame = 1 subframe
 - Long frame = 4 subframes
- **57.35us useful symbol duration**
 - 17.44kHz sub-carrier separation
- **Multiple GIs supported**
 - 5.15 us (10 sym / subframe)
 - 12.09 us (9 sym / subframe)
 - 20.78 us (8 sym / subframe)
 - 31.94 us (7 sym / subframe)
 - Scalable
 - Not always integer number of samples over GI. Useful symbol for unicast and broadcast modes
- **18 MHz occupied BW (20MHz)**
 - 4.5MHz occupied BW (5MHz)
- **Subchannel (a.k.a. sc group)**
 - 558 kHz = 32 subcarriers
 - 32, 24, 16, 8, 4, or 2 subchannels

Normal Subframe

Parameter	Carrier Bandwidth (MHz)					
	20	15	10	5	2.5	1.25
frame duration (ms)	0.625	0.625	0.625	0.625	0.625	0.625
FFT size	2048	1536	1024	512	256	128
subcarriers (occupied)	1024	768	512	256	128	64
symbol duration (us)	78.125	78.125	78.125	78.125	78.125	78.125
useful (us)	57.35	57.35	57.35	57.35	57.35	57.35
guard (us)	20.78	20.78	20.78	20.78	20.78	20.78
CP Efficiency (%)	36.23%	36.23%	36.23%	36.23%	36.23%	36.23%
guard (samples)	742	556.5	371	185.5	92.75	46.375
subcarrier spacing (kHz)	17.4375	17.4375	17.4375	17.4375	17.4375	17.4375
occupied BW (MHz)	17.86	13.39	8.93	4.46	2.23	1.12
BW Efficiency (%)	89.28%	89.28%	89.28%	89.28%	89.28%	89.28%
subchannels	32	24	16	8	4	2
subcarriers/subchannel	32	32	32	32	32	32
subchannel BW (kHz)	558	558	558	558	558	558
symbols per frame	8	8	8	8	8	8
16QAM data rate (Mbps)	39.32	29.49	19.66	9.83	4.92	2.46

Broadcast Subframe

Parameter	Carrier Bandwidth (MHz)					
	20	15	10	5	2.5	1.25
frame duration (ms)	0.625	0.625	0.625	0.625	0.625	0.625
FFT size	2048	1536	1024	512	256	128
subcarriers (occupied)	1024	768	512	256	128	64
symbol duration (us)	89.29	89.29	89.29	89.29	89.29	89.29
useful (us)	57.35	57.35	57.35	57.35	57.35	57.35
guard (us)	31.94	31.94	31.94	31.94	31.94	31.94
CP Efficiency (%)	55.69%	55.69%	55.69%	55.69%	55.69%	55.69%
guard (samples)	1140.57	855.43	570.29	285.14	142.57	71.29
subcarrier spacing (kHz)	17.4375	17.4375	17.4375	17.4375	17.4375	17.4375
occupied BW (MHz)	17.86	13.39	8.93	4.46	2.23	1.12
BW Efficiency (%)	89.28%	89.28%	89.28%	89.28%	89.28%	89.28%
subchannels	32	24	16	8	4	2
subcarriers/subchannel	32	32	32	32	32	32
subchannel BW (kHz)	558	558	558	558	558	558
symbols per frame	7	7	7	7	7	7
16QAM data rate (Mbps)	32.77	24.58	16.38	8.19	4.10	2.05