### Glossary

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<tr>
<td>3G</td>
<td>Third Generation wireless technology</td>
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<td>3GPP</td>
<td>The Third Generation Partnership Project</td>
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<td>AOD</td>
<td>Amicable Orthogonal Design</td>
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<td>AST</td>
<td>Antenna Selection Technique</td>
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<td>AWGN</td>
<td>Additive White Gaussian Noise</td>
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<td>BER</td>
<td>Bit Error Rate</td>
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<td>BLAST</td>
<td>Bell Lab Layered Space-Time</td>
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<td>BPSK</td>
<td>Binary Phase Shift Keying</td>
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<td>BS</td>
<td>Base Station</td>
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<td>CDMA</td>
<td>Code Division Multiple Access</td>
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<tr>
<td>CO STBC</td>
<td>Complex Orthogonal Space-Time Block Code</td>
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<td>COD</td>
<td>Complex Orthogonal Design</td>
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<tr>
<td>const</td>
<td>constant</td>
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<td>DPCCH</td>
<td>Dedicated Physical Control Channel</td>
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<td>DPSK</td>
<td>Differential Phase Shift Keying</td>
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<td>DS-SS</td>
<td>Direct Sequence Spread Spectrum</td>
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<tr>
<td>DSTBC</td>
<td>Differential Space-Time Block Code</td>
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<tr>
<td>DSTM</td>
<td>Differential Space-Time Modulation</td>
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<td>e.g.</td>
<td>exempli gratia</td>
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<td>ECK</td>
<td>Exact Channel Knowledge</td>
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<tr>
<td>EGC</td>
<td>Equal Gain Combining</td>
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etc.  et cetera
FEC  Forward Error Correction
FH-SS  Frequency Hoping Spread Spectrum
GCOD  Generalized Complex Orthogonal Design
GSM  Global System for Mobile Communications
i.e  id est
i.i.d.  identically independently distributed
IDFT  Inverse Discrete Fourier Transform
iff  if and only if
ISI  Inter-Symbol Interference
LAN  Local Area Network
LOS  Line Of Sight
LST  Layered Space-Time Code
M-ary  Multiple Level Modulation
MC-SS  Multi-Carrier Spread Spectrum
MIMO  Multiple Input Multiple Output
MMS  Multi-Modulation Scheme
M-PSK  M-ary Phase Shift Keying
MRC  Maximum Ratio Combining
MS  Mobile Station
OFDM  Orthogonal Frequency Division Multiplexing
PAM  Pulse Amplitude Modulation
PCU  Per Channel Use
PDF  Probability Density Function
PSK  Phase Shift Keying
QAM  Quadrature Amplitude Modulation
QPSK  Quadrature Phase Shift Keying
rms  root-mean-square
Rx antenna  Receiver antenna
SC  Scanning Combining
SCK  Statistical Channel Knowledge
SER  Symbol Error Rate
SNR  Signal-to-Noise Ratio
STBC  Space-Time Block Code
STC  Space-Time Code
STS  Symbol Time Slot
STTC  Space-Time Trellis Code
Tx antenna  Transmitter antenna
w. r. t.  with respect to
WCDMA  Wideband Code Division Multiple Access
Appendix A
Symbol Error Probability of M-ary PSK Signals

In this section, we derive the approximated symbol error probability of M-ary PSK signals in flat Rayleigh fading channels when SNR per symbol is large enough. The symbol error probability of M-ary PSK signals in L-path Rayleigh fading channels is given below (see equation (14.4-38) in [Proakis, 2001]):

\[
P_M = \frac{(-1)^{L-1}(1 - \mu^2)^L}{\pi(L-1)!} \times \left( \frac{\partial^{L-1}}{\partial b^{L-1}} \left\{ \frac{1}{1 - \mu^2} \left[ \frac{\pi(M-1)}{M} - \frac{\mu \sin(\frac{\pi}{M})}{\sqrt{1 - \mu^2 \cos^2(\frac{\pi}{M})}} \right] \right\} \right)_{b=1} \tag{A.1}
\]

where, by definition:

\[
\mu = \sqrt{\frac{\gamma_c}{\gamma_c + 1}} = \sqrt{\frac{(\gamma_b \log_2 M)/L}{(\gamma_b \log_2 M)/L + 1}} \tag{A.2}
\]

and \(\gamma_c\) and \(\gamma_b\) are the average SNR per channel and per bit, respectively. In flat Rayleigh fading scenario, we have \(L = 1\). Note that:

\[
\cot^{-1} \left( -\frac{\mu \cos(\frac{\pi}{M}) \sqrt{1 - \mu^2 \cos^2(\frac{\pi}{M})}}{\sqrt{1 - \mu^2 \cos^2(\frac{\pi}{M})}} \right) = \pi - \cot^{-1} \left( \frac{\mu \cos(\frac{\pi}{M}) \sqrt{1 - \mu^2 \cos^2(\frac{\pi}{M})}}{\sqrt{1 - \mu^2 \cos^2(\frac{\pi}{M})}} \right)
\]

then we have

\[
P_M = \frac{(1 - \mu^2)}{\pi} \left\{ \frac{1}{1 - \mu^2} \left[ \frac{\pi(M-1)}{M} - \frac{\pi \mu \sin(\frac{\pi}{M})}{\sqrt{1 - \mu^2 \cos^2(\frac{\pi}{M})}} \right] \right\}
\]

\[
+ \frac{\mu \sin(\frac{\pi}{M})}{\sqrt{1 - \mu^2 \cos^2(\frac{\pi}{M})}} \cot^{-1} \left( \frac{\mu \cos(\frac{\pi}{M}) \sqrt{1 - \mu^2 \cos^2(\frac{\pi}{M})}}{\sqrt{1 - \mu^2 \cos^2(\frac{\pi}{M})}} \right) \right\}
\]
When the SNR per symbol satisfies: $\gamma_c \gg 1$, such as $\gamma_c \geq 10$ (i.e., 10 dB), then $\mu \approx 1$. Therefore, we have:

\[
P_M \approx \frac{(1 - \mu^2)\{1 - \mu^2\} \left[\frac{\pi(M - 1)}{M} - \frac{\pi\mu\sin\left(\frac{\pi}{M}\right)}{\sqrt{1 - \mu^2}\cos^2\left(\frac{\pi}{M}\right)}\right]}{\mu\sin\left(\frac{\pi}{M}\right)} + \cot^{-1}\left(\cos\left(\frac{\pi}{M}\right)\right)\}
\]

\[
= \frac{(M - 1)(1 - \mu^2)}{M} \left\{\frac{1}{1 - \mu^2\left[1 - \frac{\mu\sin\left(\frac{\pi}{M}\right)}{\sqrt{1 - \mu^2}\cos^2\left(\frac{\pi}{M}\right)}\right]}\right\}
\]

\[
= \frac{(M - 1)(1 - \mu^2)}{M} \left[\frac{\sqrt{1 - \mu^2}\cos^2\left(\frac{\pi}{M}\right) - \mu\sin\left(\frac{\pi}{M}\right)}{(1 - \mu^2)\sqrt{1 - \mu^2}\cos^2\left(\frac{\pi}{M}\right)}\right]
\]

(A.3)

We can simplify further the above equation by noting that:

\[
1 - \mu^2 = \left[\sqrt{1 - \mu^2}\cos^2\left(\frac{\pi}{M}\right) - \mu\sin\left(\frac{\pi}{M}\right)\right] \times \left[\sqrt{1 - \mu^2}\cos^2\left(\frac{\pi}{M}\right) + \mu\sin\left(\frac{\pi}{M}\right)\right]
\]

Hence, (A.4) becomes

\[
P_M \approx \frac{(M - 1)(1 - \mu^2)}{M} \frac{1}{\sqrt{1 - \mu^2}\cos^2\left(\frac{\pi}{M}\right)} + \mu\sin\left(\frac{\pi}{M}\right)
\]

\[
\times \frac{1}{\sqrt{1 - \mu^2}\cos^2\left(\frac{\pi}{M}\right)}
\]

\[
= \frac{(M - 1)(1 - \mu^2)}{M} \frac{1}{2\mu\sin\left(\frac{\pi}{M}\right)}\mu\sin\left(\frac{\pi}{M}\right)
\]

\[
= \frac{(M - 1)(1 - \mu^2)}{2M\mu^2\sin^2\left(\frac{\pi}{M}\right)} = \frac{(M - 1)}{2M\gamma_c\sin^2\left(\frac{\pi}{M}\right)}
\]

where the last equality is due to the fact that (see (A.2)):

\[
\gamma_c = \frac{\mu^2}{1 - \mu^2}
\]

Therefore, we have

\[
P_M \approx \frac{(M - 1)}{2M(\log_2 M)\gamma_c\sin^2\left(\frac{\pi}{M}\right)}
\]

(A.5)
Appendix B
Proof of the Decision Metrics for Unitary DSTBCs

In this section, we derive the expression of the statistic $D_j$ mentioned in Eq. (6.10). Then, we prove that the detector for the symbol $s_j$ is given by: $\hat{s}_j = \text{Arg}\{ \max_{s_j \in S} \Re\{D_j^*s_j\}\}$. Before proceeding further, it is important to note that:

1. $\text{tr}(\Theta A^H A)$ is real if $\Theta$ is a Hermitian matrix, i.e. $\Theta = \Theta^H$. Consequently, $\text{Im}\{\text{tr}(\Theta A^H A)\} = 0$.

2. $\text{tr}(\Omega \Lambda) = \text{tr}(\Lambda \Omega)$ if $\Omega$ and $\Lambda$ are square matrices.

3. $Z_t^H W_{t-1} = W_t^H$.

4. $Z_t = \frac{1}{\sqrt{p}} \sum_{k=1}^{p} (X_k s_k^R + i Y_k s_k^I)$, i.e., $Z_t^H = \frac{1}{\sqrt{p}} \sum_{k=1}^{p} (X_k^H s_k^R - i Y_k^H s_k^I)$.

5. $\{X_k\}_{k=1}^{p}$ and $\{Y_k\}_{k=1}^{p}$ satisfy:

   \begin{align*}
   X_k X_k^H &= I; \quad Y_k Y_k^H = I \quad \forall k \quad (B.1) \\
   X_k X_j^H &= -X_j X_k^H; \quad Y_k Y_j^H = -Y_j Y_k^H \quad \forall k \neq j \quad (B.2) \\
   X_k Y_j^H &= Y_j X_k^H; \quad \forall k, j \quad (B.3)
   \end{align*}

One has:

\begin{align*}
R_t^H R_{t-1} &= (A W_{t-1} Z_t + N_t)^H (A W_{t-1} + N_{t-1}) \\
&= Z_t^H W_{t-1}^H A^H A W_{t-1} + Z_t^H W_{t-1}^H A^H N_{t-1} \\
&\quad + N_t^H A W_{t-1} + N_{t}^H N_{t-1} \quad (B.4)
\end{align*}
If the noise variance is small enough, the term $N_t^HN_{t-1}$ is negligible. From (B.1), (B.2), (B.4) and the $2^{nd}$, $3^{rd}$, $4^{th}$ notes as mentioned above, we have the following transforms:

\[
D_j^R \triangleq Re\{tr(R_t^HR_{t-1}X_j)\} \\
\approx \left[ Re\{tr\left( \frac{1}{\sqrt{p}} \sum_{k=1}^{p} X_k^H W_{t-1}^H A^H AW_{t-1} X_j s_k^l \right) \} \\
- Re\{tr\left( \frac{1}{\sqrt{p}} \sum_{k=1}^{p} i Y_k^H W_{t-1}^H A^H AW_{t-1} X_j s_k^l \right) \} \\
+ Re\{tr(Z_t^H W_{t-1}^H A^H N_{t-1} X_j)\} + Re\{tr(N_t^H AW_{t-1} X_j)\} \right] \\
= \left[ \frac{1}{\sqrt{p}} tr(A^H A) s_j^R \right] \\
+ Re\{tr\left( \frac{1}{\sqrt{p}} \sum_{k=1, k \neq j}^{p} X_k^H W_{t-1}^H A^H AW_{t-1} X_j s_k^l \right) \} \\
- Im\{tr\left( \frac{1}{\sqrt{p}} \sum_{k=1}^{p} X_j Y_k^H s_k^l A^H A \right) \} + Re\{tr(W_t^H A^H N_{t-1} X_j)\} \\
+ Re\{tr(N_t^H AW_{t-1} X_j)\}
\]

Let $\Gamma = \sum_{k=1}^{p} X_k Y_k^H s_k^l$. From (B.3), clearly, $\Gamma = \Gamma^H$, i.e. $\Gamma$ is a Hermitian matrix. Therefore: $Im\{tr\left( \frac{1}{\sqrt{p}} \sum_{k=1}^{p} X_j Y_k^H s_k^l A^H A \right) \} = 0$. Additionally, if $\{X_k\}_{k=1}^{p}$ satisfy (B.1) and (B.2) individually, then $Re\{tr(\sum_{k=1, k \neq j}^{p} X_k^H W_{t-1}^H A^H AW_{t-1} X_j s_k^l)\} = 0$. Hence:

\[
D_j^R \approx \frac{1}{\sqrt{p}} tr(A^H A) s_j^R + Re\{tr(W_t^H A^H N_{t-1} X_j)\} \\
+ Re\{tr(N_t^H AW_{t-1} X_j)\}
\]
Similarly, we have:

\[ D_j^I \triangleq \Re \{ \text{tr}(R_t^H R_{t-1}^i Y_j) \} \]
\[ \approx \frac{1}{\sqrt{p}} \text{tr}(A^H A)s_j^I + \Re \{ \text{tr}(W_t^H A^H N_{t-1}^i Y_j) \} \]
\[ + \Re \{ \text{tr}(N_t^H A W_{t-1}^i Y_j) \} \]

The statistic for decoding the symbol \( s_j \) is given below:

\[ D_j = D_j^R + iD_j^I \]
\[ = \frac{1}{\sqrt{p}} \text{tr}(A^H A)s_j + \Re \{ \text{tr}(W_t^H A^H N_{t-1}^i X_j) \} \]
\[ + \Re \{ \text{tr}(N_t^H A W_{t-1}^i X_j) + i \Im \{ \text{tr}(W_t^H A^H N_{t-1}^i Y_j) \} \} \]
\[ + i \Im \{ \text{tr}(N_t^H A W_{t-1}^i Y_j) \} \quad \text{(B.5)} \]

Decoding the symbol \( s_j \) is equivalent to minimizing the following expression (note that \( |s_j|^2 = 1 \)):

\[ |D_j - \frac{1}{\sqrt{p}} \text{tr}(A^H A)s_j|^2 = D_j^*D_j + \frac{1}{p} \langle \text{tr}(A^H A) \rangle^2 \]
\[ - \frac{2}{\sqrt{p}} \text{tr}(A^H A) \Re \{ D_j^*s_j \} \]

Therefore, the detector of the symbol \( s_j \) is:

\[ \hat{s}_j = \text{Arg} \{ \max_{s_j \in S} \Re \{ D_j^*s_j \} \} \quad \text{(B.6)} \]

The expressions (B.5), (B.6) are the aim of the proof. \( \square \)
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