[ETRI's OFDMA Parameters Based On Simulation Results]

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Abstract

In this presentation, we propose the OFDMA parameters based on the simulation results in various WRAN environments. The OFDMA parameters are separately proposed for the down stream and the up stream in consideration of their features. And the proposed OFDMA parameters are based on the simulation results focusing on the timing synchronization, carrier frequency offset estimation, residual frequency offset tracking, and channel estimation for proposed preamble and pilot pattern.

Contents

- **Overall System Parameters**
- **OFDMA Parameters for DS and US (for 6MHz)**
  - Including Frame Structure with Preamble and Pilot Pattern
- **Subchannelization**
- **Algorithms & Operation Procedure**
  - Top block diagram of PHY simulator
  - System model for synchronization
  - Initial synchronization: Timing & CFO(IFO+FFO) estimation
  - Channel estimation
  - FFO tracking
- **Simulation Conditions**
- **Simulation Results**
- **Conclusions**

Overall System Parameters

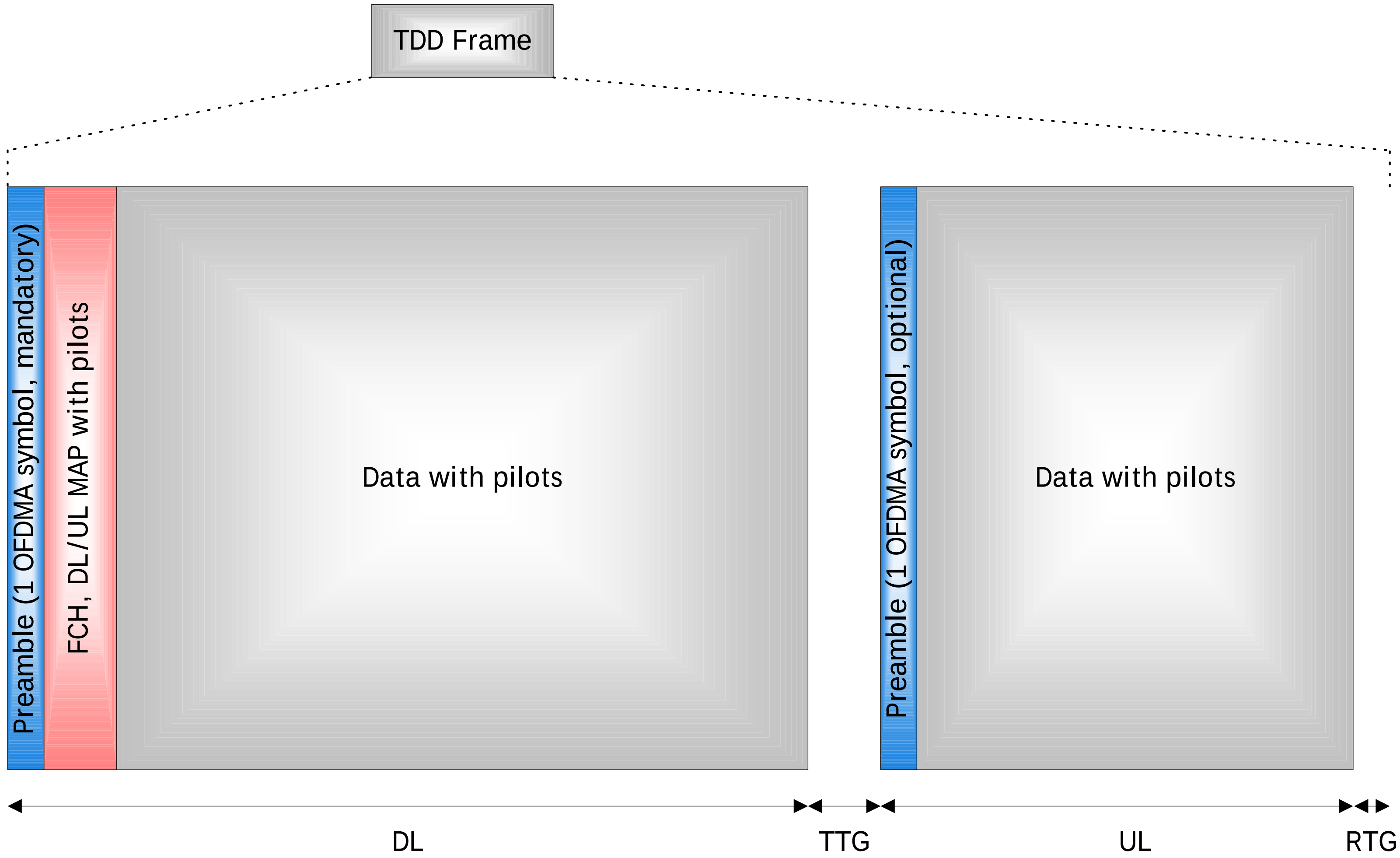
System Parameters/Single Channel (6MHz)

Mode	1K	2K	4K	6K
FFT Size	1024	2048	4096	6144
Bandwidth (k = 1, 2, …, 6)		k MHz		
Sampling Factor		8/7		
No. of Used Subcarriers (including pilot, but not DC)	140 * k	280 * k	560 * k	840 * k
Sampling Frequency	Dropped	48/7 MHz		
Subcarrier Spacing	*6.696 kHz*(***)	*3.348 kHz*	*1.674 kHz*	*1.116 kHz*
Occupied Bandwidth	*6.696* kHz*140*k	*3.348* kHz*280*k	*1.674* kHz*560*k	*1.116* kHz*840*k
Bandwidth Efficiency(*)		*93~94 %*		
FFT Time	*149.33 us*	*298.66 us*	*597.33 us*	896 us
Cyclic Prefix Time(**)	*37.33 us*	*74.66 us*	*149.33 us*	224 us
OFDMA Symbol Time	*186.66 us*	*373.33 us*	*746.66 us*	1120 us

(*) Bandwidth Efficiency = Subcarrier Spacing * (Number of Used Subcarriers + 1)/BW
(**) It is assumed that cyclic prefix mode is 1/4.
(***) Italics indicate an approximated value.

OFDMA Parameters for DS & US Including Frame Structure with Preamble & Pilot Pattern

TDD Frame Structure



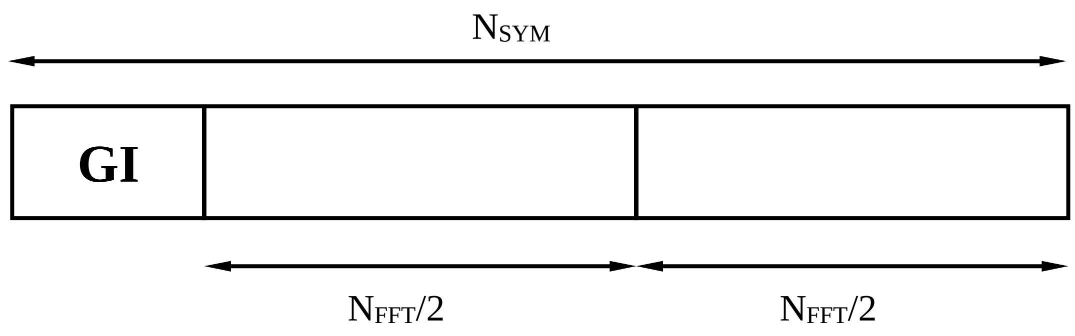
OFDMA Parameters for DS (2K FFT)

Parameter	1 TV bands		
	6	7	8
Inter-carrier spacing, ΔF (Hz) (*)	*3348*	*3906*	*4464*
FFT period, T_{FFT} (μs) (*)	*298.66*	256.00	224.00
Total no. of sub-carriers, N_{FFT}	2048		
No. of guard sub-carriers, N_G (L, DC, R)	368 (184,1,183)		
No. of used sub-carriers, $N_T = N_D + N_P$	1680		
No. of data sub-carriers, N_D	1440		
No. of pilot sub-carriers, N_P	240		
No. of sub-carriers per BIN (***)	14 (12 datas + 2 pilots)		
No. of subchannel per OFDMA symbol	30		
No. of BIN per subchannel	4		
No. of sub-carriers per subchannel (***)	56 (48 datas + 8 pilots)		
Occupied bandwidth (MHz) (*)	*5.628*	*6.566*	*7.504*
Bandwidth Efficiency (%) (**)	93.8		

(*) Italics indicate an approximated value.
(**) Bandwidth Efficiency = Subcarrier Spacing * (Number of Used Subcarriers + 1)/BW
(***) It is defined over every OFDMA symbols

Preamble Pattern

- **Two repetitions within one OFDMA symbol**
- **GI=1/4 (fixed)**
- **Preamble shall be modulated using BPSK modulation**
- **Used in channel estimation and initial synchronization**



Preamble Pattern

- **Preamble sequence**

$$P_T(k) = \begin{cases} \sqrt{2}(1-2D_m) & k = 2m,\ 0 \le m < N_{used}/4, \\ 0 & otherwise \end{cases}$$

$$P_T(k) = \begin{cases} \sqrt{2}(1-2D_m) & k = 2m+1,\ N_{used}/4 \le m < N_{used}/2 \\ 0 & otherwise \end{cases}$$

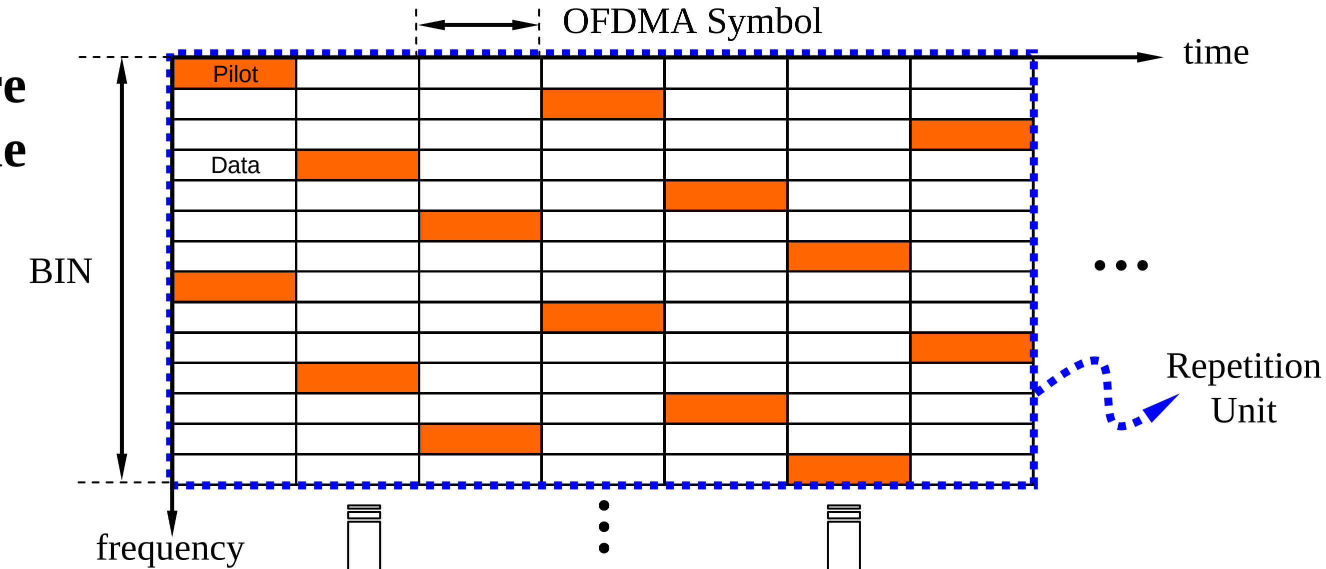
- **PN sequence generator**

$$g(x) = x^{11} + x^2 + 1$$

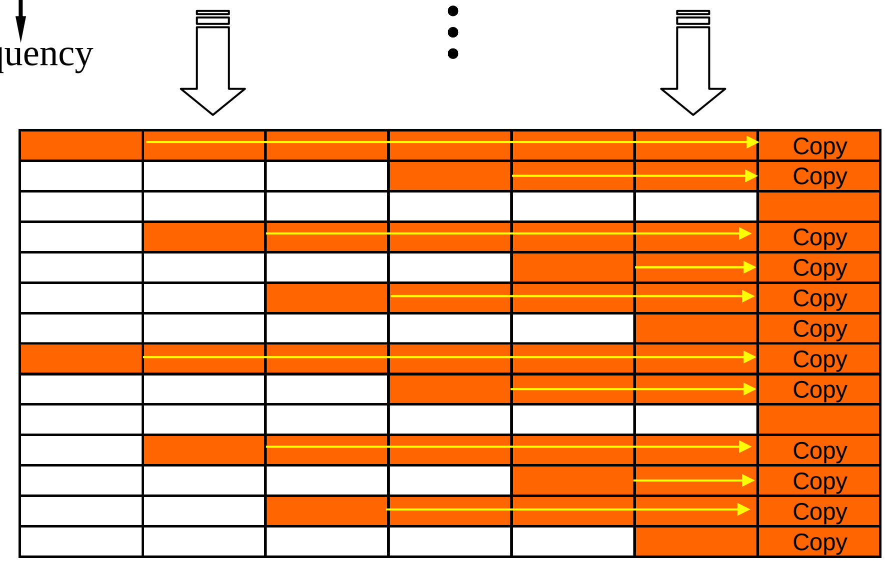
  - Initial states of PN sequence generator: 10001010100
  - Note that PN sequence has the order of 11 so that the period of preamble sequence is 2047.
    - 840 chips (half of 1680) are used for each preamble

Pilot Pattern for DS

- **Pilot Structure for Extendable Channel Estimation**



- **Available Pilot Pattern for Channel Estimation**



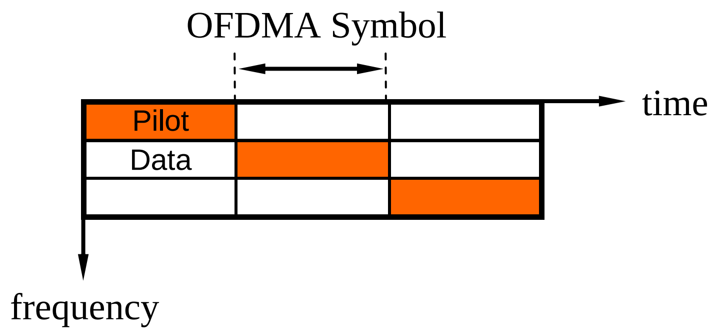
OFDMA Parameters for US (2K FFT)

Parameter	1 TV bands		
	6	7	8
Inter-carrier spacing, ΔF (Hz) (*)	*3348*	*3906*	*4464*
FFT period, T_{FFT} (μs) (*)	*298.66*	256.00	224.00
Total no. of sub-carriers, N_{FFT}	2048		
No. of guard sub-carriers, N_G (L, DC, R)	368 (184,1,183)		
No. of used sub-carriers, $N_T = N_D + N_P$	1680		
No. of data sub-carriers, N_D	1120		
No. of pilot sub-carriers, N_P	560		
No. of sub-carriers per BIN (***)	9 (6 datas + 3 pilots)		
No. of subchannel per OFDMA symbol	70		
No. of BIN per subchannel	8		
No. of sub-carriers per subchannel (***)	72 (48 datas + 24 pilots)		
Occupied bandwidth (MHz) (*)	*5.628*	*6.566*	*7.504*
Bandwidth Efficiency (%) (**)	93.8		

(*) Italics indicate an approximated value.
(**) Bandwidth Efficiency = Subcarrier Spacing * (Number of Used Subcarriers + 1)/BW
(***) It is defined over 3 OFDMA symbols

Pilot Pattern in US

- **BIN structure with pilot pattern**



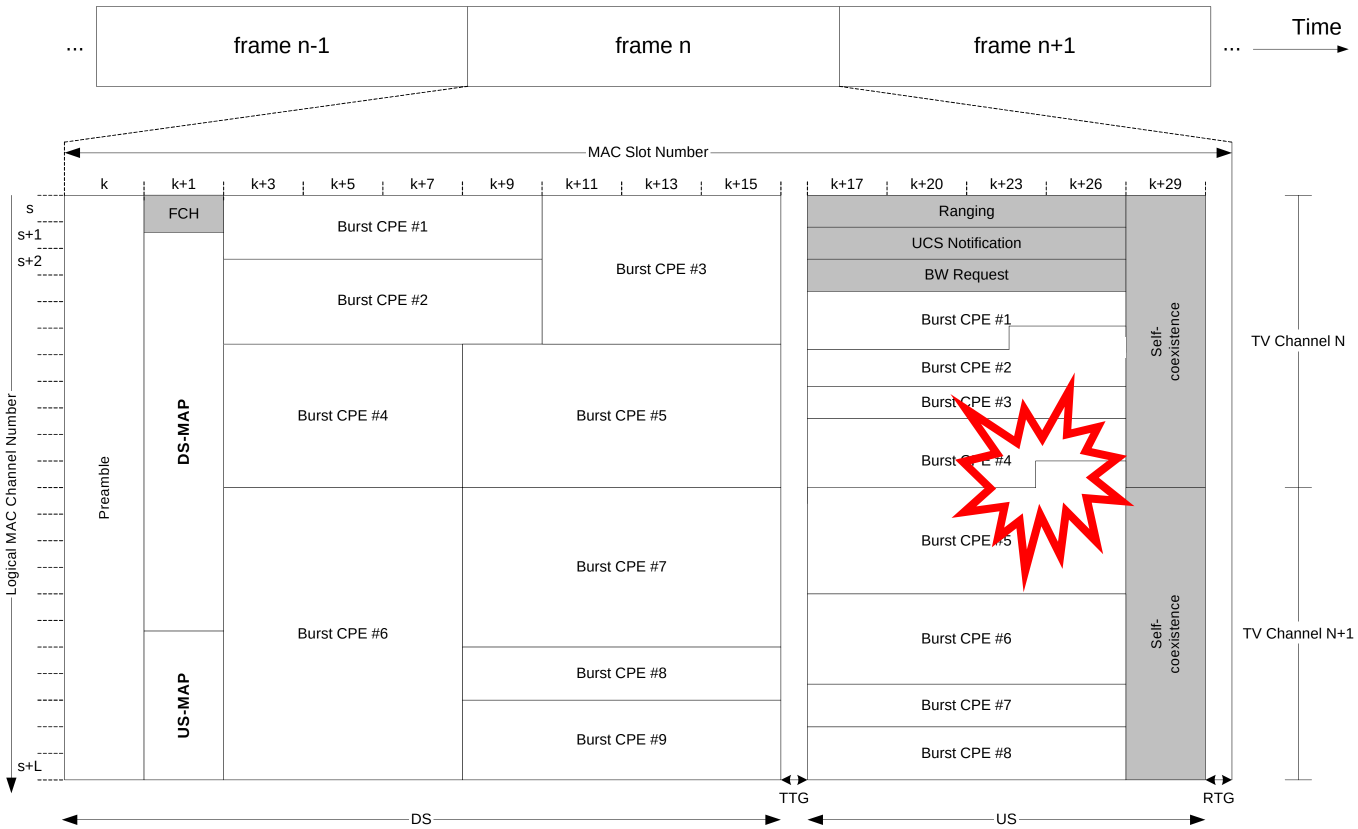
- **The subchannel is composed of 8 BINs**
- **The rule of Diversity subchannel is similar to PUSC mode of 16e US**

Short Burst Traffic in US

- **The US short burst is very possible because of an asymmetric traffic pattern**
- **If the US burst is too short for pilot to visit all subcarriers, the performance of channel estimation is getting worse.**
- **The pilots should be inserted more densely to deal with the short burst traffic in up stream.**

Shared Subchannel Case between CPEs

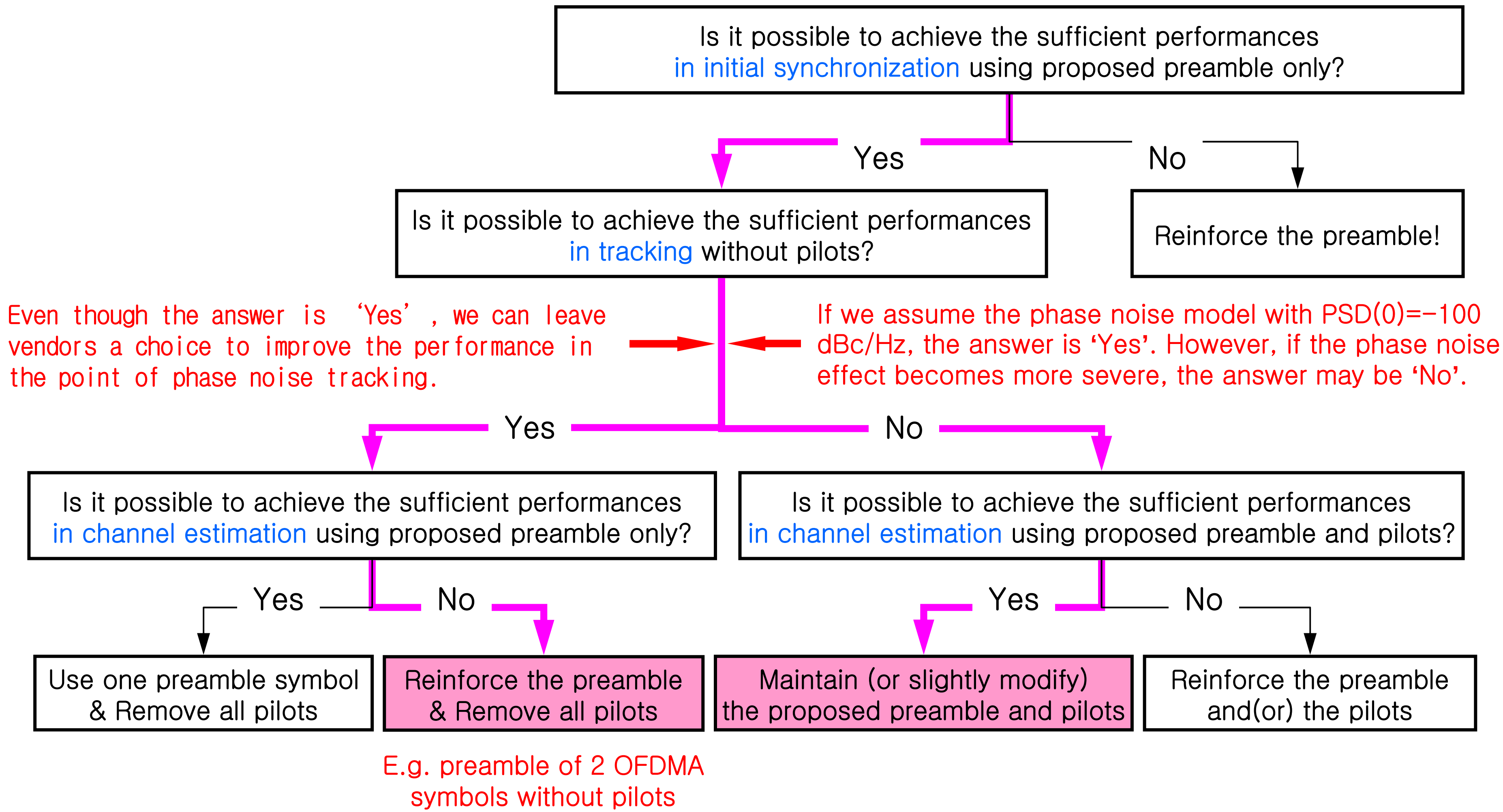
- In this case, the BS cannot use the US preamble for channel estimation of CPE.



Channel Estimation in US

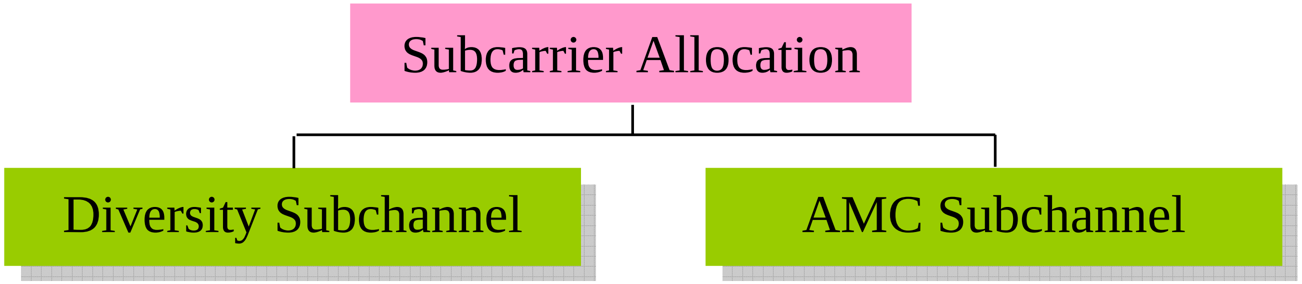
- **To reduce the performance loss of channel estimation due to the short burst and shared subchannel, we propose that the allocation unit to CPE be composed of 3 OFDMA symbols (same as PUSC mode in 16e US)**
- **The pilot symbol visits every subcarriers over 3 OFDMA symbols**
- **Using 3 OFDMA symbols, we can obtain optimum performance of channel estimation without interpolation between pilots**

Decision Procedure of Preamble and Pilot Pattern



Subchannelization

Why We Need Two Types of Subchannel?



- **In general, distributed subcarrier permutations perform very well in mobile applications or severe frequency selective environments,**
- **While adjacent subcarrier permutations can be properly used for fixed applications or flat fading environments.**

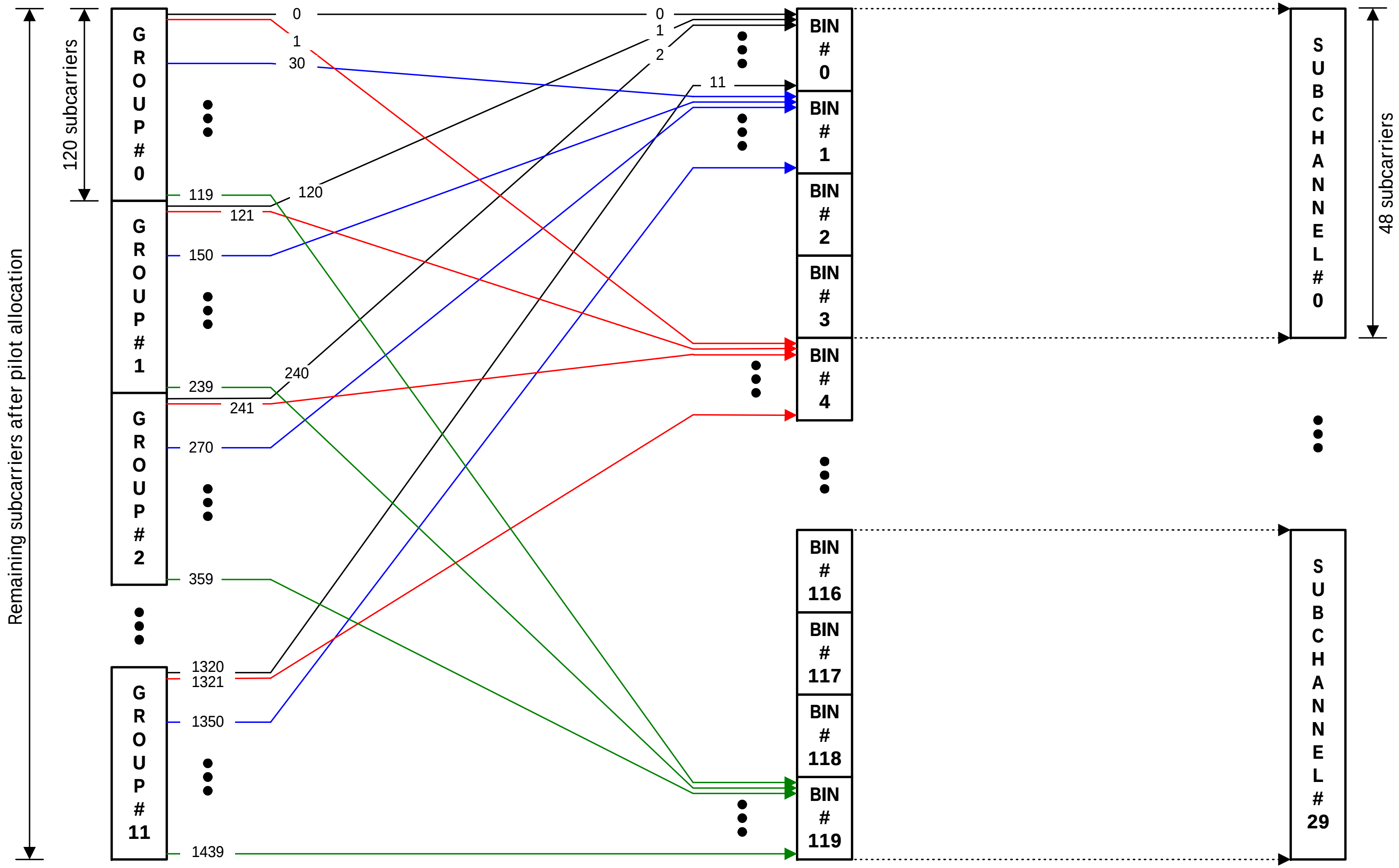
Diversity Subchannelization for DS

- **Symbol structure of Diversity subchannel in DS**
  - All the pilot subcarriers are allocated first
  - And then the remaining subcarriers are used exclusively for data transmission
  - To allocate data subchannels, the remaining subcarriers are grouped into the number of data subcarriers per BIN, $N_{subcarrier}$ (=12)
  - The number of the subcarriers in a group is equal to the number of BINs, N_{bin} (=120)
  - Thus, the number of data subcarriers is equal to $N_{subcarrier}*N_{bin}$ (=12*120)
  - The subcarrier index of subcarrier k in BIN b is according to following equation

$$subcarrier(k,b)=N_{bin}*k+N_{subchannel}*(b\%4)+int(b/4)$$

    - where,
      b is the index of BIN, from 0 to N_{bin}-1
      k is the index of subcarrier in BIN, from 0 to $N_{subcarrier}$-1
      $N_{subchannel}$ is the number of subchannel in one OFDMA symbol, equal to 30
      $int(x)$ is the integer value of x
  - The Diversity subchannel consists of 4 contiguous BINs
  - The BIN structure is a set of 12 distributed data subcarriers and 2 pilot subcarriers within an OFDMA symbol

Diversity Subchannelization for DS (Cont.)



Diversity Subchannelization for US

- **Symbol structure of Diversity subchannel in US**
  - The frequency band is divided into the number of BINs, N_{bin} (=560)
  - Divide the 560 BINs into eight groups, containing 70 adjacent BINs
  - The choice of 8 BINs to subchannel is according to following equation

$$BIN(s,n)=70*n+Pt[(s+n) \bmod 70]$$

    - where,
      n is the index of BIN, from 0 to 7
      Pt is the tile permutation
      s is the subchannel number
  - After allocating the BINs for each subchannel, the data subcarriers per subchannel are enumerated by the following process:
  - After allocating the pilot carriers within each BIN, data subcarriers is indexed from 0 to 47
  - The mapping of data into the subcarriers will follow equation

$$subcarrier(n,s)=(n+13*s) \bmod 48$$

    - where,
      n is the running index, from 0 to 47, indicating the data constellation point
      s is the subchannel number
  - The Diversity subchannel consists of 8 distributed BINs
  - The BIN structure is a set of 6 data subcarriers and 3 pilot subcarriers within 3 OFDMA symbol

AMC Subchannelization for DS & US

- **Symbol structure of AMC subchannel**
  - The AMC subchannel consists of 4 contiguous BINs
  - The BIN structure is a set of 12 contiguous data subcarriers and 2 pilot subcarriers within an OFDMA symbol
  - The j-th symbol of the 48 symbols where a band AMC subchannel is allocated is mapped onto the $(S_{per}^{off}(j)-1)$ -th subcarrier of a subchannel, *j* is [0,47]

$$S_{per}^{off}(j)=\begin{cases} P_{per}(j)+off & P_{per}(j)+off \neq 0 \\ off & P_{per}(j)+off = 0 \end{cases}$$

- where,

  $P_{per}(j)$ is the *j*-th element of the left cyclic shifted version of basic sequence P_0 by per

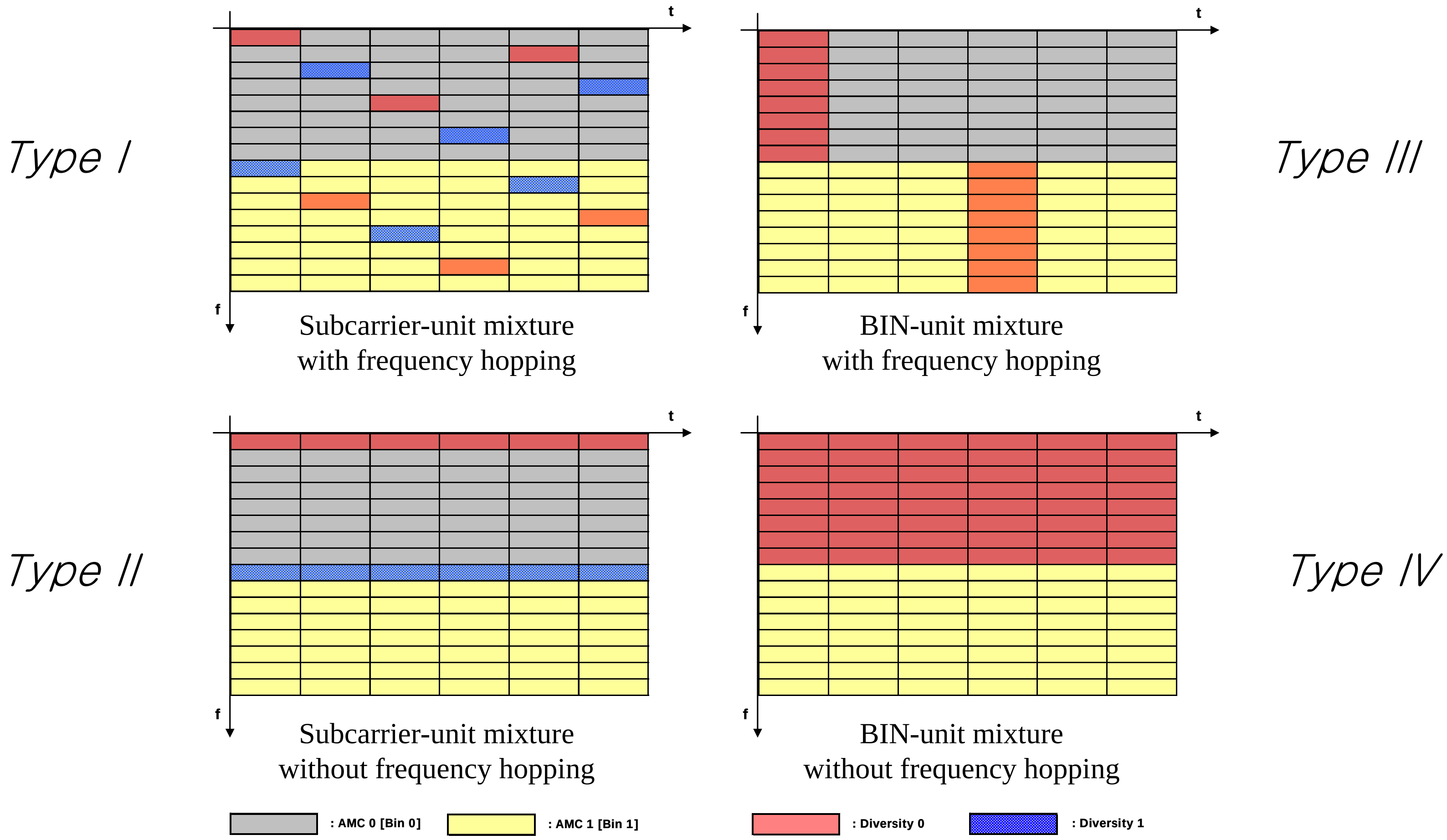
  P_0 : Basic sequence defined in GF(7^2): {01, 22, 46, 52, 42, 41, 26, 50, 05, 33, 62, 43, 63, 65, 32, 40, 04, 11, 23, 61, 21, 24, 13, 60, 06, 55, 31, 25, 35, 36, 51, 20, 02, 44, 15, 34, 14, 12, 45, 30, 03, 66, 54, 16, 56, 53, 64, 10} in hepta notation.

  per = *IDCell* mod 48

  off = (ceil(*IDcell*/48)) mod 49

Mixed Resource Composition

- **4 Types of Different Resource Composition in DL**



Subcarrier-Unit Mixture w/ Frequency Hopping

- **We assume that the ratio of Diversity to AMC is D:A**
- **The D Diversity OFDMA symbols are distributed in Ns(=D+A) OFDMA symbols**
  - If D:A is 1:5, then 1 Diversity OFDMA symbol (i.e. 30 subchannels) is distributed in 6 OFDMA symbols
  - If D:A is 2:3, then 2 Diversity OFDMA symbols (i.e. 60 subchannels) are distributed in 5 OFDMA symbols
  - So, the index of diversity subchannel (s) is varied as follows:

$$s = 0, 1, 2, \ldots, (30*D-1)$$

Subcarrier-Unit Mixture w/ Frequency Hopping

- **The subcarrier index of subcarrier *j* in subchannel s is according to following equation**

$$f_s(j) = f_s(0) + 30j,\; j = 0,1,2,\ldots,47$$

  - where,

    j is the index of subcarrier in subchannel, from 0 to 47

    s is the index of subchannel, from 0 to (30**D*-1)

    $f_s(0)$ is the first index of subcarrier in subchannel

- $\boldsymbol{f_s(0)}$ **is defined as follows:**

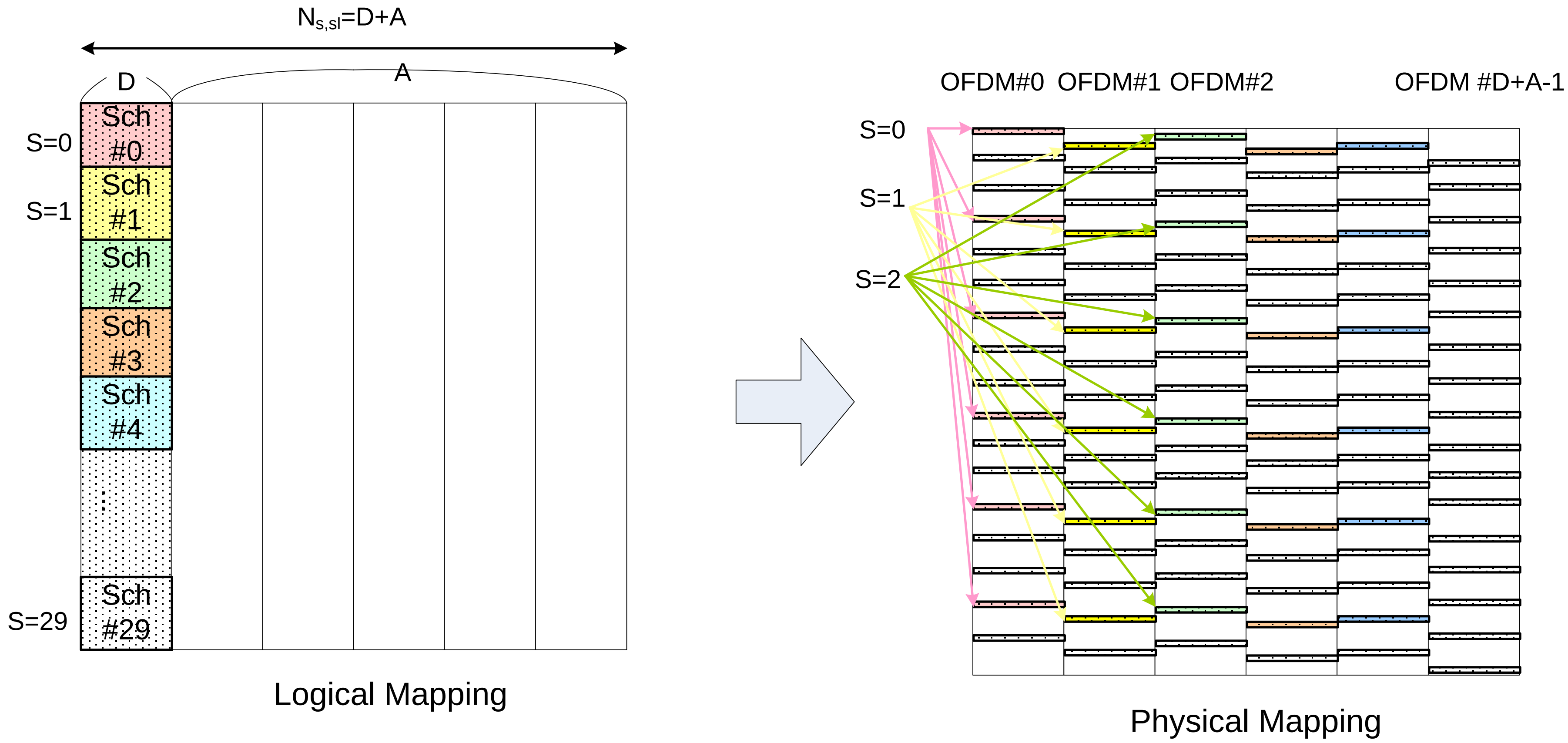
$$f_s(0) = BRO(\mathrm{mod}(s,30)) + \lfloor s/(30a) \rfloor$$

  - where, *BRO(x)* is Bit Reversal Order of *x*, and a is the $GCD(N_s,30)$

- $\boldsymbol{f_s(j)}$ **is allocated to** $\boldsymbol{t_s}$**-th OFDMA symbol**

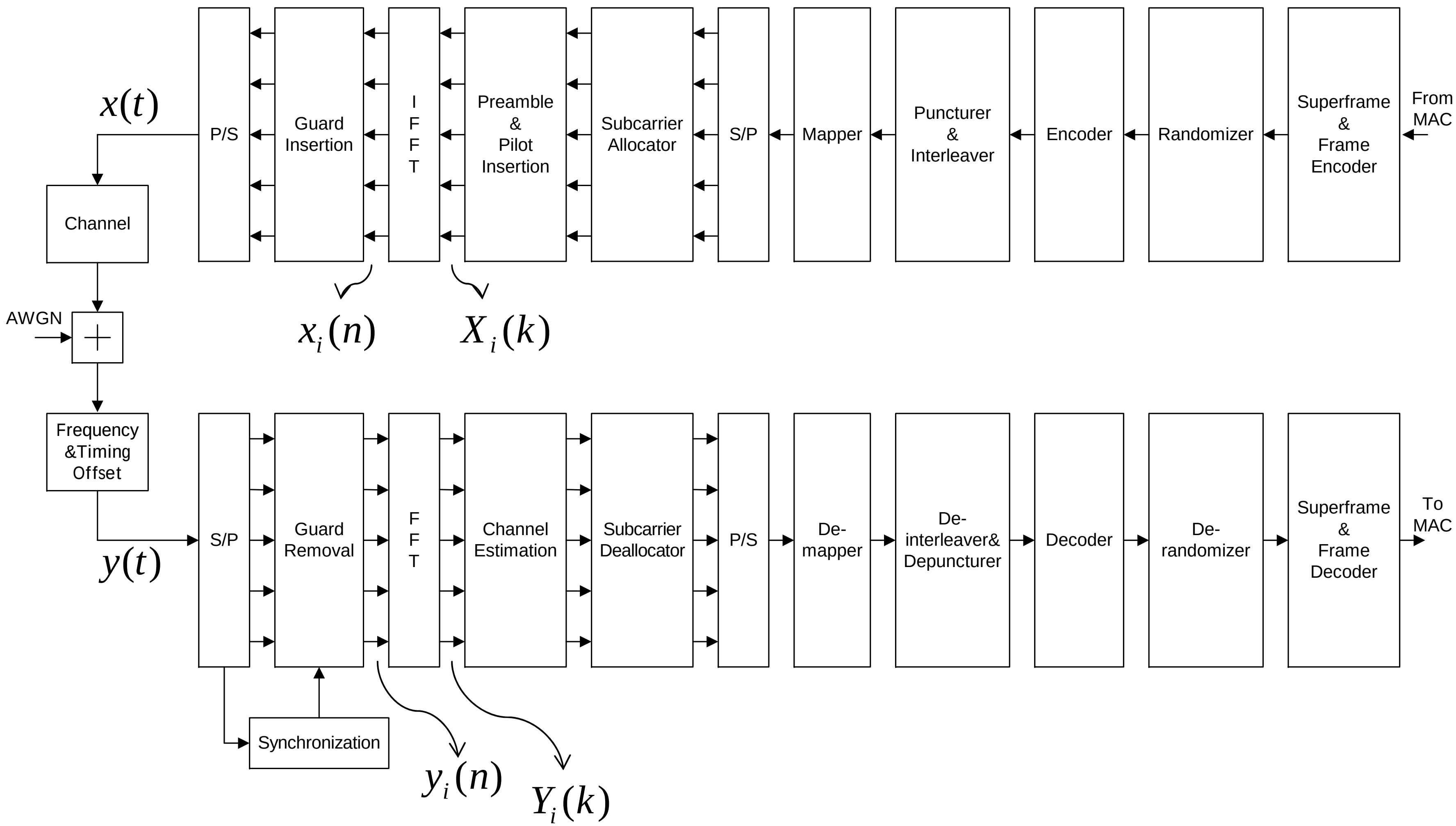
$$t_s = \mathrm{mod}(s, N_s)$$

Example of Subcarrier-Unit Mixture (D:A=1:5)



Algorithms & Operation Procedure

Top Block Diagram of WRAN PHY Simulator



Signal Model for Synchronization

- **Transmitted signal**

$$x(t)=\sum_{i=-\infty}^{\infty}\sum_{k=0}^{N-1}X_i(k)e^{j2\pi\Delta fk(t-(iT_{sym}+T_G))}p(t-(iT_{SYM}+T_G))$$, where $\Delta f=1/T$ is the subcarrier spacing

- **Received signal with carrier frequency offset (CFO)**

$$y(t)=\sum_{m=0}^{M-1}x(t-\tau_m)h_m(t)e^{j2\pi f_o t}+w(t)$$, *where*, f_0 is the carrier frequency offset

- **The time-sampled version of the received signal**

$$y(n)=\tilde{y}(n)e^{j2\pi f_o nT_S}+w(n)$$, where, T_S is the sampling time

- **Demodulated symbol at the *k*-th subcarrier in the *i*-th OFDM symbol**

$$Y_i(k)=e^{j2\pi f_0(iN_{SYM}+N_G)T_S}\cdot e^{j\theta}\cdot X_i(k)H_i(k)+W_i(k)$$

Timing Synchronization

- **With the Schmidl's method**
  - Autocorrelation method using the following

$$y(n+\frac{N}{2}) = y(n)e^{j\pi f_o N T_S}$$

  - The metric

$$TM(d) = \frac{|P(d)|}{M(d)}$$

where $P(d) = \sum_{n=0}^{D-1} y^*(d+n)y(d+n+D), \quad (D = N/2)$

$$M(d) = \sum_{n=0}^{D-1} |y(d+n)|^2$$

  - Timing $t_o = \max_d TM(d)$

Timing Synchronization

- **Enhanced timing metric**
  - to resolve the timing ambiguity in the plateau
  - to protect the timing outside the guard interval

$$NM(d) = \sum_{w=-W/2}^{W/2} TM(d+w)$$

$$t_o = \max_d NM(d)$$

CFO(FFO+IFO) Estimation

- **When the timing is obtained, the received samples corresponding to the preamble are given by**

$$y(n+N/2) = y(n)e^{j\pi f_o N T_S} = y(n)e^{j\pi\varepsilon}$$

$$P(t_o) = \sum_{n=0}^{N/2-1} y(n)^* y(n+N/2) = \sum_{n=0}^{N/2-1} |y(n)|^2 e^{j\pi\varepsilon}$$

- **FFO estimates using Preamble in time-domain**

$$\hat{\varepsilon}_f = \frac{1}{\pi}\tan^{-1}\left(\frac{\mathrm{Im}(P(t_0))}{\mathrm{Re}(P(t_0))}\right) \qquad -1 < \hat{\varepsilon}_f \le 1$$

$$-\frac{1}{T} < \hat{f}_o \le \frac{1}{T}$$

CFO(FFO+IFO) Estimation

- **Two components in the CFO**

$$\varepsilon = f_o T = 2\varepsilon_i + \varepsilon_f$$

$-1 < \varepsilon_f \le 1$: Fractional frequency offset (FFO)

$\varepsilon_i = -\mu, -\mu+1, \ldots, 0, 1, \ldots, \mu-1, \mu$: Integral frequency offset (IFO)

  - Only the FFO can be estimated in the time domain

- **Integral frequency offset (IFO) estimation**
  - After compensating ε_f , the FFT output is given by

$$y(n) = x(n)e^{j\theta_o}e^{j\frac{4\pi\varepsilon_i n}{N}} \quad \xleftrightarrow{\text{FFT}} \quad Y(k) = X(k-2\varepsilon_i)e^{j\theta_o}$$

CFO(FFO+IFO) Estimation

- **IFO estimation**
  - We can obtain the IFO using the correlation of the PN sequence

$$F(g) = \frac{\sum_{k \in S_c} Y(k+2) P_T^{*}(k+2g+2) Y^{*}(k) P_T(k+2g)}{\sum_{k \in S_c} |Y(k)|^2}, \; -\mu \le g \le \mu$$

$$\hat{\varepsilon}_i = \max_{-\mu \le g \le \mu} |F(g)|$$

- **Total CFO estimation range:**

$$-2\mu - 1 < \hat{\varepsilon} \le 2\mu + 1$$

CFO(FFO+IFO) Estimation Range

- **Requirements on the CFO estimation**
  - BS : 2 ppm
  - CPE : 8 ppm
- **Worst case scenario**
  - BS - CPE : 10 ppm at the frequency of 862 MHz
  - CFO estimation up to -8.62 kHz ~ 8.62 kHz
- **Estimation with the proposed preamble**
  - Estimation range in the time domain: ***-3.348 kHz ~ 3.348 kHz***
  - We should estimate IFO in (-2 ,2) (1 PN offset)
  - Even though the proposed method can estimate the IFO up to 682, we set the estimation range as (-8, 8) at the receiver.

FFO Tracking Algorithms Using GI

- **FFO estimation using GI in the time-domain**

$$y(n+N) = y(n)e^{j2\pi f_o N T_S} = y(n)e^{j2\pi\varepsilon}$$

$$\gamma = \sum_{n=0}^{N_G-1} y(n)^* y(n+N) = \sum_{n=0}^{N_G-1} |y(n)|^2 e^{j2\pi\varepsilon}$$

- **FFO estimates using GI in the time-domain**

$$\hat{\varepsilon}_f = \frac{1}{2\pi}\tan^{-1}\left(\frac{\mathrm{Im}(\gamma)}{\mathrm{Re}(\gamma)}\right) \qquad -0.5 < \hat{\varepsilon}_f \le 0.5$$

$$-\frac{1}{2T} < \hat{f}_o \le \frac{1}{2T}$$

FFO Tracking Algorithms Using Pilots

- **FFO estimation using Pilot in the frequency-domain**

$$Y_i(k) = e^{j2\pi f_0 (iN_{SYM} + N_G)T_S} \cdot e^{j\theta} \cdot X_i(k) H_i(k) + W_i(k)$$

$$Y_{i+1}(k + \Delta k) \approx Y_i(k) e^{j2\pi f_0 N_{SYM} T_S}$$

$$\gamma = \sum_{n=0}^{N_P - 1} \left[Y_i^*(a_n) Y_{i+1}(a_n + \Delta k) \right] = \sum_{n=0}^{N_P - 1} \left| Y_i(k) \right|^2 e^{j2\pi f_0 N_{SYM} T_S}$$

where, a_n is the index of the n th pilot,

and Δk is the subcarrier spacing between pilots in the adjacent OFDM symbol

- **FFO estimates using Pilot in the frequency-domain**

$$\hat{\varepsilon}_f = \frac{1}{2\pi(1 + R_G)} \tan^{-1}\left(\frac{\mathrm{Im}(\gamma)}{\mathrm{Re}(\gamma)} \right) \qquad -0.4848 < \hat{\varepsilon}_{f,\max} \le 0.4848$$

where, R_G is the ratio of GI size to FFT size

Channel Estimation

- **Received Signal Vector**

$$Y = XH + W$$

  - Y: received signal vector in the frequency domain
  - X: diagonal matrix containing data symbols
  - W: AWGN

- **At Pilot Positions**

$$Y_P = X_P H_P + W_P$$

X_P: diagonal matrix containing pilot symbols

H_P: channel response at pilot positions

LMMSE Channel Estimation

- **Linear minimum mean-squared error (LMMSE) estimation**
  - Minimizes the mean-squared error between the channel response H and $\hat{H}$.
  - High computational complexity but good performance.
- **To reduce the complexity in LMMSE estimation, low-rank approximations or partitioned LMMSE may be used.**

LMMSE Channel Estimation

- ***Wiener - Hopf* Equation**
  - Assume that the estimator $\hat{H}$ is constrained to be a linear function of Y_P.
  - The problem is to find the matrix K that minimizes the mean-squared error between H and the linear estimator $\hat{H} = KY_P$.
  - The necessary and sufficient condition for the mean-squared error to be minimized is for the estimation error to be orthogonal to each input sample, which is expressed by the *Wiener-Hopf* equation.

$$E\left[(H - KY_P)Y_P^H\right] = 0 \quad \rightarrow \quad K = R_{HY_P} R_{Y_PY_P}^{-1} \quad \rightarrow \quad \hat{H}_{lmmse} = R_{HY_P} R_{Y_PY_P}^{-1} Y_P$$

$$R_{HY_P} = E\left[HY_P^H\right] = R_{H\hat{P}} X_P^H$$

$$R_{Y_PY_P} = E\left[Y_P Y_P^H\right] = X_P R_{PP} X_P^H + \sigma_n^2 I$$

where $\hat{p}$ is the noisey pilot estimates, σ_n^2 is the variance of the channel noise W_p , and R_{PP} is the autocovariance matrix of the noiseless pilots.

LMMSE Channel Estimation

- **LMMSE(Linear Minimum Mean-Squared Error) Estimates**

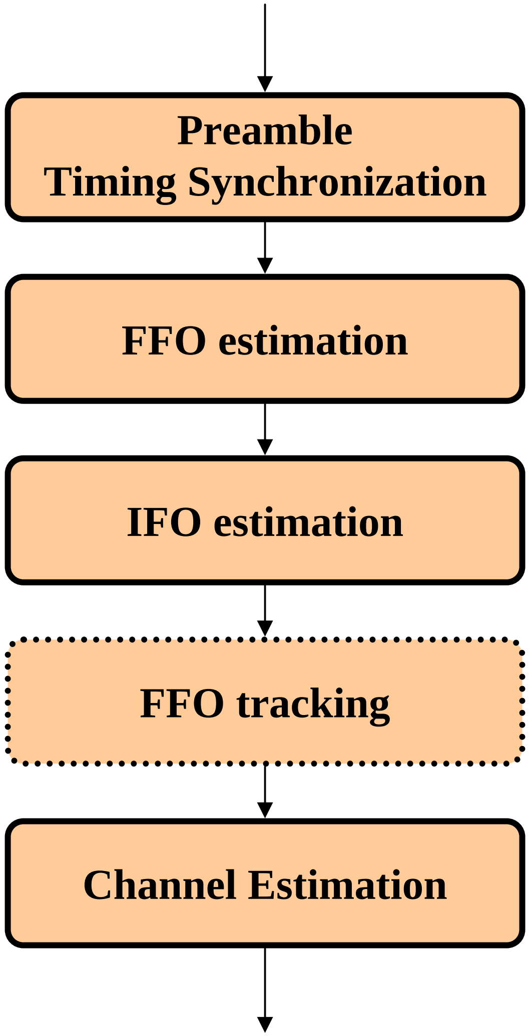
$$\begin{aligned}\hat{H}_{lmmse} &= R_{HY_P} R_{Y_P Y_P}^{-1} Y_P \\ &= R_{H\hat{P}} X_P^H \left[X_P R_{PP} X_P^H + \sigma_n^2 I \right]^{-1} Y_P \\ &= R_{H\hat{P}} \left[R_{PP} + \sigma_n^2 \left(X_P X_P^H \right)^{-1} \right]^{-1} \hat{H}_{ls} \\ &= R_{H\hat{P}} \left[R_{PP} + \frac{\beta}{SNR} I \right]^{-1} \hat{H}_{ls}\end{aligned}$$

where, $\hat{H}_{ls} = X_P^{-1} Y_P = \begin{bmatrix} \dfrac{Y_0}{X_0} & \dfrac{Y_1}{X_1} & \cdots & \dfrac{Y_{N_P-1}}{X_{N_P-1}} \end{bmatrix}^T$

$$\beta = E\left[\left| X_k \right|^2 \right] E\left[\left| 1/X_k \right|^2 \right] \qquad SNR = E\left[\left| X_k \right|^2 \right] / \sigma_n^2$$

- It also requires to know the covariance matrix of the channel and the average SNR.

Synchronization & Ch. Estimation Procedure



Simulation Conditions

Simulation Conditions

- **Channel coding**
  - 802.16e convolutional coding
  - Code rate: 1/2, 2/3, 3/4, 5/6
- **Modulation**
  - Data: QPSK, 16QAM, 64QAM
  - Preamble, Pilot: BPSK
  - No boosting
- **FFT size and GI ratio**
  - FFT size: 2K
  - GI ratio: 1/4
- **Subchannelization**
  - No. of used subcarriers for 2K: 1680 (30 subchannels x 56 subcarriers)
  - Subchannel type: Diversity & AMC

Simulation Conditions

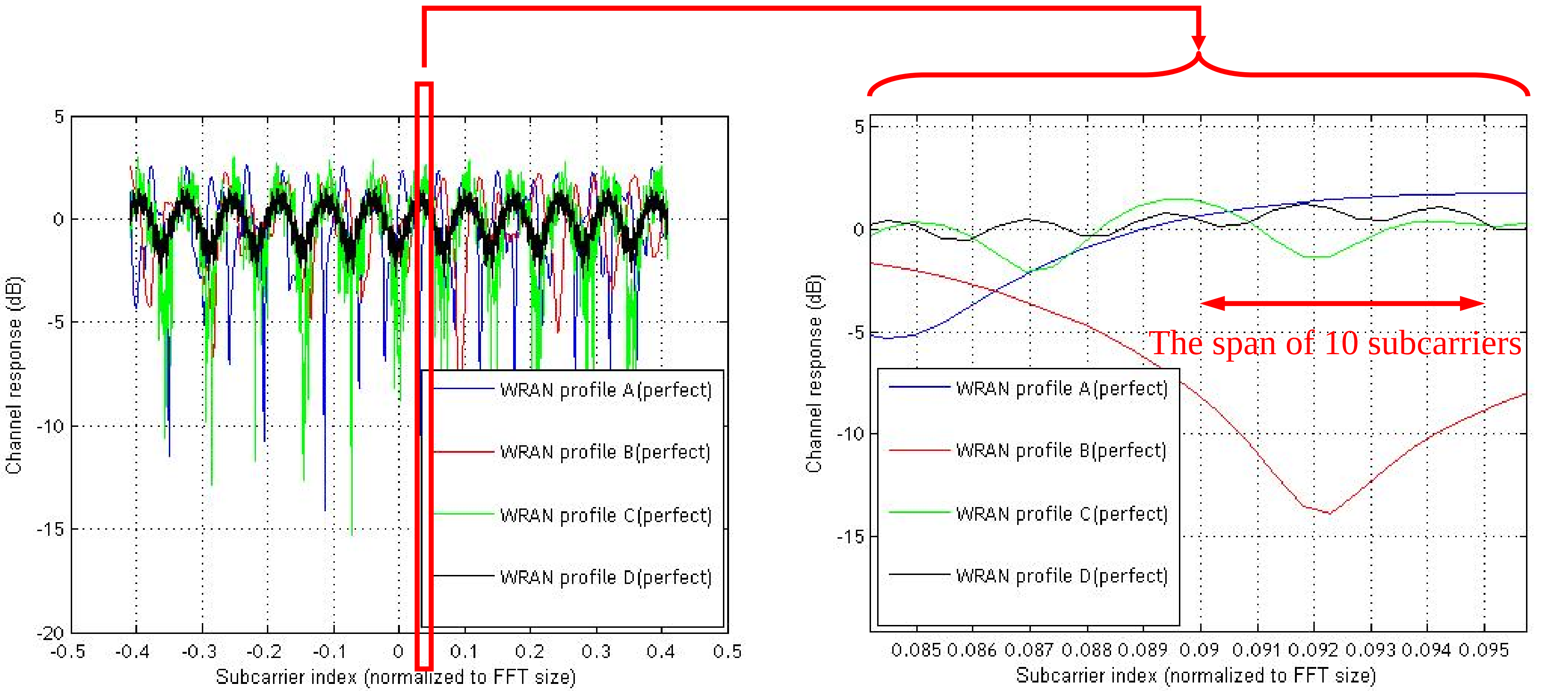
- **Channel Modeling**
  - AWGN
  - Multipath profiles & Doppler: A, B, C, D
    - Approximation to nearest sampling point
    - Jakes Rayleigh modeling method

Multipath Profile	A	B	C	D
RMS Delay Spread (us)	2.772	1.956	5.692	16.527(*)

(*) For WRAN profile D, we assume that the 6-th path has the excess delay of 60 us and relative power of -10 dB

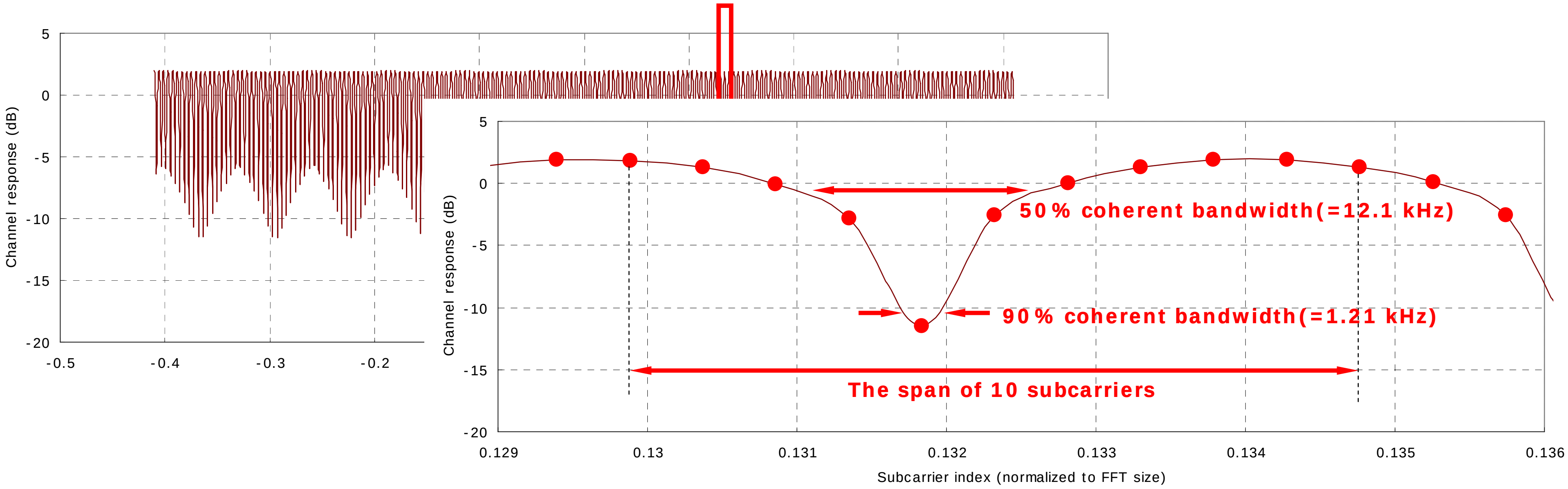
Simulation Conditions

- **Channel Modeling**
  - Multipath profiles & Doppler
    - Channel response of WRAN multipath profile



Simulation Conditions

- **Coherent bandwith vs. Nyquist rate**
  - Two ray model: one ray has 0 us delay, another ray has 33 us delay
  - The rms delay spread is 33/2=16.5 us, from the definition
  - 90% coherent BW is 1.21 kHz, from 1/(50*rms delay spread)
  - 50% coherent BW is 12.1 kHz, from 1/(5*rms delay spread)



Simulation Conditions

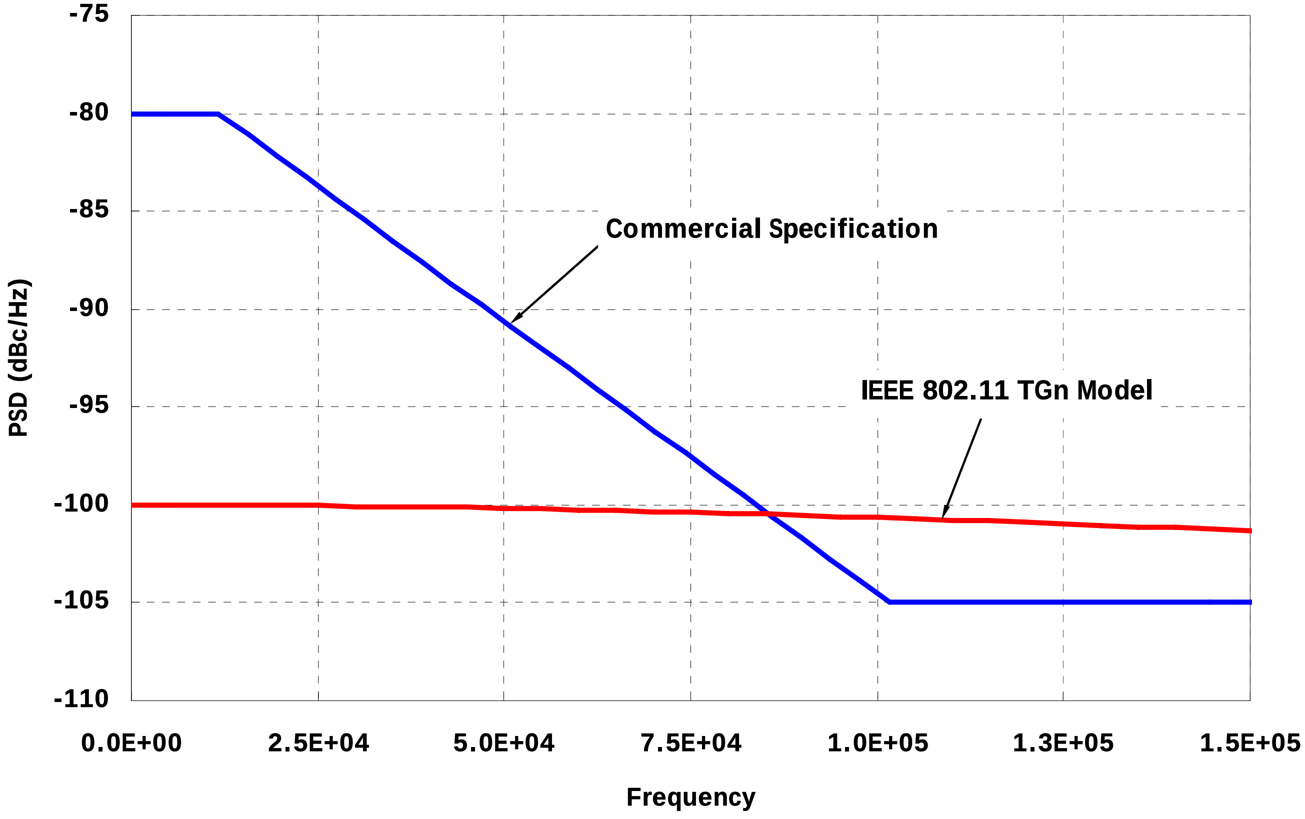
- **Phase Noise : Commercial Specifications**

Simulation Model

Application	Frequency Range	Specifications	Company
DVB-T(OFDM)	50.5 ~ 858 MHz	-80 dBc/Hz @ 1 kHz -80 dBc/Hz @ 10 kHz -105 dBc/Hz @ 100 kHz	S Company
DVB-T(OFDM)	470 ~ 860 MHz	-90 dBc/Hz @ 10 kHz	R Company
DVB-T(OFDM)	470 ~ 860 MHz	-80 dBc/Hz @ 1 kHz -91 dBc/Hz @ 10 kHz -102 dBc/Hz @ 100 kHz -128 dBc/Hz @ 1 MHz	R Company
DVB-T(OFDM)	470 ~ 862 MHz	-80 dBc/Hz @ 1 kHz -87 dBc/Hz @ 10 kHz	P Company
DVB-T(OFDM)	40 ~ 870 MHz	-85 dBc/Hz @ 10 kHz	R Company
WLAN(OFDM)	2.4 or 5 GHz	$PSD(f) = PSD(0)\frac{[1+(f/f_z)^2]}{[1+(f/f_p)^2]}$ where, $PSD(0)$=-100 dBc/Hz, f_p=250 kHz, f_z=7905.7 kHz	IEEE 802.11 TGn

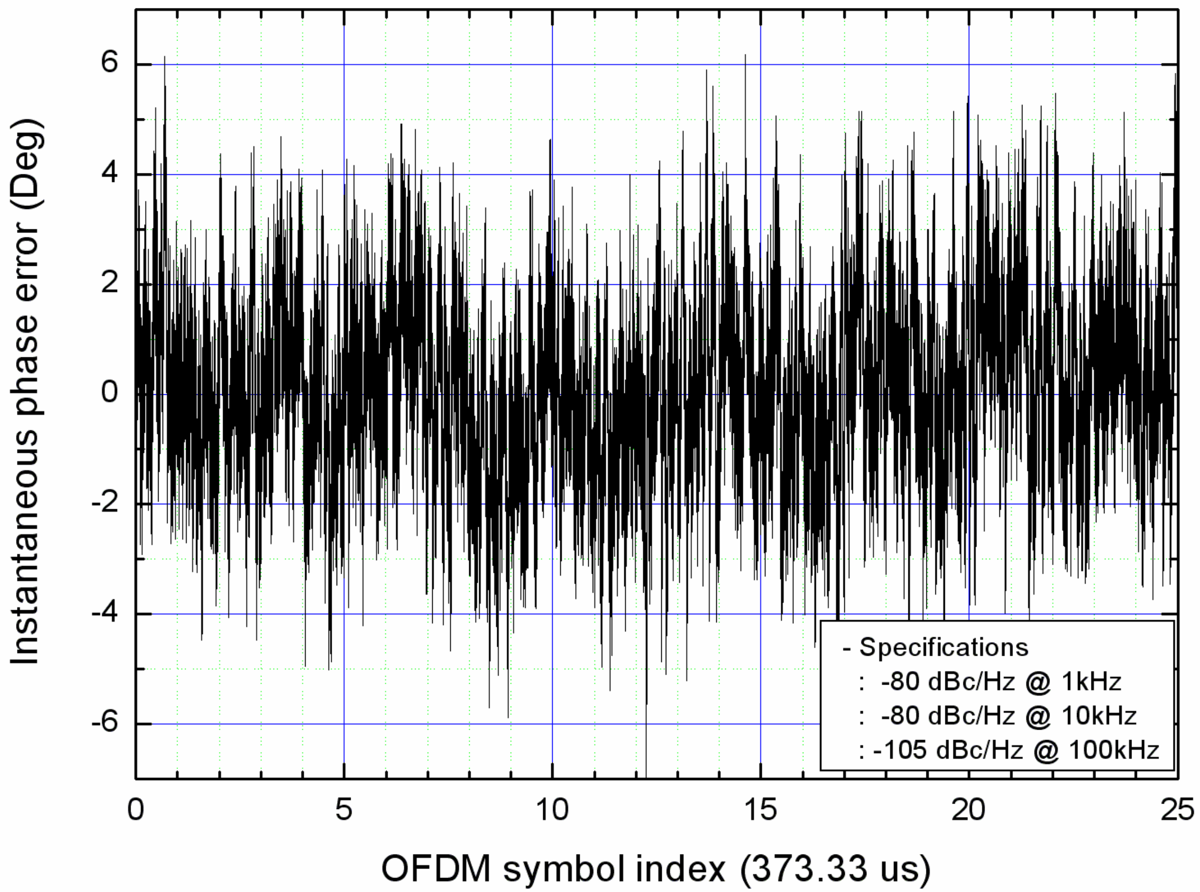
Simulation Conditions

- **Phase Noise : PSD**



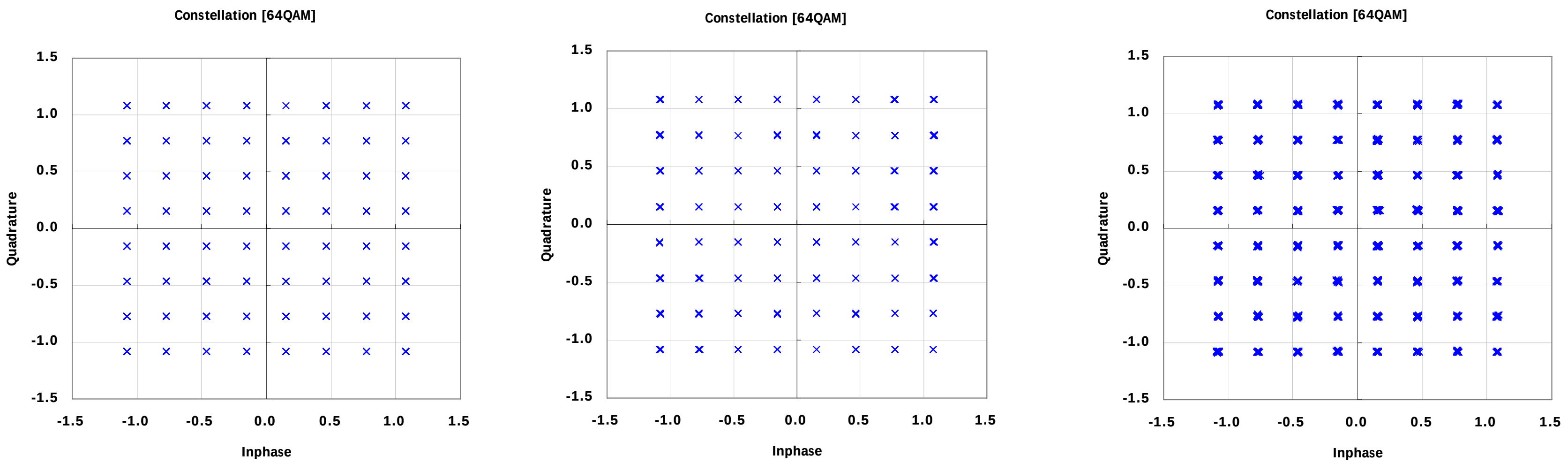
Simulation Conditions

- **Phase Noise : Instantaneous Phase Error**



Simulation Conditions

- **Phase Noise**
  - 64QAM constellations with phase noise



(a) Ideal (b) IEEE 802.11 TGn model (c) Commercial specification

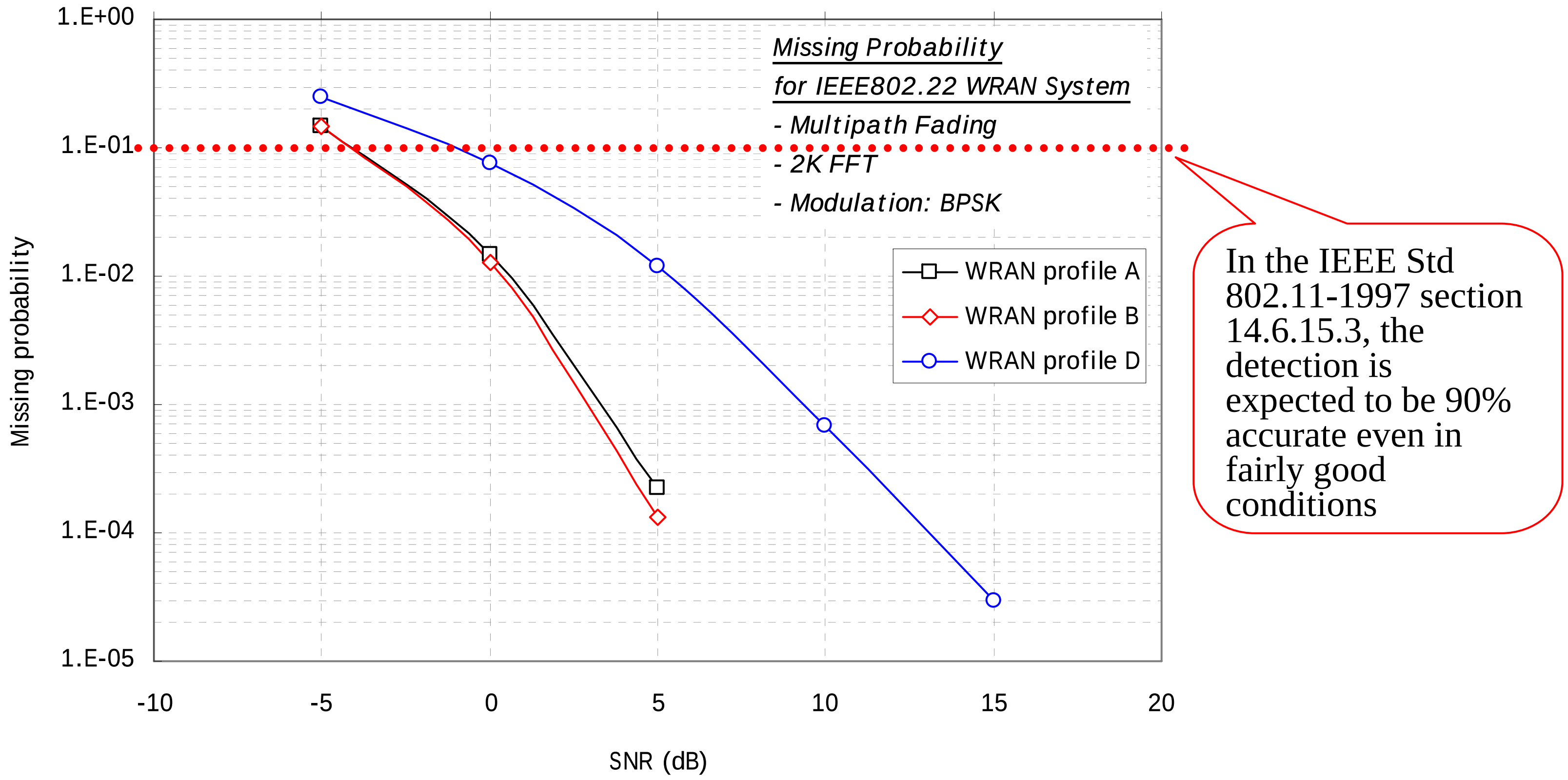
- **Carrier frequency offset (CFO) : 8.62 kHz**

Simulation Results

1. Missing probability of preamble starting point
2. MSE of CFO estimate (in acquisition)
3. MSE of FFO estimate (in tracking)
4. Uncoded BER of LMMSE estimation
5. Performance comparison for calculation method of covariance matrix
6. Performance comparison for frequency offset effect
7. Performance comparison for preamble and pilot pattern
8. Performance comparison for phase noise
9. Uncoded/Coded Bit/Block error rate performance under ideal channel estimation
10. Performance of mixed resource composition

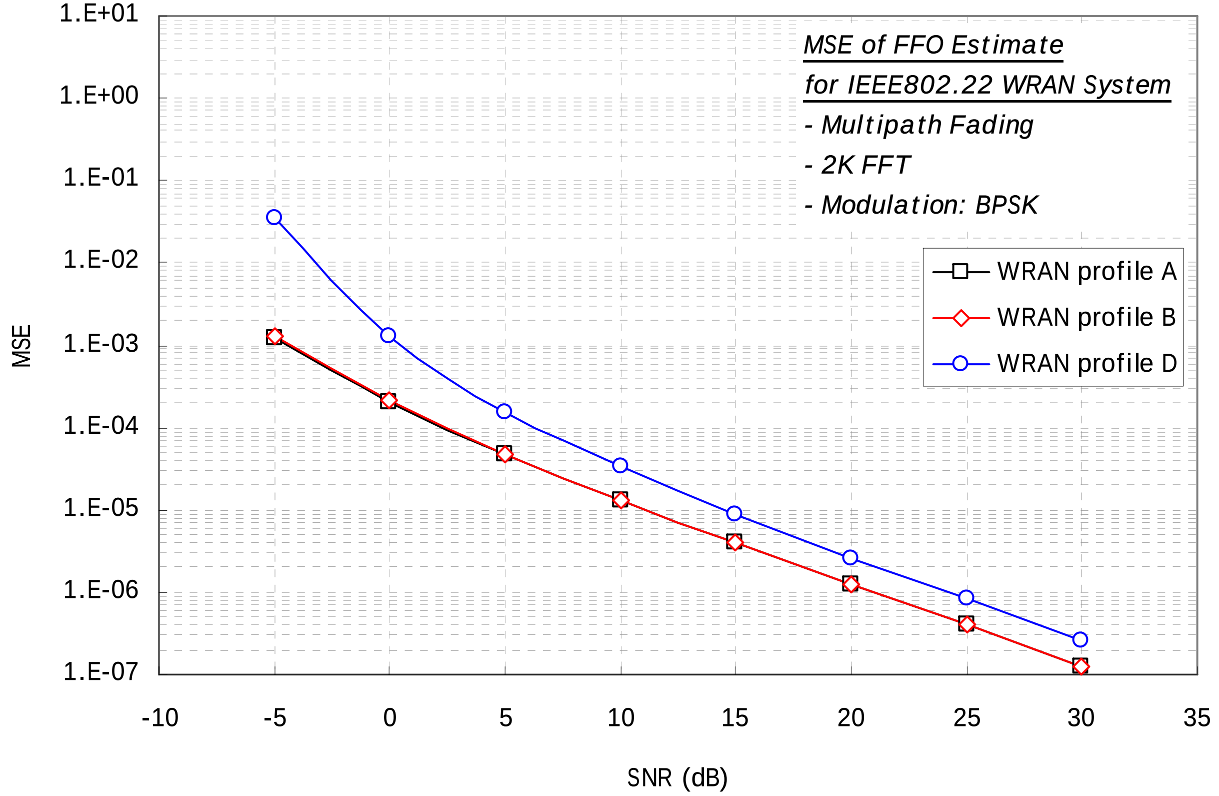
Missing Probability of Preamble Starting Point

- Window size W=64
- Missing probability is defined by the probability that the timing is obtained outside of the guard interval of the preamble.



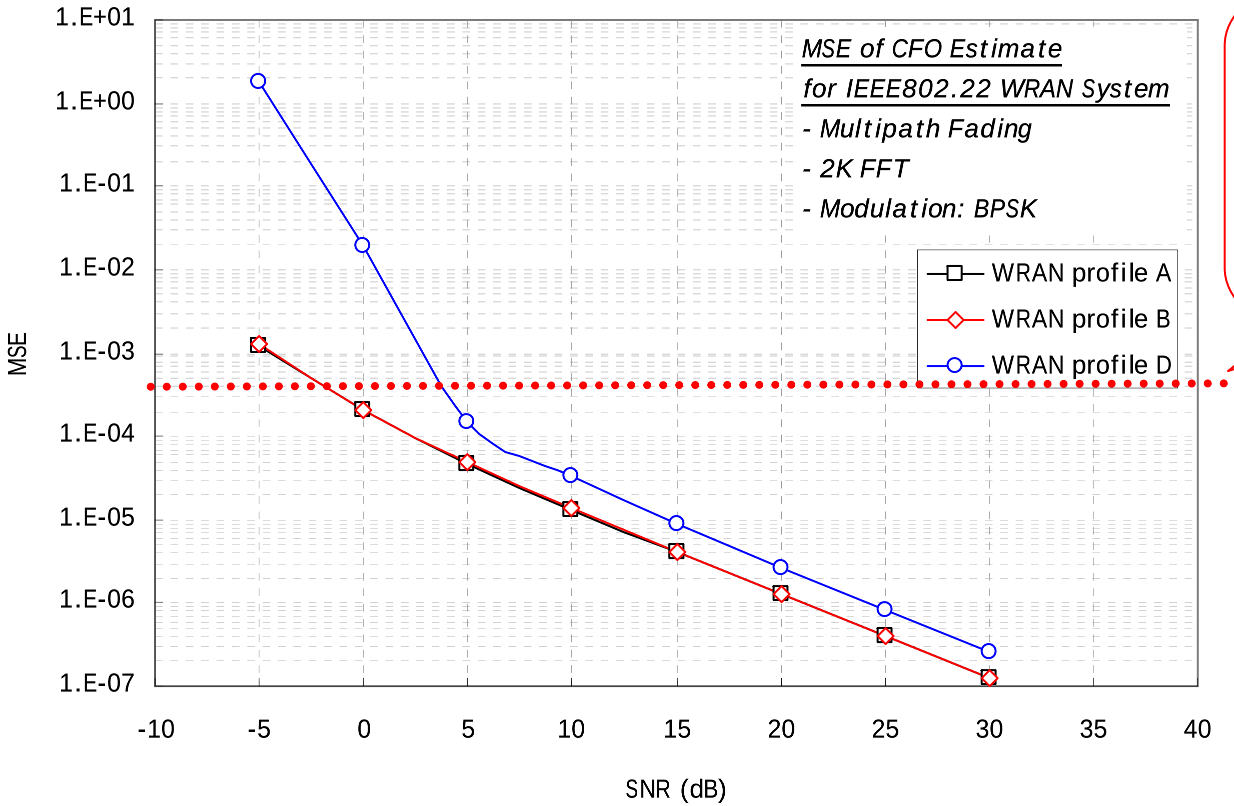
MSE of FFO Estimate (Using DS Preamble)

- $MSE = E\{|\,\varepsilon_f - \hat{\varepsilon}_f\,|^2\}$



MSE of CFO Estimate (Using DS Preamble)

- $MSE = E\{|\varepsilon - \hat{\varepsilon}|^2\}$

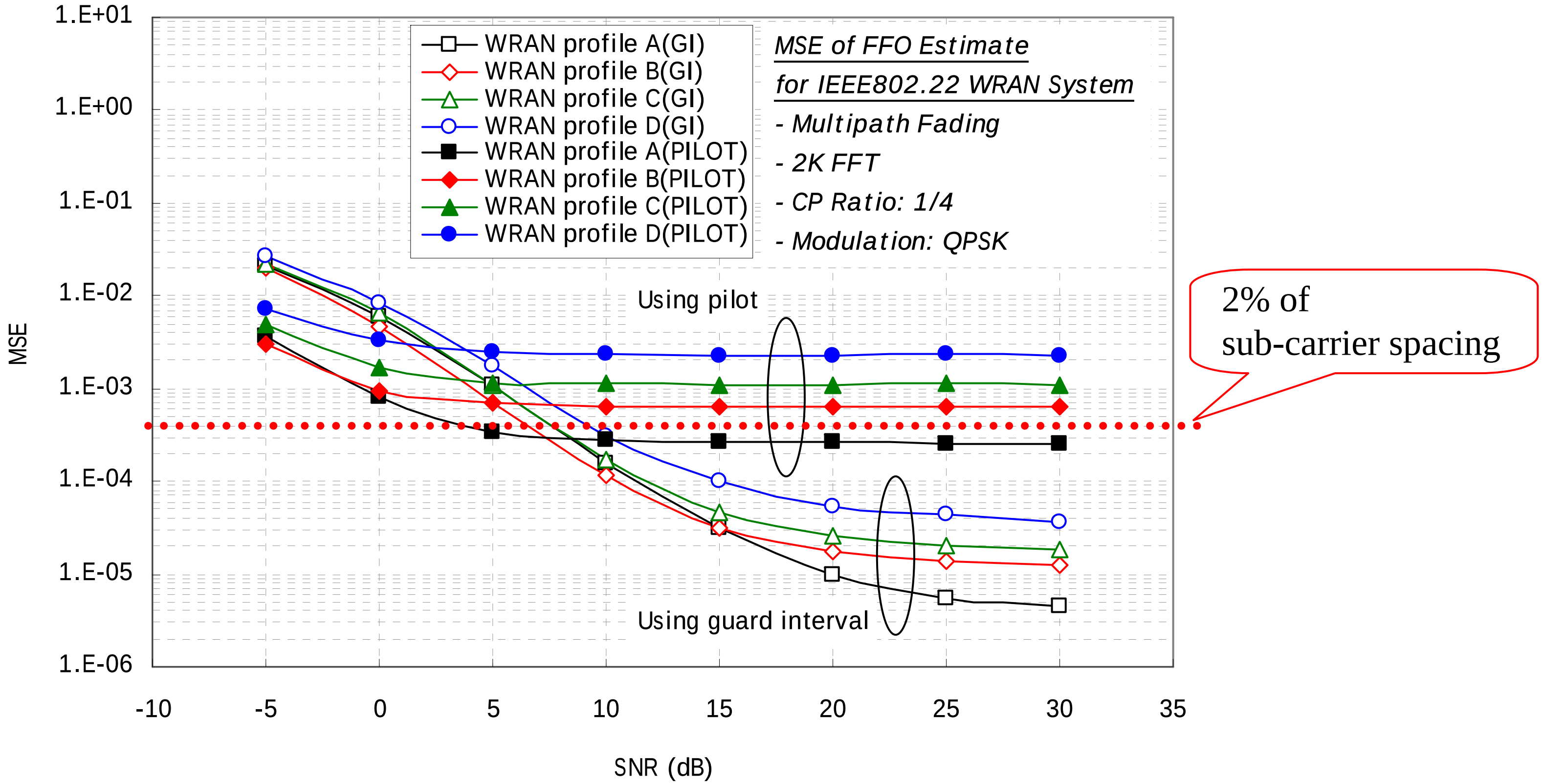


In the IEEE Std 802.16-2004 section 8.4.14.1, CPE shall be synchronized to the BS with a tolerance of maximum 2% of sub-carrier spacing

Assumptions for FFO Tracking Simulation

- **Residual frequency offset: 2% of subcarrier spacing**
- **2 algorithms for FFO tracking**
  - Using guard interval
  - Using pilot
- **Consider the phase noise model in IEEE 802.11 TGn comparison criteria**
- **2K FFT size & GI ratio of 1/4**

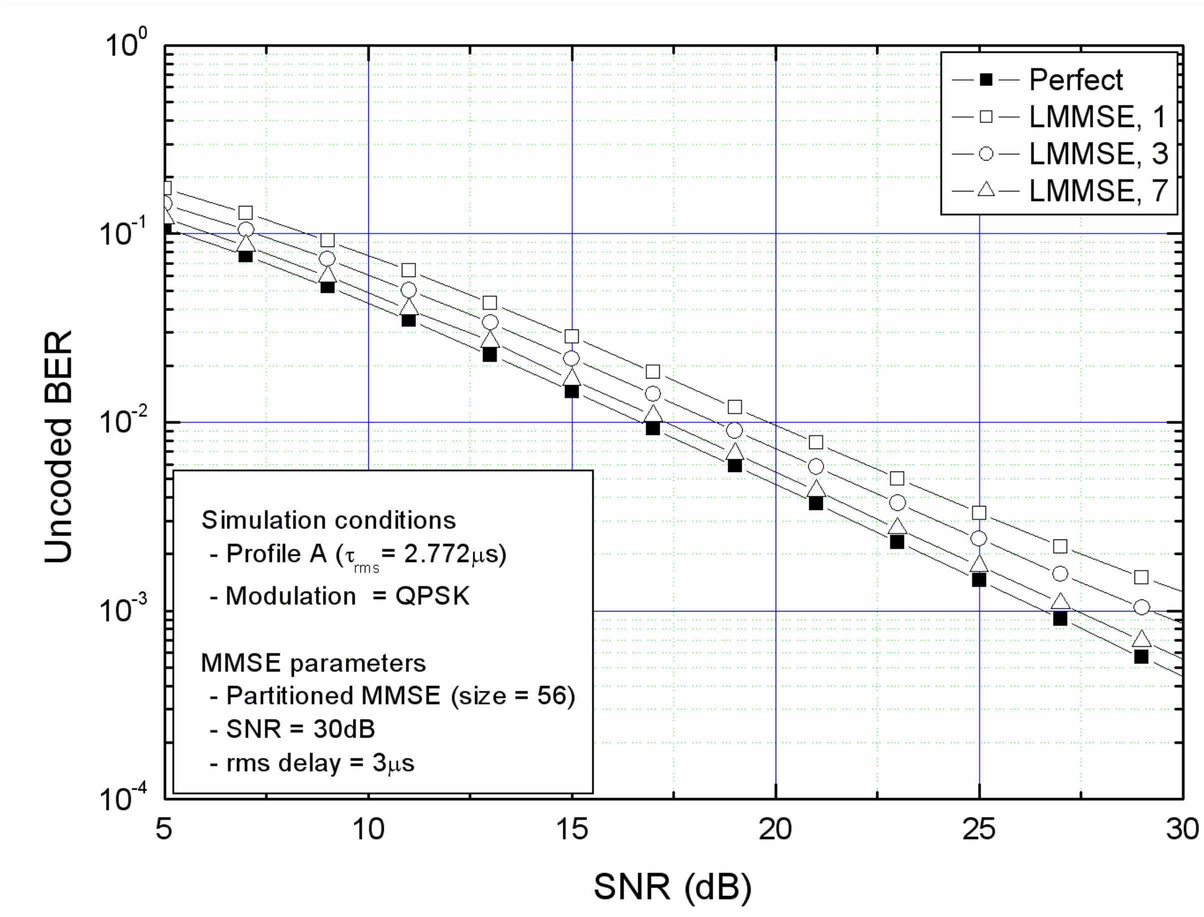
MSE of FFO Estimate (Using GI or Pilot)



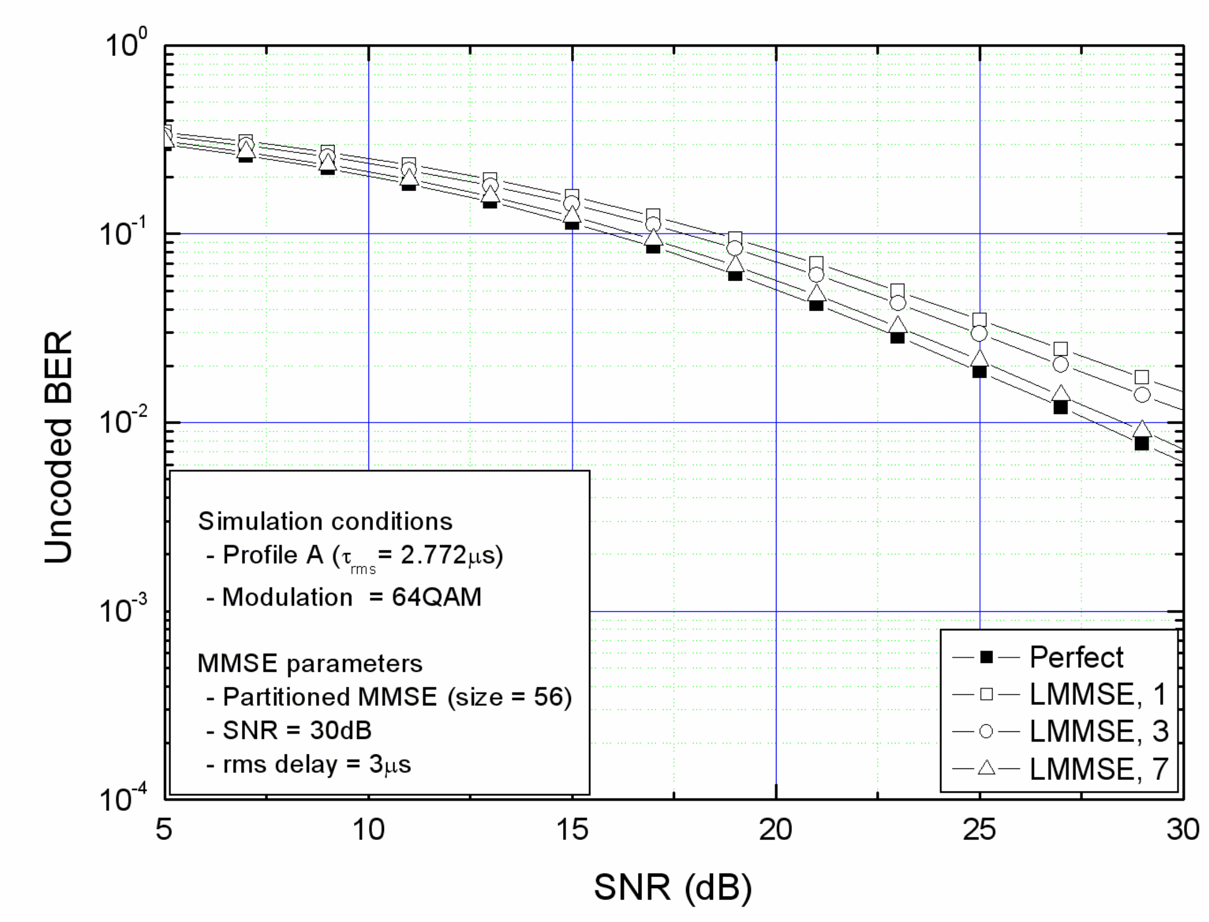
Assumptions for Channel Estimation Simulation

- **3 Types of Partitioned LMMSE**
  - LMMSE, 1 : Channel estimation using the pilot of each OFDM symbol
  - LMMSE, 3 : Channel estimation using the pilot of 3 OFDM symbols
  - LMMSE, 7 : Channel estimation using the pilot of 7 OFDM symbols
- **Apply the partitioned LMMSE to reduce the complexity in LMMSE estimation (Subcarrier size = 56).**
- **Calculation method of covariance matrix**
  - Method 1: Pre-calculation assuming exponential model
  - Method 2: Real-time calculation using actual measured model
- **No channel coding employed**
- **Initial frequency offset: 2KHz**
  - Assume that the CFO estimation using preamble is successful (< 2% of subcarrier spacing)
  - Fine frequency offset tracking loop is ON

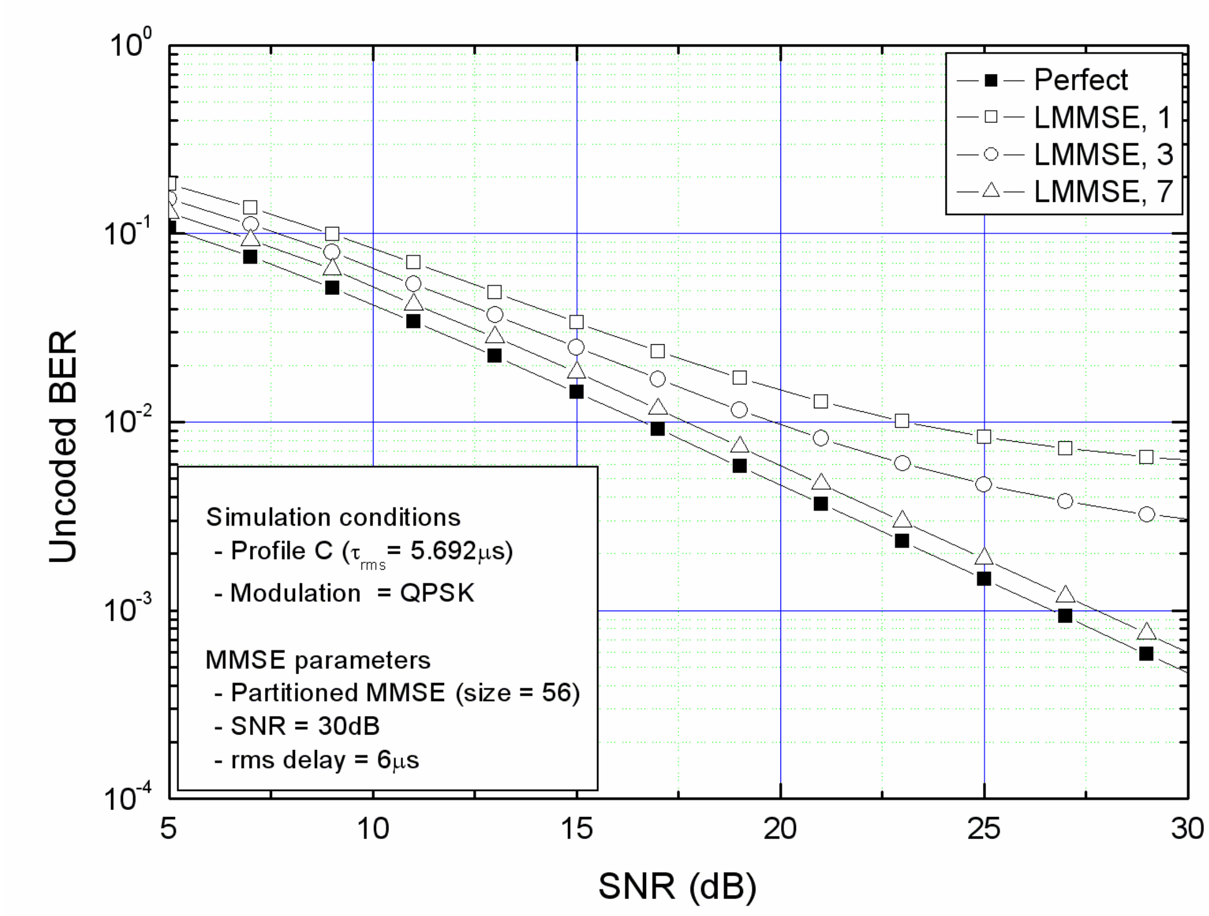
Uncoded BER Performance (Profile A, QPSK)



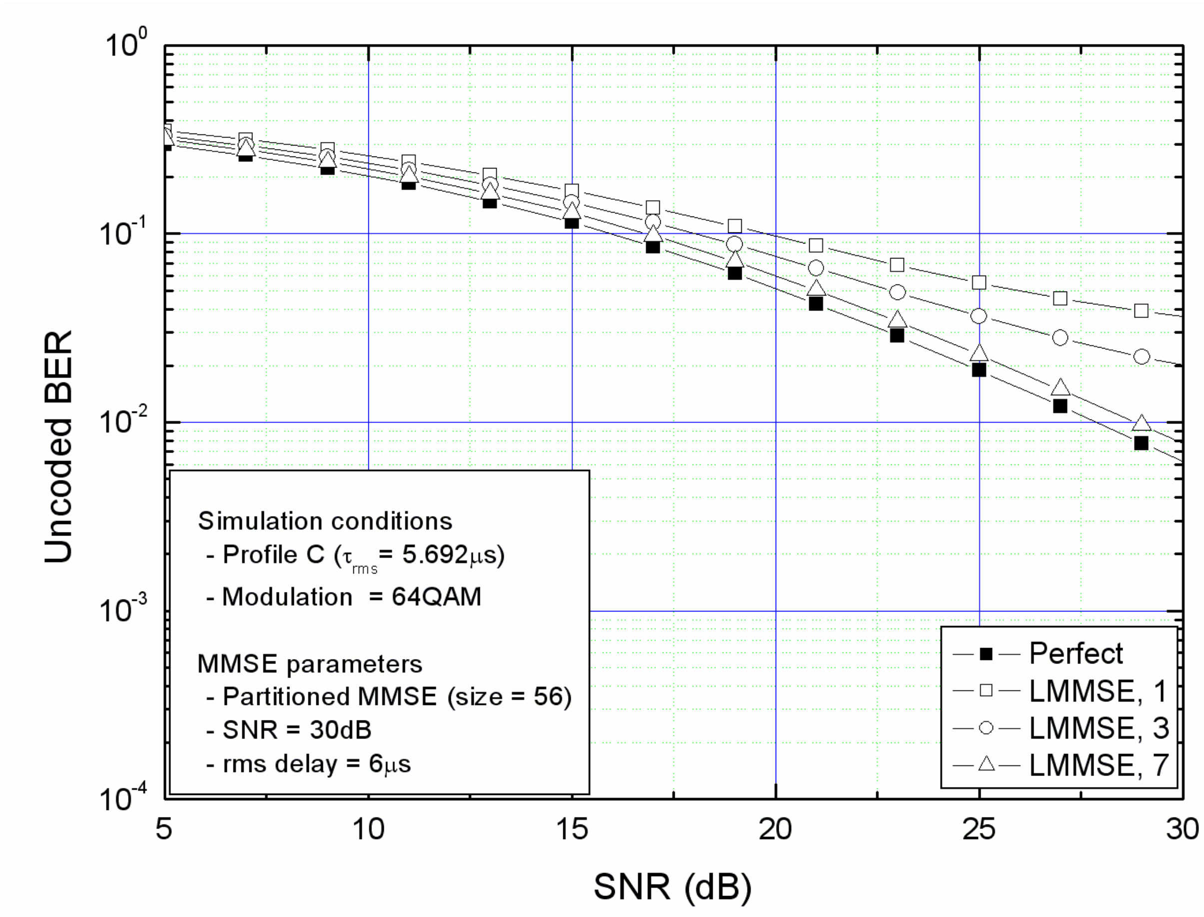
Uncoded BER Performance (Profile A, 64QAM)



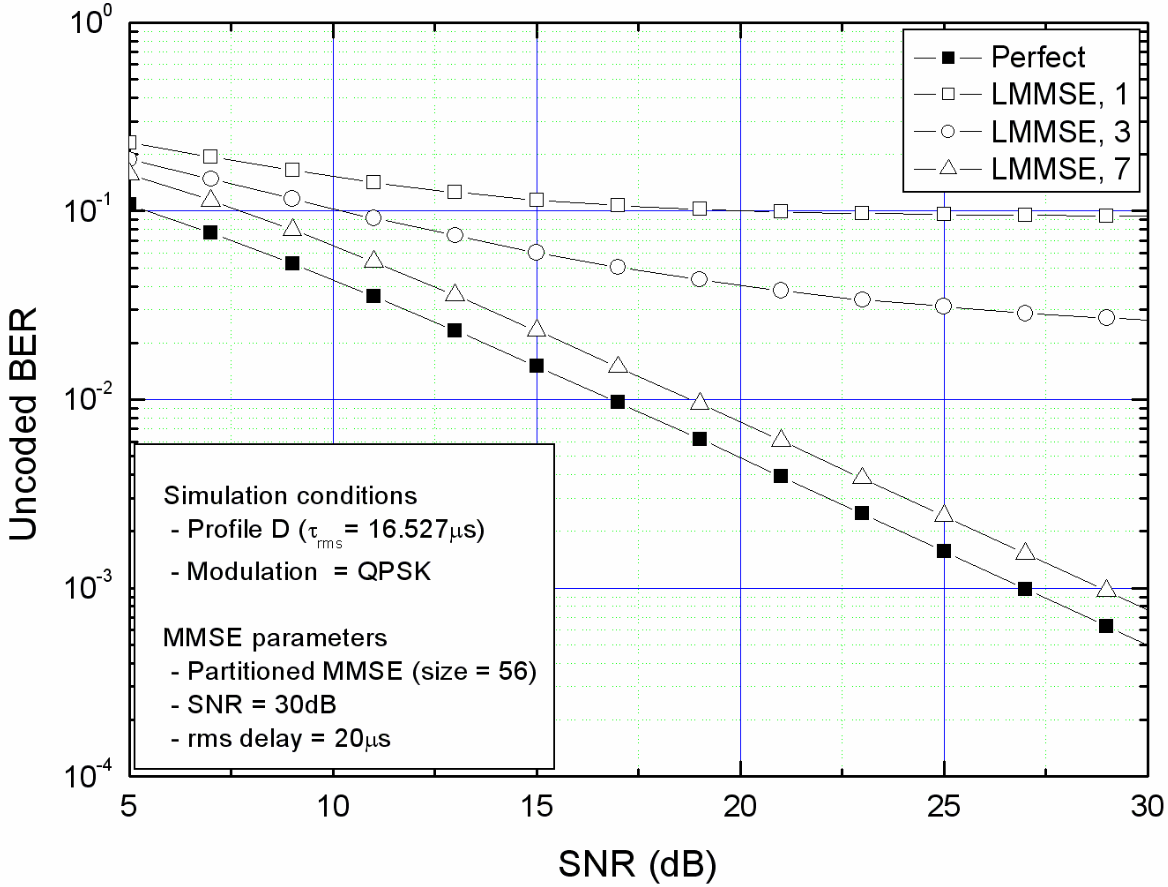
Uncoded BER Performance (Profile C, QPSK)



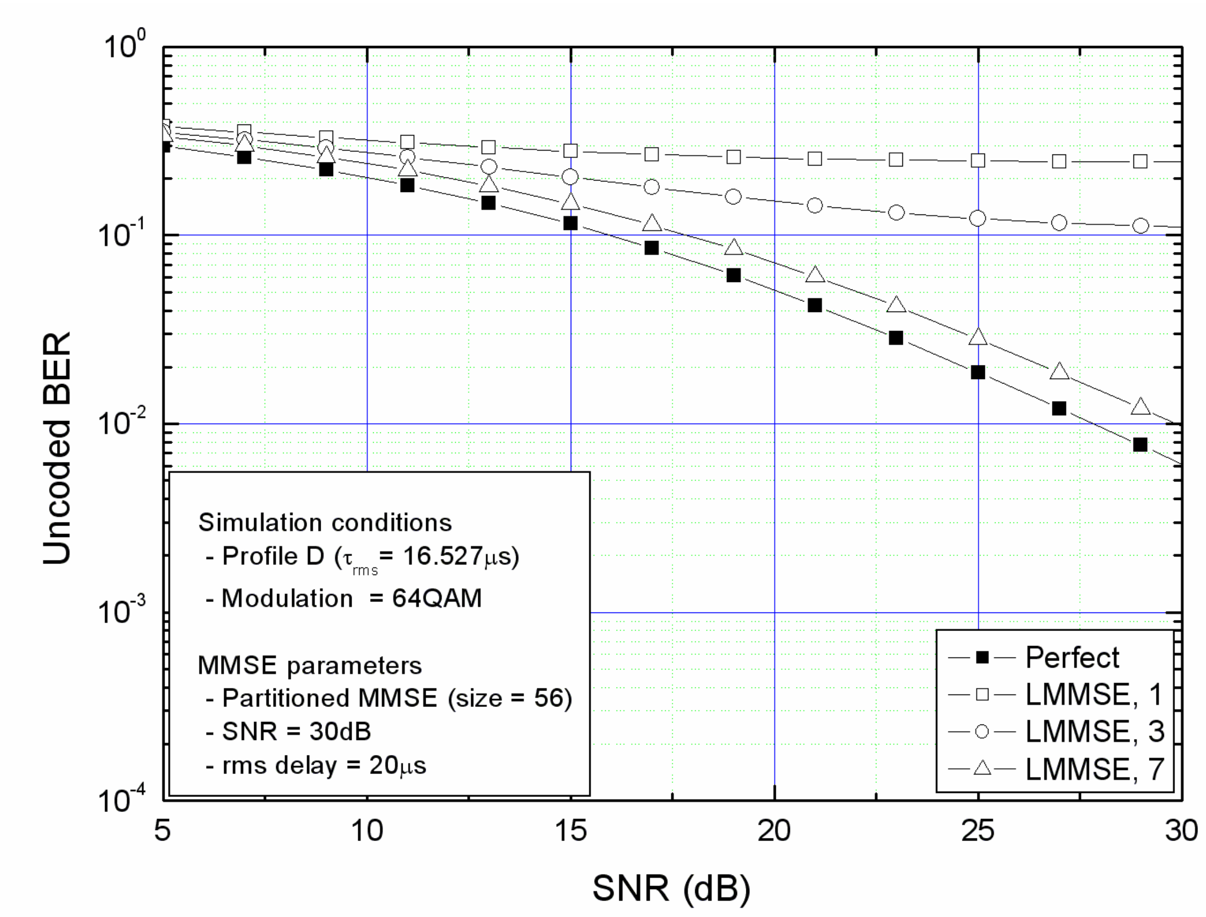
Uncoded BER Performance (Profile C, 64QAM)



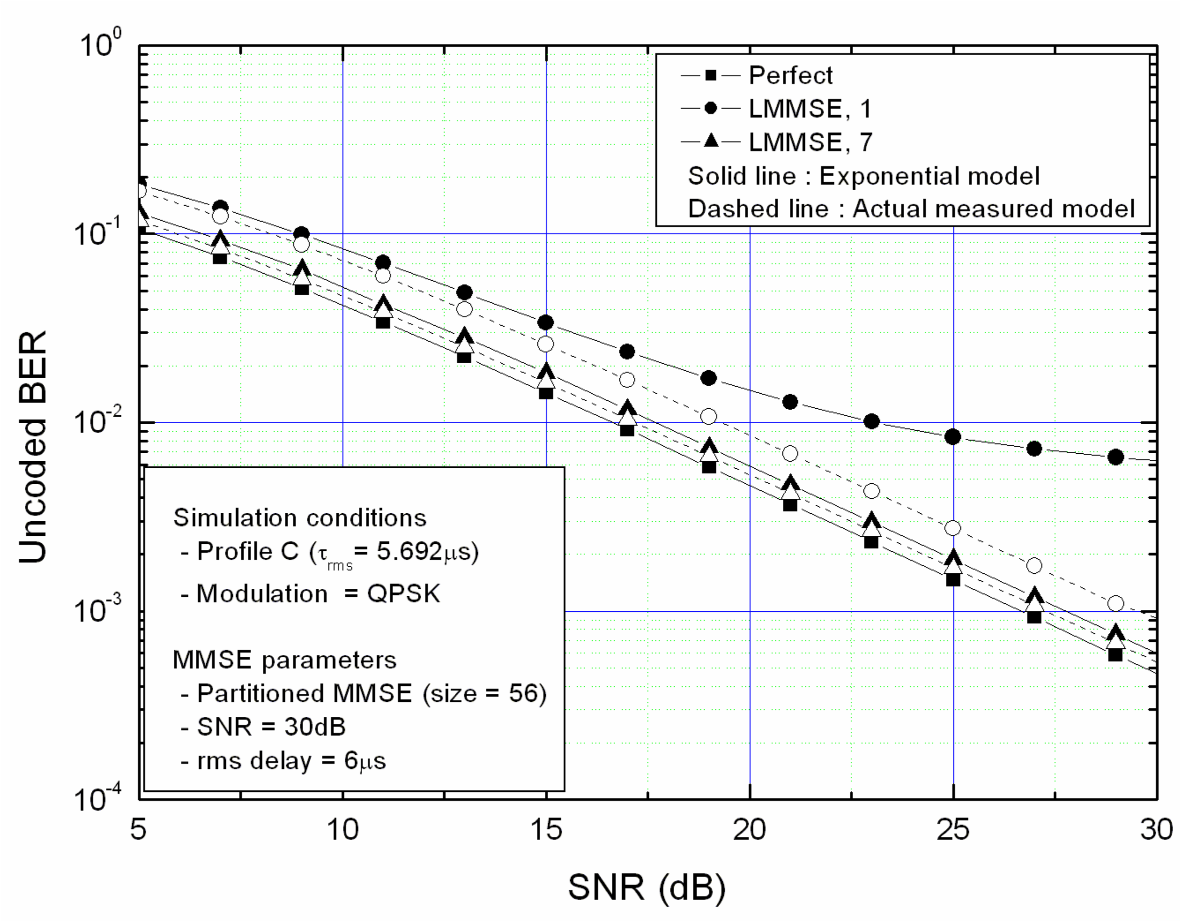
Uncoded BER Performance (Profile D, QPSK)



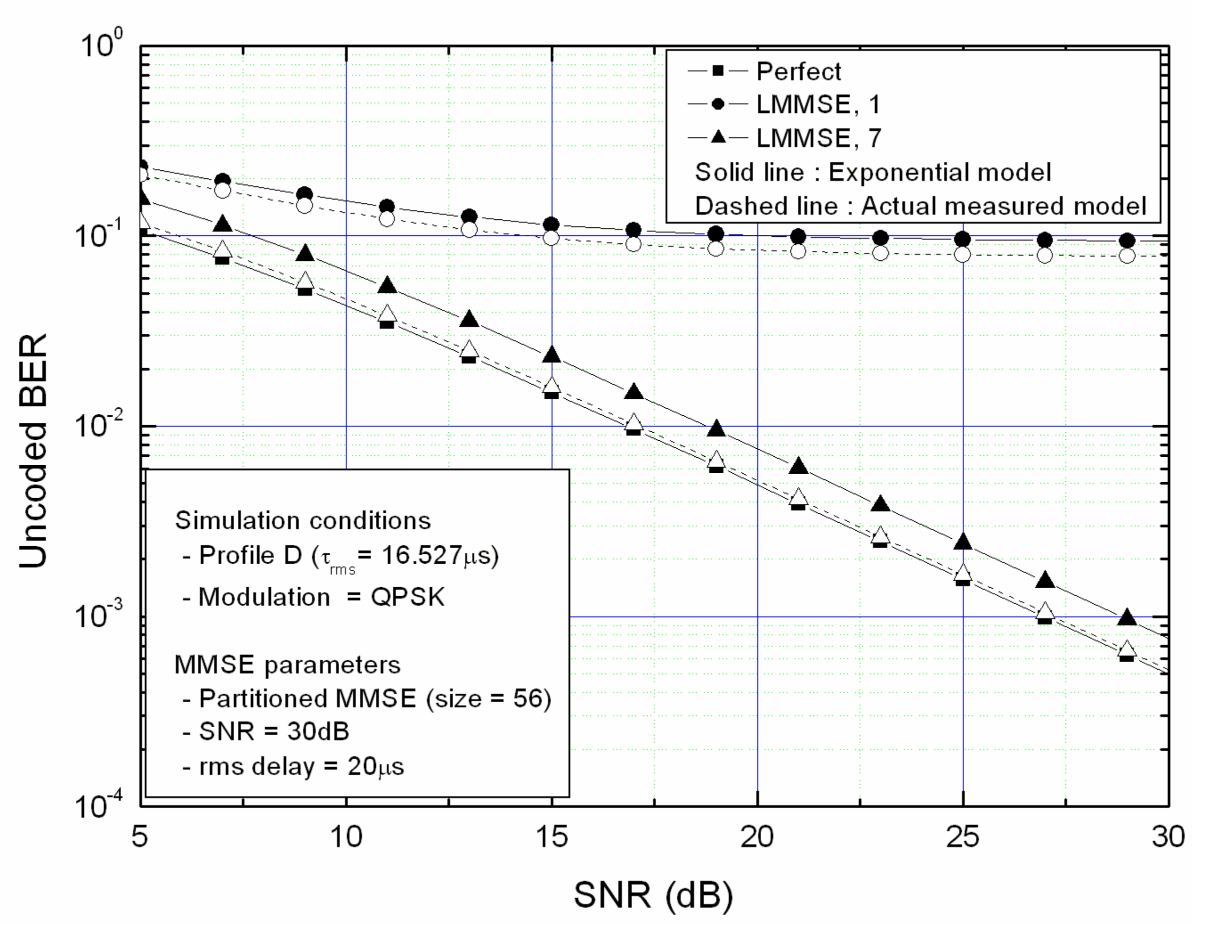
Uncoded BER Performance (Profile D, 64QAM)



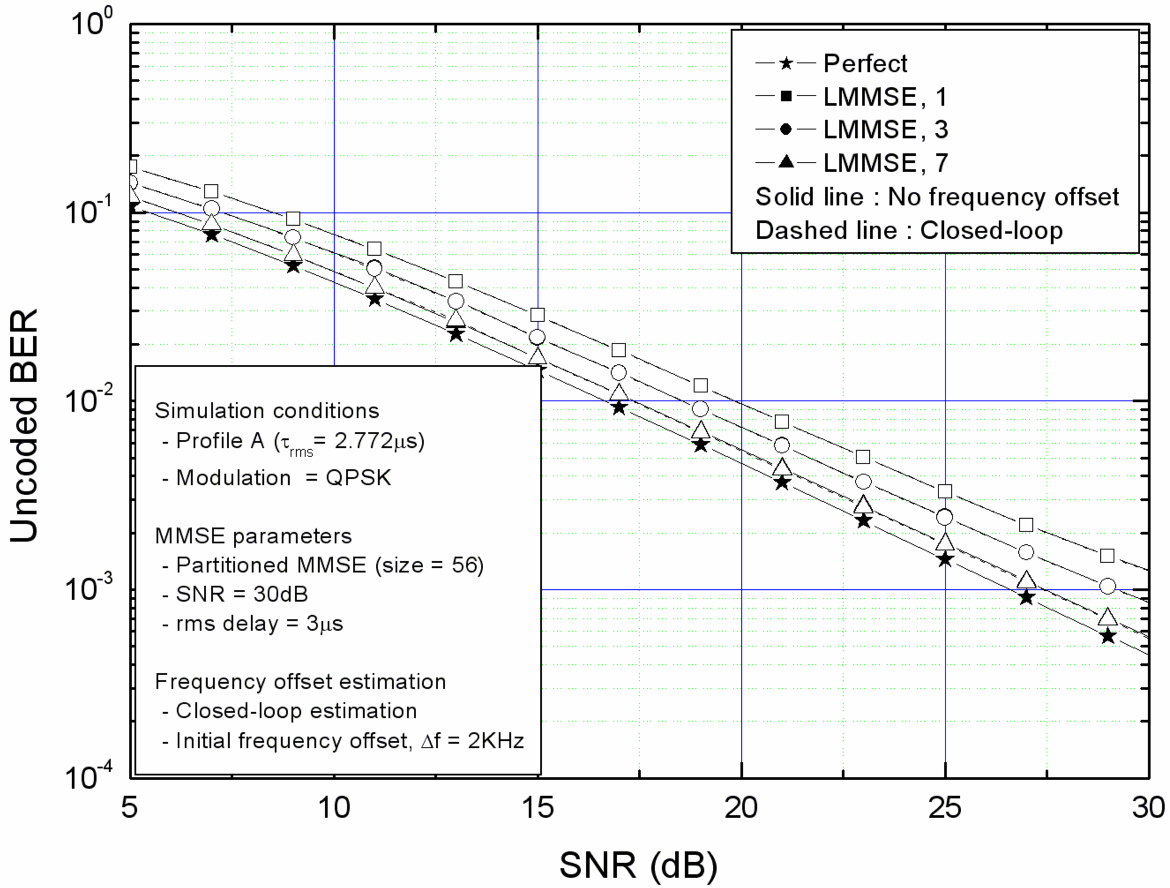
Performance Comparison for Calculation Method of Covariance Matrix (Profile C, QPSK)



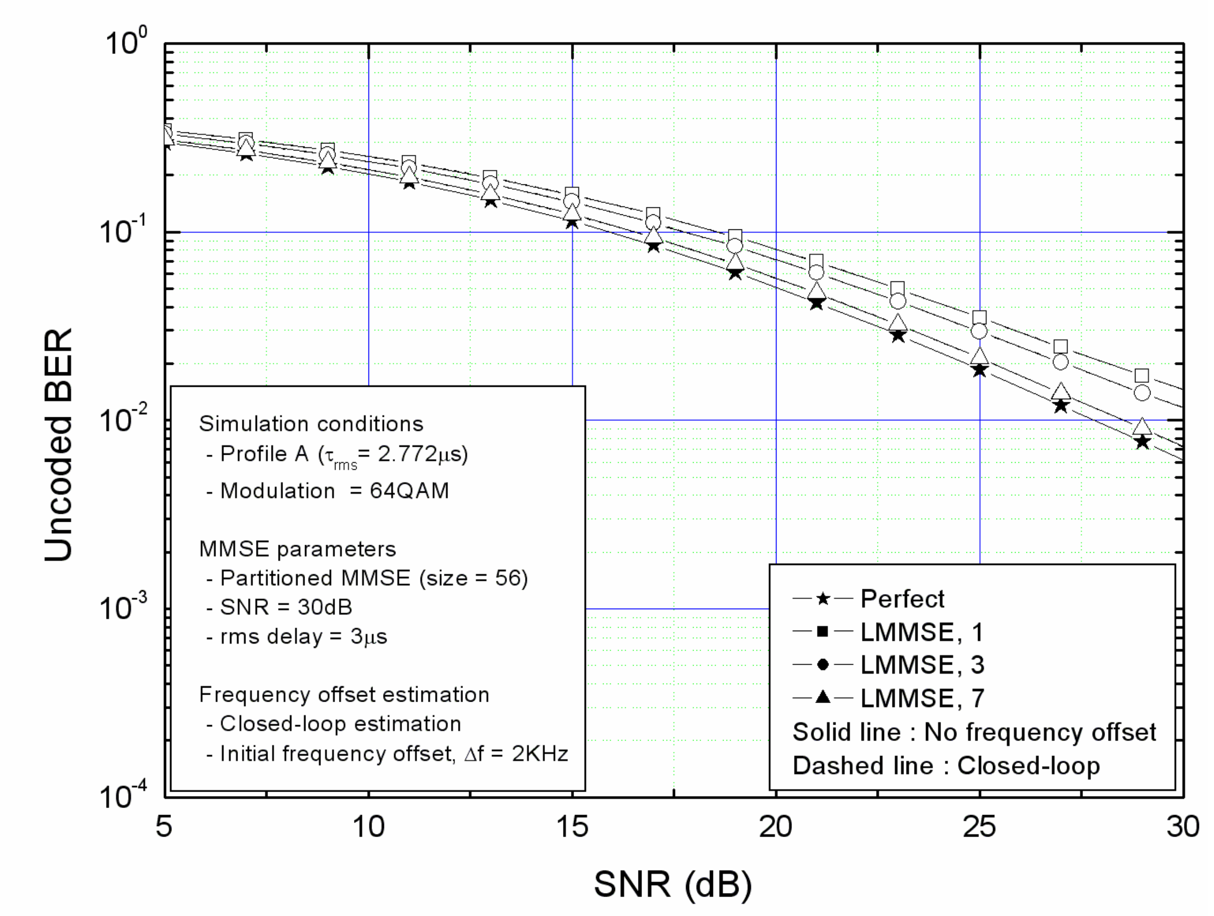
Performance Comparison for Calculation Method of Covariance Matrix (Profile D, QPSK)



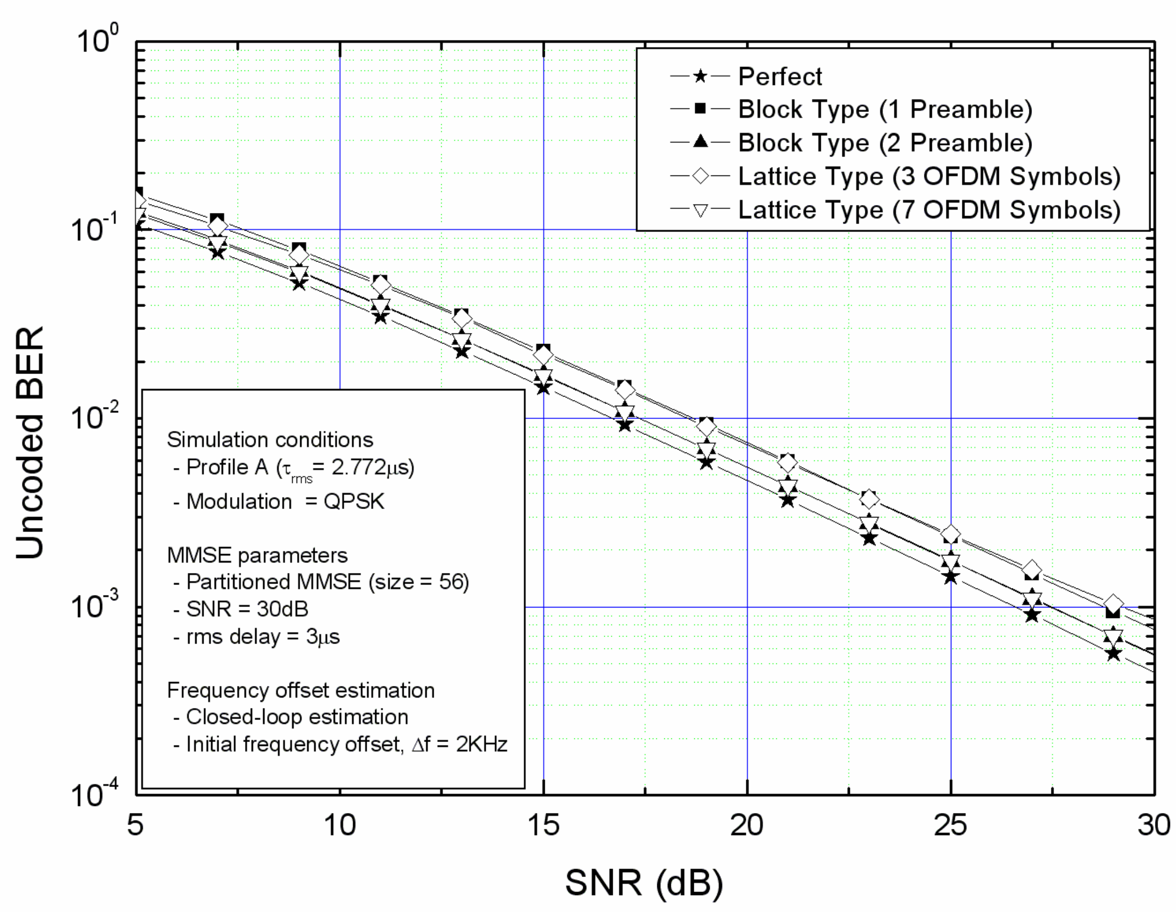
Performance Comparison for Frequency Offset Effect (Profile A, QPSK)



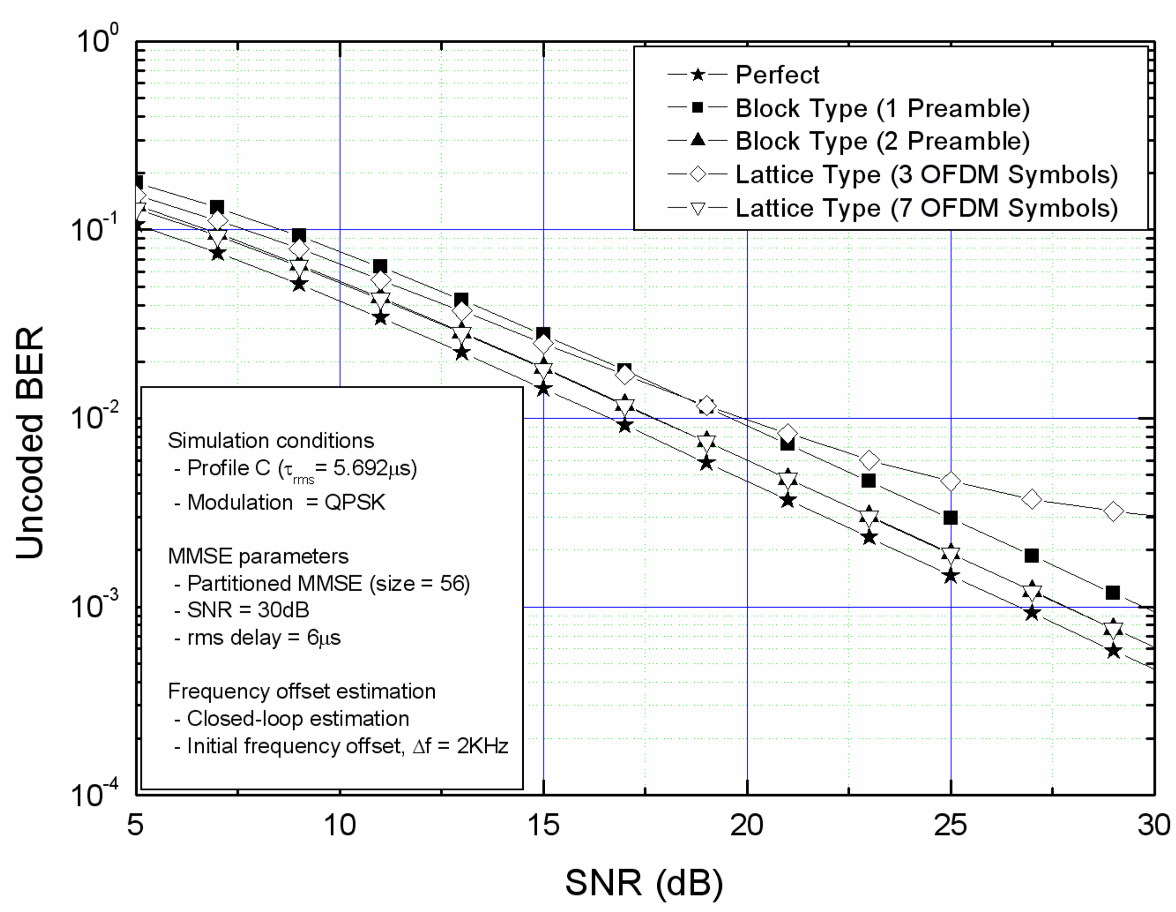
Performance Comparison for Frequency Offset Effect (Profile A, 64QAM)



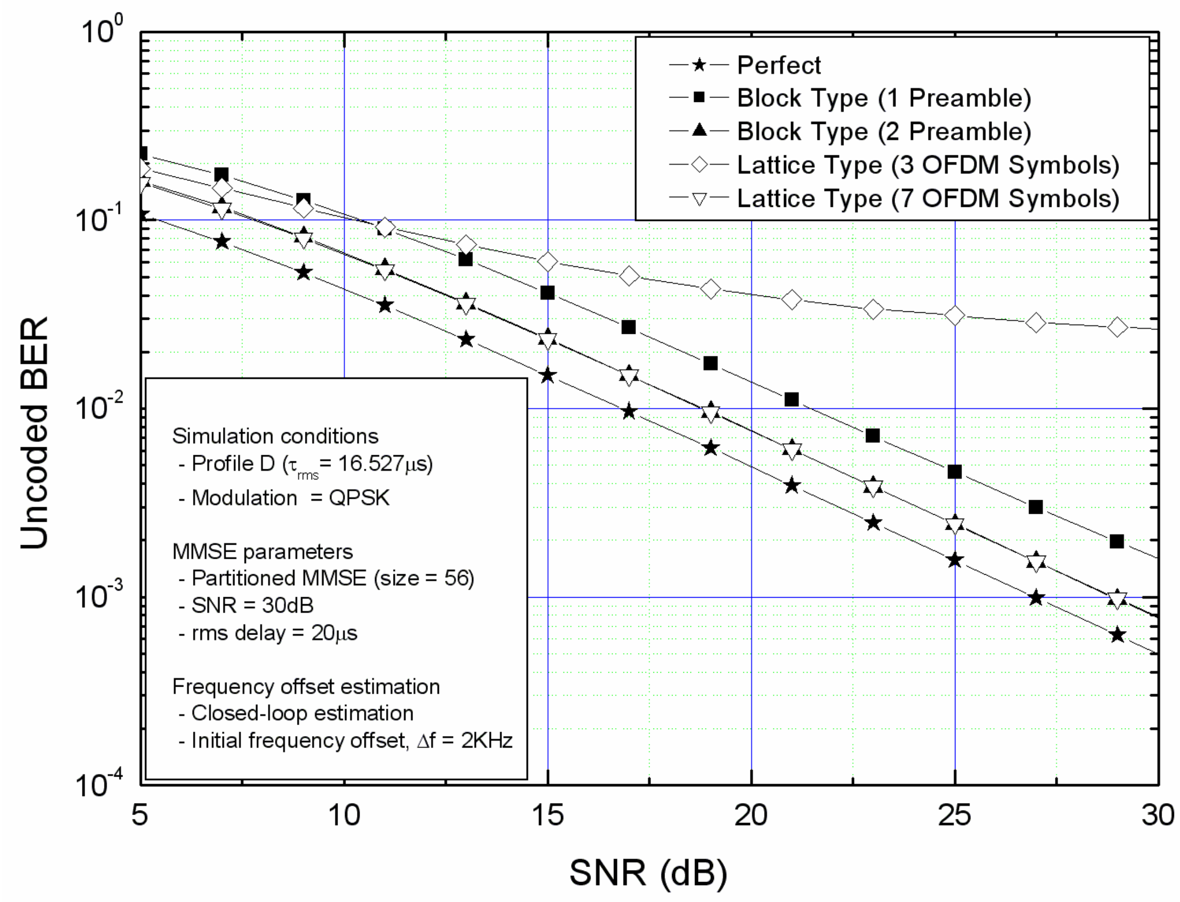
Performance Comparison for Preamble/Pilot Pattern (Profile A, QPSK)



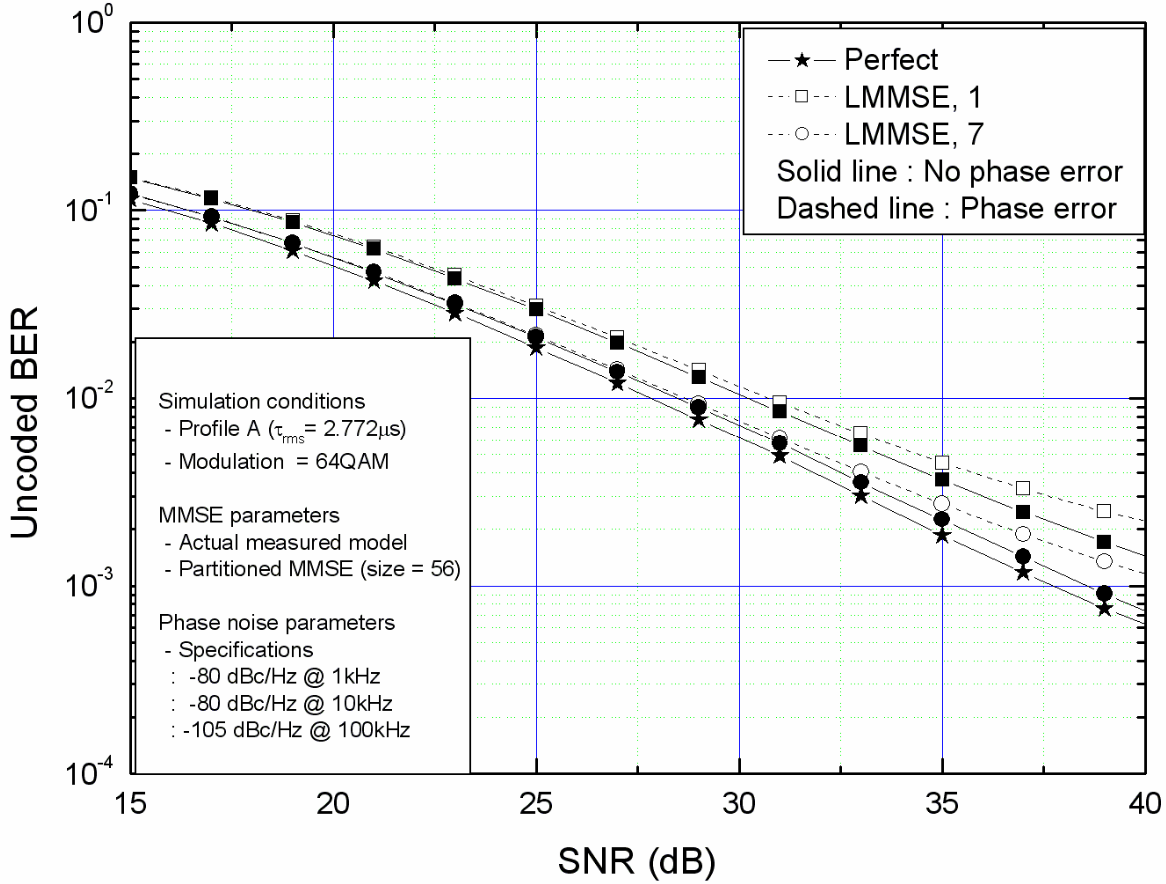
Performance Comparison for Preamble/Pilot Pattern (Profile C, QPSK)



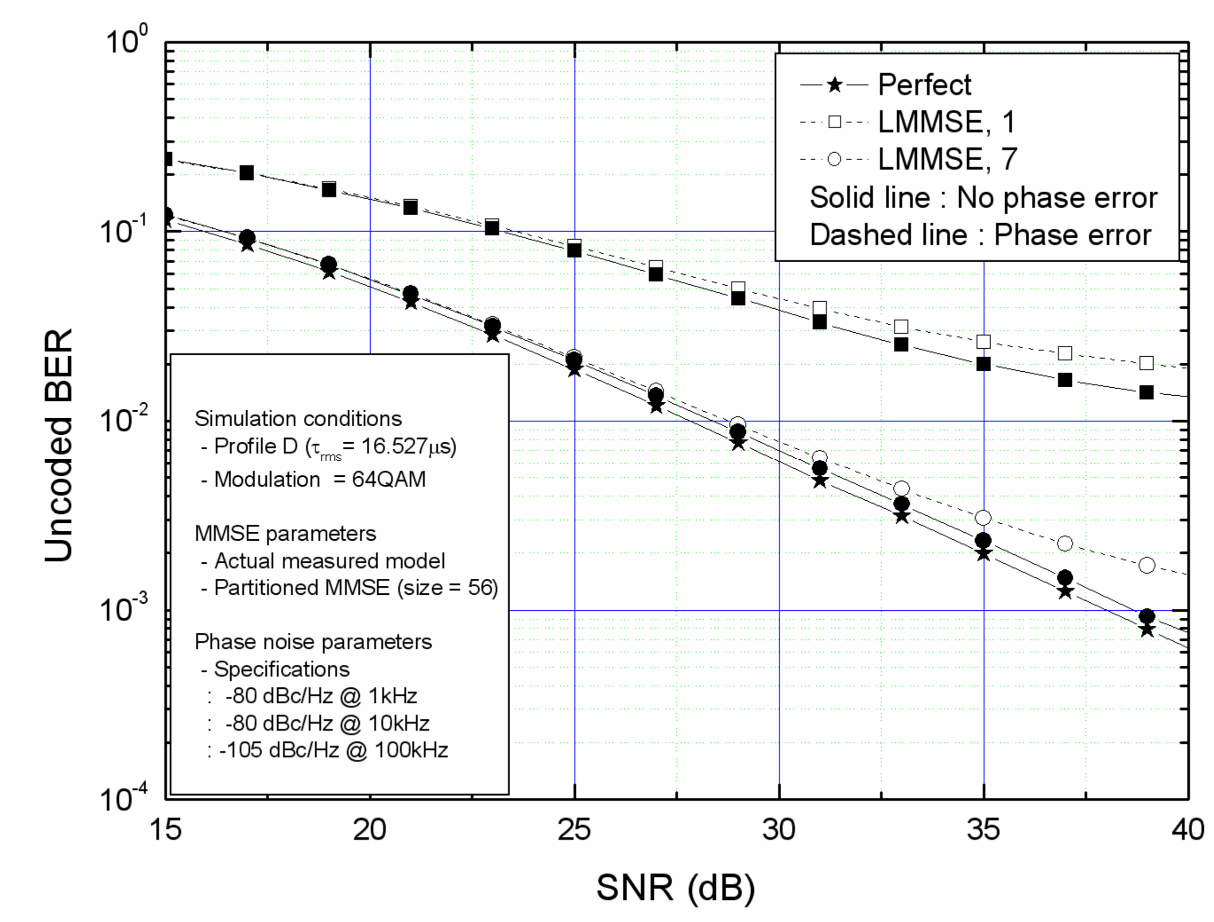
Performance Comparison for Preamble/Pilot Pattern (Profile D, QPSK)



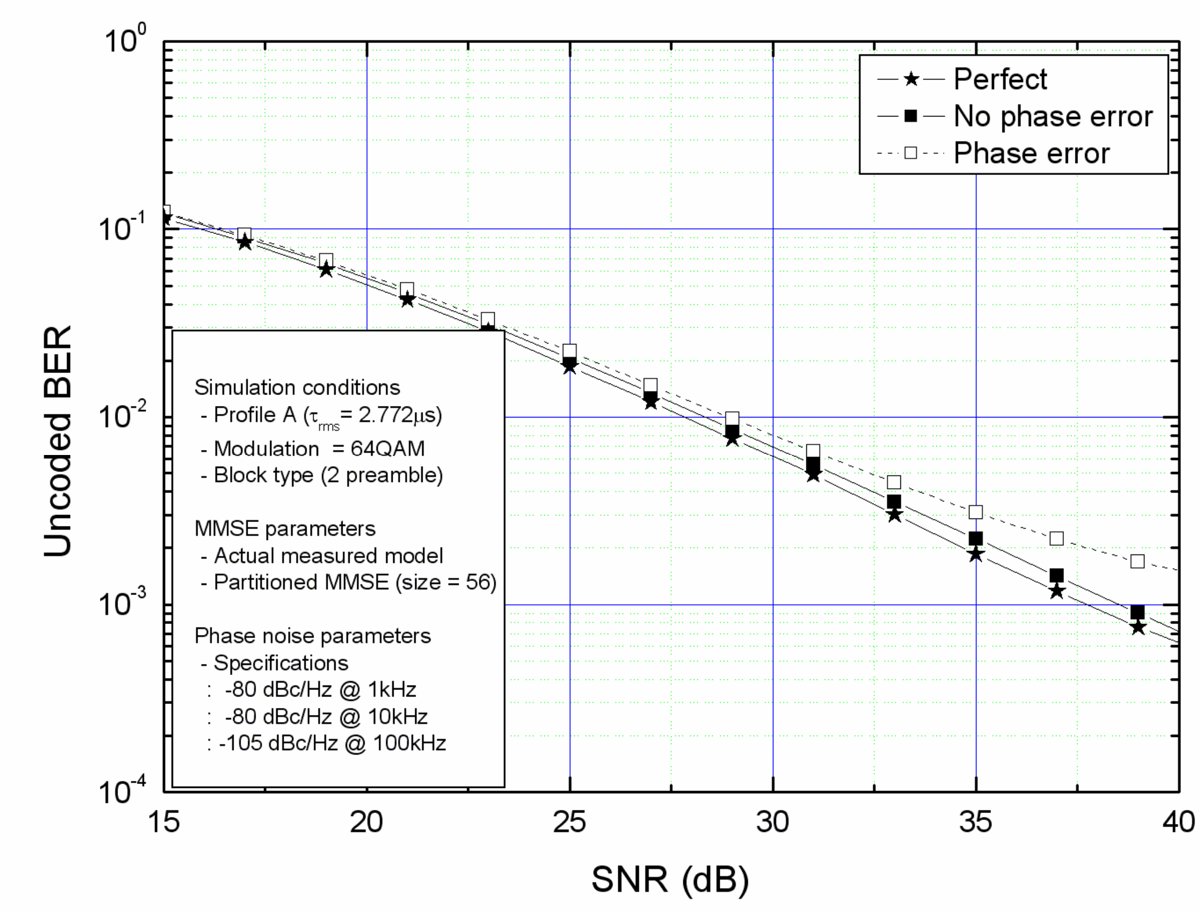
Performance Comparison for Phase Noise (Profile A, 64QAM, Preamble w/ Pilot)



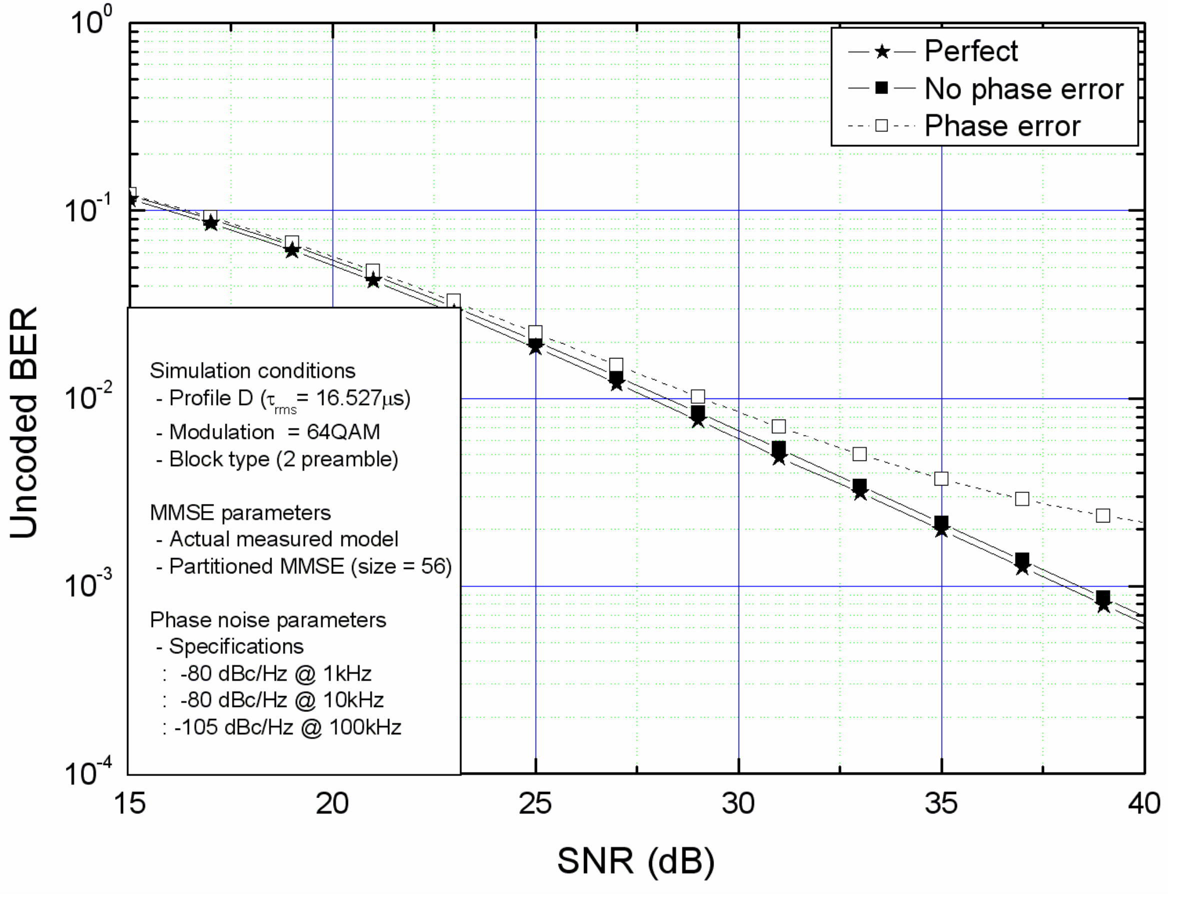
Performance Comparison for Phase Noise (Profile D, 64QAM, Preamble w/ Pilot)



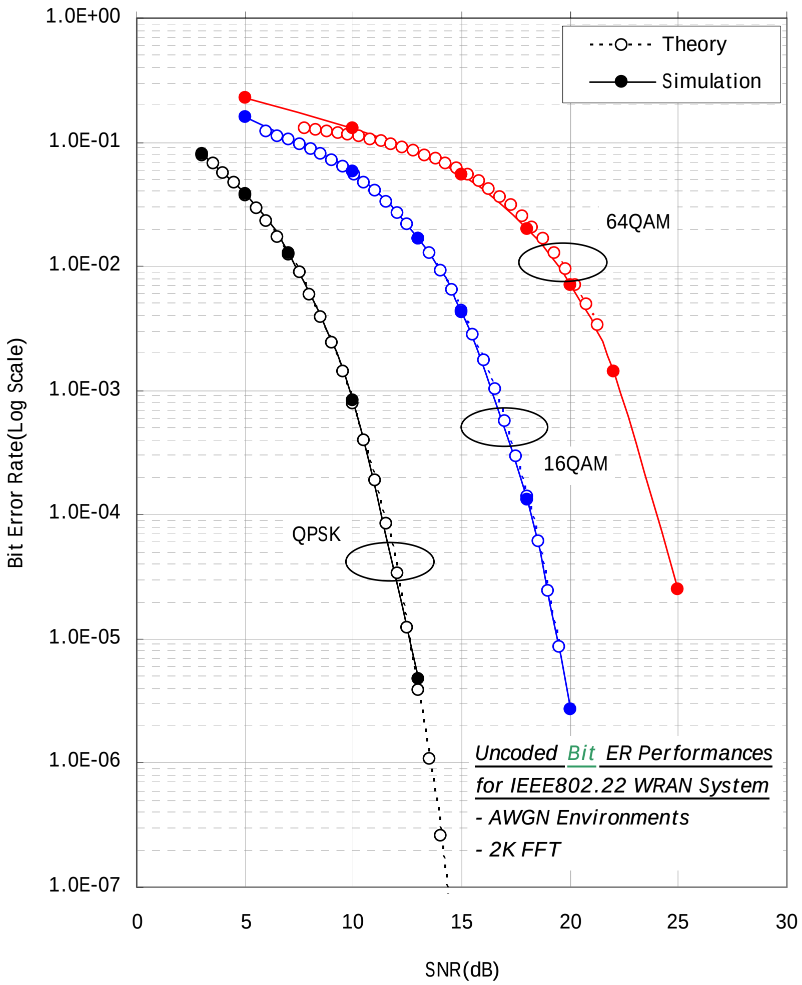
Performance Comparison for Phase Noise (Profile A, 64QAM, 2 Symbol Preamble only)

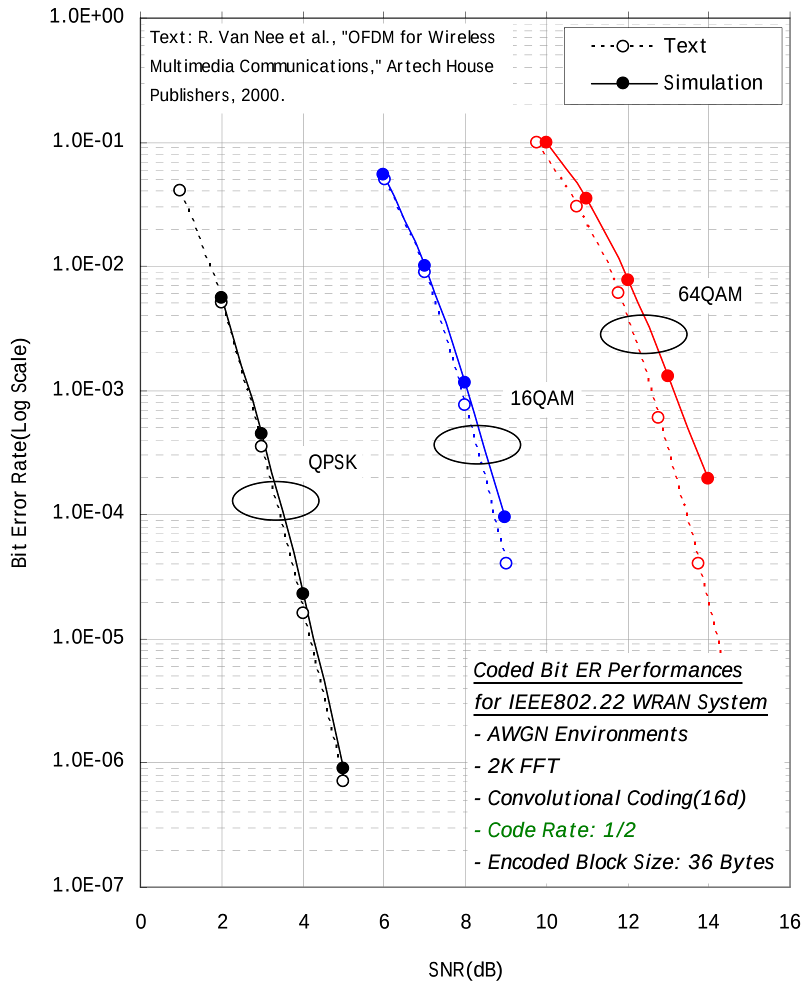


Performance Comparison for Phase Noise (Profile D, 64QAM, 2 Symbol Preamble only)

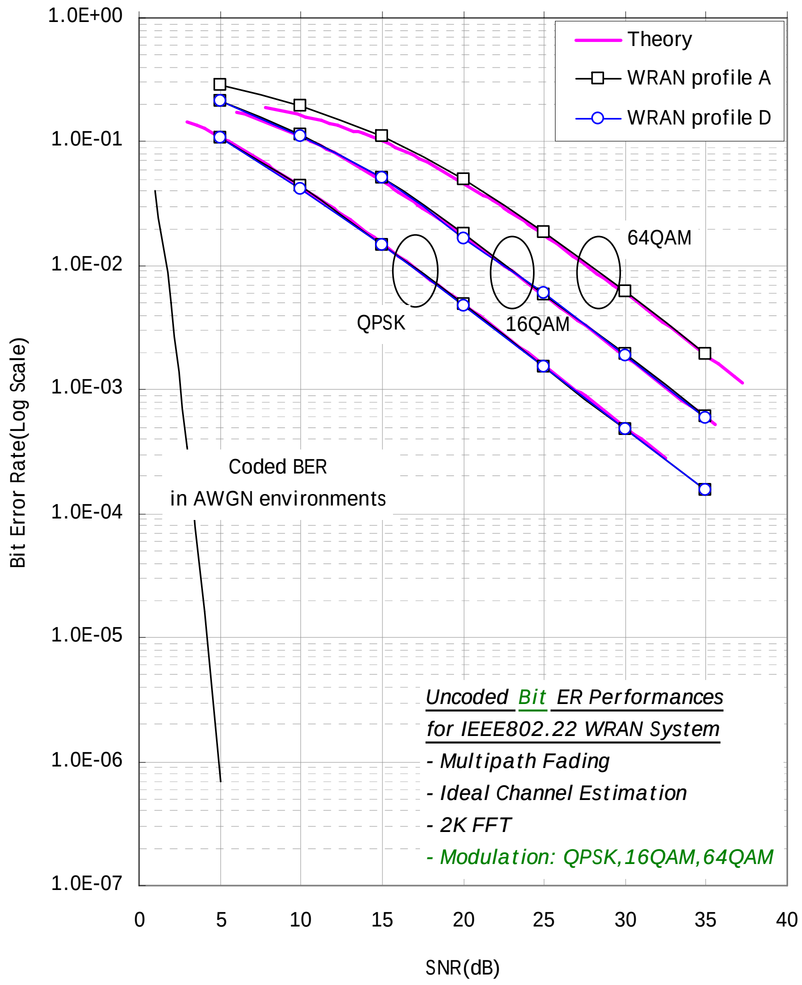


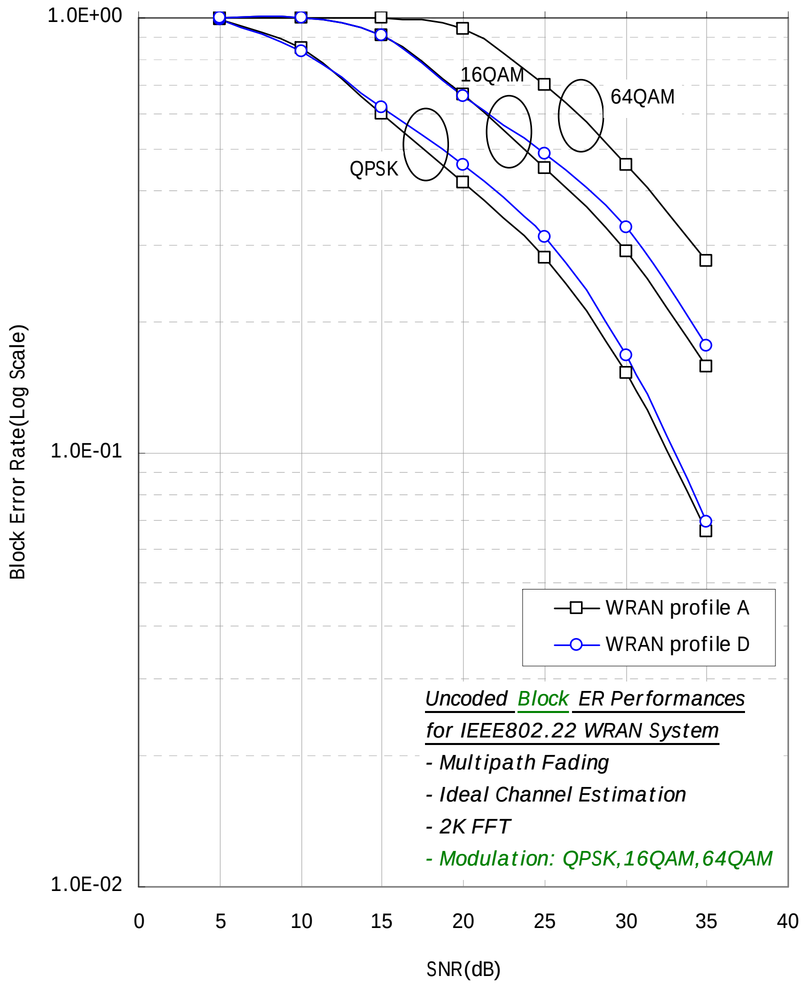
Uncoded/Coded Bit Error Rate in AWGN





Uncoded Bit/Block Error Rate in Fading Channel

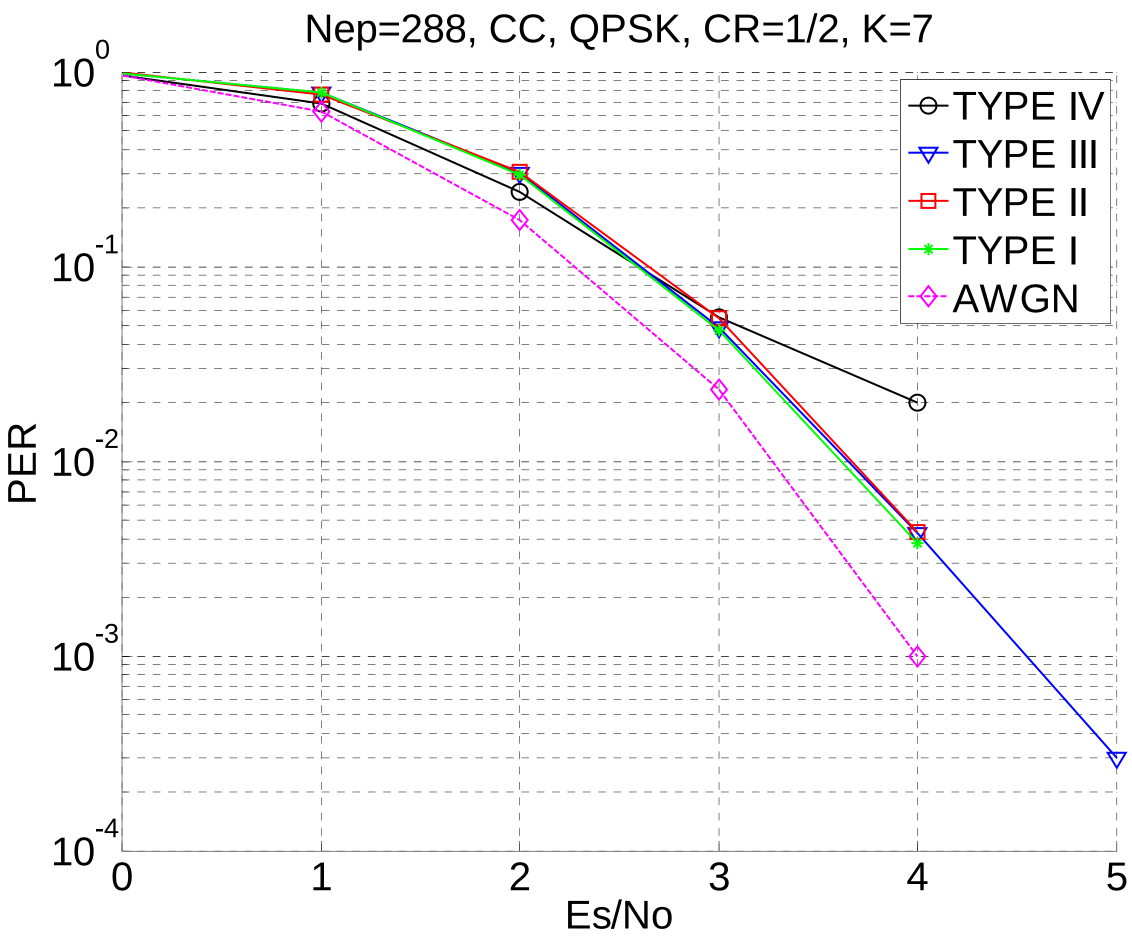




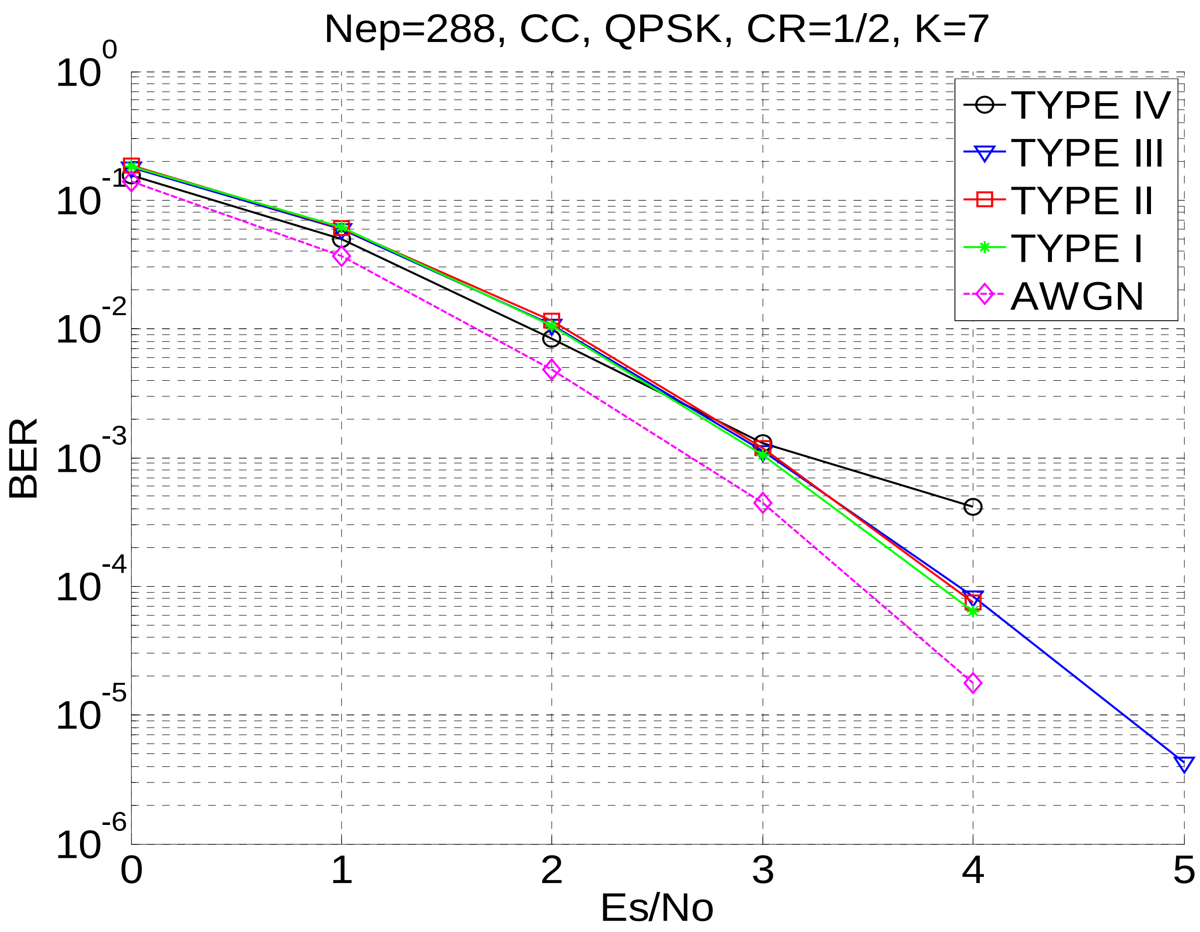
Assumptions for Mixed Resource Composition

- IEEE 802.22 WRAN multipath profile A
- 2K FFT
- Number of data subcarriers per BIN = 12
- One subchannel consists of 48 data subcarriers
- Perfect channel estimation
- Convolutional code (CC) and convolutional turbo code (CTC) are used for channel coding
- No phase noise
- No frequency offset

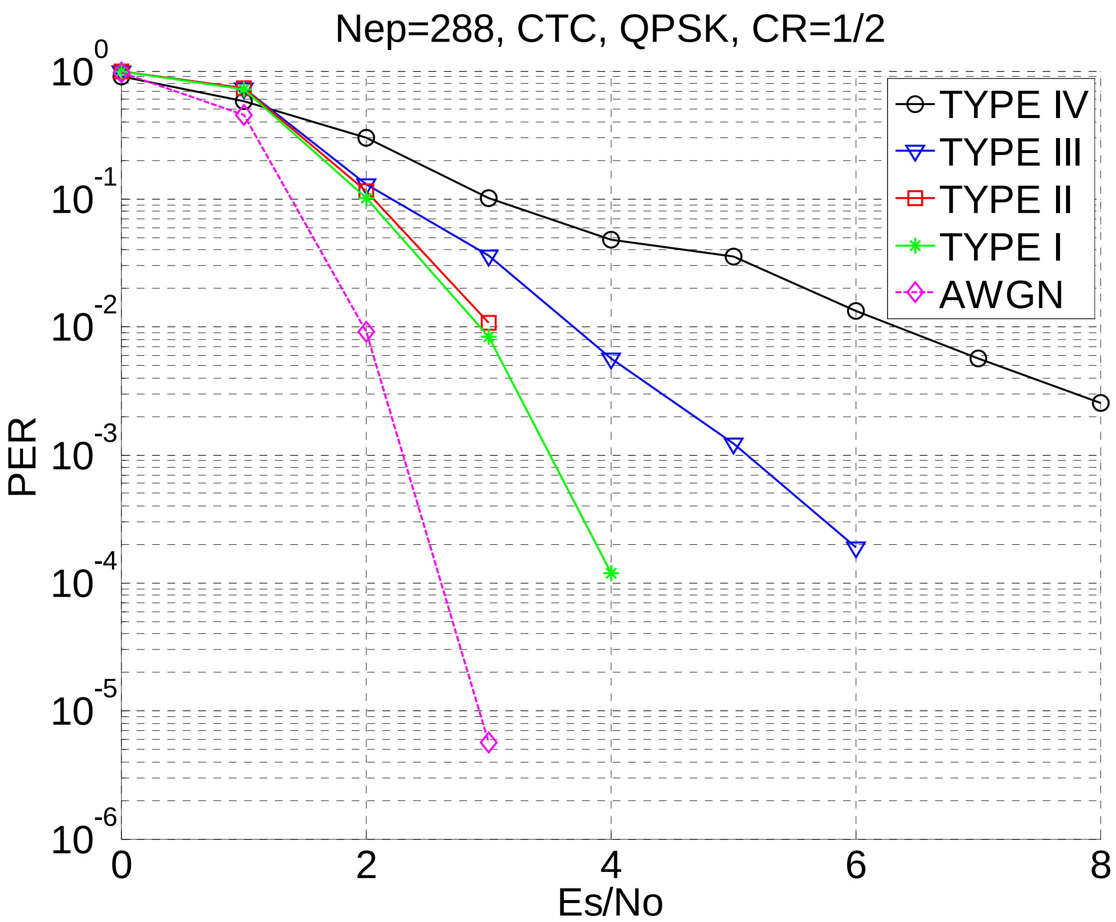
Performances of Mixed Resource Composition



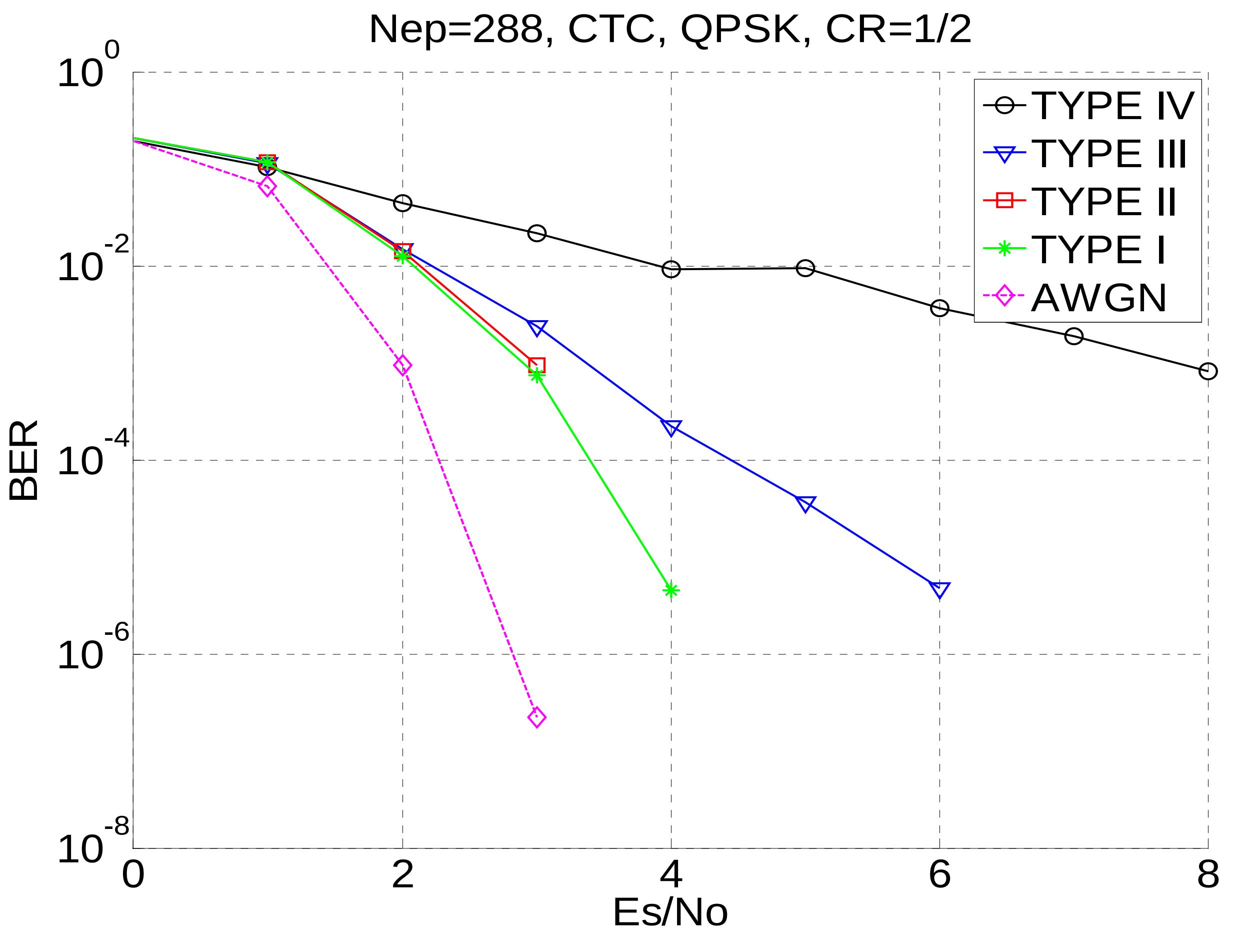
Performances of Mixed Resource Composition



Performances of Mixed Resource Composition



Performances of Mixed Resource Composition



Conclusions

- **From the simulations of initial synchronization**
  - In the WRAN profile A, B, and C, we obtain 90% preamble detection probability at -4 dB SNR.
  - Even in the WRAN profile D, we obtain 90% preamble detection probability at -2 dB SNR
  - In the WRAN profile A, B, and C, we can synchronize the CPE to the BS within 2 % of sub-carrier spacing at -2 dB SNR
  - Even in the WRAN profile D, we can synchronize the CPE to the BS within 2 % of sub-carrier spacing at 4 dB SNR

Conclusions

- **From the simulations of FFO tracking**
  - The performance using guard interval is better than that using pilot. Here, we assume the GI ratio of 1/4, i.e. 512 subcarriers for 2K FFT size.
  - The performance difference is because the correlation size is different, the number of GI subcarriers is 512 and the number of pilot subcarriers is 240.
  - Another reason is because the pilot in adjacent OFDM symbol has experienced the different channel distortion from the pilot in the previous OFDM symbol.

Conclusions

- **From the simulations of LMMSE channel estimation**
  - If 7 OFDM symbols are used in LMMSE estimation, there are the performance degradation of 0.2~0.5 dB and 2.0~2.5 dB compared to ideal channel estimation for profile A and D, respectively. If 1 or 3 OFDM symbols are used in LMMSE estimation, there are huge performance loss.
  - Therefore, to prevent huge performance loss, it is necessary for pilot symbol to visit every subcarriers. It will be established using preamble and scattered pilot.
  - Regarding the calculation method of covariance matrix, the real-time calculation using actual measured model has a much better performance than that of pre-calculation assuming exponential model. Even though the complexity is increasing, because the WRAN system is fixed, we can decrease the complexity by stopping the training of channel information after several frames.

Conclusions

- **From the simulations of LMMSE channel estimation (Cont'd)**
  - If we use the frequency offset tracking, the performance loss due to residual frequency offset is ignorable.
  - The performance using two preamble alone (without pilots) is similar to the performance using 7 OFDMA symbols (with pilots).
  - Below the SNR of about 25dB, the Gaussian noise is dominant. However, above the SNR of about 25dB, the phase noise is dominant.
  - We can reduce the effect of constant phase error (CPE) and inter-carrier interference (ICI) due to phase noise by using scattered pilots.

Conclusions

- **From the simulations of mixed resource composition**
  - Among four types of mixed resource composition, the subcarrier-unit mixture with frequency hopping has the best performance.
  - The subcarrier allocation method is similar as conventional Diversity subchannel, except the adjacent subchannel is allocated to adjacent OFDMA symbol
  - When we use convolutional code, we can achieve the improvement above the SNR of 3dB
  - We can achieve the more improvements by using the convolutional turbo code than convolutional code