Topics on Channel Architecture

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Intent / Overview

- This presentation is meant to stimulate some thoughts on:
  - Specifying frequency
  - Channel Provisioning
  - Number of channels
  - Accommodating regional diplexers
  - A look at math and rules for meeting technical decisions

Specifying Frequency

Introducing the notion 25KHz increments (thanks to Saif):

- Encode frequency values as increments of 25KHz and not Hz, KHz, or MHz
  - Matches both 4K and 8K FFT sub-carrier sizes
  - Maintains alignment of sub-carrier spacing
  - Simple conversion to any Hz
- For example:
  - DC to 5 GHz in 25KHz is then:
    - 0 to 200,000 (base 10)
    - 0 to 110000110101000000 (base 2 – 18 bits)
  - DC to 1212 MHz in 25KHz is then:
    - 0 to 48,480 (base 10)
    - 0 to 1011110101100000 (base 2 – 16 bits)

Aligning an OFDM Channel

- Aligns OFDM channel to fixed “grid”
- Specify frequency in 25KHz of either:
  - First sub-carrier of 192 MHz -> Channel[x]Fstart, or
  - Center frequency -> Channel[x]Fcenter
- Working in binary:
  - For 25 KHz sub-carriers – all bits significant
  - For 50 KHz sub-carriers – mask/force LSB to 0
    - Only use even (every two) 25KHz

Straightforward Calcs

- With Fstart:
  - Center frequency:
    - Fcenter[x] = Channel[x]Fstart + 3840 25KHz
  - Channel occupancy (coverage) is:
    - Channel[x]Fstart to Channel[x]Fstart + 7680 25KHz
- With Fcenter:
  - Start frequency:
    - Fstart[x] = Channel[x]Fcenter - 3840 25KHz
  - Channel occupancy (coverage) is:
    - Channel[x]Fcenter - 3840 to Channel[x]Fcenter + 3840 25KHz

Provisioning an OFDM Channel

- What is needed to describe and provision an OFDM Channel?
  - Present: yes/no
  - Enabled: yes/no
  - Alignment frequency (center or start)
  - FFT size
  - Cyclic Prefix (CP) size
  - PHY Link
    - Enabled: yes/no
    - Starting frequency
  - (and other information)

Expressed As a Channel Table

Channel ID#	Present (Yes/No)	Enabled (Yes/No)	Alignment Frequency (25KHz)	FFT Size (4k / 8k)	Cyclic Prefix Size	PHY Link Enabled? (Yes/No)	PHY Link Start Frequency (25KHz)
0							
1							
2							
3							
4							
5							

Assumptions:

- 0 based indexing
- Sub-carrier #0 is the lowest in frequency
- Separate Downstream (DS) and Upstream (US) channel tables
- Not all OFDM channels have to have an established PHY Link channel

Now: How Many Channels?

- Architecturally: should include operation to 10Gbps
  (per Objectives and discussions, refer to Page 12
  http://www.ieee802.org/3/epoc/public/may12/minutes_0512.pdf)
  - "In assigned spectrum and channel conditions that permit":
  - Assumption: bit rate to/from the MAC/PLS service interface
- Architectural capability ≠ specification requirements
  - What the TF decides as requirements are T.B.D.
  - Likely different requirements for FDD and TDD

Now: How Many FDD Channels?

- Found 3 different methods to get at a suggested answer.
- Method 1: raw modulation rate with 20% overhead:
  - Downstream
    - Assume max: 4096 QAM (12 bps/Hz) in 192 MHz = 2.3 Gbps [TD #6]
    - 10 Gbps / (2.3*0.833) Gbps = 5.22 = 5 or 6 OFDM channels
  - Upstream
    - Assume max: 1024 QAM (10 bps/Hz) in 192 MHz = 1.92 Gbps [TD #6]
    - 10 Gbps / (1.92*0.833) Gbps = 6.25 = 6 or 7 OFDM channels

How Many FDD Channels?

- Method 2: 1.6 Gbps MAC/PLS per 192 MHz DS channel [TD #40]
  - Downstream
    - 10 Gbps / 1.6 Gbps = 6.25 = 6 or 7 OFDM channels
  - Upstream
    - No technical decision.

- Method 3: FDD "low return" based on available spectrum and 192 MHz:
  - Downstream
    - Between 1212 – 54 = 1158 MHz / 192 MHz = 6.03 = 6 OFDM channels
    - And 1212 – 292 = 902 MHz / 192 MHz = 4.79 = **5 OFDM channels**
  - Upstream
    - Between 42 – 5 = 37 MHz / 192 MHz = 0.19 = 1 OFDM Channel
    - and 234 – 5 = 229 MHz /192 MHz = 1.19 = **1** or 2 **OFDM channel**
  - This method better matches FDD spectrum usage.

How Many FDD Channels?

- Architecturally, specifying channel tables and a “PHY processing pipeline” in the transmitter that supports up to 5 or 6 OFDM channels in each direction is required.
  - Results: 3 bit channel ID index.
- Practically: technical consensus must select the required number of channels separately for DS and US separately for both FDD and TDD.

CNU Diplexer Table – A Suggestion

Refer to: adhoc_rfspectrum_laubach_3bn_01_0613.pdf pages 6 – 8.

Diplexer ID	Lower Edge Frequency (25KHz)	Upper Edge Frequency (25KHz)
0		
1		
…		

Architecturally, the CNU should support one or more diplexer configurations, each identified by an ID. Suggest max = 3 bits.

Practically, a fixed single-configuration diplexer is the most likely implementation choice by manufacturers with a CNU configuration based on target international and regional requirements

- Single (and/or default) diplexer configuration as ID 0. (values used for further provisioning rules)

Sub-Carrier Provisioning

- In practical operation, a sub-carrier is either going to be configured “off” –> no energy, or it is going to be assigned to a PHY “functional process block”. For example:
  - Data
    - Includes FEC, Interleaving, Markers, Scattered Pilots, framing, profiles, etc.
  - PHY Link channel
  - Continuous Pilot
  - Channel Probing
  - Etc.
- When not “off”, time (symbol) and frequency (sub-carrier) configuration will be determined by that PHY function.
  - Details are T.B.D.

Indexing Sub-Carriers

- One suggestion: index to any subcarrier for Channel X:
  - E.g.: Channel[x] -> Sub-carrier[Index], or Sub-carrier[x][index]
- Indexing from 0 to
  - 8k FFT (25 KHz spacing)
    - 7680 (base 10)
    - 1 1110 0000 0000 (base 2, 13 bits)
  - 4k FFT (50 KHz spacing)
    - 7680 / 2 = 3860 (base 10)
    - 1111 0000 0000 (base 2, 12 bits)
- Working Notion:
  - Always index as 25KHz with 12 bits
    - 4k FFT forces Index LSB to 0
    - 4k FFT only counts in even increments: 2 x 25 KHz = 50 KHz
- Observation: (Frequency of interest in 25KHz) – (Channel[x][Fstart]) will yield the sub-carrier index number for that OFDM channel
- Indexing +/- a center frequency is slightly more challenging but doable

Potential Rules

- The alignment frequency (start or center) of an OFDM channel, if Present and Enabled, will always be provisioned within the operating band of interest
  - Sub-carriers lying outside of the band MUST be “Off”
- OFDM channels in the same directions may overlap
  - The lower indexed channel’s sub-carriers has priority,
    - The overlapping higher indexed channel’s sub-carriers MUST be “Off”

Math Rules

- Table based formulas permit math rules to implement technical decisions
- For example
  - For any channel x,
    and Channel[x][Present] == Yes
    and Channel[x][Enabled] == Yes:
    then Channel[x][Fstart] MOD 40 MUST = 0
  - TD #30 : center frequency granularity is 1 MHz.

Other rules, example:

Operating next to the lower / upper edges of a diplexer:

- For a given operating DiplexerID and Channel X:
- IF Channel[x][Present] == Yes
  and Channel[x][Enabled] == Yes:
  - If operating above DiplexerID[Upper]
    - Channel[x][Fstart/Fcenter] >= DiplexerID[Upper]
  - If operating below DiplexerID[Lower]
    - For any Index + Channel[x][Fstart/Fcenter] > DiplexerID[Lower]
      - Then the state of Sub-Carrier[Index] MUST be “OFF”
- (needs more work for all cases)

Now can add other rules. Example:

- Let
  - "Top" = highest frequency of a region of interest
  - "Bottom" = lowest frequency of a region of interest
- TD #58 – Minimum exclusion sub-band size = 1 MHz
  - In an OFDM channel,
    - When sub-carriers are set to "Off" for use as an exclusion sub-band, then:
    - $Index_{top} – Index_{bottom}$ >= 10 1000 (base 2) (40 or 2x20 base 10)

Conclusions

- Our higher level requirements need to be reduced to protocol elements:
  - Architecture needs to meet Objectives
  - Tables, indexes, math rules can be useful
- Probably can be a few different approaches
  - Pick one and get started
- Number of actual DS and US channels -> T.B.D.
  - Table-wise, looking like 5 to 6 channels each direction to meet the 10 Gbps capability requirement
    - Further work needed for tone mapping / bonding / etc.
    - Raises questions about how many modes / models

Thank you