Adaptive Antenna Array for Reliable OFDM Transmission

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Contents of This Presentation

* What are 4G Systems?
* Motivation,
* Adaptive Antenna Array for
  Suppression of Doppler-Shifted Signals,
* Adaptive Antenna Array for
  Suppression of Delayed Signals beyond
  Guard Interval,
* Conclusions.

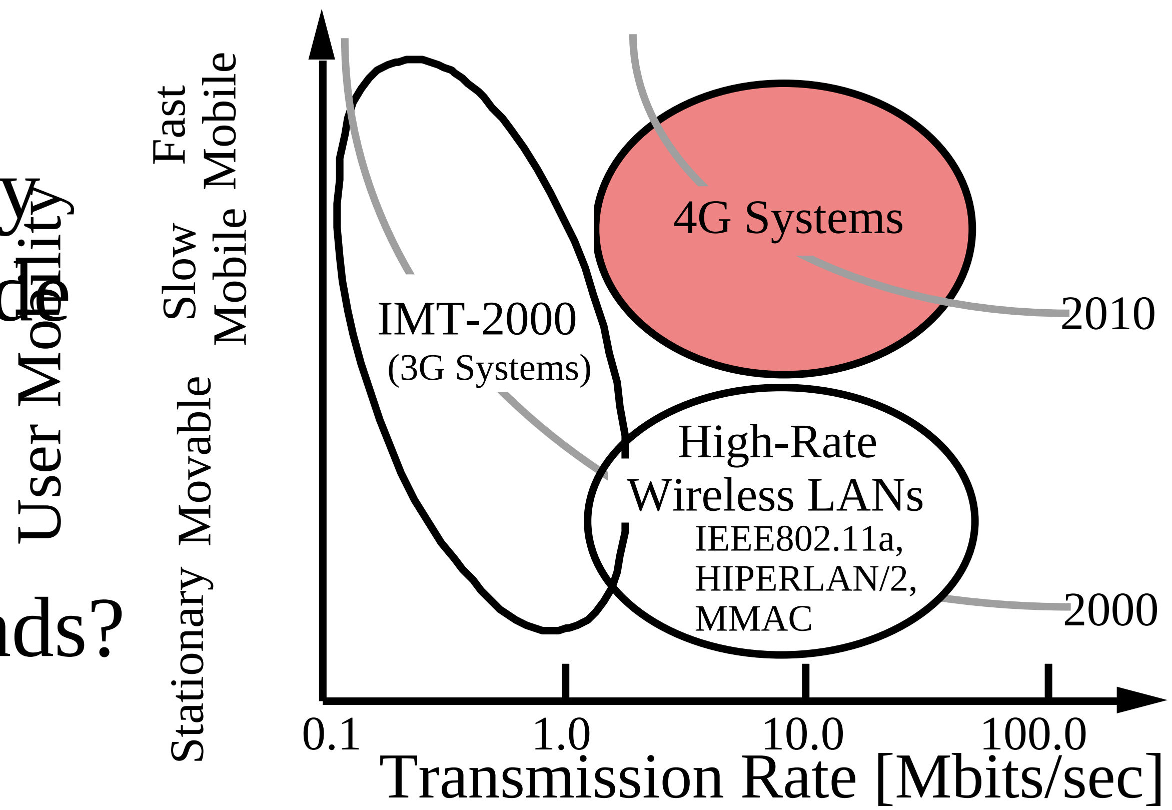
What are 4G Systems ?

4G Systems should support

20~100Mbps transmission in downlink, and 2~20 Mbps transmission in uplink, even for high-speed cruising mobiles.

Where in frequency band can we provide the services?

3 (< 5~6) GHz bands?



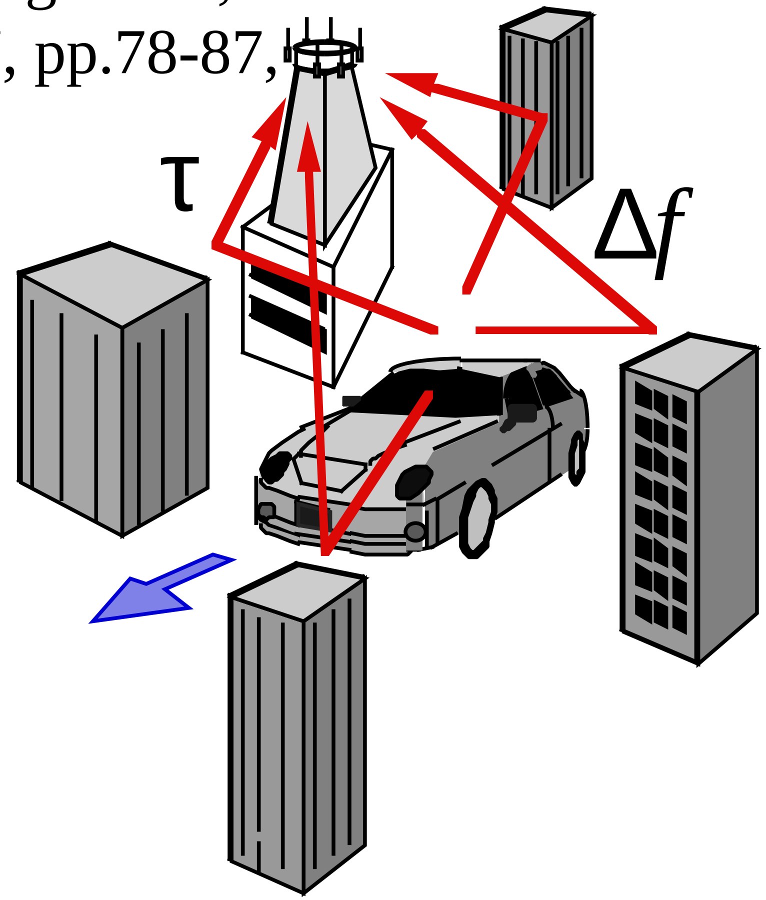
OFDM scheme is a candidate as a physical layer protocol for 4G systems.

J.Chuang and N.Sollenberger,
"Beyond 3G: Wideband Wireless Data Access Based on OFDM and Dynamic Packet Assignment,"
IEEE Commun. Mag., Vol.38, No.7, pp.78-87, July 2000.

The BER of OFDM scheme is degraded by

Doppler-Shifted Signals

Delayed Signals beyond Guard Interval



Motivation

Here, focusing our attention on
Doppler-shifted signals and
delayed signals beyond Guard interval,
"How can we suppress them?"

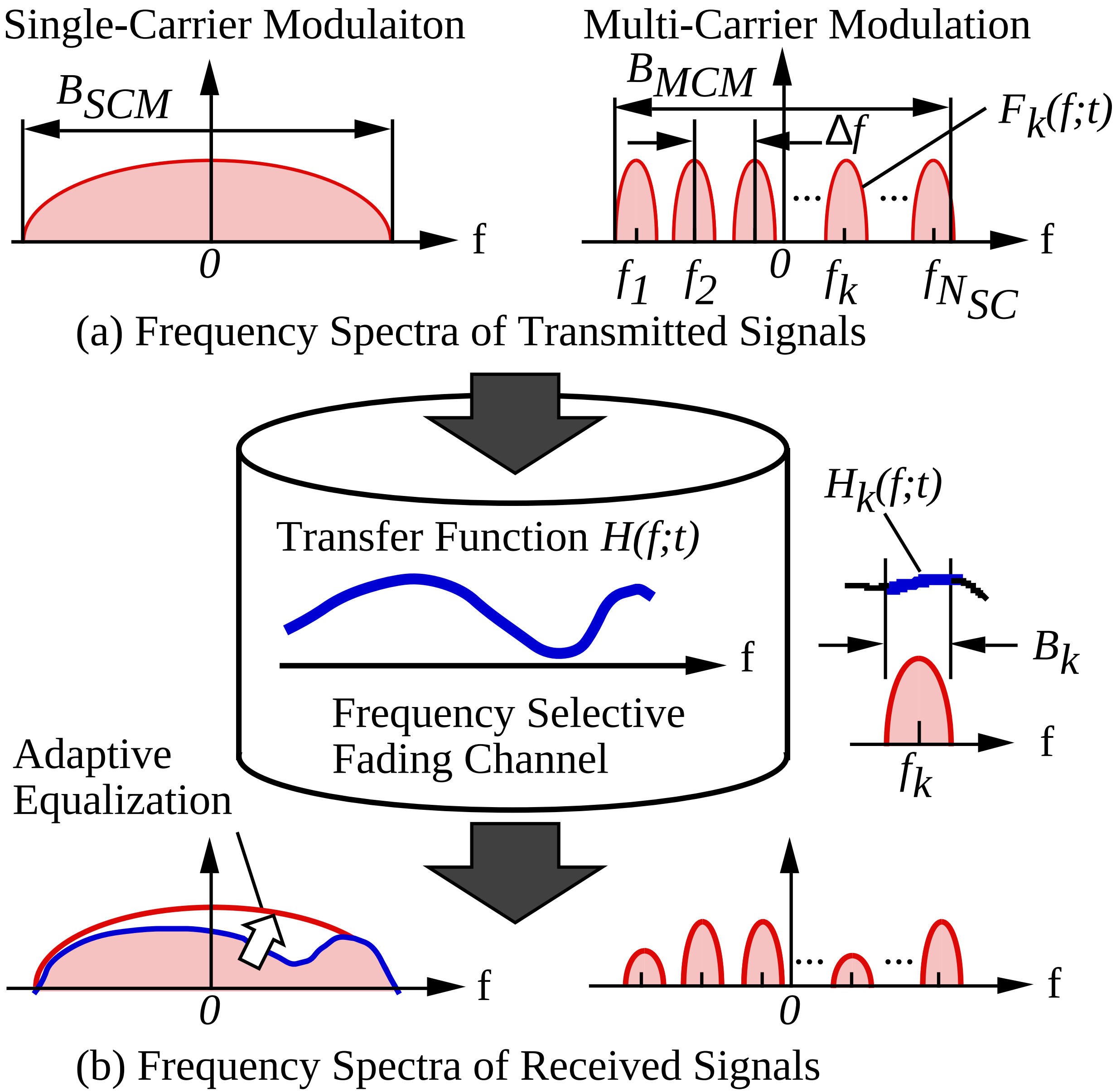
Temporal Equalization

high computational complexity
(against concept of OFDM)

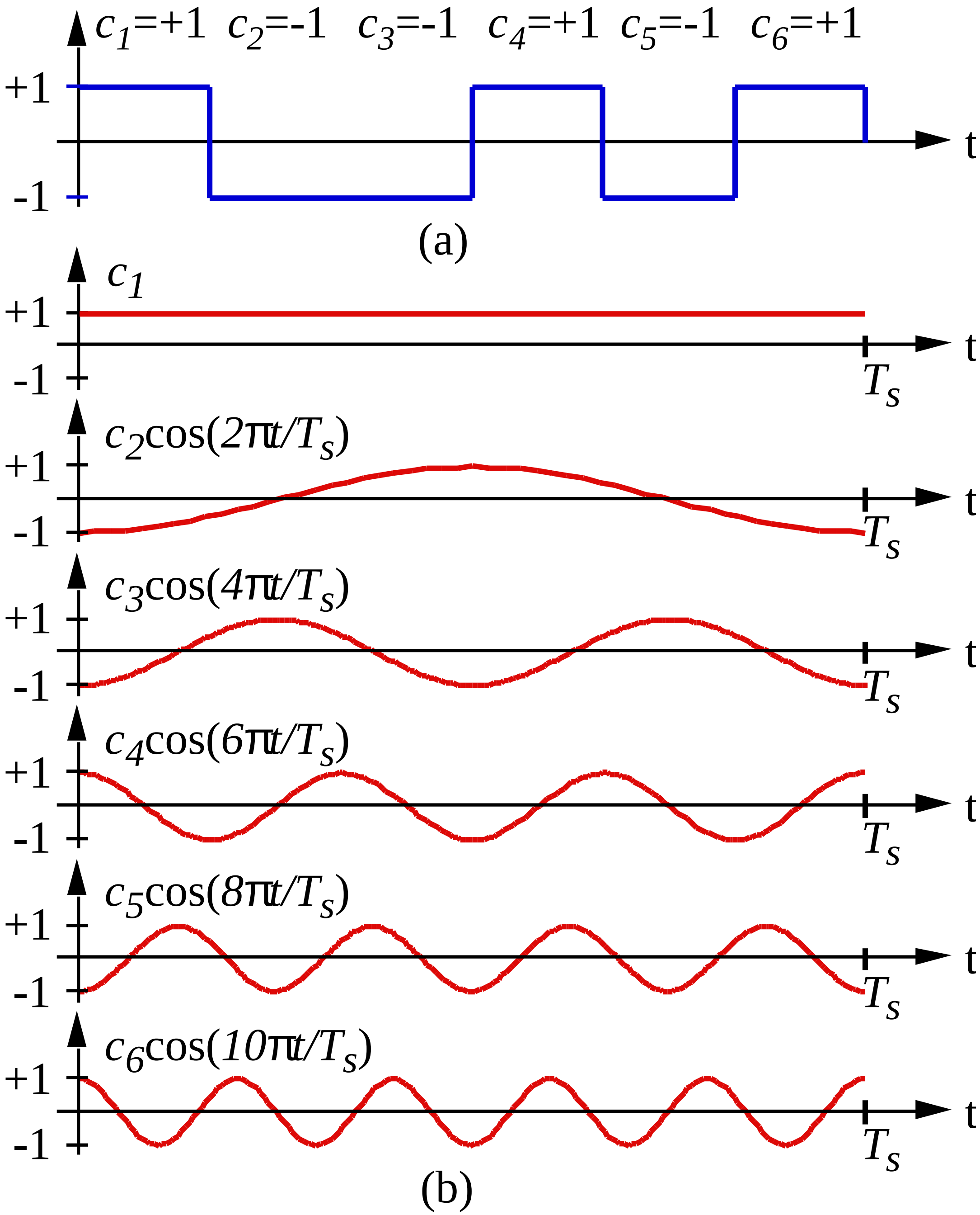
Adaptive Antenna Array

must be a good solution!

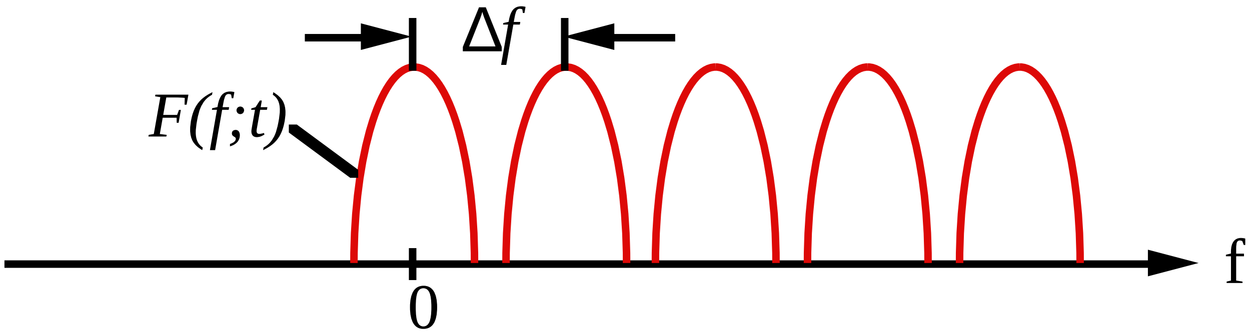
OFDM Basics



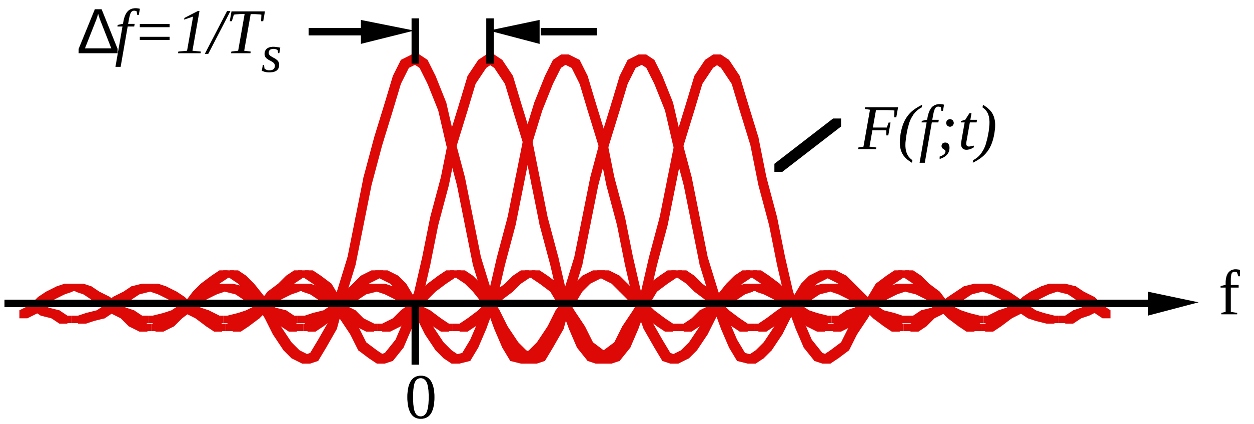
Single-Carrier Modulaiton
Multi-Carrier Modulation
B_{SCM}
B_{MCM}
Δf
$F_k(f;t)$
f
0
f_1 f_2 0 f_k $f_{N_{SC}}$
(a) Frequency Spectra of Transmitted Signals
Transfer Function $H(f;t)$
Frequency Selective
Fading Channel
$H_k(f;t)$
B_k
f_k
Adaptive
Equalization
(b) Frequency Spectra of Received Signals



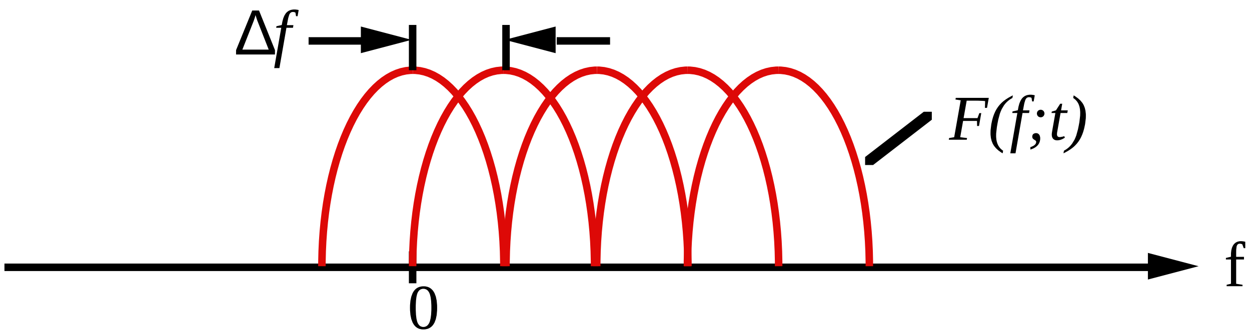
c_1=+1 c_2=-1 c_3=-1 c_4=+1 c_5=-1 c_6=+1
+1
-1
t
(a)
c_1
$c_2\cos(2\pi t/T_s)$
$c_3\cos(4\pi t/T_s)$
$c_4\cos(6\pi t/T_s)$
$c_5\cos(8\pi t/T_s)$
$c_6\cos(10\pi t/T_s)$
T_s
(b)



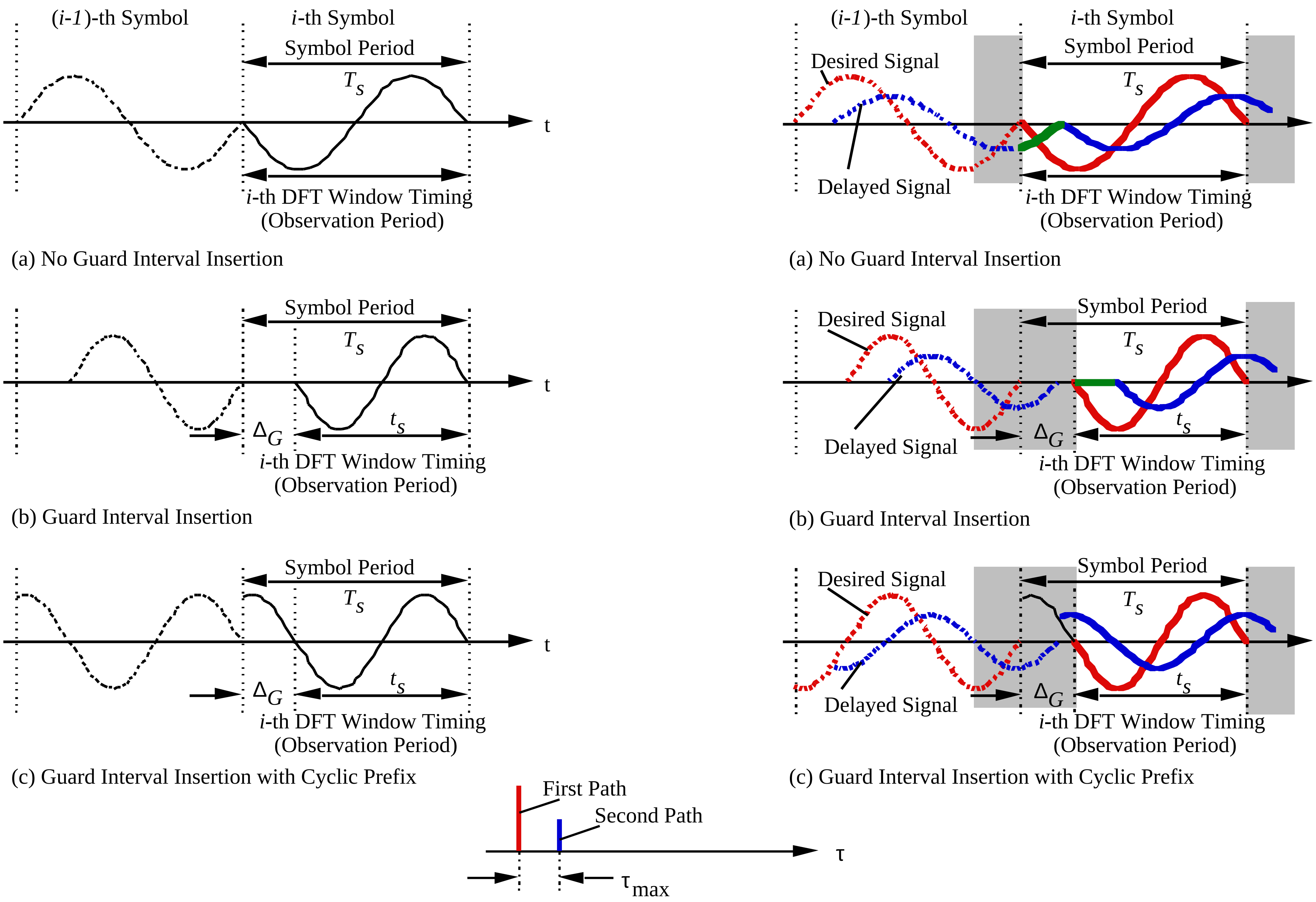
(a) Non-Overlapped Band-Limited Orthogonal Signals

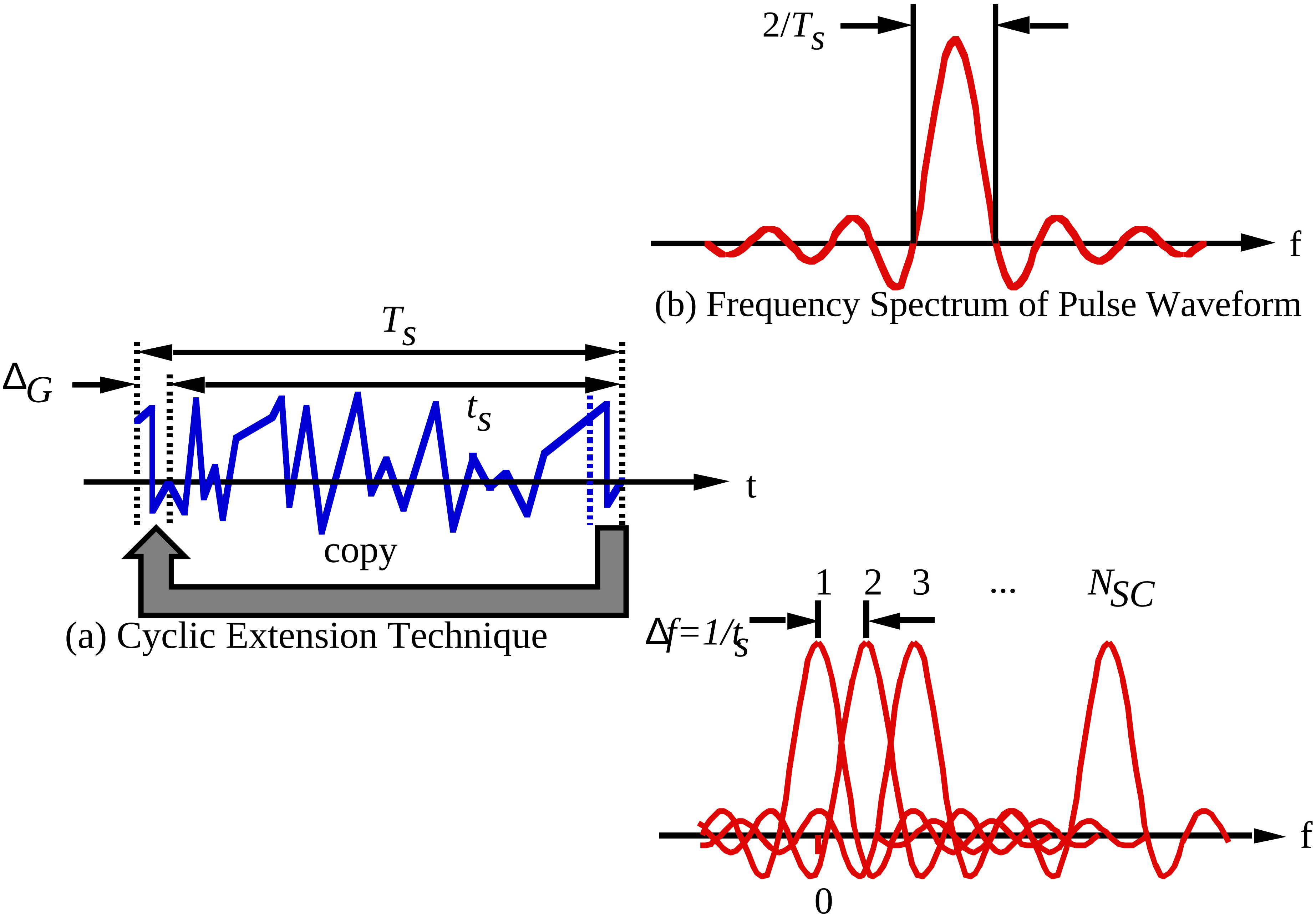


(b) Overlapped Time-Limited Orthogonal Signals



(c) Overlapped Band-Limited Orthogonal Signals


(i-1)-th Symbol
i-th Symbol
Symbol Period
T_s
t
i-th DFT Window Timing
(Observation Period)
(a) No Guard Interval Insertion
Symbol Period
T_s
Δ_G
t_s
i-th DFT Window Timing
(Observation Period)
(b) Guard Interval Insertion
Symbol Period
T_s
Δ_G
t_s
i-th DFT Window Timing
(Observation Period)
(c) Guard Interval Insertion with Cyclic Prefix
(i-1)-th Symbol
i-th Symbol
Symbol Period
Desired Signal
Delayed Signal
i-th DFT Window Timing
(Observation Period)
(a) No Guard Interval Insertion
Desired Signal
Delayed Signal
(b) Guard Interval Insertion
Desired Signal
Delayed Signal
(c) Guard Interval Insertion with Cyclic Prefix
First Path
Second Path
τ
τ_{max}



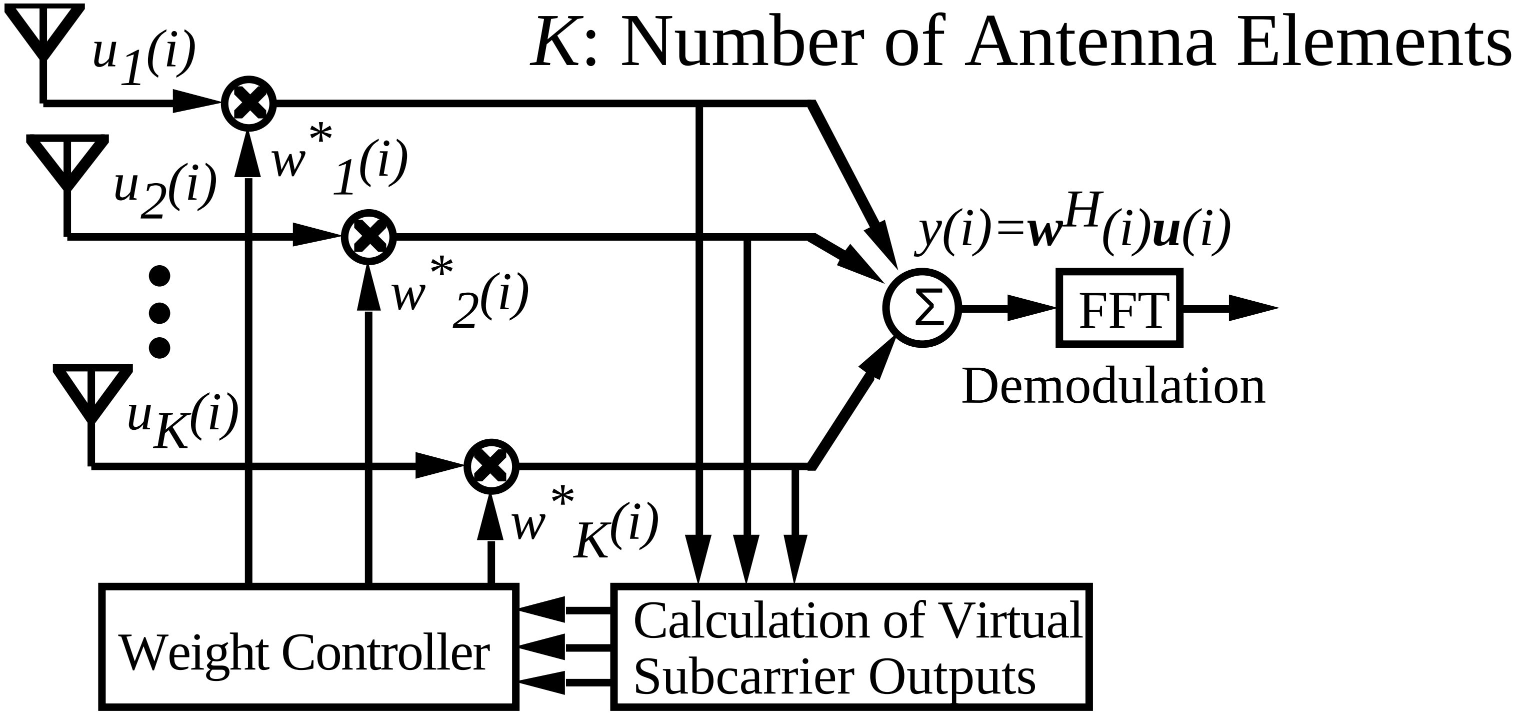
(b) Frequency Spectrum of Pulse Waveform

(a) Cyclic Extension Technique

(c) Frequency Spectrum of OFDM Signal

Suppression of Doppler-Shifted Signals

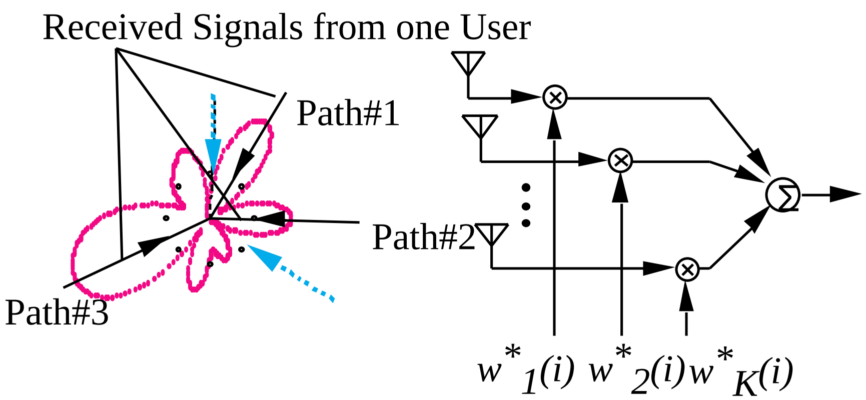
Weight per User/Pre-FFT Type
OFDM Adaptive Antenna Array

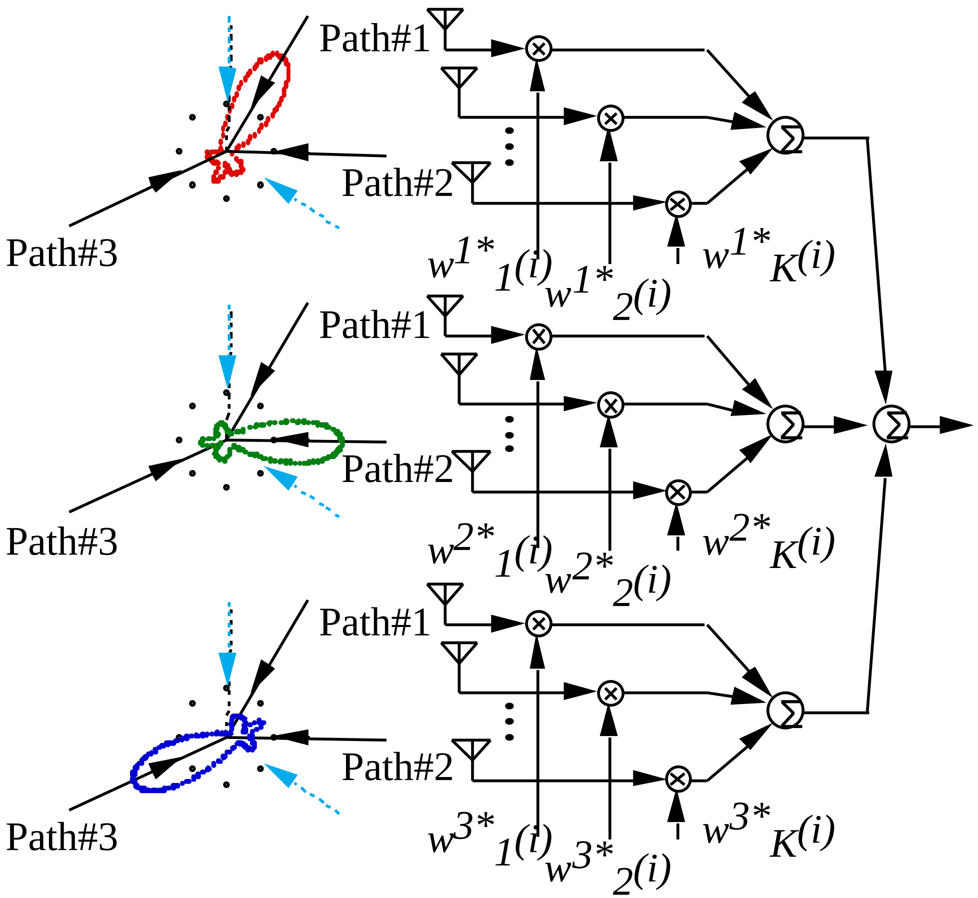


$\boldsymbol{u}(i)=[u_1(i), \ldots, u_K(i)]^T$ (Received Signal Vector)

$\boldsymbol{w}(i)=[w_1(i), \ldots, w_K(i)]^T$ (Array Weight Vector)

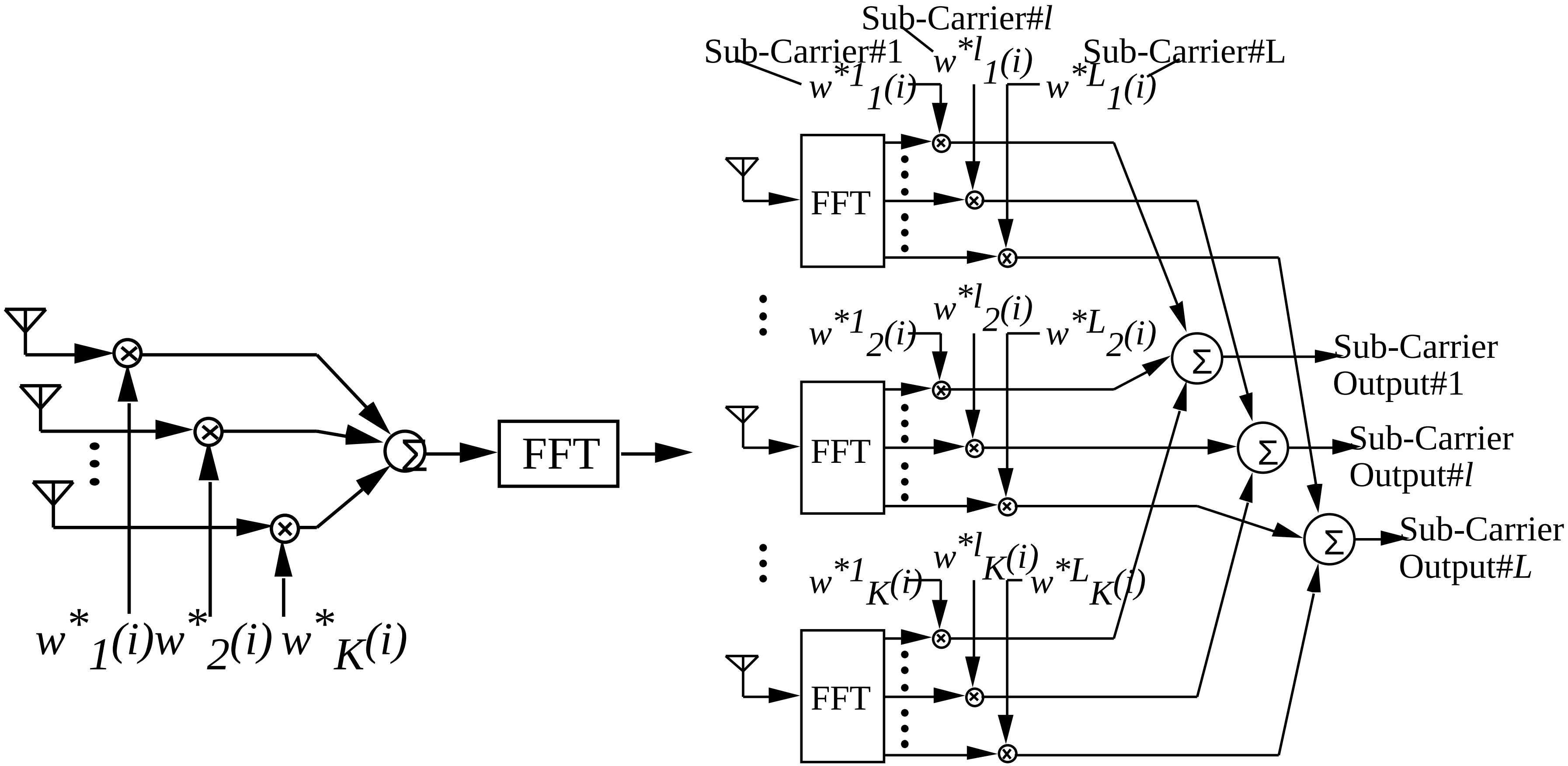
OFDM Adaptive Antenna Array





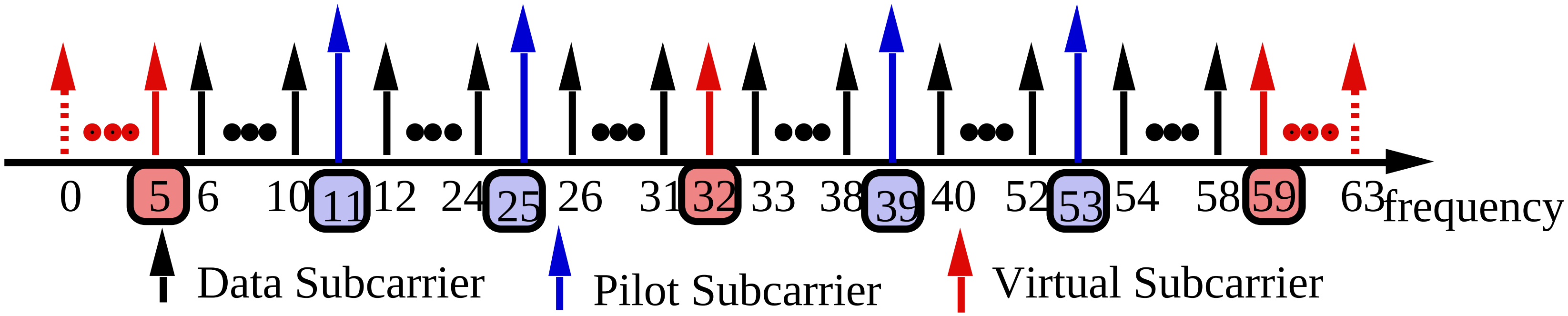
Weight-per-User Type

Weight-per-Path Type

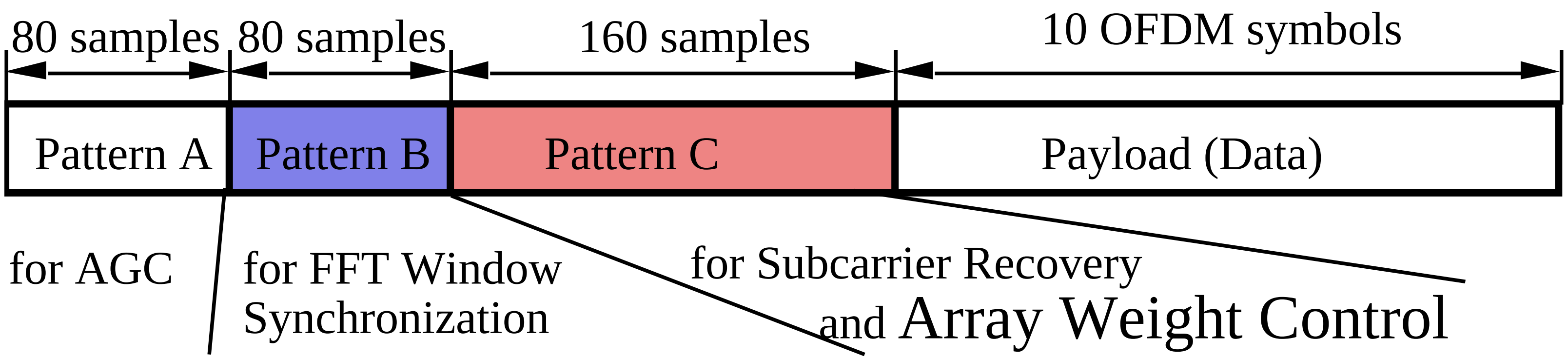


Pre-FFT Type　　　　Post-FFT Type

Subcarrier Arrangement

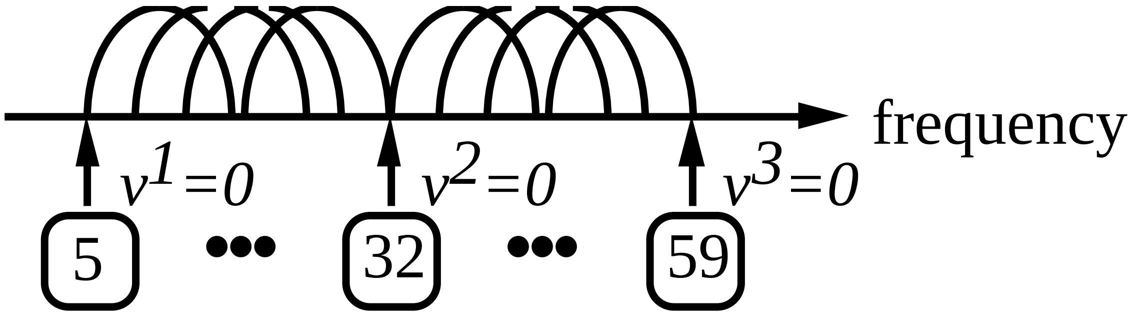


Signal Burst Format

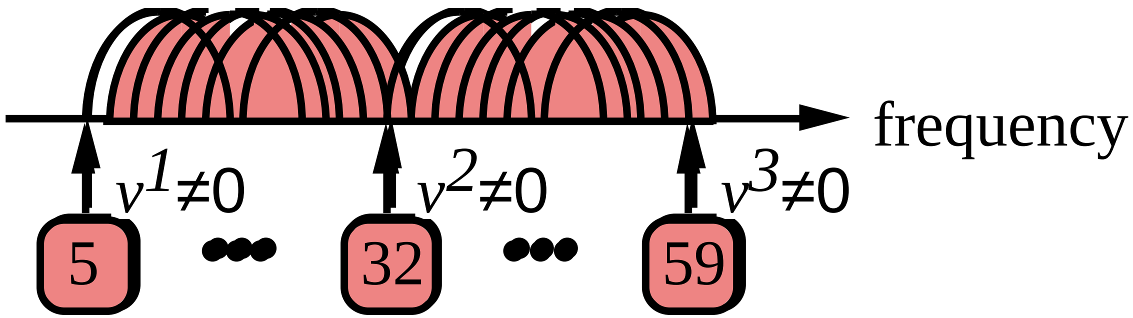


Array Weight Control Principle

Simple Null Steering for Doppler-Shifted Signals Based on Observation of Virtual Subcarrier Outputs



When received signals contain no Doppler-shifted signals.



When received signals contain some Doppler-shifted signals.

Weight Control Criterion

Number of Virtual Subcarriers Considered

Array Weight Vector

$$\text{minimize } e_v(i)=\sum_{j=1}^{3}\left|0-w^H(i)\mathbf{v}^j(i)\right|^2$$

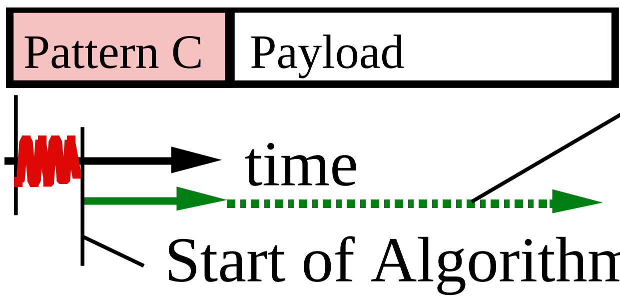
Desired Response

$\mathbf{v}^j(i)$: the *j*-th Virtual Subcarrier Output Vector

$$\mathbf{v}^j(i)=[v^j_1(i), \dots , v^j_K(i)]^T$$

↓

LMS Algorithm



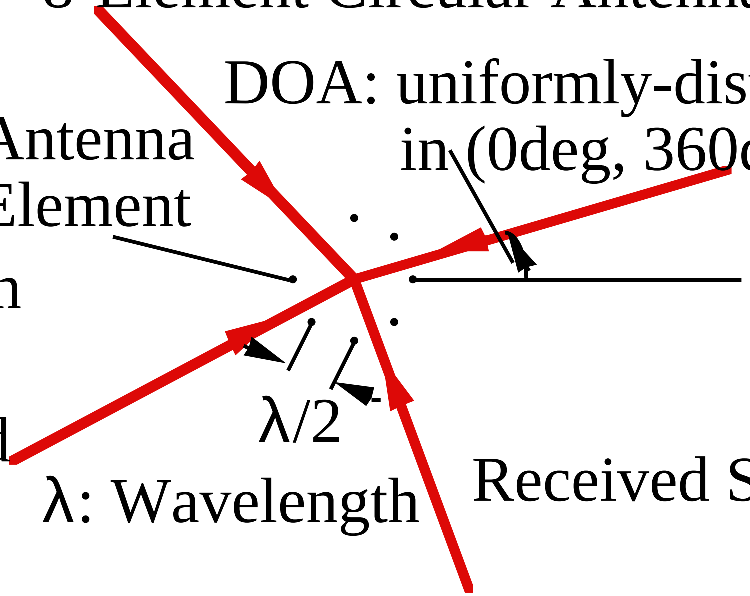
This algorithm is workable in payload part, because it requires no pilot signal!

Down-conversion requires 64 samples to give the Algorithm the first virtual subcarrier output.

Numerical Results
by Computer Simulation

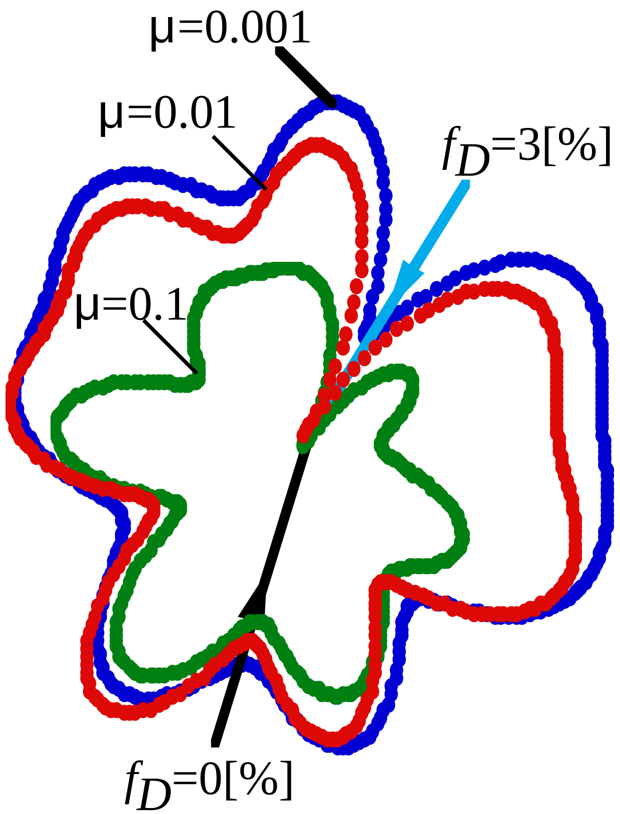
Envelope: Rayleigh-distributed with the same average power

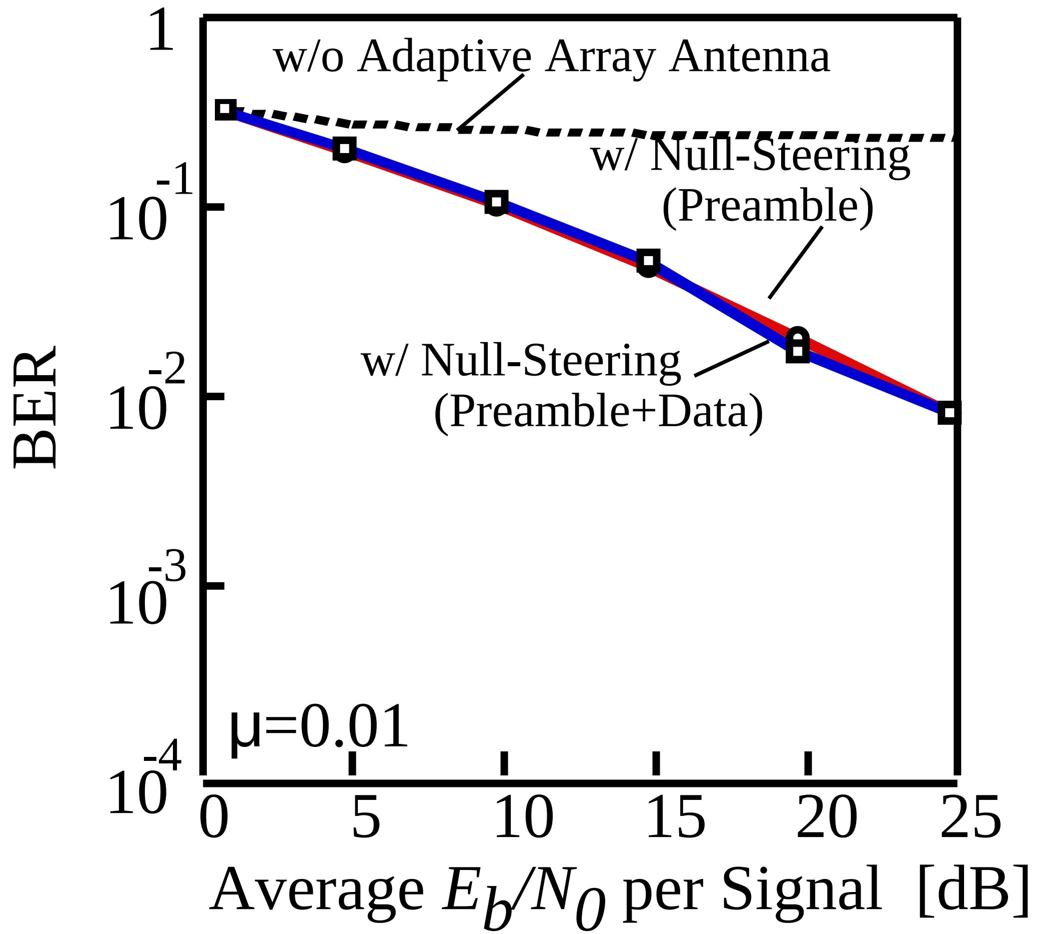
Arrival Time: uniformly-distributed within guard interval



Number of Subcarriers	52 (including 4 Pilot Subcarriers)
Modulation/Detection	QPSK/Coherent Detection
FFT Length/Guard Interval Length	64[samples]/16[samples]
Forward Error Correction	Convolutional Encoding/ Viterbi Decoding (R=1/2, K=7)
Over-sampling Factor	4
Number of Virtual Subcarrier Used	3 (#5, #32, #59)

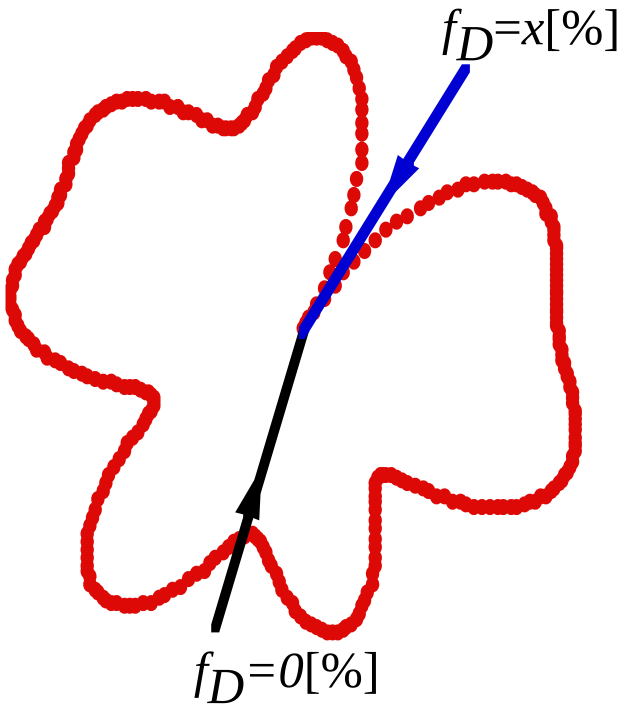
2 Received Signals (f_D=0[%], f_D =3[%])

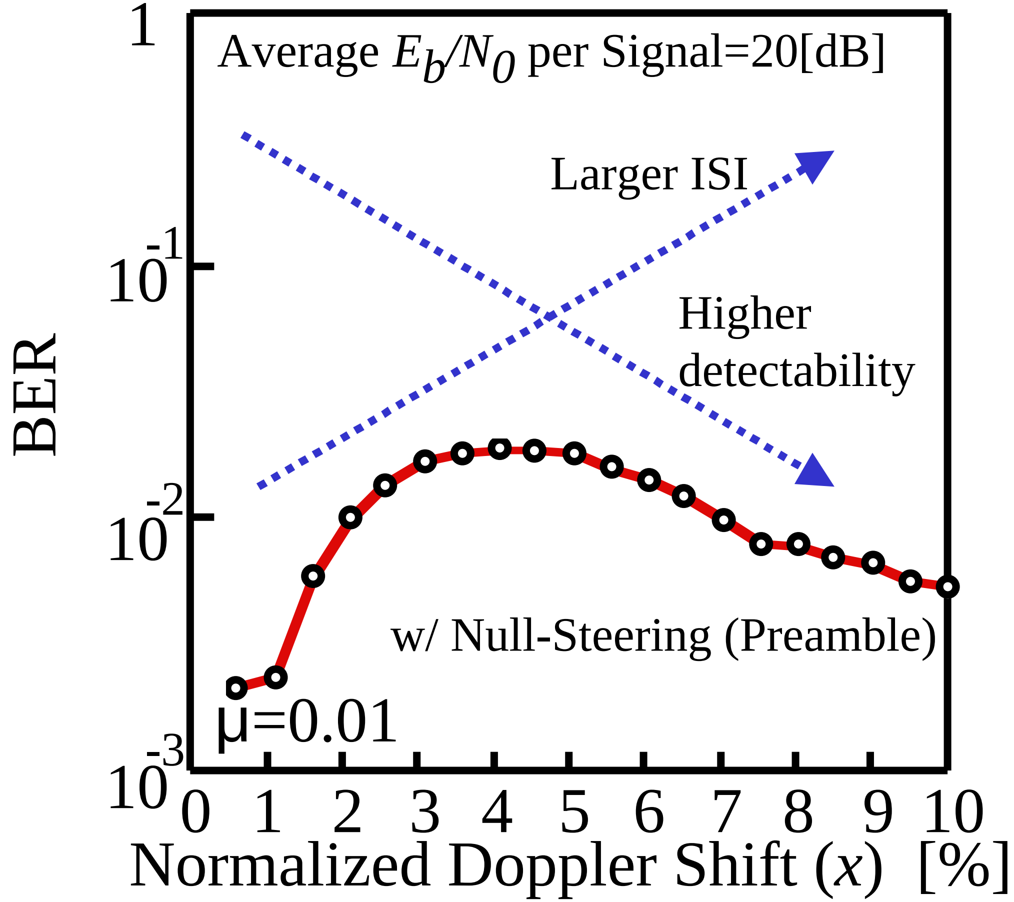




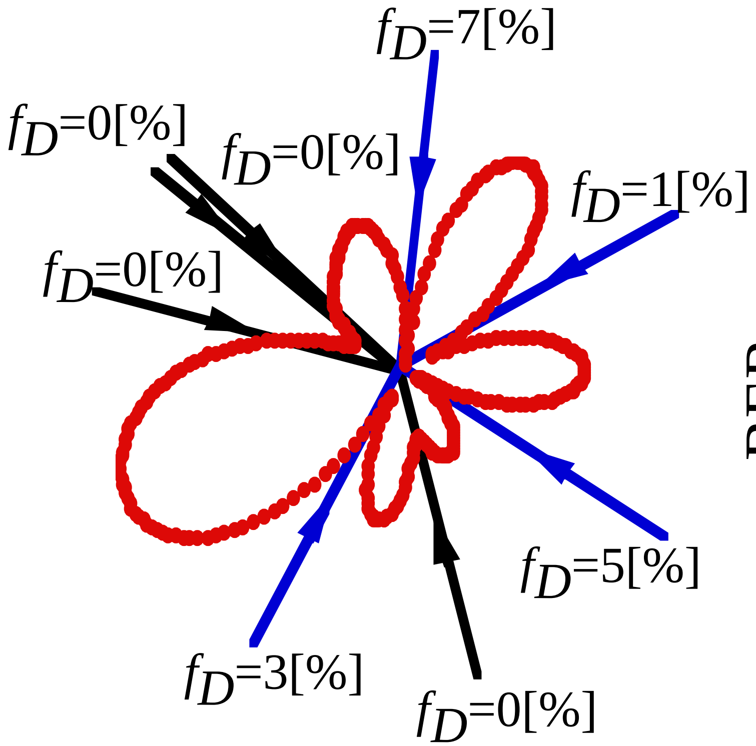
BER against Normalized Doppler Shift

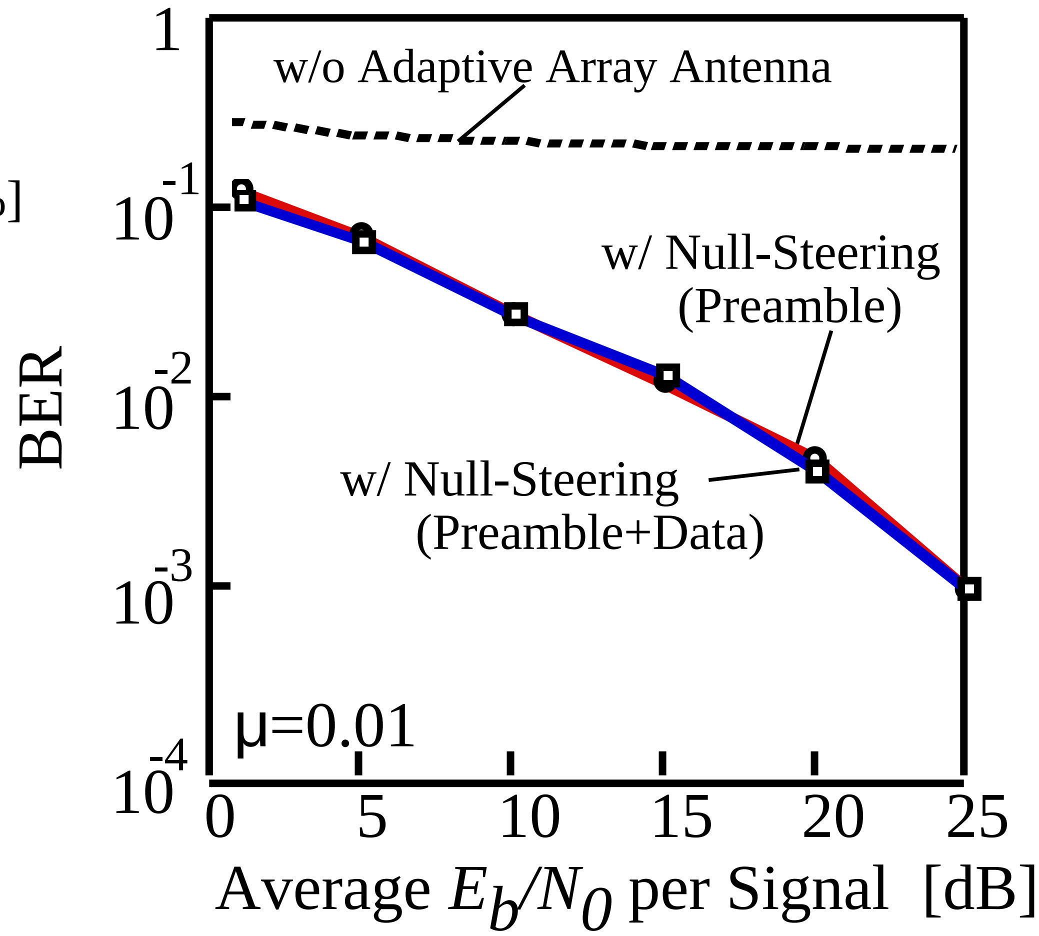
2 Received Signals



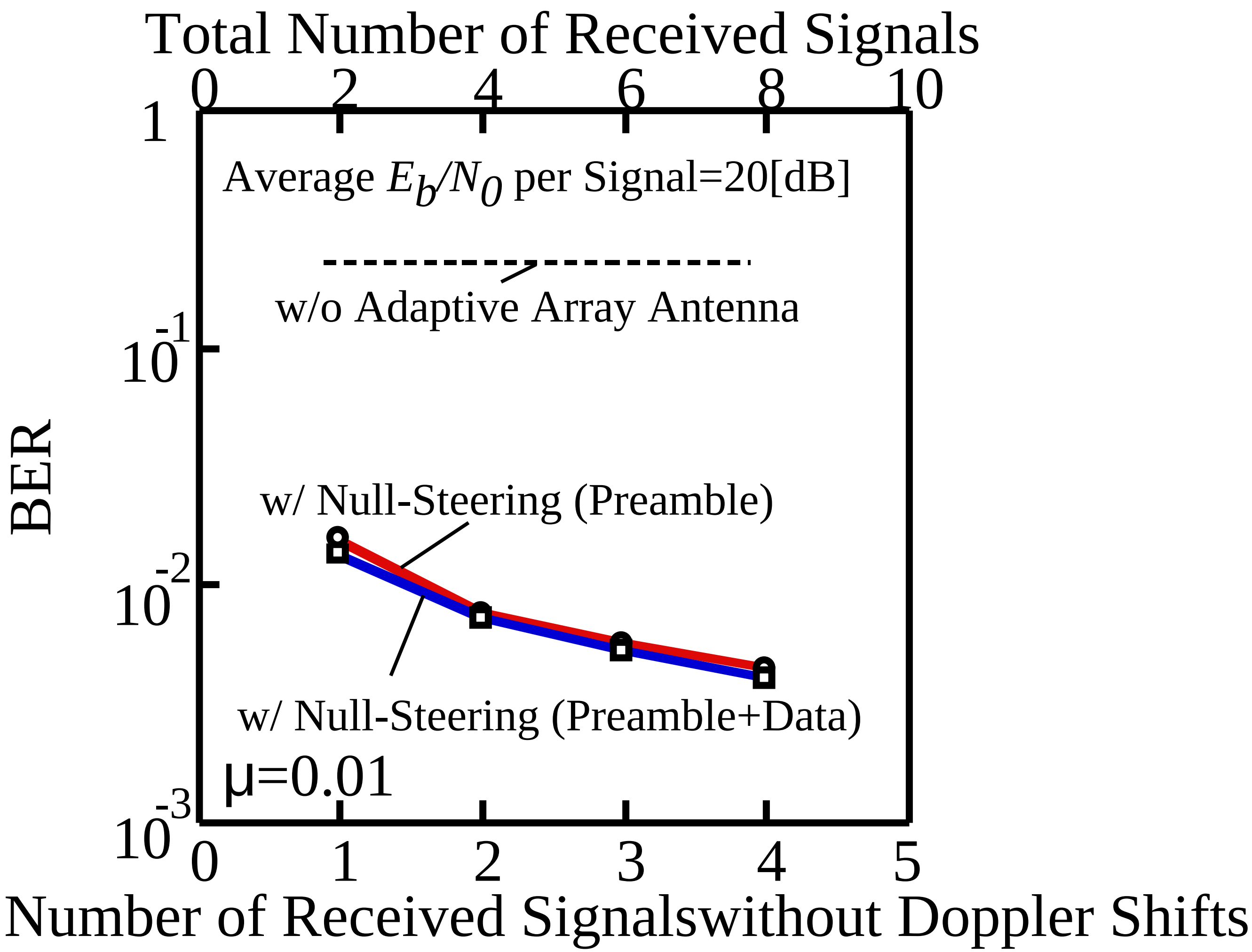


8 Received Signals (f_D=0[%], f_D =0[%], f_D =0[%], f_D =0[%], f_D =1[%], f_D =3[%], f_D =5[%], f_D =7[%])





BER against Number of Received Signals



Discussions

* Longer observation of virtual subcarrier outputs does not always result in better BER performance.

  $\boldsymbol{w}=[0, \ldots , 0]^T$ is a solution!

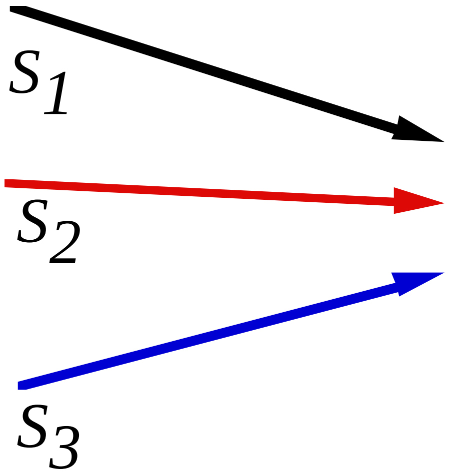
* Diversity gain is not obtained, when the number of received signals without Doppler shifts increases.

  This method just steers nulls toward undesired signals, namely, it tries to suppress Doppler-shifted signals but does not try to effectively catch desired signals.

* Can we always receive signals without Doppler shifts?

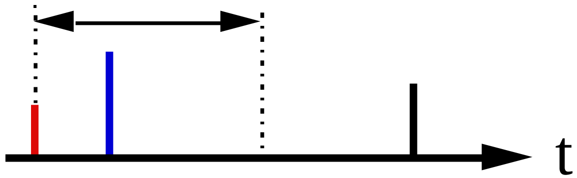
  No!

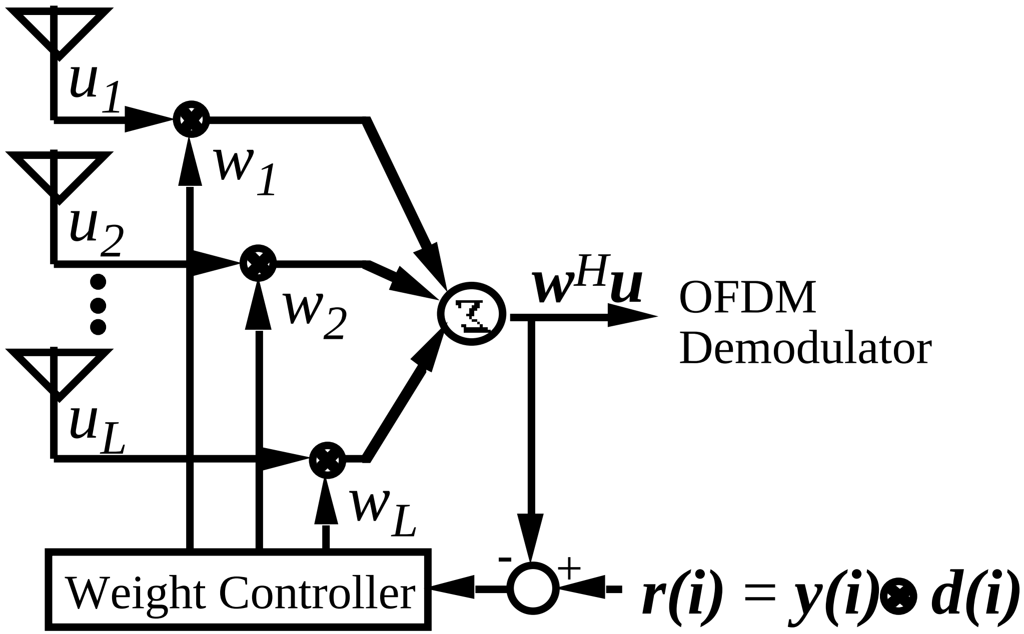
Suppression of Delayed Signals beyond Guard Interval



Channel Impulse Response

Guard Interval

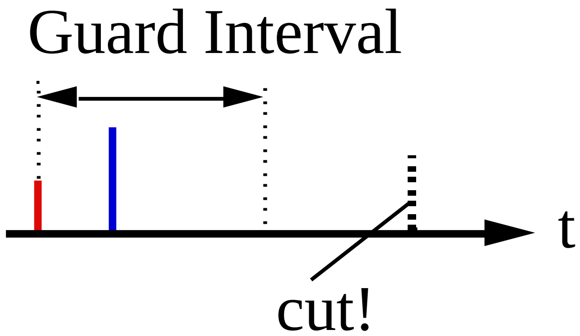


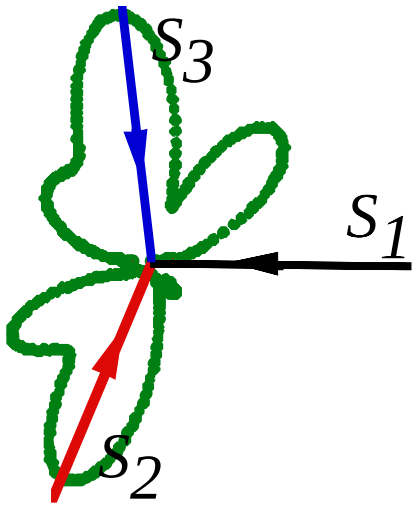


r(i): Reference Signal
d(i): Pilot Signal
y(i): Impulse Response

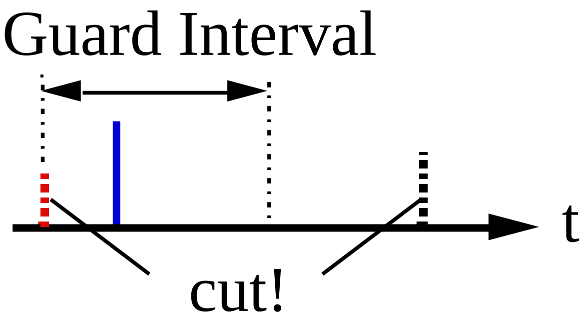
The BER performance depends on ***y(i)***.

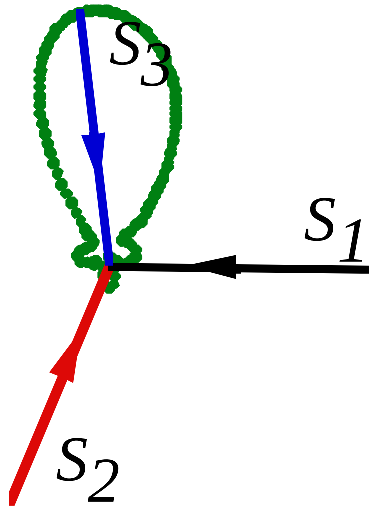
How can we determine ***y(i)*** ?





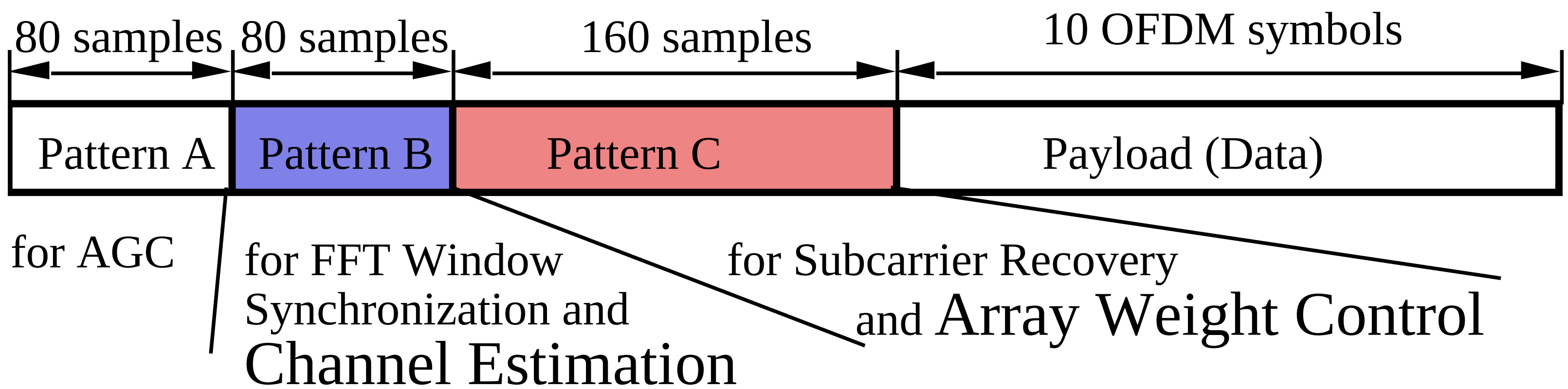
Combining Diversity Effect
Frequency Selective Fading





Selection Diversity Effect
Frequency Non-Selective Fading

Number of Subcarriers	52 (including 4 Pilot Subcarriers)
Modulation/Detection	QPSK/Coherent Detection
FFT Length/Guard Interval Length	64[samples]/16[samples]
Forward Error Correction	Convolutional Encoding/ Viterbi Decoding (R=1/2, K=7)
Over-sampling Factor	4



Channel Estimation

We *cannot* apply the well-known maximum length shift-register code (2^N-1: N=number of stages) to 80 sample-long Pattern B, which is composed of 52 subcarriers.

We use a chaotic random sequence generation method.

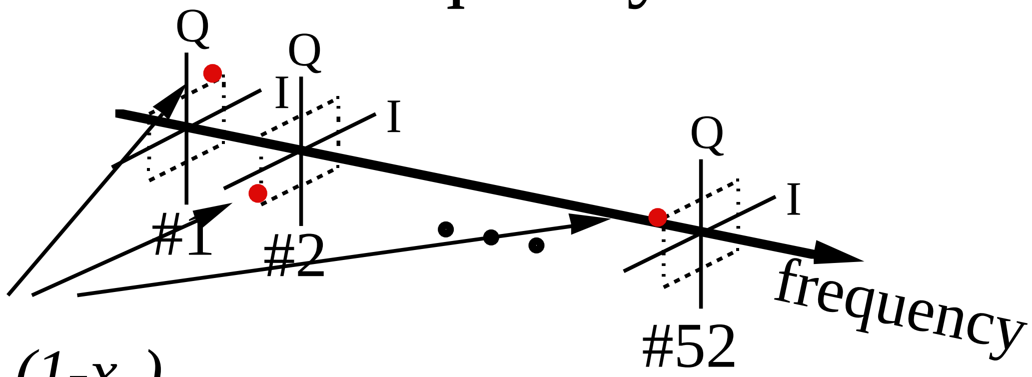
The logistic map $x_{n+1}=4x_n(1-x_n)$

generates a random sequence

uniformly distributed in [0, 1.0)

with infinite length.

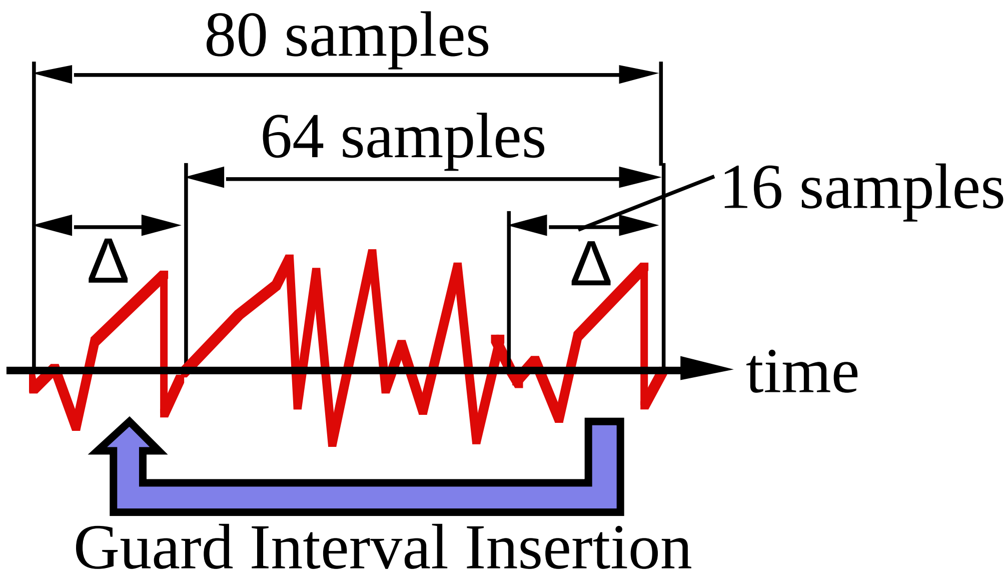
PN Sequence in Frequency Domain



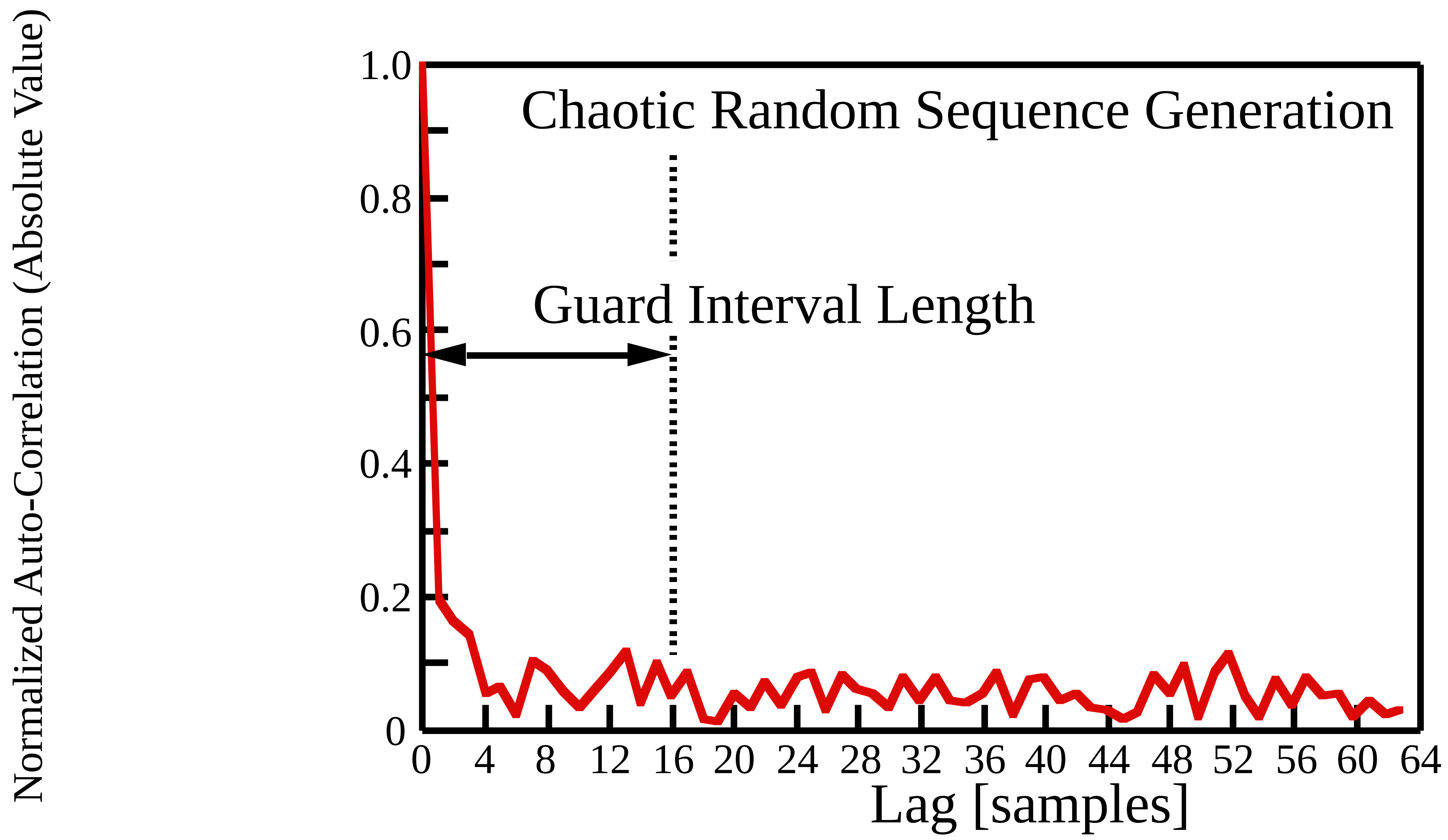
$x_{n+1}=4x_n(1-x_n)$

64 Point-IFFT

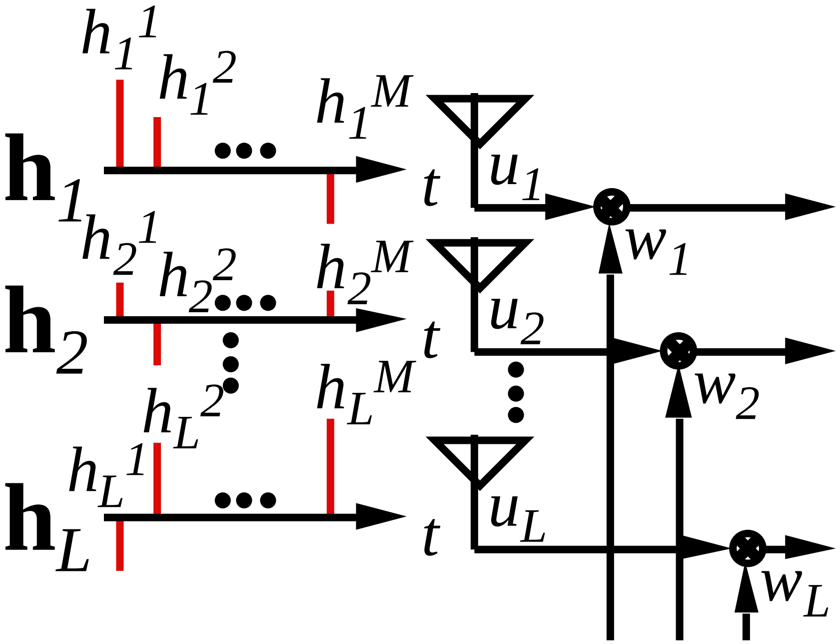
PN Sequence in Time Domain



Auto-Correlation Property of Generated Sequence



Impulse Responses for Reference Signal Generation



$\mathbf{h}_l=[h_l^1, \ldots, h_l^M]^T$ (l-th Impulse Response Vector),
$\mathbf{w}=[w_1, \ldots, w_L]^T$ (Array Weight Vector),
$\mathbf{H}=[\mathbf{h}_1, \ldots, \mathbf{h}_L]$ (Impulse Response Matrix),
L: Number of Antenna Elements,
M: Number of Samples in Guard Interval.

Method A: *L* Element-Based Optimum Combining

Any realizable impulse response, which can be used for reference signal generation, can be written as a weighted sum of L impulse response vectors:

$$\mathbf{h}_{ref} = [h_{ref}{}^{1}, \ldots, h_{ref}{}^{M}]^{T} = \mathbf{Hw}.$$

If OFDM prefers frequency selective fading channels, a reference signal with maximum total power within guard interval may give a better performance.

Signal-to-Noise Power Ratio (*SNR*) at array output is given by

$$SNR = \frac{\sigma^2_x \mathbf{w}^H \mathbf{R}_\mathrm{H} \mathbf{w}}{\sigma^2_n \mathbf{w}^H \mathbf{w}} .$$

$\mathbf{R}_\mathrm{H} = \mathrm{E}[\mathbf{H}^H \mathbf{H}]$: Channel Correlation Matrix,

σ^2_x: Signal Power, σ^2_n: Noise Power.

We can find $\mathbf{w}^{max}$ (= *arg max SNR*) by solving an equation: $(\mathbf{R}_\mathrm{H} - p^{max})\mathbf{w}^{max} = 0$,

p^{max}: The largest eigenvalue of $\mathbf{R}_\mathrm{H}$,

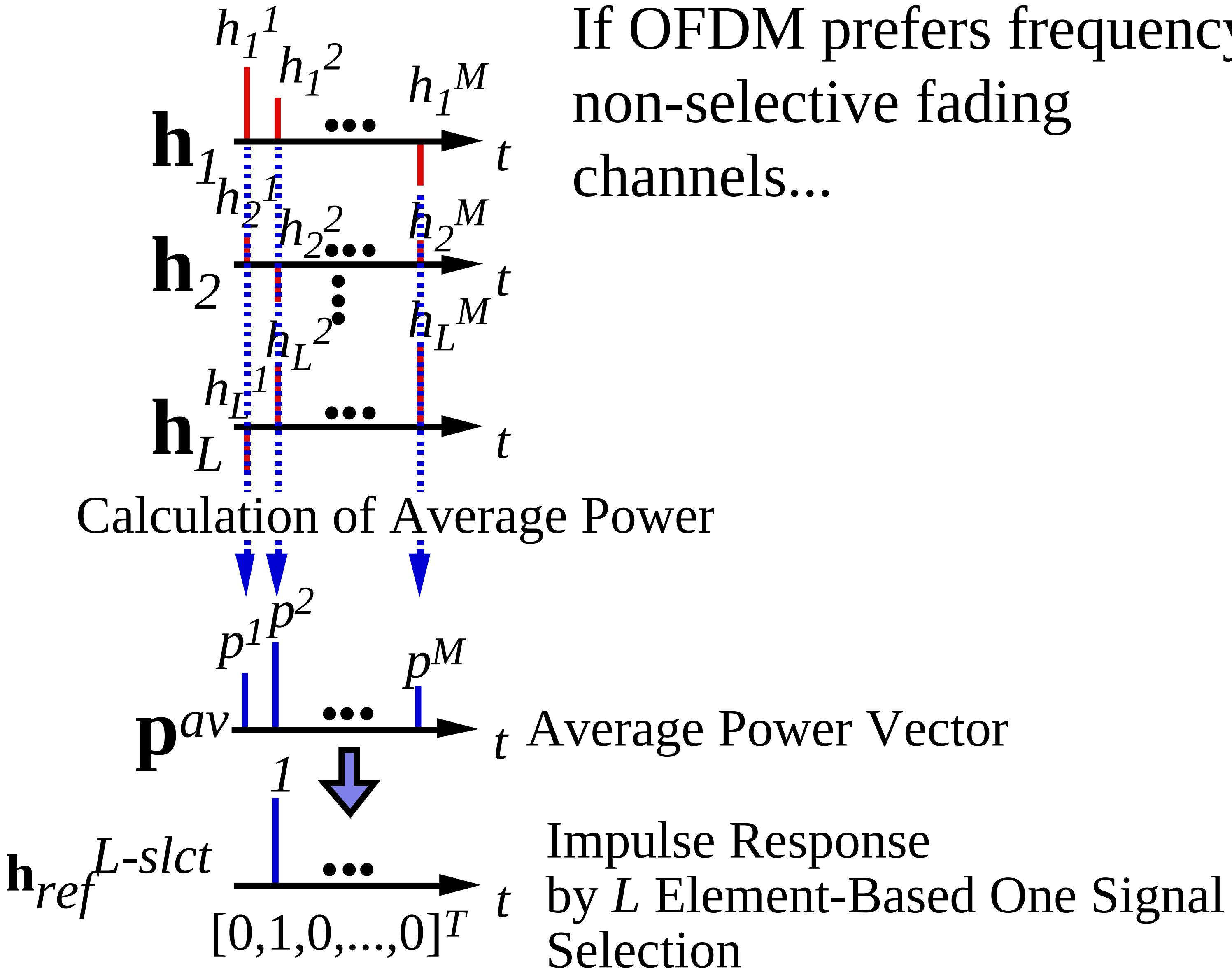
$\mathbf{w}^{max}$: The eigenvector corresponding to the eigenvalue.

Impulse Response by *L* Element-Based Optimum Combining is calculated as:

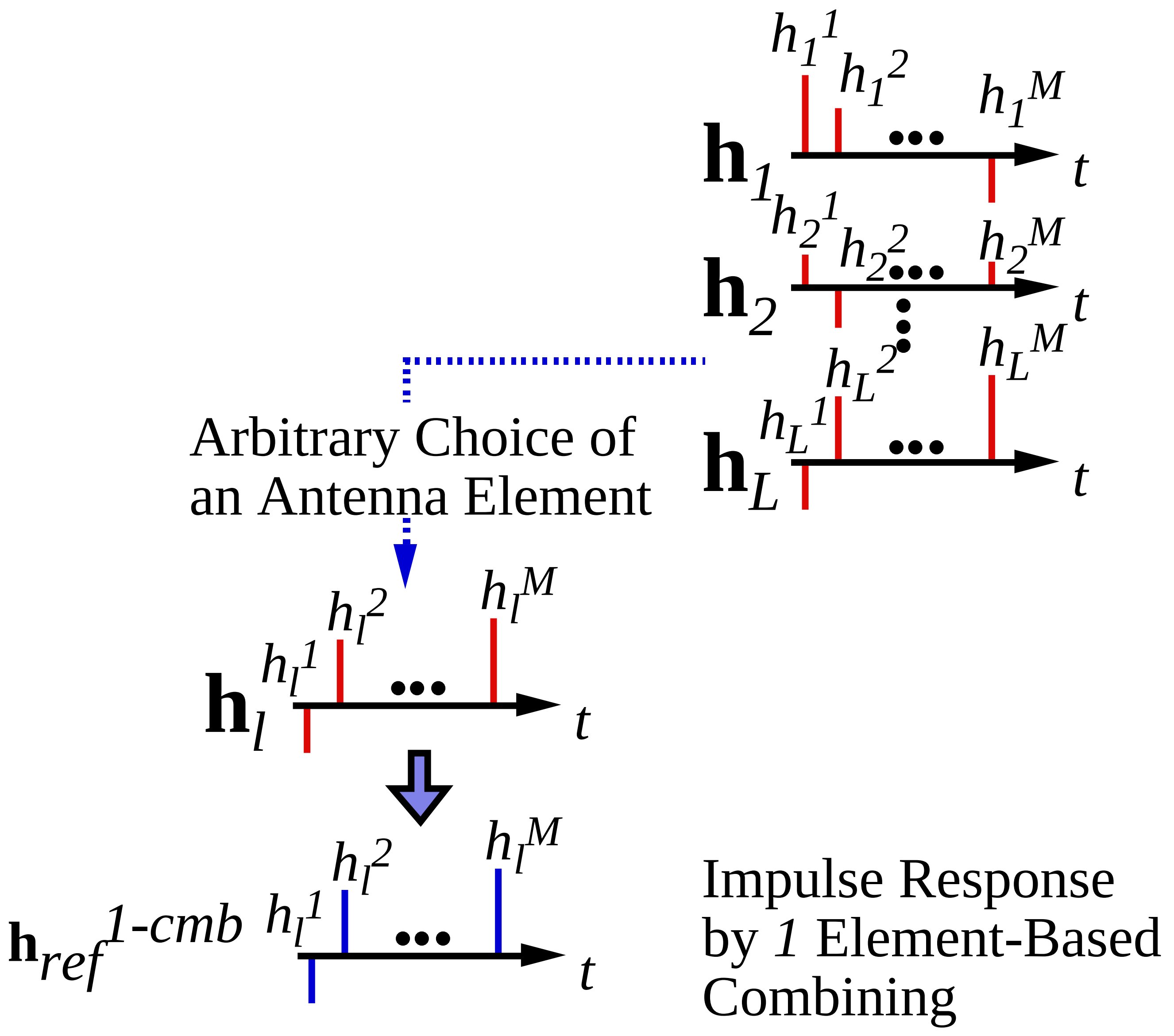
$$\mathbf{h}_{ref}^{L\text{-}opt} = \mathbf{H}\mathbf{w}^{max}.$$

Method B: *L* Element-Based One Signal Selection

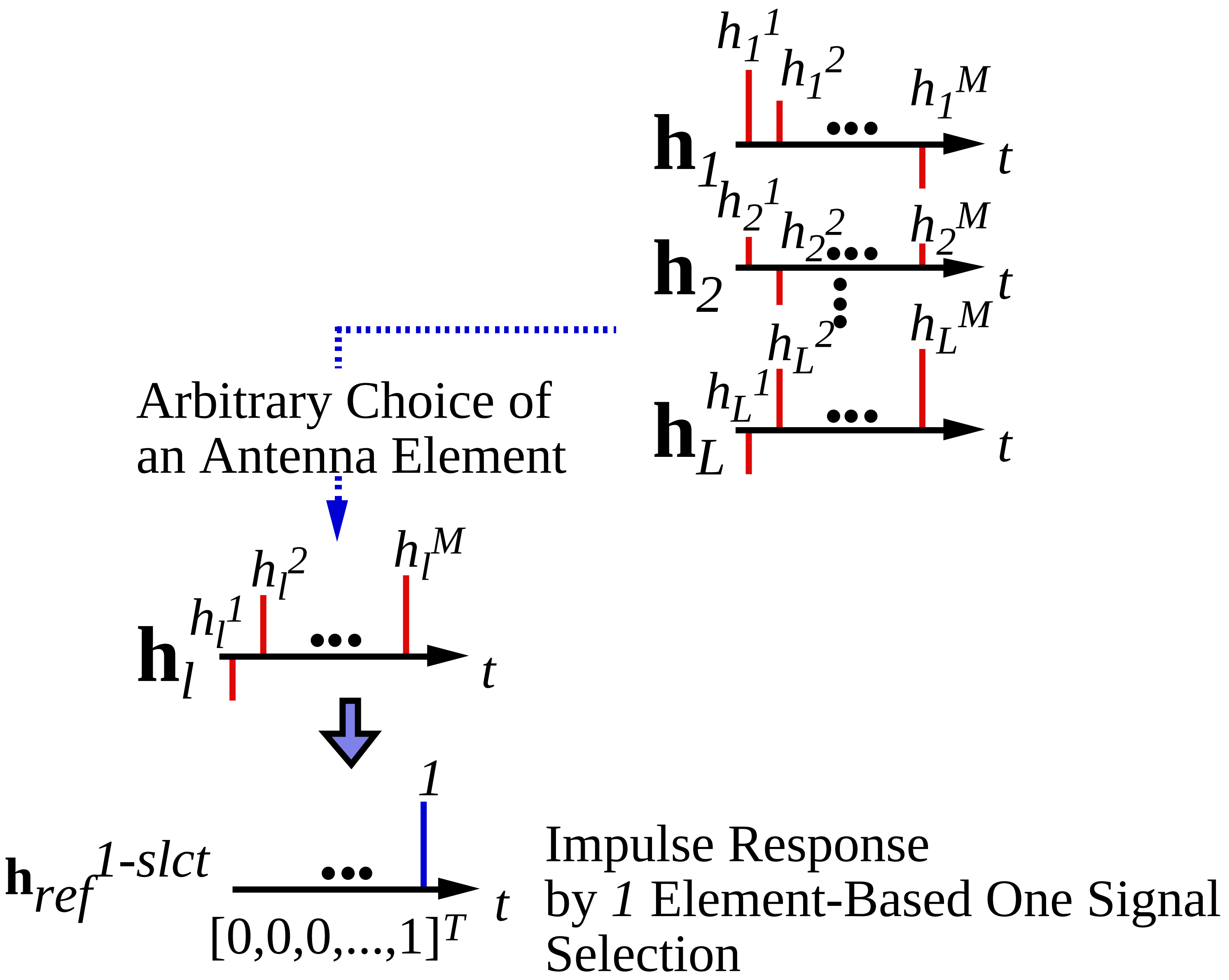
If OFDM prefers frequency non-selective fading channels...



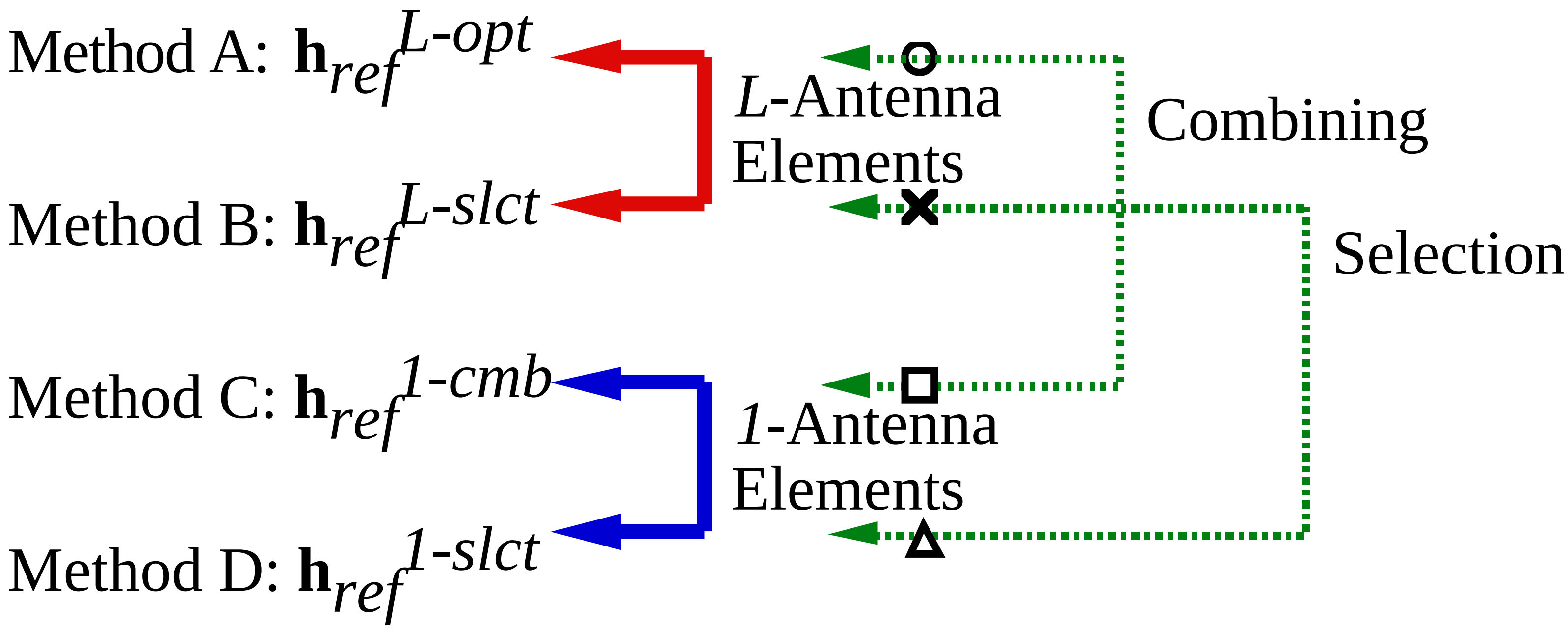
Method C: *1* Element-Based Combining



Method D: *1* Element-Based One Signal Selection



Array Weight Control Methods (Summary)

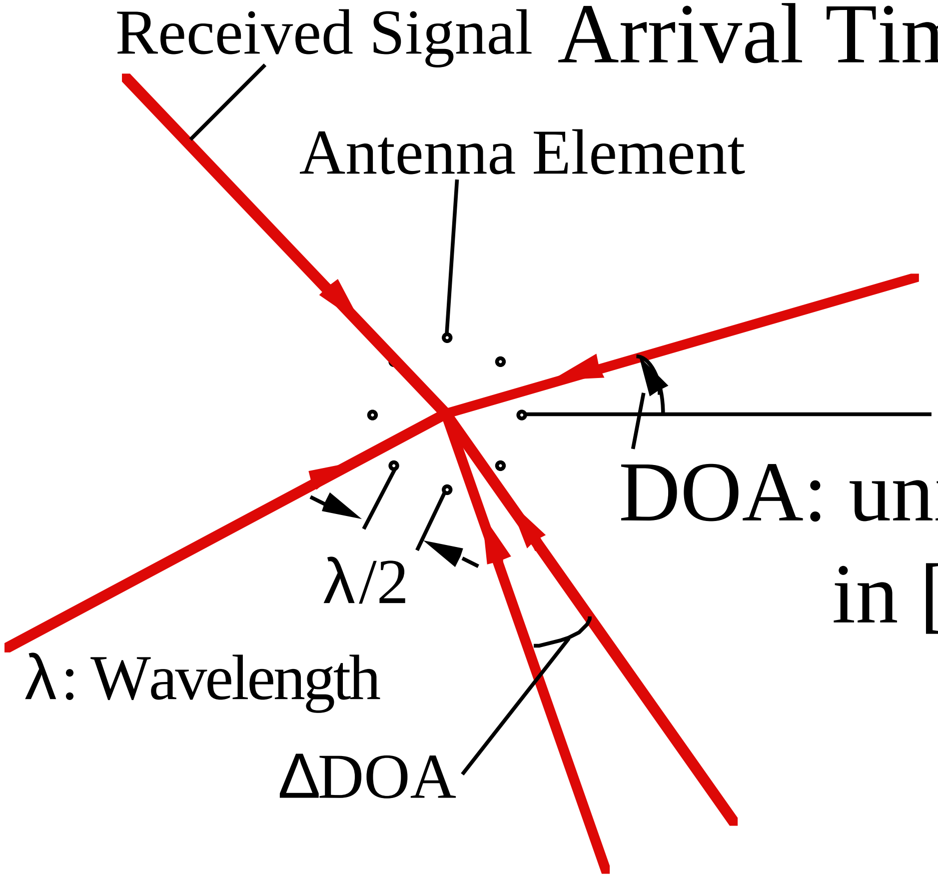


Numerical Results (by Computer Simulation)

8 Element-Circular Antenna Array (*L*=8)

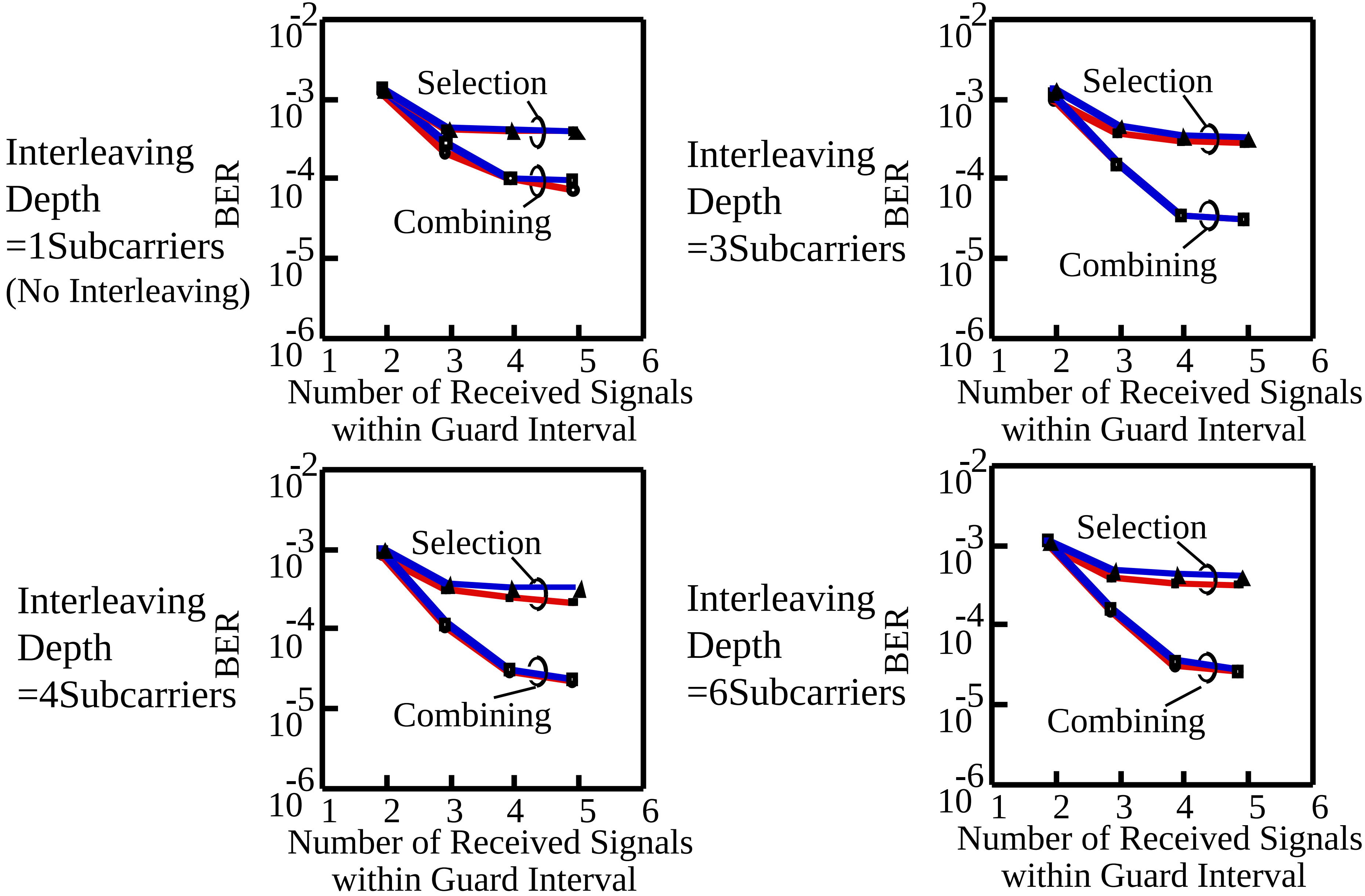
Envelope: Rayleigh distributed

Arrival Time: uniformly distributed within guard interval



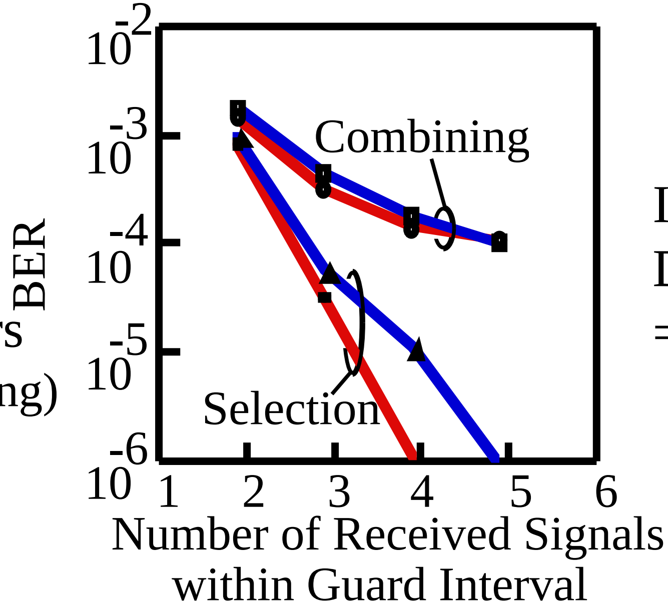
DOA: uniformly distributed in [0deg, 360deg)

One Signal beyond Guard Interval (Average E_b/N_0 per Signal=3 [dB], ΔDOA > 0 [deg])

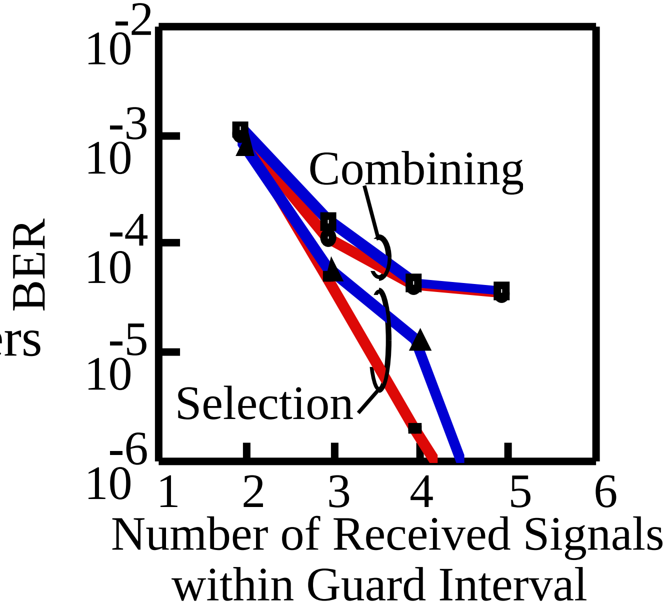


One Signal beyond Guard Interval (Average E_b/N_0 per Signal=3 [dB], ΔDOA > 30 [deg])

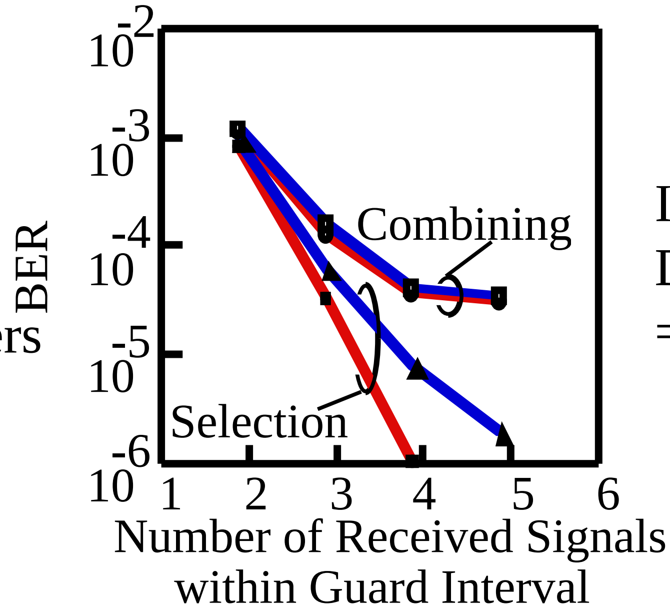
Interleaving Depth =1Subcarriers (No Interleaving)



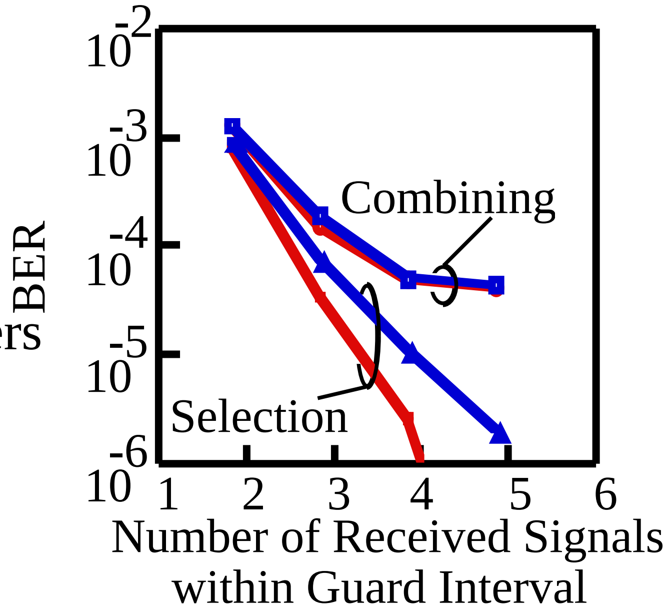
Interleaving Depth =3Subcarriers



Interleaving Depth =4Subcarriers



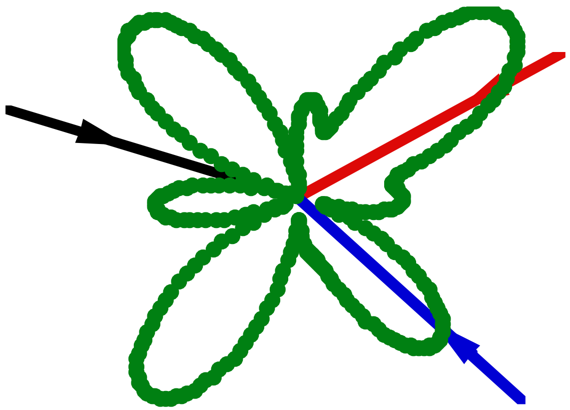
Interleaving Depth =6Subcarriers

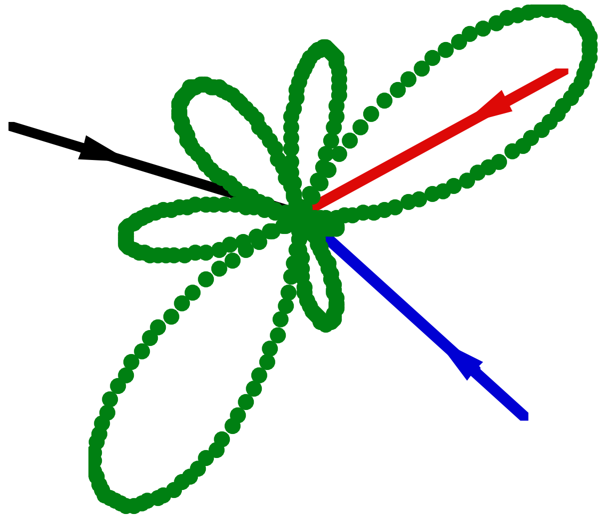


Two Signals within Guard Interval/One Signal beyond Guard Interval

8 Element-Optimum Combining

1 Element-One Signal Selection





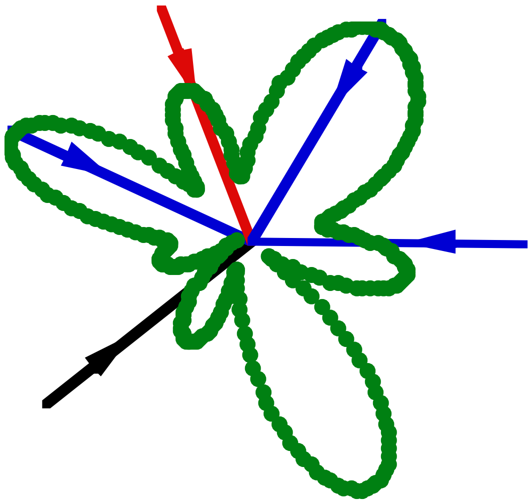
Combining Diversity Effect

Selection Diversity Effect
Frequency Non-Selective Fading

Signal within Guard Interval with Largest Power
Signal within Guard Interval
Signal beyond Guard Interval

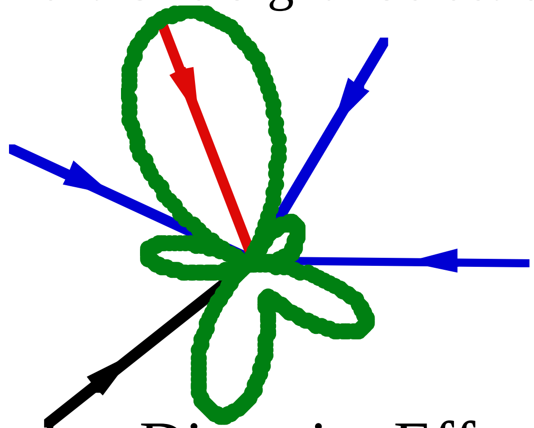
Four Signals within Guard Interval/One Signal beyond Guard Interval

8 Element-Optimum Combining



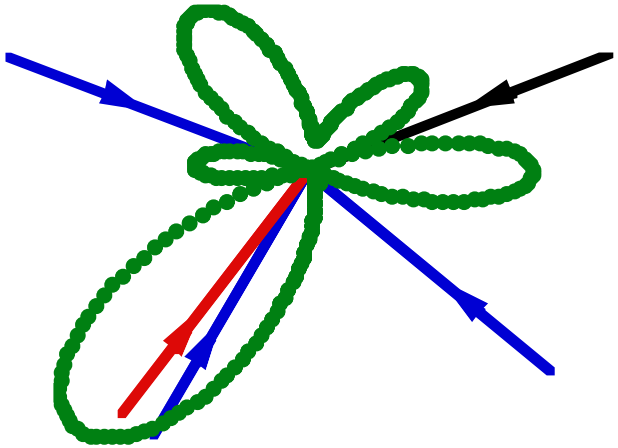
Combining Diversity Effect

1 Element-One Signal Selection



Selection Diversity Effect

Frequency Non-Selective Fading



Loss of Received Signal Power

Frequency Selective Fading

Conclusions

Suppression of Doppler-Shifted Signals

Our proposed array works well.

There are many interesting applications based on this method.

Suppression of Delayed Signals beyond Guard Interval

Our results suggest that change of array control criterion can improve the BER according to DOA pattern.

Publications

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[3] A.Nishikawa, Y.Hara and S.Hara, “An OFDM Adaptive Array for Doppler-Shifted Wave Suppression,” *Proceedings of the 2001 IEICE General Conference*, B-5-151, p.549, Mar. 2001.

[4] S.Hara, A.Nishikawa and Y.Hara, “A Novel OFDM Adaptive Antenna Array for Delayed Signal and Doppler-Shifted Signal Suppression,'” in *Proceedings of IEEE International Conference on Communications (ICC) 2001*, pp.2302-2306, Helsinki, Finland, 11-14 June 2001.

[5] S.Hane, Y.Hara, and S.Hara, “Selective Signal Reception for OFDM Adaptive Array Antenna,'” *Technical Report of IEICE*, AP-2001-69, pp.35-41, Aug. 2001.

[6] S.Hara, S.Hane and Y.Hara, “Adaptive Antenna Array for Reliable OFDM Transmission,” *Proceedings of 6th International OFDM Workshop*, pp.1.1-1.4, Hamburg, Germany, 18-19 September 2001.

[7] S.Hara, S.Hane and Y.Hara, “Does OFDM Really Prefer Frequency Selective Fading Channels,” *Proceedings of 2001 Third International Workshop on Multi-Carrier Spread-Spectrum (MCSS2001) and Related Topics*, pp.1-4, Oberpfaffenhofen, Germany, 26-28 September 2001.