# 2017 2Q
## Wireless Communication Engineering

# #12 Spread Spectrum & Code Division Multiple Access (CDMA)


Kei Sakaguchi
sakaguchi@mobile.ee.


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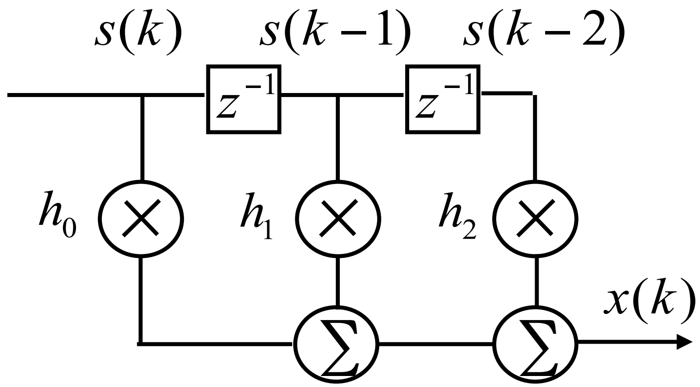
# Course Schedule (2)

| | Date | Text | Contents |
|---|---|---|---|
| #9 | July 10 | 4.6 | Error correction coding |
| #10 | July 13 | | Adaptive modulation coding |
| | July 17 | | No class |
| #11 | July 20 | 4.3 | Inter symbol interference and adaptive equalizer |
| #12 | July 24 | 3.6, 4.5 | Spread spectrum and code division multiple access (CDMA) |
| #13 | July 27 | 3.5 | Orthogonal frequency division multiplexing (OFDM) |
| #14 | July 31 | | Collaborative exercise for better understanding 2 |
| #15 | Aug 7 | All | Final examination @ S421 |

# From Previous Lecture

- Multi-path channel with delay spread

$$x(k) = \sum_{i=0}^{\infty} h_i s(k-i) + n(k)$$




- Linear equalizer（ZF, MMSE）

$$y(k) = \sum_{i=-\infty}^{\infty} w_i^* x(k-i)$$

ZF: $\mathbf{w}^* = \overleftrightarrow{\mathbf{H}}^{-1}\mathbf{e}_0$ MMSE: $\mathbf{w} = \mathbf{R}_x^{-1}\mathbf{h}$

- Maximum likelihood sequence estimation（MLSE）

$$\hat{s}(k), \hat{s}(k-1), \hat{s}(k-2) = \arg \min_{\tilde{s}(k), \tilde{s}(k-1), \tilde{s}(k-2)} \left| x(k) - \sum_{i=0}^{\infty} h_i \tilde{s}(k-i) \right|^2$$

- Frequency domain equalizer（FDE）

$$\mathbf{y} = \mathbf{F}^{-1}\mathbf{W}\mathbf{F}\mathbf{x} \qquad \tilde{\mathbf{W}} = \mathrm{diag}\left\lfloor 1/\tilde{h}_0 \quad 1/\tilde{h}_1 \quad \cdots \quad 1/\tilde{h}_{N-1} \right\rfloor$$

# Contents

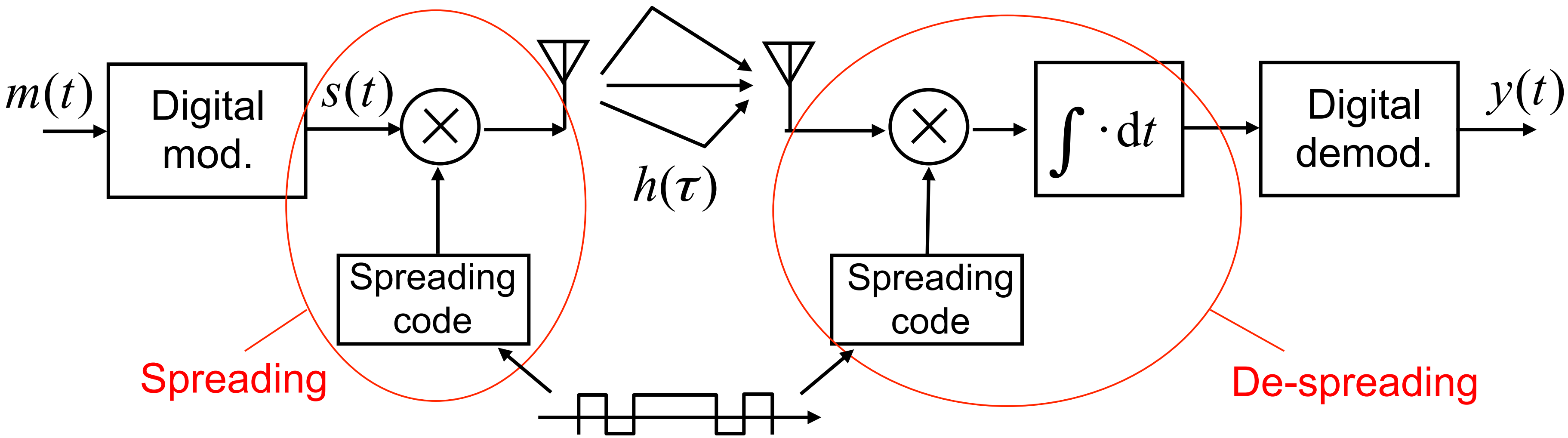
- Spread Spectrum (SS) system
- Direct Sequence Spread Spectrum (DSSS) and de-spreading
- Features of spreading code
- Application of DSSS
  - Rake receiver
  - Code Division Multiple Access (CDMA)
- Frequency Hopping SS (FHSS)
- Demonstration

# IEEE802.11 WLAN

WLAN standardized by IEEE 802 committee working group (WG) 11

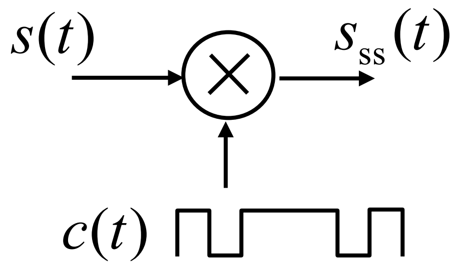
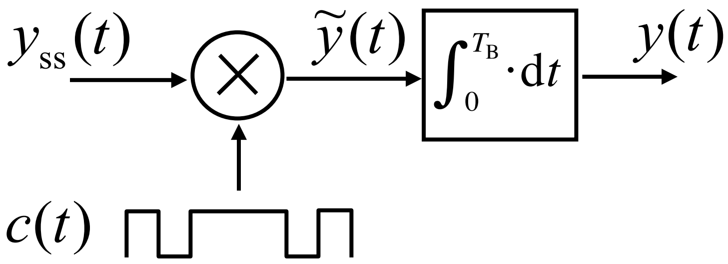
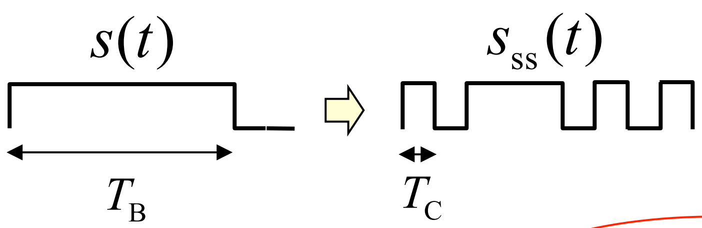
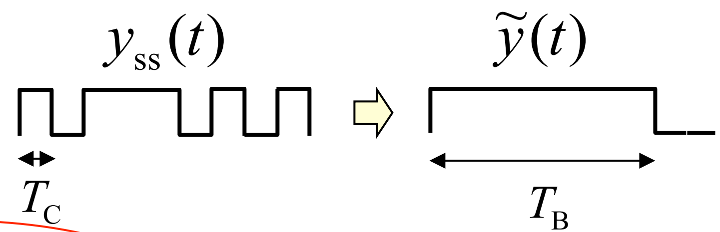
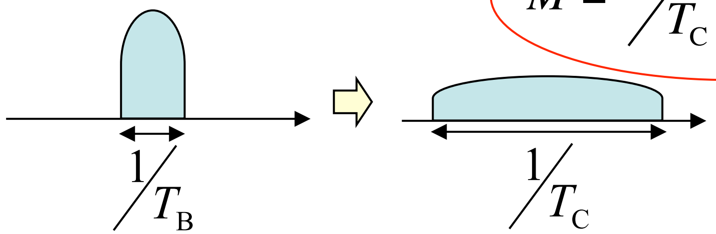
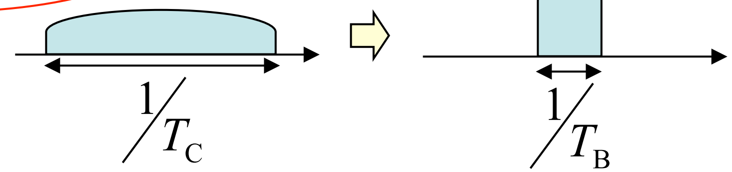
| | 802.11b | 802.11a | 802.11g | 802.11n | 802.11ac |
|---|---|---|---|---|---|
| Year of approval | 1999 | 1999 | 2003 | 2009 | 2014 |
| RF band | 2.4GHz | 5GHz | 2.4GHz | 2.4 & 5GHz | 5GHz |
| Channel bandwidth | 20MHz | 20MHz | 20MHz | 20/40MHz | 20/40/80/ 160MHz |
| Modulation | DSSS, CCK | OFDM, AMC | OFDM, AMC, CCK | MIMO-OFDM, AMC, CCK | MIMO-OFDM, AMC256Q, MU-MIMO |
| Max data rate | 11Mbps | 54Mbps | 54Mbps | 600Mbps | 6.93Gbps |
| MAC | CSMA/CA | CSMA/CA | CSMA/CA | CSMA/CA | CSMA/CA +MU-MIMO |

# Spread Spectrum System



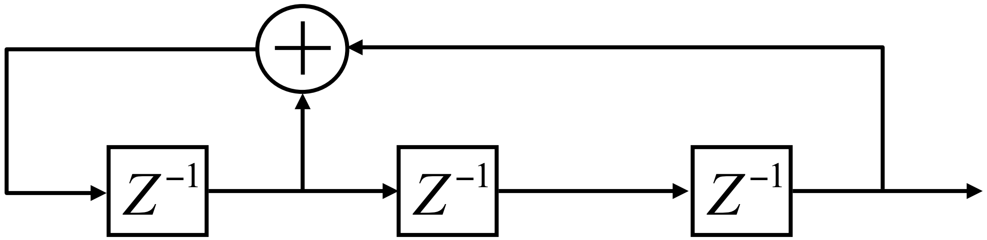

- Using common spreading code between Tx & Rx
- Multi-plath combining using auto-correlation property in spreading code (Rake receiver)
- Code Division Multiple Access (CDMA) using cross-correlation property between different spreading codes

# Direct Sequence Spread Spectrum (DSSS)

| | Spreading (transmitter) | De-spreading (receiver) |
|---|---|---|
| Block |  |  |
| Math | $s_{SS}(t) = c(t)s(t)$ | $y(kT_B) = \int_0^{T_B} c(t) y_{SS}(t) \mathrm{d}t$ |
| Time |  |  |
| Freq |  $M = T_B/T_C$ Spreading gain |  |

# Spreading Code (M Sequence)

*N* tap feedback shift register




- Maximum code length

$$M = 2^N - 1$$

- Balance

  # of 1 = # of 0 + 1

- # of successive sequence

  0, 1 → 1/2
  00 → 1/4
  111 → 1/4

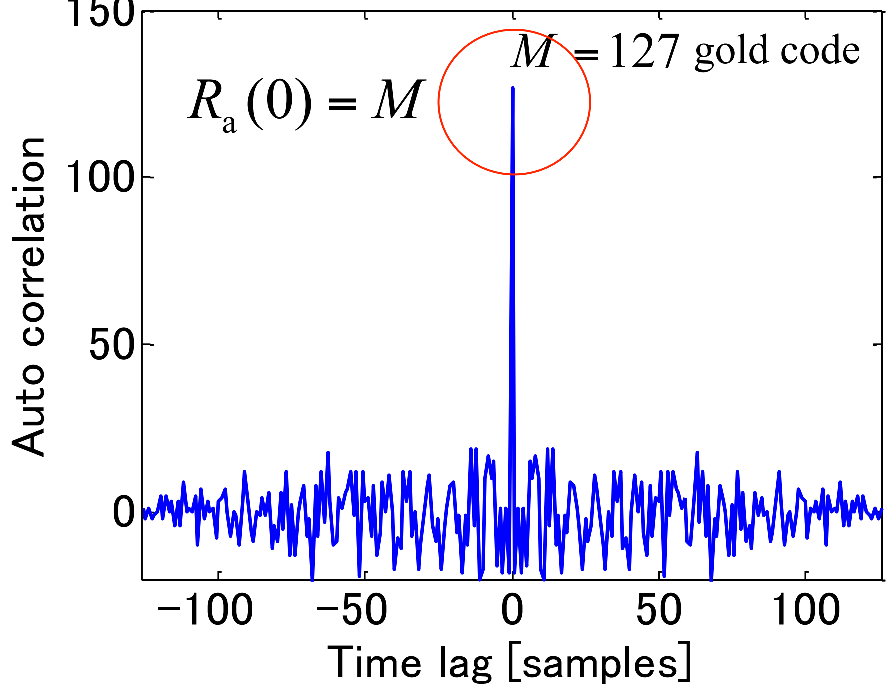
| | Register 1 | Register 2 | Register 3 |
|---|---|---|---|
| #1 | 1 | 0 | 0 |
| #2 | 1 | 1 | 0 |
| #3 | 1 | 1 | 1 |
| #4 | 0 | 1 | 1 |
| #5 | 1 | 0 | 1 |
| #6 | 0 | 1 | 0 |
| #7 | 0 | 0 | 1 |
| #8 | 1 | 0 | 0 |

# Features of Spreading Sequence

- Spreading sequence with sharp peak in auto-correlation and small peak in cross-correlation

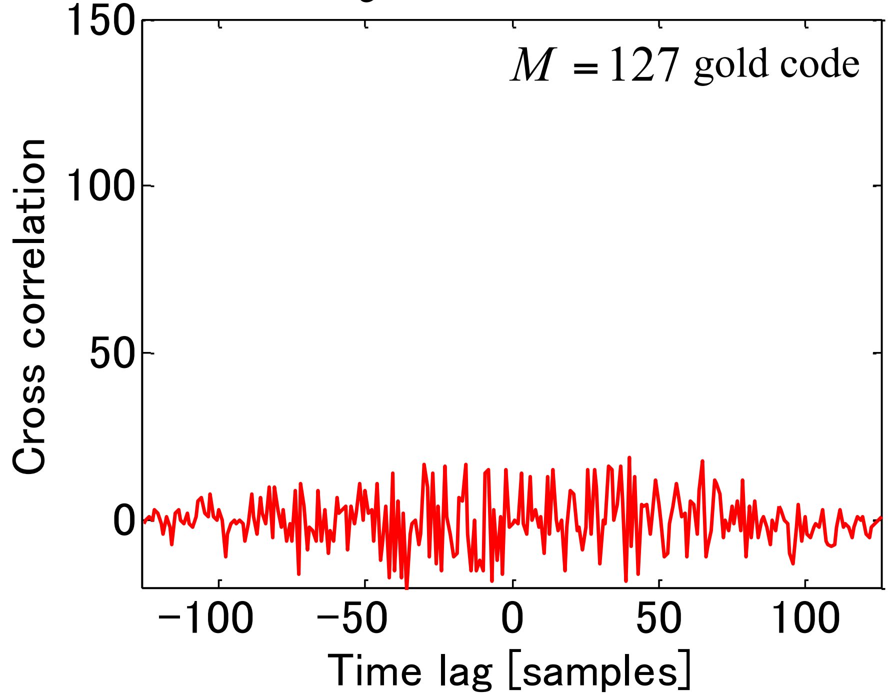
Auto-correlation

$$R_{\mathrm{a}}(\tau) = \int c(t)c(t+\tau)\mathrm{d}t$$




Cross-correlation

$$R_{\mathrm{c}}(\tau) = \int c_1(t)c_2(t+\tau)\mathrm{d}t$$



# Delay Spread & De-spreading

Receive signal

$$y_{ss}(t) = \int h(\tau)c(t-\tau)\mathrm{d}t + n(t)$$

2-path model

$$y_{ss}(t) = h(0)c(t) + h(\Delta\tau)c(t-\Delta\tau) + n(t)$$

De-spreading

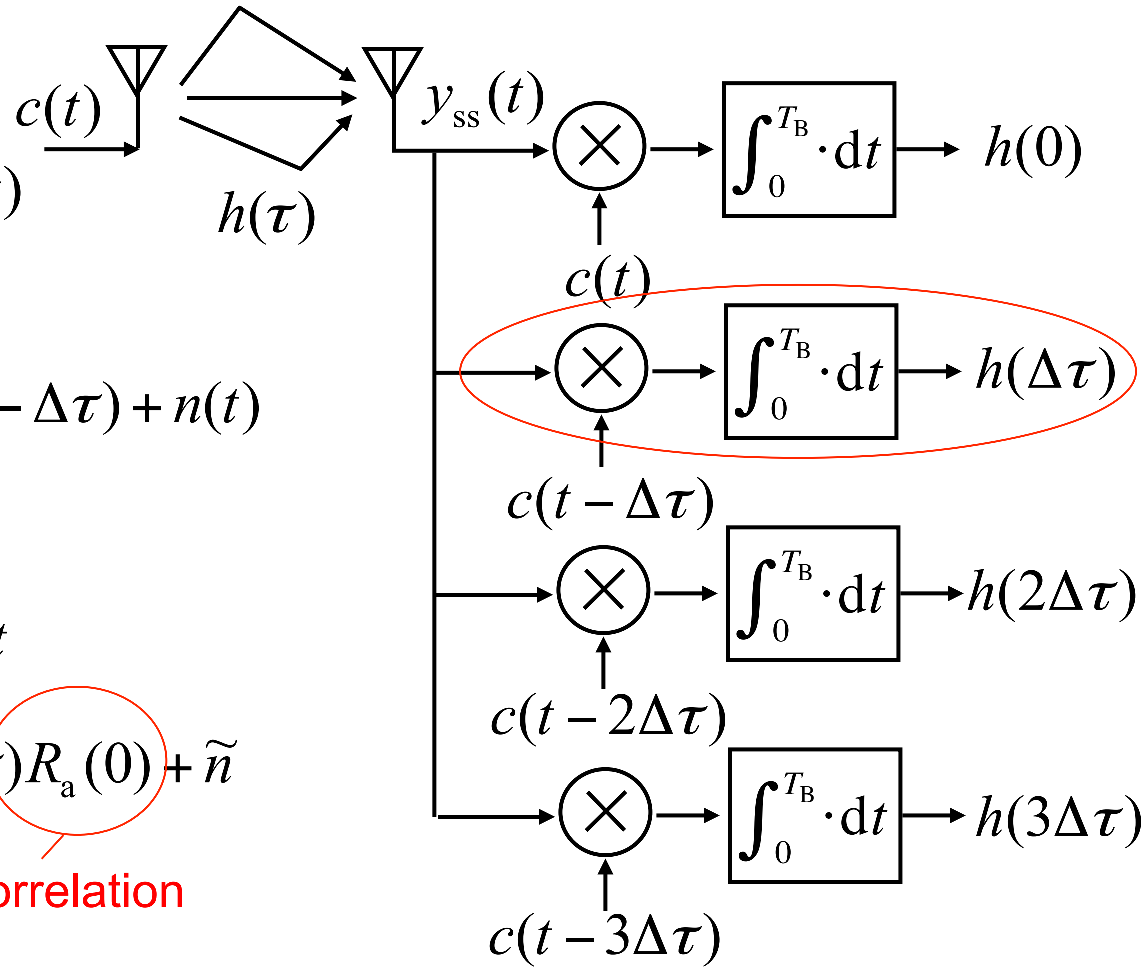
$$y(\Delta\tau) = \int_0^{T_B} y_{ss}(t)c(t-\Delta\tau)\mathrm{d}t$$

$$= h(0)R_a(\Delta\tau) + h(\Delta\tau)R_a(0) + \tilde{n}$$

$$\cong Mh(\Delta\tau)$$

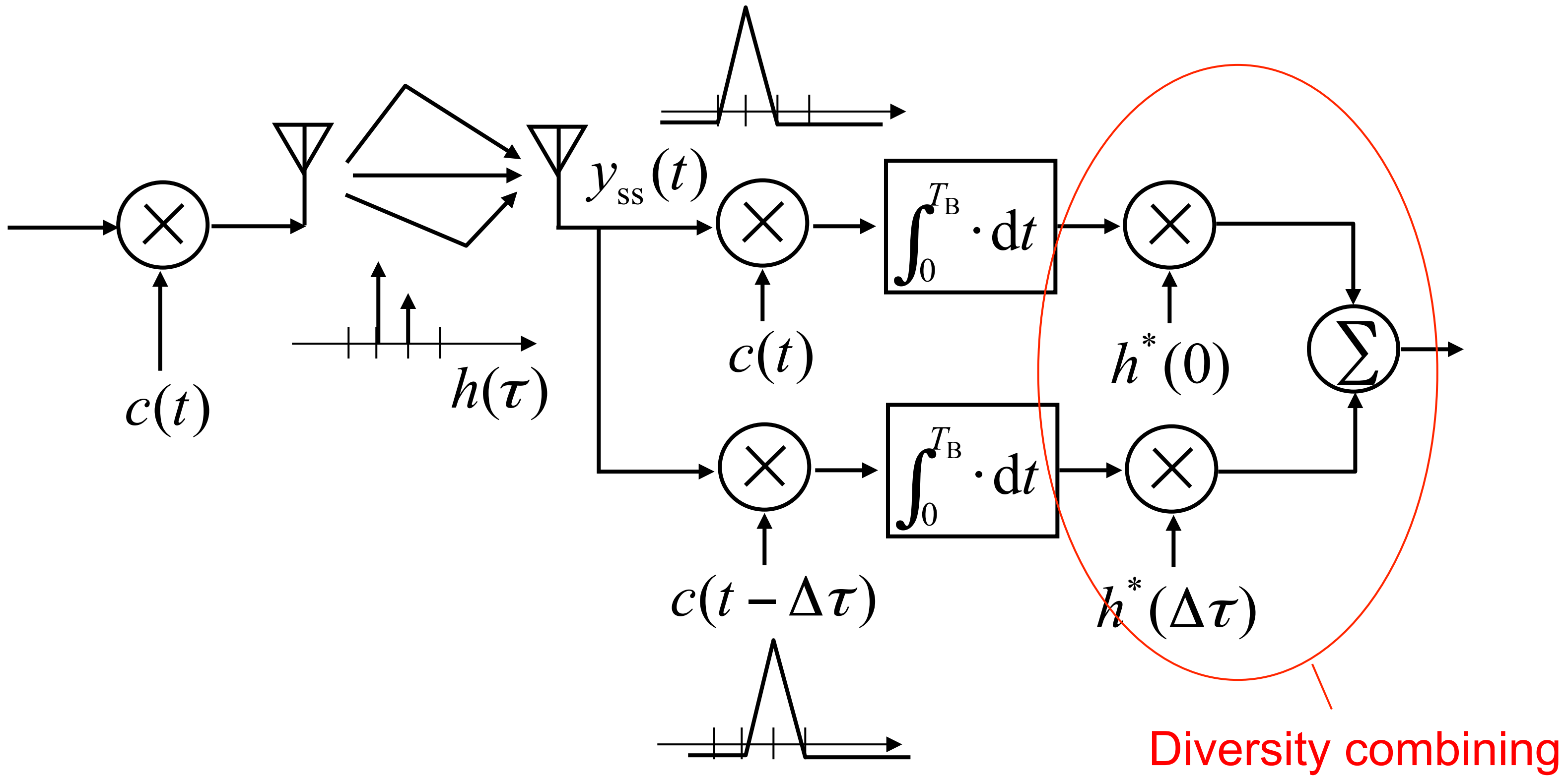
Auto-correlation

Multi-path separation by de-spreading



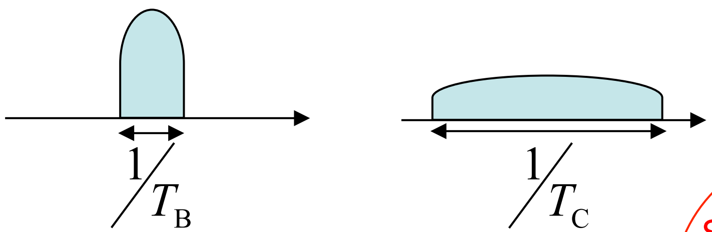
# RAKE Receiver

- Separation of multi-path signals by using auto-correlation property of spreading sequence
- Diversity combining of multi-path signals after de-spreading



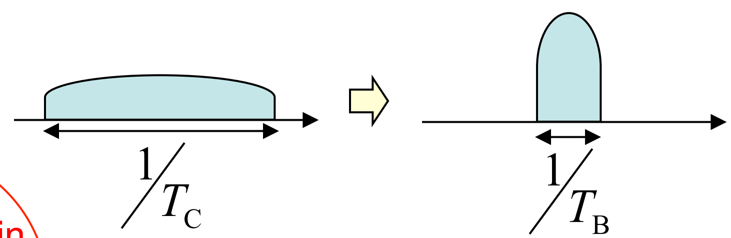
# SNR Performance of SS Systems

## Spreading




$$s_{ss}(t) = c(t)s(t)$$

## De-spreading




$$y(kT_B) = \int_0^{T_B} c(t)y_{ss}(t)\,\mathrm{d}t$$

Spreading gain

$$M = T_B / T_C$$

### Signal power

$P$ ⇨ $P$

Density: $T_B P$ ⇨ $T_C P$

### Noise power

$N_0 / T_B$ ⇨ $N_0 / T_C$

### SNR before spreading

$$\gamma = PT_B / N_0$$

### Signal power

$P$ ⇨ $M^2 P$

### Noise power

$N_0 / T_C$ ⇨ $M\, N_0 / T_C$

### SNR after de-spreading

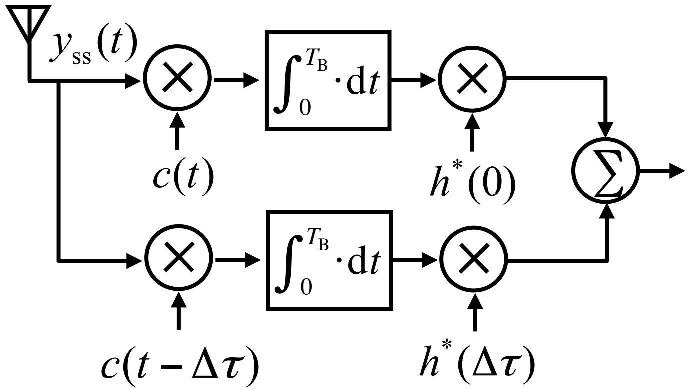
$$\gamma = M^2 PT_C / MN_0 = PT_B / N_0$$

⇨ Same SNR

# Performance of Rake Receiver

Auto-correlation

$$R_a(\tau) = \int c(t)c(t+\tau)\mathrm{d}t \qquad R_a(0) = M$$




2-path model

$$y_{ss}(t) = h(0)c(t)s + h(\Delta\tau)c(t-\Delta\tau)s + n(t)$$

SINR of each Rake branch

$$\gamma(0) = \frac{PR_a^2(0)|h(0)|^2}{PR_a^2(\Delta\tau)|h(\Delta\tau)|^2 + R_a(0)\sigma^2} \qquad \gamma(\Delta\tau) = \frac{PR_a^2(0)|h(\Delta\tau)|^2}{PR_a^2(\Delta\tau)|h(0)|^2 + R_a(0)\sigma^2}$$

SINR after Rake combining

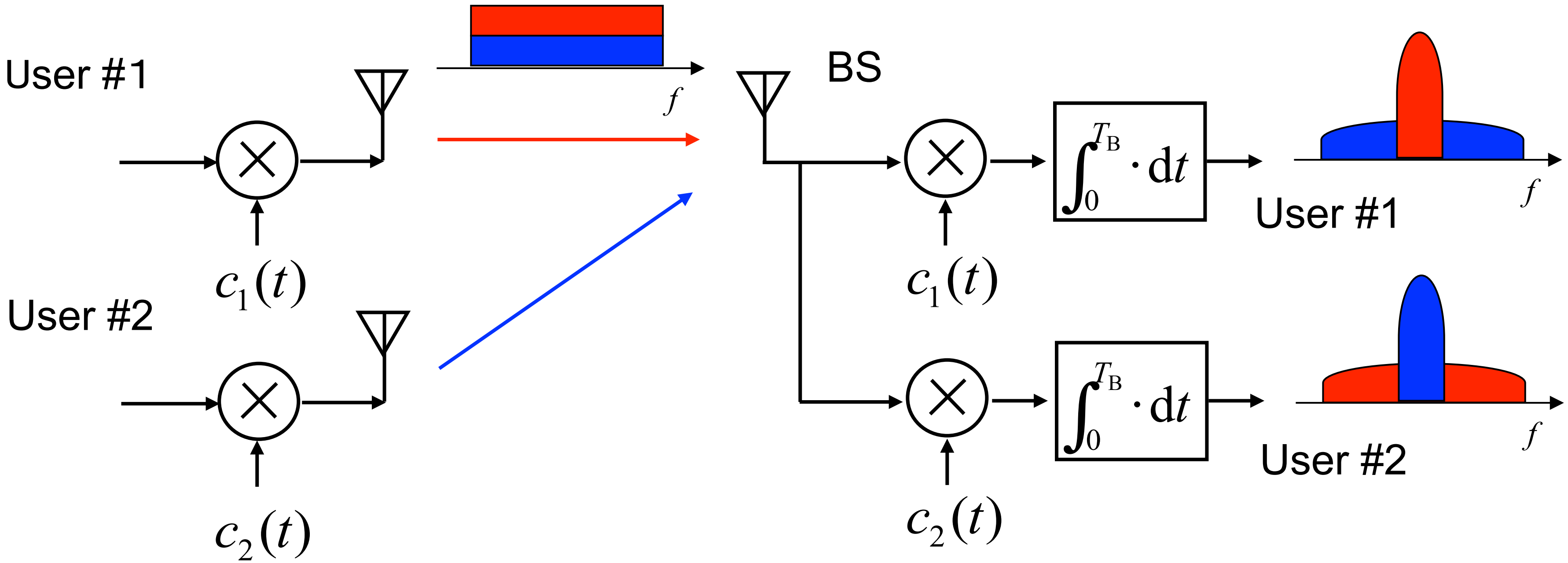
$$\gamma = \gamma(0) + \gamma(\Delta\tau) \approx \frac{PM\left(|h(0)|^2 + |h(\Delta\tau)|^2\right)}{\sigma^2} = \frac{PT_B\left(|h(0)|^2 + |h(\Delta\tau)|^2\right)}{N_0}$$

$$M = T_B / T_C \qquad \sigma^2 = N_0 / T_C$$

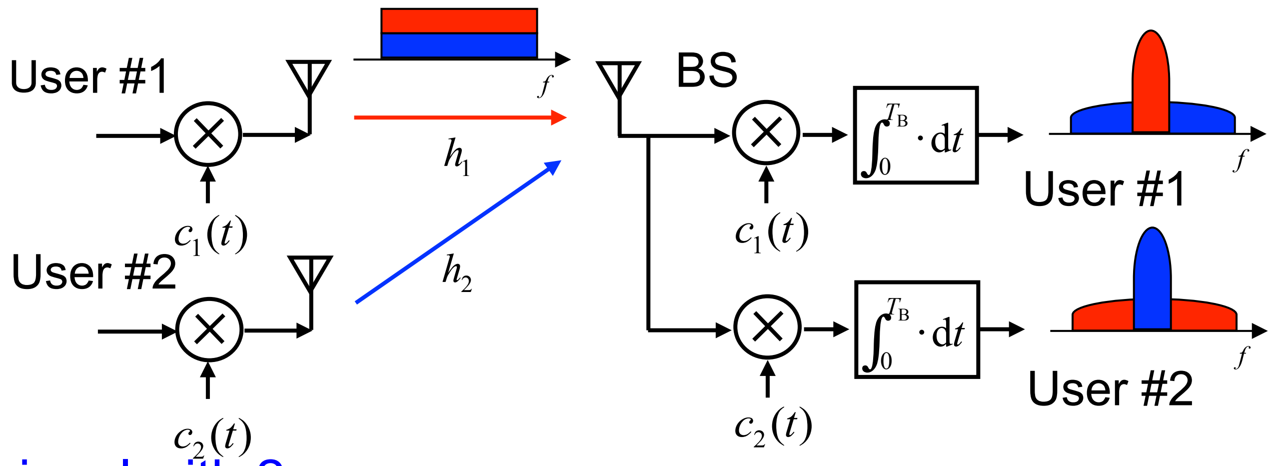
Diversity combining

# Code Division Multiple Access (CDMA)

- Multiple access with users using different spreading codes
- BS separates users using corresponding spreading codes
- Improve SIR by a factor of spreading gain



# Performance of CDMA




**Receive signal with 2 users**

$$y_{ss}(t) = h_1 c_1(t) s_1 + h_2 c_2(t) s_2 + n(t)$$

**Cross-correlation**

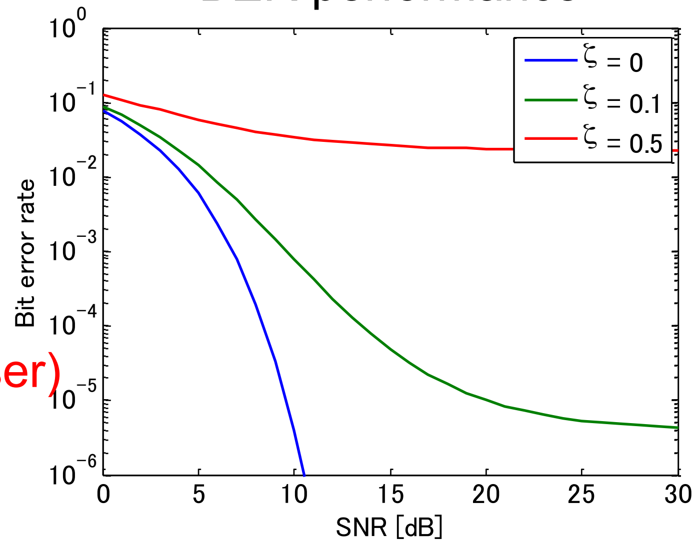
$$R_c(\tau) = \int c_1(t) c_2(t+\tau) \mathrm{d}t$$

**SINR**

$$\gamma = \frac{P_1 |R_a(0) h_1|^2}{P_2 |R_c h_2|^2 + R_a(0)\sigma^2}$$

Inter system (user) interference

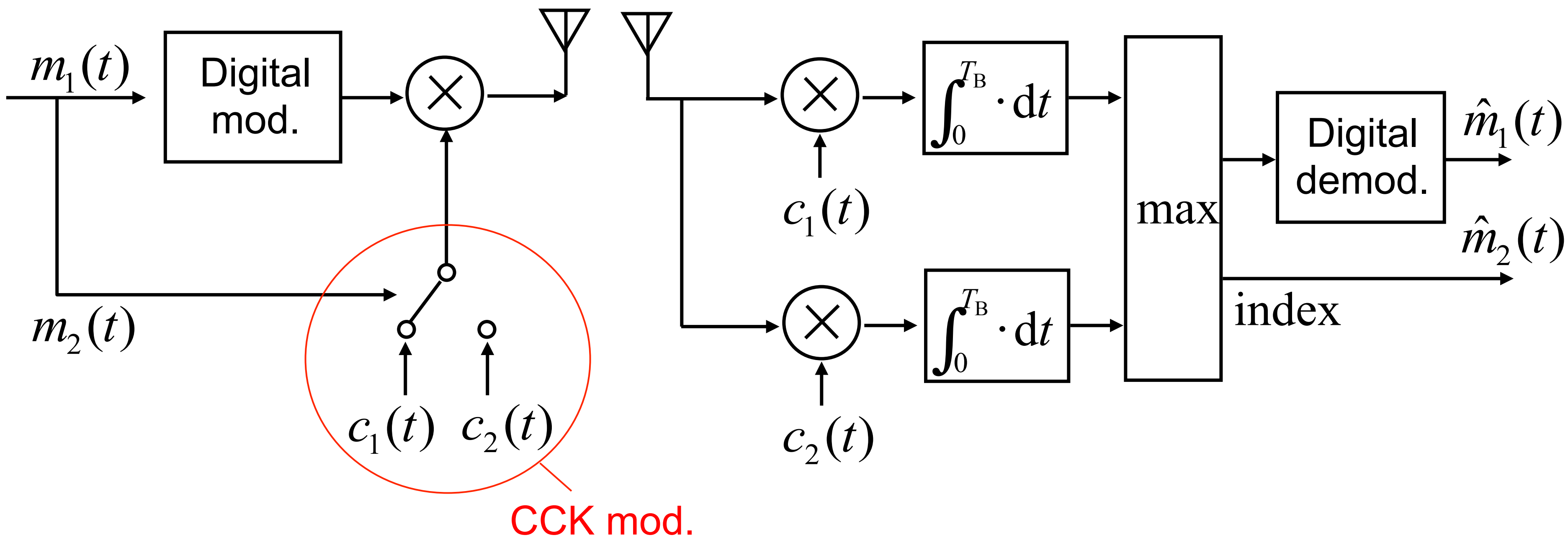
BER performance




$$\zeta = P_2 |R_c h_2|^2 / P_1 |R_a(0) h_1|^2$$

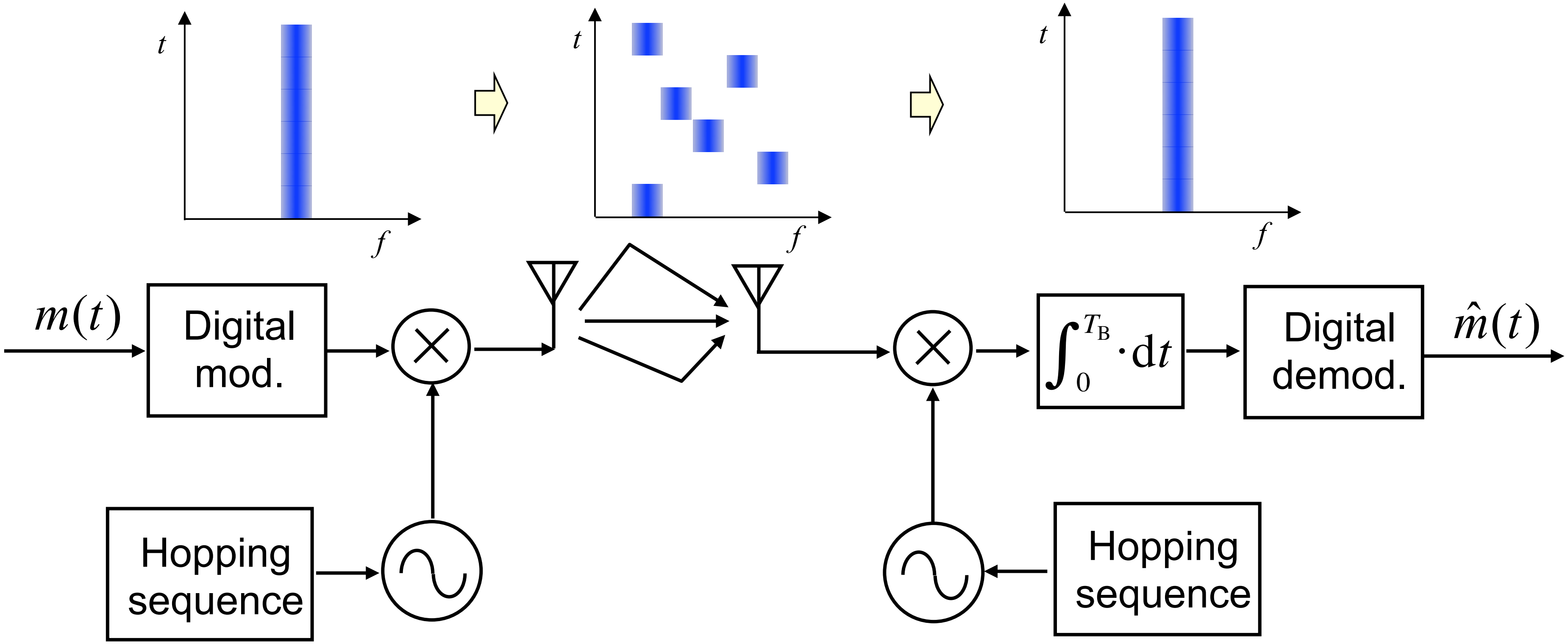
# Complementary Code Keying (CCK)

- Select spreading sequence based on message $m_2(t)$
- Achieve higher data rate without expanding bandwidth



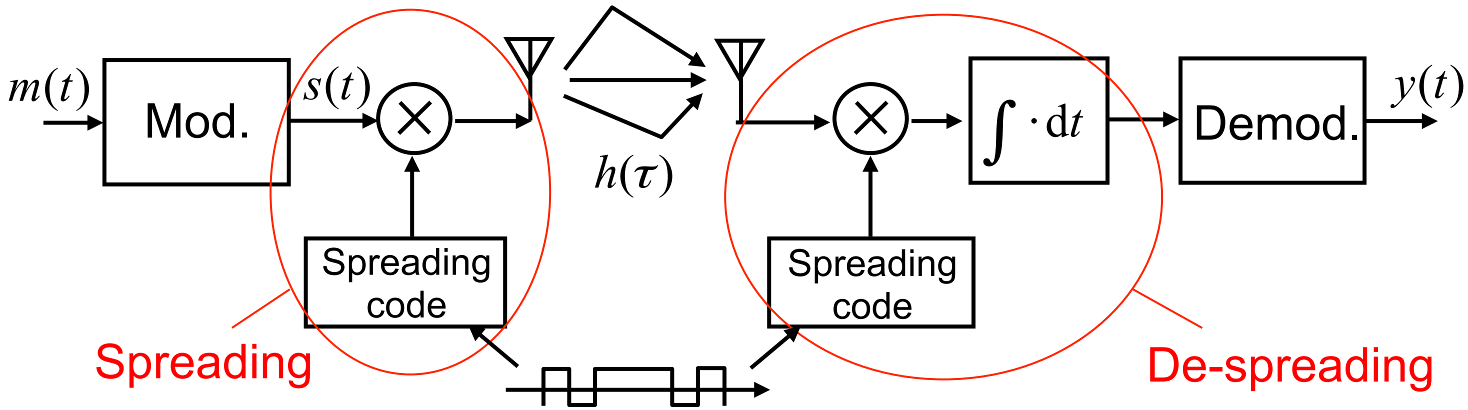
# Frequency Hopping Spread Spectrum (FHSS)

- Spread spectrum by using hopping carrier frequency in time
- Inter system interference is reduced due to de-spreading using the same hopping carrier frequency in receiver



# Summary

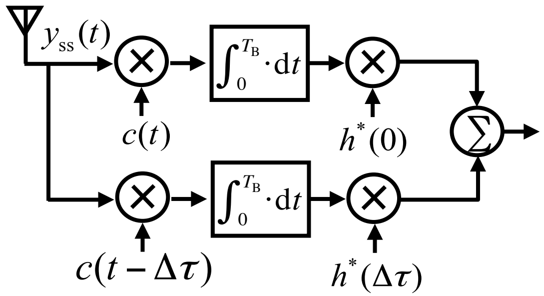
- **Spread spectrum**




- **RAKE receiver**

Diversity

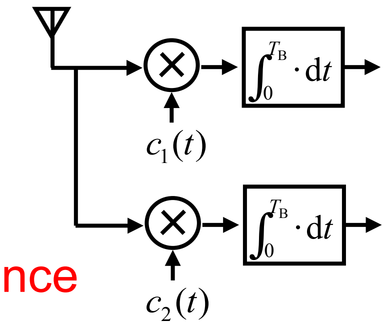
$$\gamma = \gamma_1 + \gamma_2 \qquad \gamma_i = \frac{PR_{\mathrm{a}}^2(0)\left|h_i\right|^2}{PR_{\mathrm{a}}^2(\Delta\tau)\left|h_{j\neq i}\right|^2 + R_{\mathrm{a}}(0)\sigma^2}$$



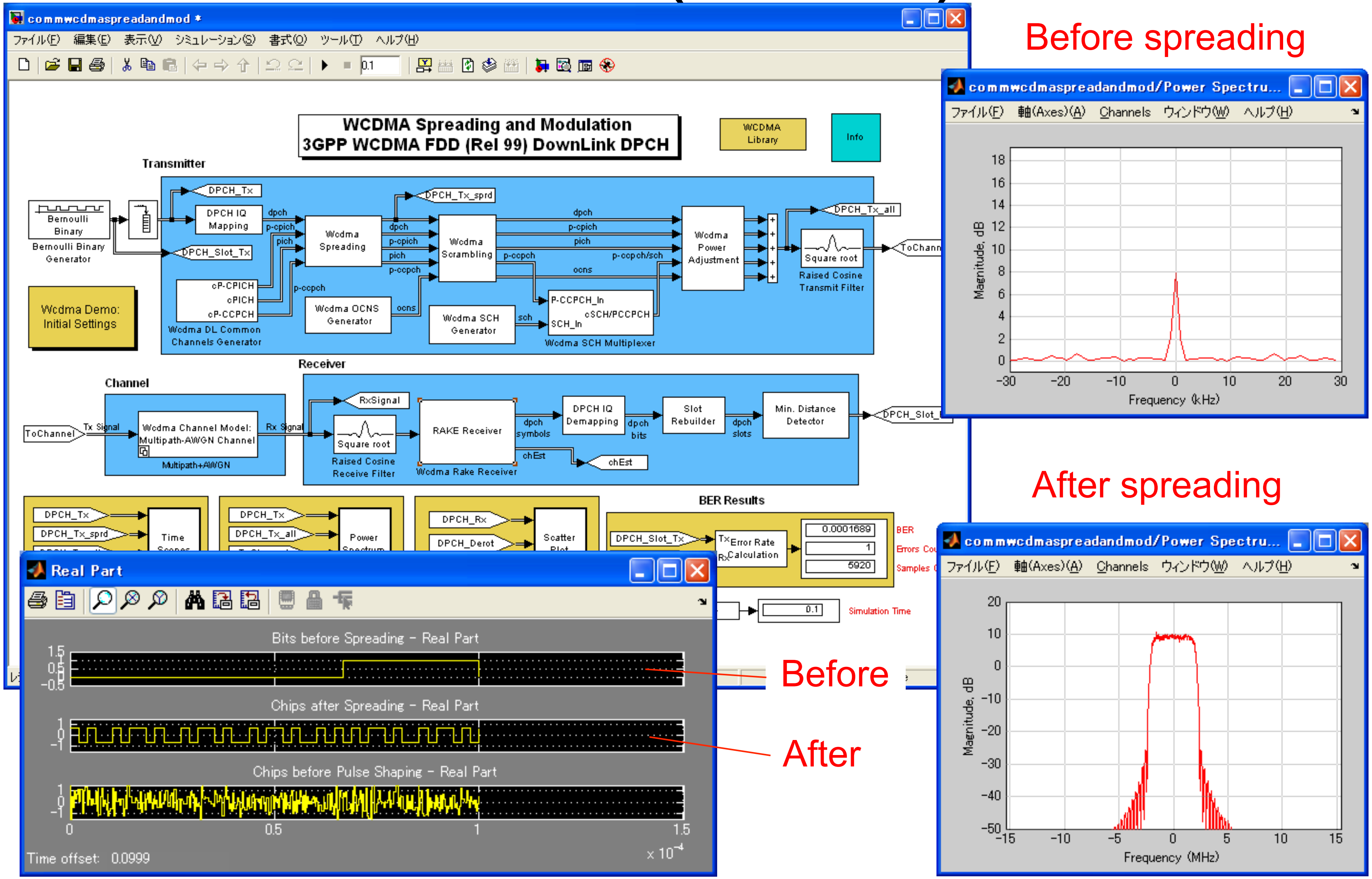

- **Code Division Multiple Access (CDMA)**

$$\gamma = \frac{P\left|R_{\mathrm{a}}(0)h_1\right|^2}{P\left|R_{\mathrm{c}}h_2\right|^2 + R_{\mathrm{a}}(0)\sigma^2}$$

Inter system (user) interference



# Demo (DSSS)

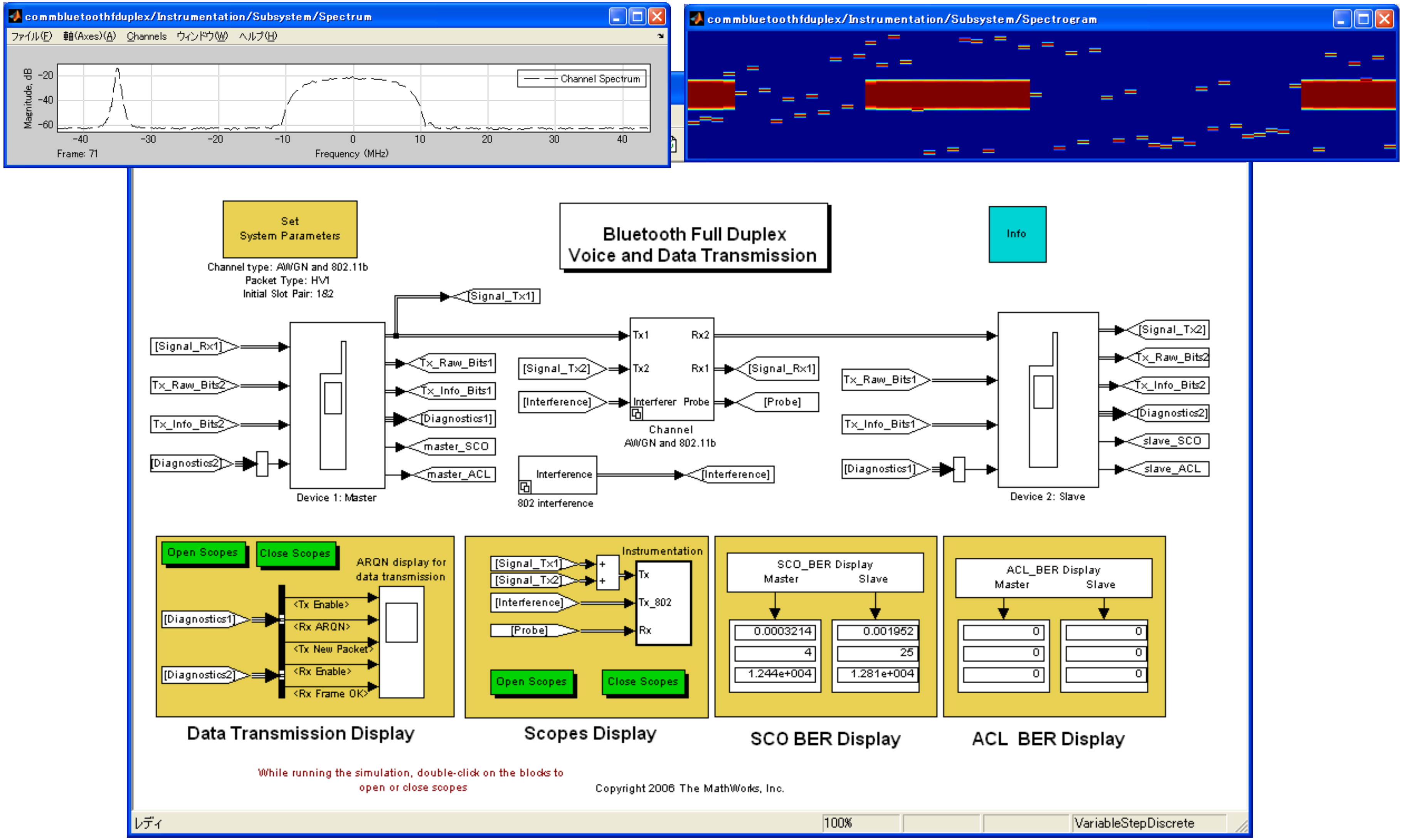


commwcdmaspreadandmod *
WCDMA Spreading and Modulation
3GPP WCDMA FDD (Rel 99) DownLink DPCH
WCDMA Library
Info
Transmitter
Bernoulli Binary Generator
DPCH IQ Mapping
Wcdma Spreading
Wcdma Scrambling
Wcdma Power Adjustment
Square root Raised Cosine Transmit Filter
Wcdma DL Common Channels Generator
Wcdma OCNS Generator
Wcdma SCH Generator
Wcdma SCH Multiplexer
Wcdma Demo: Initial Settings
Receiver
Channel
Wcdma Channel Model: Multipath-AWGN Channel
Multipath+AWGN
Square root Raised Cosine Receive Filter
RAKE Receiver
Wcdma Rake Receiver
DPCH IQ Demapping
Slot Rebuilder
Min. Distance Detector
BER Results
Error Rate Calculation
0.0001689
1
5920
Simulation Time
Before spreading
commwcdmaspreadandmod/Power Spectru...
Magnitude, dB
Frequency (kHz)
After spreading
Magnitude, dB
Frequency (MHz)
Real Part
Bits before Spreading - Real Part
Chips after Spreading - Real Part
Chips before Pulse Shaping - Real Part
Time offset: 0.0999
Before
After

# Demo (FHSS)

Spectrum

Spectorogram



# Macro Diversity

- Separate interference signal by de-spreading at coverage edge
- Transmit same signal from different BSs (macro diversity)
- Improve SNR at coverage edge by Rake combining