MIMO-OFDM Wireless Communications with MATLAB®

Chapter 5. OFDM Senkronizasyonu

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Chapter 5. OFDM Senkronizasyonu

$x_l[n]$

$$y_l[n] = \text{IDFT}\{Y_l[k]\} = \text{IDFT}\{H_l[k]\,X_l[k] + Z_l[k]\}$$
$$y_l[n] = \frac{1}{N}\sum_{k=0}^{N-1} H_l[k]\,X_l[k]\,e^{j2\pi(k+\varepsilon)(n+\delta)/N} + z_l\,[n] \qquad (5.1)$$

ideal kanal ve sıfır gürültü

$$y_l[n] = \sum_{k=0}^{N-1} X_l[k]\, e^{j2\pi \frac{kn}{N}}$$

CFO $\rightarrow$ $\tilde{y}_l[n] = \sum_{k=0}^{N-1} X_l[k]\, e^{j2\pi \frac{(k+\varepsilon)n}{N}}$

STO $\rightarrow$ $y_l[n] = \sum_{k=0}^{N-1} X_l[k]\, e^{j2\pi \frac{k(n+\delta)}{N}}$ = $e^{j\frac{2\pi kn}{N}}\, e^{j\frac{2\pi k\delta}{N}}$

Chapter 5. OFDM Senkronizasyonu
5.1 STO Etkisi

	Received Signal	STO(δ)
Time domain	$y[n]$	$x[n+\delta]$
Frequency domain	$Y[k]$	$e^{j2\pi k\delta/N}X[k]$

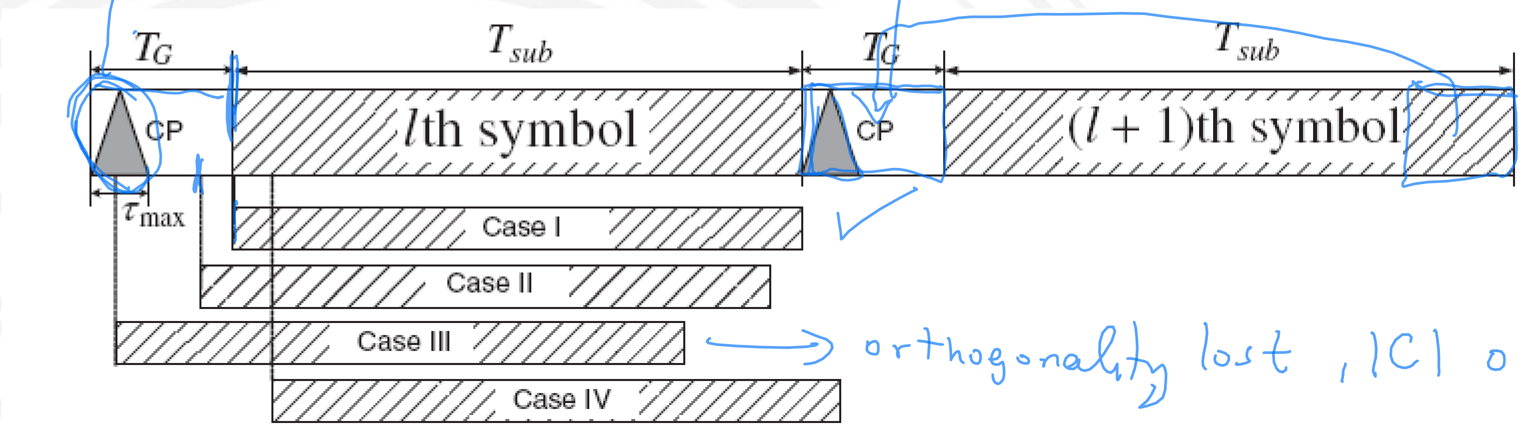
Table 5.1 The effect of symbol time offset (STO).

5.1 STO Etkisi

Symbol Timing Offset

delay spread

sonraki OFDM sembolünün CP'li



orthogonality lost, ICI occurs

Figure 5.1 Four different cases of OFDM symbol starting point subject to STO.

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5.1 STO Etkisi – Case 2 (No ISI)

önceki OFDM sembolü ile karışmıyor.

$$
\begin{aligned}
Y_l[k] &= \frac{1}{N}\sum_{n=0}^{N-1} x_l[n+\delta]\, e^{-j2\pi nk/N} \\
&= \frac{1}{N}\sum_{n=0}^{N-1}\left\{\sum_{p=0}^{N-1} X_l[p]\, e^{j2\pi(n+\delta)p/N}\right\} e^{-j2\pi nk/N} \\
&= \frac{1}{N}\sum_{p=0}^{N-1} X_l[p]\, e^{j2\pi p\delta/N}\sum_{n=0}^{N-1} e^{j2\pi\frac{(p-k)}{N}n} \\
Y_l[k] &= X_l[k]\, e^{j2\pi k\delta/N}
\end{aligned}
\qquad (5.2)
$$

$$\frac{1}{N}\sum_{p=0}^{N-1} X_l(p)\, e^{j\frac{2\pi p\delta}{N}}\sum_{n=0}^{N-1} e^{j\frac{2\pi(p-k)n}{N}}$$

→ ISI yok. sadece fazda kayma var.

$$\sum_{n=0}^{N-1} e^{j2\pi\frac{(p-k)}{N}n} = e^{j\pi(p-k)\frac{N-1}{N}}\,\frac{\sin[\pi(k-p)]}{\sin[\pi(k-p)/N]}$$

$$= \begin{cases} N & \text{for} \quad k = p \\ 0 & \text{for} \quad k \neq p \end{cases}$$

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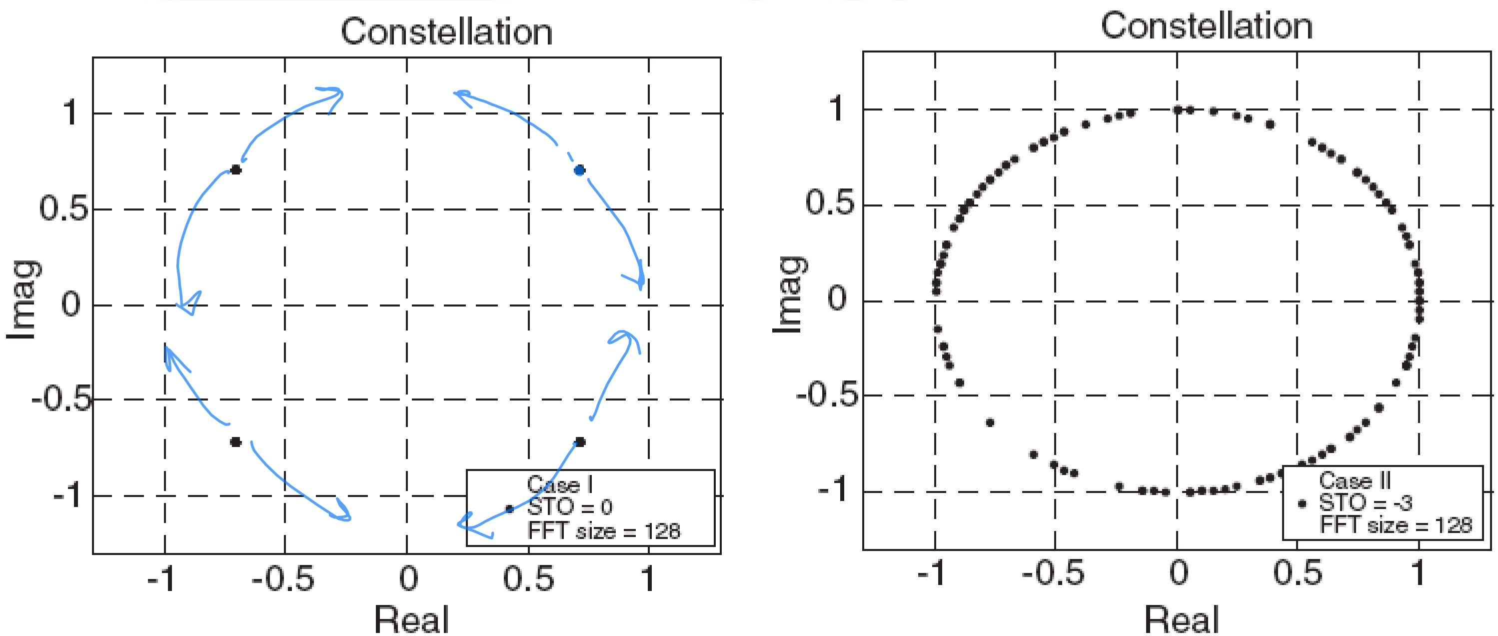
5.1 STO Etkisi

can be compensated by single tap frequency domain equalizer.



(a) Case I: $\delta = 0$ (b) Case II: $\delta = -3$

Figure 5.2 Signal constellation subject to STO.

5.1 STO Etkisi – Case 4

$$y_l[n]=\begin{cases} x_l[n+\delta] & \text{for} \quad 0\le n\le N-1-\delta \\ x_{l+1}[n+2\delta-N_g] & \text{for} \quad N-\delta\le n\le N-1 \end{cases} \tag{5.3}$$

ilk δ-1 örnek alınmamış

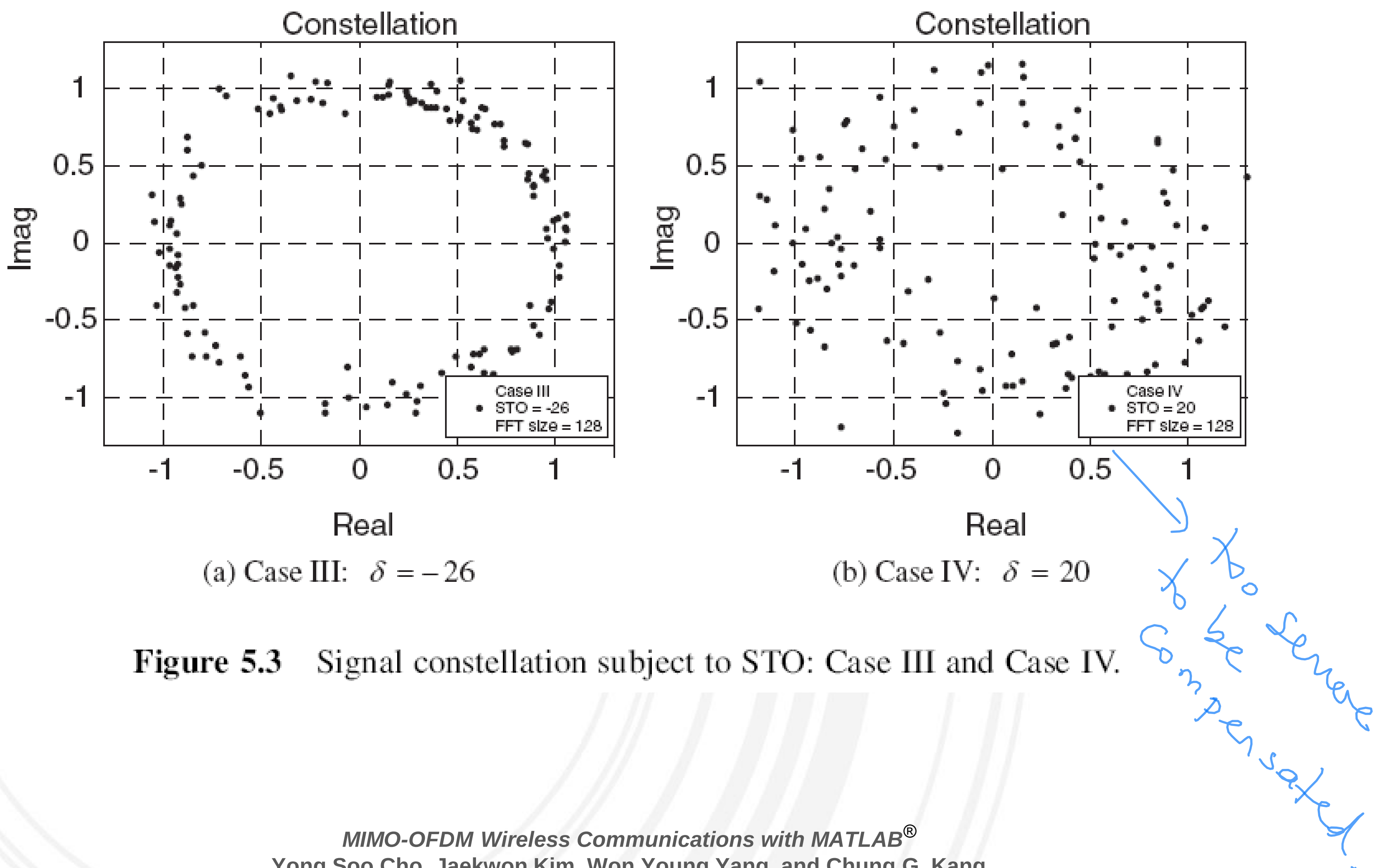
sonraki sembolün ilk δ-1 örneği

$$\begin{aligned} Y_l[k] &= \text{FFT}\{y_l[n]\} \\ &= \sum_{n=0}^{N-1-\delta} x_l[n+\delta]\, e^{-j2\pi nk/N} + \sum_{n=N-\delta}^{N-1} x_{l+1}[n+2\delta-N_g]\, e^{-j2\pi nk/N} \\ &= \sum_{n=0}^{N-1-\delta}\left(\frac{1}{N}\sum_{p=0}^{N-1} X_l[p]\, e^{j2\pi(n+\delta)p/N}\right) e^{-j2\pi nk/N} \\ &\quad + \sum_{n=N-\delta}^{N-1}\left(\frac{1}{N}\sum_{p=0}^{N-1} X_{l+1}[p]\, e^{j2\pi(n+2\delta-N_g)p/N}\right) e^{-j2\pi nk/N} \\ &= \frac{1}{N}\sum_{p=0}^{N-1} X_l[p]\, e^{j2\pi p\delta/N} \sum_{n=0}^{N-1-\delta} e^{j2\pi\frac{(p-k)}{N}n} + \frac{1}{N}\sum_{p=0}^{N-1} X_{l+1}[p]\, e^{j2\pi p(2\delta-N_g)/N} \sum_{n=N-\delta}^{N-1} e^{j2\pi\frac{(p-k)}{N}n} \\ &= \frac{N-\delta}{N} X_l[p] e^{j2\pi p\delta/N} + \sum_{p=0,p\ne k}^{N-1} X_l[p]\, e^{j2\pi p\delta/N} \sum_{n=0}^{N-1-\delta} e^{j2\pi\frac{(p-k)}{N}n} \\ &\quad + \frac{1}{N}\sum_{p=0}^{N-1} X_{l+1}[p]\, e^{j2\pi p(2\delta-N_g)/N} \sum_{n=N-\delta}^{N-1} e^{j2\pi\frac{(p-k)}{N}n} \end{aligned} \tag{5.4}$$

ICI (kendi sembolünün diğer carrier'ları)

Sonraki sembol (ISI)

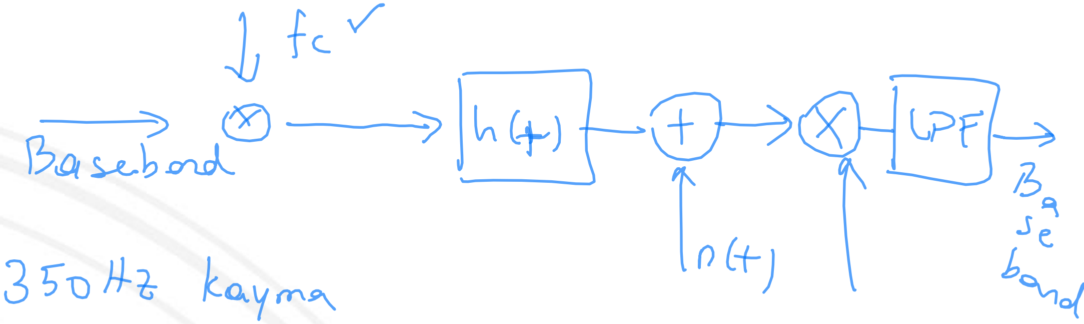
5.2 CFO Etkisi



(a) Case III: $\delta = -26$ (b) Case IV: $\delta = 20$

Figure 5.3 Signal constellation subject to STO: Case III and Case IV.

5.2 CFO Etkisi



$$f_d = \frac{v \cdot f_c}{c} \quad (5.5)$$

$$\varepsilon = \frac{f_{\text{offset}}}{\Delta f} \quad (5.6)$$

$$y_l[n] = \frac{1}{N} \sum_{k=0}^{N-1} H[k] X_l[k] \, e^{j2\pi(k+\varepsilon)n/N} + z_l[n] \quad (5.7)$$

5.2 CFO Etkisi

System	Carrier Frequency	Subcarrier Spacing	Velocity	Maximum Doppler Frequency	Normalized CFO
DMB	375MHz	1KHz	120km/h	41.67Hz	0.042
3GPP	2GHz	15kHz	120km/h	222.22Hz	0.0148
WiBro	2.3GHz	9.765KHz	120km/h	255.55Hz	0.0263

Table 5.2 Doppler frequency and normalized CFO: an example.

	Received signal	Effect of CFO on the received signal
Time-domain signal	$Y[k]$	$e^{j2\pi n\varepsilon/N}x[n]$
Frequency-domain signal	$y[n]$	$X[k-\varepsilon]$

Table 5.3 The effect of CFO on the received signal.

5.2 CFO Etkisi

$$y_l[n] = \frac{1}{N}\sum_{k=0}^{N-1} H_l[k]\, X_l[k]\, e^{j2\pi\frac{(k+\varepsilon)n}{N}} + z$$

$$y_l[n] = \frac{1}{N}\sum_{k=0}^{N-1} H_l[k]\, X_l[k]\, e^{j2\pi\frac{kn}{N}}\, e^{j2\pi\frac{n\varepsilon}{N}}$$

Her örnekte daha fazla faz kayması oluyor.

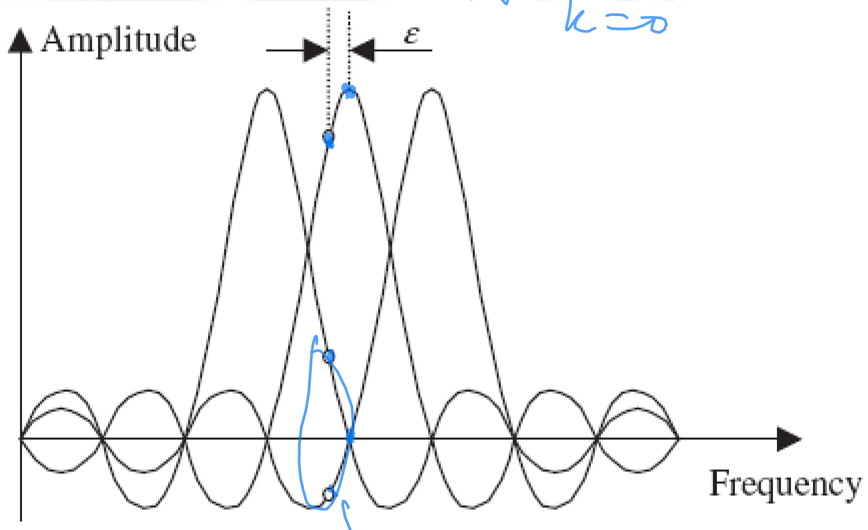
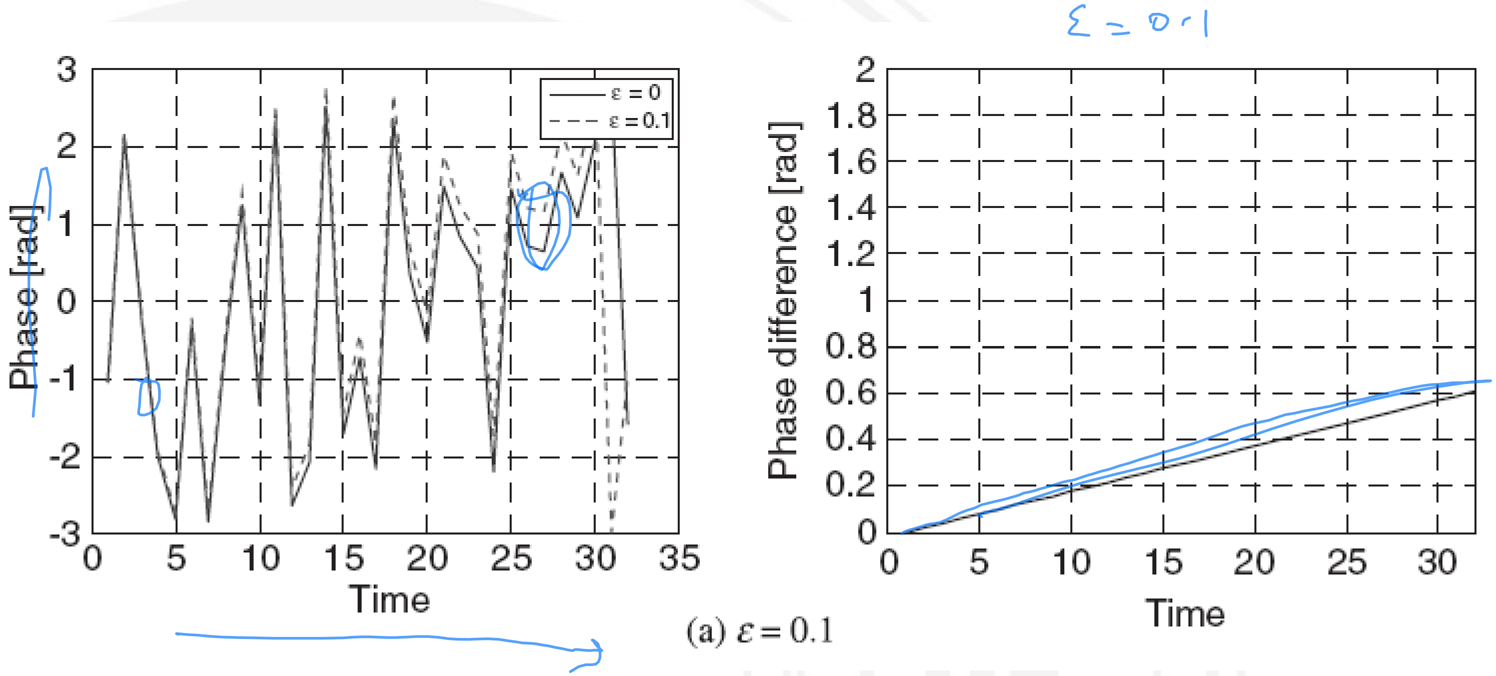


Figure 5.4 Inter-carrier interference (ICI) subject to CFO.

ICI oluyor.

5.2 Effect of CFO

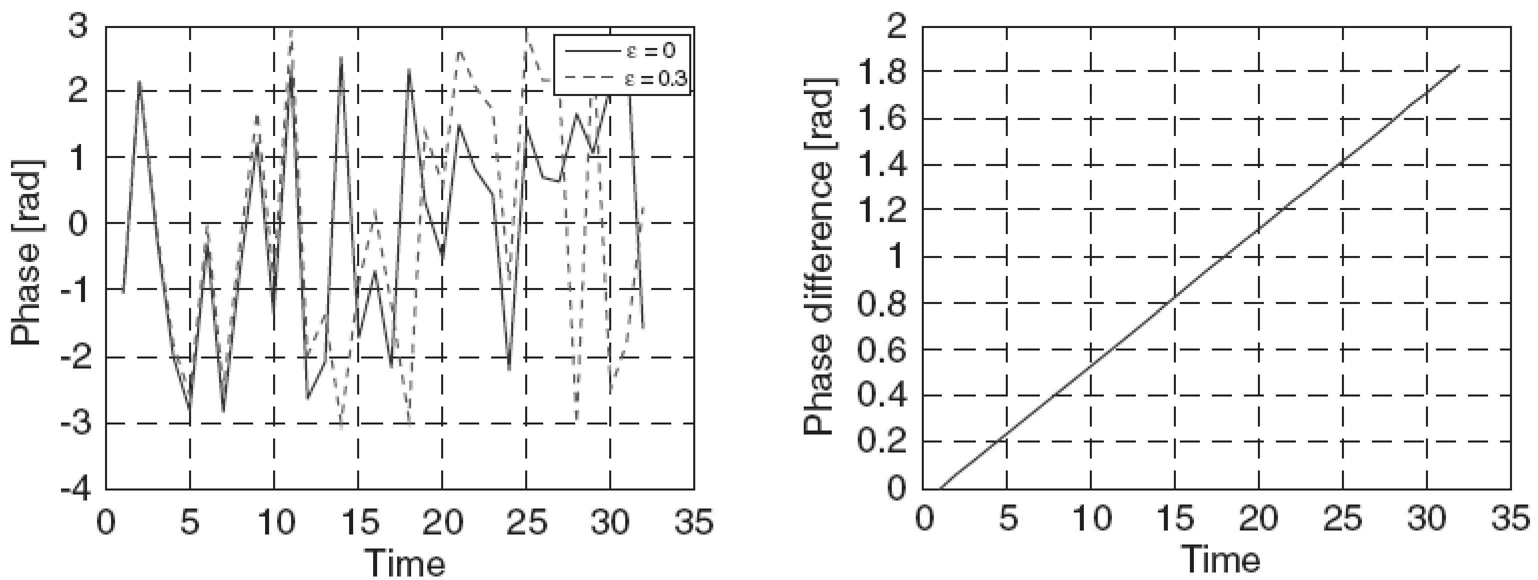


(a) $\varepsilon = 0.1$

Figure 5.5 Effects of CFO ε on the phase of the time-domain signal.

5.2 CFO Etkisi

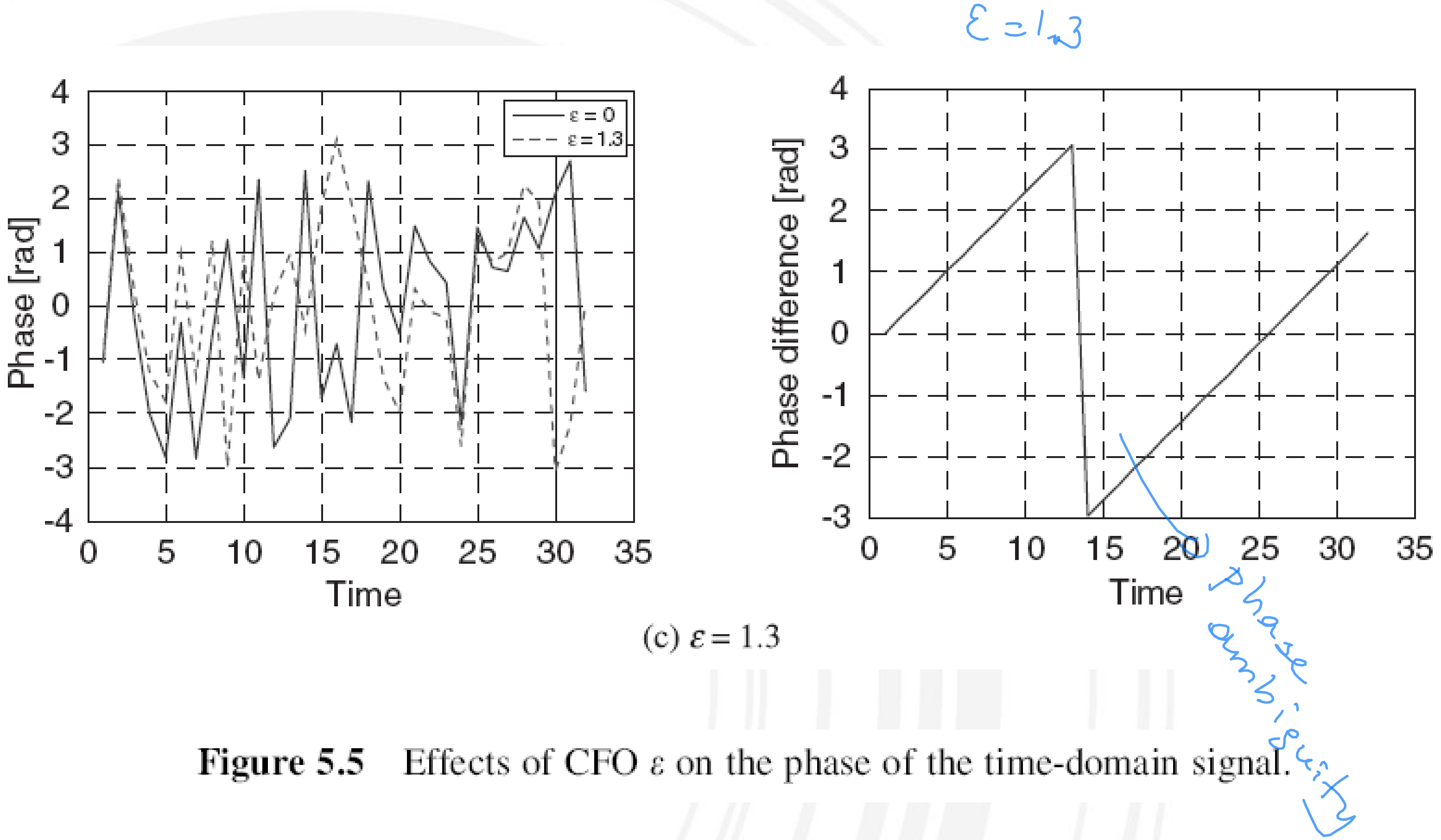
ε = 0.3



(b) $\varepsilon = 0.3$

Figure 5.5 Effects of CFO ε on the phase of the time-domain signal.

5.2 CFO Etkisi



(c) $\varepsilon = 1.3$

Figure 5.5 Effects of CFO ε on the phase of the time-domain signal.

5.2.1 Tamsayı CFO (IFO) Etkisi

$\varepsilon = 1.3 \rightarrow \varepsilon_i = 1 + \varepsilon_f = 0.3$

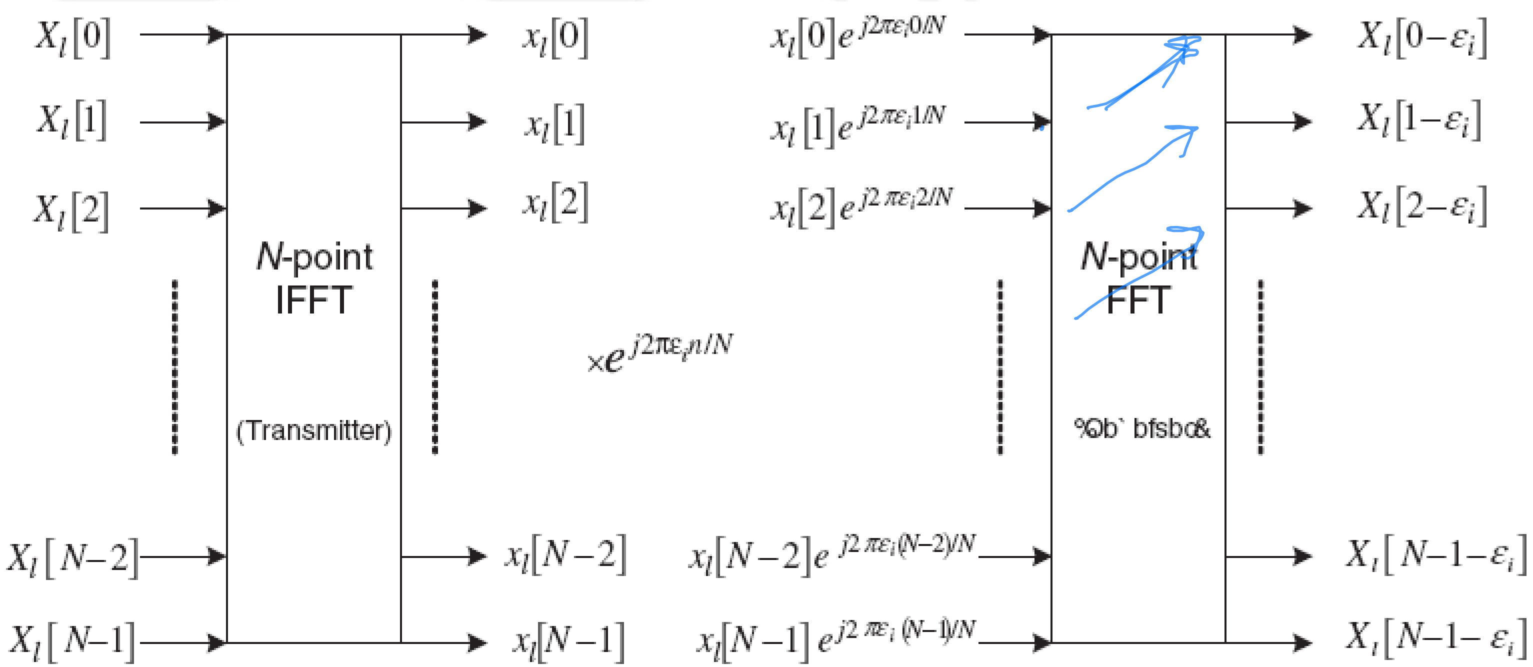


Figure 5.6 Effect of integer CFO on the received signal.

Ancak, orthogonality (diklik) korunuyor)

5.2.2 Kesirli CFO (FFO) Etkisi

$$
\begin{aligned}
Y_l[k] &= \mathrm{FFT}\{y_l[n]\} = \sum_{n=0}^{N-1} y_l[n] e^{-j2\pi kn/N} \\
&= \sum_{n=0}^{N-1} \frac{1}{N} \sum_{m=0}^{N-1} H[m]X_l[m]\, e^{j2\pi(m+\varepsilon_f)n/N} e^{-j2\pi kn/N} + \sum_{n=0}^{N-1} z_l[n] e^{-j2\pi kn/N} \\
&= \frac{1}{N} \sum_{m=0}^{N-1} H[m]X_l[m] \sum_{n=0}^{N-1} e^{j2\pi(m-k+\varepsilon_f)n/N} + Z_l[k] \\
&= \frac{1}{N} H[k]X_l[k] \sum_{n=0}^{N-1} e^{j2\pi\varepsilon_f n/N} + \frac{1}{N} \sum_{m=0, m\neq k}^{N-1} H[m]X_l[m] \sum_{n=0}^{N-1} e^{j2\pi(m-k+\varepsilon_f)n/N} + Z_l[k] \\
&= \frac{1}{N} \frac{1-e^{j2\pi\varepsilon_f}}{1-e^{j2\pi\varepsilon_f/N}} H[k]X_l[k] + \frac{1}{N} \sum_{m=0, m\neq k}^{N-1} H[m]X_l[m] \frac{1-e^{j2\pi(m-k+\varepsilon_f)}}{1-e^{j2\pi(m-k+\varepsilon_f)/N}} + Z_l[k] \\
&= \frac{1}{N} \frac{e^{j\pi\varepsilon_f}\left(e^{-j\pi\varepsilon_f}-e^{j\pi\varepsilon_f}\right)}{e^{j\pi\varepsilon_f/N}\left(e^{-j\pi\varepsilon_f/N}-e^{j\pi\varepsilon_f/N}\right)} H[k]X_l[k] \\
&\quad + \frac{1}{N} \sum_{m=0,\, m\neq k}^{N-1} H[m]X_l[m] \frac{e^{j\pi(m-k+\varepsilon_f)}\left(e^{-j\pi(m-k+\varepsilon_f)}-e^{j\pi(m-k+\varepsilon_f)}\right)}{e^{j\pi(m-k+\varepsilon_f)/N}\left(e^{-j\pi(m-k+\varepsilon_f)/N}-e^{j\pi(m-k+\varepsilon_f)/N}\right)} + Z_l[k] \\
&= e^{j\pi\varepsilon_f(N-1)/N} \left\{ \frac{\sin(\pi\varepsilon_f)}{N\sin(\pi\,\varepsilon_f/N)} \right\} H_l[k]X_l[k] \\
&\quad + e^{j\pi\varepsilon_f(N-1)/N} \sum_{m=0,\, m\neq k}^{N-1} \frac{\sin(\pi(m-k+\varepsilon_f))}{N\sin(\pi(m-k+\varepsilon_f)/N)} H[m]X_l[m]\, e^{j\pi(m-k)(N-1)/N} + Z_l[k] \\
&= \left\{ \frac{\sin\pi\varepsilon_f}{N\sin(\pi\varepsilon_f/N)} \right\} e^{j\pi\varepsilon_f(N-1)/N} H_l[k]X_l[k] + I_l[k] + Z_l[k] \qquad (5.8)
\end{aligned}
$$

kendi taşıyıcılar (l)

diğer taşıyıcılar

sin

Amplitude & Phase Distortion

ICI (orthogonality lost)

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5.2.2 Kesirli CFO (FFO) Etkisi

$$I_l[k] = e^{j\pi\varepsilon_f(N-1)/N} \sum_{m=0,\, m\neq k}^{N-1} \frac{\sin(\pi(m-k+\varepsilon_f))}{N\sin(\pi(m-k+\varepsilon_f)/N)} H[m]X_l[m]\, e^{j\pi(m-k)(N-1)/N} \qquad (5.9)$$

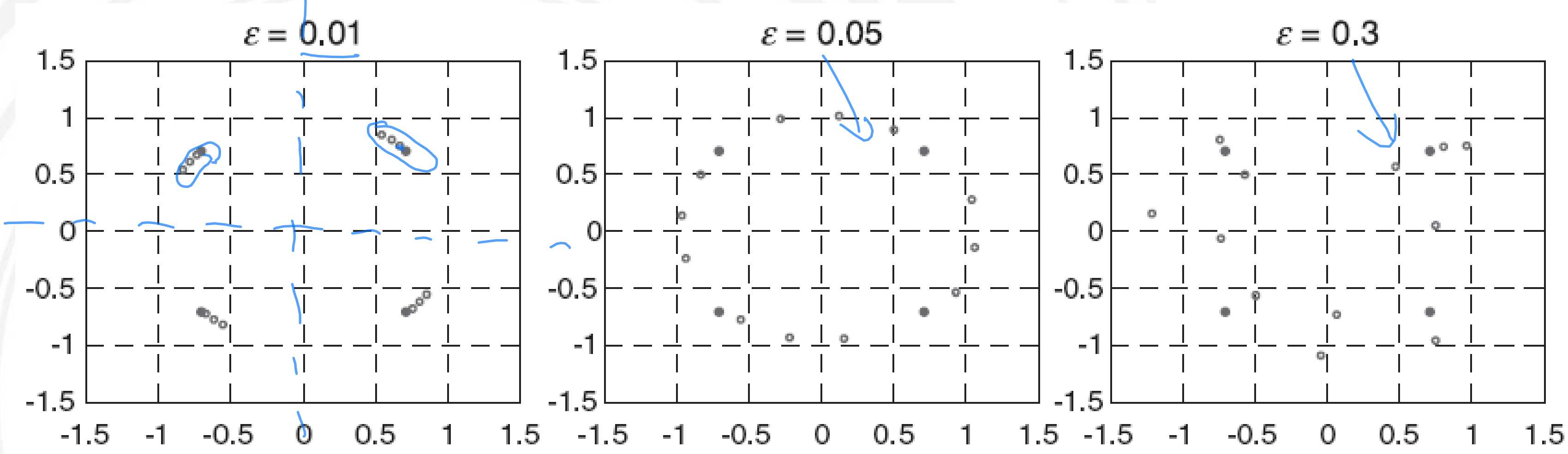

Figure 5.7 Constellation of received symbols with CFO ε

5.3 STO Kestirim Teknikleri

5.3.1 Zaman Alanın STO Kestirimi

5.3.1.1 Çevrimsel Önek Kullanımı (Cyclic Prefix(CP))

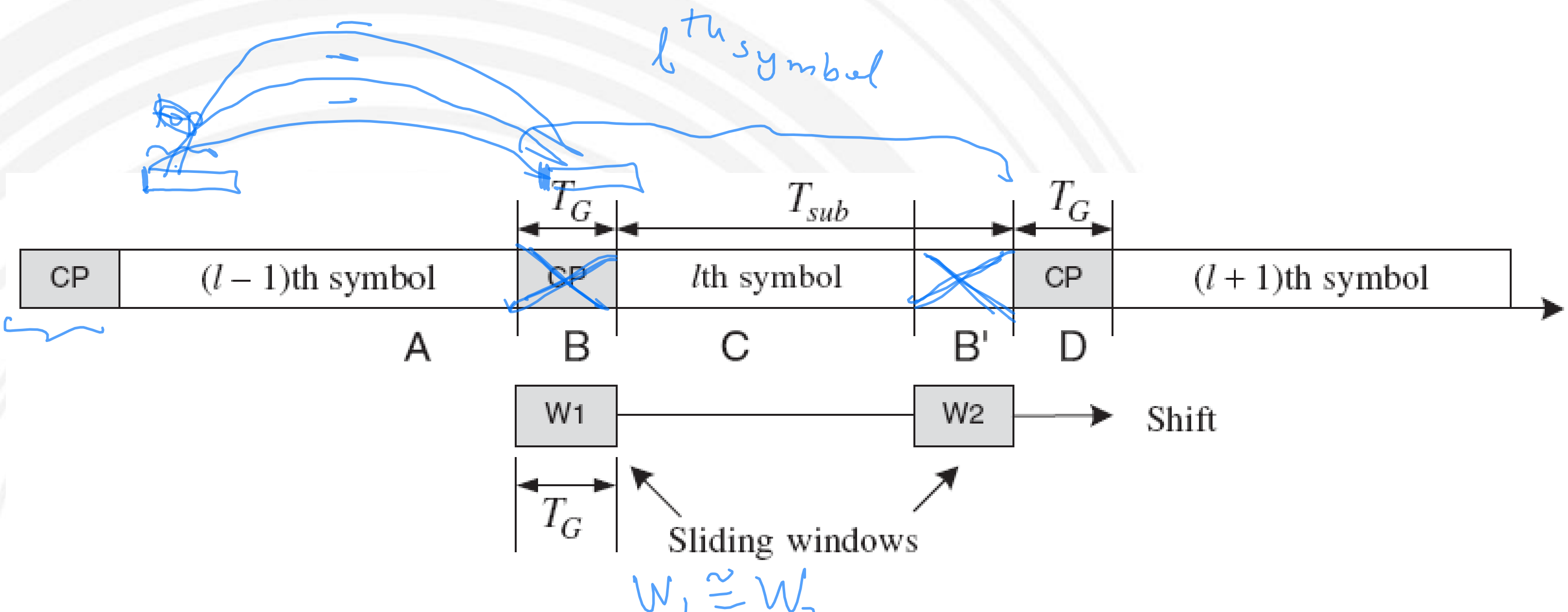

Figure 5.8 STO estimation technique using double sliding windows.

5.3.1.1 Çevrimsel Önek Kullanımı (Cyclic Prefix(CP))

N_G : CP uzunluğu

min

$$\hat{\delta} = \arg\min_{\delta} \left\{ \sum_{i=\delta}^{N_G-1+\delta} |y_l[n+i] - y_l[n+N+i]| \right\} \quad (5.10)$$

difference

min

$$\hat{\delta} = \arg\min_{\delta} \left\{ \sum_{i=\delta}^{N_G-1+\delta} (|y_l[n+i]| - |y_l^*[n+N+i]|)^2 \right\} \quad (5.11)$$

max

$$\hat{\delta} = \arg\max_{\delta} \left\{ \sum_{i=\delta}^{N_G-1+\delta} |y_l[n+i] y_l^*[n+N+i]| \right\} \quad (5.12)$$

correlation

$$\hat{\delta}_{ML} = \arg\max_{\delta} \sum_{i=\delta}^{N_G-1+\delta} \left[2(1-\rho)\mathrm{Re}\{y_l[n+i] y_l^*[n+N+i]\} - \rho \sum_{i=\delta}^{N_G-1+\delta} |y_l[n+i] - y_l[n+N+i]| \right] \quad (5.13)$$

Maximum Likelihood

ρ: SNR/SNR+1

5.3.1.1 Çevrimsel Önek Kullanımı (Cyclic Prefix(CP))

Hem STO hem CFO kestirebiliyor.

$$\hat{\delta}_{ML} = \arg\max_{\delta}\{|\gamma[\delta]| - \rho\,\Phi[\delta]\} \quad (5.14)$$

$$\gamma[m] = \sum_{n=m}^{m+L-1} y_l[n]y_l^*[n+N],$$

and $$\Phi[m] = \frac{1}{2}\sum_{n=m}^{m+L-1}\left\{|y_l[n]|^2 + |y_l[n+N]|^2\right\} \quad (5.15)$$

5.3.1.2 Eğitim Dizisi Kullanımı

Training Symbol

$W_1 = W_2$

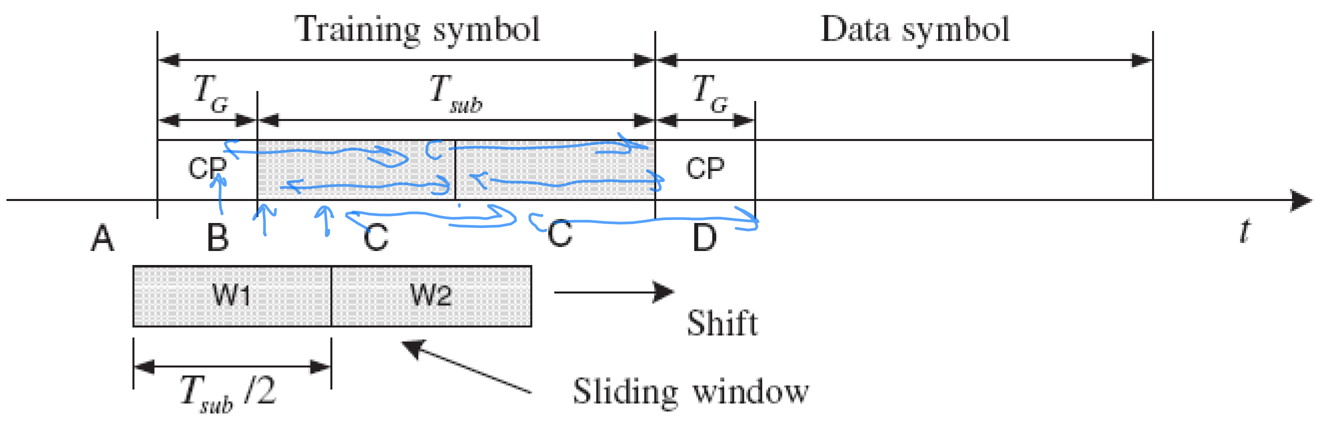

Figure 5.9 STO estimation using the repetitive training symbol (period = $T_{sub}/2$).

5.3.1.2 Eğitim Dizisi Kullanımı

$$\hat{\delta} = \arg\min_{\delta} \left\{ \sum_{i=\delta}^{\frac{N}{2}-1+\delta} \left| y_l[n+i] - y_l^*\left[n+\frac{N}{2}+i\right] \right|^2 \right\} \quad (5.16)$$

$$\hat{\delta} = \arg\max_{\delta} \left\{ \frac{\left| \sum_{i=\delta}^{\frac{N}{2}-1+\delta} y_l[n+i]\, y_l^*\left[n+\frac{N}{2}+i\right] \right|^2}{\left| \sum_{i=\delta}^{\frac{N}{2}-1+\delta} y_l\left[n+\frac{N}{2}+i\right] \right|^2} \right\} \quad (5.17)$$

$$\hat{\delta} = \arg\max_{\delta} \left(\frac{1}{N_G+1} \sum_{m=-N_G+i}^{i} s_l[n+m] \right) \quad (5.18)$$

5.3.1.2 Eğitim Dizisi Kullanımı

$$s_l[n] = \frac{\left| \sum_{i=\delta}^{N/2-1+\delta} y_l[n+i] y_l^*\left[n+\frac{N}{2}+i\right] \right|^2}{\left(\frac{1}{2} \left| \sum_{i=\delta}^{N-1+\delta} y_l[n+i] \right|^2 \right)^2} \tag{5.19}$$

$$\hat{\delta} = \arg\max_{\delta} \frac{\left| \sum_{i=\delta}^{N/4-1+\delta} y_l\left[n+i+\frac{N}{2}m\right] y_l^*\left[n+i+\frac{N}{4}+\frac{N}{2}m\right] \right|^2}{\left(\sum_{m=0}^{1} \sum_{i=\delta}^{N/4-1+\delta} \left| y_l\left[n+i+\frac{N}{4}+\frac{N}{2}m\right] \right|^2 \right)^2} \tag{5.20}$$

5.3.1.2 Eğitim Dizisi Kullanımı

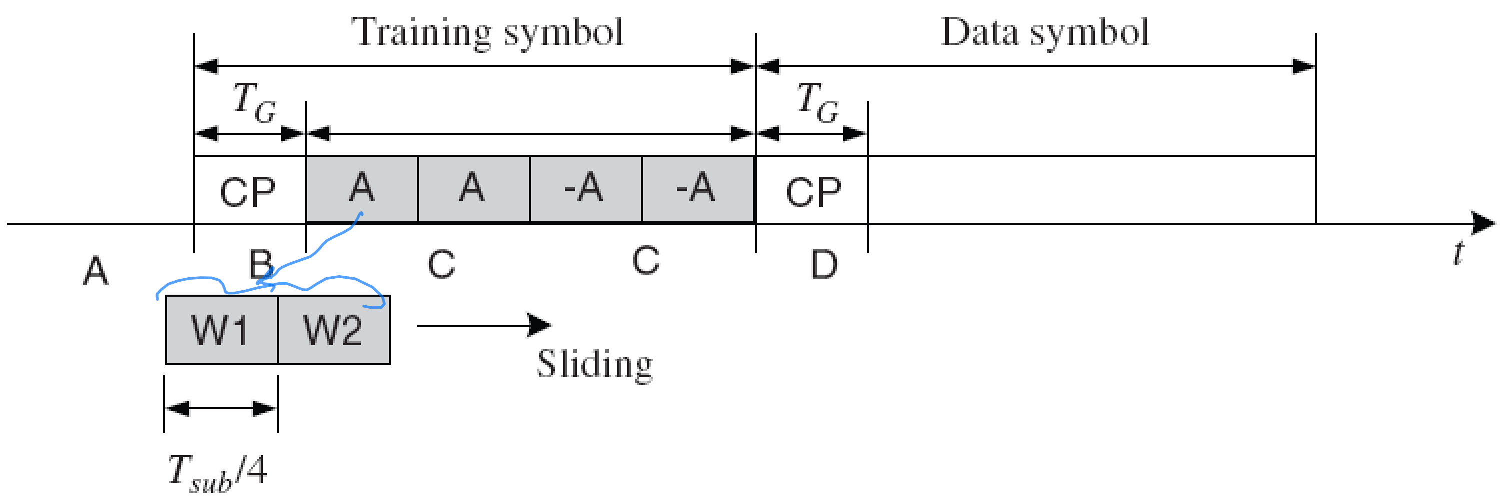

Figure 5.10 STO estimation using the repetitive training symbol (period $= T_{\text{sub}}/4$).

5.3.1.2 Eğitim Dizisi Kullanımı

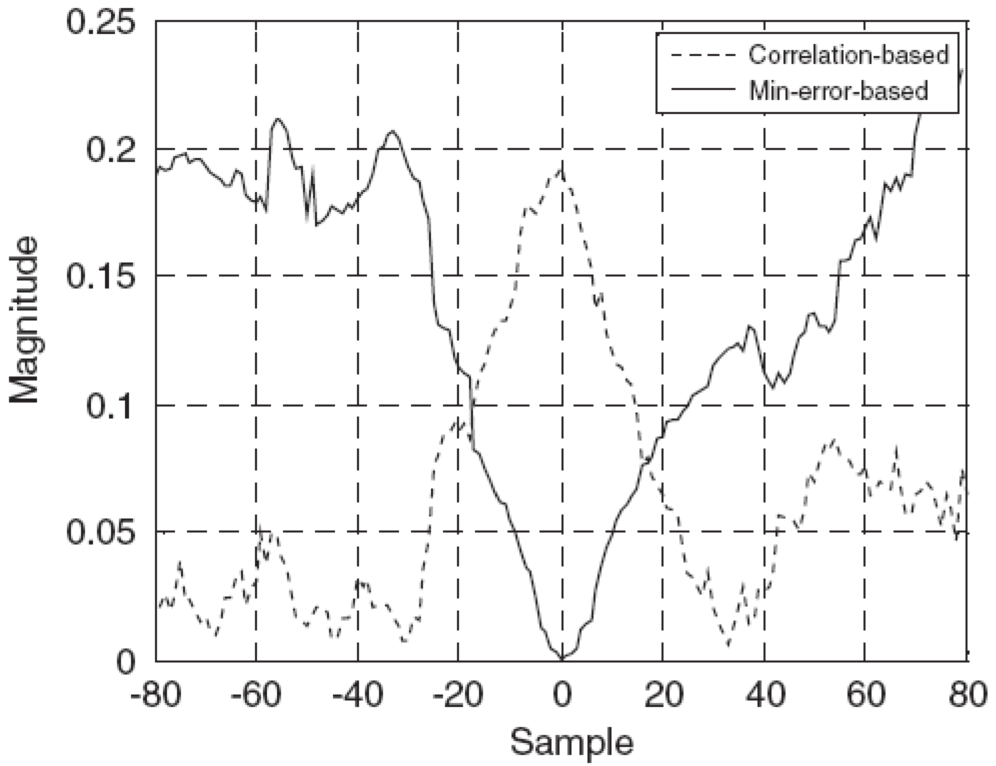

Figure 5.11 Performance of CP-based STO estimation: maximum correlation-based vs. minimum difference-based estimation.

5.3.2 Frekans Alanı STO Kestirim Teknikleri

$$\hat{\delta} = \frac{N}{2\pi}\arg\left(\sum_{k=1}^{N-1} Y_l[k]Y_l^*[k-1]\right) \quad (5.21)$$

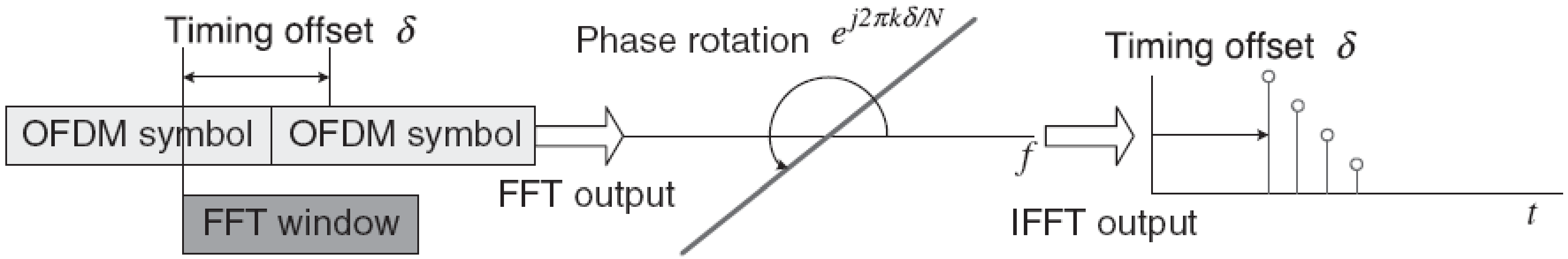

Figure 5.12 STO estimation using the channel impulse response.

5.3.2 Frekans Alanı STO Kestirim Teknikleri

$$
\begin{aligned}
y_l^X[n] &= \text{IFFT}\left\{Y_l[k]e^{j2\pi\delta k/N}X_l^*[k]\right\} \\
&= \frac{1}{N}\sum_{k=0}^{N-1} Y_l[k]e^{j2\pi\,\delta k/N}X_l^*[k]e^{j2\pi nk/N} \\
&= \frac{1}{N}\sum_{k=0}^{N-1} H_l[k]X_l[k]X_l^*[k]e^{j2\pi(\delta+n)k/N} \\
&= \frac{1}{N}\sum_{k=0}^{N-1} H_l[k]e^{j2\pi(\delta+n)k/N} \\
&= h_l[n+\delta]
\end{aligned}
\qquad (5.22)
$$

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5.3.2 Frekans Alanı STO Kestirim Teknikleri

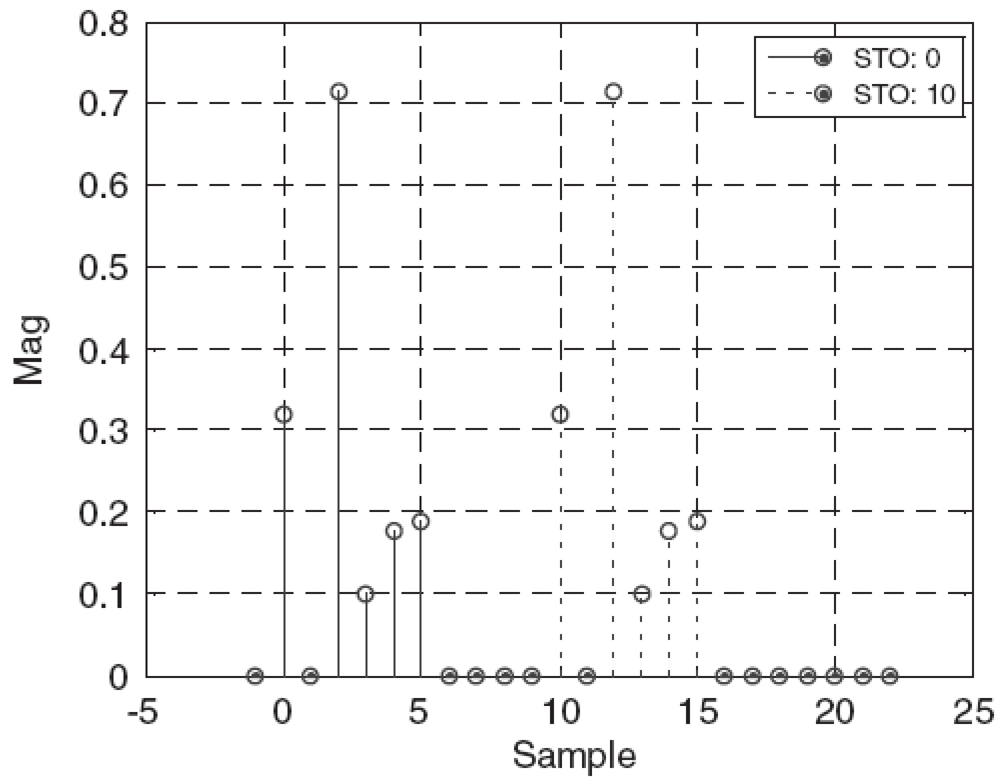

Figure 5.13 Examples of STO estimation using channel impulse response.

5.4 CFO Kestirim Teknikleri

5.4.1 Zaman Alanı CFO Kestirim Teknikleri

5.4.1.1 Çevrimsel Önek (Cyclic Prefix)Kullanımı

$$\hat{\varepsilon} = \frac{1}{2\pi}\arg\left\{\sum_{n=-N_G}^{-1} y_l^*[n]\,y_l[n+N]\right\} \tag{5.23}$$

$$e_\varepsilon = \frac{1}{L}\sum_{n=1}^{L}\mathrm{Im}\{y_l^*[n]\,y_l[n+N]\} \tag{5.24}$$

$$E\{e_\varepsilon\} = \frac{\sigma_d^2}{N}\sin\left(\frac{2\pi\varepsilon}{N}\right)\sum_{k \text{ corresponding to useful carriers}} |H_k|^2 \approx K\varepsilon \tag{5.25}$$

5.4.1.1 Çevrimsel Önek (Cyclic Prefix)Kullanımı

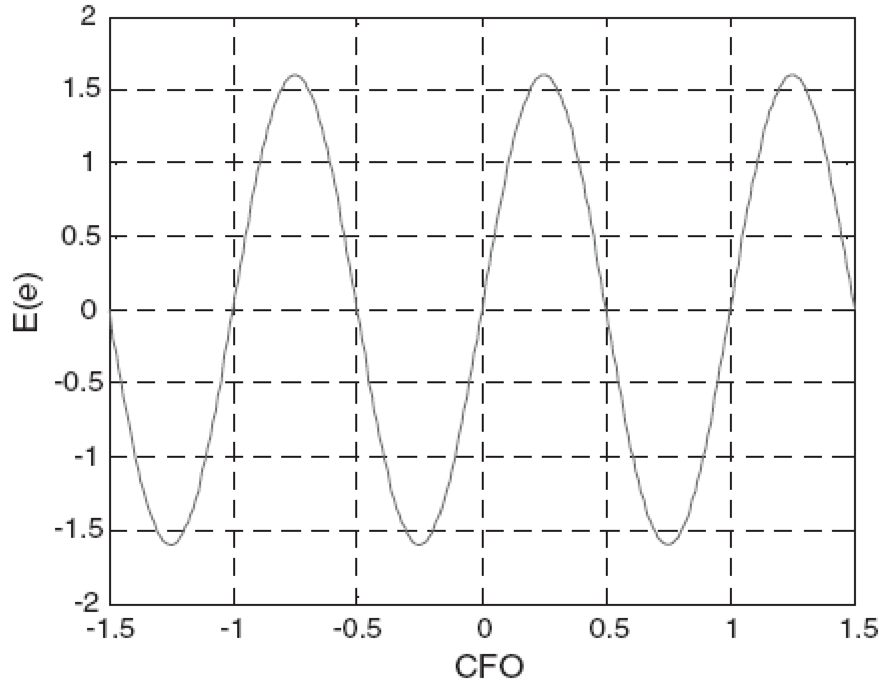

Figure 5.14 Characteristic curve of the error function Equation (5.25).

5.4.1.2 Eğitim Dizisi Kullanımı

ilk senkronizasyonda gereklidir.

$$X_l[k] = \begin{cases} A_m, & \text{if} \quad k = D \cdot i, i = 0, 1, \ldots, (N/D-1) \\ 0, & \text{otherwise} \end{cases} \tag{5.26}$$

D arttıkça başarısı artar.

açı

$$\hat{\varepsilon} = \frac{D}{2\pi} \arg\left\{ \sum_{n=0}^{N/D-1} y_l^*[n] y_l[n+N/D] \right\} \tag{5.27}$$

$$\hat{\varepsilon} = \frac{D}{2\pi} \arg\left\{ \sum_{m=0}^{D-2} \sum_{n=0}^{N/D-1} y_l^*[n+mN/D] y_l[n+(m+1)N/D] \right\} \tag{5.28}$$

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5.4.1.2 Eğitim Dizisi Kullanımı

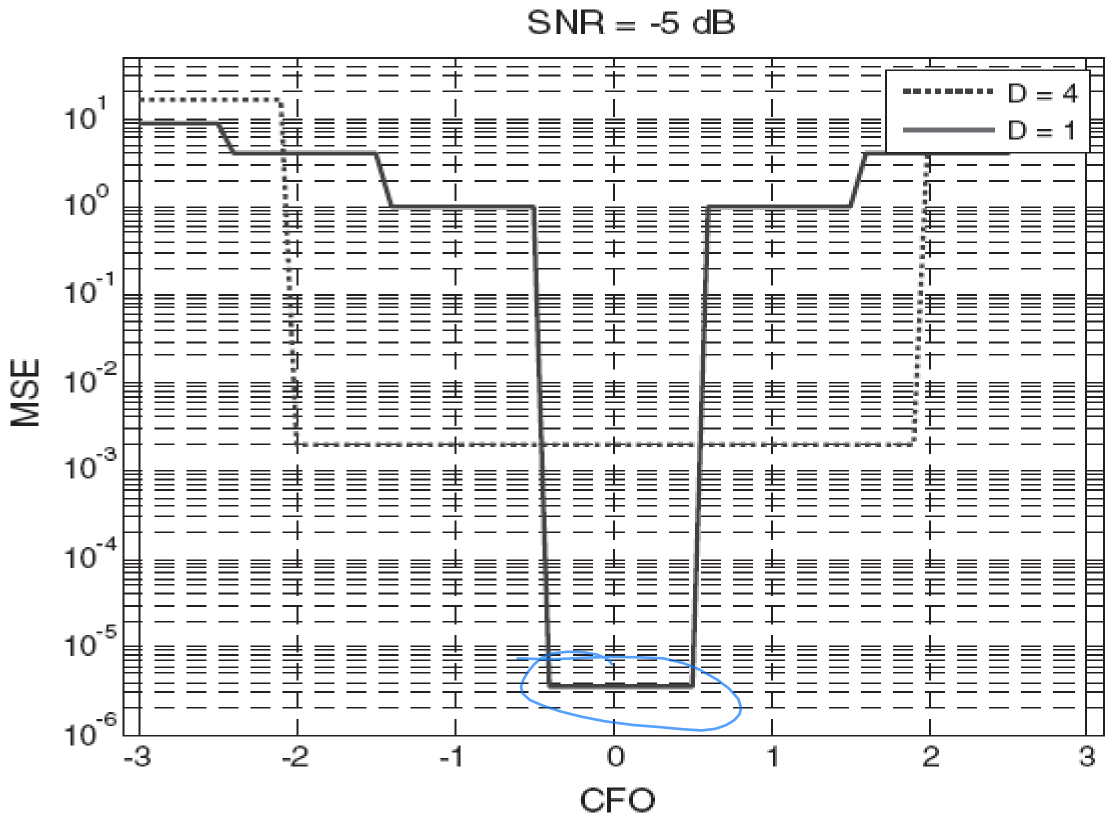


Figure 5.15 Estimation range of CFO vs. MSE performance.

5.4.2 Frekans Alanı CFO Kestirim Teknikleri

$$y_2[n] = y_1[n]e^{j2\pi N\varepsilon/N} \leftrightarrow Y_2[k] = Y_1[k]e^{j2\pi\varepsilon} \tag{5.29}$$

$$\hat{\varepsilon} = \frac{1}{2\pi}\tan^{-1}\left\{\sum_{k=0}^{N-1}\mathrm{Im}\left[Y_1^*[k]Y_2[k]\right] \Big/ \sum_{k=0}^{N-1}\mathrm{Re}\left[Y_1^*[k]Y_2[k]\right]\right\} \tag{5.30}$$

$$\hat{\varepsilon}_{acq} = \frac{1}{2\pi \cdot T_{\mathrm{sub}}}\max_{\varepsilon}\left\{\left|\sum_{j=0}^{L-1} Y_{l+D}[p[j],\varepsilon]Y_l^*[p[j],\varepsilon]\, X_{l+D}^*[p[j]]X_l[p[j]]\right|\right\} \tag{5.31}$$

$$\hat{\varepsilon}_f = \frac{1}{2\pi \cdot T_{\mathrm{sub}} \cdot D}\arg\left\{\sum_{j=1}^{L-1} Y_{l+D}[p[j],\hat{\varepsilon}_{\mathrm{acq}}]Y_l^*[p[j],\hat{\varepsilon}_{\mathrm{acq}}]\, X_{l+D}^*[p[j]]X_l[p[j]]\right\} \tag{5.32}$$

5.4.2 Frekans Alanı CFO Kestirim Teknikleri

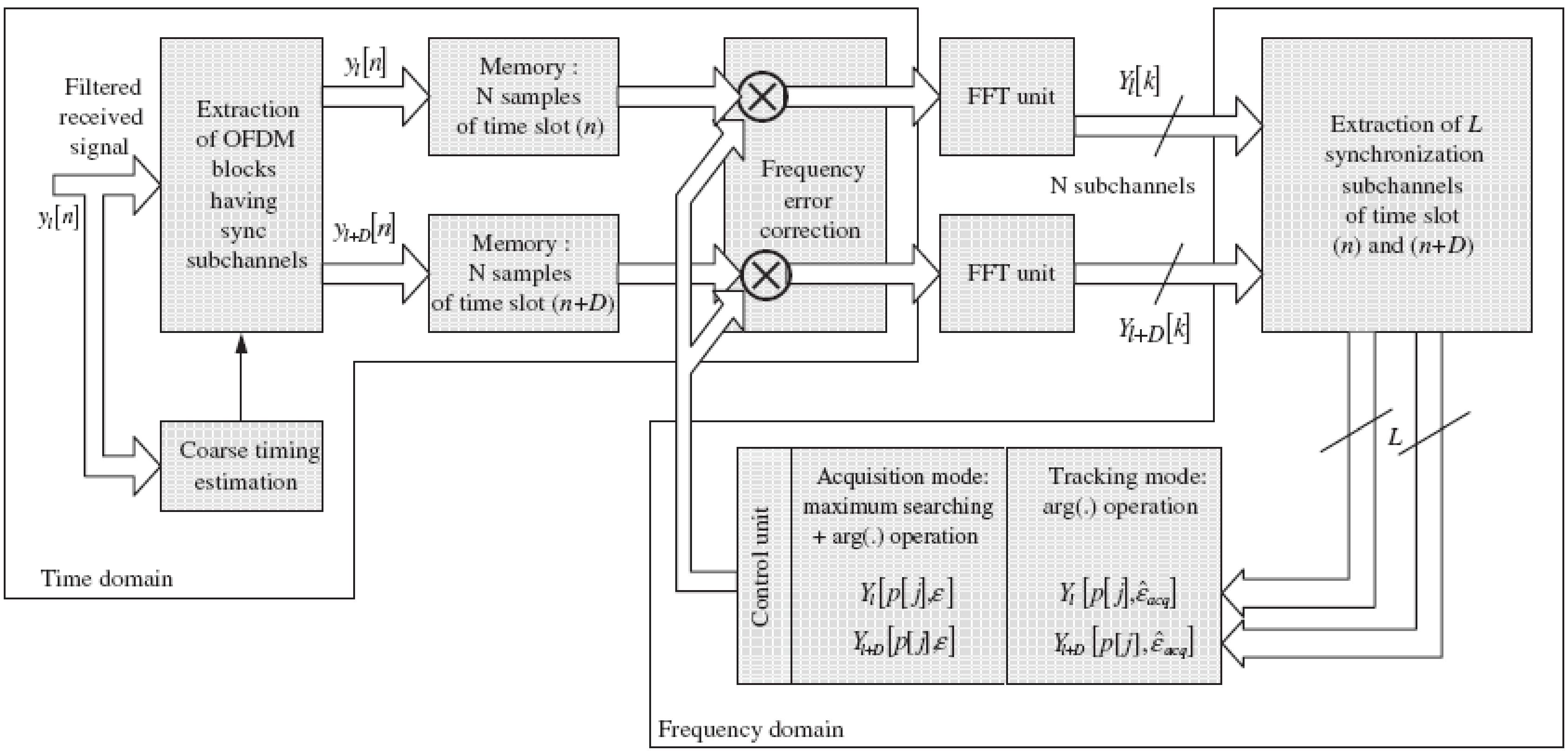


Figure 5.16 CFO synchronization scheme using pilot tones.

5.4.2 Frekans Alanı CFO Kestirim Teknikleri

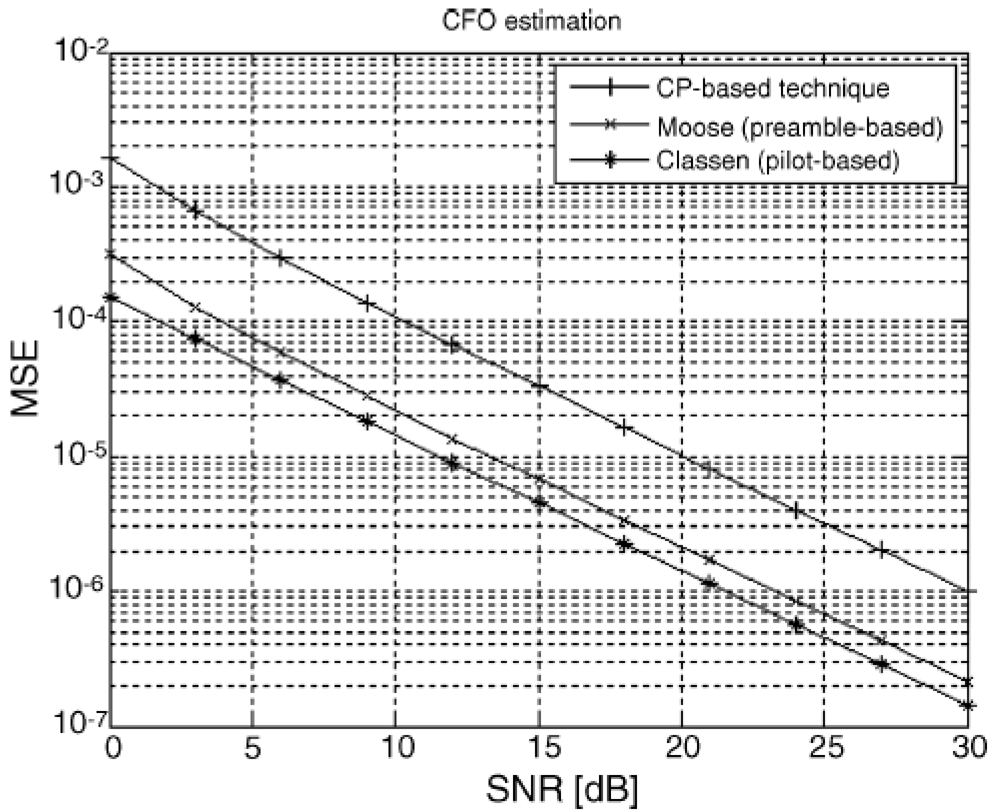


Figure 5.17 MSE of CFO estimation techniques (obtained by running "CFO_estimation.m").

5.5 Örnekleme Saat Hatasının Etkisi

5.5.1 Örnekleme Saatinde faz Kayması Etkisi

Sampling Clock offset $\frac{1}{N\Delta f}$ sampling $= T_s$

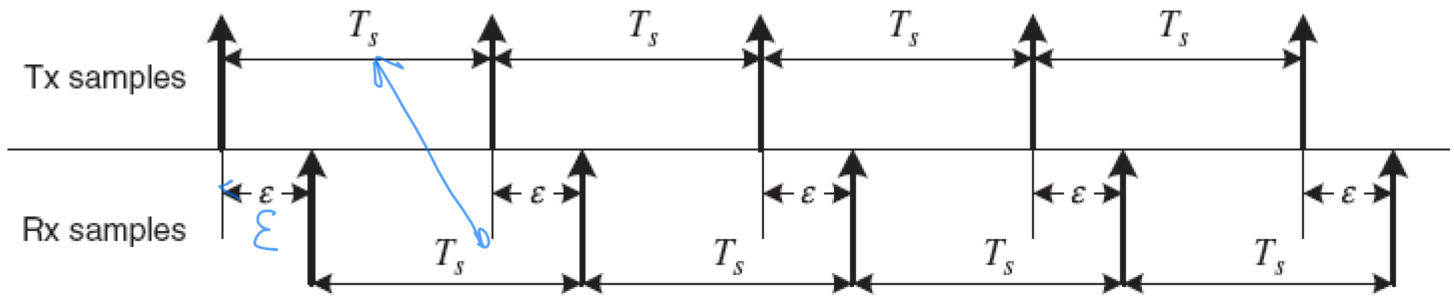


Figure 5.18 Phase offset in sampling clocks: an illustration.

5.5.1 Örnekleme Saatinde faz Kayması Etkisi

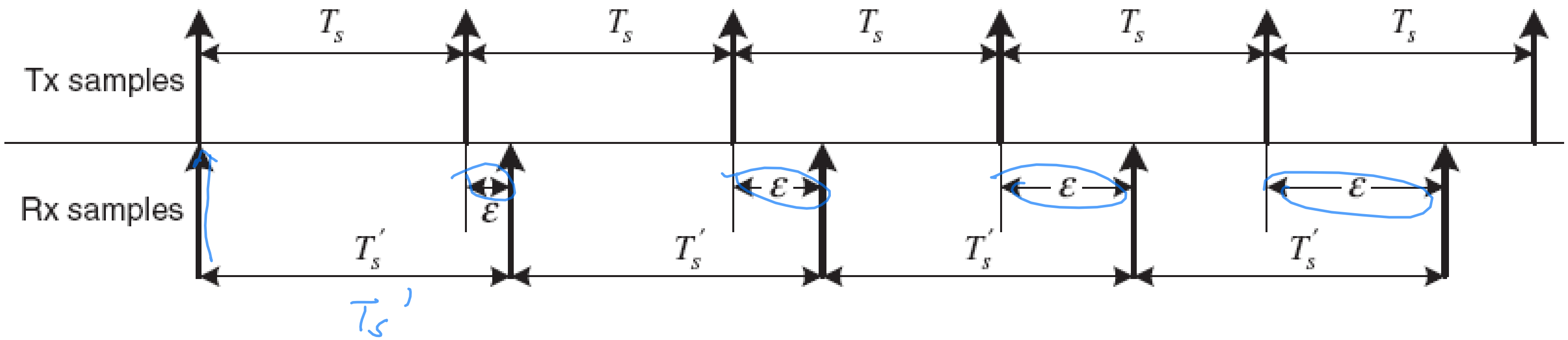


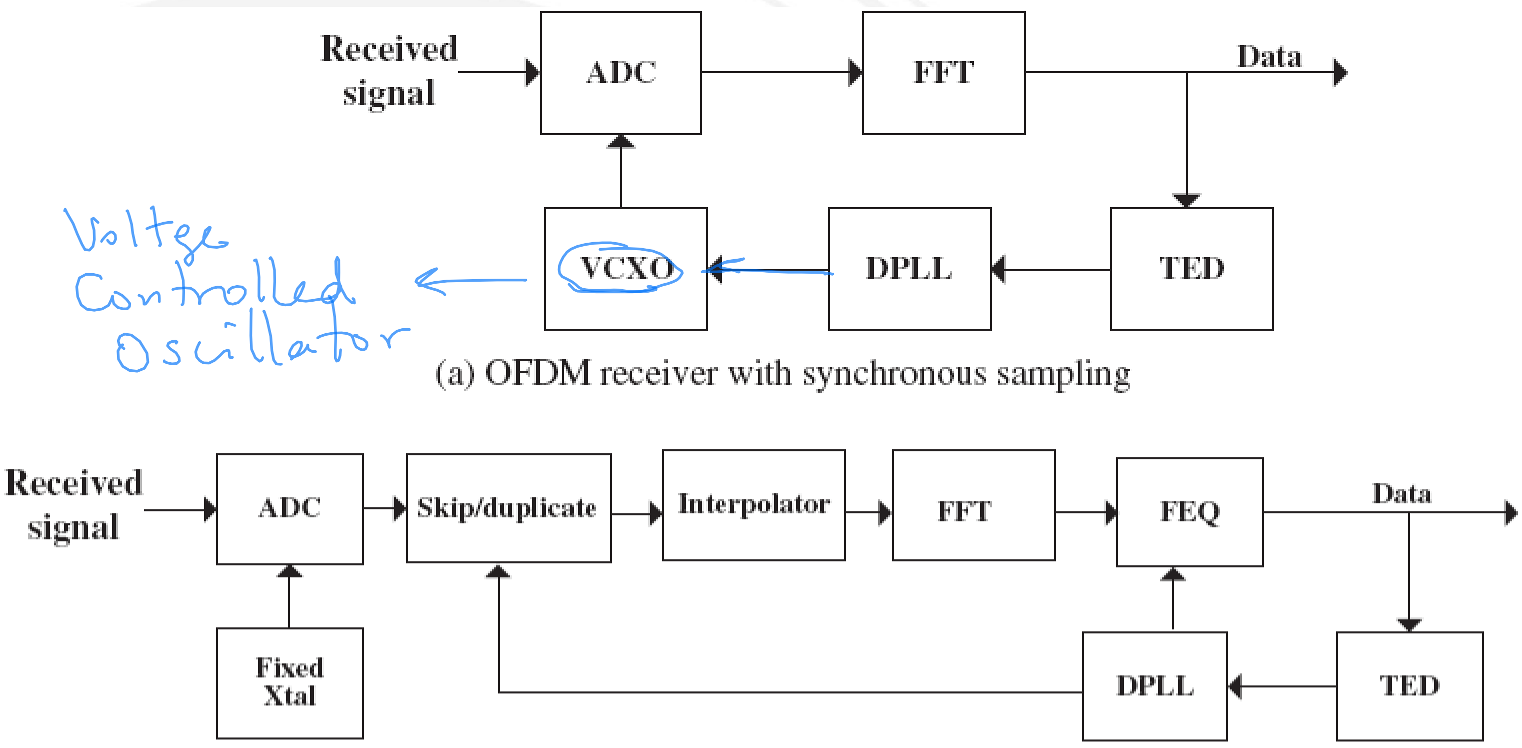
Figure 5.19 Frequency offset in the sampling clocks: an illustration.

$$\tilde{Y}[k] = Y[k] \cdot \frac{\sin(\pi \Delta k)}{\sin(\pi \Delta k / N)} \cdot e^{\frac{-j\pi\Delta k(N-1)}{N}} + z_{ICI}[k] \quad \text{with} \quad \Delta = \frac{T_s - T'_s}{T_s} \tag{5.33}$$

$$\text{var}\{z_{ICI}[k]\} = \frac{\pi^2}{3}(\Delta k)^2 \tag{5.34}$$

5.6 Örnekleme Saat Hatası Telafisi

Digital Phase Locked Loop



(a) OFDM receiver with synchronous sampling

(b) OFDM receiver with non-synchronous sampling

Figure 5.20 Block diagrams for OFDM receivers with synchronous/non-synchronous sampling.

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5.6 Örnekleme Saat Hatası Telafisi

	Synchronous sampling	Non - synchronous sampling
Required components	VCXO (NCO) PLL (DPLL)	XO FIR interpolation filter
Disadvantage	Usage of VCXO is undesirable • higher cost & noise jitter than XO • discrete component	Performance degradation • Slowly time-varying ICI • Usually, requires oversampling or high-order interpolation filter
Synchronization Scheme	• Pilot tone-based synchronization	• Discrete time-domain correction • Hybrid time-domain/frequency-domain correction

Table 5.4 Synchronous sampling vs. non-synchronous sampling in OFDM systems.

5.7 Hücresel Sistemlerde Senkronizasyon

Downlink : BS → MS
Uplink : MS → BS

(5) ranging response (TA)
power level

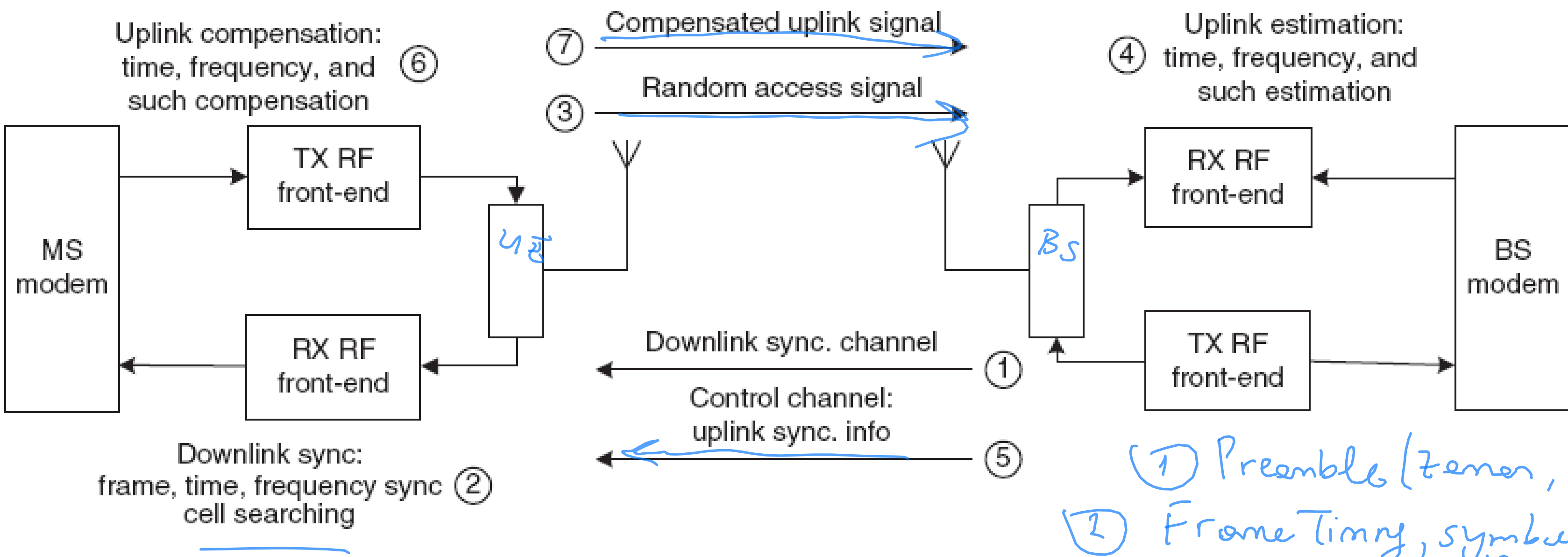

Figure 5.21 Cell search and synchronization process in a cellular system.

(1) Preamble (zaman, fr)
(2) Frame Timing, symbol timing
fc, CELL ID
(3) random access preamble
(4) Timing, fc, etc.

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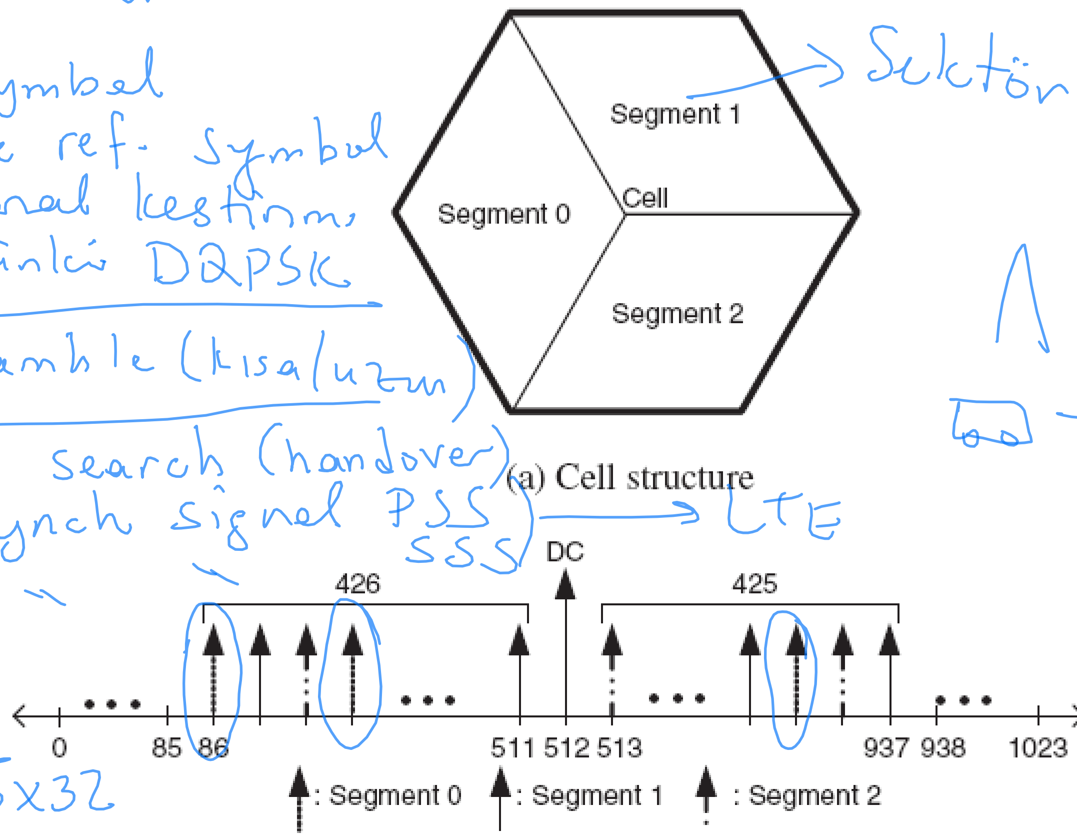
5.7.1 Aşağı Gönderimde Senkronizasyon

Downlink

DAB: Null symbol
phase ref. symbol
Pilot yok, kanal kestirimi yok, güncü DQPSK

802.11 : preamble (kısa/uzun)

Cellular : cell search (handover)
Primary Synch signal PSS
Seondary SSS → LTE



(b) Preamble structure in the frequency domain

114 sequence
96 tane = 3x32
32 cell ID

PN seq.
Gold seq.
CAZAC seq.

CP → FFO (ε<1)

Figure 5.22 Cell and preamble structures in Mobile WiMAX system.

5.7.1 Aşağı Gönderimde Senkronizasyon (LTE)

P-SCH Primary (symbol timing, CFO)

S-SCH: Secondary (cell ID, frame timing.)

1ms = 2slot (2x 0,5ms)

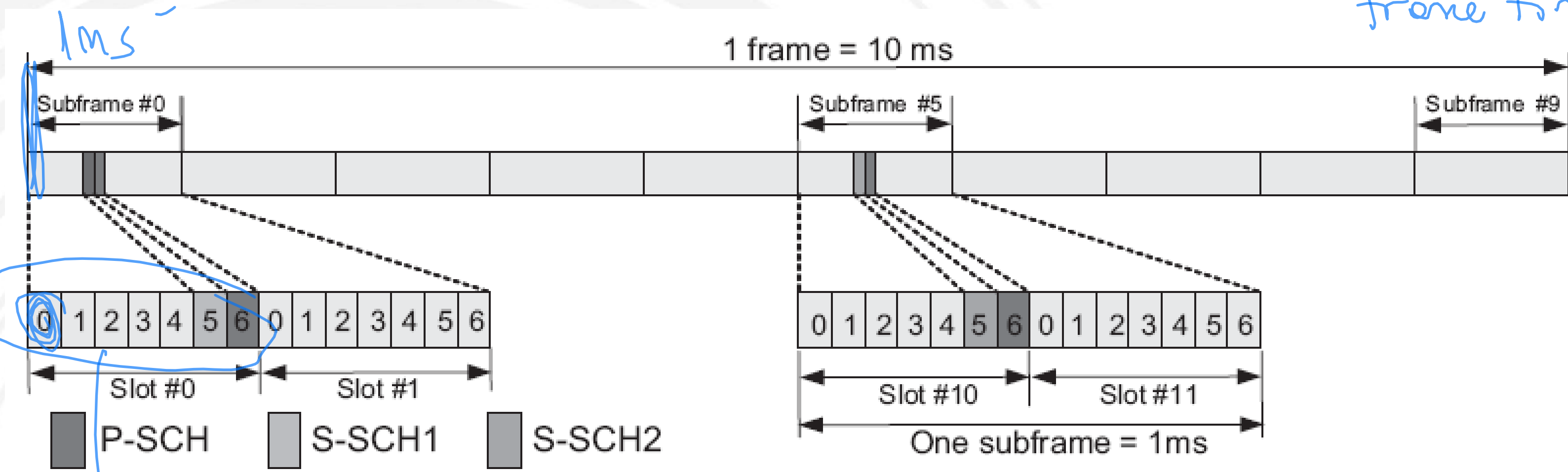


Figure 5.23 Downlink frame structure in 3GPP-LTE system (normal CP).

168 phy layer cell ID

1slot = 7 OFDM sembolü

5.7.2 Yukarı Gönderimde Senkronizasyon

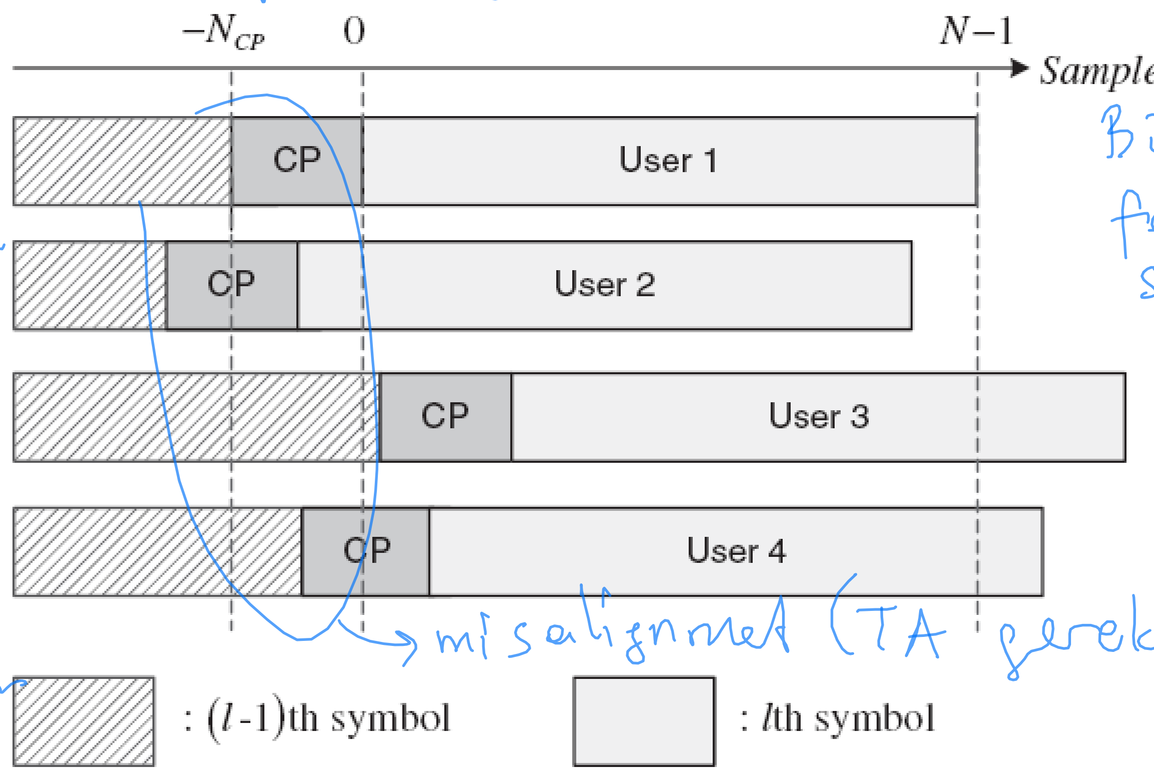


Figure 5.24 Timing misalignments among MS bursts received at BS in OFDMA system.

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5.7.2 Yukarı Gönderimde Senkronizasyon

MS gönderiyor.

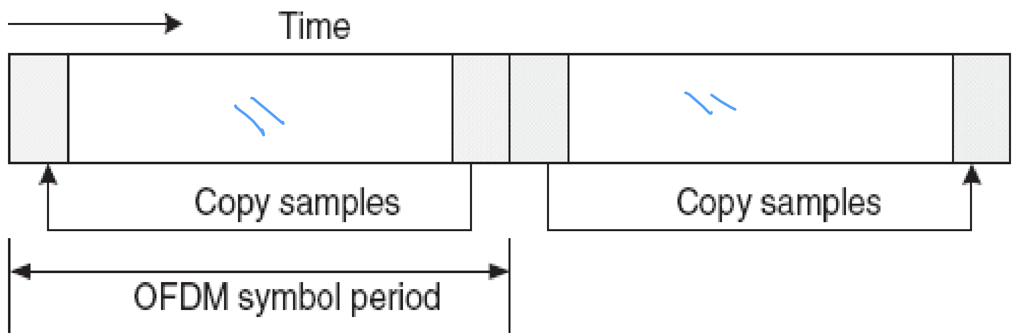
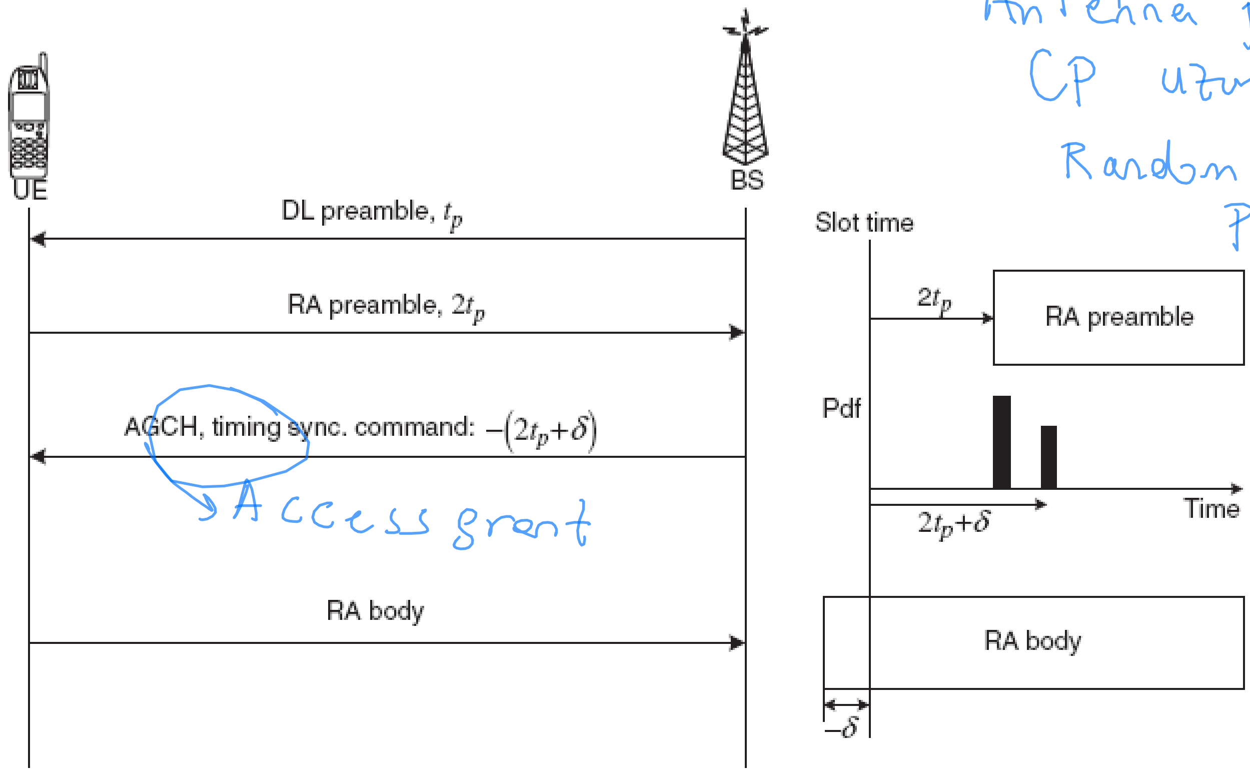


Figure 5.25 Initial ranging symbol in mobile WiMAX system.

TA için

5.7.2 Yukarı Gönderimde Senkronizasyon

Bandwidth
Antenna port number
CP uzunluğu
Random Access
Parametreleri



Access grant

Figure 5.26 Uplink timing acquisition process.

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5.7.2 Yukarı Gönderimde Senkronizasyon

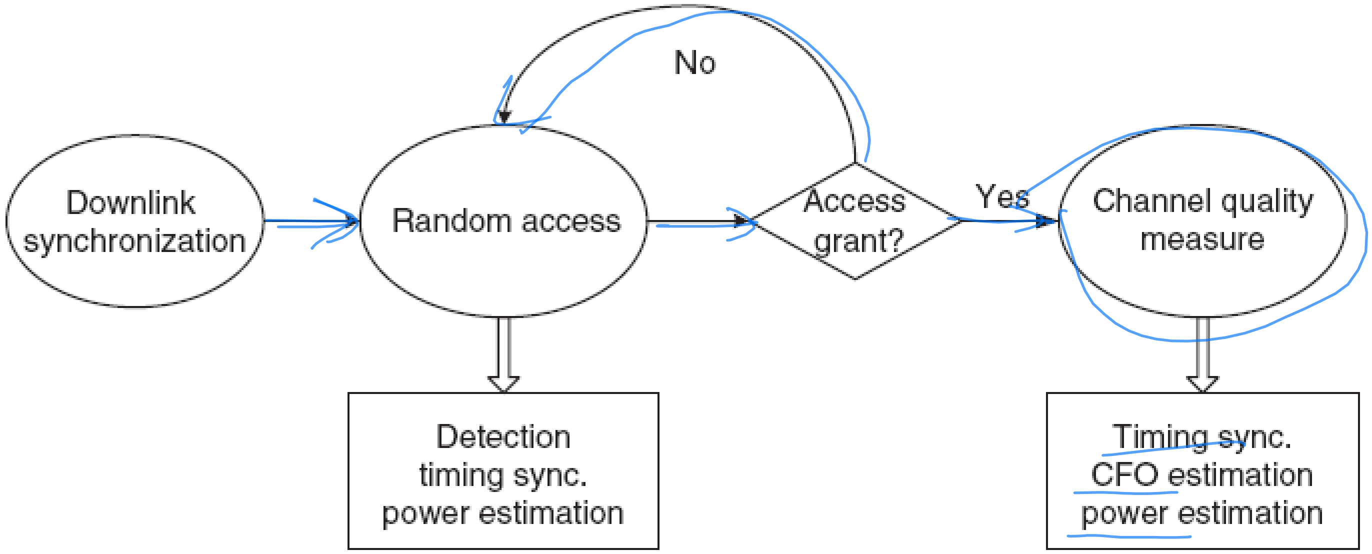

Figure 5.27 Uplink synchronization procedure.