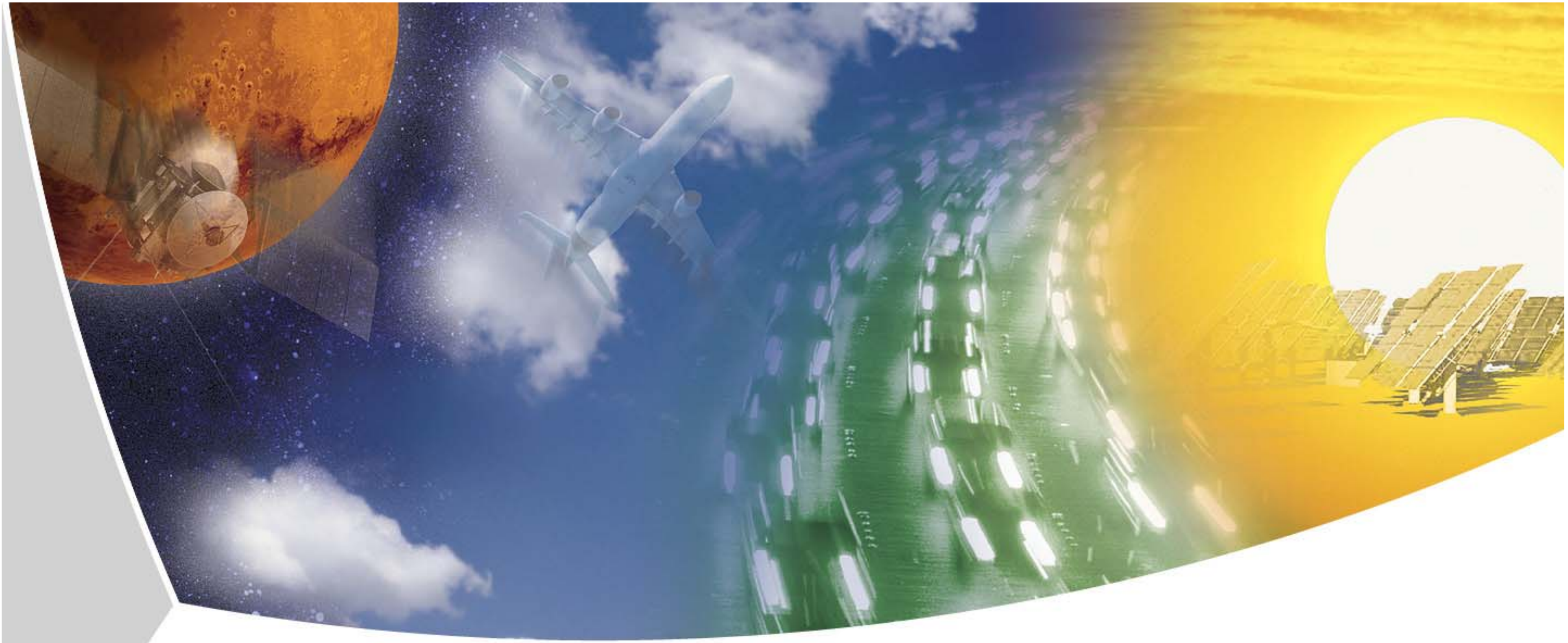


Correlation Properties in Time-Varying Cyclic Delay Diversity (TV-CDD)

Simon Plass

German Aerospace Center (DLR)

Florence, 30-31 October, 2006

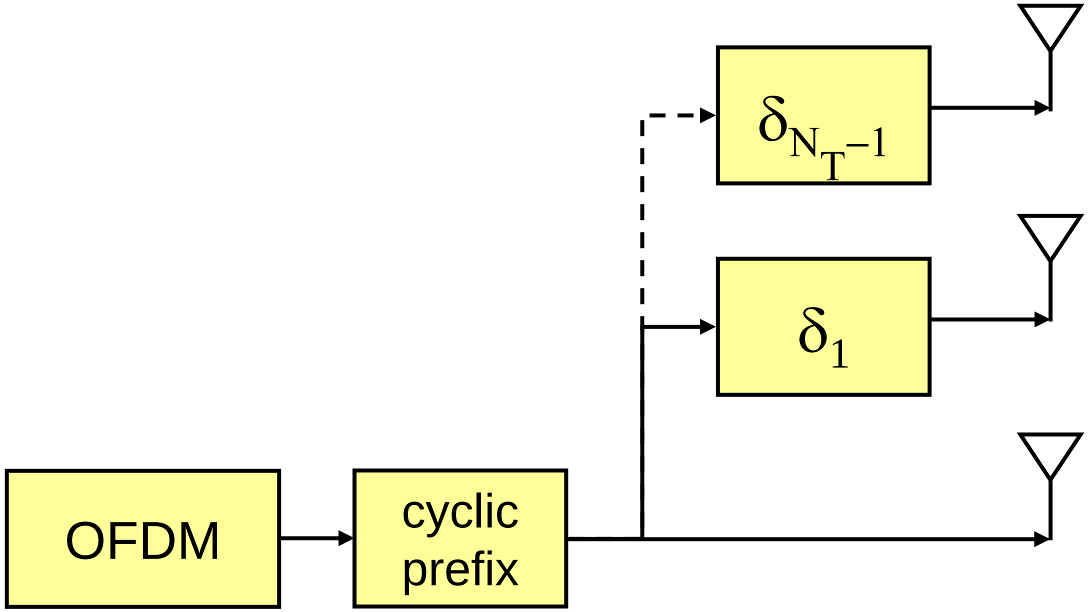
DLR German Aerospace Center

Outline

- Transmit Diversity Techniques for OFDM
  - From Delay Diversity (DD)
  - To Cyclic Delay Diversity (CDD)
  - ➔ Time-Varying Cyclic Delay Diversity (TV-CDD)
- Resulting Channel Characteristics from TV-CDD
- Influence of Maximum Cyclic Delay
- Conclusions

Transmit Diversity Technique: Delay Diversity (DD)[1]

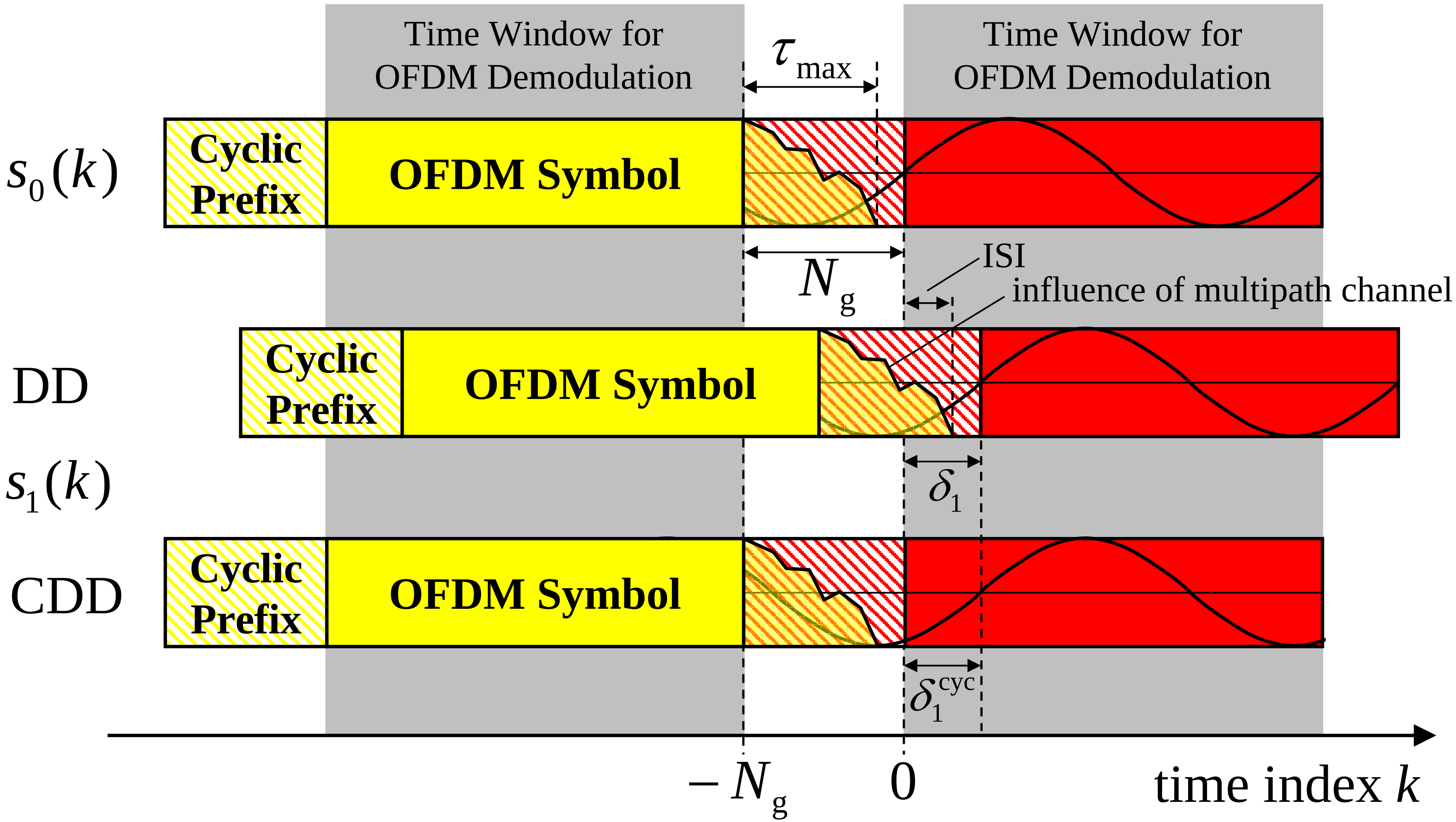
- Idea: Increase number of propagation paths
- Method: Delay of TX-signal in time domain
- Result: Increased frequency diversity on receiver side



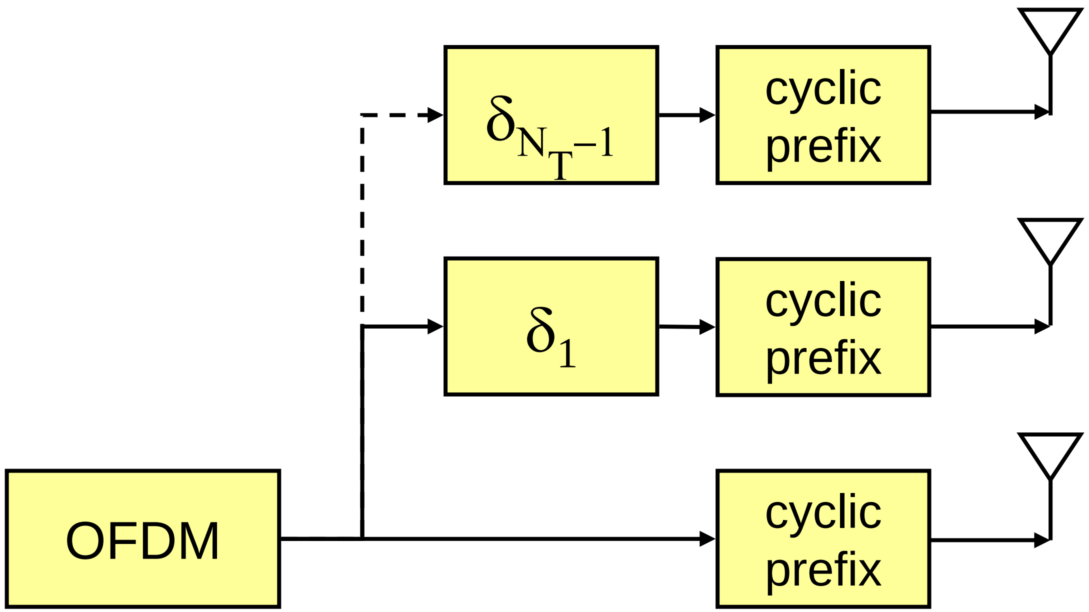
- ⇧ very low complexity
- ⇧ no additional complexity at mobile
- ⇩ additional delay

[1] A. Wittneben, “A new bandwidth efficient transmit antenna modulation diversity scheme for linear digital modulation,” in *Proceedings IEEE International Conference on Communications (ICC 1993), Geneva, Switzerland*, May 1993, pp. 1630–1634.

From Delay Diversity to Cyclic Delay Diversity (CDD)



Cyclic Delay Diversity (CDD)[2]

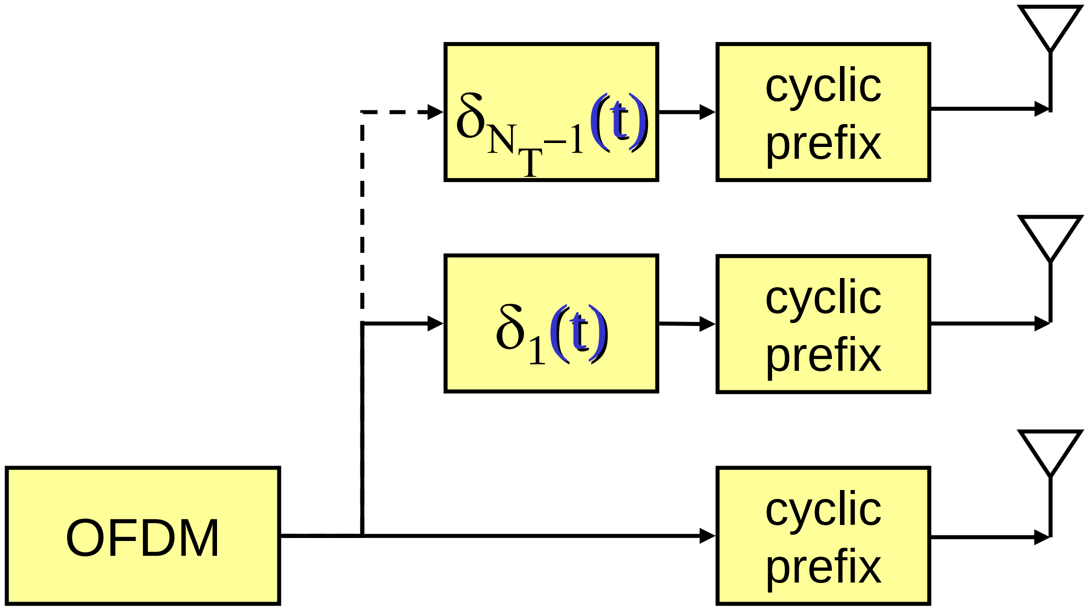


- ⇧ no additional inter-symbol interference
- ⇧ no additional complexity at mobile
- ⇩ higher complexity compared to DD

[2] A. Dammann and S. Kaiser, "Performance of low complex antenna diversity techniques for mobile OFDM systems," in *Proc. Workshop on Multi-Carrier Spread Spectrum (MC-SS 2001), Oberpfaffenhofen, Germany*, Sept. 2001, pp. 53–64.

Time-Varying Cyclic Delay Diversity (TV-CDD)[3]

- Method: Include time-variant randomly chosen cyclic delays



- same benefits as CDD
- additional time diversity

[3] G. Richter, M. Bossert, E. Costa, and M. Weckerle, "On time-varying cyclic delay diversity," *European Transactions on Telecommunications*, vol. 17, no. 3, pp. 361–370, May 2006.

Signal Structure of TV-CDD

Transmitted signal at each antenna branch:

$$S'_n(k,t) = 1/\sqrt{N_\mathsf{T}} \cdot S(k) e^{-j\frac{2\pi}{N_\mathsf{FFT}} k \delta_n^{\mathsf{cyc}}(t)}$$

TV-CDD component

$$\delta_n^{\mathsf{cyc}}(t) \in \mathbf{S} = [0, \ldots, N_\mathsf{FFT} - 1]$$

Received signal:

$$R(k,t) = \sum_{n=0}^{N_\mathsf{T}-1} S'_n(k,t) \cdot H_n(k,t) + n(k,t)$$

$$R(k,t) = S(k) \cdot \underbrace{\frac{1}{\sqrt{N_\mathsf{T}}} \sum_{n=0}^{N_\mathsf{T}-1} e^{-j\frac{2\pi}{N_\mathsf{FFT}} k \delta_n^{\mathsf{cyc}}(t)} H_n(k,t)}_{H'(k,t)} + n(k,t)$$

Channel Correlation Properties

$$H'(k,t) = \frac{1}{\sqrt{N_\mathrm{T}}} \sum_{n=0}^{N_\mathrm{T}-1} e^{-j\frac{2\pi}{N_\mathrm{FFT}} k \delta_n^{\mathrm{cyc}}(t)} H_n(k,t)$$

$$\Phi(k_1,k_2,t_1,t_2) = E\{H'(k_1,t_1) H'^*(k_2,t_2)\}$$

- Assumptions:
  - Uncorrelated sub-channels $E\{|H_n(k,t)|^2\} = 1$
  - No Doppler shifts $E\{H_n(k,t_1) \cdot H_n^*(k,t_2)\} = 1$

Correlation Properties in Time Direction

$$\Phi(k, t_1 \neq t_2) = \frac{1}{N_\mathsf{T}} \sum_{n=0}^{N_\mathsf{T}-1} E\{e^{-j\frac{2\pi}{N_\mathsf{FFT}} k\delta_n^{\mathsf{cyc}}(t_1)}\} \cdot E\{e^{+j\frac{2\pi}{N_\mathsf{FFT}} k\delta_n^{\mathsf{cyc}}(t_2)}\} E\{H_n(k, t_1) H_n^*(k, t_2)\}$$

$\Phi(k, t_1 \neq t_2)$ depends on $P(\delta) = 1/N_\mathsf{FFT}$

First sub-carrier: $\Phi(k = 0, t_1 \neq t_2) = 1$

Other sub-carriers: $\Phi(k \neq 0, t_1 \neq t_2) = 0$

➔ Uncorrelated Rayleigh fading channel

Correlation Properties in Frequency Direction

$$\Phi(k_1 \neq k_2, t) = 0$$

Impact on Large Cyclic Delays

Constraint for no change of channel estimation process:

$$\tau'_{\text{max}} = \tau_{\text{max}} + \delta^{\text{cyc}}_{\text{max}} \leq N_{\text{G}}$$

Now, we choose from a new set of cyclic delays:

$$\mathbf{S}_a = [0, \ldots, \delta^{\text{cyc}}_{\text{max}}] \quad \text{where} \quad \delta^{\text{cyc}}_{\text{max}} = \frac{N_{\text{FFT}}}{a} - 1\,, \quad a \in 2^m$$

Influence of New Maximum Cyclic Delay

$\Phi(k_1, k_2, t_1, t_2)$ depends on $P(\delta)$

Now: $P(\delta) = a/N_{\mathrm{FFT}}$

The resulting correlation properties in time direction:

First sub-carrier: $\Phi(k = 0, t_1 \neq t_2) = 1$

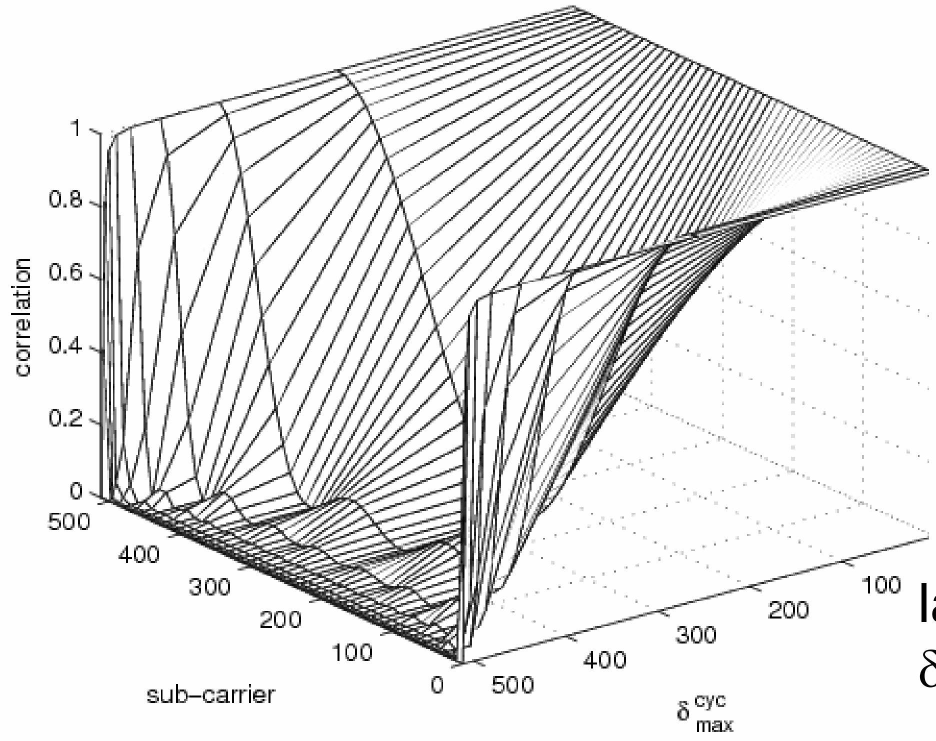
Other sub-carriers:

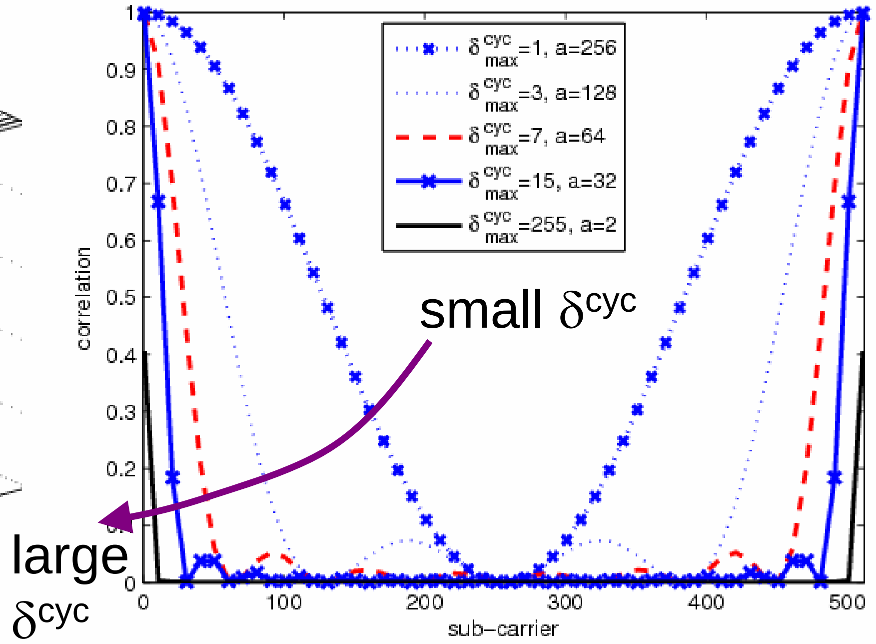
$$\Phi(k \neq 0, t_1 \neq t_2) = \frac{1}{N_{\mathrm{T}}} \sum_{n=0}^{N_{\mathrm{T}}-1} E\{|e^{-j\frac{2\pi}{N_{\mathrm{FFT}}}k\delta_n(t_1)}|^2\}$$

The resulting correlation properties in frequency direction:

The same as in the case of time direction

Correlation Properties in Time Direction

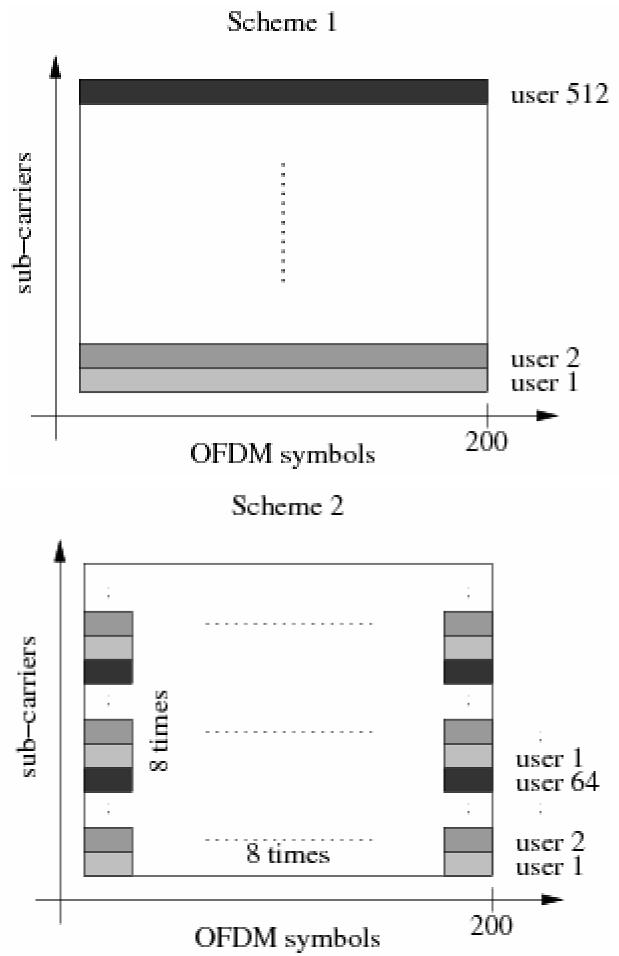




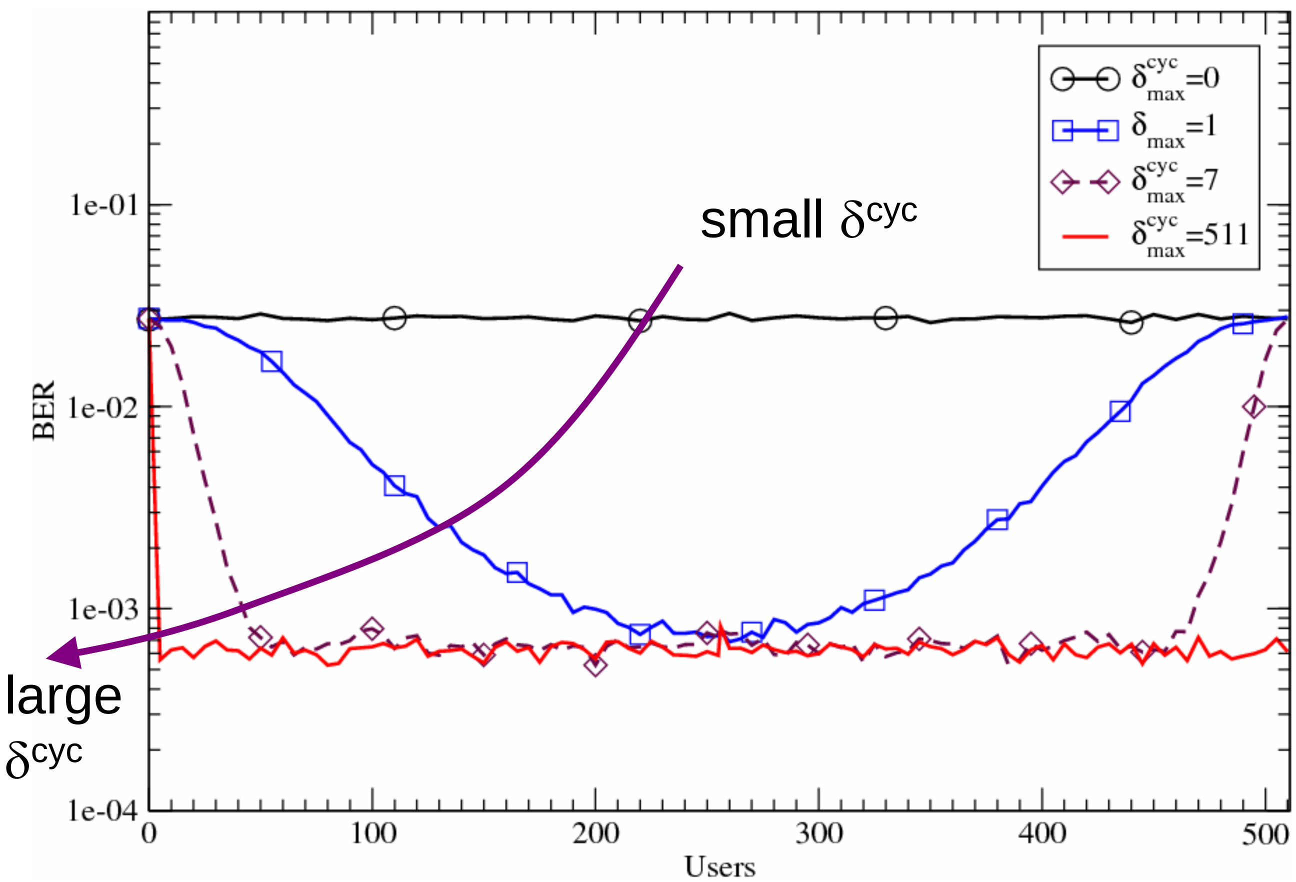
Simulation Results

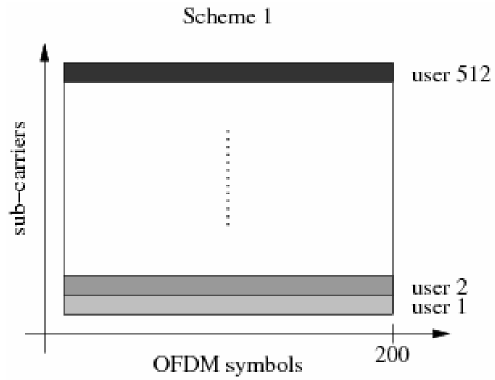
System Parameters & Channel Model

Carrier frequency	5 GHz
Bandwidth	20 MHz
FFT length	512
OFDM symbols / Frame	200
Modulation	BPSK
Coding	Conv. Code, R=1/2
Channel model	Exponetial decaying power profile with 15 taps
Maximum channel delay	5µs
Transmit antennas	4
SNR	10 dB

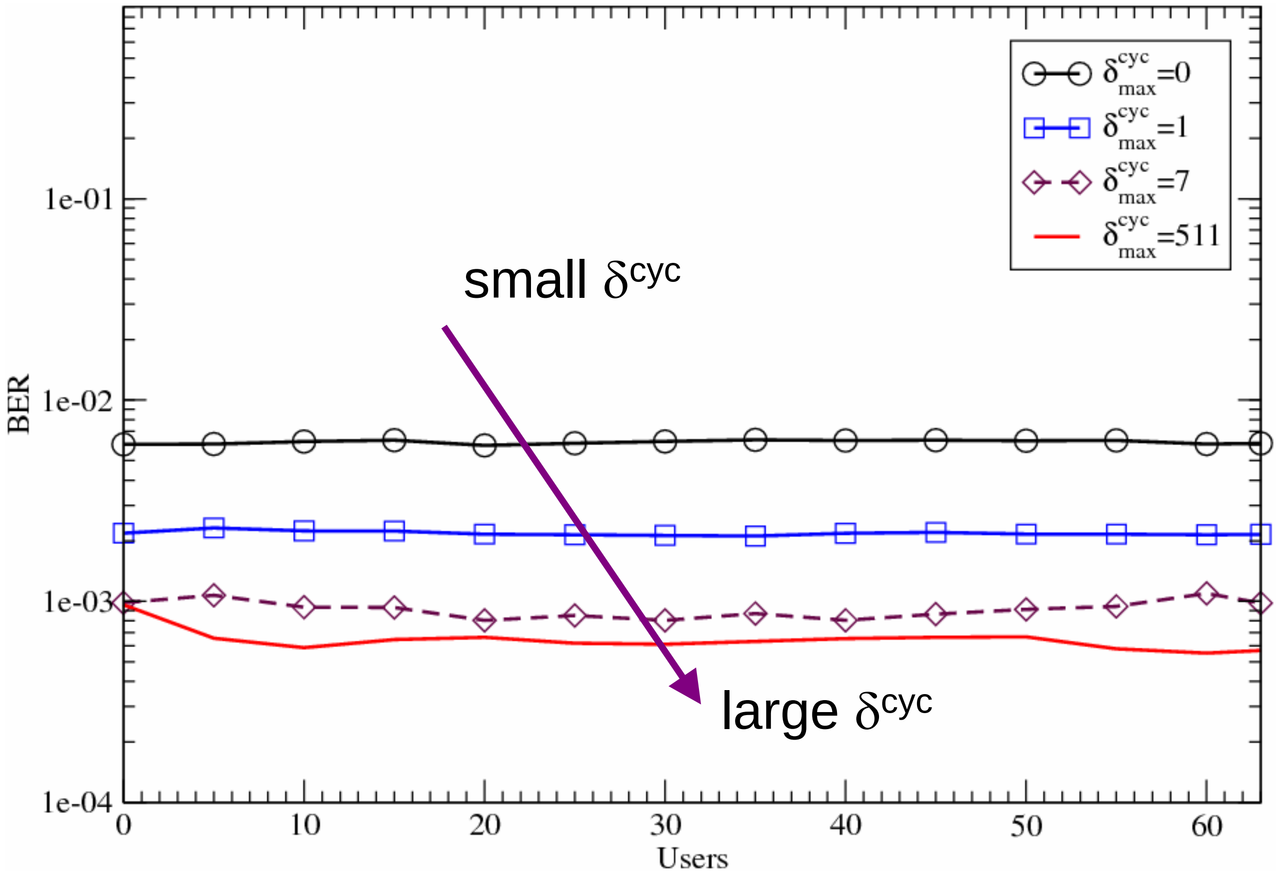


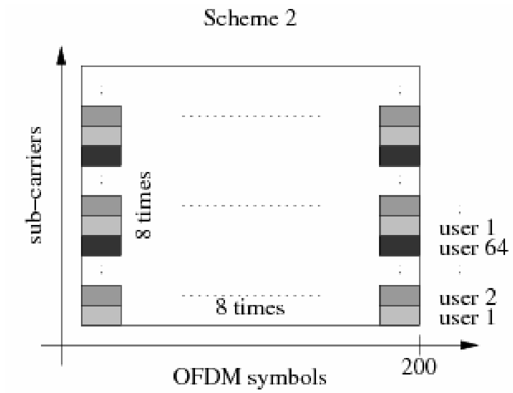
Impact on Error Performance for Scheme 1



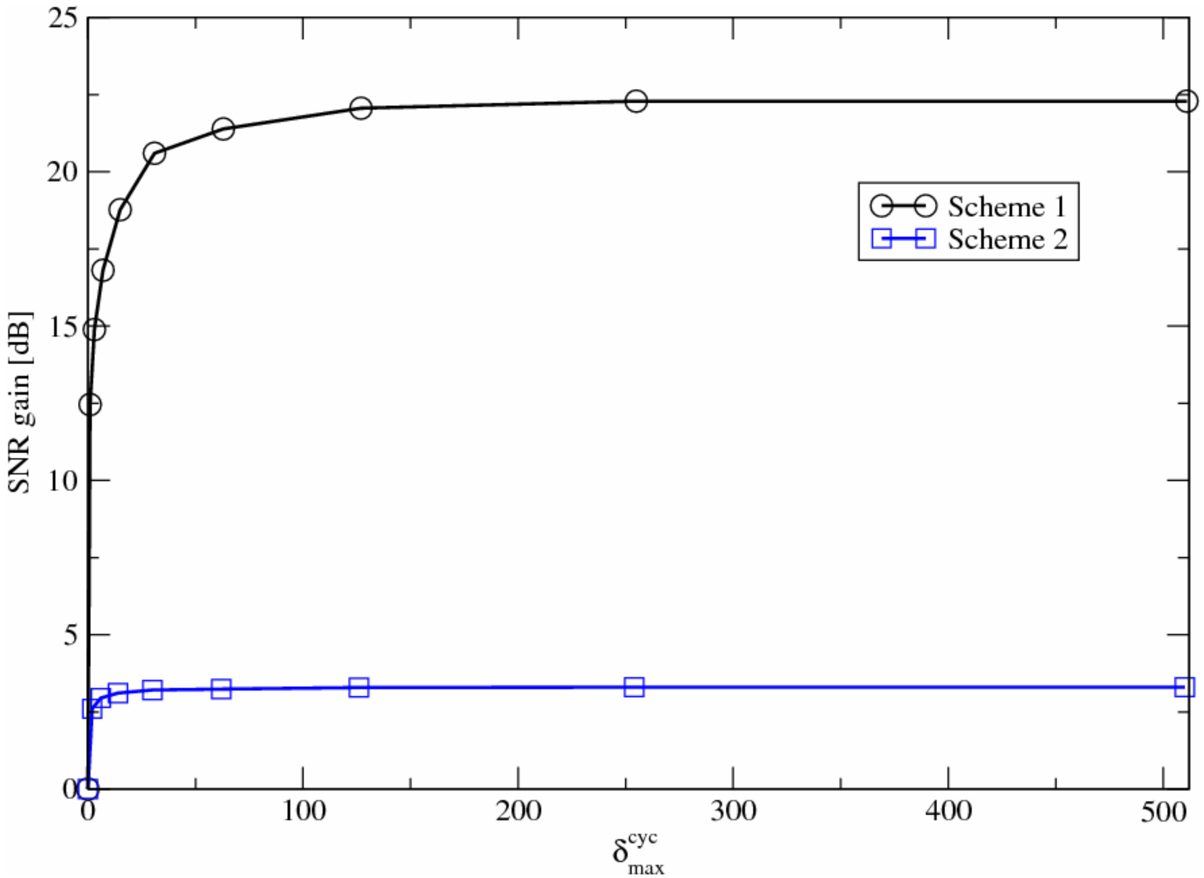


Impact on Error Performance for Scheme 2





SNR Gain for Varying Maximum Cyclic Delay



- Fast saturation of performance gain
- Since each users allocates one sub-carrier in Scheme 1, very large SNR gain

Conclusions

- Brief Introduction of transmit diversity techniques:
  Delay Diversity (DD) ➔ Cyclic Delay Diversity (CDD) ➔
  Time-Varying CCD (TV-CDD)
- Analytical study about the resulting channel characteristics of TV-CDD in an OFDM system
  - Except for the first sub-carrier, an uncorrelated Rayleigh fading channel is generated
- Choice of maximum cyclic delay δ^{cyc} influence the correlation characteristics
  - A small δ^{cyc} guarantees no changes at the receiver structure and still sufficient good performances

Thank you!