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# Block-spread CDMA: Unifying Multiple Access in Cellular Networks

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# Evolution…

**1G**

- AMPS, TACS, NMT
- Analogue, FM
- FDMA

**2G**

- GSM (TDMA)
- IS-95 (CDMA)
- PDC (TDMA)

***2G+***

- *GPRS, 1x-RTT*
- *EDGE, EGPRS, IMT-SC*

**3G**

- UMTS (CDMA)
- CDMA2000 (CDMA)

**4G**

- LTE, LTE-Adv (OFDMA/SC-FDMA)
- Mobile WiMAX (OFDMA)

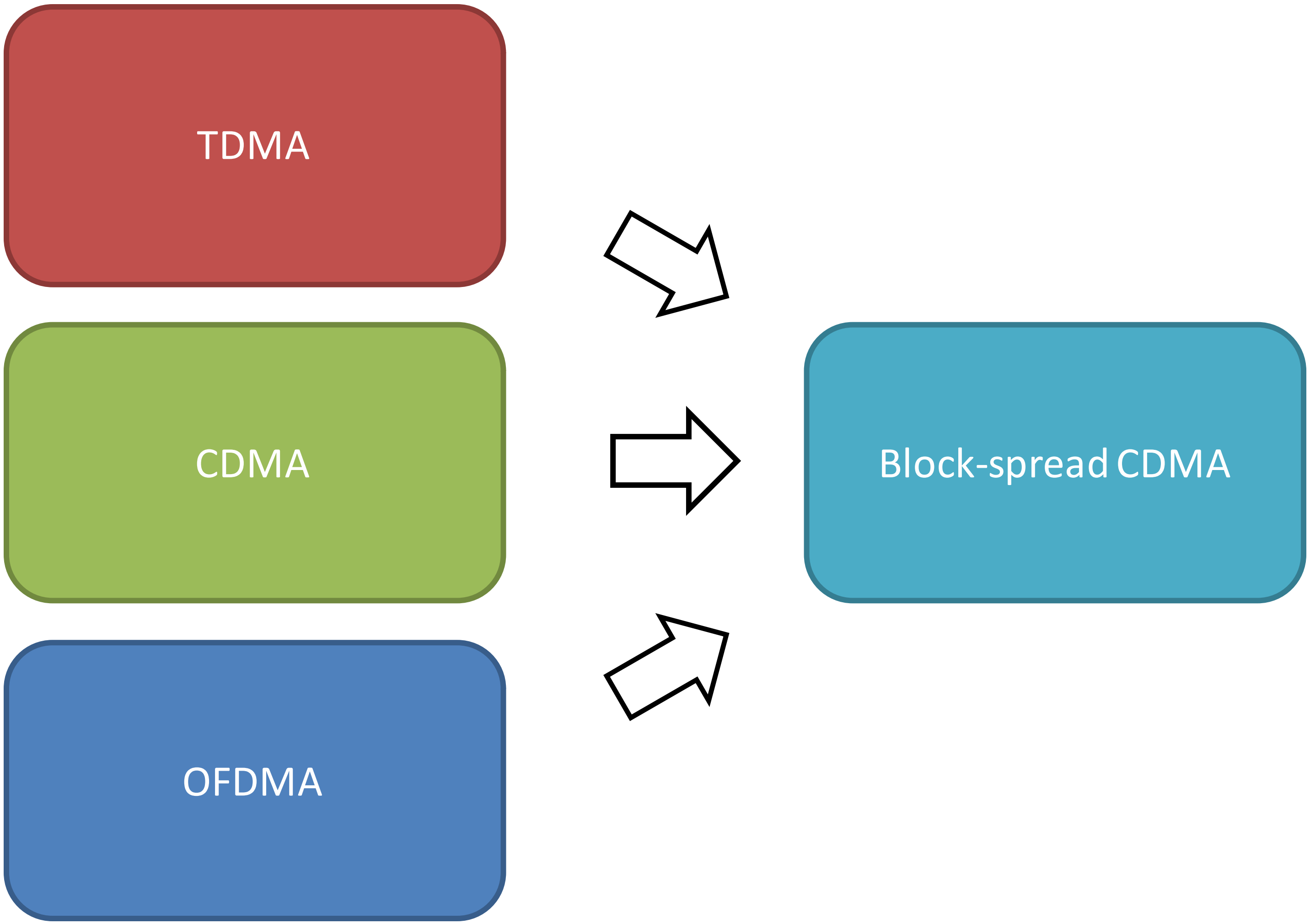
# Beyond 4G

**Key aspects of future systems…**

- Backward compatible
- Power efficient
- Flexible
- Support convergence
- Unify

*Radio access technologies should be harmonised (subject to these conditions)*

# Multiple Access

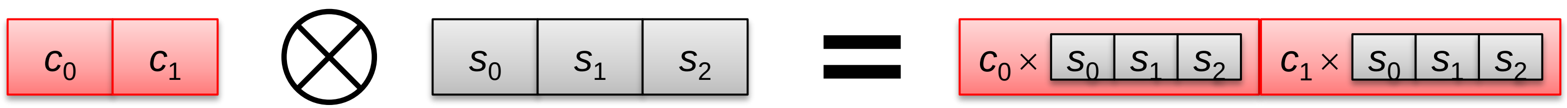


# BS-CDMA: Concept

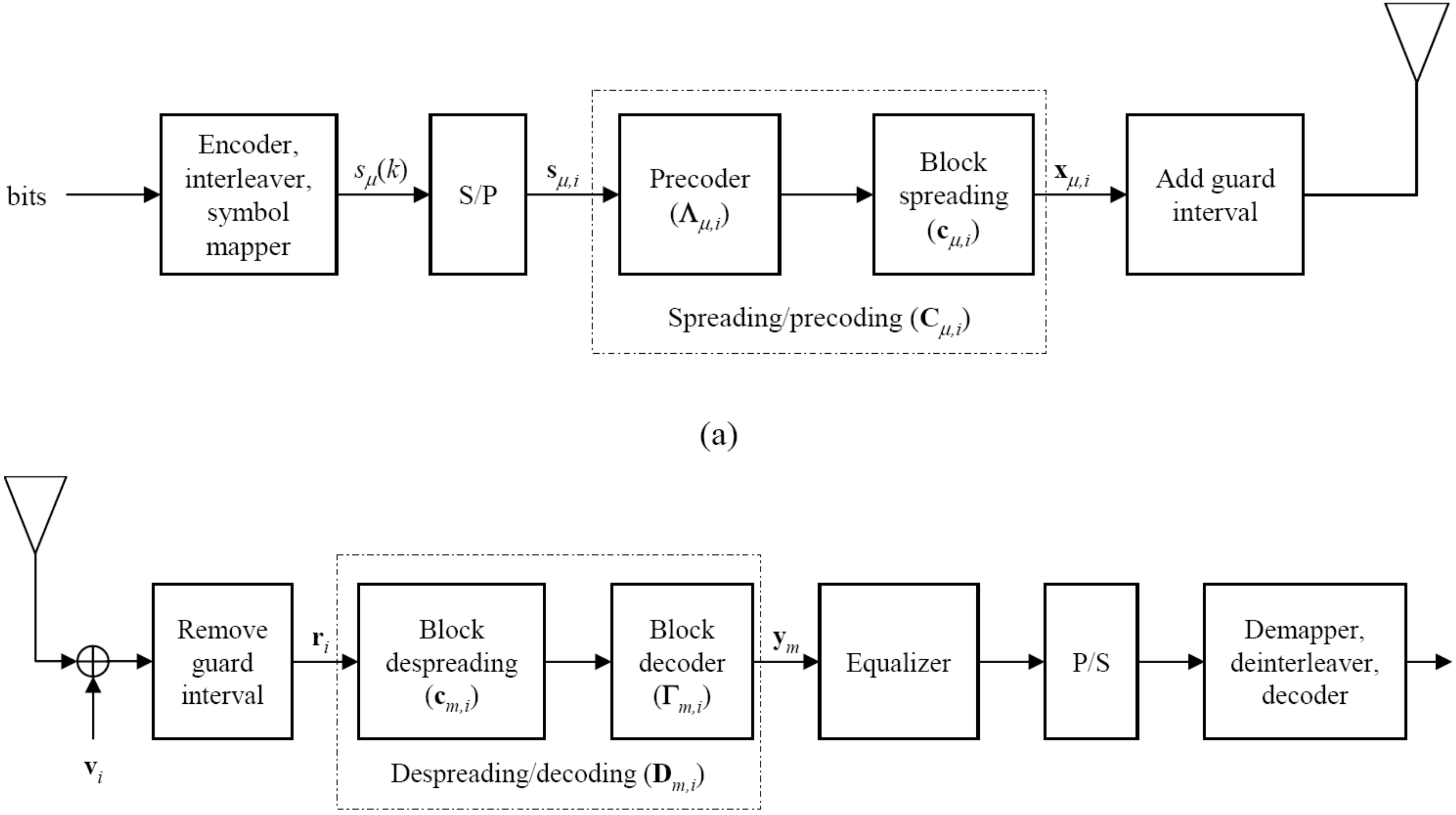
**BS-CDMA can be viewed as being dual to DS-CDMA**

- **DS-CDMA: Each symbol is spread with a chip sequence**


- **BS-CDMA: Each chip is spread with a symbol sequence**



# System Model




Block diagram of BS-CDMA (a) transmitter and (b) receiver architectures.

# System Model

## Data is precoded and spread in a block fashion

$$\mathbf{x}_{\mu,i} = \mathbf{c}_{\mu,i} \otimes \mathbf{\Lambda}_{\mu,i}\mathbf{s}_{\mu,i}$$

*spreading code (length M)* — $\mathbf{c}_{\mu,i}$

*precoder (P × K)* — $\mathbf{\Lambda}_{\mu,i}$

*data (length K)* — $\mathbf{s}_{\mu,i}$

## Guard interval is used as with OFDM and SC-FDE

$$\mathbf{r}_i = \sum_{\mu=1}^{M_a} \mathbf{H}_{\mu,i}\mathbf{x}_{\mu,i} + \mathbf{v}_i$$

*number of active users* — $M_a$

*circulant channel* — $\mathbf{H}_{\mu,i}$

*noise* — $\mathbf{v}_i$

## Despread signal using $\mathbf{D}_m := \mathbf{c}_m \otimes \mathbf{\Gamma}_m$

*decoder* — $\mathbf{\Gamma}_m$

$$\mathbf{y}_m = \mathbf{D}_m^H \mathbf{r}$$

# System Model

## Circulant channel can be rewritten (*key step*)

$$\mathbf{H}_\mu = \mathbf{I}_M \otimes \mathbf{H}_\mu^l + \mathbf{J}_M \otimes \mathbf{H}_\mu^u$$

- $\mathbf{I}_M$: *identity*
- $\mathbf{H}_\mu^l$: *lower triangular (P × P)*
- $\mathbf{J}_M$: *cyclic shift (by 1)*
- $\mathbf{H}_\mu^u$: *upper triangular (P × P)*

## Thus, received, despread signal can be written as

$$\mathbf{y}_m = \sum_{\mu=1}^{M_a} \left(\mathbf{c}_m^H \mathbf{c}_\mu\right) \mathbf{\Gamma}_m^H \mathbf{H}_\mu^l \mathbf{\Lambda}_\mu \mathbf{s}_\mu + \sum_{\mu=1}^{M_a} \left(\mathbf{c}_m^H \mathbf{J}_M \mathbf{c}_\mu\right) \mathbf{\Gamma}_m^H \mathbf{H}_\mu^u \mathbf{\Lambda}_\mu \mathbf{s}_\mu + \mathbf{D}_m^H \mathbf{v}$$

# Spreading Code Design

**From system equation, it follows that MUI is eliminated at RX if**

$$\mathbf{c}_m^H \mathbf{c}_\mu = 0, \quad \forall \mu \neq m$$

$$\mathbf{c}_m^H \mathbf{J}_M \mathbf{c}_\mu = 0, \quad \forall \mu \neq m$$

**In other words...**

***Spreading codes must be mutually shift orthogonal***

**Codes that satisfy this orthogonality criterion:**

- DFT codes (i.e. columns of a DFT matrix)
- Chu sequences (also *self* shift orthogonal)

# Pre-/decoder Design

***Objective: facilitate frequency-domain equalisation***

**Using DFT spreading codes, the despread signal is**

$$\mathbf{y}_m = \underbrace{M\boldsymbol{\Gamma}_m^H \left(\mathbf{H}_m^l + e^{-j\frac{2\pi}{M}(1-m)}\mathbf{H}_m^u\right)\boldsymbol{\Lambda}_m}_{\widetilde{\mathbf{H}}_m} \mathbf{s}_m + \mathbf{D}_m^H \mathbf{v}$$

*Proposition 1:* The $m$th user's equivalent despread channel matrix $\widetilde{\mathbf{H}}_m$ is circulant when DFT spreading codes are employed and the precoding and decoding matrices are given by

$$\boldsymbol{\Lambda}_m = \boldsymbol{\Gamma}_m = \mathrm{diag}\left\{e^{j\theta_{m,0}}, \ldots, e^{j\theta_{m,P-1}}\right\}$$

where $\theta_{m,p} = -2\pi p(m-1)/(MP)$.

# Special Cases

## Low-complexity OFDMA

- Redesign precoder and decoder matrices
- **Advantage**: smaller DFT can be used to realise OFDMA
- **Disadvantage**: user subcarrier allocation must be equispaced

$$\mathbf{\Lambda}_m = \mathbf{\Gamma}_m = \mathrm{diag}\left\{e^{j\theta_{m,0}}, \ldots, e^{j\theta_{m,K-1}}\right\}\mathbf{F}^H$$

## Chip-interleaved BS-CDMA

- Precoder applies zero padding to each subblock
- Decoder is identity

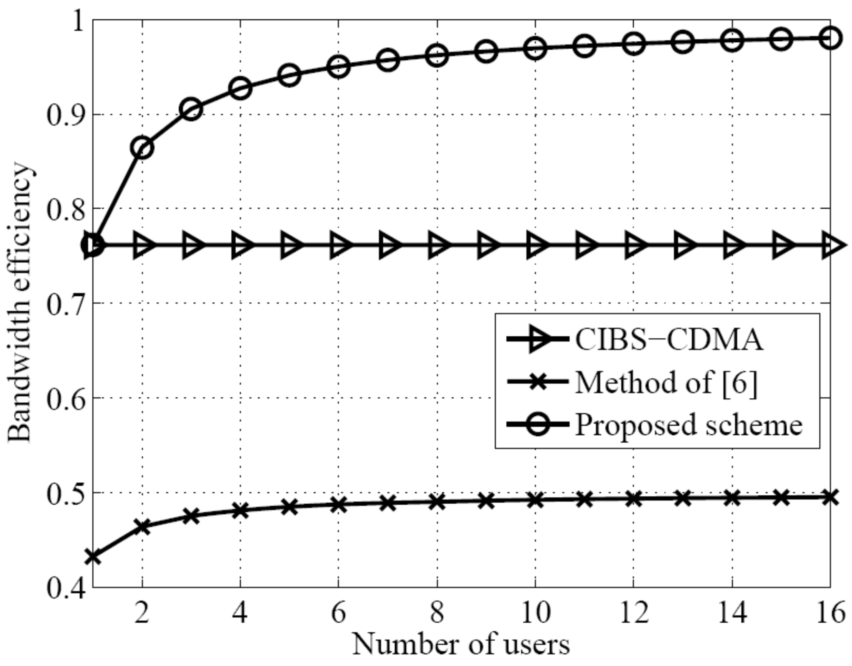
$$\mathbf{\Lambda}_\mu = \mathbf{T}_{\mathrm{ZP}} = \left[\mathbf{I}_K \ \mathbf{0}_{K\times L}\right]^T$$

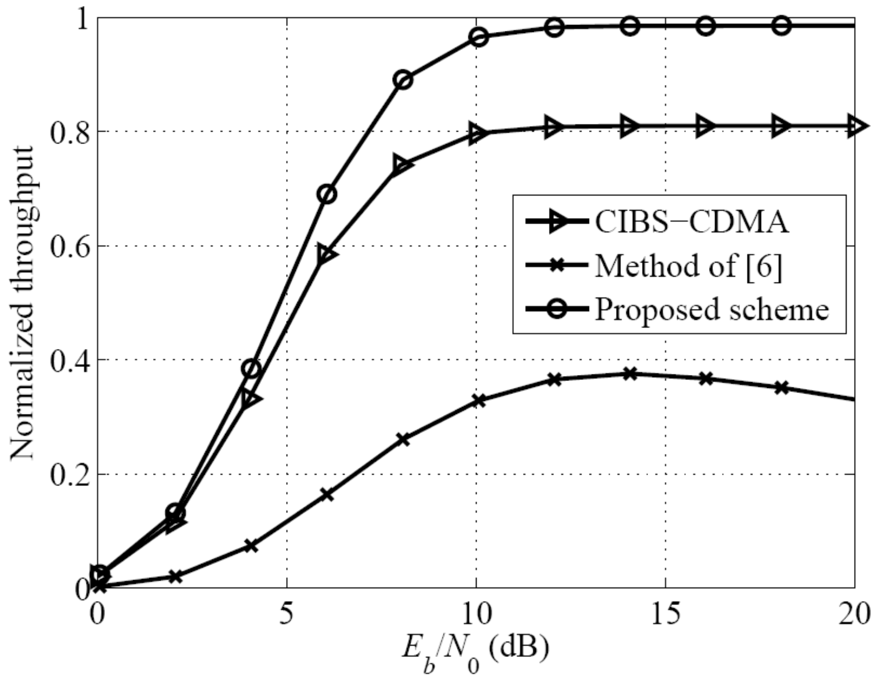
## TDMA

- CIBS-CDMA with unit vector spreading codes

# Bandwidth Efficiency & Throughput

- ***Most bandwidth efficient BS-CDMA scheme***
- **Only requires one guard interval per *spread* block**
- **CIBS-CDMA requires one guard interval per *sub*block**
- **Other methods are at best as efficient as CIBS-CDMA**

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# Performance

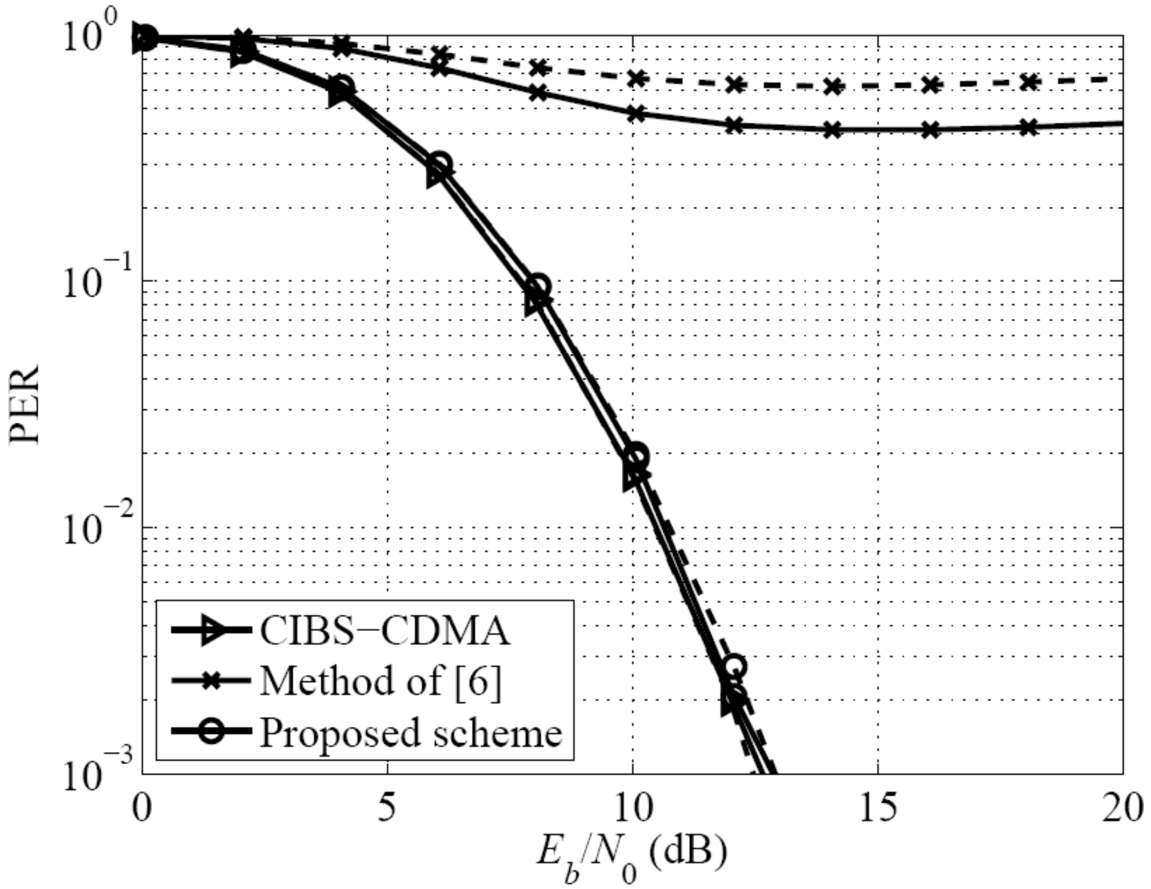


Fig. 3. PER vs. $E_b/N_0$. Solid lines (—) denote systems with $M_a = 6$ active users; dashed lines (– –) denote systems with $M_a = M = 16$ active users.

# Technical Extensions

- **Spreading code design for mitigating effects of**
  - Carrier frequency offset
  - Asynchronous reception
- **Linear and nonlinear equalisers for asynchronous reception**
- **FEC code strategies for BS-CDMA**
- **Different precoder designs to enhance flexibility**
- **Estimation and tracking of time-varying channels**

# Applications (Present & Future)

- **3GPP LTE**
  - Precoding and spreading sequence is specified in the PUCCH for Rel-8 of LTE
- **MTC/M2M**
  - Low complexity implementations are suitable for MTC terminals
  - Potential for "MTC mode" added to future standards for compatibility
- **5G and beyond**
  - Ability of BS-CDMA to be implemented as other access methods suggests it is a logical candidate for future networks

# Further Reading


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