2016 2Q

Wireless Communication Engineering

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

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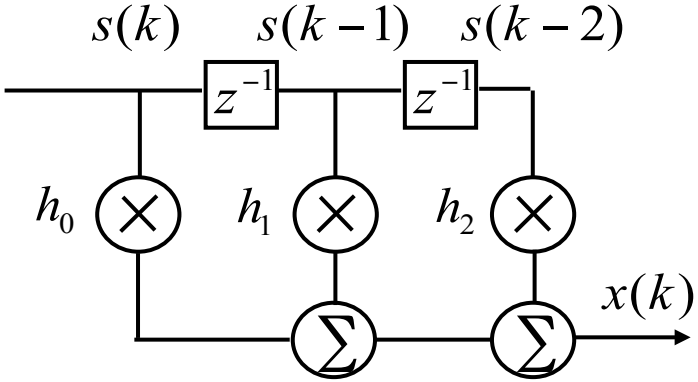
Course Schedule (2)

	Date	Text	Contents
#7	July 15	4.6	Error correction coding
#8	July 15		Adaptive modulation coding
#9	July 22	4.3	Inter symbol interference and adaptive equalizer
#10	July 22	3.6, 4.5	Spread spectrum and code division multiple access (CDMA)
#11	July 29	3.5	Orthogonal frequency division multiple access (OFDM)
#12	July 29		Array signal processing and MIMO spatial multiplexing
#13	Aug 5	all	Final examination

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: $\mathbf{w}^* = \widetilde{\mathbf{H}}^{-1}\mathbf{e}_0$ 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）

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

Contents

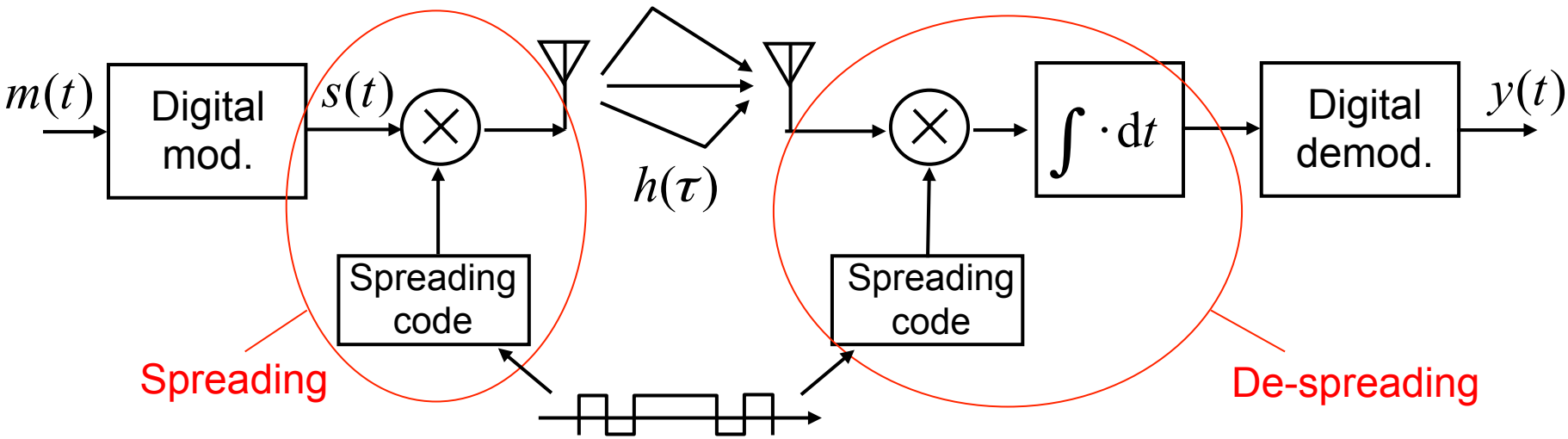
- Spread Spectrum (SS) system
- Direct Sequence Spread Spectrum (DSSS) and de-spreading
- Feature of spreading code
- Application of DSSS
  - Rake receiver
  - Macro diversity
  - Code Division Multiple Access (CDMA)
- Frequency Hopping SS (FHSS)
- Demonstration

IEEE802.11 WLAN

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

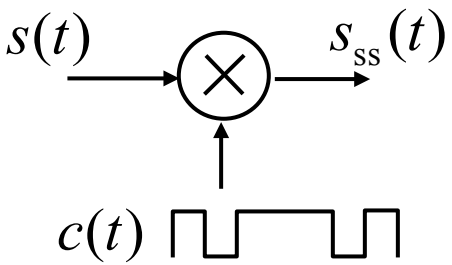
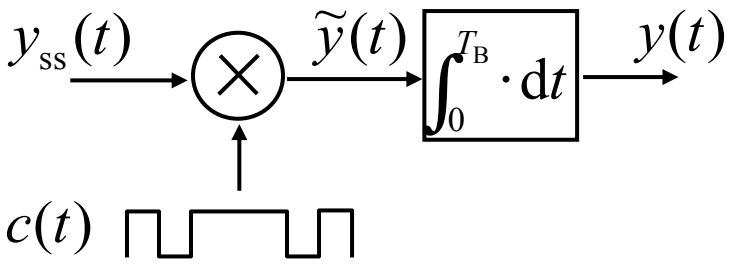
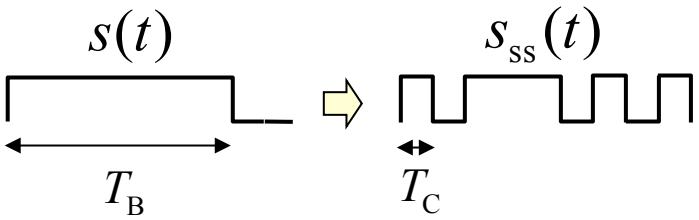
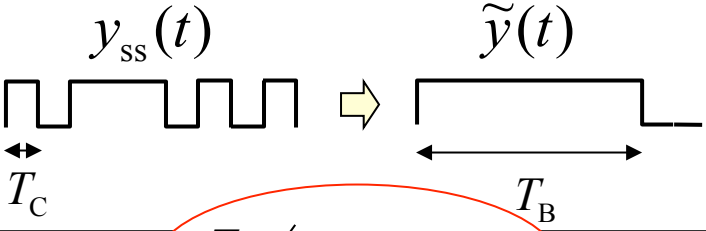
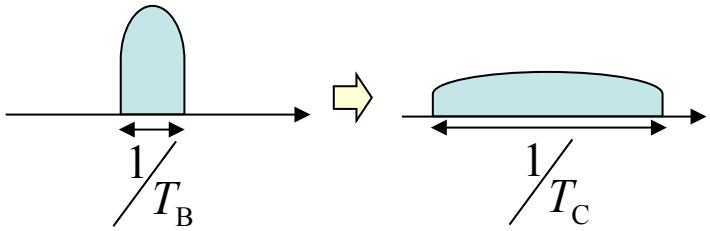
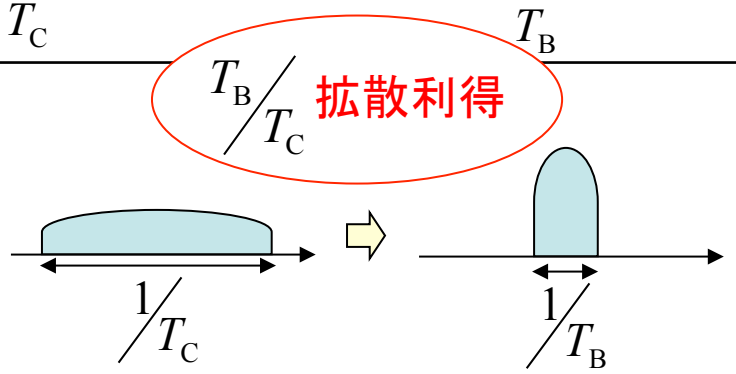
	802.11b	802.11a	802.11g	802.11n	802.11ac
Year of approval	1999	1999	2003	2009	2014
RF band	2.4GHz	5GHz	2.4GHz	2.4 & 5GHz	5GHz
Channel bandwidth	20MHz	20MHz	20MHz	20/40MHz	20/40/80/ 160MHz
Modulation	DSSS, CCK	OFDM, AMC	OFDM, AMC, CCK	MIMO-OFDM, AMC, CCK	MIMO-OFDM, AMC256Q, MU-MIMO
Max data rate	11Mbps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

Spread Spectrum System



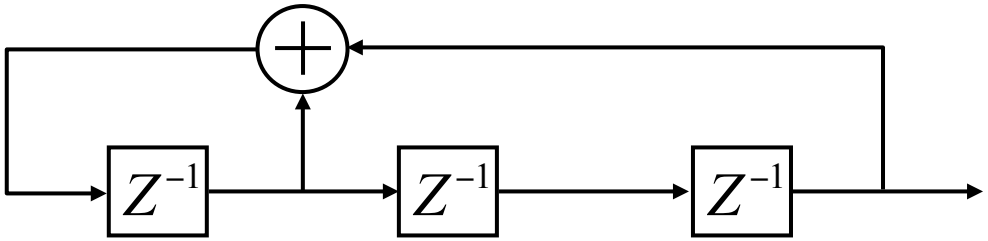
- Using common spreading code between Tx & Rx
- Multi-plath combining using auto-correlation property in spreading code (Rake receiver)
- Code Division Multiple Access (CDMA) using cross-correlation property between different spreading codes

Direct Sequence Spread Spectrum (DSSS)

	Spreading (transmitter)	De-spreading (receiver)
Block		
Math	$s_{ss}(t) = c(t)s(t)$	$y(kT_B) = \int_0^{T_B} c(t)y_{ss}(t)dt$
Time		
Freq		

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

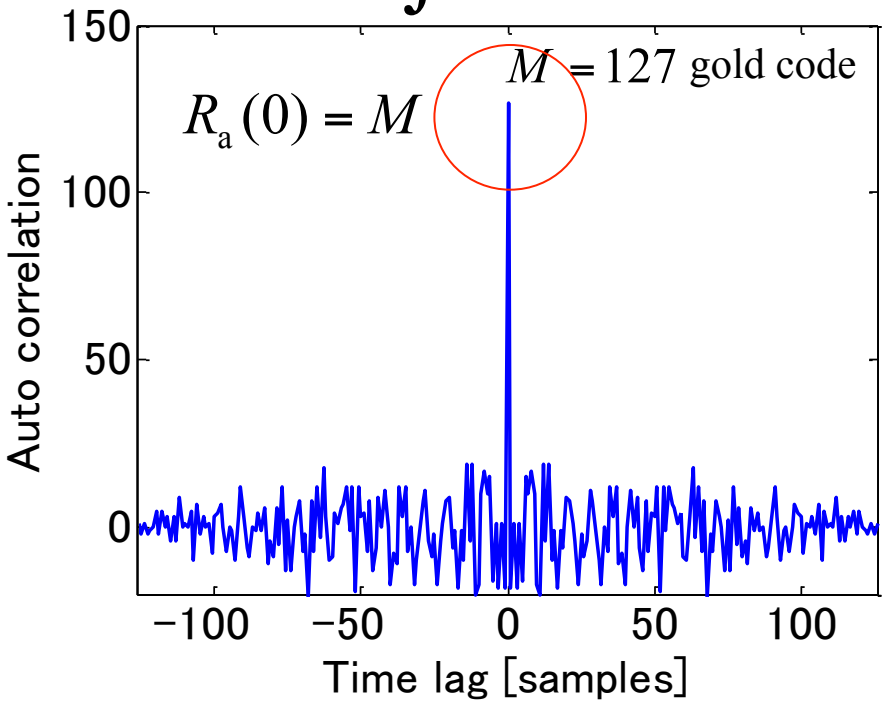
	Register 1	Register 2	Register 3
#1	1	0	0
#2	1	1	0
#3	1	1	1
#4	0	1	1
#5	1	0	1
#6	0	1	0
#7	0	0	1
#8	1	0	0

Feature of Spreading Sequence

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

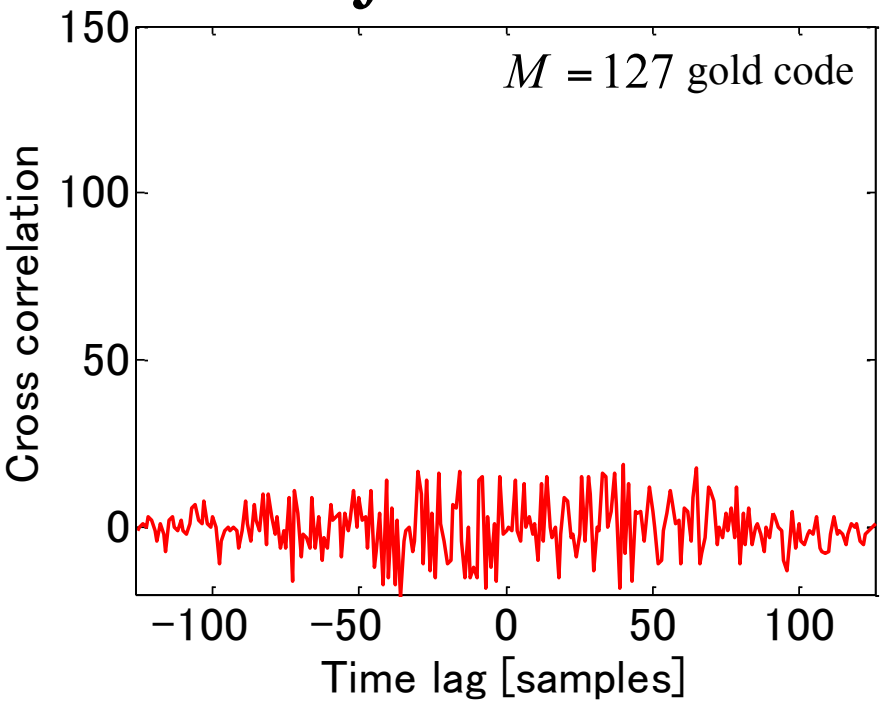
Auto-correlation

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



Cross-correlation

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



Delay Spread & De-spreading

Receive signal

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

2-path model

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

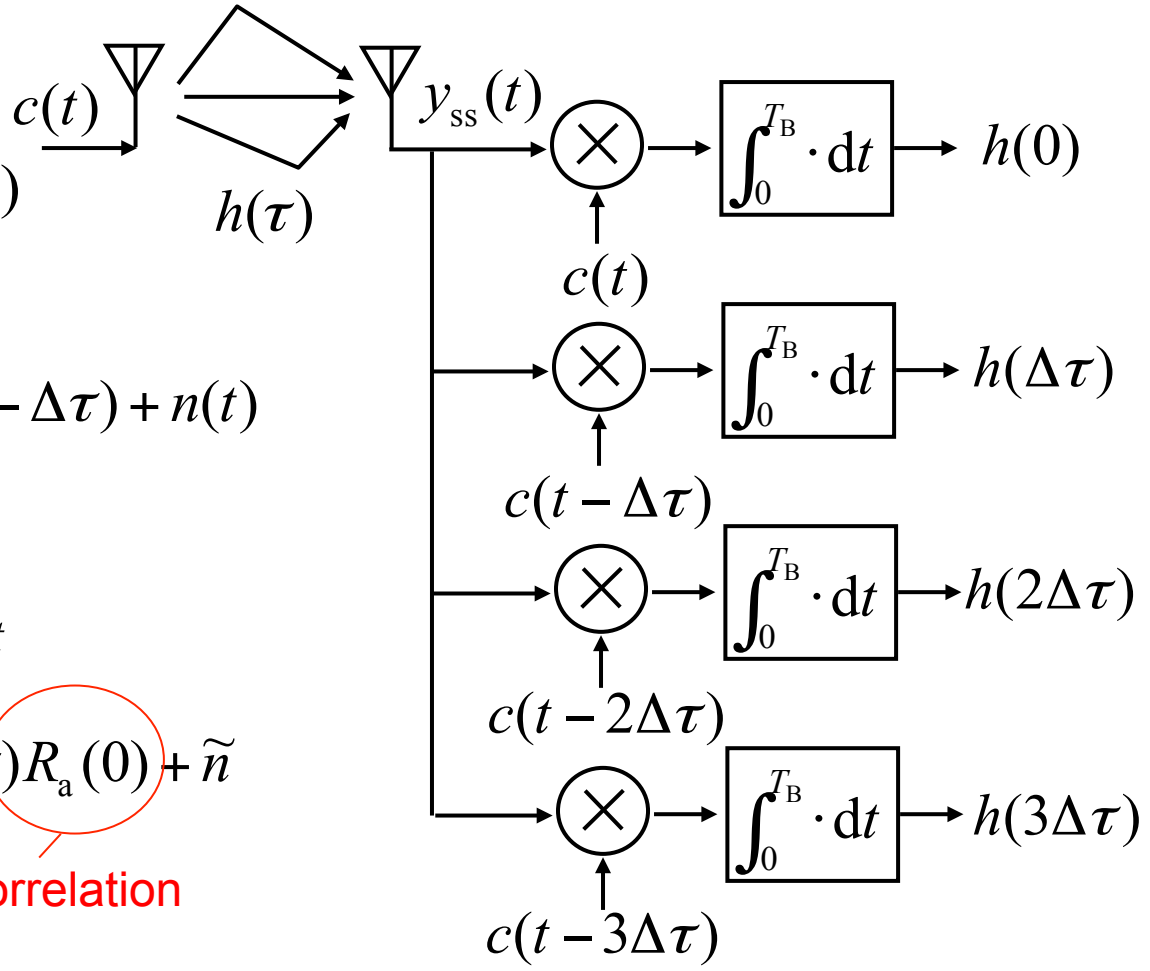
De-spreading

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

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

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

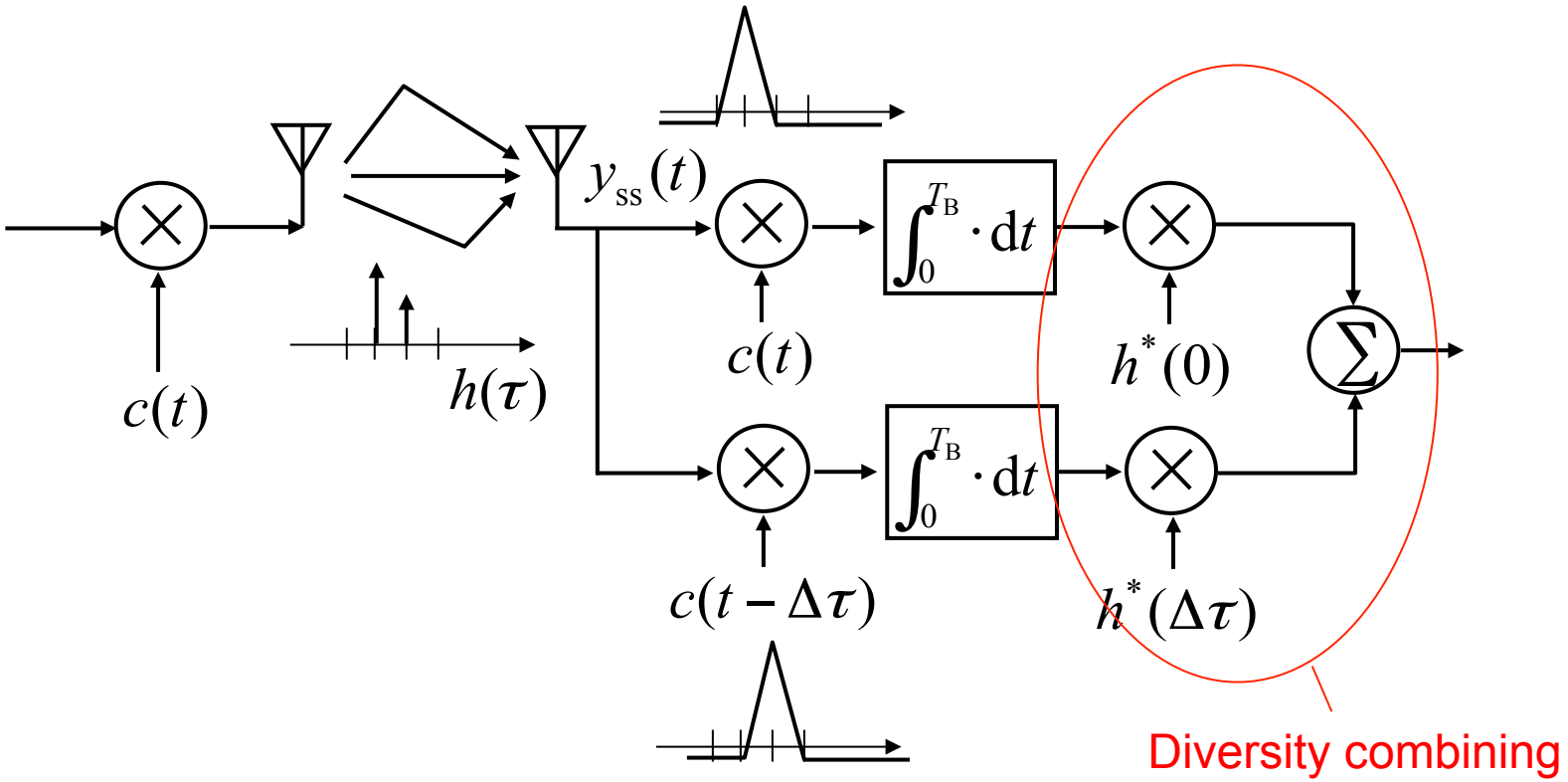
Auto-correlation



Multi-path separation by de-spreading

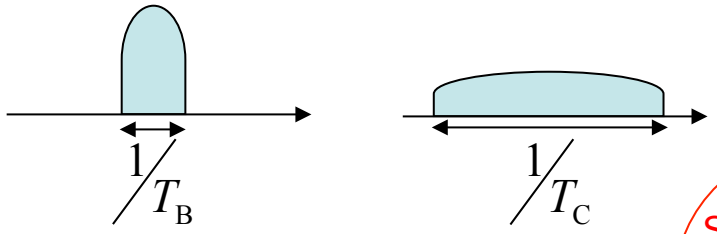
RAKE Receiver

- 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



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

Spreading gain

$$M = T_B / T_C$$

Signal power

Density: $P \Rightarrow P$, $T_B P \Rightarrow T_C P$

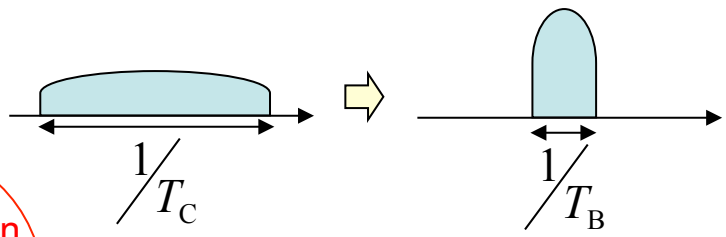
Noise power

$N_0 / T_B \Rightarrow N_0 / T_C$

SNR before spreading

$$\gamma = PT_B / N_0$$

De-spreading



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

Signal power

$P \Rightarrow M^2 P$

Noise power

$N_0 / T_C \Rightarrow M N_0 / T_C$

SNR after de-spreading

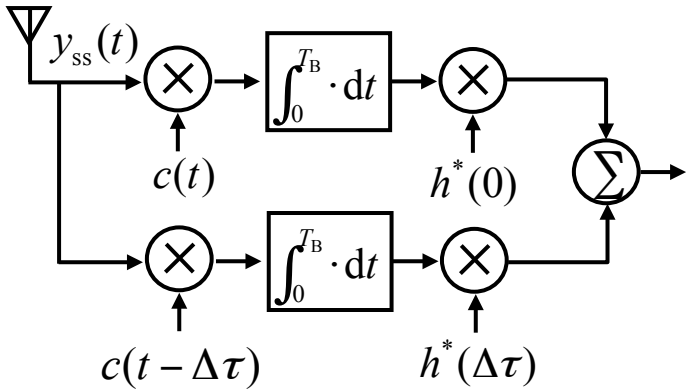
$$\gamma = M^2 PT_C / MN_0 = PT_B / N_0$$

Same SNR

Performance of Rake Receiver

Auto-correlation

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



2-path model

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

SINR of each Rake branch

$$\gamma(0)=\frac{PR_{\mathrm{a}}^2(0)\left|h(0)\right|^2}{PR_{\mathrm{a}}^2(\Delta\tau)\left|h(\Delta\tau)\right|^2+R_{\mathrm{a}}(0)\sigma^2} \qquad \gamma(\Delta\tau)=\frac{PR_{\mathrm{a}}^2(0)\left|h(\Delta\tau)\right|^2}{PR_{\mathrm{a}}^2(\Delta\tau)\left|h(0)\right|^2+R_{\mathrm{a}}(0)\sigma^2}$$

SINR after Rake combining

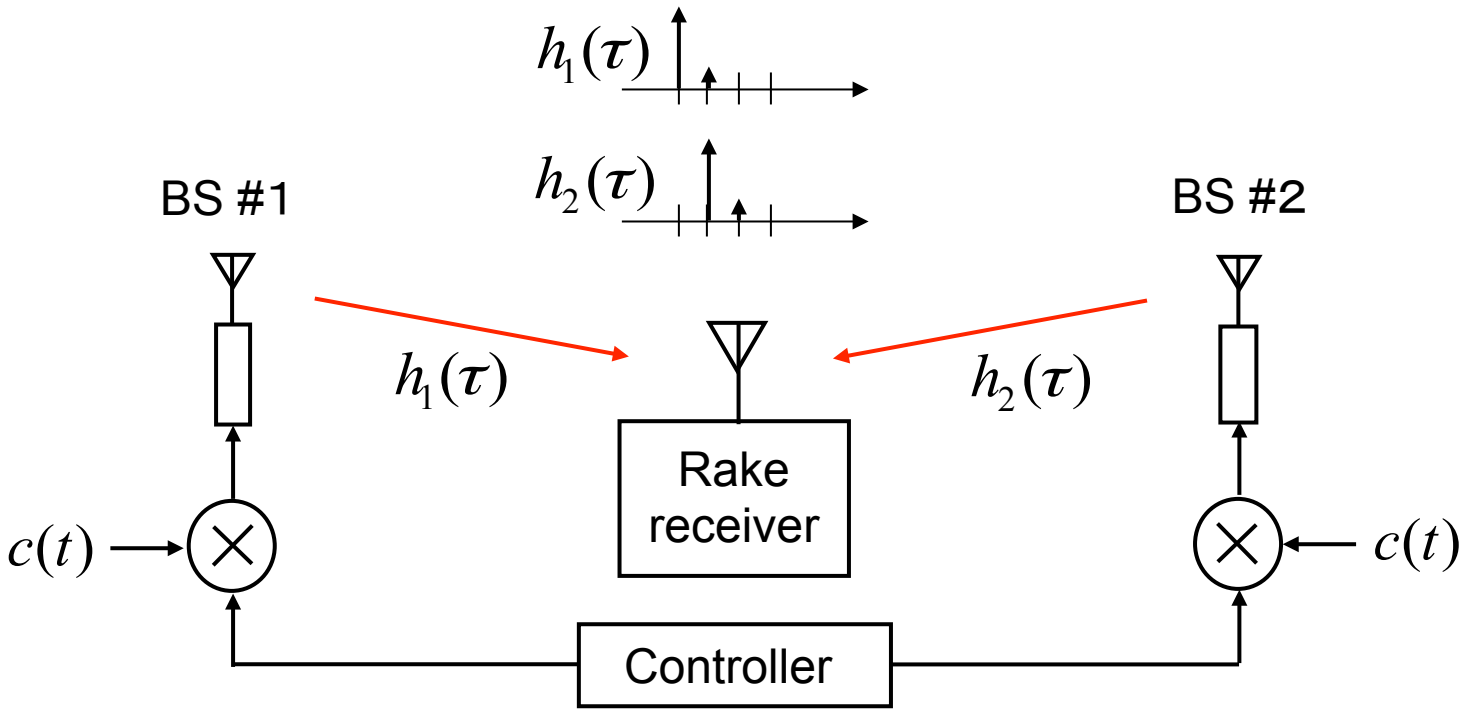
$$\gamma=\gamma(0)+\gamma(\Delta\tau)\approx\frac{PM\left(\left|h(0)\right|^2+\left|h(\Delta\tau)\right|^2\right)}{\sigma^2}=\frac{PT_{\mathrm{B}}\left(\left|h(0)\right|^2+\left|h(\Delta\tau)\right|^2\right)}{N_0}$$

$M=T_{\mathrm{B}}/T_{\mathrm{C}}$ $\qquad \sigma^2=N_0/T_{\mathrm{C}}$

Diversity combining

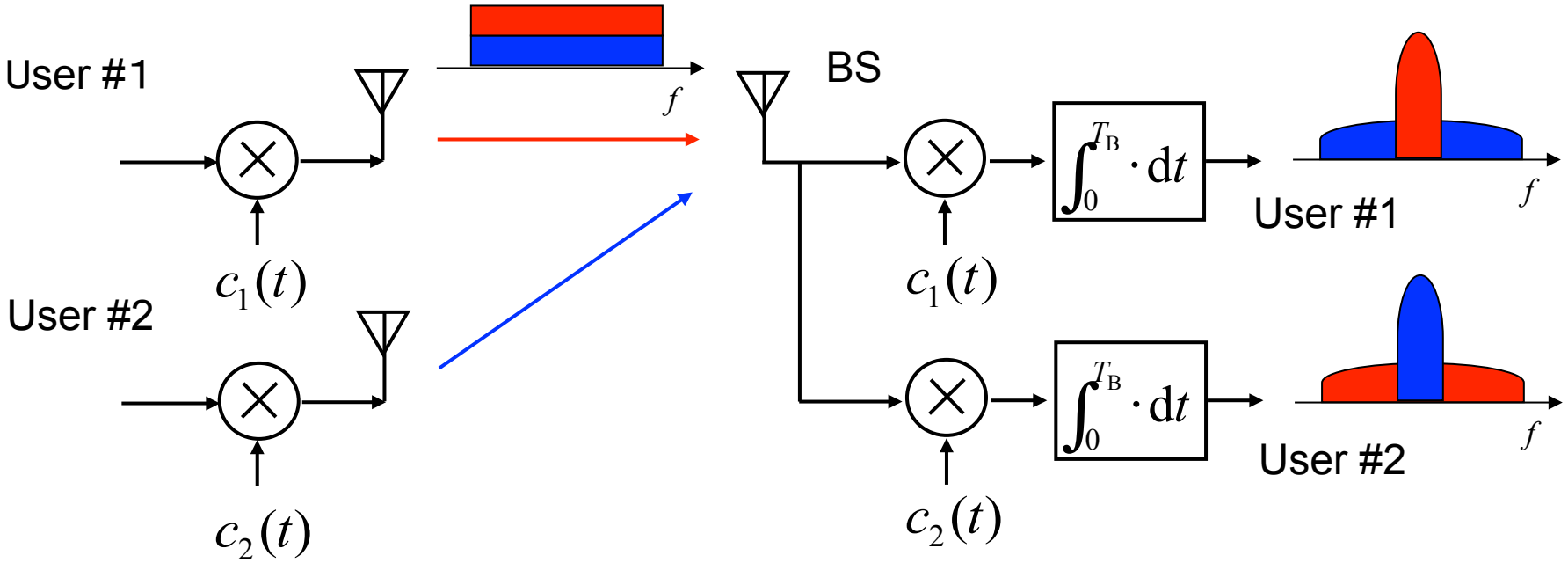
Macro Diversity

- 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

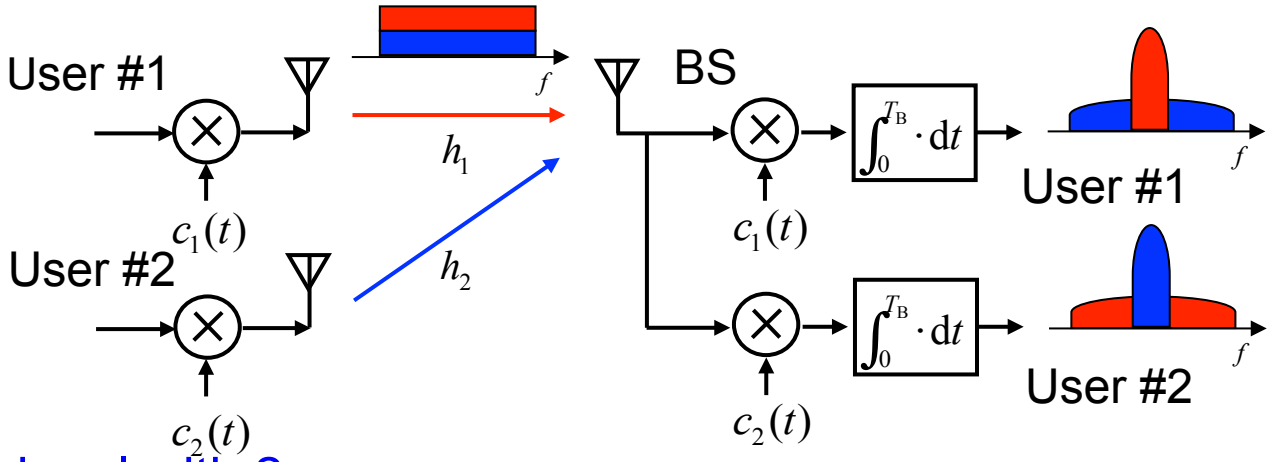


Code Division Multiple Access (CDMA)

- 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

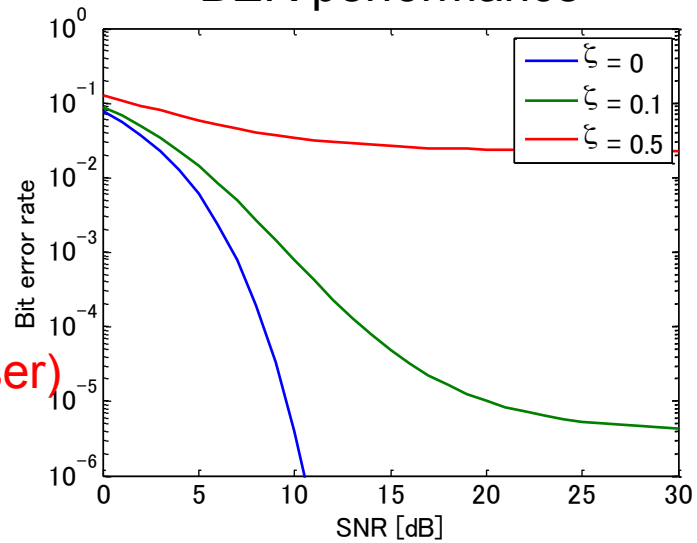
$$R_c(\tau) = \int c_1(t) c_2(t+\tau) \mathrm{d}t$$

SINR

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

Inter system (user) interference

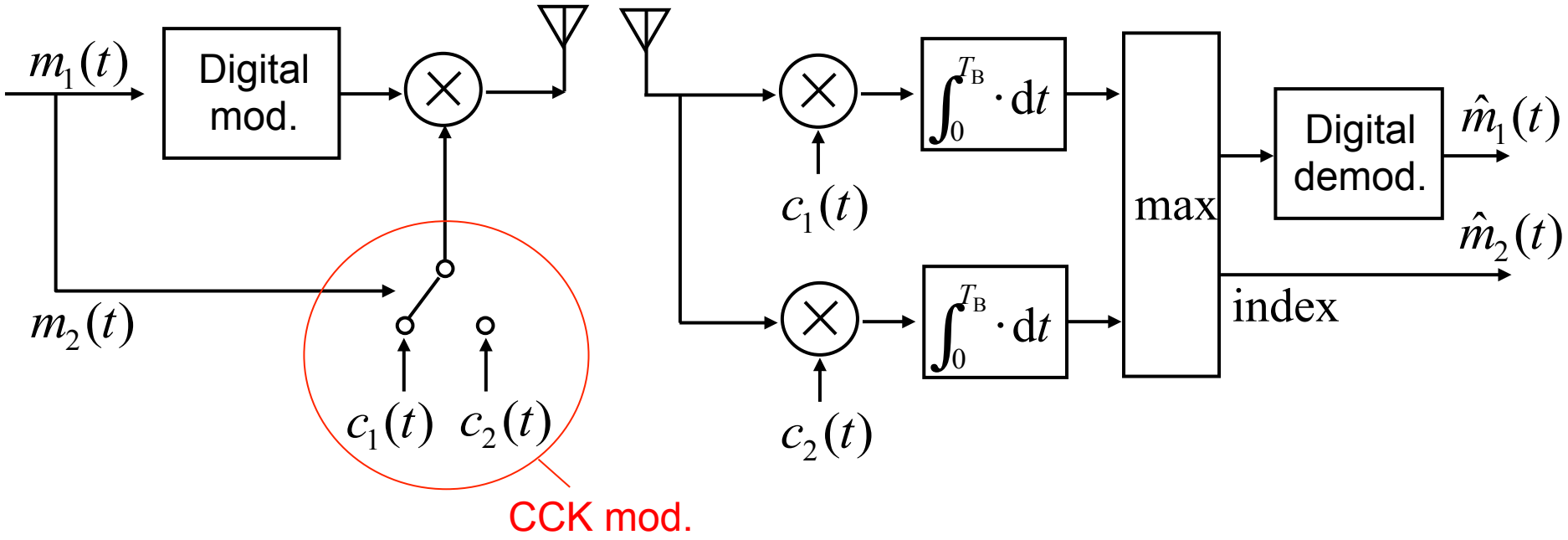
BER performance



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

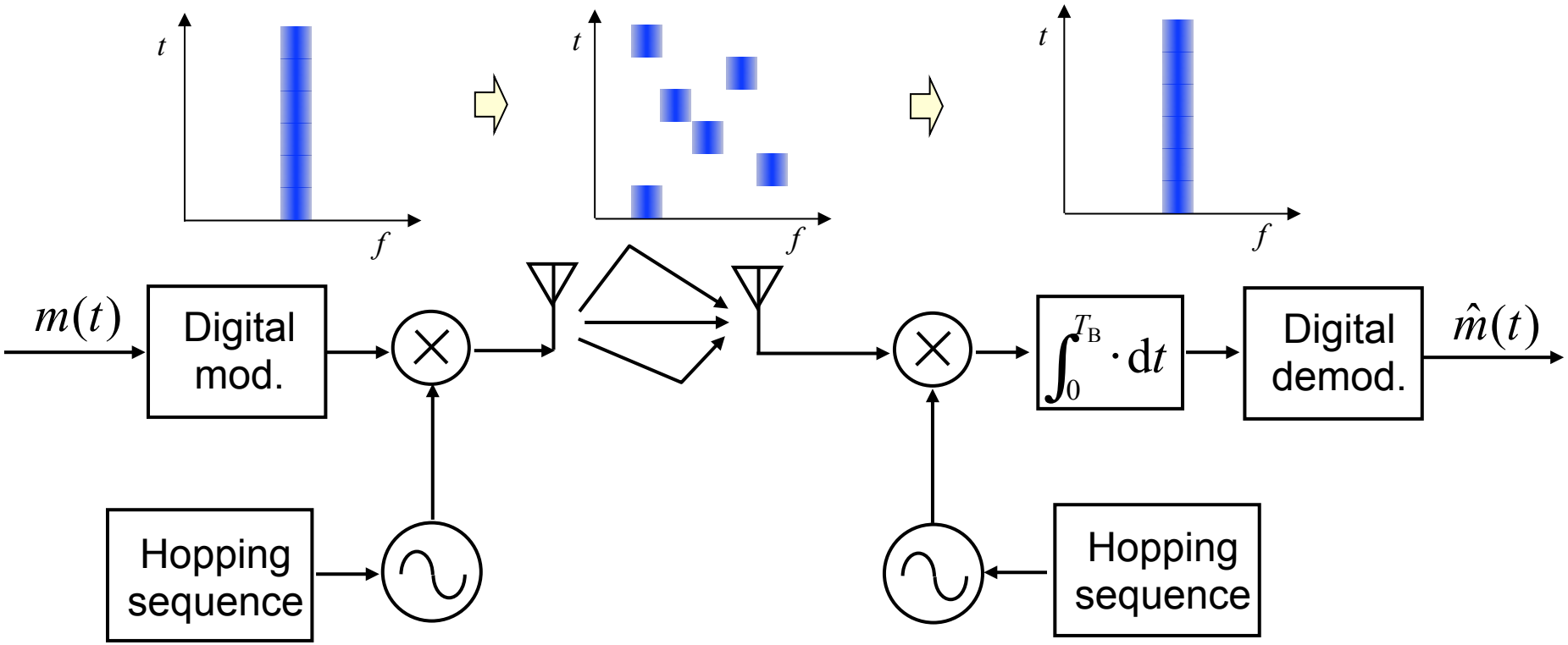
Complementary Code Keying (CCK)

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



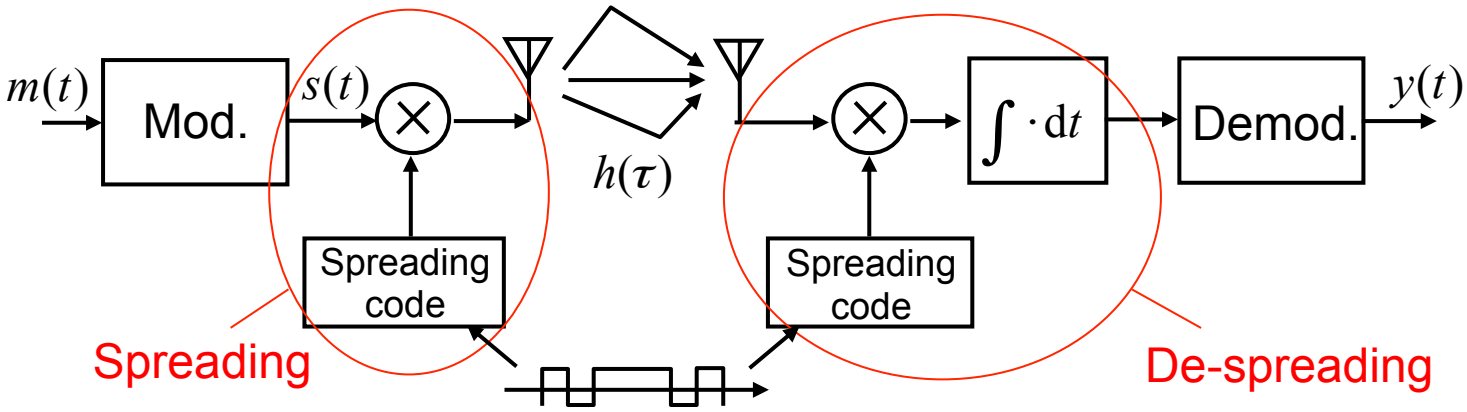
Frequency Hopping Spread Spectrum (FHSS)

- 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

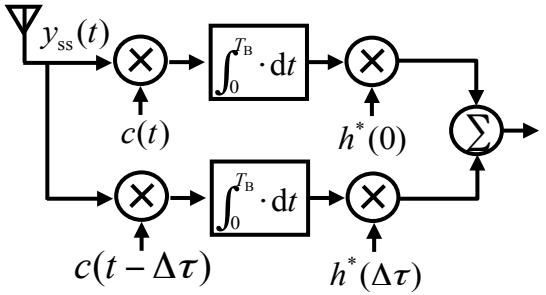


- RAKE receiver

Diversity

$$\gamma = \gamma_1 + \gamma_2$$

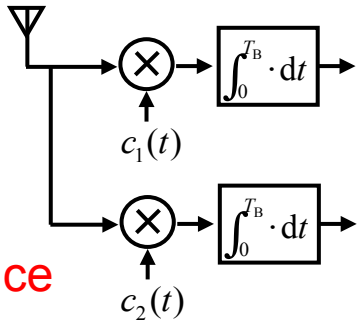
$$\gamma_i = \frac{PR_a^2(0)\left|h_i\right|^2}{PR_a^2(\Delta\tau)\left|h_{j\neq i}\right|^2 + R_a(0)\sigma^2}$$



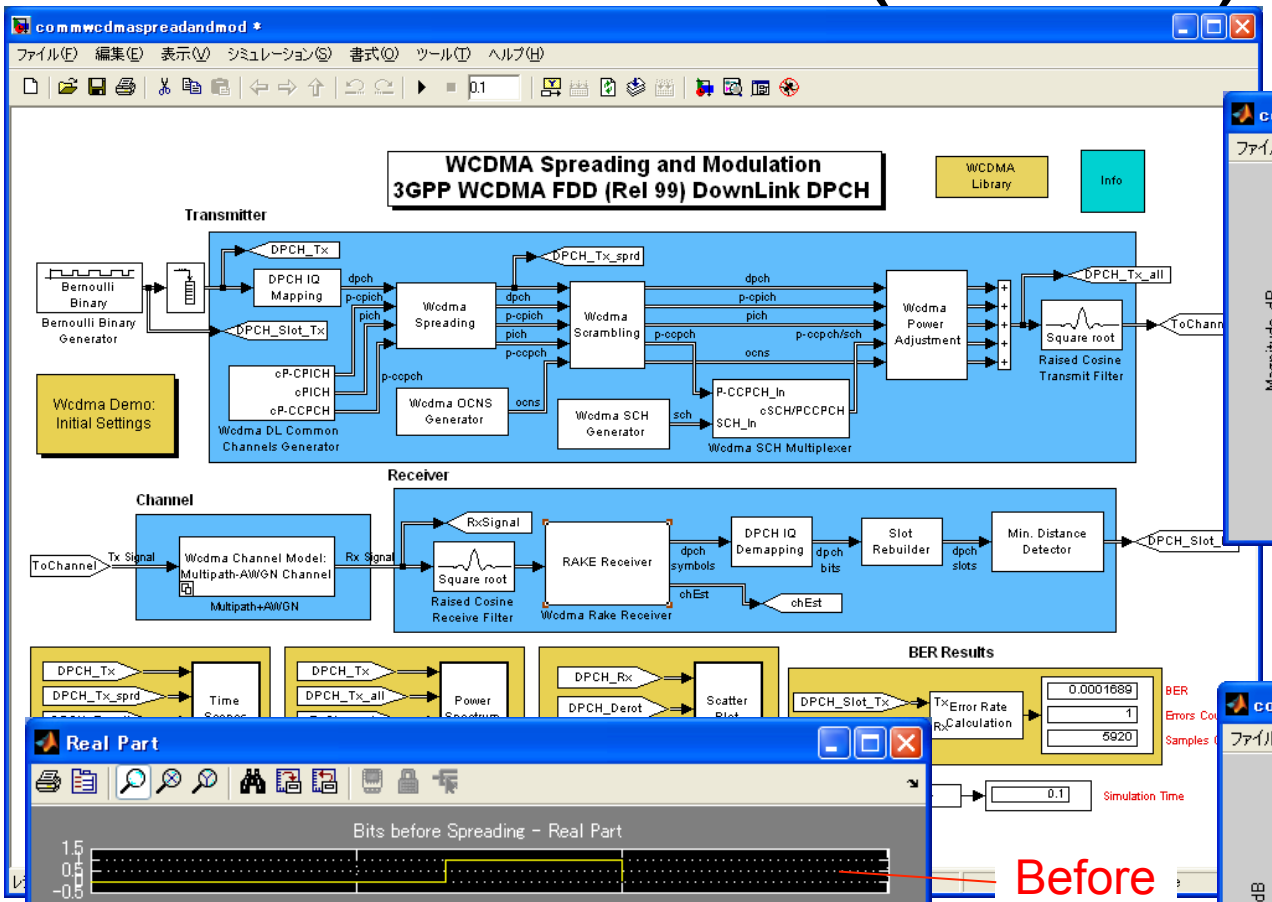
- Code Division Multiple Access (CDMA)

$$\gamma = \frac{P\left|R_a(0)h_1\right|^2}{P\left|R_c h_2\right|^2 + R_a(0)\sigma^2}$$

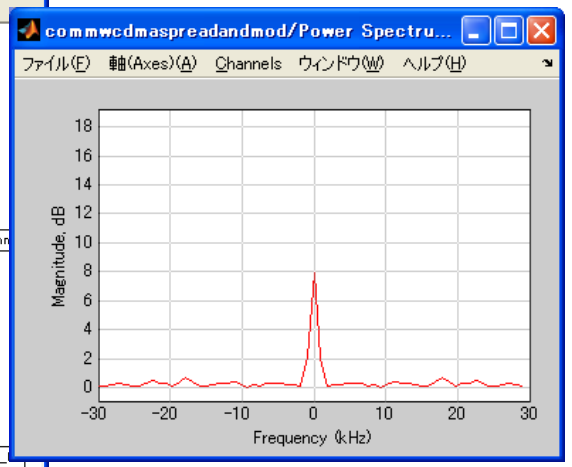
Inter system (user) interference



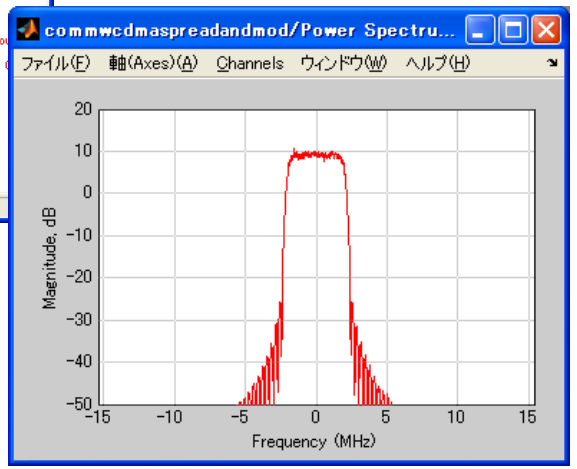
Demo (DSSS)

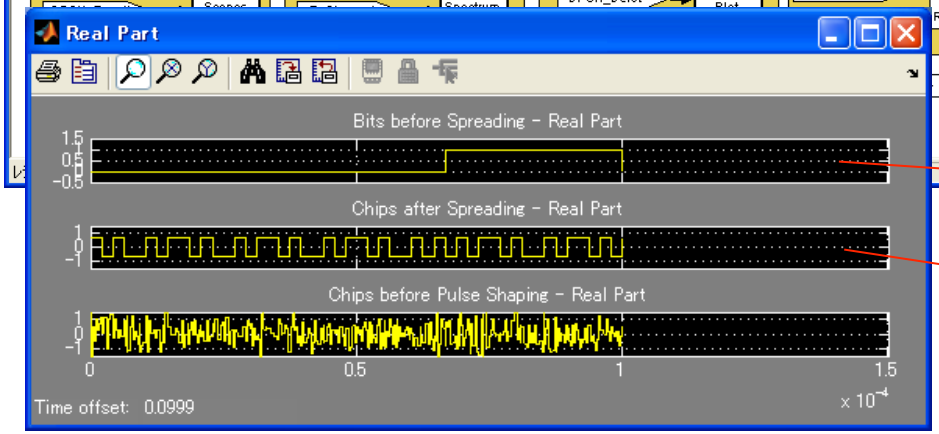


Before spreading



After spreading





Before

After

Demo (FHSS)

Spectrum

Spectorogram