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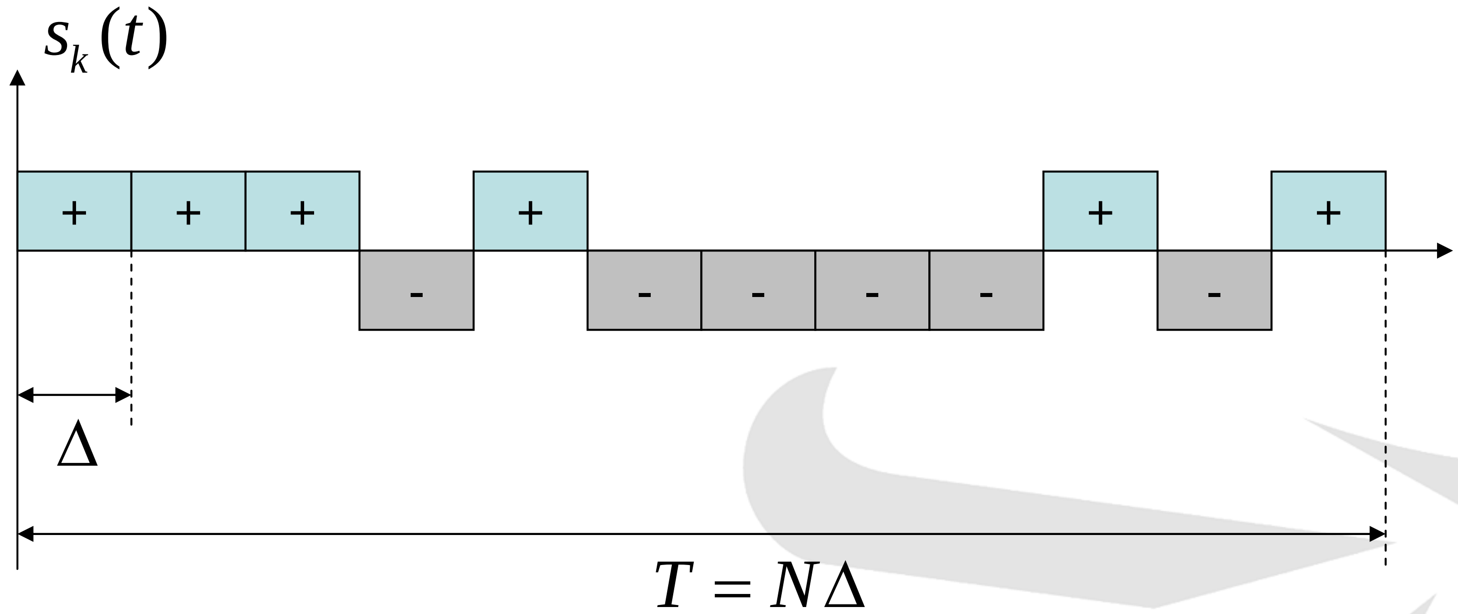
Signature-Interleaved DS CDMA

Direct Sequence CDMA



$$s_k(t) = A_k b_k \sum_{i=0}^{N-1} s_k(i) c_0(t - i\Delta), \quad b_k = \{\pm 1\}$$

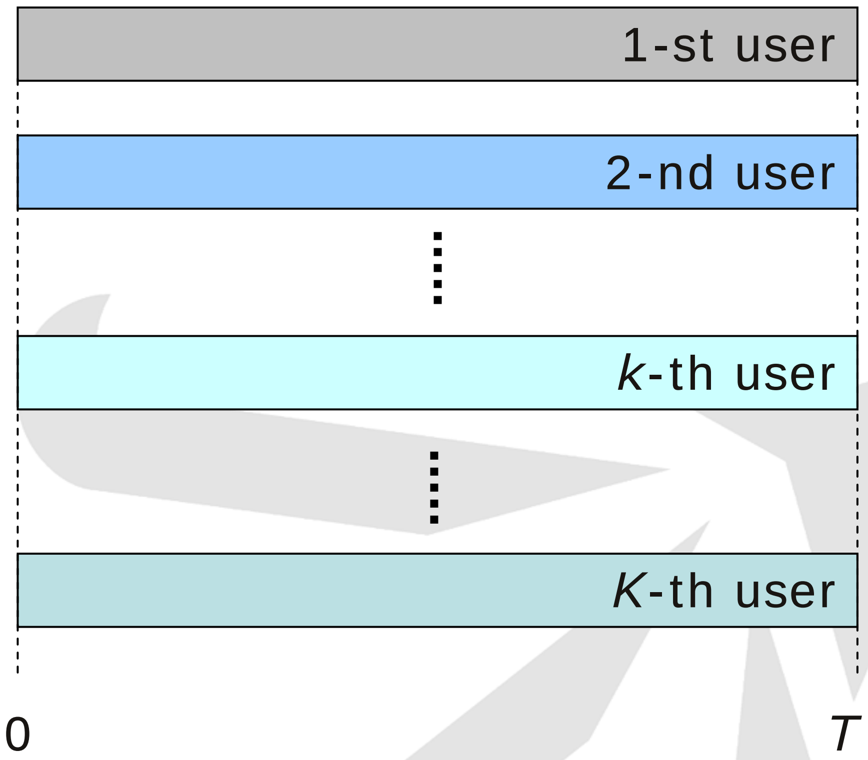
$$\mathbf{s}_k = \left[s_k(0),\, s_k(1),\, \ldots,\, s_k(N-1) \right]$$

Synchronous DS CDMA

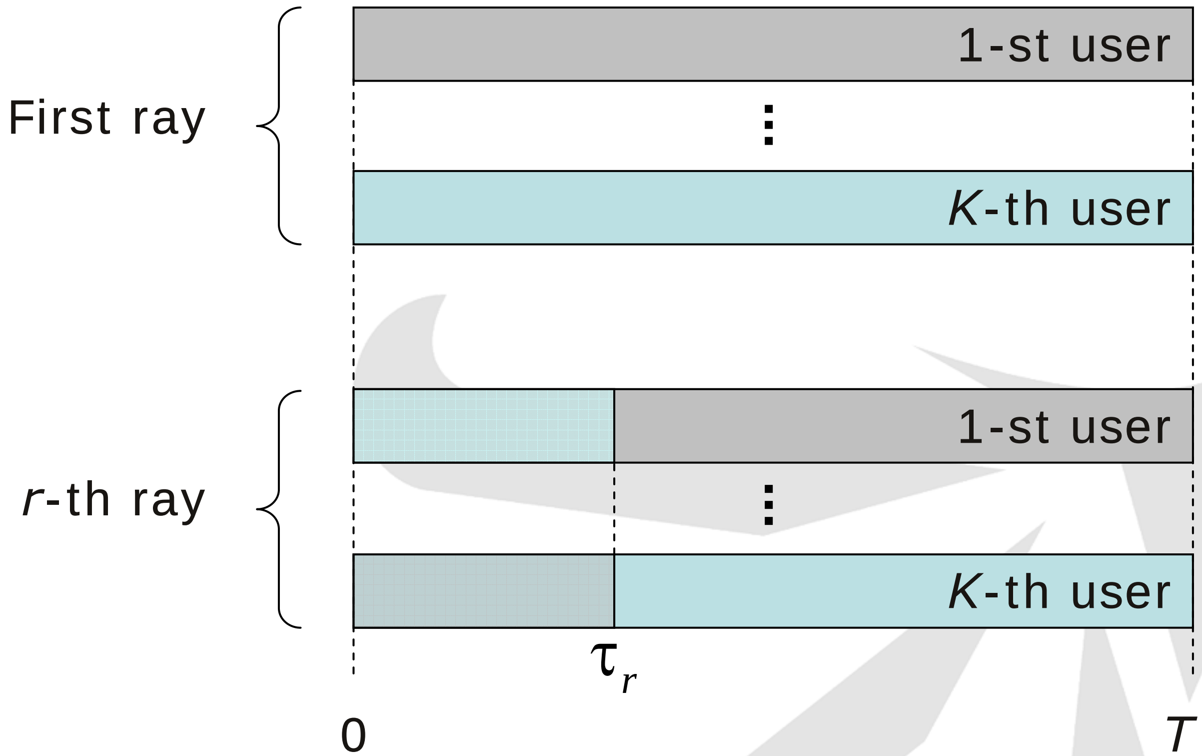
Single-user receiver output:

$$z_k = A_k b_k + \sum_{\substack{l=1 \\ l \neq k}}^{K} A_l b_l R_{kl} + n_k$$

$$R_{kl} = \mathbf{s}_k \mathbf{s}_l^T = \sum_{i=0}^{N-1} s_k(i) s_l(i)$$



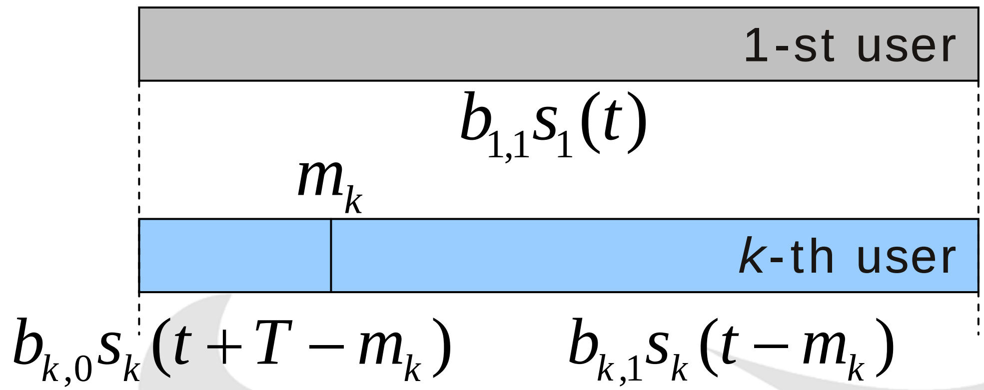
Synchronous DS CDMA, multipath



Even/odd correlations

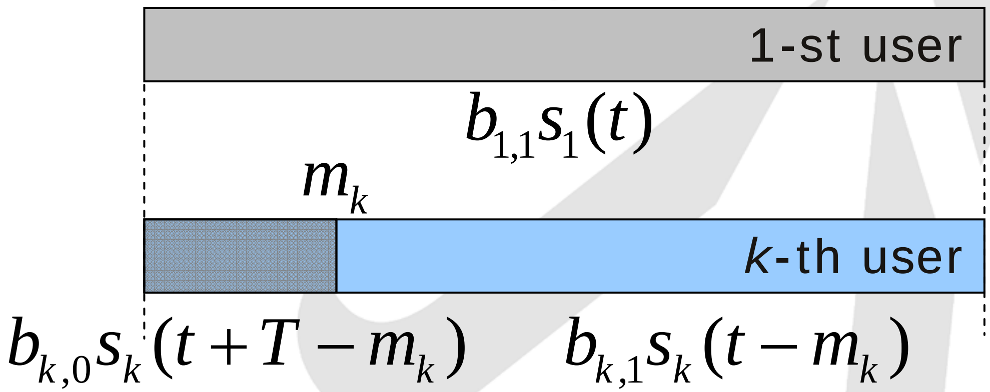
Even correlation: $b_{k,0} = b_{k,1}$

$$z_{1k} = b_{k,1} R_{1k}^{p}(m_k)$$



Odd correlation: $b_{k,0} \neq b_{k,1}$

$$z_{1k} = b_{k,0} R_{1k}^{a}(m_k - N) + b_{k,1} R_{1k}^{a}(m_k)$$



Average MAI power conventional single-user detector

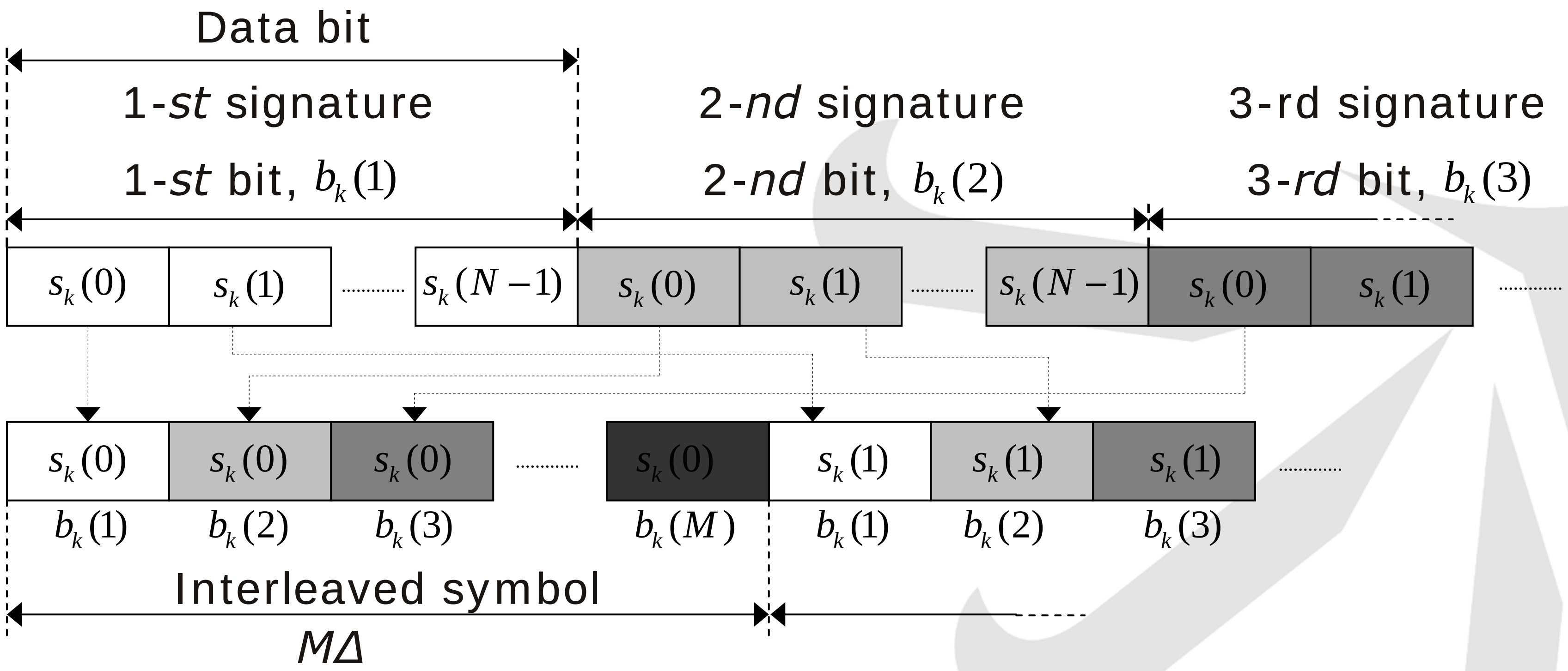
$$\overline{P_{MAI,k}} = \alpha_1^2 \sum_{\substack{l=1 \\ l\neq k}}^{K} R_{kl}^2(0) + \frac{1}{2}\sum_{r=2}^{R}\alpha_r^2 \sum_{l=1}^{K}\left(R_{kl}^2(m_r - N) + R_{kl}^2(m_r)\right)$$

- Average MAI power depends on the values of aperiodic correlations of shifts up to $\max(m_r) = L$

- For typically used signature ensembles values of those occur almost at random and are practically uncontrollable

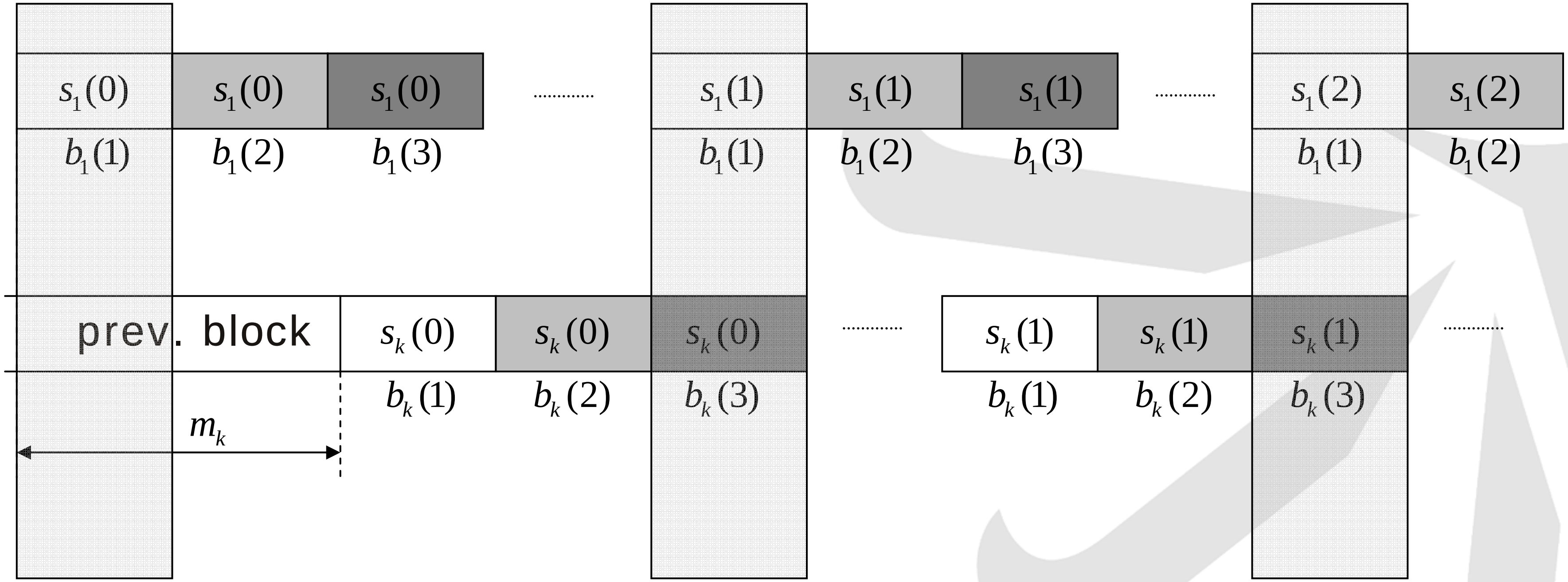
Signature Interleaving

- Each user is assigned $\max(m_r) = L$ different signatures
- Interleaving is performed for *M* consecutive data bits
- After the rearrangements chips of a user signature are distanced from each other by space *MΔ*



Bit processing

- Processing of the bit $b_1(1)$
- Asynchronism is reduced to one chip only for any delay $m_k \leq L$



TUCS

Signature Interleaving DS CDMA

Advantages of Signature Interleaving DS CDMA:

- Possible mutual time shifts of interleaved signatures are pressed into one chip
- Odd correlation peak is *independent* of the delay spread
- Odd correlation peak is almost equal to the even one
- Average MAI power:

$$\overline{P_{MAI,k}} = \alpha_1^2 \sum_{\substack{l=1 \\ l\neq k}}^{K} R_{(k,i),(l,i)}(0) + \frac{1}{2}\sum_{r=2}^{R}\alpha_r^2 \sum_{k=1}^{K} \chi_{k,l}(i,r)$$

$$\chi_{k,l}(i,r) = \begin{cases} R^2_{(k,i),(l,i')}(0), & i \geq m_r \\ 1/N^2 + R^2_{(k,i),(l,i')}(1), & i < m_r \end{cases}$$

Signature ensemble demands

DS CDMA

- *K* signatures
- Good correlation properties for

$$R_{k,l}(m), \quad 0 \le m \le L$$

SI DS CDMA

- *KM* signatures
- Good correlation properties for

$$R_{k,l}(m), \quad m \in \{0,1\}$$

Zero- and Low Correlation Zone Ensembles

- Zero correlation zone ensembles:

$$ZCZ(P,Z,N): R_{k,l}(m)=0 \qquad 1 \le k,l \le P, \quad k \ne l, \quad 0 \le m \le Z$$

- Even cyclic shifts of a sequence with perfect PACF (ternary sequence, Frank sequence)

$$R(m) = 0, \quad 0 < m < N-1$$

- Low correlation zone ensembles: even cyclic shifts of a minimax sequence (*m*-sequence, Legendre sequence)

$$|R(m)| = 1, \quad 0 < m < N-1$$

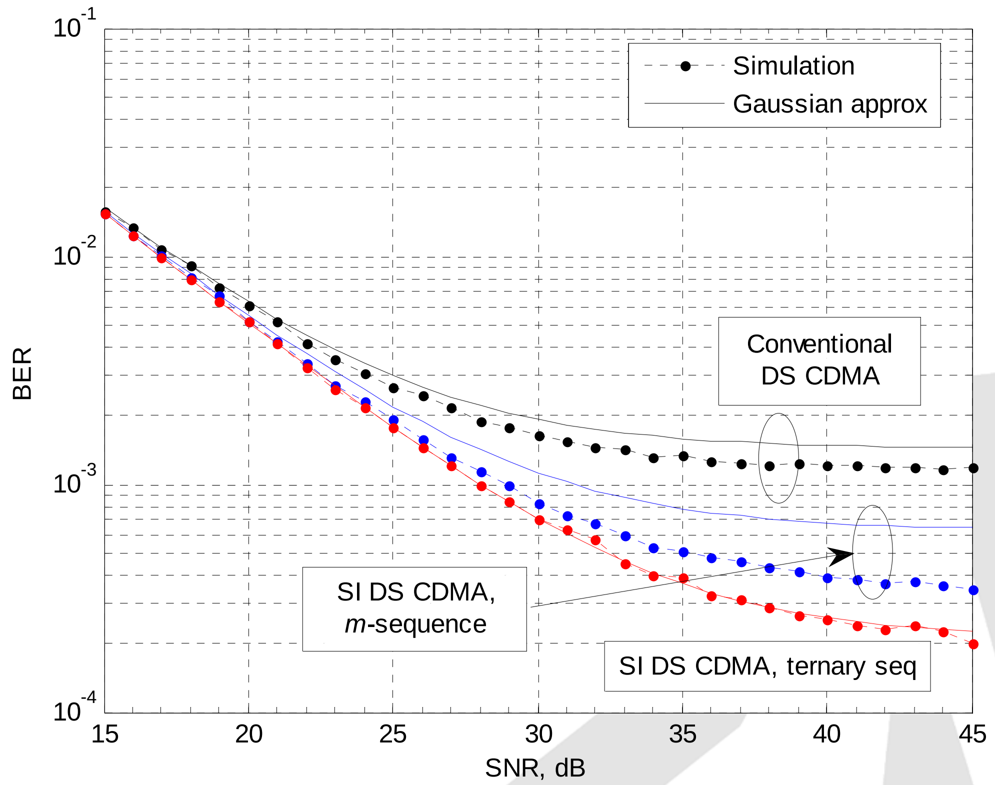
Example

- K = 10
- N = 127
- 4 rays Rayleigh channel
- Ray delays:

τ = [0, 1, 3, 5] chips

- Ray energies:

E = [0, -3, -4, -5] dB



Bigger correlation

- $|R(m)| > 1$: Gold ensemble of size *P* and length *N*

$$R_{k,l}(0) = -1, \quad 1 \le k,l \le P, \quad k \ne l$$

- Number of candidate signatures is usually much greater than number of necessary ones:

$$\lfloor PN/2 \rfloor >> KM$$

- Optimal ensemble is obtained after random search, minimizing average MAI power

- Orthogonal Gold ensemble:

$$R_{k,l}(0) = 0 \quad 1 \le k,l \le P, k \ne l$$

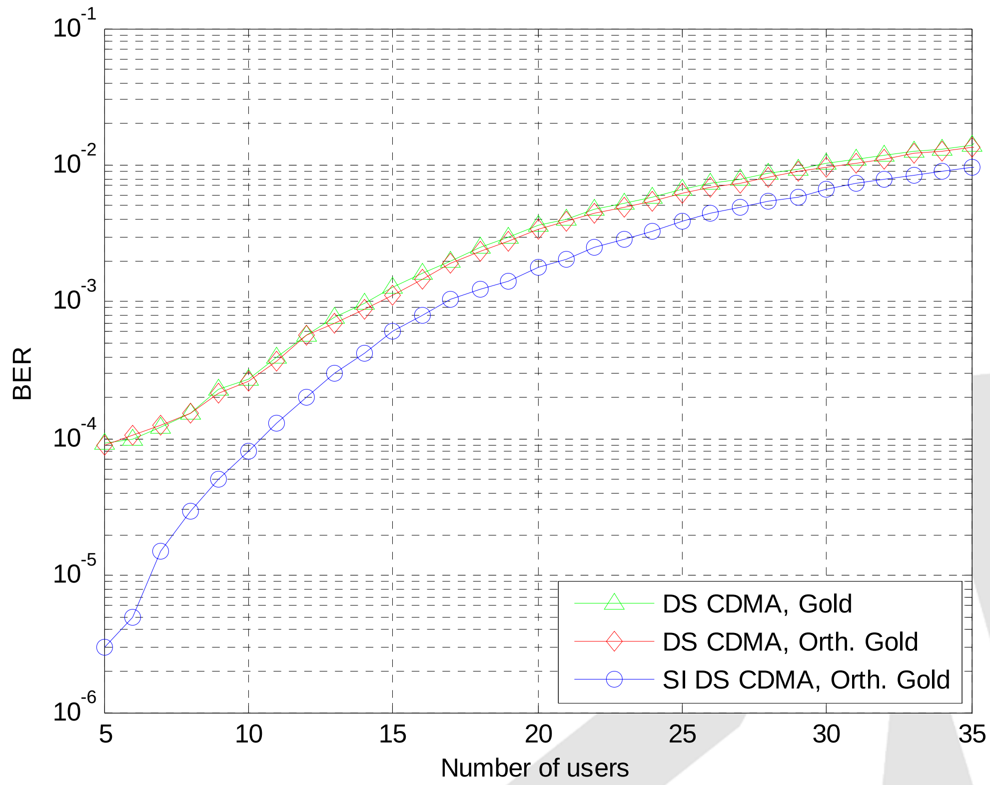
Example

- RAKE receiver, EGC
- SNR = 20 dB
- N = 127
- 4 rays Rayleigh channel
- Ray delays:

τ = [0, 3, 4, 7] chips

- Ray energies:

E = [0, -6, -11.9, -17.9] dB



Chip interleaving with zero padding

- Chip stream at the transiever is divided into blocks
- Length of the block M is bigger than the channel delay spread L
- Chip interleaving: first chips of every M bits form first *frame*, which is then followed by L zeros
- After the interleaving chips are distanced by (M+L) positions
- System rate is reduced due to bigger number of chips (M+L)N instead of MN in conventional DS CDMA
- The difference can be made as small as one wishes:

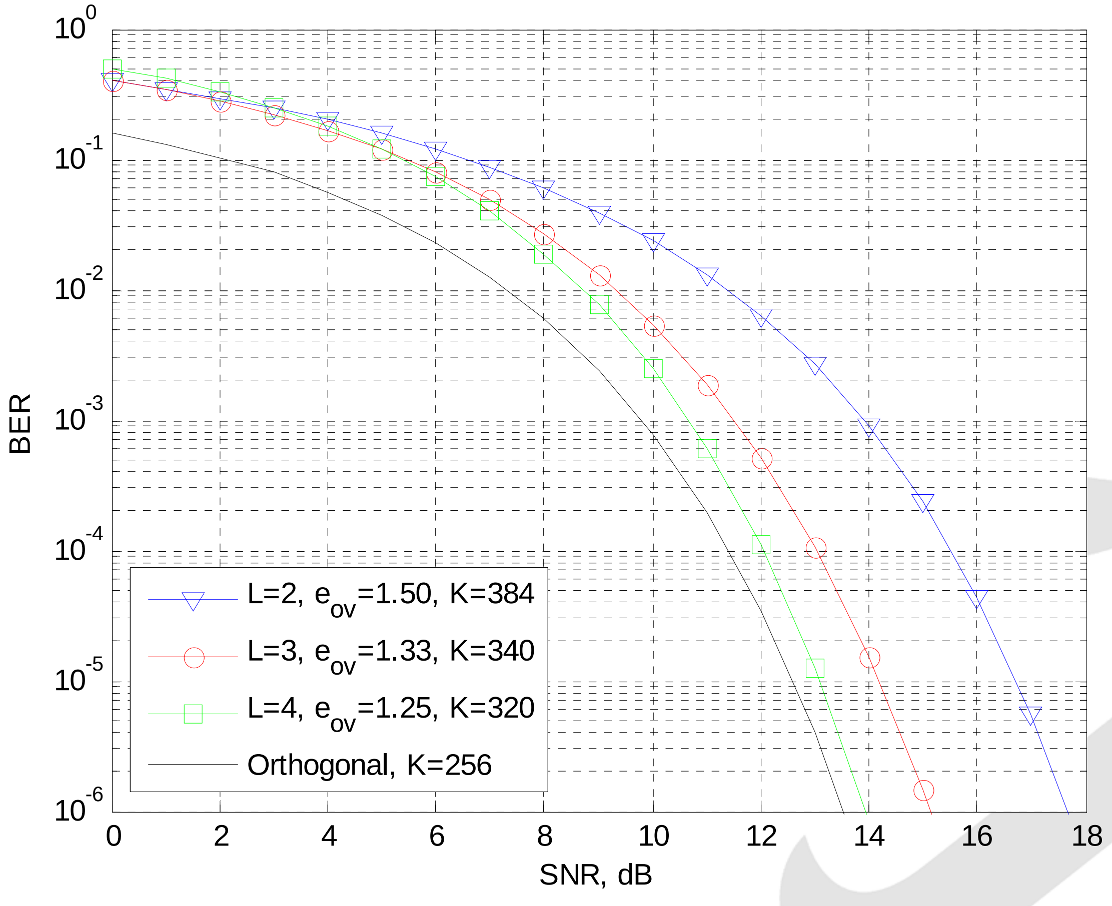
$$\frac{(M+L)N}{MN} \xrightarrow[M>>1]{} 1$$

Asynchronous oversaturated CDMA

- Allows to allocate up to 1.5 times more users
- Strictly synchronous by design

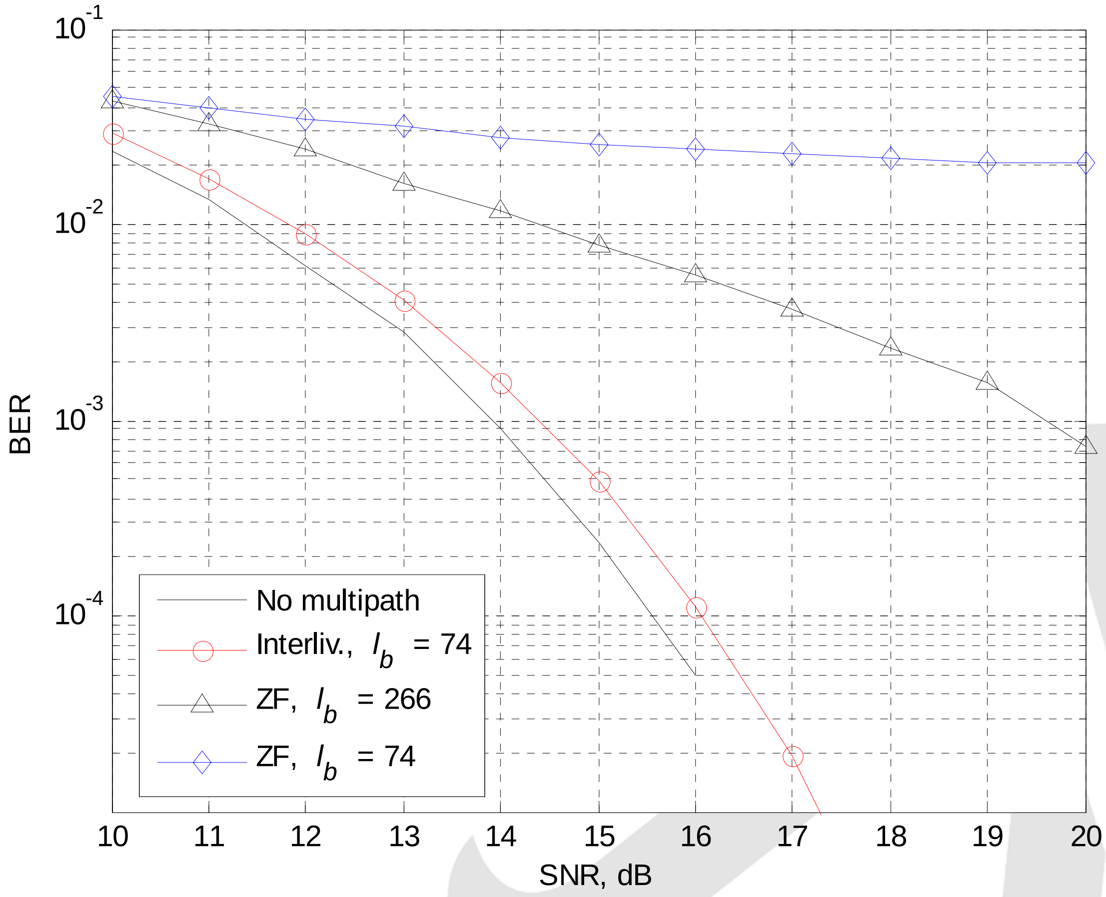
- At the receiving side delay of $m<N$ chips turns into delay of *m bits*
- User signals are bit-synchronous
- For every bit interval number of user bit is changed or user signal is replaced by zeros
- Receiver structure can be simplified
- The system can work with *any* asynchronous delay

Asynchronous oversaturated DS CDMA



Oversaturated CDMA in multipath channels

- TU6 multipath channel is used
- Zero forcing equalizer with lengths *l*=74 and *l*=266 was implemented
- Chip-interleaving with zero padding allows to reduce residual MAI



Thank you.