minimization for this quantizer structure for \( N \)-clusters and \( R \)-bit feedback is given by

\[
\begin{align*}
\min & \quad F_N(s_1^{(N)}) \\
\text{s.t.} & \quad \sum_{j=1}^{L-1} \Lambda_j \left[ F_N(s_j^{(N)}) - F_N(s_{j+1}^{(N)}) \right] + \Lambda_L \left[ 1 - F_N(s_L^{(N)}) + F_N(s_1^{(N)}) \right] \leq NP_{av} \\
& \quad 0 \leq s_{i,j} \leq s_{i,j+1} \quad \forall i, j.
\end{align*}
\]

where \( \Lambda_j = \sum_{i=1}^{N} P_{i,j} \) denotes the elementwise sum of the power codeword \( P_j^{(N)} \).

III. POWER ALLOCATION SCHEMES AND SOLUTIONS

A. CSIR and Full CSIT

Problem (2) is solved in [4] for block-fading channels with CSIR and full CSIT. Before we state the result first we need to introduce some notations and definitions. Define the regions \( \mathcal{R}(u) \) and \( \mathcal{R}(u) \), and the boundary surface \( \mathcal{B}(u) \) for some non-negative \( u \) as \( \mathcal{R}(u) = \{ h \in \mathbb{R}_+^N : \langle \mathbf{P}(h) \rangle < u \} \), \( \mathcal{B}(u) = \{ h \in \mathbb{R}_+^N : \langle \mathbf{P}(h) \rangle \leq u \} \) and \( \mathcal{B}(u) = \{ h \in \mathbb{R}_+^N : \langle \mathbf{P}(h) \rangle = u \} \). In order to obtain \( u^* \), we need to define the two average power sums as \( P(u) = \int_{\mathcal{R}(u)} \langle \mathbf{P}(h) \rangle dF(h) \) and \( \overline{P}(u) = \int_{\mathcal{B}(u)} \langle \mathbf{P}(h) \rangle dF(h) \), where \( F(h) \) denotes the c.d.f of \( h \). Finally, the power sum threshold \( u^* \) and the weight \( w^* \) are given as \( u^* = \sup \{ u : P(u) < P_{av} \} \) and \( w^* = \frac{P_{av} - P(u^*)}{\overline{P}(u^*) - P(u^*)} \) respectively.

The optimal power allocation \( \hat{\mathbf{P}}(h) \triangleq \hat{P}_1(h), \ldots, \hat{P}_N(h) \) is

\[
\hat{\mathbf{P}}(h) = \begin{cases} 
\mathbf{P}^*(h), & \text{if } h \in \mathcal{R}(u^*) \\
0, & \text{if } h \notin \mathcal{R}(u^*)
\end{cases}
\]

while if \( h \in \mathcal{B}(u^*) \), \( \hat{\mathbf{P}}(h) = \mathbf{P}^*(h) \) with probability \( w^* \) and \( \hat{\mathbf{P}}(h) = 0 \) with probability \( 1 - w^* \). \( 0 \) denotes the zero-power vector, \( \mathbf{P}^*(h) \triangleq \left( P_1^*(h), \ldots, P_N^*(h) \right) \) and the \( i \)th power is

\[
P_i^*(h) = \frac{C_i G_i}{H_i} \left[ \frac{\sqrt{\bar{\eta}_i}}{\bar{\rho}_0(h, N_1)} - 1 \right]^+, \quad i = 1, \ldots, N
\]

where \( N_1 \) is a unique integer in \( \{1, \ldots, N\} \) required to evaluate \( \bar{\rho}_0(h, N_1) \). \( G_i = U_i / V_i \), \( H_i = h_i U_i / (\sigma_{C_2}^1) \), \( \bar{\eta}_i = \bar{H}_i / C_i \) and \( \bar{\rho}_0 = D(N_1) / \bar{C}(N_1) \). Variables with a bar on top indicate that they depend on \( h \). \( D(i) = \)