1. *Transmitter Bit Loading for Symbol Mapping*

All subcarriers of an OFDM symbol may not have the same constellation; the constellation for each subcarrier is given in a table that details the bit loading pattern. This bit-loading pattern may change from profile to profile. This section describes how the bits to symbol mapping is performed, with reference to a bit-loading pattern, in the presence of interleaving, continuous pilots, scattered pilots and excluded subcarriers.

Excluded subcarriers are subcarriers that are forced to zero-valued modulation at the transmitter. Subcarriers are excluded to prevent interference to other transmissions that occupy the same spectrum as the ~~DOCSIS 3.1~~ EPoC OFDM transmission, for example, to accommodate legacy channels. Subcarriers are also excluded outside of the active OFDM bandwidth.

Excluded subcarriers are common to all profiles. The non-excluded subcarriers are referred to as active subcarriers. Active subcarriers are never zero-valued. The notation $S^{(E)}$ is used here to define the set of excluded subcarriers. This set will never be empty because there are always excluded subcarriers at the edges of the OFDM channel.

Continuous pilots are pilots that occur at the same frequency location in every OFDM symbol. The notation $S^{(C)}$ is used here to define the set of continuous pilots.

The PLC resides in a contiguous set of subcarriers in the OFDM channel. The ~~CMTS~~ CLT adds the PLC to the OFDM channel after time and frequency interleaving; the ~~CM~~CNU extracts the PLC subcarriers before frequency and time de-interleaving. These subcarriers occupy the same spectral locations in every symbol. The notation $S^{(P)}$ is used here to define the set of PLC subcarriers.

For bit loading, continuous pilots and the PLC are treated in the same manner as excluded subcarriers; hence, the set of subcarriers that includes the PLC, continuous pilots and excluded subcarriers is defined as:

$$S^{(PCE)} = S^{(P)} \cup S^{(C)} \cup S^{(E)}$$

The subcarriers in the set $S^{(PCE)}$ do not carry data (PLC carry signaling information). The other subcarriers that do not carry data are the scattered pilots. However, scattered pilots are not included in the set $S^{(PCE)}$ because they do not occupy the same spectral locations in every OFDM symbol.

The modulation order of the data subcarriers is defined using bit-loading profiles. These profiles include the option for zero bit-loading. Such subcarriers are referred to as zero-bit-loaded subcarriers and are BPSK modulated using the randomizer LSB, as described in section TBD~~7.5.5.3~~.

All active subcarriers with the exception of pilots are transmitted with the same average power. Pilots are transmitted boosted by a factor of ~~2~~ TBD in amplitude(approximately ~~6~~TBD dB).

Scattered pilots do not occur at the same frequency in every symbol; in some cases scattered pilots will overlap with continuous pilots. If a scattered pilot overlaps with a continuous pilot, then that pilot is no longer considered to be a scattered pilot. It is treated as a continuous pilot.

Because the locations of scattered pilots change from one OFDM symbol to another, the number of overlapping continuous and scattered pilots changes from symbol to symbol. Since overlapping pilots are treated as continuous pilots, the number of scattered pilots changes from symbol to symbol.

The following notation is used here:

N: The total number of subcarriers in the OFDM symbol, equaling either 4096 or 8192

N_C: The number of continuous pilots in an OFDM symbol

N_S: The number of scattered pilots in an OFDM symbol

N_E: The number of excluded subcarriers in an OFDM symbol

N_P: The number of PLC subcarriers in an OFDM symbol

N_D: The number of data subcarriers in an OFDM symbol

The values of N, N_C, N_E and N_P do not change from symbol to symbol for a given OFDM template; the values of N_S and N_D change from symbol to symbol.

The following equation holds for all symbols:

$$N = N_C + N_S + N_E + N_P + N_D$$

The value of N is 4096 for 50 kHz subcarrier spacing and 8192 for 25 kHz subcarrier spacing. From this equation it is clear that $(N_S + N_D)$ is a constant for a given OFDM template. Therefore, although the number of data subcarriers (N_D) and the number of scattered pilots (N_S) in an OFDM symbol changes from symbol to symbol, the sum of these two numbers is invariant over all symbols. Interleaving and de-interleaving are applied to the set of data subcarriers and scattered pilots of size $N_I = N_D + N_S$.

1.1 Bit Loading

The bit loading pattern defines the QAM constellations assigned to each of the 4096 or 8192 subcarriers of the OFDM transmission. This bit loading pattern can change from profile to profile. Continuous pilot locations, PLC locations and exclusion bands are defined separately, and override the values defined in the bit-loading profile. Let the bit loading pattern for profile i be defined as $A_i(k)$, where:

k is the subcarrier index that goes from 0 to (N-1)

N is either 4096 or 8192

$A_i(k) \in \{0, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14\}$. A value of 0 indicates that the subcarrier k is zero-bit-loaded. Other values indicate that the modulation of subcarrier k is QAM with order $2^{A_i(k)}$.

Let the sequence $\{A_i(k),\ k = 0, 1, \ldots\ ,\ (N-1),\ k \notin S^{PCE}\}$ be arranged as N_I consecutive values of another sequence:

$$B_i(k),\ k = 0, 1, \ldots\ ,\quad (N_I - 1)$$

Given the locations of the excluded subcarriers, continuous pilots and the PLC in the OFDM template, it is possible to obtain the bit-loading pattern $B_i(k)$ that is applicable only to spectral locations excluding excluded subcarriers, continuous pilots, and PLC subcarriers. However, note that $B_i(k)$ does contain the spectral locations occupied by scattered pilots; these locations change from symbol to symbol.

It is more convenient to define bit loading profiles in the domain in which subcarriers are transmitted. It is in this domain that signal-to-noise-ratios of subcarriers are calculated. Furthermore, defining the bit-loading patterns in the transmission domain allows significant data compression to be achieved, because a relatively large number of contiguous spectral locations can share the same QAM constellation.

Although the bit loading pattern is defined in the domain in which subcarriers are transmitted, the bit loading is not applied in that domain. Bit loading is applied prior to interleaving, as shown in ~~Figure 7-46~~TBD. Hence there is a permutation mapping of subcarriers, defined by the interleaving function, between the domain in which bit loading is applied to subcarriers and the domain in which subcarriers are transmitted.

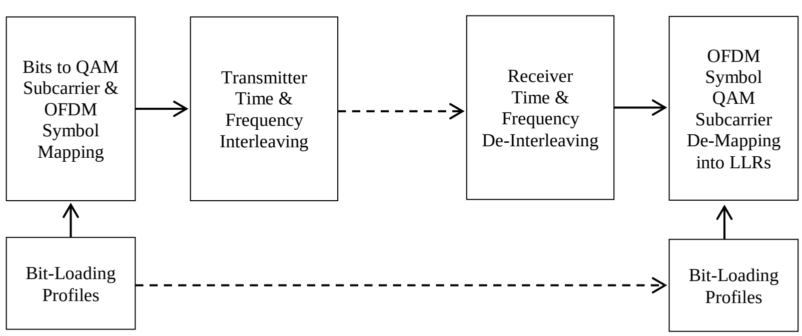

Figure ? – Bit Loading, Symbol Mapping, and Interleaving

The excluded subcarriers, PLC subcarriers, and continuous pilots are excluded from the processes of interleaving and de-interleaving; scattered pilots and data subcarriers are subject to interleaving and de-interleaving. Hence, the total number of subcarriers that pass through the interleaver and de-interleaver is $N_I = (N_D + N_S)$ and this number does not change from symbol to symbol.

The interleaver introduces a 1-1 permutation mapping P on the N_I subcarriers. Although interleaving consists of a cascade of two components, namely time and frequency interleaving, it is only frequency interleaving that defines the mapping P. This is because time interleaving does not disturb the frequency locations of subcarriers.

The corresponding permutation mapping applied at the receiver de-interleaver is P^{-1}.

In order to perform bit-loading, it is necessary to work out the bit loading pattern at the node at which it is applied, i.e., at the input to the interleavers. This is given by:

$$C_i(k) = P^{-1}(B_i(k))$$

Since the time interleaver does not change the frequency locations of subcarriers, the sequence $C_i(k)$ is obtained by sending $\{B_i(k), k = 1, 2, \dots, N_I - 1\}$ through the frequency de-interleaver.

Note that $C_i(k)$ gives the bit-loading pattern for N_I subcarriers. Yet, some of these subcarriers are scattered pilots that have to be avoided in the bit-loading process. Hence, a two-dimensional binary pattern $D(k,j)$ is used to identify subcarriers to be avoided during the process of bit-loading. Because the scattered pilot pattern has a periodicity of ~~128~~TBD in the time dimension, this binary pattern also has periodicity ~~128~~TBD in the column dimension *j*.

$D(k,j)$ is defined for $k = 0, 1, \dots, (N_I - 1)$ and for $j = 0, 1, \dots,$ ~~127~~TBD

The process to create the binary pattern $D(k,j)$ begins with the transmitted scattered pilot pattern defined in Section ~~7.5.6~~TBD. There are two scattered pilot patterns, one for 4K FFTs and the other for 8K FFTs; both patterns are defined in reference to the preamble of the PLC and have a periodicity of ~~128~~ TBD symbols.

The CMTS executes the following steps to obtain the pattern $D(k,j)$:

1. Define a two-dimensional binary array $P(k,j)$ in the subcarrier transmitted domain that contains a one for each scattered pilot location and zero otherwise:

   $P(k,j)$, for $k = 0, 1, \dots, N - 1$ and for $j = 0, 1, \dots,$ TBD~~127~~

   Here, the value of *N* is either 4096 or 8192. The first column of this binary sequence corresponds to the first OFDM symbol following the preamble of the PLC.

2. Exclude the rows corresponding to excluded subcarriers, continuous pilots, and PLC from the two-dimensional array $P(k,j)$ to give an array $Q(k,j)$. The number of rows of the resulting array is N_I and the number of columns is ~~128~~TBD.

3. Pass this two-dimensional binary array $Q(k,j)$ through the frequency de-interleaver and then the time de-interleaver, with each column treated as an OFDM symbol. After the 128 columns of the pattern have been input into the interleaver, re-insert the first *M* columns, where *M* is the depth of the time interleaver. This is equivalent to periodically extending $Q(k,j)$ along the dimension j and passing (128+*M*) columns of this extended sequence through the frequency de-interleaver and the time de-interleaver.

4. Discard the first *M* symbols coming out of the time de-interleaver and collect the remaining 128 columns into an array to give the binary two-dimensional array $D(k,j)$ of size $(N_I \times 128)$.

For bit loading the CMTS accesses the appropriate column j of the binary pattern bit $D(k,j)$ together with the appropriate bit loading profile $C_i(k)$. If the value of the bit $D(k,j)$ is 1, the ~~CMTS~~ CLT MUST skip this subcarrier k and move to the next subcarrier. This subcarrier is included as a placeholder for a scattered pilot that will be inserted in this subcarrier location after interleaving. After each symbol the column index j has to be incremented modulo ~~128~~TBD.

The ~~CMTS~~CLT MUST use this binary two-dimensional array $D(k,j)$ of size $(N_I \times 128)$ in order to do bit-loading of OFDM subcarriers, as described earlier in this section.

The corresponding operation in the ~~CM~~CNU is de-mapping the QAM subcarriers to get Log-Likelihood-Ratios (LLRs) corresponding to the transmitted bits. This operation, described below, is much simpler than the mapping operation in the transmitter.

The scattered pilots and data subcarriers of every received symbol are subjected to frequency and time de-interleaving. The scattered pilots have to be tagged so that these can be discarded at the output of the time and frequency de-interleavers. This gives N_I subcarriers for every OFDM symbol. The ~~CM~~CNU accesses theses N_I de-interleaved subcarriers together with the bit-loading pattern $C_i(k)$ to implement the de-mapping of the QAM subcarriers into LLRs. If the subcarrier k happens to be a scattered pilot, then this subcarrier, as well as the corresponding value $C_i(k)$, is skipped and the CM moves to the next subcarrier $(k+1)$.

1.2 Update Bit Loading Profiles for FDD

1.3 Update Bit Loading Profiles for TDD

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