TSG-RAN Working Group 1 *TSG R1-00-1394*

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Document for: Discussion and decision

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1. Introduction

Soft decision decoding metric is critical to turbo decoding. A sample metric has been disclosed in Section 12.1.4 of HSDPA Technical Report [1]. Other contributions are [3-5]. However, this sample metric can only be applied to single-path channel (i.e., AWGN or single-path fading channel). For multipath channels, a revised metric is needed in order to assess the performance. This paper proposes a soft decision decoding metric for multipath channel with higher order modulation (e.g., QAM). For single-path channels, the metric will still apply as a special case.

2. Proposed Metric

The proposed metric is as follows. The approximation to the log-likelihood ratio of bit *i* for a symbol duration can be calculated as

$$\lambda^{(i)}(\mathbf{Y}) = K_f \left[\min_{Q_j \in S^{(i)}} \left\{ \sum_{l=1}^{L} \left| y_l - Q_j \hat{w}_l \hat{A}_T(l) \right|^2 \right\} - \min_{Q_j \in \bar{S}^{(i)}} \left\{ \sum_{l=1}^{L} \left| y_l - Q_j \hat{w}_l \hat{A}_T(l) \right|^2 \right\} \right] \qquad (1)$$

i = 0, 1, 2, …, $\log_2$(M-1),

where M is the modulation alphabet size, i.e., 8, 16, 32, or 64,

$$\mathbf{Y} = [y_1 \quad y_2 \quad \cdots \quad y_L] \qquad (2)$$

is the observation vector,

L is the total number of paths (i.e., number of active fingers),

y_l is the de-spreader output of the traffic code channel for the l^{th} path (finger),

Q_j is the hypothesized transmitted QAM symbol,

$$S_{(i)} = \{QAM\ \ symbols\ whose\ i^{th}\ \ information\ bit,\ b^{(i)}, = "0"\}$$
$$\overline{S}_{(i)} = \{QAM\ \ symbols\ whose\ i^{th}\ \ information\ bit,\ b^{(i)}, = "1"\} \tag{3}$$

$\hat{w}_l$ is the estimate of complex channel fading (w_l) at the l^{th} path via pilot channel,

$\hat{A}_T(l)$ is the estimate of traffic code channel gain (amplitude) including the spreading gain at the l^{th} path,

K_f is a scale factor proportional to the received signal-to-interference ratio.

Note that the traffic code channel amplitude can be obtained as

$$A_T = \sqrt{\frac{E_c}{I_{or}} \cdot spreading\ \ factor} \tag{4}$$

where Ec/Ior is the transmit power fraction for the traffic code channel.

3. Derivation

Figure 1 shows the multipath model. Each path has an independent complex channel fading gain (w_l) and the associated delay. At the front end of the rake receiver, the aggregate other interference (from any sources other than the desired base station) is assumed to be zero mean with per chip variance = I_{oc}. Figure 2 shows the de-spreader operation at each finger. Without loss of generality, the output of the de-spreader for a traffic code channel in the l^{th} path can be formulated as

$$y_l = x \cdot w_l N_T A_T(l) + n(l) \tag{5}$$

where

x is the transmitted QAM symbol,

w_l is the complex-valued short term fading (namely, multiplicative distortion, MD) for the l^{th} path,

N_T is the traffic code channel integration period in chips, i.e., the spreading factor (chips per symbol),

$A_T(l)$ is the amplitude of the traffic code channel in the l^{th} path, including transmit power for the channel, path loss, shadow fading, antenna gain, except the short term fading (w_l), *n(l)* is the interference to the traffic code channel in the l^{th} path.

Being prevalent in the literature, the complex channel fading (w_l) is modeled as complex Gaussian (with non-zero mean if Rician or zero-mean if Rayleigh). The power distribution among L paths is normalized as

$$\sum_{l=1}^{L} E\left\{|w_l|^2\right\} = I_{or} \tag{6}$$

Simplified from [2], the interference to the traffic channel is assumed to be zero mean independent complex Gaussian and has the following properties

$$\begin{aligned} &E\left\{n(m)n(l)^*\right\} = N_T J(l)\delta(m-l), \\ &J(l) = I_{oc} + \sum_{\substack{m=1 \\ m\neq l}}^{L} E\left\{|w_m|^2\right\} \end{aligned} \tag{7}$$

where

J(l) is the per chip interference, i.e., the interference density in the l^{th} path,

I_{oc} is the variance of the interference from other base stations' transmission as shown in Fig. 2,

$\sum_{\substack{m=1 \\ m\neq l}}^{L} E\left\{|w_m|^2\right\}$ represents the interference power from other paths (but the same base station).

The log likelihood ratio given the observations at all the L paths (fingers) is

$$\begin{aligned} \lambda^{(i)}(\mathbf{Y}) &= \ln\left(P\left(\mathbf{Y}\middle|b^{(i)}="0"\right)\right) - \ln\left(P\left(\mathbf{Y}\middle|b^{(i)}="1"\right)\right) \\ &= \ln\left(\frac{1}{M}\sum_{Q_j\in S^{(i)}} P\left(\mathbf{Y}\middle|Q_j\right)\right) - \ln\left(\frac{1}{M}\sum_{Q_j\in \bar{S}^{(i)}} P\left(\mathbf{Y}\middle|Q_j\right)\right) \end{aligned} \tag{8}$$

Since y_l in (5) is complex Gaussian, the conditional mean is

$$E\left\{y_l \middle| x, \hat{A}_T(l), \hat{w}_l\right\} = x \cdot \hat{w}_l N_T \hat{A}_T(l) \tag{9}$$

where $\hat{A}_T(l)$ is the estimate of $A_T(l)$ and the short term complex channel fading can be estimated by the pilot channel observations.

The probability $P(\mathbf{Y}|Q_j)$ can thus be obtained as

$$Prob(\mathbf{Y}|Q_j,\hat{\mathbf{W}},\hat{\mathbf{A}}_T) = \prod_{l=1}^{L} Prob(y_l|Q_j,\hat{w}_l,\hat{A}_T(l)) = \prod_{l=1}^{L} \frac{1}{\pi V_l}\exp\left(-\frac{\left|y_l - Q_j\hat{w}_l N_T \hat{A}_T(l)\right|^2}{V_l}\right) \tag{10}$$

where

$$V_l = E\left\{\left|y_l - Q_j\hat{w}_l N_T\hat{A}_T(l)\right|^2\right\} = N_T^2\left|Q_j\right|^2 E\left\{\left|w_l A_T(l) - \hat{w}_l\hat{A}_T(l)\right|^2\right\} + N_T J(l) \tag{11}$$

is the variance for the l^{th} path.

Since the probabilities of $P(\mathbf{Y}|Q_j)$ are dominated by the exponential terms, the log likelihood ratio in (8) can be approximated as

$$\begin{aligned}
\Lambda^{(i)}(\mathbf{Y}) &= \ln\left(\frac{1}{M}\sum_{Q_j\in S^{(i)}} P(\mathbf{Y}|Q_j)\right) - \ln\left(\frac{1}{M}\sum_{Q_j\in \bar{S}^{(i)}} P(\mathbf{Y}|Q_j)\right) \\
&\approx \ln\left(\max_{Q_j\in S^{(i)}} P(\mathbf{Y}|Q_j)\right) - \ln\left(\max_{Q_j\in \bar{S}^{(i)}} P(\mathbf{Y}|Q_j)\right) = \max_{Q_j\in S^{(i)}}\left\{\ln\left(P(\mathbf{Y}|Q_j)\right)\right\} - \max_{Q_j\in \bar{S}^{(i)}}\left\{\ln\left(P(\mathbf{Y}|Q_j)\right)\right\} \\
&= \max_{Q_j\in S^{(i)}}\left\{\sum_{l=1}^{L} -\ln(\pi V_l) - \frac{\left|y_l - Q_j\hat{w}_l N_T\hat{A}_T(l)\right|^2}{V_l}\right\} \\
&\quad - \max_{Q_j\in \bar{S}^{(i)}}\left\{\sum_{l=1}^{L} -\ln(\pi V_l) - \frac{\left|y_l - Q_j\hat{w}_l N_T\hat{A}_T(l)\right|^2}{V_l}\right\}
\end{aligned} \tag{12}$$

Usually the variance at the l^{th} path, V_l, in (11) is dominated by the other cell interference because 1) the first term at the right hand side of (11) can be neglected given adequate channel estimation by pilot and 2) the interference density at the l^{th} path, $J(l)$ in (7), is usually dominated by Ioc or roughly of the same magnitude for all l (assuming active fingers are within a few dB of each other). Therefore (12) can be further simplified and become (1) with N_T merged into A_T and

$$K_f \;?\; \frac{I_{or}}{I_{oc} \;?\; ?\frac{L ? 1}{L}? I_{or}} \qquad (13)$$

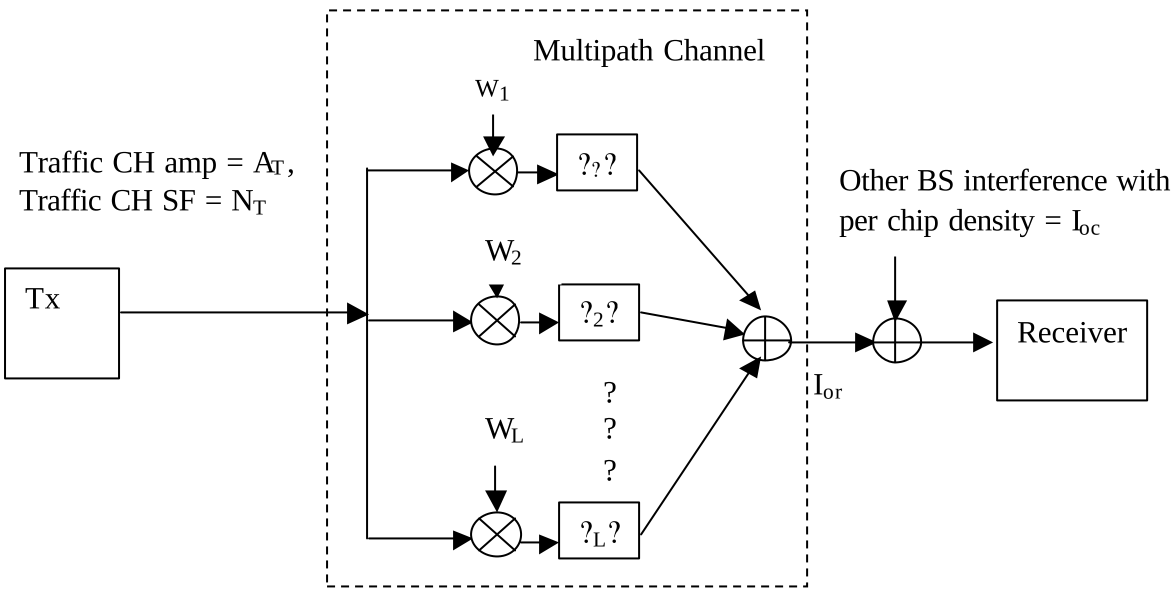

Fig. 1 Multipath channel model

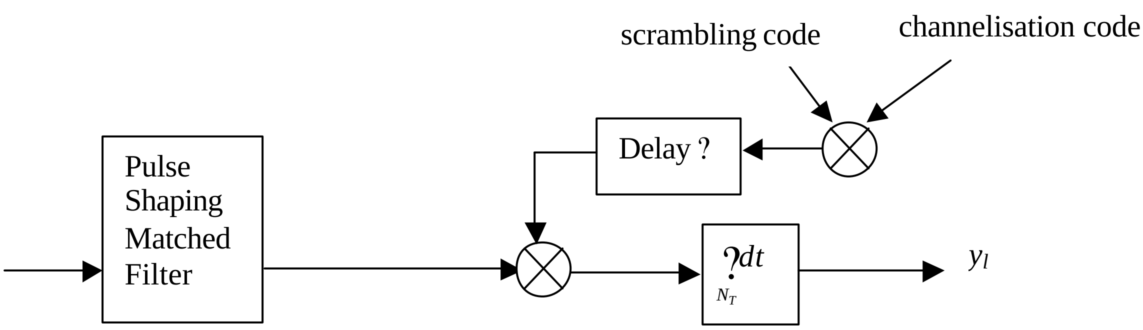

Fig. 2 De-spreader at each finger

References

[1] 3GPP TSGR1#16(00)1316, "Physical Layer Aspects of UTRA High Speed Downlink Packet Access", 10/13/2000.

[2] Wen-Yi Kuo, "Analytic Forward Link Performance of Pilot-Aided Coherent DS-CDMA under Correlated Rician Fading", IEEE Journal of Selected Area on Communications, July 2000, pp. 1159-1168.

[3] Wiscom Technologies, "Influence of channel estimation on the link level performanc of HSDPA," TSGR1#17(00) 1327, TSG-RAN Working Group 1 Meeting #17, Stocholm, Sweden, November 21-24, 2000.

[4] Wiscom Technologies, TSG-RAN Working Group 1 Meeting #17,Link Level Simulations for HSDPA, TSGR1#17(00) 1326, TSG-RAN Working Group 1 Meeting #17, Stocholm, Sweden, November 21-24, 2000.

[5]] Wiscom Technologies, "Use of Long-Range Prediction for channel estimation and its application in HSDPA," TSGR1#17(00) 1393, TSG-RAN Working Group 1 Meeting #17, Stocholm, Sweden, November 21-24, 2000.