A tapped Delay Line Model of Multipath Channel for CDMA Systems

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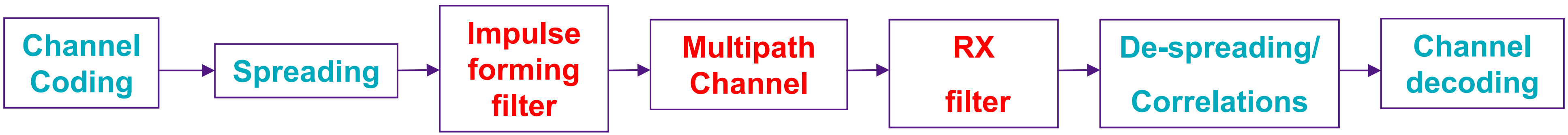
Outline

- Introduction
- Existing methods to obtain an equivalent model
- Equivalent channel model
- Advantages - Limitations
- Conclusion

Introduction

Need of an equivalent channel model

- Real channel models (*Pedestrian, Indoor…*) have paths delays that are not multiple of the chip period T_c
- Simulations, therefore, need several samples per chip



- Aim: Equivalent channel

$$h(\tau;t) = \sum_{i=0}^{L-1} h_i(t)\delta(\tau - \tau_i) \quad \Rightarrow \quad h'(\tau;t) = \sum_{n} h'_n(t)\delta(\tau - nT_c)$$

- Equivalence criterium:

  signal after the channel or at the output of the Rake receiver
- Avantages: 1 sample per chip and one can discard the filters' influence

Existing methods

Former works

- ***J. G. Proakis [1]: equivalence at the channel output***
  - Filter $u(t)$ is band limited

$$\text{Paths :} \quad h'_i(t) = \sum_{n=0}^{L-1} h_n(t)\,\mathrm{sinc}\!\left(\frac{\tau_i}{T_c} - i\right)$$

$$\text{Channel :} \; h'(t;\tau) = \sum_{i=-\infty}^{\infty} h'_i(t)\,\delta(\tau - iT_c)$$

- ***Fechtel [2]: equivalence at the channel output***
  - Projection to basis $\{u(t-nT_c)\}_n$:

$$\text{Paths :} \quad h'_i(t) = \sum_{n=0}^{L-1} h_n(t)\, g(\tau_n - iT_c)$$

$$\text{Channel :} \; h'(t;\tau) = \sum_{i=-\infty}^{\infty} h'_i(t)\,\delta(\tau - iT_c)$$

- **Mutually dependant paths**
- **The number of coefficients (paths) is large**

Equivalent channel model

Chip equivalent channel (1)

- **Assumptions : channel perfectly known, perfect spreading, WCDMA**

- **Output of the Rake receiver:**

$$\hat{s}_k = \sqrt{E_s}\underbrace{\left(\sum_{i=0}^{L-1}\sum_{j=0}^{L-1} h_i^*(kT_s)h_j(kT_s)g(\tau_i-\tau_j)\right)}_{\gamma_k=\mathbf{h}_k^*\mathbf{G}\mathbf{h}_k \;\; where\; \mathbf{h}_k=[h_0(kT_s),\dots,h_{L-1}(kT_s)]^t} s_k + b_k$$

- **Characteristic function of the energy**

$$\psi_{\gamma_k}(v) = \frac{1}{\det(\mathbf{I}_L - jv\mathbf{GC})} = \frac{1}{\det(\mathbf{I}_L - jv\mathbf{D})}$$

  - **G: Autocorrelation matrix of the filters, C: covariance matrix of the channel taps**
  - **D** is the diagonal matrix of **CG**

Chip equivalent channel (2)

- **Definition of the equivalent channel**
  - Average powers of the paths: $\left\{\overline{\gamma}_i'\right\}_{i=0}^{L-1}$ values of the diagonal of $\mathbf{D}$
- **Same performance for an uncoded system**

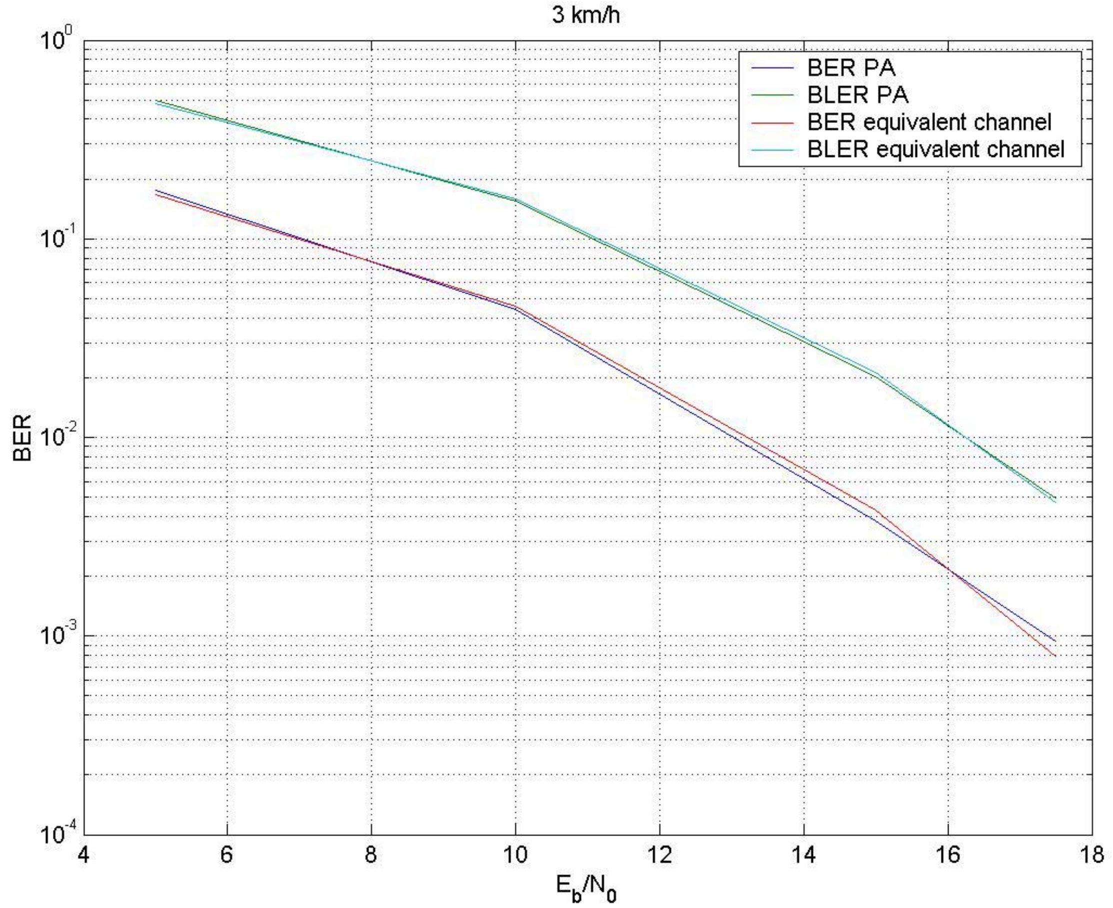
$$BER = \int Q\left(\sqrt{\frac{\gamma_k E_s}{N_0}}\right) p(\gamma_k) d\gamma_k = \int Q\left(\sqrt{\frac{\gamma_k' E_s}{N_0}}\right) p(\gamma_k') d\gamma_k'$$

- **Placing the paths at multiples of T_c ⇨ there's no influence of the filters.**
- **Let's consider $\gamma_k' = \mathbf{h}'^{*}_k . \mathbf{h}'_k$ with $\mathbf{h}'_k$ a vector with L Gaussian processes of the diagonal matrix $\mathbf{D}$**
- **We proved the equality of the two processes γ_k and γ_k'**
  ⇨ **same performance after decoding** ⇨ **channel is equivalent**

$$\begin{cases} \forall k \qquad p(\underline{\gamma}) = p(\underline{\gamma}') \\ où \quad \underline{\gamma} = (\gamma_0, \gamma_1, \ldots, \gamma_{k-1}) \; et \; \underline{\gamma}' = (\gamma_0', \gamma_1', \ldots, \gamma_{k-1}') \end{cases}$$

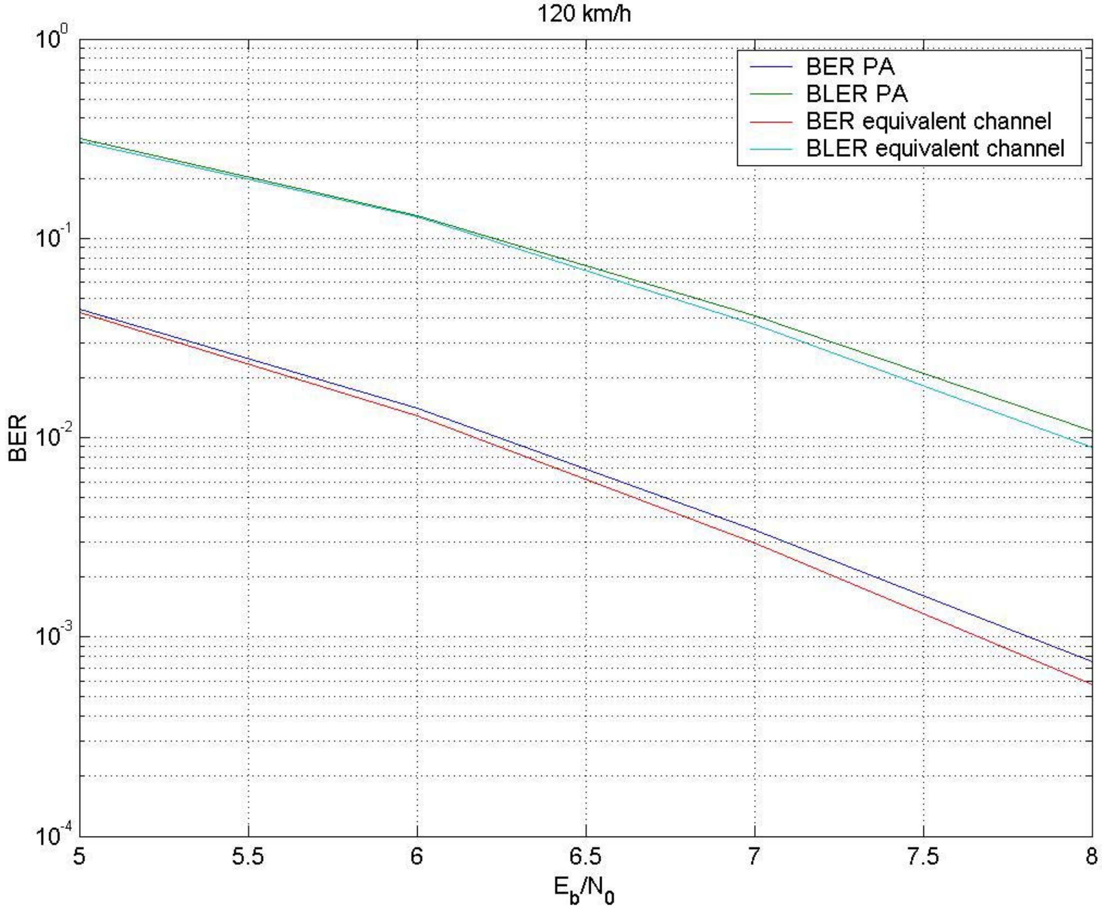
Simulation results

- **12.2 kbps Service UMTS mode FDD:** Spreading factor 64, convolutional code 1/3



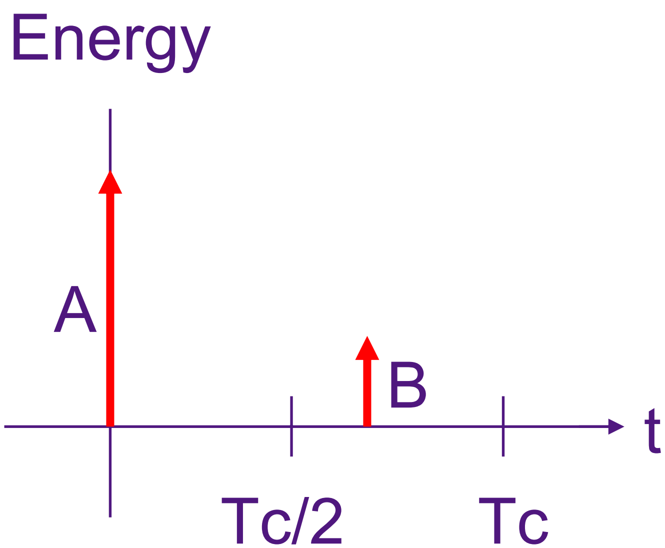
Simulation results

- **12.2 kbps Service UMTS mode FDD:** Spreading factor 64, convolutional code 1/3

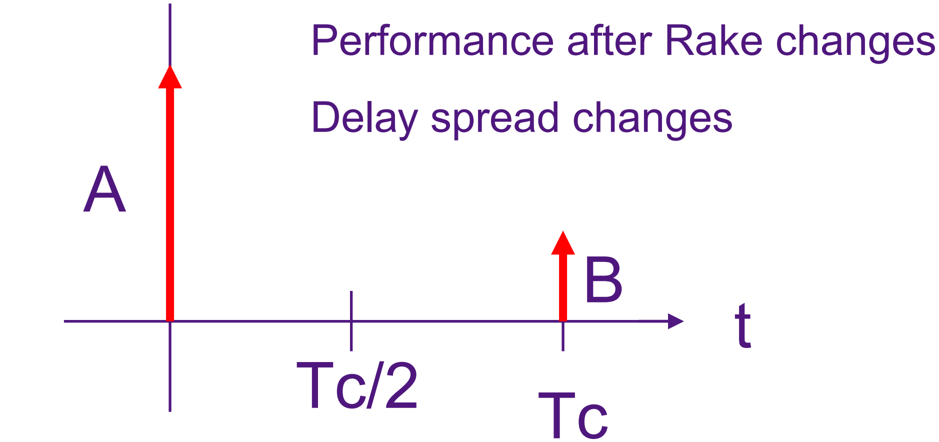


Comparison of different strategies when a path is not multiple of Tc

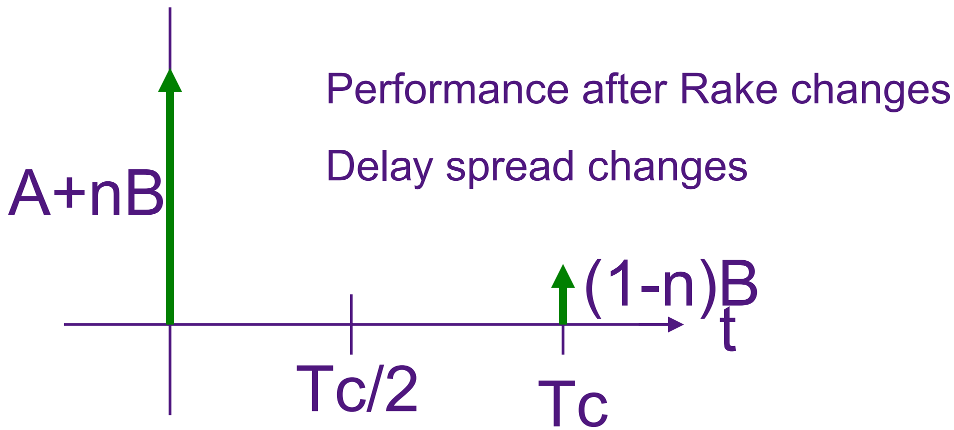
Comparison



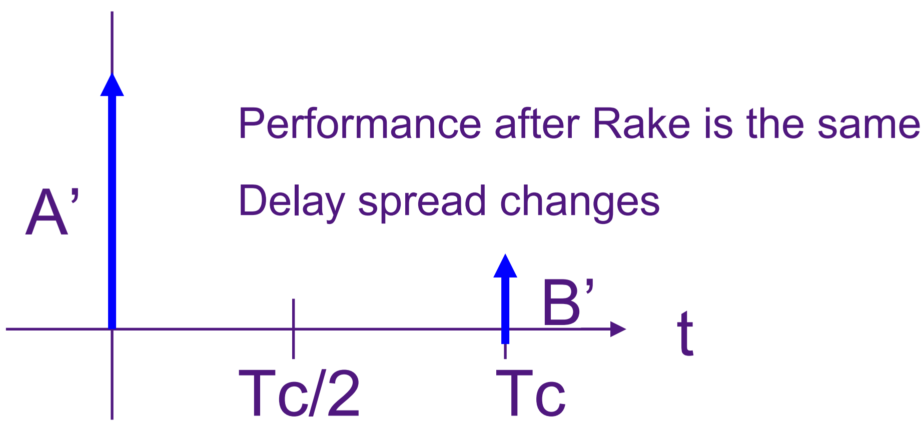
Energy
A
B
t
Tc/2
Tc



Performance after Rake changes
Delay spread changes
A
B
t
Tc/2
Tc

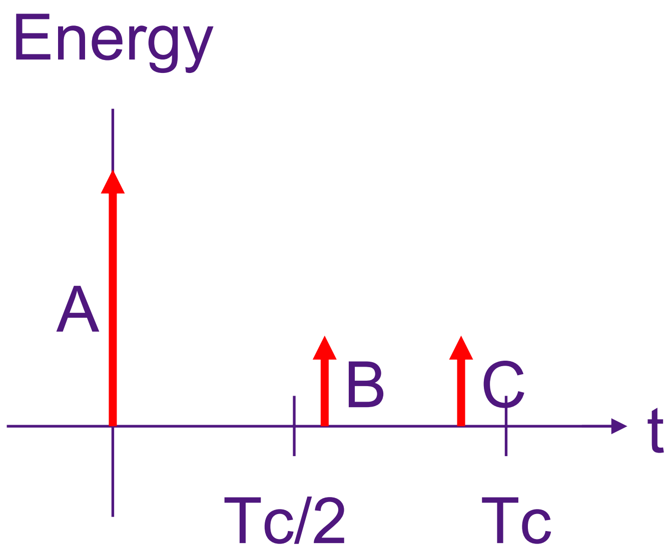


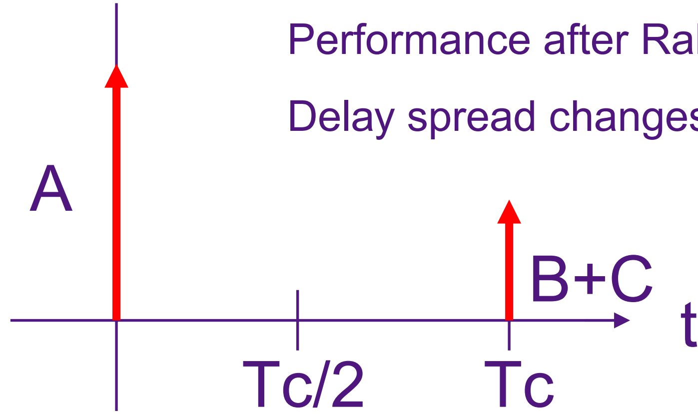
Performance after Rake changes
Delay spread changes
A+nB
(1-n)B
t
Tc/2
Tc



Performance after Rake is the same
Delay spread changes
A'
B'
t
Tc/2
Tc

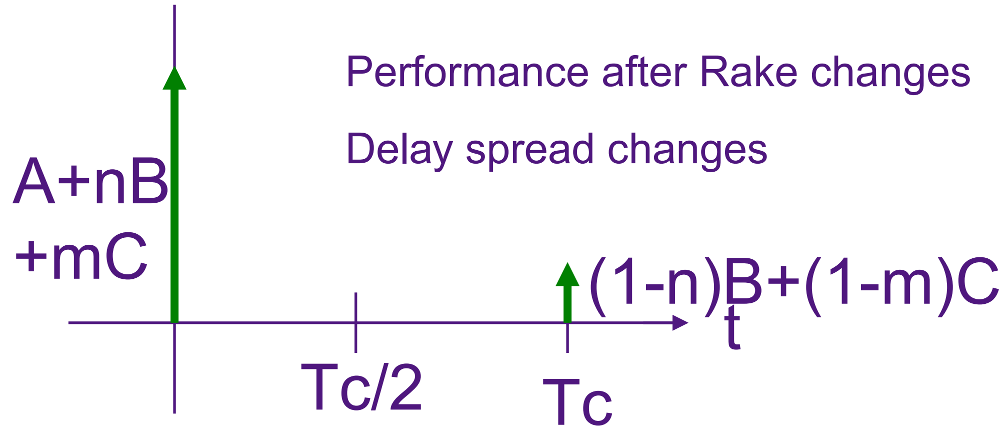
Comparison





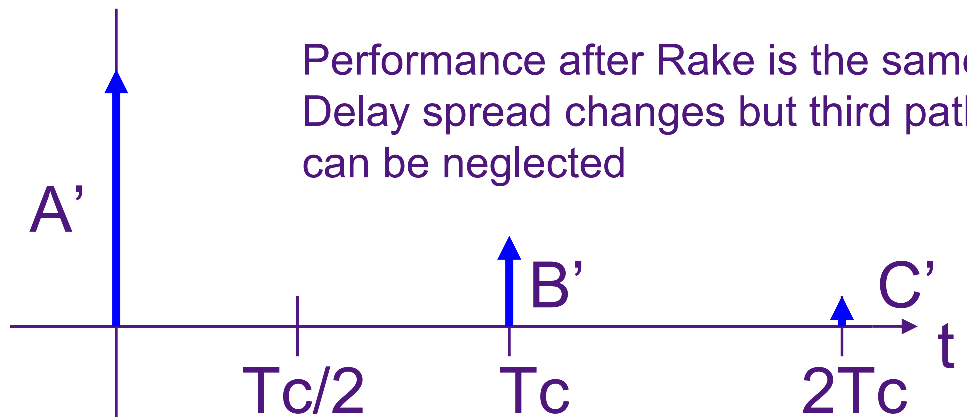
Performance after Rake changes

Delay spread changes



Performance after Rake changes

Delay spread changes



Performance after Rake is the same
Delay spread changes but third path can be neglected

Advantages – Limitations of the proposed equivalent channel

Annotations

- **Avantages**
  - The paths are mutually independant, i.e uncorrelated
  - Reduction of the number of paths is possible
  - Comparison between channel models

ITU Indoor-A	
$\bar{\gamma}_i$ (dB)	τ_i (ns)
0.0	0
-2.99	50
-10.0	110
-17.99	170
-26.14	290
-31.88	310

Equivalent channel	
$\bar{\gamma}_i$ (dB)	τ_i (ns)
0.0	0
-12.54	260
-25.74	520
-37.67	*790*
-58.48	*1040*
-81.9	*1300*

ITU Pedestrian-A	
$\bar{\gamma}_i$ (dB)	τ_i (ns)
0.0	0
-9.7	110
-19.2	190
-22.8	410

Equivalent channel	
$\bar{\gamma}_i$ (dB)	τ_i (ns)
0.0	0
-12.67	260
-22.7	520
-33.88	*790*

- **Limitations**
  - Inter-Symbol-Interference and Inter-Path-Interference(residual correlation) are different

Conclusions

- **Chip equivalent model for WCDMA systems**
  - mutually independant paths
  - Reduction of the number of paths possible
  - ISI and IPI is neglected (true for spreading factor > 16)
  - order and exact place (at which multiple of Tc) of the paths are to be defined according to needs

References

[1] "Digital Communications", J.G. Proakis, McGraw-Hill, 1985.

[2] "A novel approach to modeling an efficient simulation of frequency selective fading radio channels", S. A. Fechtel, Proc. IEEE JSAC, vol.11, issue 3, April 1993.

[3] "Tapped delay line model of linear randomly time-variant WSSUS channel", J. Sykora, IEEE Electronic letters, Vol. 36, No. 19, Sept. 2000.

[4] "An Equivalent Multi-Path Channel Chip Model for CDMA Systems", A. Saadani, S. Wendt, P. Gelpi and D. Duponteil, accepted at ISCCSP 2004, Hammamet.