EE6323 Feb-May, 2021

Class #12 (May 04, 2021)

Note Title 27-03-2020

Timing & Freq. Synchronisation in OFDM (OFDMA)

Example: (1) $\Delta f_{sub} = 10\,kHz$; ← Design Parameter

Bandwidth (Apparent) → $N \Delta f_{sub}$, $N = 2^k$ → FFT based → mod/demod, code/decode

$N = 1024$ ⇒ $BW = 10.24\,MHz$; WiMax ←

Rx complexity $\propto N$; $\times 2$ ($10\,MHz \to 1024 \to C$, $20\,MHz \to 2048 \to 2C$)

(*) → Useful Symbol Duration $T_u = \frac{1}{\Delta f_{sub}} = 100\,\mu sec$; ←

(*) Cyclic Prefix length $T_{cp} = \frac{1}{8} \cdot T_u = 12.5\,\mu sec$; ←

($\frac{1}{8}$)

(*) Sampling Rate ② $f_s = 10.24\ MH_3$ ← Design Parameter

← $T_s = \frac{1}{10.24}\ \mu sec$;

$T_{OFDM} = 112.5\mu$

12.5μ + 100μ

⇒ 1024 samples → 100μsec

1024

Guard Subs. 128

$N_{cp} = 128$; $N_u = 1024 = N$

$N_{OFDM} = 1152$ samples.

15.12 + 15.12

Apparent BW = $1024 \times 10kH_3 = 10.24\ MH_3$

N=1024

+512 → 62×10 → 620

−450

+1

−1

−450

−511 → 61

901 ×10 ≈ 9.01 MHz

f

zero DC

t

112.5μ

t

$F = \left[\frac{1}{q_0} \; \frac{1}{q_1} \; .. \; \frac{1}{q_{N-1}} \right]$

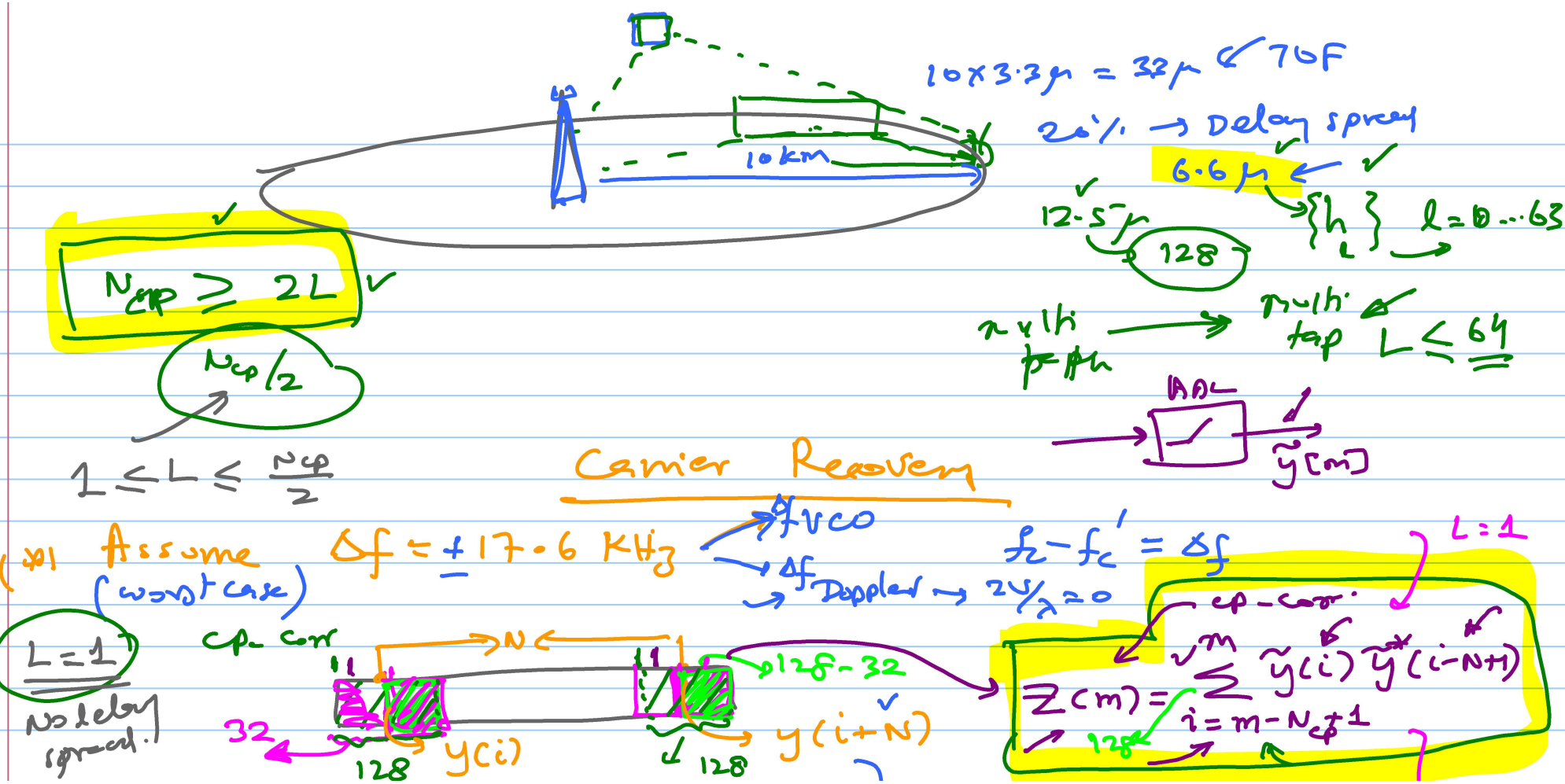
N/2 → 9 MHz

360

624

10MHz

600 × 15


10 km
$10 \times 3.3\mu = 32\mu$ < TGF
20% → Delay spread
6.6 μ
12.5 μ
128
$\{h_l\}$ $l = 0 \cdots 63$
$N_{cp} \geq 2L$
$N_{cp}/2$
$1 \leq L \leq \frac{N_{cp}}{2}$
multi path
multi tap $L \leq 64$
AGC
$\tilde{y}[m]$
Carrier Recovery
$\Delta f \simeq \pm 17.6$ KHz
f_{VCO}
$\Delta f_{Doppler} \rightarrow 2v/\lambda = 0$
$f_c - f_c' = \Delta f$
(#1 Assume (worst case)
$L = 1$
No delay spread
cp-corr
N
128-32
32
128
y(i)
y(i+N)
$L = 1$
cp-corr.
$Z(m) = \sum_{i=m-N_{cp}+1}^{m} \tilde{y}(i)\, \tilde{y}^*(i-N+1)$

$y(i)\, e^{-j2\pi \Delta f\, i T_s}$ ✓ $\quad$ $y(i+N)\, e^{-j2\pi \Delta f\,(i+N) T_s}$ ✓

$L = 32$

$N_{cp} = 128$

$$z(i) = y(i) e^{-j2\pi \Delta f\, i T_s} \cdot y^*(i+N)\, e^{+j2\pi \Delta f\,(i+N) T_s}$$

$$|y(i)|^2 \cdot e^{j2\pi \Delta f\, N T_s}$$

$$\pm 2\pi \Delta f\, N \cdot T_s \leq \pm \pi$$

$$\Rightarrow \quad 2 \cdot \Delta f \cdot N \cdot \frac{1}{N \cdot \Delta f_{sub}} \leq 1$$

Check: $\Delta f = 17.6$ kHz

$N = 1024$

$T_s = \frac{1}{10.24}$ μsec ≈ 0.09 μs

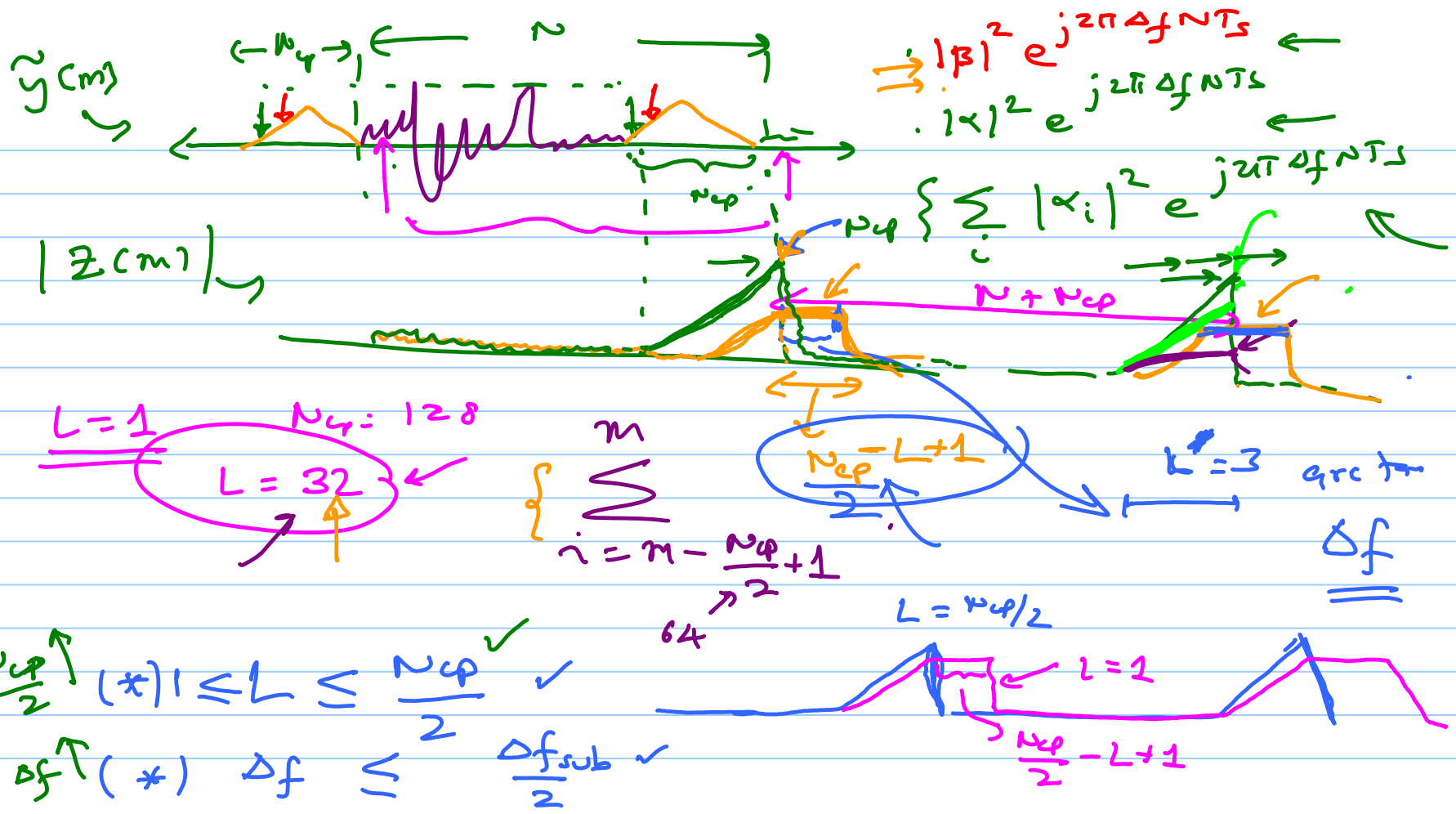
$$\pm 2 \times 17.6 \times 10^{3} \times \frac{100}{10^{8}} \times 10^{-6} \leq 1$$

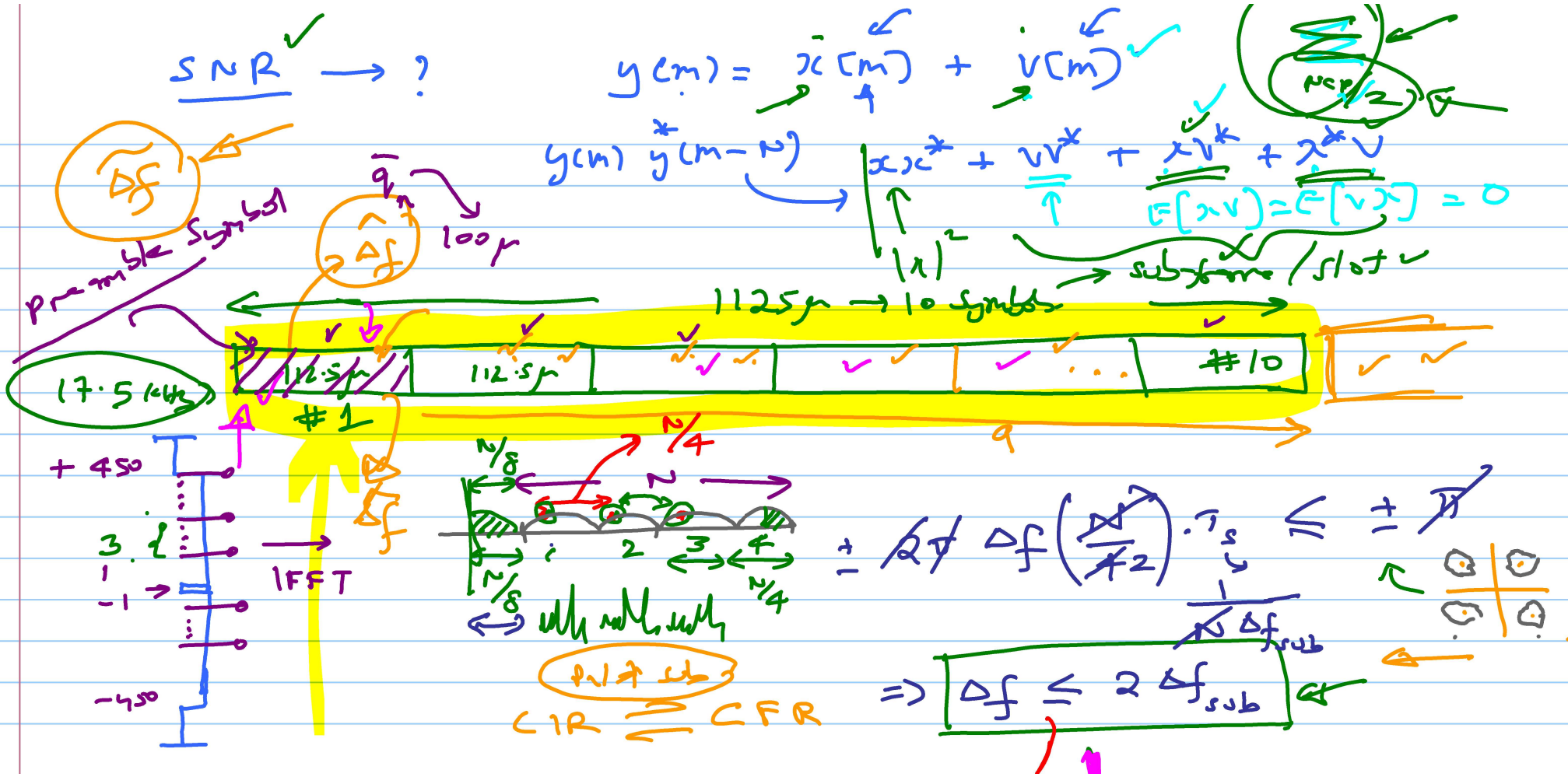
$$2 \times 1.76 \not\leq 1$$

$$T_s = \frac{1}{N \cdot \Delta f_{sub}}$$

5 kHz

$$\Delta f \leq \frac{\Delta f_{sub}}{2}$$


$\tilde{y}(m)$
N_{cp}
N
$|Z(m)|$
$\Rightarrow |\beta|^2 e^{j2\pi \Delta f N T_s}$
$\cdot |\alpha|^2 e^{j2\pi \Delta f N T_s}$
$N_{cp} \left\{ \sum_i |\alpha_i|^2 e^{j2\pi \Delta f N T_s} \right.$
$N + N_{cp}$
$L = 1$
$N_{cp} : 128$
$L = 32$
m
$\left\{ \sum \right.$
$i = m - \frac{N_{cp}}{2} + 1$
$\frac{N_{cp}}{2} - L + 1$
$L = 3$
arc tan
Δf
64
$L = N_{cp}/2$
$L = 1$
$\frac{N_{cp}}{2} - L + 1$
$\frac{N_{cp}}{2} \uparrow$ (*) $1 \leq L \leq \frac{N_{cp}}{2}$ ✓
$\Delta f \uparrow$ (*) $\Delta f \leq \frac{\Delta f_{sub}}{2}$ ✓

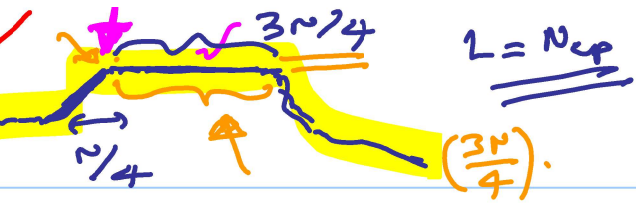

SNR → ?
y(m) = x[m] + v[m]
y(m) y*(m−N)
|x|²
E[xv] = E[vx] = 0
sub frame / slot
1125μ → 10 symbols
preamble Symbol
17.5 kHz
112.5μ
#1
#10
100μ
+450
-450
3.1
-1
IFFT
N/8
N/4
N
1 2 3 4
CIR ⇌ CFR
⇒ Δf ≤ 2 Δf_sub

$|Z(m)|$ ← $\arctan(\cdot)$ → Δf

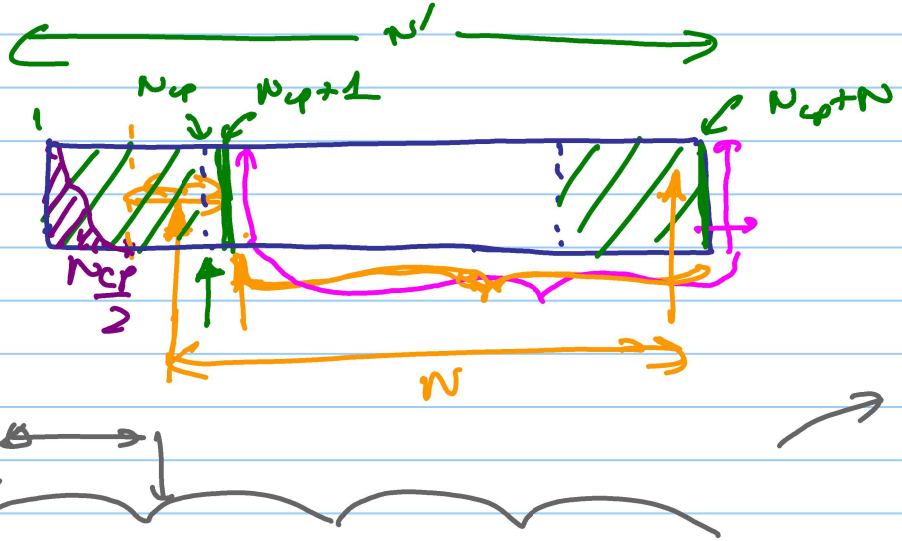
$Z(m) = \sum_{i=m-N/4}^{m} y(i)\, y^{*}(i - N/4)$

# of collisions

$D = 4$



$\Delta f \le D \cdot \left(\frac{\Delta f_{sub}}{2}\right)$, $D = 1, 2, 4, 8, 16 \ldots$ (2^k)



Schmidl & Cox

$$Z(m) = \frac{\sum_{i=m-\frac{N}{D}}^{m} y(i)\, y^*\left(i-\frac{N}{D}\right)}{\sum_{i=m-\frac{N}{D}}^{m} |y(i)|^2}$$

S-C algo

$|Z(m)|$ → timing

$\arctan(Z(m))$ → $\hat{\Delta}_f$

L. Hanzo

OFDM Channel Estimation

2-4.30pm