DNN과 m-sequence를 활용한 시간 지연 추정 방법

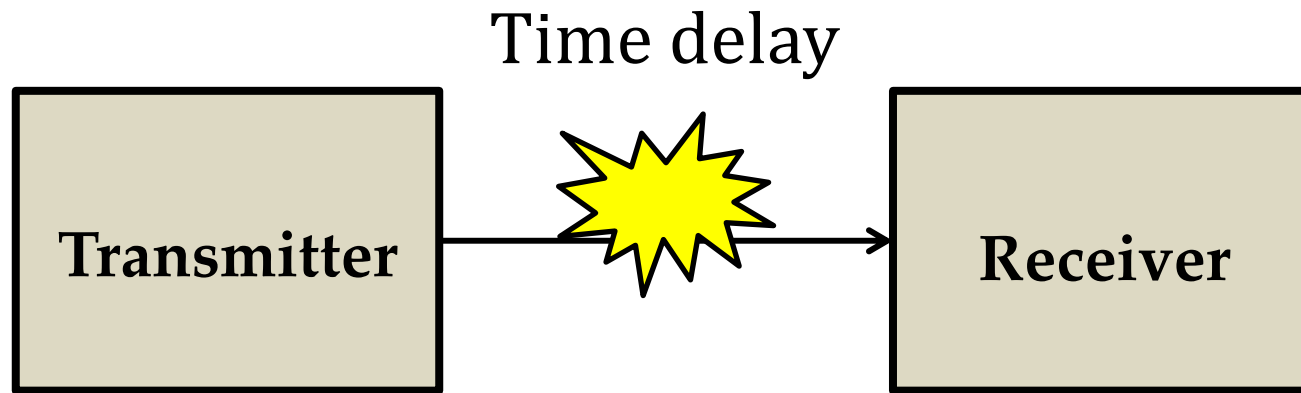CSDL

이민형, 김강산, 송홍엽

연세대학교 통신신호설계연구실

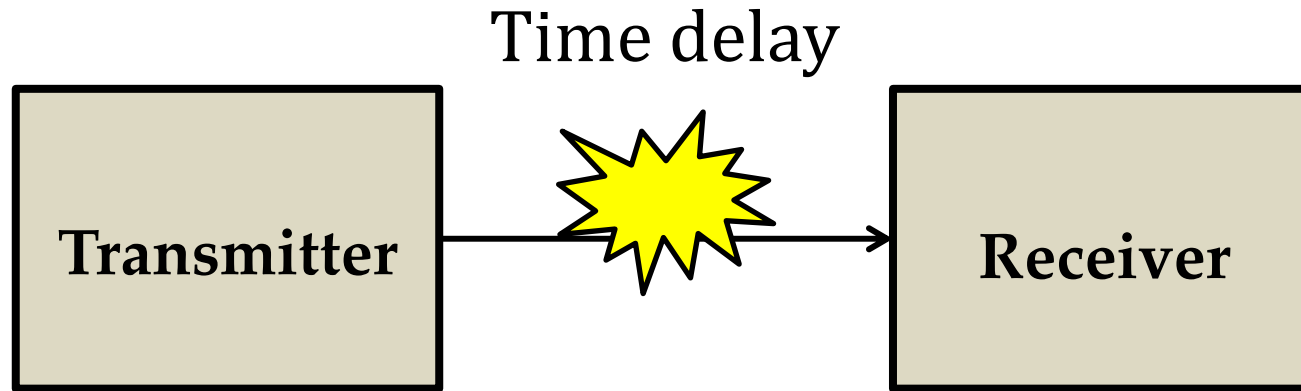**2019 한국통신학회 동계종합학술발표회**
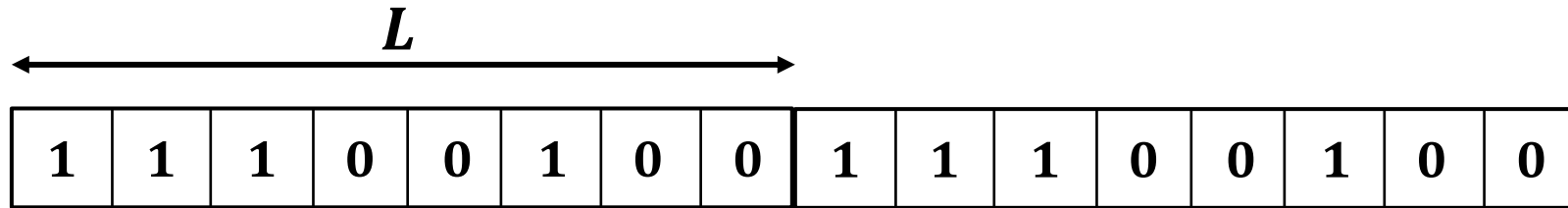
시간 지연 추정

Time delay

Transmitter → **Receiver**

이민형

시간 지연 추정

Time delay

Transmitter		**Receiver**

Synchronization

Transmitted sequence period L

L

1	1	1	0	0	1	0	0	1	1	1	0	0	1	0	0

이민형

시간 지연 추정

Transmitted sequence period L
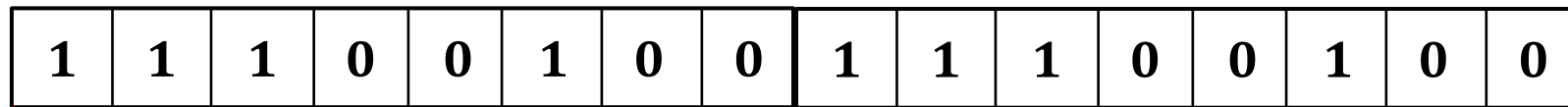
1	1	1	0	0	1	0	0	1	1	1	0	0	1	0	0

Received sequence shifted as τ

τ
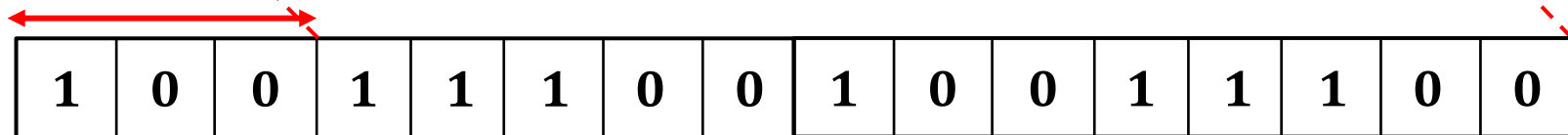
1	0	0	1	1	1	0	0	1	0	0	1	1	1	0	0

이민형

이민형

시간 지연 추정

Received sequence

1	0	0	1	1	1	0	0	1	0	0	1	1	1	0	0

1	−1	−1	−1	−1	1	1	1	= 0

1	1	1	0	0	1	0	0

Calculate correlation

Reference sequence

τ	0	1	2	3	4	5	6	7
Cor.	0							

이민형

Received sequence

1	0	0	1	1	1	0	0	1	0	0	1	1	1	0	0

-1 -1 1 -1 -1 -1 -1 -1 $= -6$

1	1	1	0	0	1	0	0

τ	0	1	2	3	4	5	6	7
Cor.	0	-6						

이민형

시간 지연 추정

Received sequence

1	0	0	1	1	1	0	0	1	0	0	1	1	1	0	0

$$-1 \quad 1 \quad 1 \quad -1 \quad 1 \quad -1 \quad -1 \quad 1 \quad = 0$$

1	1	1	0	0	1	0	0

τ	0	1	2	3	4	5	6	7
Cor.	0	-6	0					

이민형

시간 지연 추정

Received sequence

1	0	0	1	1	1	0	0	1	0	0	1	1	1	0	0

1 1 1 1 1 1 1 1 = **8**

1	1	1	0	0	1	0	0

τ	0	1	2	3	4	5	6	7
Cor.	0	-6	0	8				

시간 지연 추정

Received sequence

1	0	0	1	1	1	0	0	1	0	0	1	1	1	0	0

$$1 \quad -1 \quad -1 \quad -1 \quad -1 \quad 1 \quad 1 \quad 1 \quad = 0$$

1	1	1	0	0	1	0	0

τ	0	1	2	3	4	5	6	7
Cor.	0	-6	0	8	0	-4	0	0

이민형

시간 지연 추정

Estimated

$\tau = 3$

τ	0	1	2	3	4	5	6	7
Cor.	0	-6	0	8	0	-4	0	0

이민형

시간 지연 추정

Estimated

$$\tau = 3$$

τ	0	1	2	3	4	5	6	7
Cor.	0	-6	0	8	0	-4	0	0

But if the sequence is very long ?

시간 지연 추정

periodic sequence of period L

L

periodic sequence shifted as τ

τ

k

Estimator

Estimated Code Phase

$\hat{\tau}$

part of shifted sequence of length k

이민형

시간 지연 추정

k
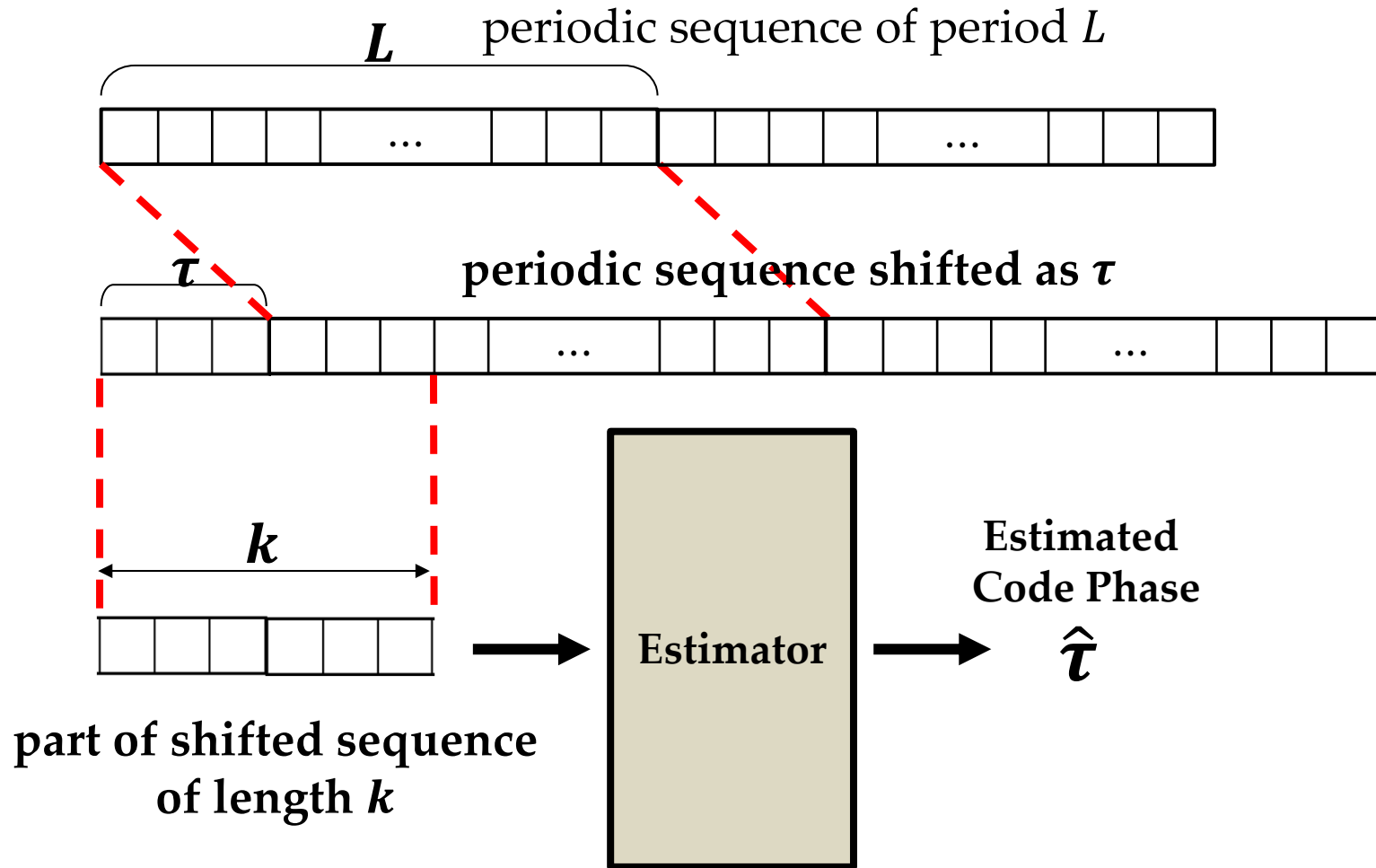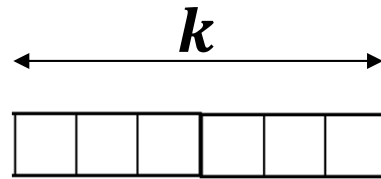
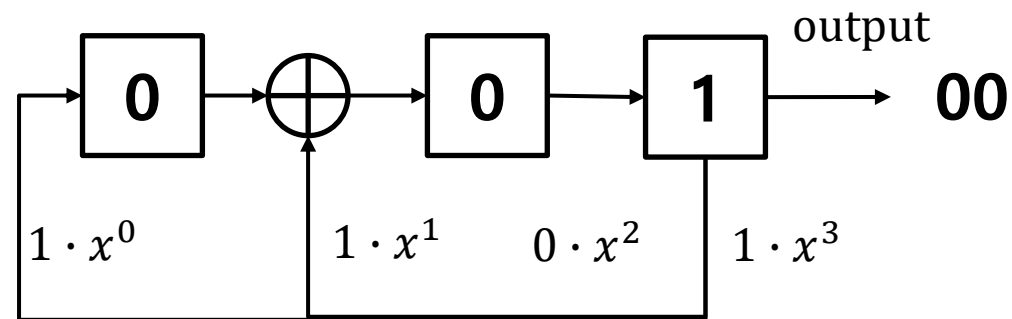part of shifted sequence
of length k

Don't repeated in
one period

L
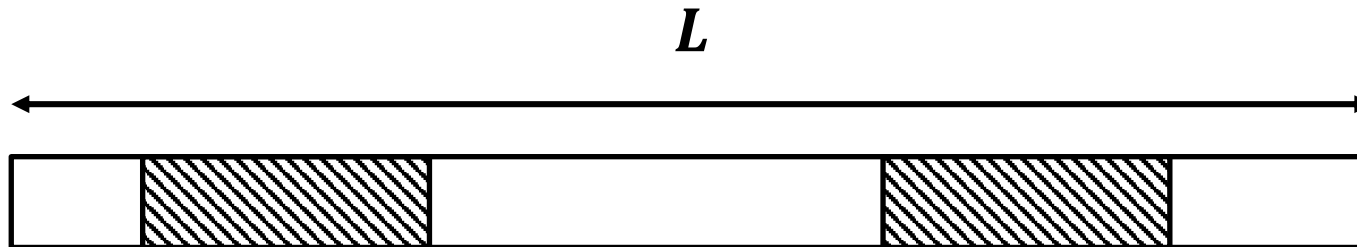
Which one?

m-sequence

m-sequence

m-sequence of length $2^n - 1$ be generated by LFSR, from primitive polynomial of degree n.

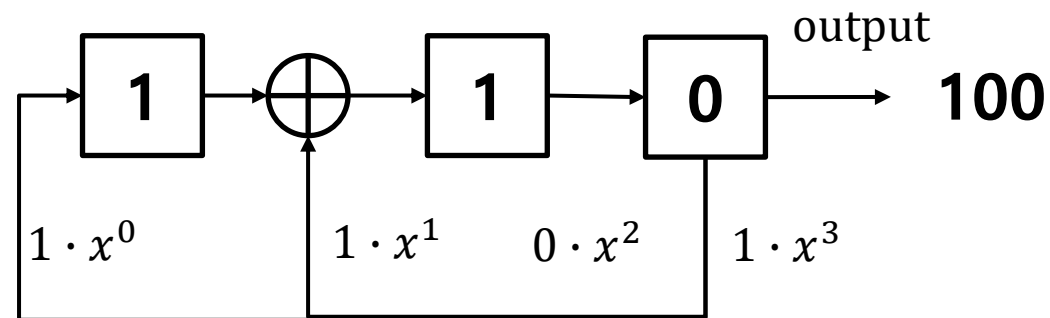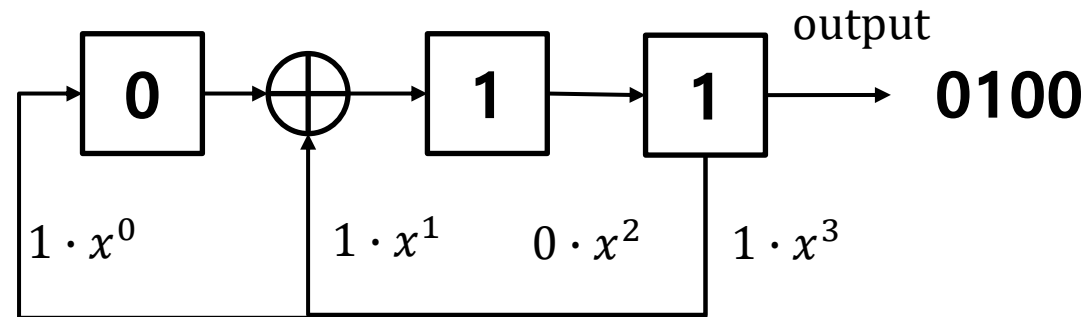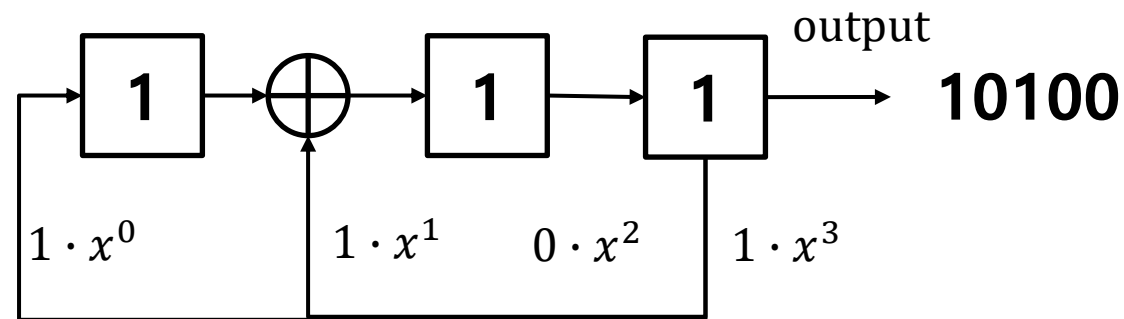$$L \quad \text{periodic} \quad \text{sequence of period } L$$

m-sequence

m-sequence

m-sequence of length $2^n - 1$ be generated by LFSR, from primitive polynomial of degree n.

$$f(x) = x^3 + x + 1$$

m-sequence

m-sequence

m-sequence of length $2^n - 1$ be generated by LFSR, from primitive polynomial of degree n.

$f(x) = x^3 + x + 1$

output

| 0 | ⊕ | 1 | 0 | → 0 |

$1 \cdot x^0 \qquad 1 \cdot x^1 \qquad 0 \cdot x^2 \qquad 1 \cdot x^3$
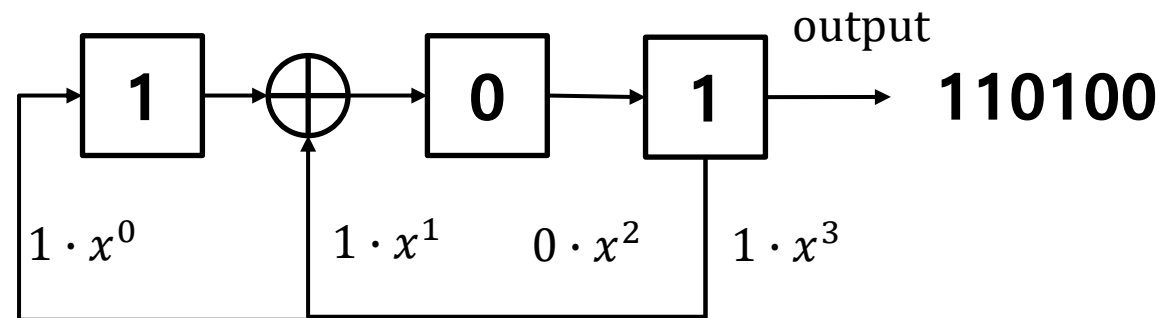
이민형

m-sequence

m-sequence

m-sequence of length $2^n - 1$ be generated by LFSR, from primitive polynomial of degree n.

$f(x) = x^3 + x + 1$

m-sequence

m-sequence

m-sequence of length $2^n - 1$ be generated by LFSR, from primitive polynomial of degree n.

$$f(x) = x^3 + x + 1$$

output

100

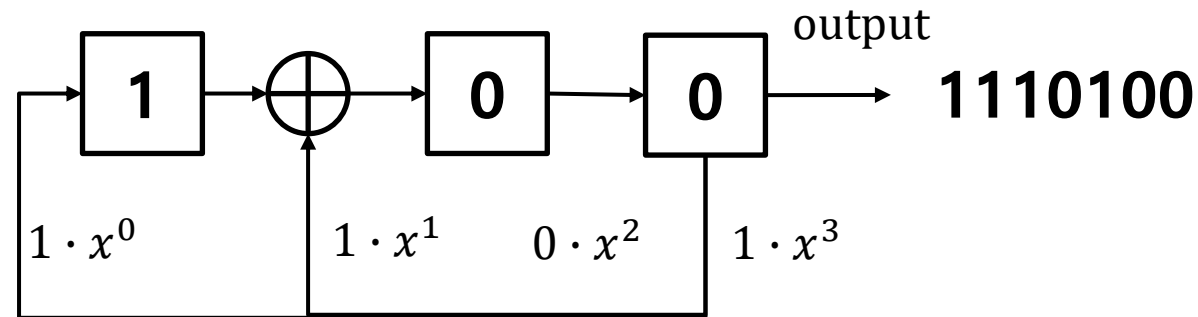$1 \cdot x^0$ $1 \cdot x^1$ $0 \cdot x^2$ $1 \cdot x^3$

이민형

m-sequence

m-sequence

m-sequence of length $2^n - 1$ be generated by LFSR, from primitive polynomial of degree n.

$$f(x) = x^3 + x + 1$$

output

0100

$1 \cdot x^0 \qquad 1 \cdot x^1 \qquad 0 \cdot x^2 \qquad 1 \cdot x^3$

이민형

m-sequence

m-sequence

m-sequence of length $2^n - 1$ be generated by LFSR, from primitive polynomial of degree n.
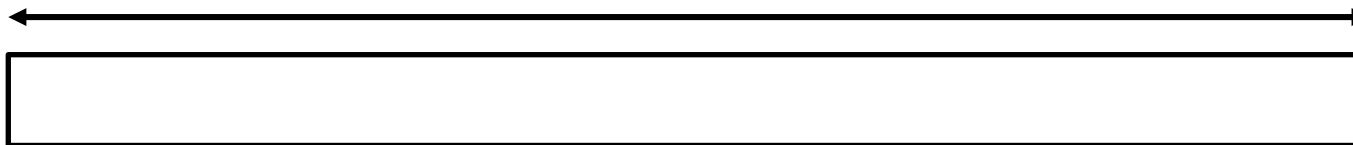
$$f(x) = x^3 + x + 1$$

output
10100

$1 \cdot x^0$ $1 \cdot x^1$ $0 \cdot x^2$ $1 \cdot x^3$

이민형

m-sequence

m-sequence

m-sequence of length $2^n - 1$ be generated by LFSR, from primitive polynomial of degree n.

$f(x) = x^3 + x + 1$

output

$1 \cdot x^0$ $1 \cdot x^1$ $0 \cdot x^2$ $1 \cdot x^3$

110100

이민형

m-sequence

m-sequence

m-sequence of length $2^n - 1$ be generated by LFSR, from primitive polynomial of degree n.

$$f(x) = x^3 + x + 1$$

$$1 \cdot x^0 \qquad 1 \cdot x^1 \qquad 0 \cdot x^2 \qquad 1 \cdot x^3$$

이민형

m-sequence

Span property

For any m-sequence of period $2^n - 1$, as consisting of 0 and 1, all the binary n-tuples except the all-zero appear exactly once in each period.

$$2^n - 1$$

m-sequence

Span property

For any m-sequence of period $2^n - 1$, as consisting of 0 and 1, all the binary n-tuples except the all-zero appear exactly once in each period.

$$2^n - 1$$

$$n$$
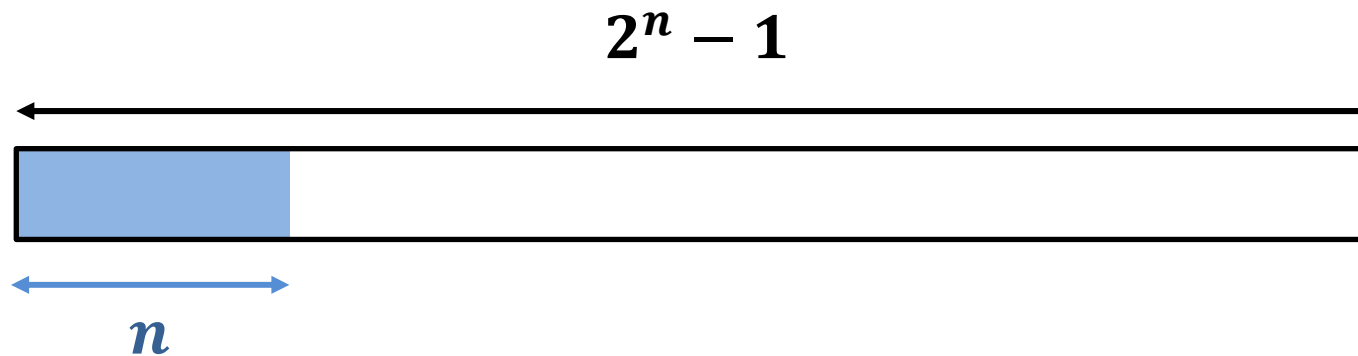
m-sequence

1110100

m-sequence

1110100

001	
010	
011	
100	
101	
110	
111	1

이민형

m-sequence

1110100

001	
010	
011	
100	
101	
110	1
111	1

m-sequence

1110100

001	
010	
011	
100	
101	1
110	1
111	1

이민형

m-sequence

1110100

001	1
010	1
011	1
100	1
101	1
110	1
111	1

이민형

m-sequence

By Span property

Part of m-sequence length $k, (k \geq n)$ is not repeated in one period

$$2^n - 1$$

k

시간 지연 추정

$2^n - 1$ periodic m-sequence of period $2^n - 1$

periodic s m-sequence shifted as τ

τ

k

Estimator

Estimated Code Phase

$\hat{\tau}$

part of shifted sequence of length k

$$k \geq n$$
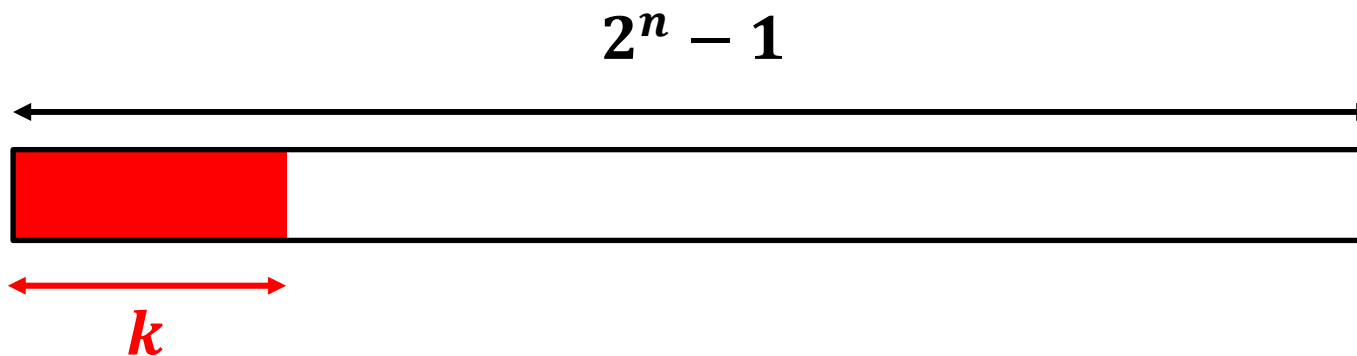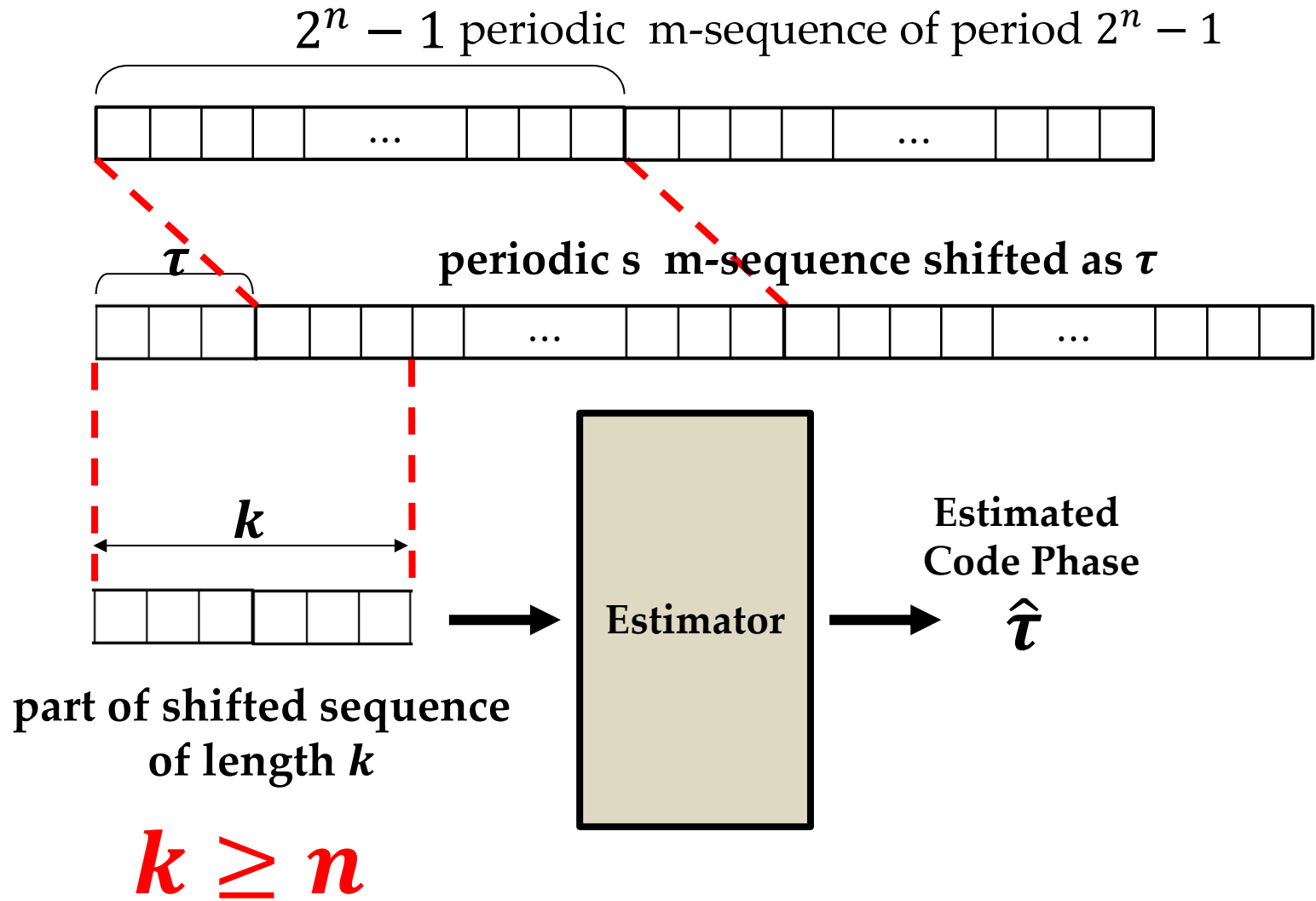
DNN
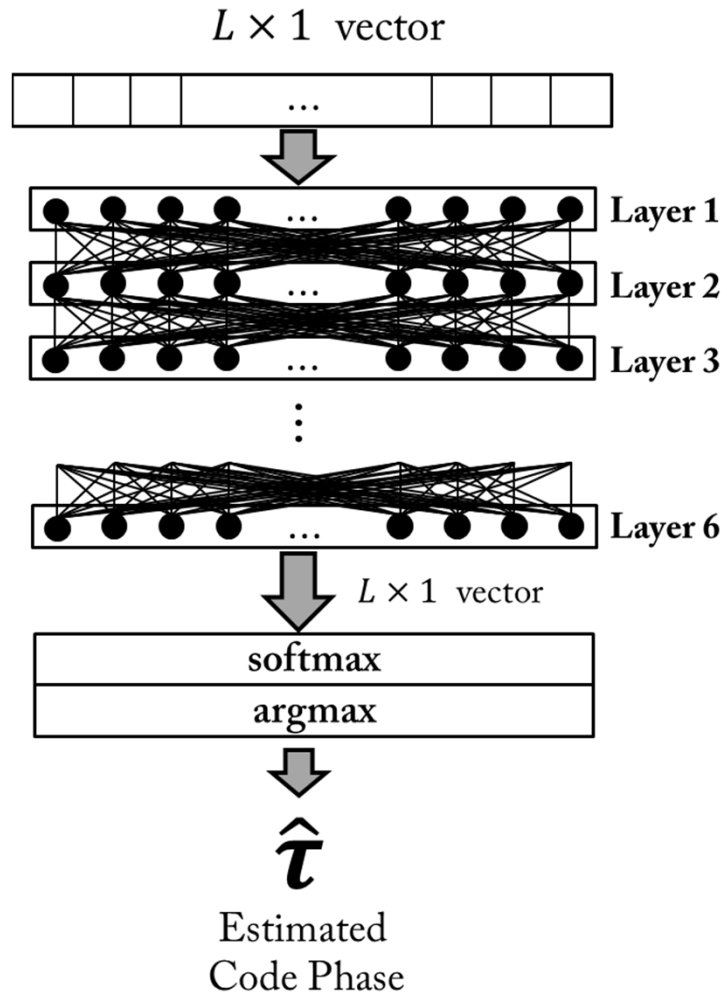
Deep Neural Network

DNN
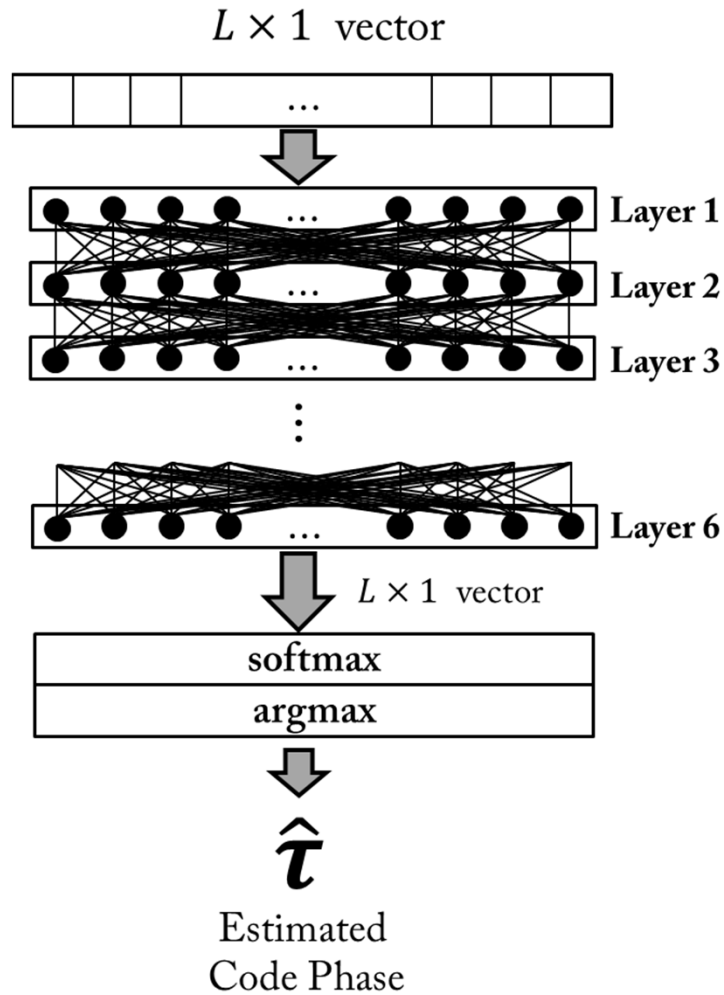
Fully Connected layer

Activate function : ReLU

Neurons in each layer : $10L$
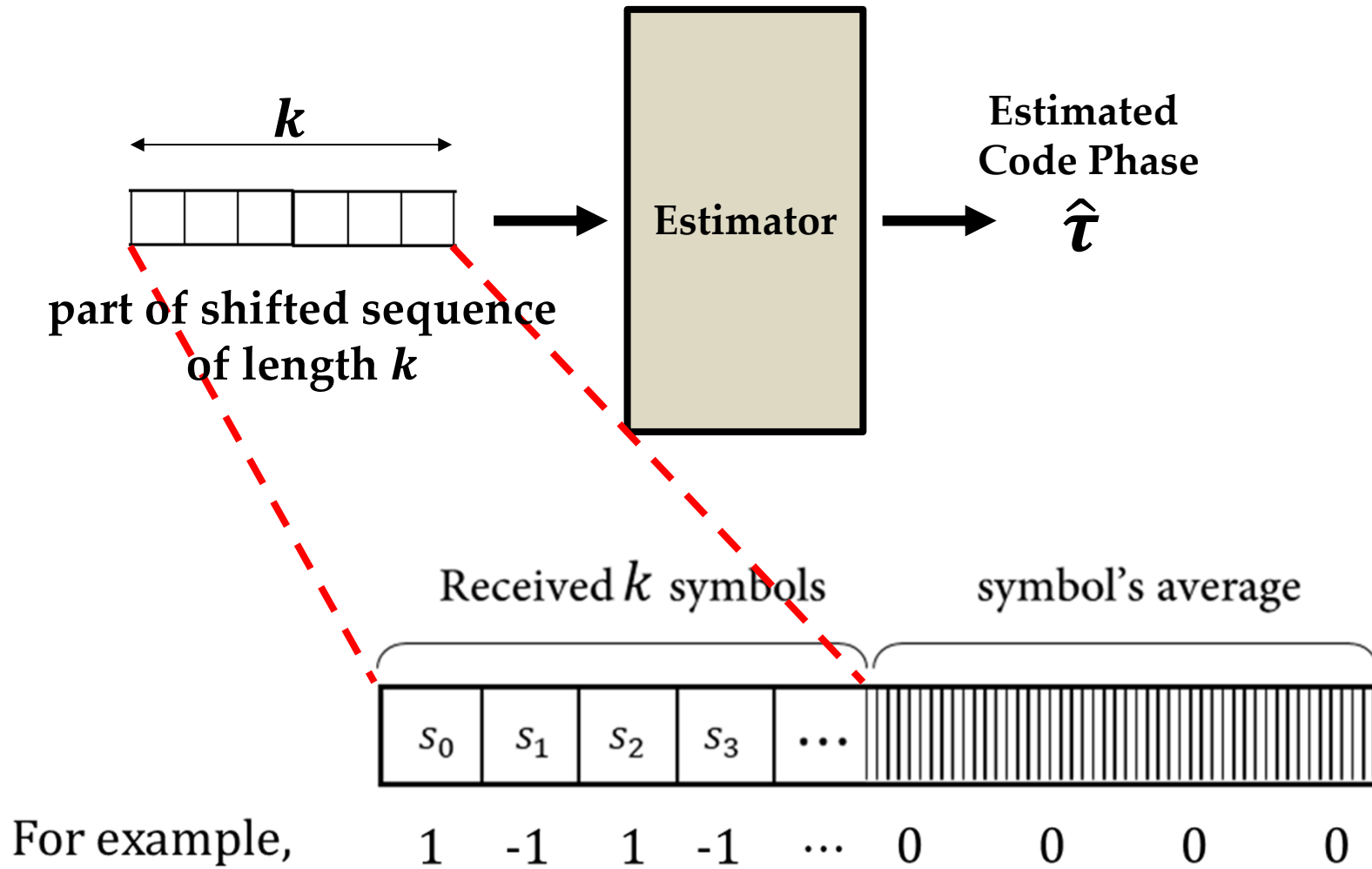
Tensorflow 1.12.0

이민형

Training set

$$10^6 \text{ times}$$

$$10^3 \text{ times}$$

이민형

Test set

$L \times 1$ vector

Layer 1

Layer 2

Layer 3

Layer 6

$L \times 1$ vector

softmax

argmax

$\hat{\tau}$

Estimated
Code Phase

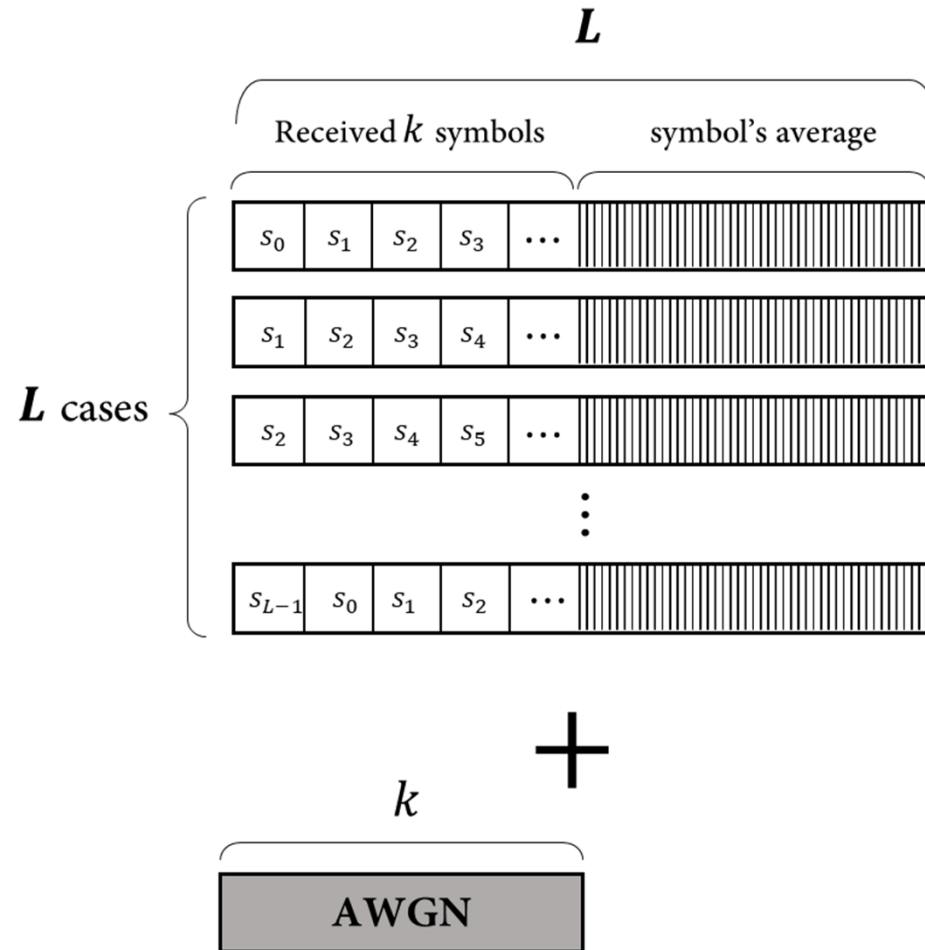Received k symbols

symbol's average

s_0 | s_1 | s_2 | s_3 | $\cdots$
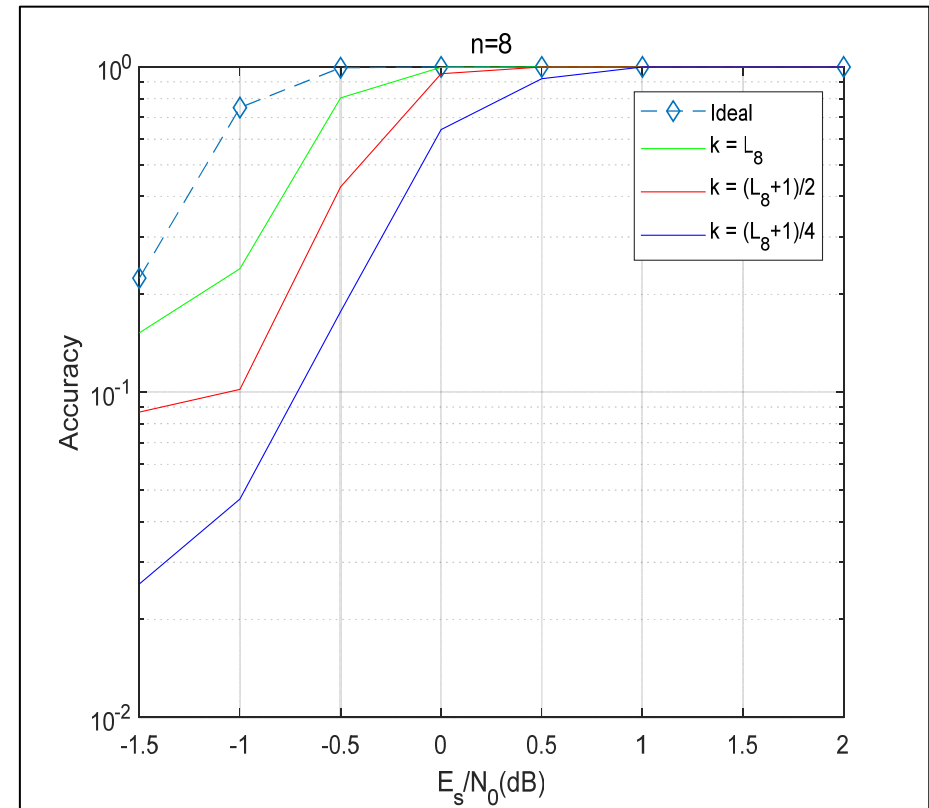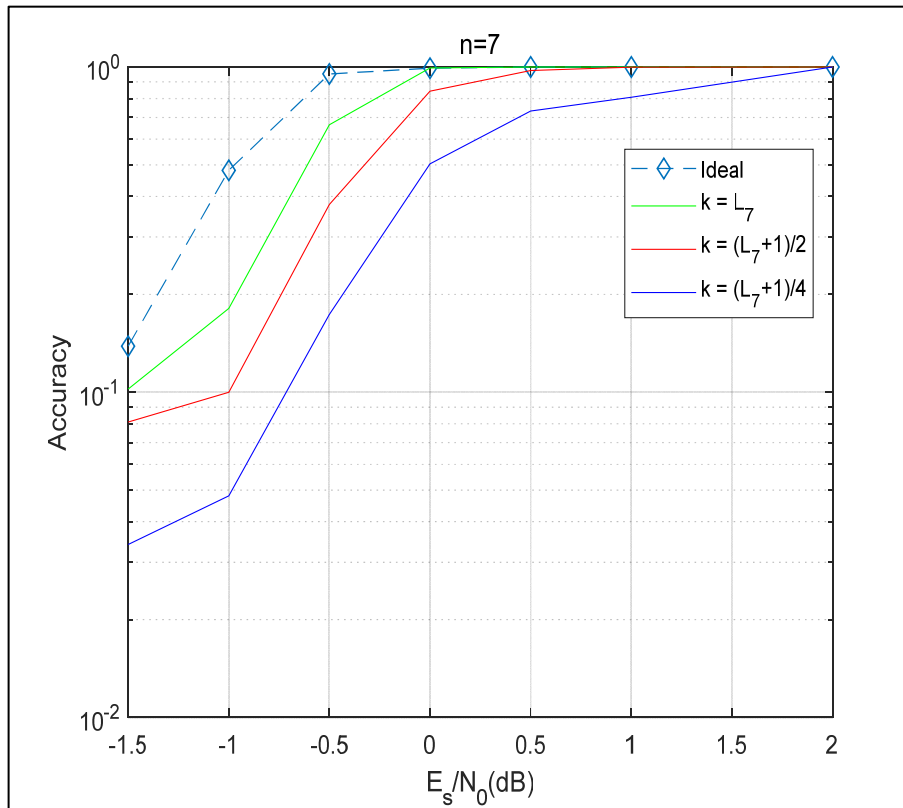
송민규
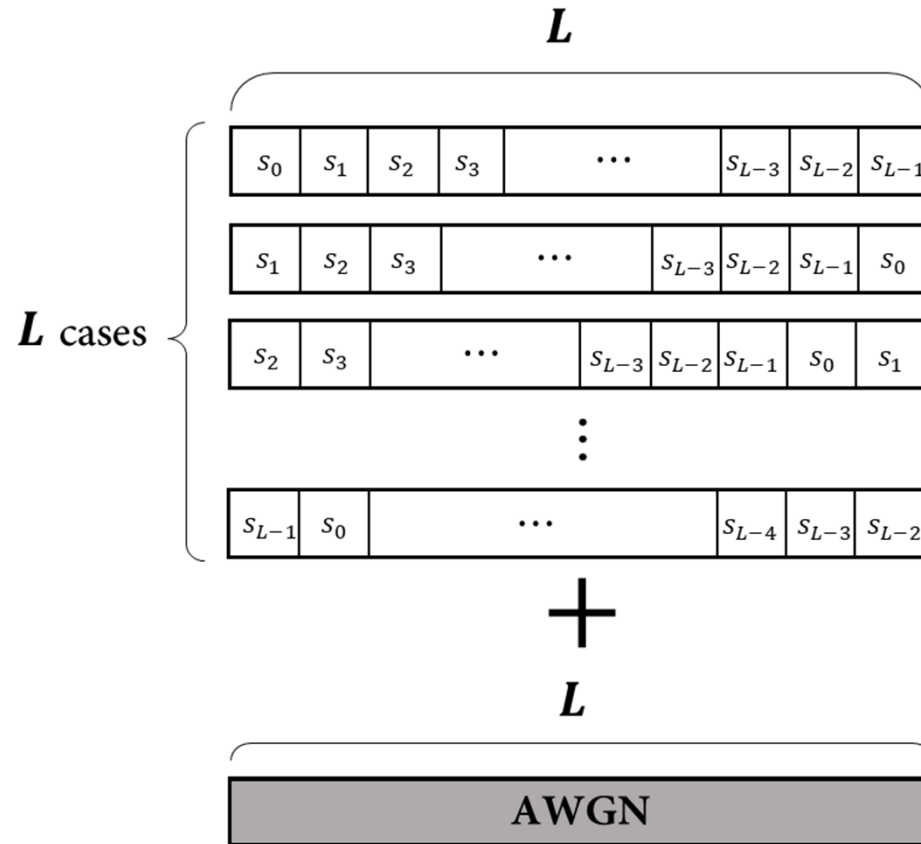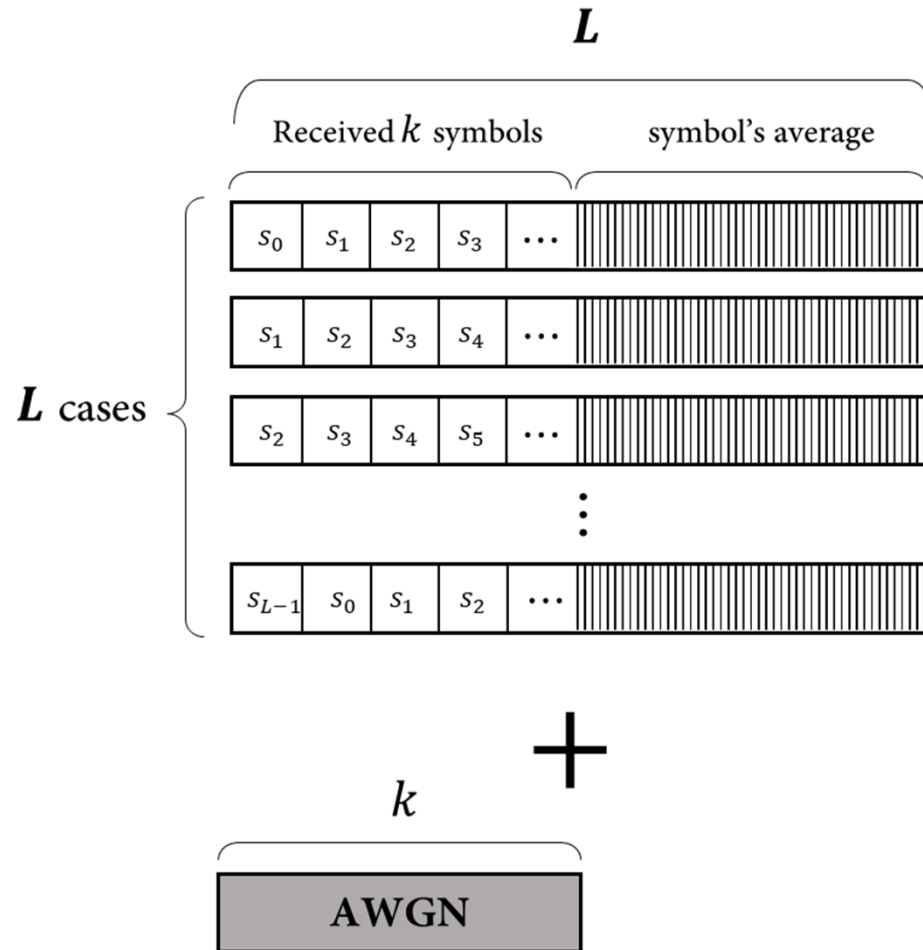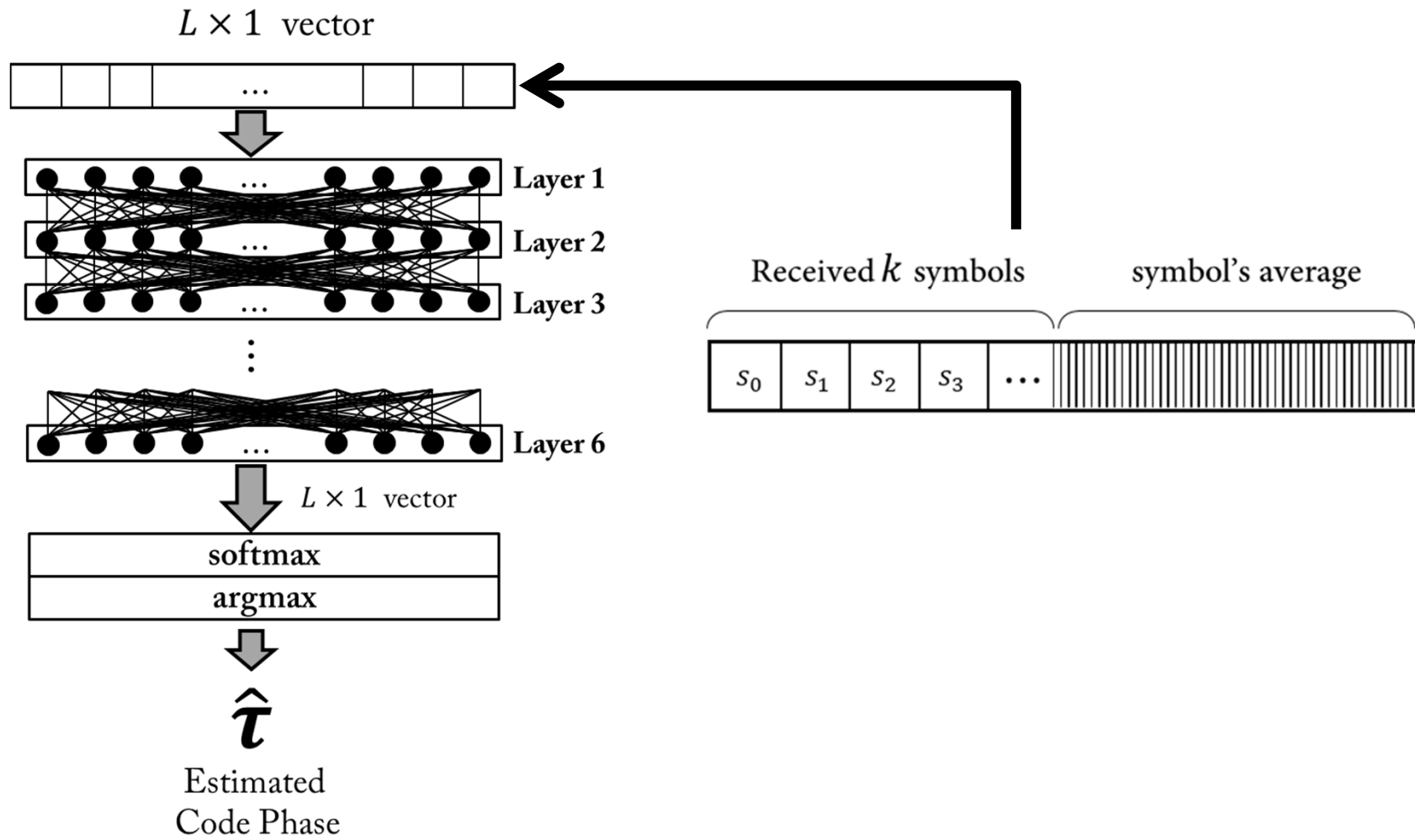
Test set

10^3 times

Simulation Result
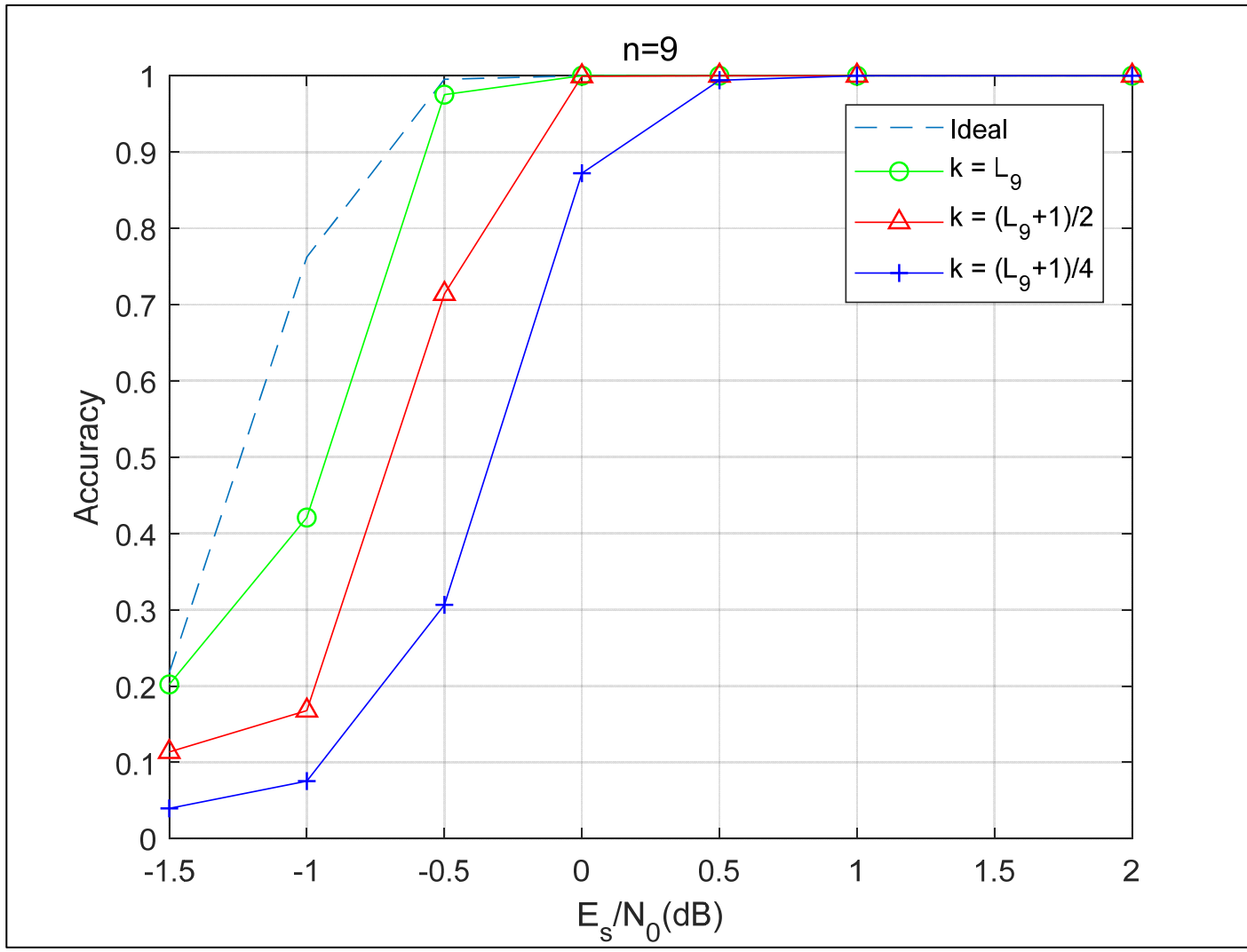
$$\text{Accuracy} = \frac{\text{Number of Successful Estimation}}{\text{Number of Total Number to Estimate}}$$

Simulation Result

DNN + m-sequence

We can estimate time-delay τ with only part of sequence.

The length of received symbols can be changed by channel.

$$\boxed{?}\text{NN} + \boxed{?}\text{sequence}$$

It can be possible to estimate the time-delay accurately, using other NN and other sequence.