OFDM NUMEROLOGY FOR EPOC

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OUTLINE

- **OFDM symbol duration – analysis of key tradeoffs:**
  - Cyclic prefix and throughput efficiency
    - Effects of “uncovered” echo energy
    - Efficiency estimates
  - Latency and burst protection
    - Latency estimates vs. Interleaver depth
  - Hardware complexity
  - Conclusion and a proposal
- **OFDM numerology**
  - Parameter set proposal for EPoC downstream

Cyclic Prefix and Throughput Efficiency

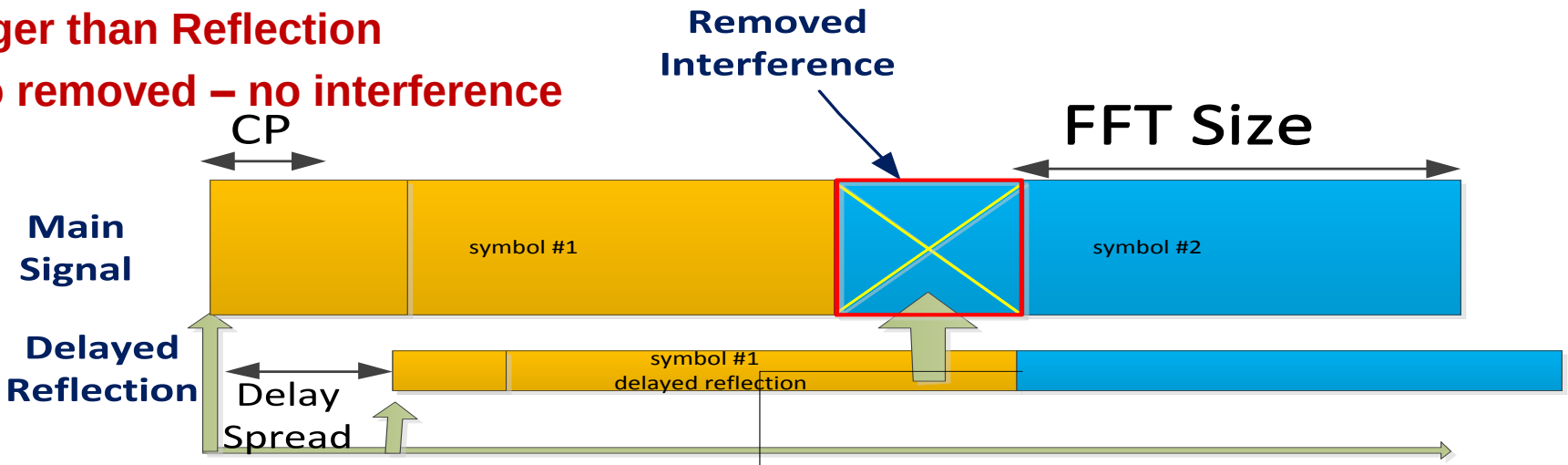
Cyclic Prefix and Throughput Efficiency Overview

- **Cyclic prefix (CP) is basically "idle" time between symbols during which the transmitter and receiver "wait" for echoes to die down**
  - Efficiency = (symbol time) / (symbol time + cyclic prefix duration)
  - For a given CP length, a longer symbol is more efficient
- **CP duration is related to delay spread, but it need not be equal to delay spread**
- **Total throughput efficiency may be the same or even higher using a shorter CP and allowing a small amount of degradation due to residual interference from "uncovered" echo energy**
- **A large majority of installations can be accommodated with relatively short CP sizes**

Micro-Reflections Spread and CP Size

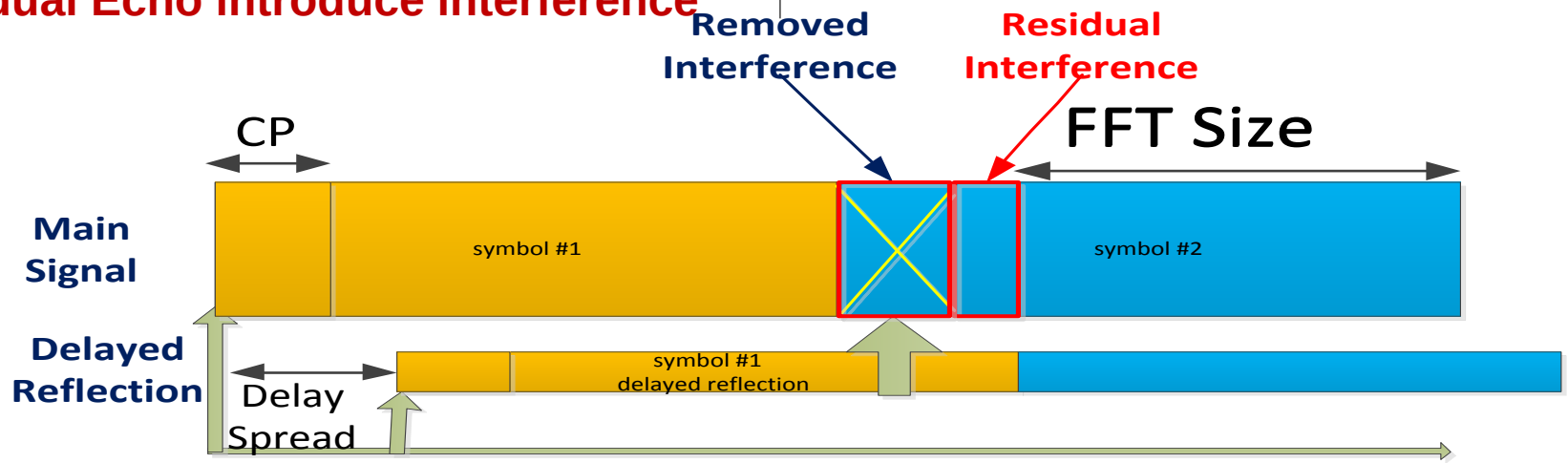
CP longer than Reflection

Echo removed – no interference



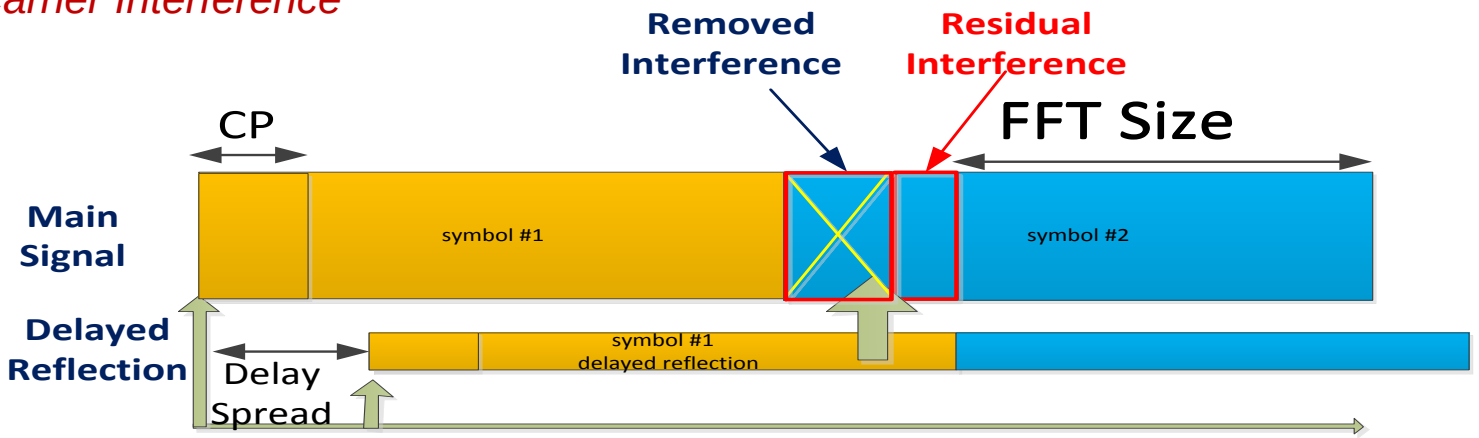
CP shorter than Interference

Residual Echo introduce interference



CP SIZE DOES NOT NEED TO BE LONGER THAN DELAY SPREAD TO BE EFFECTIVE

ISI: Inter Symbol Interference
ICI: Inter Carrier Interference



- **CP size does NOT need to be equal to the channel delay spread to be effective**
  - Interference is relative to residual echo to OFDM symbol size ratio
- **Residual ICI/ISI is approximated by:**

$$ISI\_ICI\ (dBc) =$$

$$uRef\ (dBc) + 10*log10((uRef\_delay - CP\_size)/Symbol\_Size) + 3$$

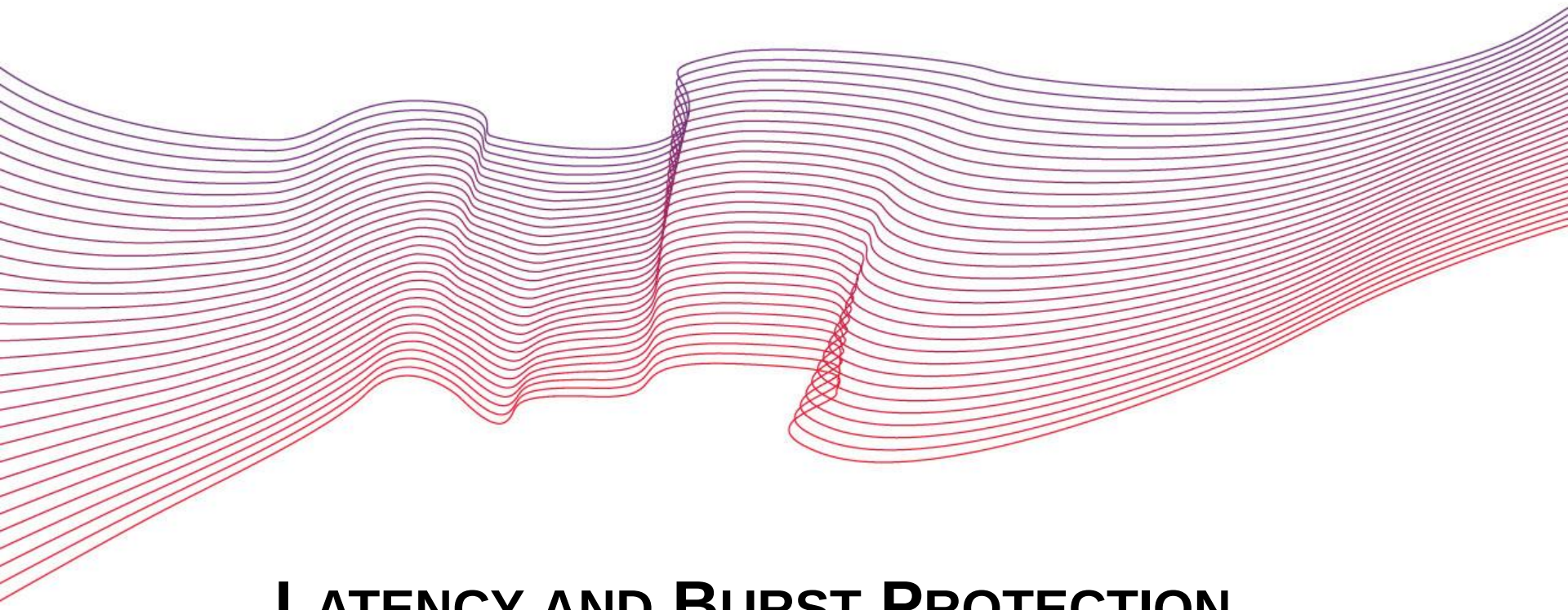
- **Example: uRef = -40 dBc and 2.9 uSec and CP size = 1.0 uSec**
  - Symbol_size = 20 uSec
  - ISI_ICI(dBc) = -40 + 10*log10(1.9/20)+3 = -47.2 dBc

Example: Analysis of CP size with Long Reflections

- **Consider two long reflections**
  - -40 dBc and 2.98 uSec
  - -45 dBc and 5.0 uSec
- **No need to use CP sizes of 2.5 uSec and 5 uSec to compensate these reflections**
  - Using shorter CP sizes provides better throughput efficiency
- **Estimated throughput efficiency with different CP sizes and symbols sizes are calculated in the spreadsheet (next slide)**
- **Results show only small advantages to larger symbol sizes**
  - 80 uSec to 20 uSec < 5%
  - 80 uSec to 40 uSec < 1.5%
- **Examples reflect 99% worst case scenarios**

99% Worst Case Micro-Reflections as per Cable Labs Analysis From STB Statistics (3)

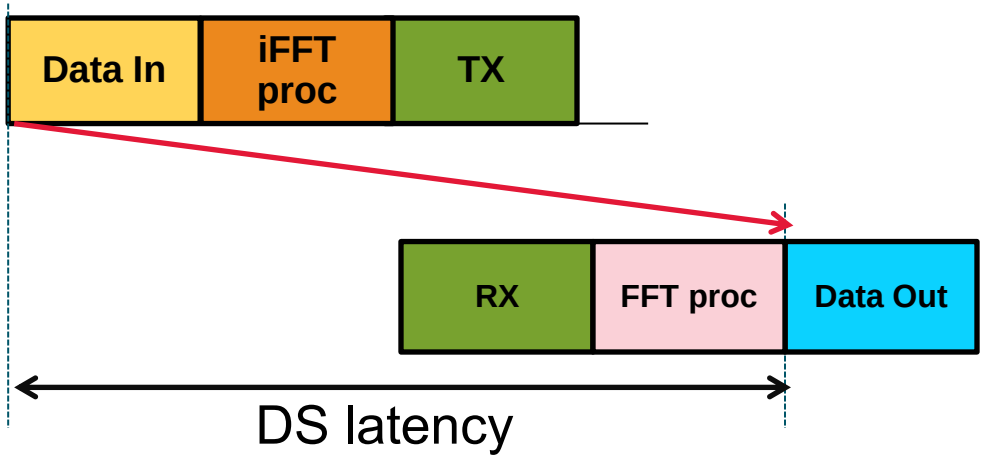
Reflection amp (dBc)	Reflection delay (uSec)	Symbol size (uSec)	CP (uSec)	Impl Noise (dBc)	ISI+ICI (dBc)	loss in SNR (dB) 42	CP overhead (%)	Loss in Bits (%)	Throughput Loss (%)
-40	3	20	0.75	50	-46.49	1.80	3.61%	6.01%	**9.40%**
-40	3	20	1.5	50	-48.25	1.45	6.98%	4.83%	11.47%
-40	3	20	2.98	50	-67.00	0.65	12.97%	2.17%	14.86%
-40	3	40	0.75	50	-49.50	1.26	1.84%	4.20%	**5.96%**
-40	3	40	1.5	50	-51.26	1.06	3.61%	3.54%	7.03%
-40	3	40	2.98	50	-70.01	0.64	6.93%	2.15%	8.93%
-40	3	80	0.75	50	-52.51	0.96	0.93%	3.20%	**4.10%**
-40	3	80	1.5	50	-54.27	0.86	1.84%	2.85%	4.64%
-40	3	80	2.98	50	-73.02	0.64	3.59%	2.14%	5.65%
-45	5	20	0.75	50	-48.73	1.37	3.61%	4.57%	**8.02%**
-45	5	20	1.5	50	-49.57	1.25	6.98%	4.17%	10.85%
-45	5	20	2.98	50	-51.96	1.00	12.97%	3.34%	15.87%
-45	5	40	0.75	50	-51.74	1.02	1.84%	3.40%	**5.18%**
-45	5	40	1.5	50	-52.58	0.96	3.61%	3.18%	6.68%
-45	5	40	2.98	50	-54.97	0.82	6.93%	2.75%	9.49%
-45	5	80	0.75	50	-54.75	0.83	0.93%	2.78%	**3.68%**
-45	5	80	1.5	50	-55.59	0.80	1.84%	2.67%	4.46%
-45	5	80	2.98	50	-57.98	0.73	3.59%	2.44%	5.95%



Latency and Burst Protection

PHY Modulation Latency

- **Downstream Modulation latency**
  - 4 to 6 symbols pipeline
    - Depends on implementation
    - Assume five for this analysis



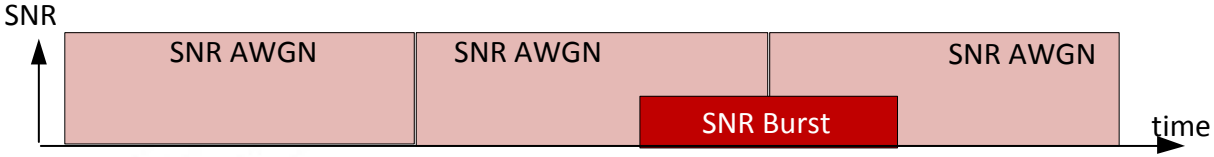
Symbol Size (uSec)	Latency (uSec)
20	100
40	200
80	400

- Latency moderate with 20 uSec symbols
- Prohibitive with 80 uSec symbols

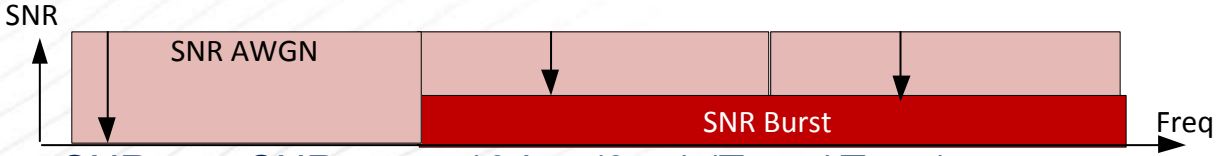
INTERLEAVER LATENCY

- **Interleaving Latency**
  - Burst noise may hit one or two symbols (if < 20 uSec)
  - If wideband all sub-carriers in the symbol are hit with reduced SNR

Burst noise in time domain



Burst noise in sub-carriers domain



$SNR_{burst} = SNR_{impulse} - 10 \log (0.5 * (T_{burst} / T_{OFDM})$

Simulation results with proposed code words

Symbol Size (uSec)	Latency (uSec)	
20	160	400
40	320	800
80	640	1600

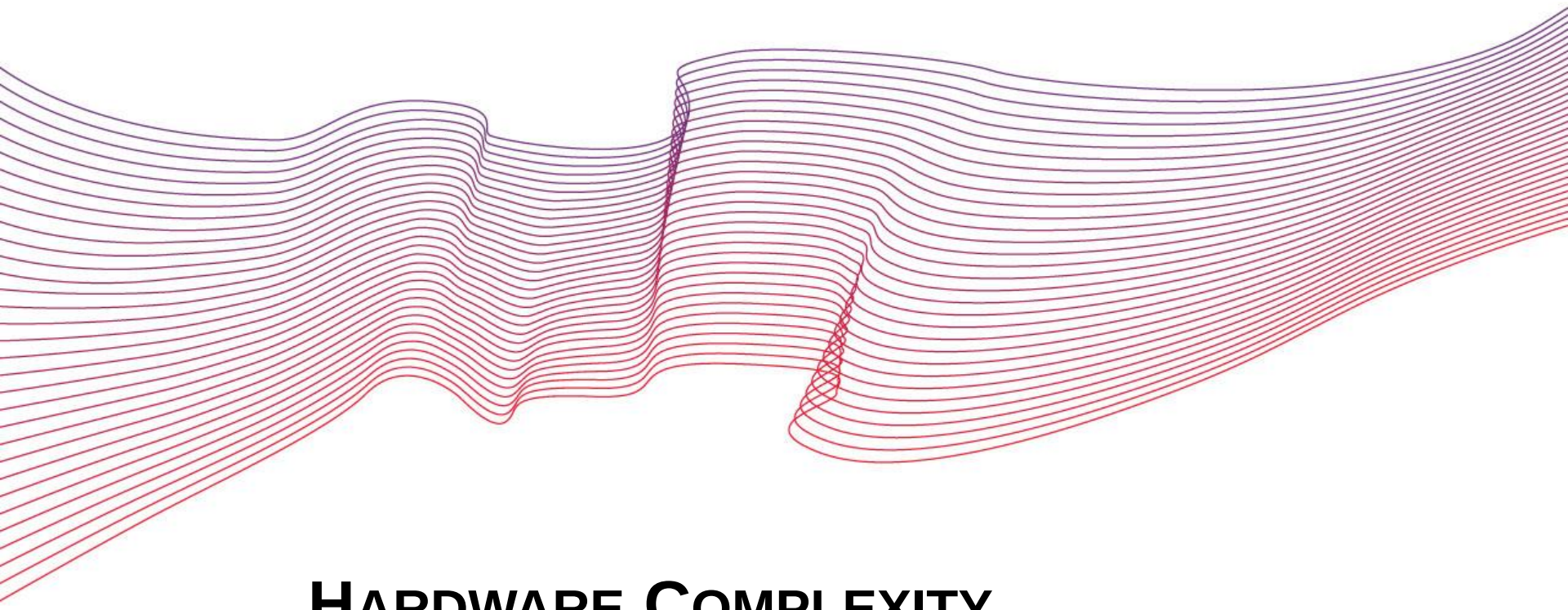
- **Interleaver depth given in symbols**
  - Per simulations about 8 to 20 symbols depth with 20 uSec burst event
  - Burst SNR between 0 to 20 dB

Latency Vs. Symbol Time Comparison

- **Modulation + Interleaver Latency:**

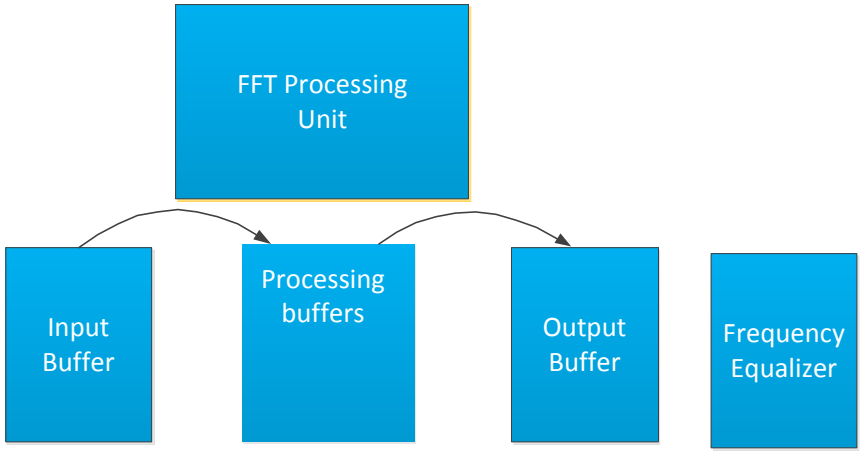
Symbol Size (uSec)	Latency vs, Interleaver depth (uSec)			
	0	8	16	20
20	100	260	420	500
40	200	520	840	1000
80	400	1040	1680	2000

- **With 80uSec symbol against burst noise is not possible at all**
  - Latency long even with no Interleaver at all
- **With 40uSec only low burst noise is protectable**
- **With a 20usec symbol, a significant amount of interleaving can be provided**



HARDWARE COMPLEXITY

HARDWARE COMPLEXITY REDUCTION



- FFT processing unit processing
  - Small and difference between FFT sizes are small
- Buffer Sizes
  - Increase linearly with number of sub-carriers and become substantial with large FFT size
  - FFT implementations require 3FFT-size long buffers per FFT processor (depending on implementations)

- Memory size for 4K FFT size
  - 4*(2*16bits)*4K = 32KB per block
- Memory size for 8K FFT size
  - 4*(2*16bits)*8K = 64KB per block
- Memory size for 16K FFT size
  - 4*(2*16 bits)*16K = 128KB per block
- ***Large memory adds significant PHY complexity and power consumption***

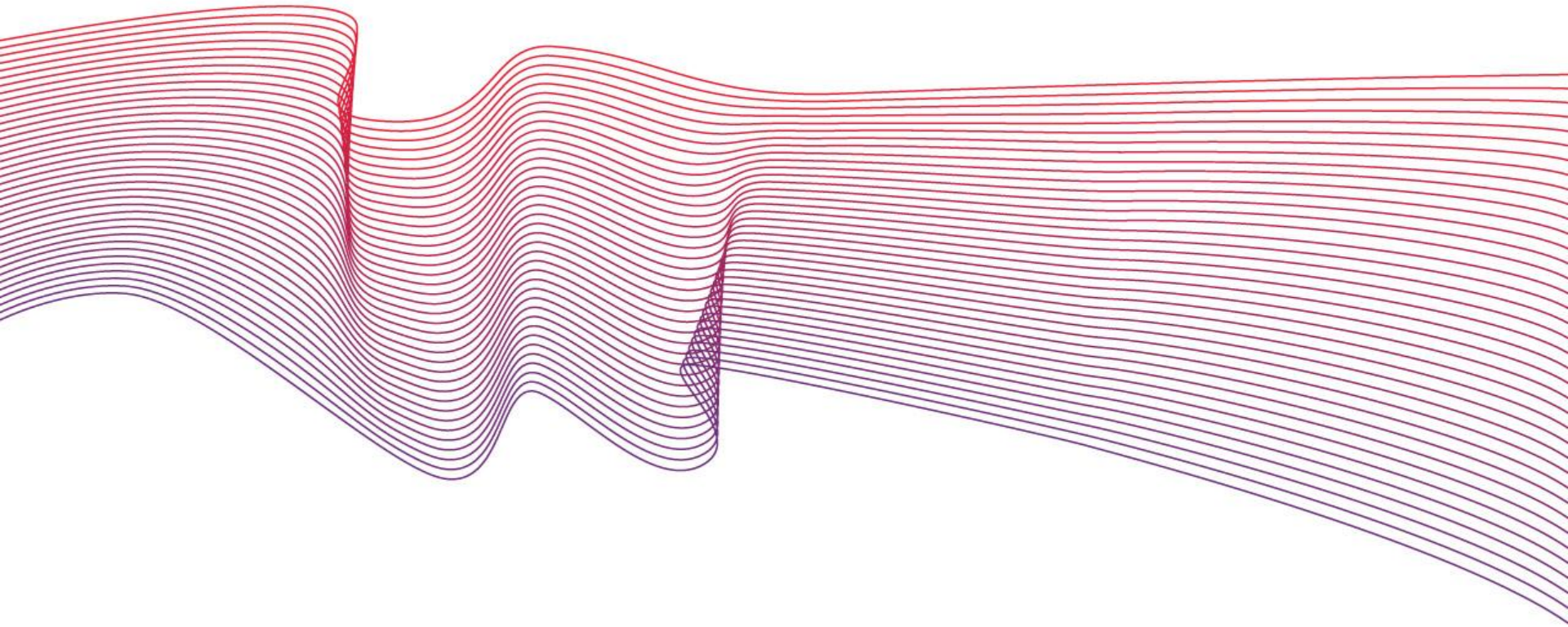
- Complexity of two 192 MHz channels with 20 uSec symbols is similar to that of a single channel with 80 uSec symbol size (for entire PHY, not just FFT alone)

Comparison Summary

- **Performance with micro-reflection**
  - Longer symbol introduce lower overheads
    - 80 uSec symbol size advantage over 40 uSec symbol size is marginal
    - 40 uSec symbol size provides some advantage over 20 uSec with very large micro-reflections
  - ***< 4% more throughput compared to 20 uSec with very long micro-eflections in the downstream***
- **Burst noise protection and latency**
  - 20 uSec provides the best performance with burst noise
  - 80 uSec doesn't allow Interleaving
  - ***20 uSec provides best performance with high level burst noise***
  - ***Latency with 80 uSec symbol is only acceptable if no time interleaving is performed***
- **Complexity**
  - with 80 uSec symbols is significantly larger than with 20 uSec or 40 uSec symbols
  - ***20 uSec has the lowest complexity***

SYMBOL SIZE DECISION

- **EPoC downstream must support both 20 uSec and 40 uSec symbols sizes**
  - Configurable by provisioning
- **If a single symbol size is preferred we recommend to use 20 uSec**
  - Best performance/latency/complexity trade off
  - Best latency and performance with burst noise with only a minimal performance loss with long micro-reflections



OFDM PARAMETERS

29 Nov 2012

Downstream 192 MHz OFDM Channel Parameters

- Symbol size: 20 uSec or 40 uSec
- Sub-carrier spacing is 50 KHz or 25 KHz
  - FFT size of 4096 and 8192 with sampling frequency of 204.8 MHz
- Configurable Cyclic Prefix size from 0.75 to 3.5 uSec
  - Eight CP values
  - Plus, “extreme” worst case CP size of 5uSec to protect against broken loops
- Configurable window shaping
  - Four different Alpha values to accommodate different guard-band overhead per
    - Available bandwidth
    - Number of bandwidth exclusions
- Constellation size for data
  - Odd and even constellations from QAM256 to QAM4096
  - Enables 1.5 dB 0.5 bit granularity
  - Bit loading per sub-carrier TBD

DOWNSTREAM 192 MHZ OFDM CHANNEL PILOTS

- Staggered Pilots
  - Rotating pilots over all sub-carriers for channel estimation
  - Pilots on every subcarrier with 20 uSec
  - Pilots on every second subcarrier with 40 uSec
  - 32 staggered pilots in each OFDM symbol (1/128 of the subcarriers)
  - A single Channel Estimation iteration every 128 OFDM symbols
  - No need for interpolation
  - No sensitivity to excluded bandwidth
- Continuous pilots
  - If required then 32 pilots should be used for both staggered and continuous pilots


Thank You!