Mobile Communications (KECE425)

Lecture Note 20

5-19-2014

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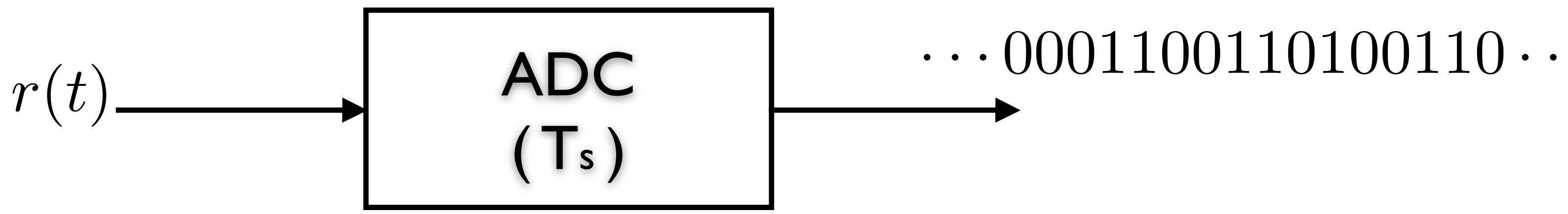
Summary

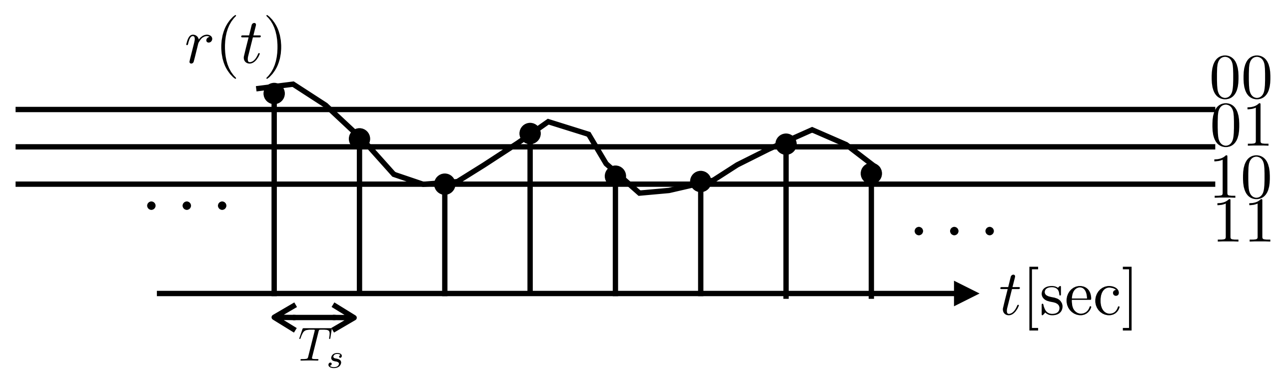
- Complexity issues of diversity systems
  - ADC and Nyquist sampling theorem
- Transmit diversity
  - Channel is known at the transmitter (Closed-loop transmit diversity: CLTD)
  - Channel is unknown at the transmitter (Space-time block coding: STBC)
- Transmit-Receive diversity (Maximal ratio transmission)

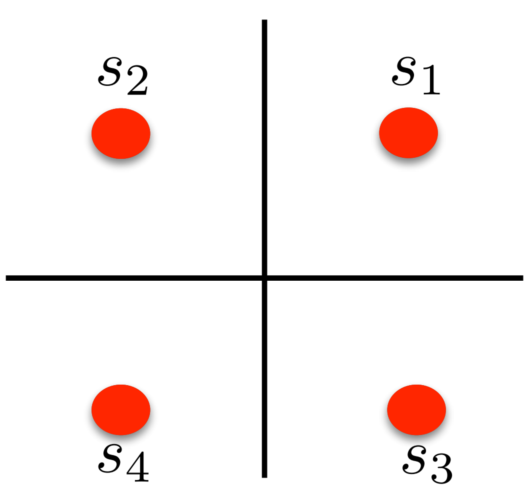
Analog-to-Digital Converter (ADC)

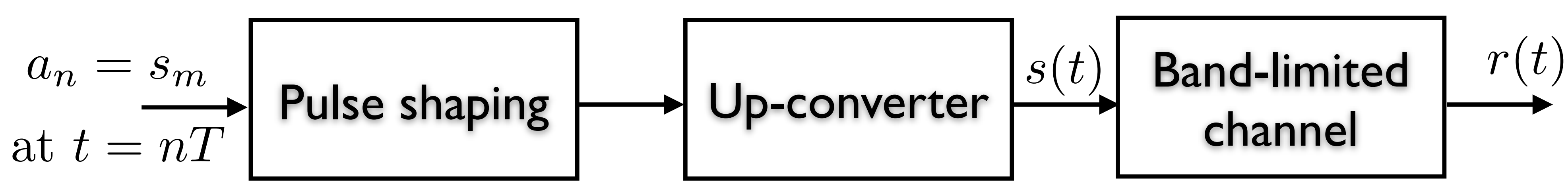
- ADC consists of two circuit blocks: Sampling and quantization



T_s : sampling interval







$$s(t) = \Re\left[\sum_{n=-\infty}^{\infty} a_n p(t - nT) e^{j2\pi f_c t}\right]$$

- Sampling interval: T_s [sec/sample]

- Sampling rate: $R_s = \frac{1}{T_s}$ [samples/sec]

- Quantization level, n [bits/sample]

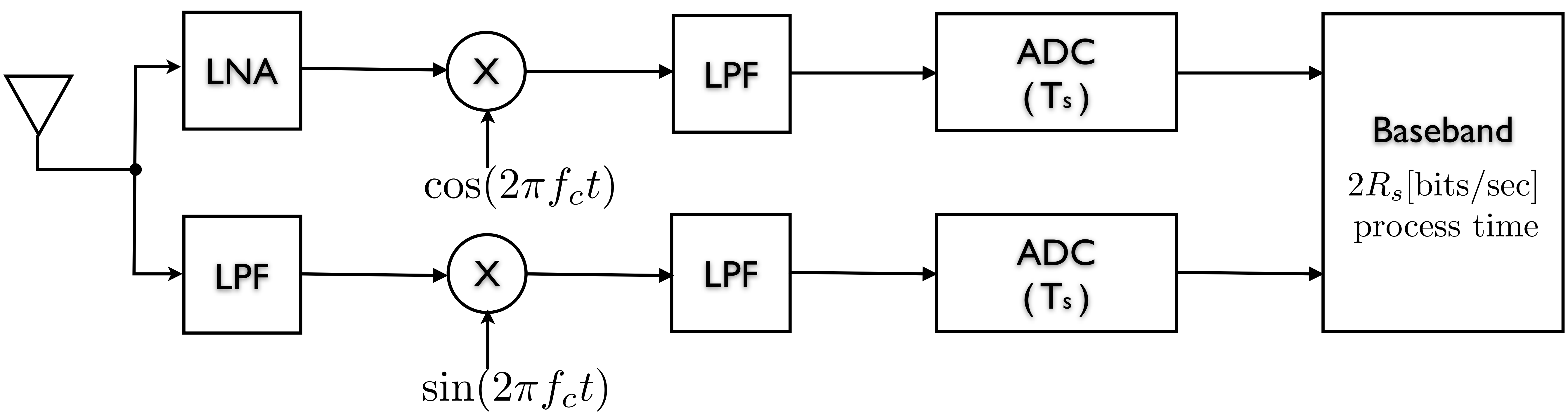
- Sampling rate: $R_s = \frac{n}{T_s}$ [bits/sec]

- Example
  - 10MHz bandwidth and 16-QAM

$$T_s = \frac{1}{20 \times 10^6} = 50 \text{ [ns/sample]}$$

We need at least 4 levels for hard decision of 16-QAM symbols in each of I and Q channels.

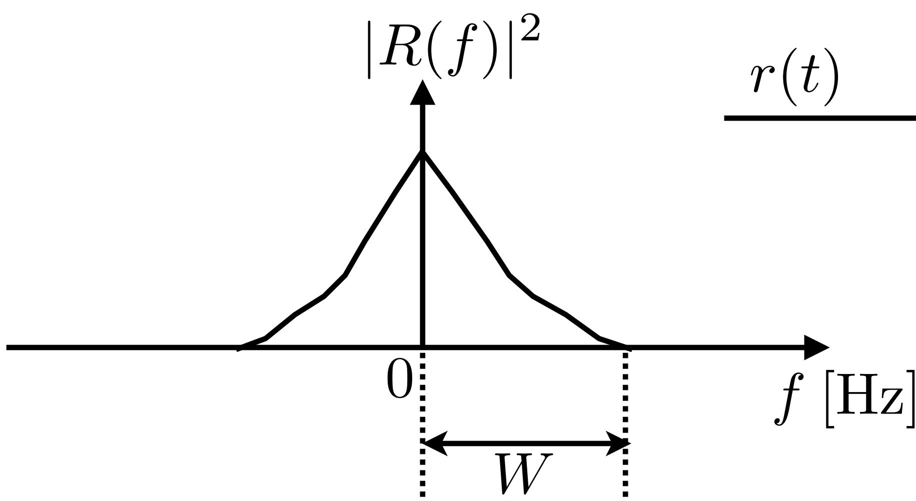
$$R_s = 2 \times 20 \times 10^6 \text{ [bits/sec]}$$

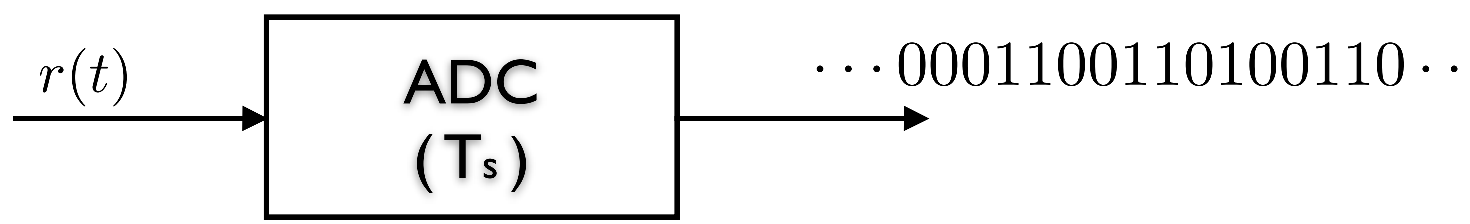


Nyquist Sampling Theorem

- Nyquist sampling theorem tells us two things for ISI free communications over band-limited channels:

    1) The sampling rate in ADC (analog-to-digital converter) should be as fast as twice the signal bandwidth.





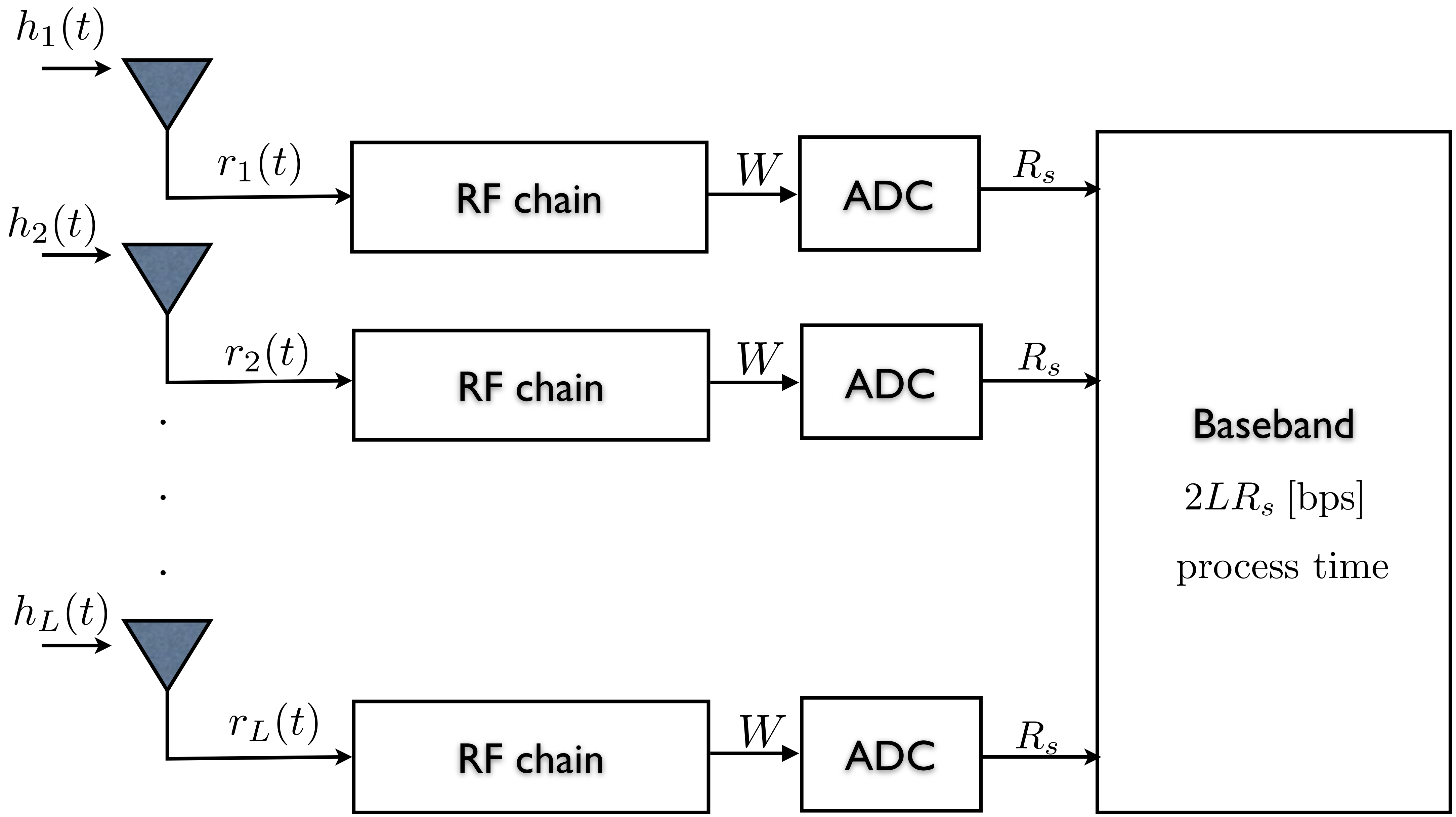
$$T_s \leq \frac{1}{2W} \text{ samples/sec}$$

$$r(t) = \sum_{n=-\infty}^{\infty} a_n x(t - nT) + n(t)$$

2) The pulse shape should satisfy the Nyquist condition.

$$x(nT) = \begin{cases} 1, & n = 0 \\ 0, & n \neq 0 \end{cases}$$

Diversity Combining with *L* ADC



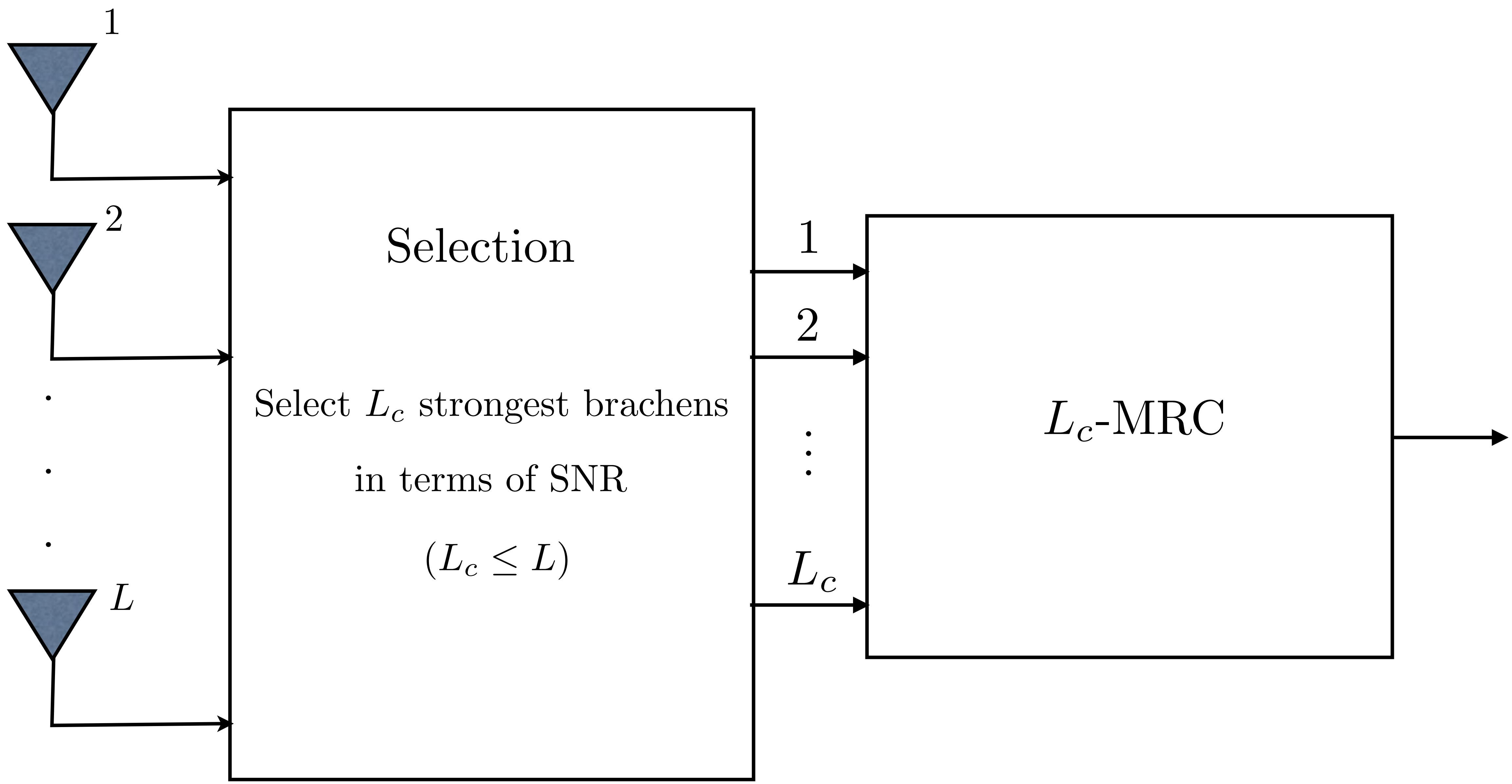
Complexity Comparisons

- MRC, EGC and SC requires L RF chains as well as L ADCs at the receiver.

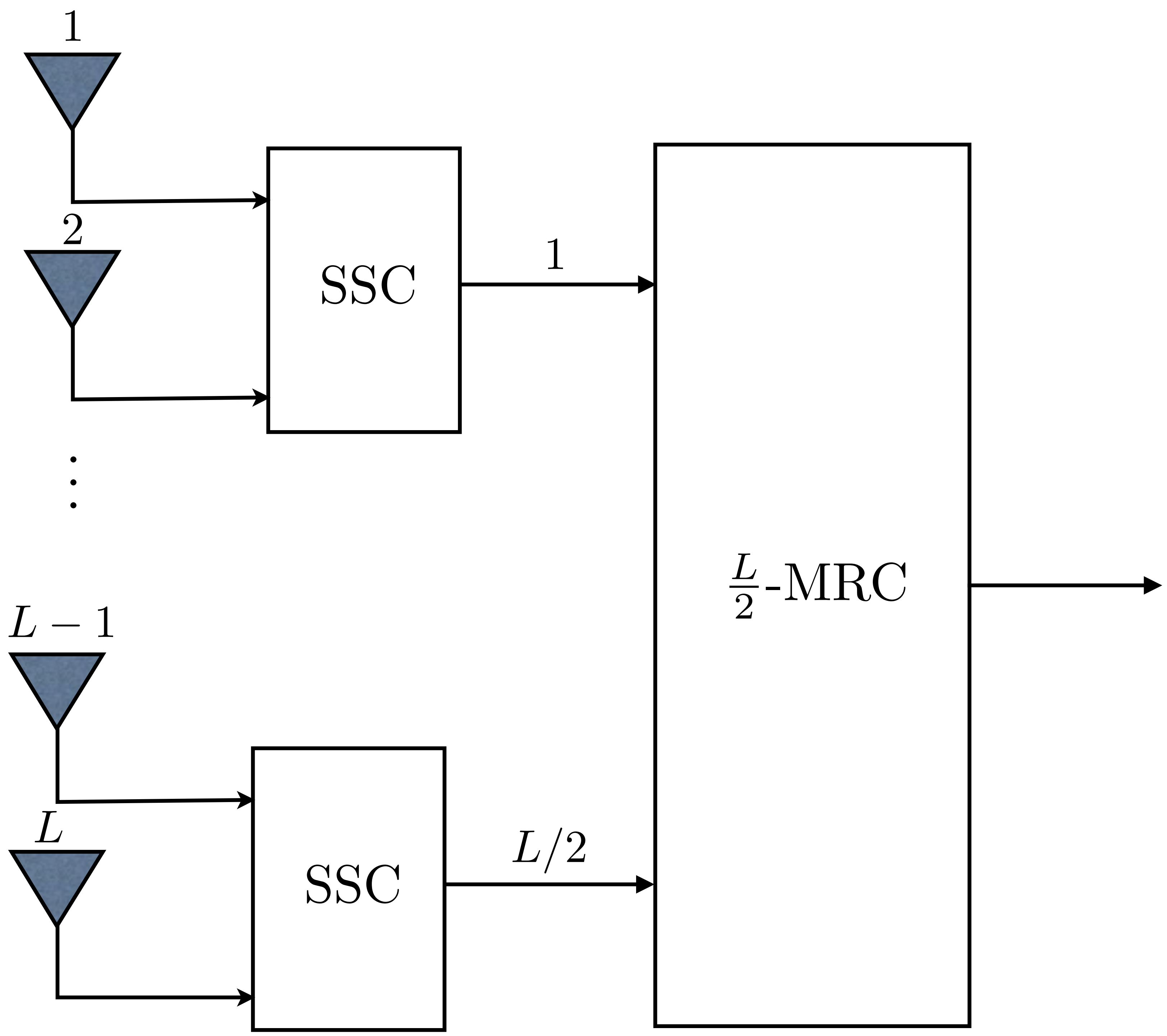
- Only switched diversity requires only one ADC.

Some Combinations of Diversity Schemes

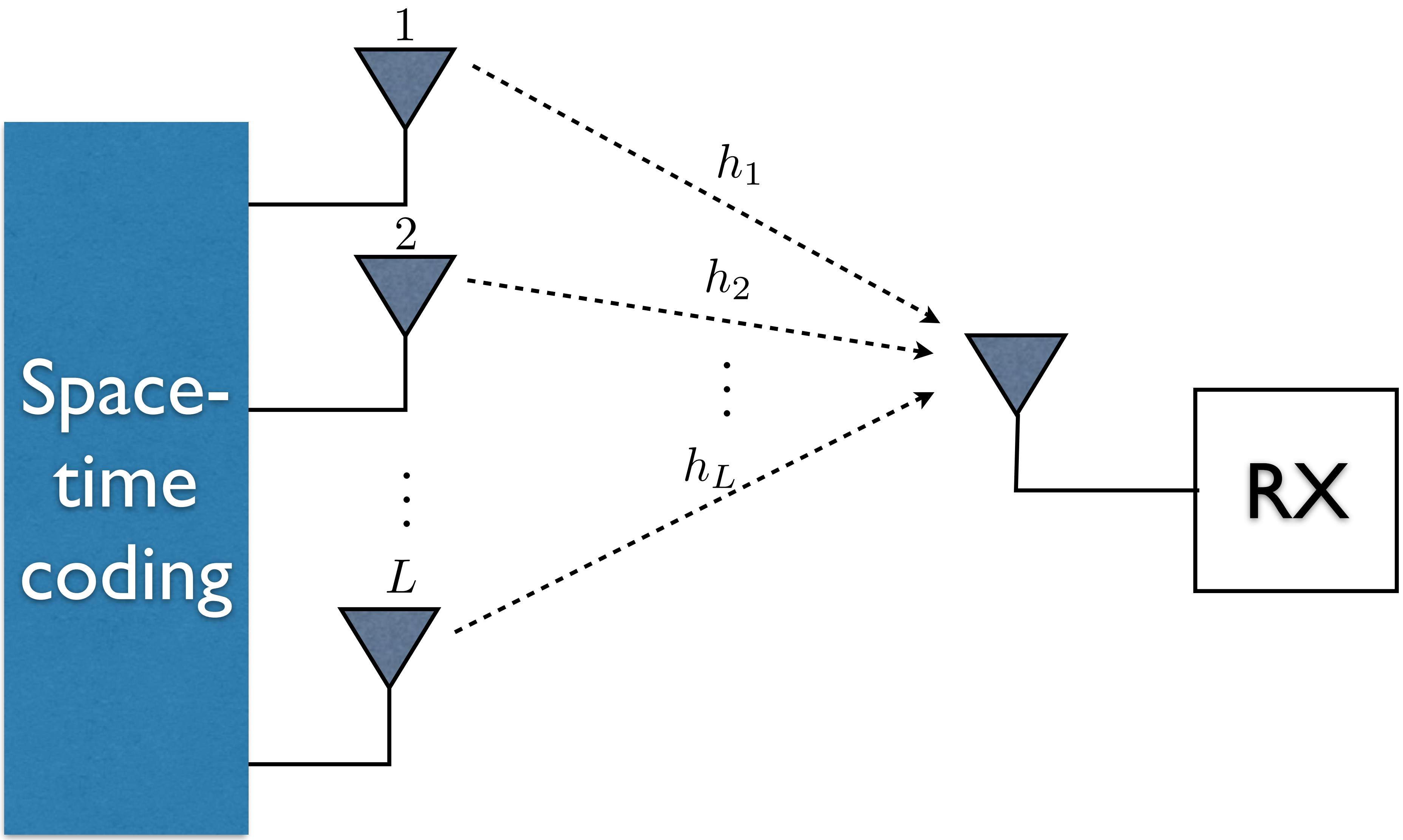
- Generalized Selection Combining (GSC)
  - Maximal ration combining L_c strongest branches out of L branches



- Generalized switched-and-stay combining (GSSC)

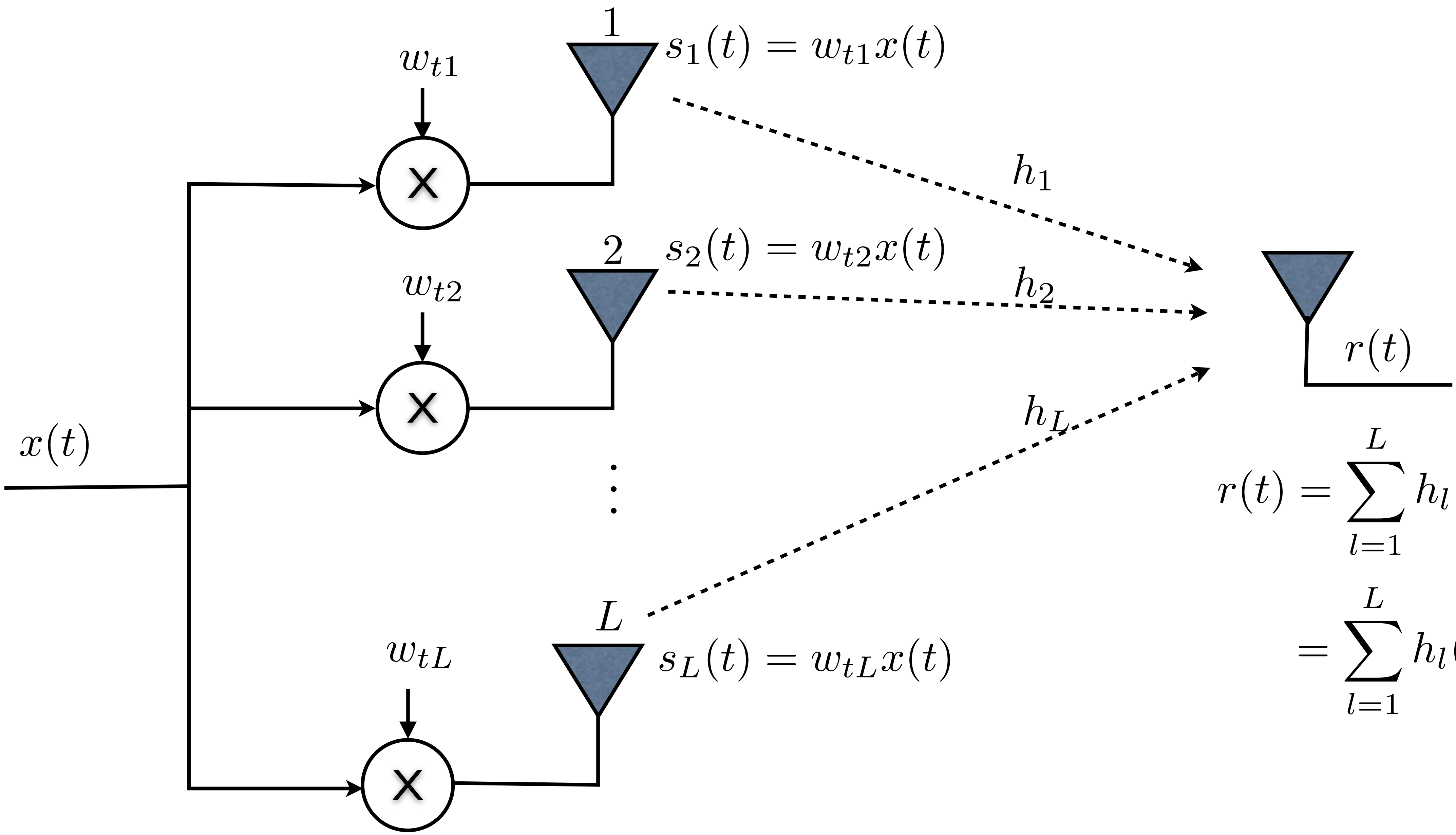


Transmit Diversity Systems



- Channel known at the transmitter
  $\Longrightarrow$ Closed-loop transmit diversity (CLTD)
- Channel unknown at the transmitter
  $\Longrightarrow$ Open-loop transmit diversity (OLTD)

Transmit Diversity with Known Channel State



$$r(t) = \sum_{l=1}^{L} h_l(t)s_l(t) + n(t)$$
$$= \sum_{l=1}^{L} h_l(t)w_{tl}x(t) + n(t)$$

- Optimum transmit weights: $w_{tl} = c_l h_{tl}^*$

- Power constraint condition

$$\sum_{l=1}^{L} E[|s_l(t)|^2] \le P_t$$

- c_l must be adjusted to satisfy the power constraint condition.

If $E[|x(t)|^2] = 1,$ $\qquad c_l = \sqrt{\frac{P_t}{L\sum_{l=1}^{L}|h_l|^2}}$

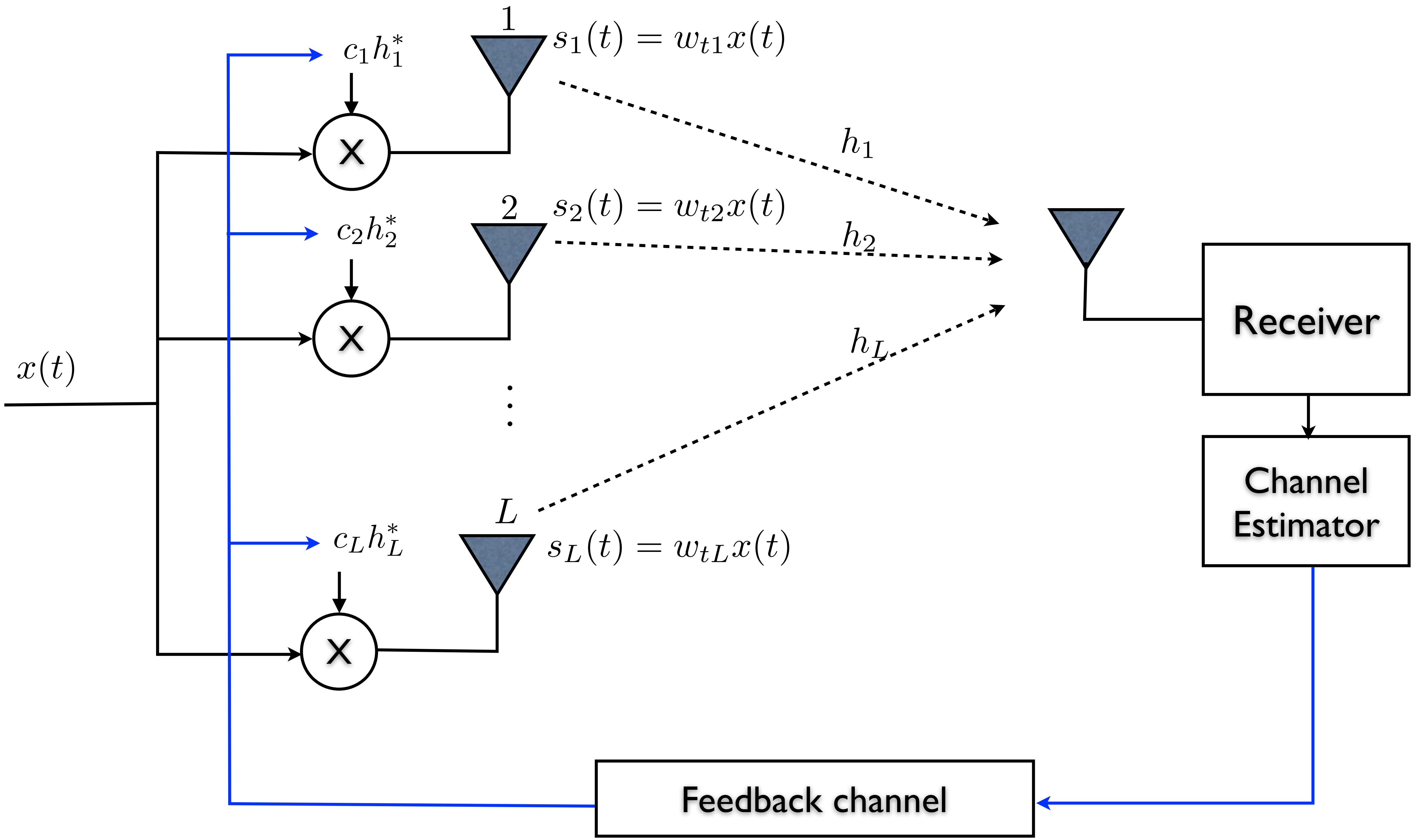
- Received signal

$$r(t) = x(t)\sum_{l=1}^{L} c_l |h_l|^2 + n(t)$$

- SNR of the received signal

$$\gamma = \frac{\left(\frac{P_t}{L\sum_{l=1}\alpha_l^2}\right)\left(\sum_{l=1}^{L}\alpha_l^2\right)^2}{N_0} = \frac{\sum_{l=1}^{L}\alpha_l^2}{LN_0} = \frac{1}{L}\sum_{l=1}^{L}\gamma_l$$

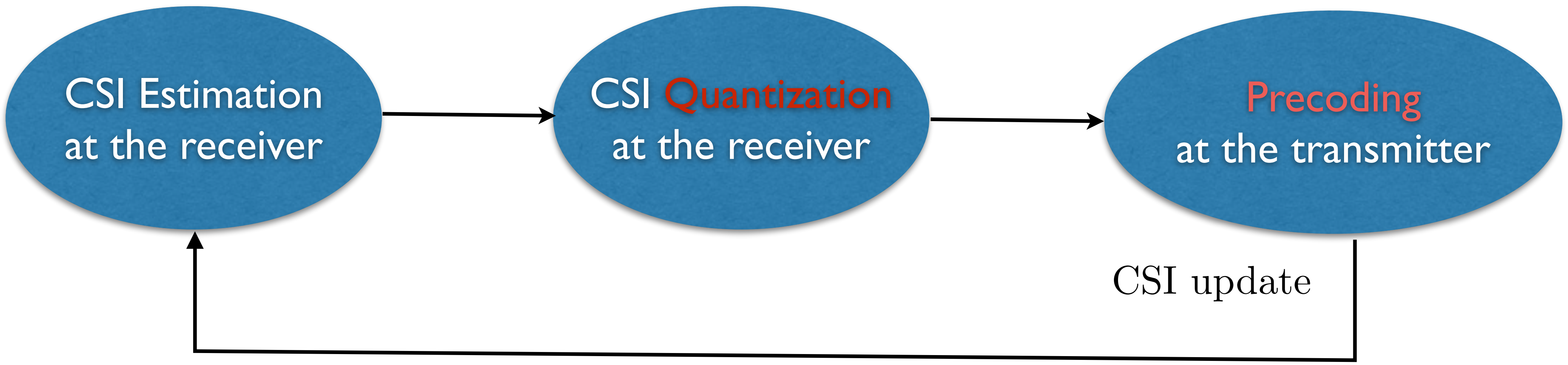
- Feedback channel for acquiring the downlink channel at the transmitter



  - Hence we call this as closed-loop diversity system.

- Channel state information (CSI)
  - We call h_l for $l = 1, ..., L$ as the channel state information (CSI).
  - There are two separate CSI: amplitude and phase of the channel h_l.
    - Channel direction information (CDI): $\angle(h_l)$
    - Channel quality information (CQI): $|h_l|$

- CSI feedback



- CSI quantization
  - n_1-bit and n_2-bit level quantization for CQI and CDI, respectively.
  - Total n-bit level quantization which means we have 2^n different channel state.

- CSI update
  - CSI should be updated every coherence time.

- Performance of closed-loop diversity systems
  - Received SNR is

$$\gamma_t = \frac{1}{L}\sum_{l=1}^{L}\gamma_l$$

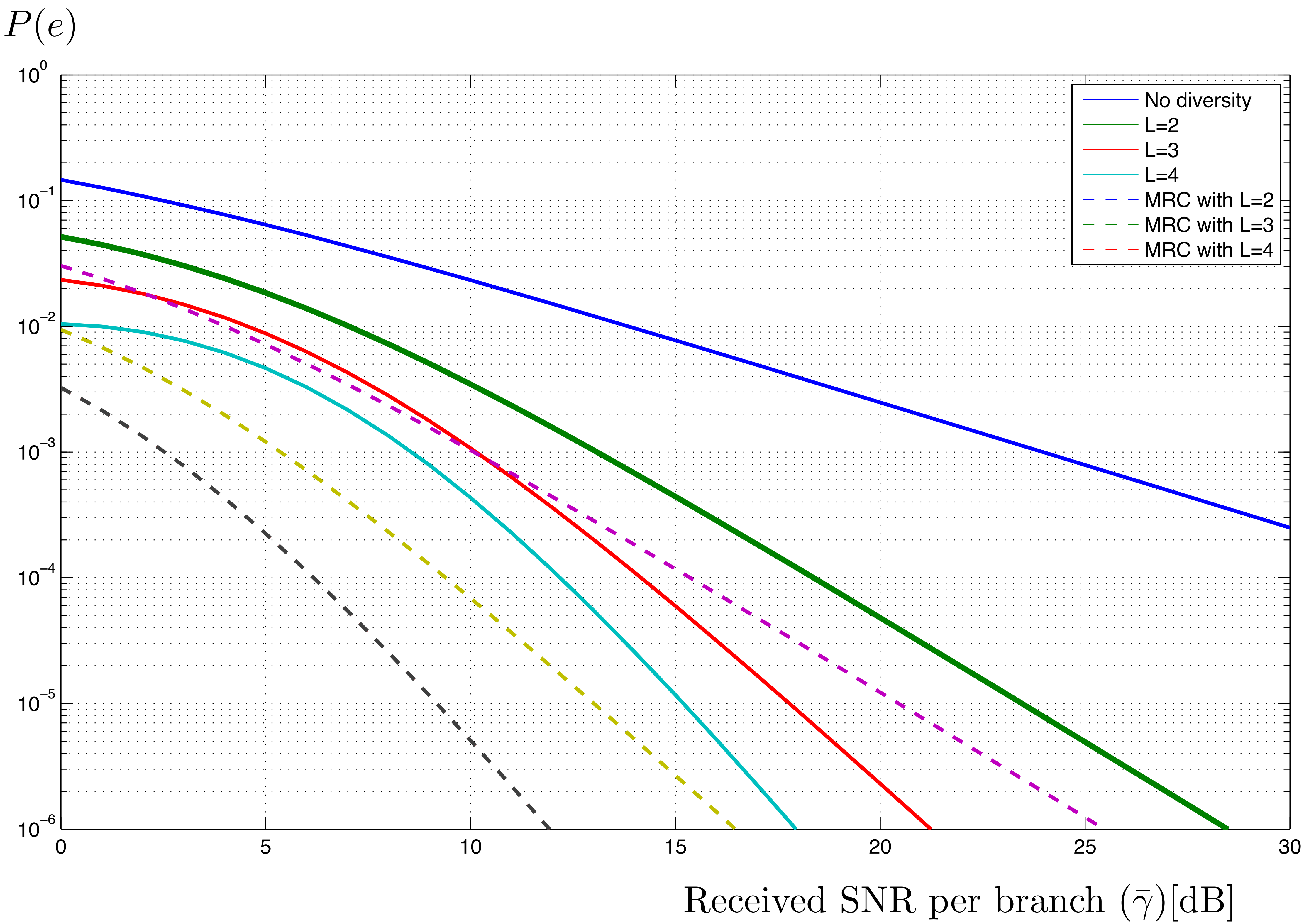
  - Hence, the BER/SER of closed-loop transmit diversity will be the same as the one of MRC by substituting $\bar{\gamma}/L$ into $\bar{\gamma}$.

  - For i.i.d. Rayleigh channel with BPSK, we have

$$P(e) = \left[\frac{1-\mu}{2}\right]^L \sum_{k=0}^{L-1}\binom{L-1+k}{k}\left[\frac{1+\mu}{2}\right]^k$$

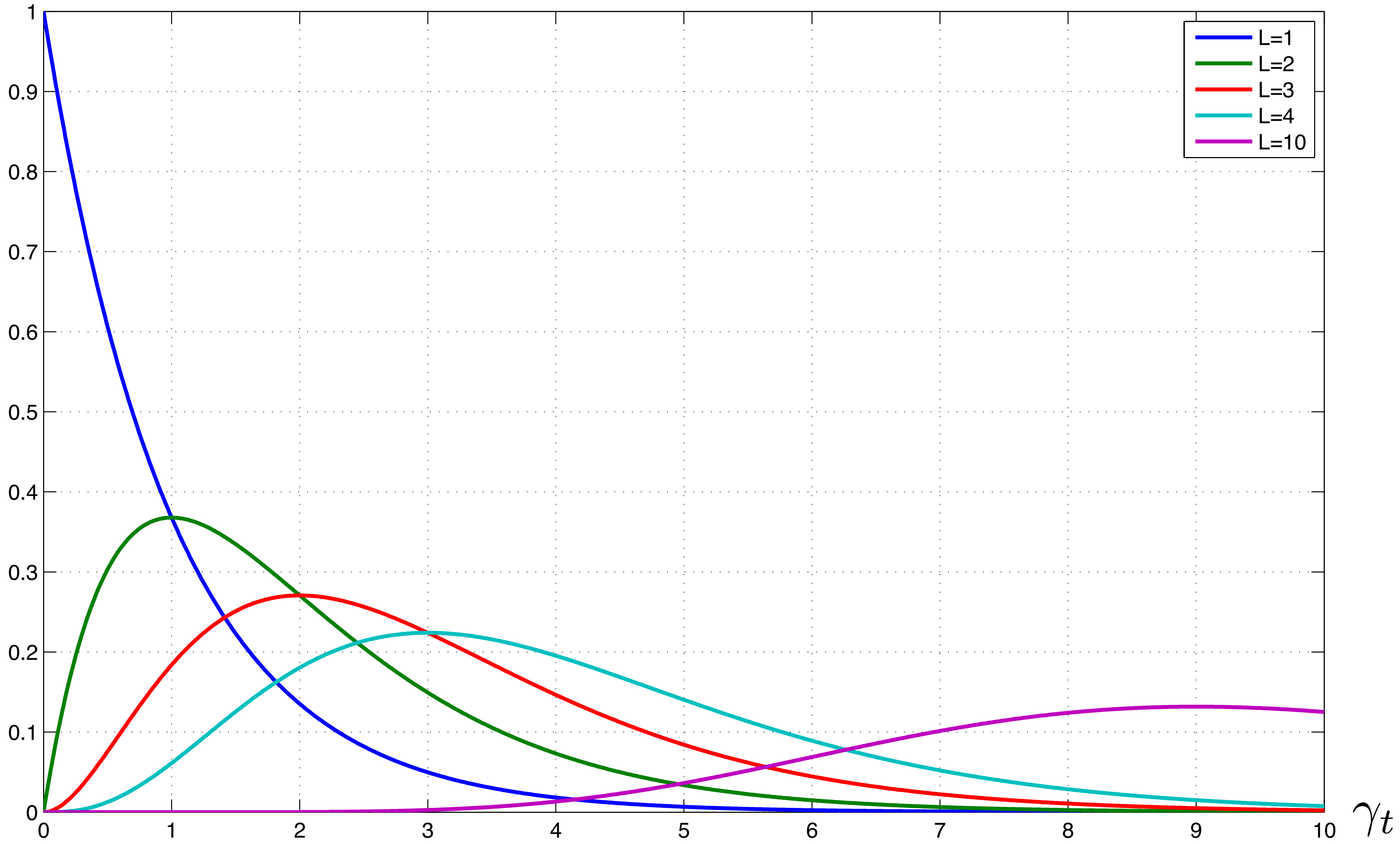
$$\text{where} \quad \mu = \sqrt{\frac{\bar{\gamma}/L}{1+\bar{\gamma}/L}} = \sqrt{\frac{\bar{\gamma}}{L+\bar{\gamma}}}$$

- BER of BPSK using MRC and closed-loop TD over Rayleigh channels



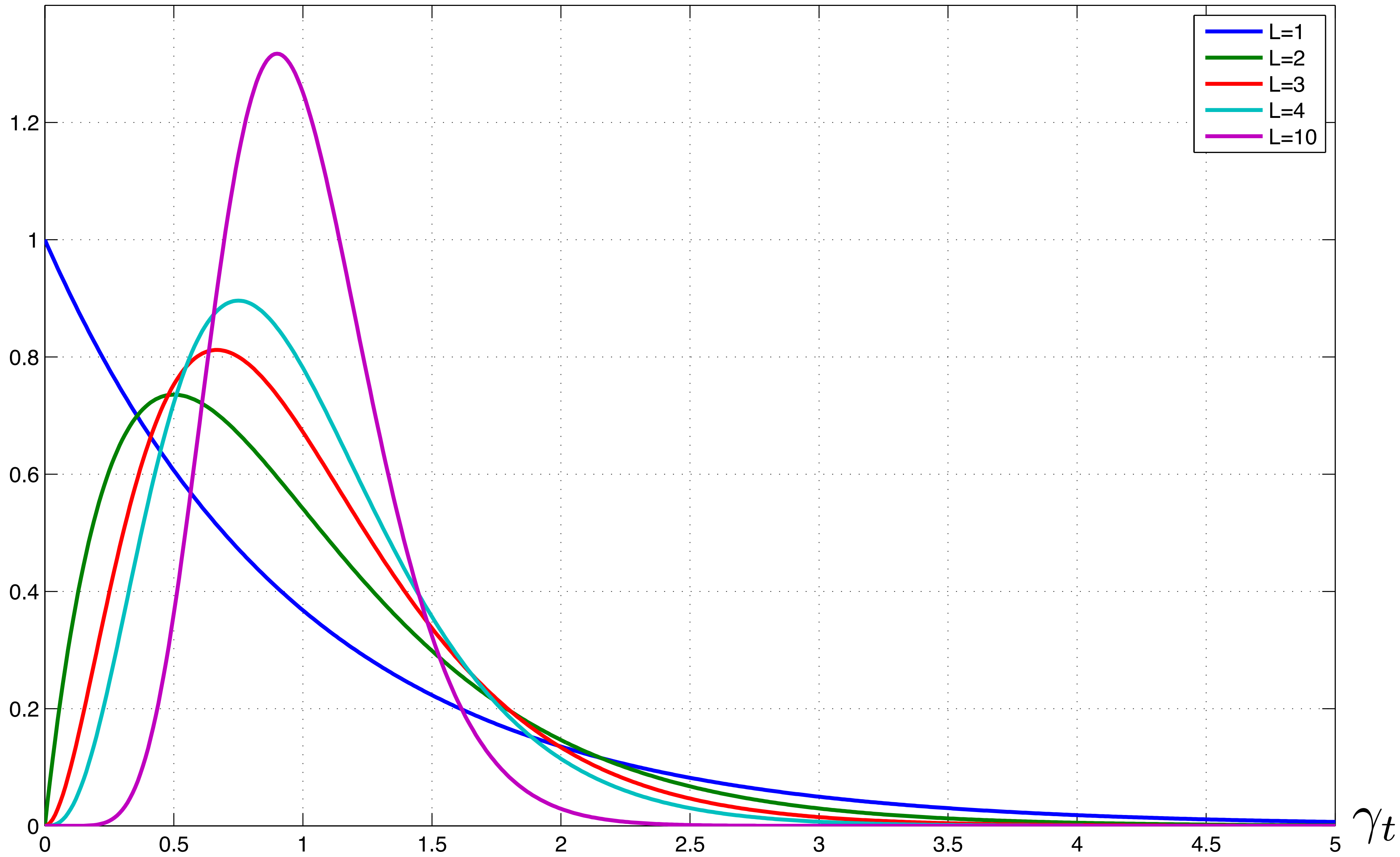
- PDF of the combined output SNR γ_t for L branches MRC

$$p_{\gamma_t}(\gamma_t) = \frac{1}{(L-1)!(\bar{\gamma})^L}\gamma_t^{L-1}e^{-\gamma_t/\bar{\gamma}}$$



- PDF of the combined output SNR γ_t for L branches CLTD

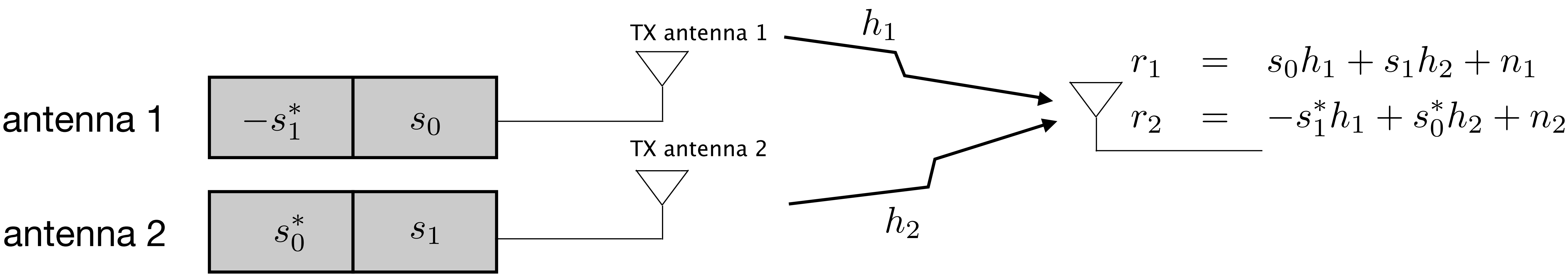
$$p_{\gamma_t}(\gamma_t) = \frac{1}{(L-1)!(\bar{\gamma}/L)^L}\gamma_t^{L-1}e^{-L\gamma_t/\bar{\gamma}}$$



Open-Loop Transmit Diversity

- There are many open loop transmit diversity schemes.
- Out of them, we only study the space-time block coding (STBC) with dual transmit antennas.
- Alamouti devised the STBC with two antennas in 1998 and it is often called as Alamouti coding.

- Alamouti coding (2×1)



[Space-time block code (STBC)]

	antenna1	antenna2
time t	s_0	s_1
time t+T	$-s_1^*$	s_0^*

- QPSK example

$$
\begin{aligned}
00 \to s^1 &= 1+j \\
01 \to s^2 &= 1-j \\
11 \to s^3 &= -1+j \\
10 \to s^4 &= -1-j
\end{aligned}
$$

[Space-time block code (STBC)

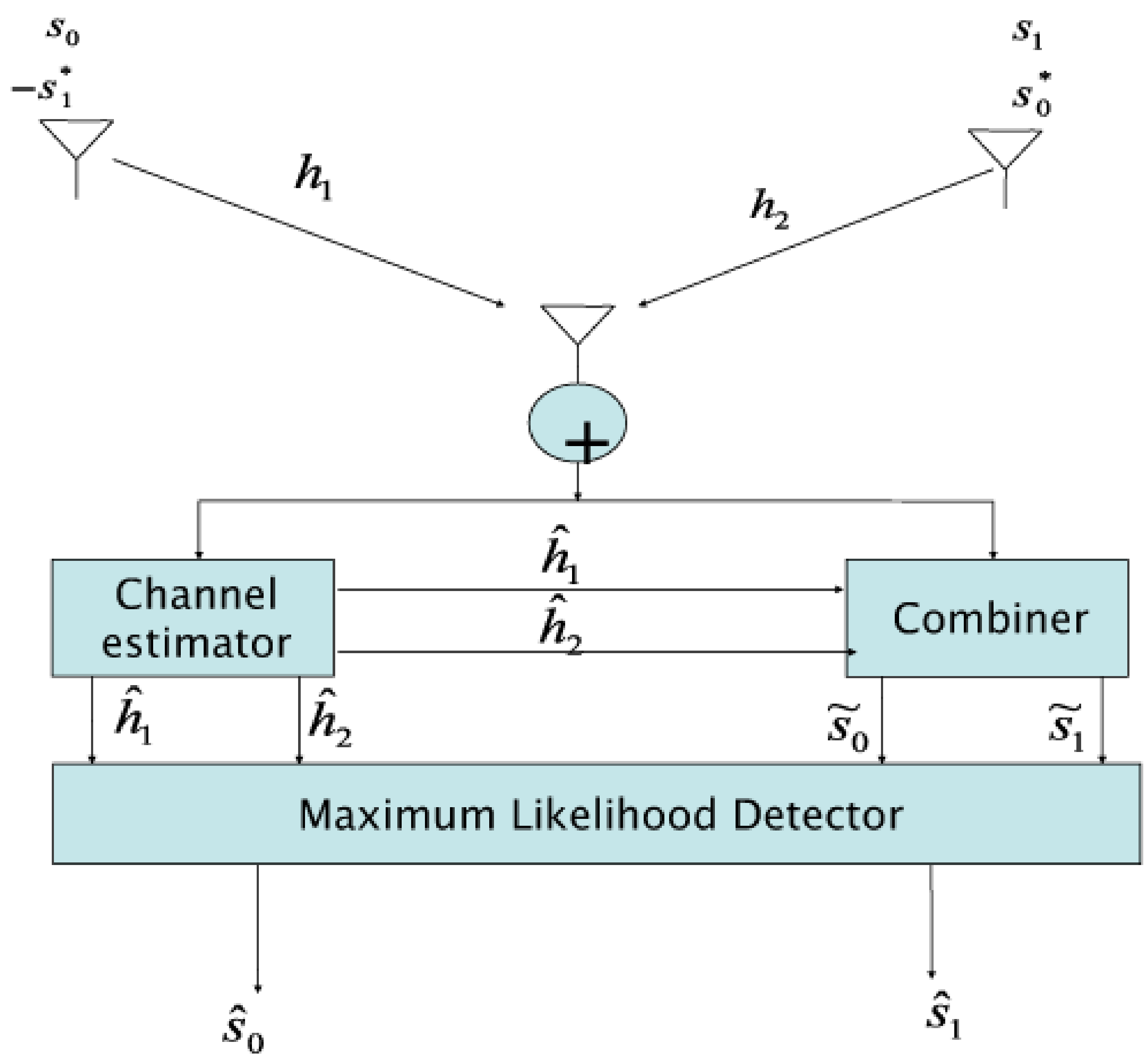
	antenna1	antenna2
time t	s_0	s_1
time t+T	$-s_1^*$	s_0^*

data: $01001011\cdots \quad \Longrightarrow \quad s_0 s_1 s_2 s_4 \cdots = s^2 s^1 s^4 s^3 \cdots$

time	ant1	ant2
T	$1-j$	$1+j$
$2T$	$-1+j$	$1+j$
$3T$	$-1-j$	$-1+j$
$4T$	$1+j$	$-1+j$
	$\vdots$	

$$
\begin{aligned}
r_1 &= s_0 h_1 + s_1 h_2 + n_1 \\
r_2 &= -s_1^* h_1 + s_0^* h_2 + n_2 \\
r_3 &= s_2 h_1 + s_3 h_2 + n_1 \\
r_4 &= = -s_3^* h_1 + s_2^* h_2 + n_2
\end{aligned}
$$

- Detection of space-time block coding signal



$$
\begin{aligned}
r_1 &= s_0 h_1 + s_1 h_2 + n_1 \\
r_2 &= -s_1^* h_1 + s_0^* h_2 + n_2
\end{aligned}
$$

$$
\begin{aligned}
v_1 &= h_1^* r_1 + h_2 r_2^* \\
v_2 &= h_2^* r_1 - h_1 r_2^*
\end{aligned}
$$

$$
\begin{aligned}
v_1 &= (|h_1|^2 + |h_2|^2) s_0 + h_1^* n_1 + h_2 n_2^* \\
v_2 &= (|h_1|^2 + |h_2|^2) s_1 + h_2^* n_1 - h_2 n_2^*
\end{aligned}
$$