OFDM(A) principle/ synchronization/ channel estimation/ power allocation

3-4 hr

Outline

- Review: FT, DTFT, DFT, and FFT
- OFDM(A) principle
- Synchronization of DVB-T (an OFDM system)
- Channel estimation of DVB-T (an OFDM system)

Review: FT, DTFT, DFT, and FFT

離散時間傳立葉轉換 (DTFT，DISCRETE-TIME FOURIER TRANSFORM)

由於電腦內的資料都是離散（Discrete）的形式，因此上面這種連續性積分的公式，並不太適用於電腦資料的運算上，於是便有離散式傳立葉轉換公式的需要。

傳立葉轉換

$$F\left\{f_{sp}(t)\right\}=\int_{-\infty}^{\infty}\hat{f}(t)e^{-i\omega t}dt=\int_{-\infty}^{\infty}f(nT)\delta(t-nT)e^{-i\omega t}dt$$

取樣序列 $f(nT)$ 的DTFT

$$F_{DTFT}\left(e^{i\omega T}\right)=\sum_{n=-\infty}^{\infty}f(nT)e^{-in\omega}$$

離散時間傳立葉轉換 (DTFT，DISCRETE-TIME FOURIER TRANSFORM)

通常將採樣間隔T=1，得公式：

離散時間傳立葉轉換：

$$F_{DTFT}\left(e^{i\omega}\right)=\sum_{n=-\infty}^{\infty} f\left(n\right)e^{-in\omega}$$

離散時間傳立葉逆轉換：

$$f\left(n\right)=\frac{1}{2\pi}\int_{-\pi}^{\pi} F_{DTFT}\left(e^{i\omega}\right)e^{in\omega}d\omega$$

離散傳立葉轉換 (DFT，DISCRETE FOURIER TRANSFORM)

公式：

離散傳立葉轉換：

$$X[k]=\sum_{n=0}^{N-1} e^{-i\frac{2\pi}{N}nk}x[n], \text{ where } \omega=\frac{2\pi}{N}k \quad \text{其中} \quad k=0,1,\ldots,N-1$$

離散傳立葉逆轉換：

$$x[n]=\frac{1}{N}\sum_{k=0}^{N-1} e^{i\frac{2\pi}{N}nk}X[k] \quad \text{其中} \quad n=0,1,\ldots,N-1$$

FT、DTFT、DFT比較

傅立葉轉換	時域	頻域
FT	連續 非週期性	連續 非週期性
DTFT	離散 非週期性	連續 週期性
DFT	離散 週期性	離散 週期性

快速傅立葉轉換 (FFT，FAST FOURIER TRANSFORM)

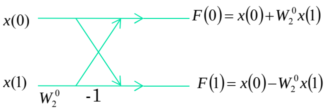
說明：快速傅立葉轉換是離散傅立葉轉換的快速演算法，也可用於計算離散傅立葉轉換的逆轉換

計算 DFT，所需要的複雜度是 $O(n^2)$，但在 1965 年，有兩位學者提出來一套更精簡的演算法，所需的複雜度只有 $O(n \log n)$，這一套演算法稱為「快速傅立葉轉換」（Fast Fourier Transform，簡稱 FFT），換句話說，FFT 是用來計算 DFT 的快速方法。

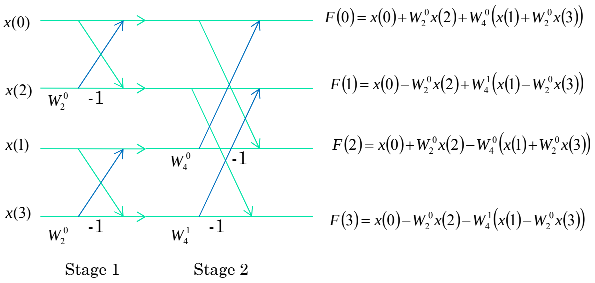
快速傅立葉轉換 (FFT，FAST FOURIER TRANSFORM)

Butterfly diagram

2-inputs, 2-output



4-inputs, 4-output



2. 離散傅氏轉換之性質

(a) 線性性質：

$$\alpha x[n]+\beta y[n] \underset{\text{IDFT}}{\overset{\text{DFT}}{\rightleftarrows}} \alpha X[k]+\beta Y[k],\ \forall\alpha,\beta\in R$$

(b) 時間延遲性質：

$$x[n-n_0] \underset{\text{IDFT}}{\overset{\text{DFT}}{\rightleftarrows}} X[k]\exp[-j\frac{2\pi}{N}kn_0]$$

(c) DFT 與 IDFT 互換性質：

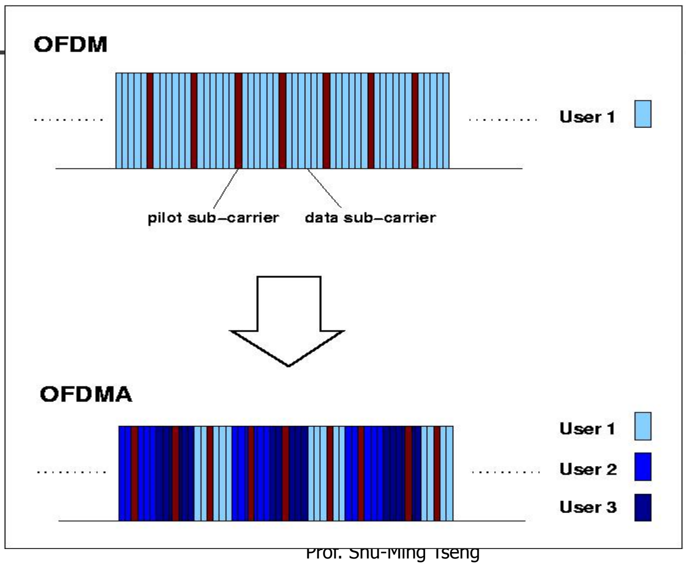
$$x[n]=\frac{1}{N}(\mathrm{DFT}\{X^*[k]\})^*$$

(d) 時間領域週期迴旋和性質：

$$x[n]\boxtimes y[n]=\sum_{\lambda=0}^{N-1}x[\lambda]y[n-\lambda] \underset{\text{IDFT}}{\overset{\text{DFT}}{\rightleftarrows}} X[k]Y[k]$$

Circular convolution

OFDM(A) principle



- OFDM: orthogonal frequency division multiplexing
- OFDMA: orthogonal frequency division multiple access (orthogonal +FDMA)

Introduction

- Because the growth in scientific, military, and entertainment applications, cloud computing, and development of 4G result in high-speed, reliable wireless system.
- thus we need multicarrier transmission method (for higher data rate) , such OFDMA, and we make an overview of OFDMA here.

High spectrum efficiency

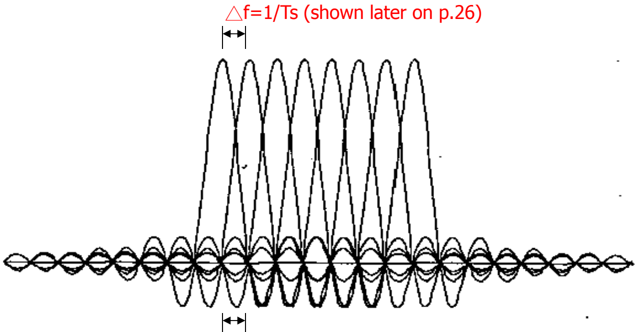


Figure 1. An OFDM Symbol in frequency domain (before the subcarriers are summed).

OFDM block diagram

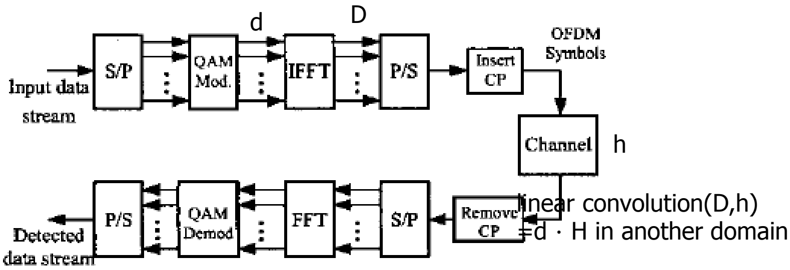


Figure 2. A simplified block diagram of an OFDM system

QAM Modulation=I/Q mapping (NOT modulated to carrier)

OFDMA= FDMA+orthogonal subcarrier+CP

- The symbol rate on each carrier is lower (1/carrier no)
- A cyclic prefix (CP) or zero prefix can be used to avoid the ISI (frequency-selective fading)
- Simple IFFT and FFT circuits for modulation and demodulation=> OFDM become practical since 1990s

Cyclic Prefix (CP)

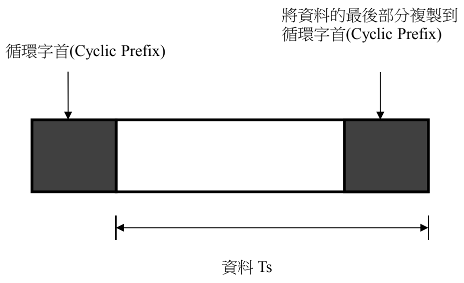


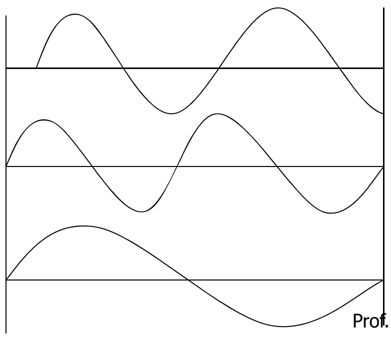
圖 OFDM和OFDMA的循環字首

Cyclic Prefix

- CP >delay spread to prevent ISI.
- CP can convert linear convolution (with channel) into circular convolution (periodic nature); thus we get data multiply DFT(⇔circular convolution, not linear convolution!) of channel.
- CP doesn't contain any information so it reduces throughput. But CP redundancy ratio is reduced as carrier no increases (OFDM symbol duration=non-OFDM symbol duration*carrier no).
- CP can also simplify the synchronization problem (timing and fractional frequency synchronization).
- CP is to prevent inter-carrier interference (ICI) in multipath environment (next page)

Guard interval

- If guard interval = zero padding, A and B are orthogonal, but A' and B are not orthogonal (higher freq components=>$\Delta f \neq 1/T$)!
- If guard interval=cyclic prefix, A' and B are not orthogonal ($\Delta f \neq 1/T$)



A'=Delayed version of A (path2)

Original version of A (path 1)

Original version of B

OFDM in NG-PON2 (next generation passive optical network 2) and PLC (power line communications)

- Anti-dispersion (色散) - In optical fiber, different frequency travel in different speed, so the arrival time is different (dispersion). This is similar to ISI due to multipath in wireless channels, so cyclic prefix can be used.
- Disadvantage: PAPR Source: Networked Communication Program (NCP) newsletter No. 24
- PLC: impedance (50 or 75Ω) mismatch causes EM wave reflections => multipath fading in PLC

The criterion of carriers m∆f and n∆f to be orthogonal

If $\Delta f = 1/Ts$, where Ts is OFDM symbol interval

then

$$1/Ts\int_0^{Ts} e^{j2\pi m\Delta ft} e^{-j2\pi n\Delta ft} dt = \begin{cases} 1 & m = n \\ 0 & m \neq n \end{cases}$$

proof : skipped (hint : sinc function)

OFDMA advantages

- higher spectrum efficiency(=>higher data rate)
- Transfer frequency selective fading to a large number of flat fading subchannels (easy to equalize, ex 1-tap equalizer).
- two orthogonal sinusoid are orthogonal even in asynchronous operation (orthogonal criterion: frequency difference=1/T async only affect phase diff), not true for CDMA

+ - + -

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- The division of signal will provide flexibility needed for future multimedia services (data rate可微調)

OFDMA disadvantages

- OFDMA is sensitive to frequency shifts such as Doppler shift and carrier frequency offsets (CFO)

P.S. OFDMA users may have different CFO due to tuner inaccuracy etc.

- Peak to Average Power Ratio (PAPR) problem for power amplifiers.

DFT IMPLEMENTATION TRANSMITTER

- Transmitted signal can be obtained using a Discrete Fourier Transform

$$x_b(t) = \sum_{k=0}^{N-1} a[k] e^{j2\pi k \boxed{\Delta f t}}, \quad 0 \le t \le T_s$$

$f = k \Delta f$

$t = n \Delta t = n \frac{Ts}{N}$

- If sampled at a rate of $\boxed{T_s/N,}$

$$x_b[n] = x_b\left(\frac{n}{N} T_s\right) = \sum_{k=0}^{N-1} a[k] e^{j2\pi nk \Delta f T_s / N}$$

- For orthogonality, $\boxed{\Delta f T_s = 1}$,

$$x_b[n] = \sum_{k=0}^{N-1} a[k] e^{j2\pi nk/N} = \text{IDFT}\{a[k]\}$$

- Efficient FFT implementation

DFT IMPLEMENTATION

RECEIVER

$$\hat{a}[k] = \mathrm{DFT}\{x_b[n]\}$$
$$= \frac{1}{N}\sum_{n=0}^{N-1} x_b[n]\, e^{-j2\pi nk/N}$$
$$= \frac{1}{N}\sum_{n=0}^{N-1}\sum_{m=0}^{N-1} a[m]\, e^{j2\pi n(m-k)/N}$$
$$= \frac{1}{N}\sum_{m=0}^{N-1} a[m] \sum_{n=0}^{N-1} e^{j2\pi n(m-k)/N}$$
$$= \frac{1}{N}\sum_{m=0}^{N-1} a[m]\, N\delta[m-k]$$
$$= a[k]$$ Restore original signal

OFDM(A) synchronization and channel estimation: PC-based DVB-T software defined radio example

Study spec well before developing products

Synchronization of DVB-T (an OFDM system)

Prof. Shu-Ming Tseng 29

Functional block diagram

(Taiwan now)
Data: 16QAM
Pilot: BPSK
non-hierarchical mode
(no dashed-line boxes)
8K carriers

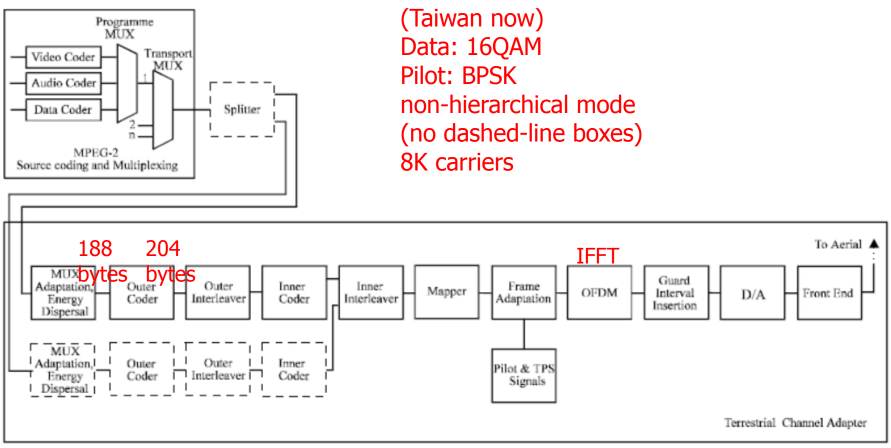
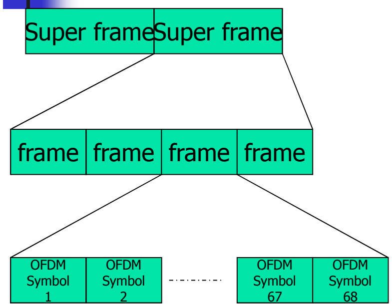


Figure 1: Functional block diagram of the System

Frame structure (for code rate 2/3, 16QAM, ¼ CP



1 super frame= 4 frames
1 frame=68 OFDM symbols
=672 packets (RS codeword)
P.S. 在台灣採用的mode 解資料可以以frame為單位（因為1 OFDM symbol含非整數個packets）
一般來說解資料必須以superframe為單位 packet數才會整數

2688 packets (on the next page) per super frame
=672 packet per frame

OFDM frame structure

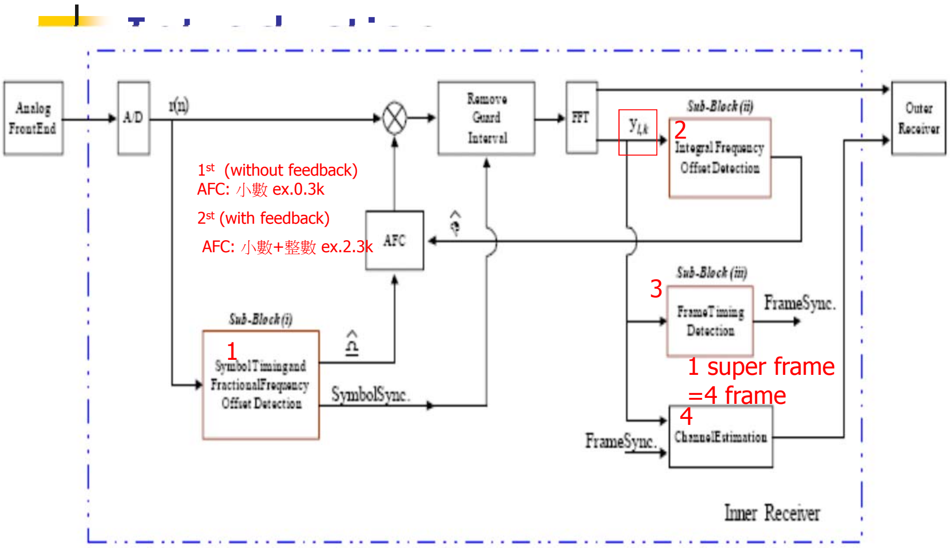
- The OFDM frame structure allows for an <u>integer</u> number of Reed-Solomon 204 byte packets to be transmitted <u>in an OFDM super-frame (for all code rate and modulation)</u>, and therefore avoids the need for any stuffing, whatever the constellation, the guard interval length, the coding rate or the channel bandwidth may be. See table 16.

Table 16: Number of Reed-Solomon packets per OFDM super-frame for all combinations of guard interval, code rates and modulation forms

Code rate	QPSK		16-QAM		64-QAM	
	2K mode	8K mode	2K mode	8K mode	2K mode	8K mode
1/2	252	1008	504	2016	756	3024
2/3	336	1344	672	2688	1008	4032
3/4	378	1512	756	3024	1134	4536
5/6	420	1680	840	3360	1260	5040
7/8	441	1764	882	3528	1323	5292

OUTLINE

- Introduction
- Fractional frequency offset and symbol timing offset: joint ML by cyclic prefix
- Integral frequency: by continual pilot
- Frame timing: by 16 bits of transmission parameter signaling (TPS)- other bits are code rate, modulation etc.
- Scattered pilots are used in channel estimation, not synchronization.

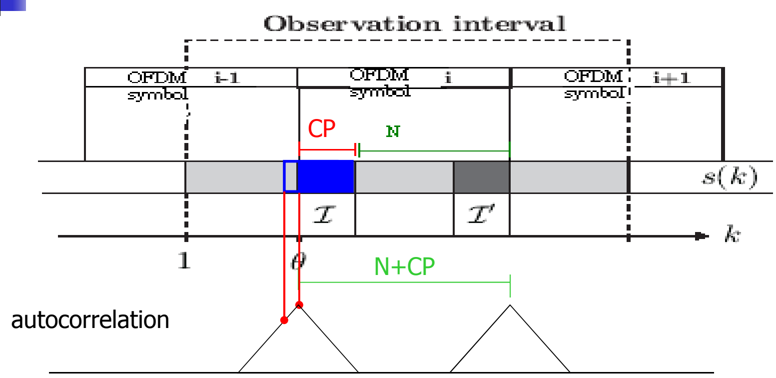


9.953Mbps for real-time DVB-T receiver (at Viterbi decoder input)

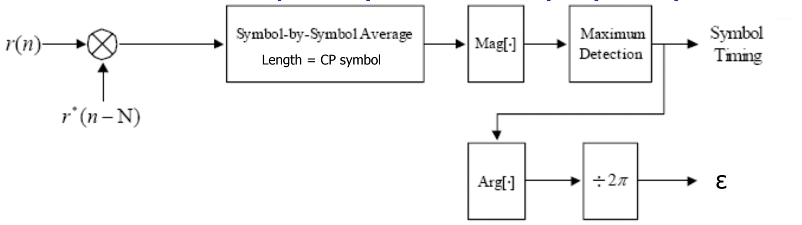
Table E.5: Useful bitrate (Mbit/s) for all combinations of guard interval, constellation and code rate for non-hierarchical systems for 6 MHz channels

Modulation	Code rate	Guard interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	*3,732*	*4,147*	*4,391*	*4,524*
	2/3	*4,976*	*5,529*	*5,855*	*6,032*
	3/4	*5,599*	*6,221*	*6,587*	*6,786*
	5/6	*6,221*	*6,912*	*7,318*	*7,540*
	7/8	*6,532*	*7,257*	*7,684*	*7,917*
16-QAM	1/2	*7,465*	*8,294*	*8,782*	*9,048*
	2/3	*9,953*	*11,059*	*11,709*	*12,064*
	3/4	*11,197*	*12,441*	*13,173*	*13,572*
	5/6	*12,441*	*13,824*	*14,637*	*15,080*
	7/8	*13,063*	*14,515*	*15,369*	*15,834*
64-QAM	1/2	*11,197*	*12,441*	*13,173*	*13,572*
	2/3	*14,929*	*16,588*	*17,564*	*18,096*
	3/4	*16,796*	*18,662*	*19,760*	*20,358*
	5/6	*18,662*	*20,735*	*21,955*	*22,620*
	7/8	*19,595*	*21,772*	*23,053*	*23,751*

NOTE: Figures in italics are approximate values.
For the hierarchical schemes the useful bit rates can be obtained from table E.5 as follows:
HP stream: figures from QPSK columns;
LP stream, 16-QAM: figures from QPSK columns;
LP stream, 64-QAM: figures from 16-QAM columns.



joint ML estimation of symbol timing Θ and fractional frequency offset ε by cyclic prefix



- Receive signal: $r(n)= x_t(n)e^{j2\pi\varepsilon n/N}$
- Do auto correlation ;

  $M_r(n)=r(n)r^*(n-N)=x_t(n)x_t^*(n)e^{j2\pi\varepsilon}$

$$C(\theta)=\frac{1}{CP}\sum_{n=\theta}^{\theta+CP}\mathrm{M_r}[n]$$

- $\Theta' = \text{MAX } |C(\Theta)|$
- $\varepsilon = 1/2\pi \arg |C(\Theta')|$

continual pilot (177 carriers)
(寫程式時要建表)

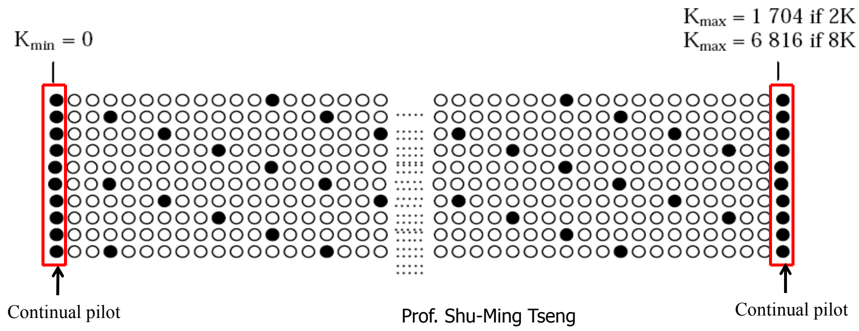
Table 7: Carrier indices for continual pilot carriers

Continual pilot carrier positions (index number k)													
2K mode							8K mode						
0	48	54	87	141	156	192	0	48	54	87	141	156	192
201	255	279	282	333	432	450	201	255	279	282	333	432	450
483	525	531	618	636	714	759	483	525	531	618	636	714	759
765	780	804	873	888	918	939	765	780	804	873	888	918	939
942	969	984	1 050	1 101	1 107	1 110	942	969	984	1 050	1 101	1 107	1 110
1 137	1 140	1 146	1 206	1 269	1 323	1 377	1 137	1 140	1 146	1 206	1 269	1 323	1 377
1 491	1 683	1 704					1 491	1 683	1 704	1 752	1 758	1 791	1 845
							1 860	1 896	1 905	1 959	1 983	1 986	2 037
							2 136	2 154	2 187	2 229	2 235	2 322	2 340
							2 418	2 463	2 469	2 484	2 508	2 577	2 592
							2 622	2 643	2 646	2 673	2 688	2 754	2 805
							2 811	2 814	2 841	2 844	2 850	2 910	2 973
							3 027	3 081	3 195	3 387	3 408	3 456	3 462
							3 495	3 549	3 564	3 600	3 609	3 663	3 687
							3 690	3 741	3 840	3 858	3 891	3 933	3 939
							4 026	4 044	4 122	4 167	4 173	4 188	4 212
							4 281	4 296	4 326	4 347	4 350	4 377	4 392
							4 458	4 509	4 515	4 518	4 545	4 548	4 554
							4 614	4 677	4 731	4 785	4 899	5 091	5 112
							5 160	5 166	5 199	5 253	5 268	5 304	5 313
							5 367	5 391	5 394	5 445	5 544	5 562	5 595
							5 637	5 643	5 730	5 748	5 826	5 871	5 877
							5 892	5 916	5 985	6 000	6 030	6 051	6 054
							6 081	6 096	6 162	6 213	6 219	6 222	6 249
							6 252	6 258	6 318	6 381	6 435	6 489	6 603
							6 795	6 816					

8K mode: 8192 subcarriers, 6817 data+pilot (continual,TPS,scattered pilots),
1st 45 of *K mode is the same as 2K mode=> one table for 2K and 8K

Integral frequency synchronization

- The same subcarrier index k=0,48,54,… have the same value of the continual pilot . We can take advantage of this property to find integral frequency offset.



- The value of continual pilot (不同OFDM symbol index 用一樣的):

  $\mathrm{Re}\{C_{m,l,k}\} = 4/3 \times 2(1/2 - w_k)$, $\mathrm{Im}\{C_{m,l,k}\}=0$

  m: frame index *l*: symbol index *k*: subcarrier index
- P.S. 4/3 :boosted power; $2(1/2 - w_k)$:0,1=>-1,+1
- w_k is generated by generate matrix

  $X^{11}+X^9+1$

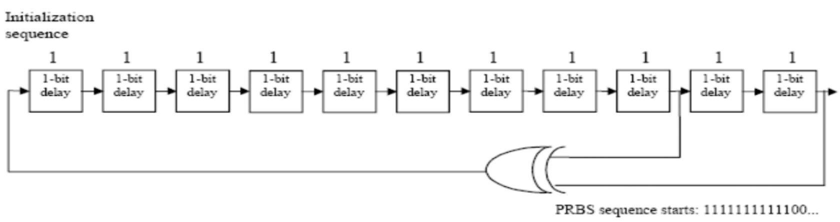
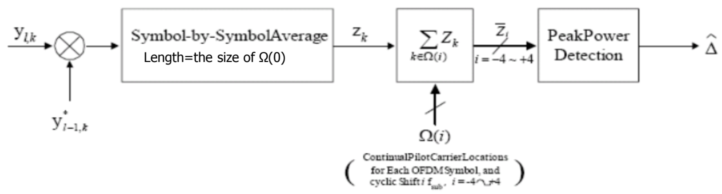


Figure 10: Generation of PRBS sequence

Adjacent OFDM symbols (l, l-1), same carrier index k, same continual pilot



- The set of subcarrier of continue pilot of one symbol is Ω(0)
- Ω(i) : i is circular shift of the number of subcarrier
- Ω(0)={0,48,54,…}, Ω(1)={1,49,55,…} (Table 7)
- $Z_i = \sum_{k \in \Omega(i)} y_{l,k-i} \bullet y^*_{l-1,k-i}$
- The Integral frequency offset is " i " that make Z is a peak value

TPS pilot (68 carriers)

Table 8: Carrier indices for TPS carriers

2K mode					8K mode							
34	50	209	346	413	34	50	209	346	413	569	595	688
569	595	688	790	901	790	901	1 073	1 219	1 262	1 286	1 469	1 594
1 073	1 219	1 262	1 286	1 469	1 687	1 738	1 754	1 913	2 050	2 117	2 273	2 299
1 594	1 687				2 392	2 494	2 605	2 777	2 923	2 966	2 990	3 173
					3 298	3 391	3 442	3 458	3 617	3 754	3 821	3 977
					4 003	4 096	4 198	4 309	4 481	4 627	4 670	4 694
					4 877	5 002	5 095	5 146	5 162	5 321	5 458	5 525
					5 681	5 707	5 800	5 902	6 013	6 185	6 331	6 374
					6 398	6 581	6 706	6 799				

Frame Timing: 1 frame=68 OFDM symbols

Bit number	Purpose/Content
s_0	Initialization
$s_1 - s_{16}$	Synchronization word
$s_{17} - s_{22}$	Length indicator
s_{23}, s_{24}	Frame number
s_{25}, s_{26}	Constellation
s_{27}, s_{28}, s_{29}	Hierarchy information
s_{30}, s_{31}, s_{32}	Code rate, HP stream
s_{33}, s_{34}, s_{35}	Code rate, LP stream
s_{36}, s_{37}	Guard interval
s_{38}, s_{39}	transmission mode
$s_{40} - s_{53}$	Reserved for future use
$s_{54} - s_{67}$	Error protection BCH code

- TPS(transmission parameter sequence) is used to record some information of signal.
- 1 frame has 68 OFDM symbol. 1 OFDM symbol has 1 value of TPS. TPS carriers of 1 OFDM symbol are the same(repeat 68 times in 8K mode)
- It use $s_1 \sim s_{16}$ to do frame synchronization
- DBPSK modulation (resistant to phase errors)

$x_{l,k} = x_{l-1,k}(-1)^{s_l}$

$k \in \Gamma$ Γ is the location of TPS

$l = 0,1,\ldots,67$ is the OFDM symbol index within a frame

Frame Timing: 1 superframe=4 frames

1	2	3	4

- Bits 1 to 16 of the TPS is a synchronization word.
- The first and third TPS block in each super-frame have the following synchronization word:

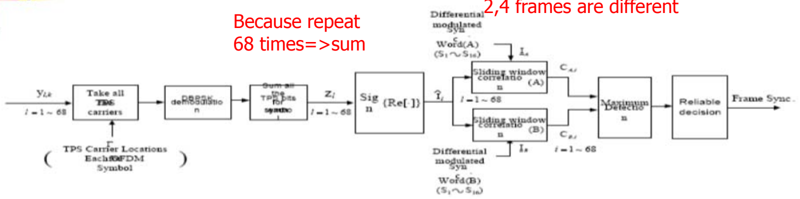
  s1 - s16 = 0011010111101110.
- The second and fourth TPS block have the following synchronization word:

  s1 - s16 = 1100101000010001.

Frame synchronization

Because repeat 68 times=>sum

1,3 frames and 2,4 frames are different



- It use sliding window to find synchronization word.
- The size of sliding window is 16 ,so it must find 16 s_l first.
- Find s_l :

DPSK modulation

$$y_{l,k} = x_{l,k} \bullet H_{l,k} + n_{l,k} \boxed{= x_{l-1,k}(-1)^{s_l} \bullet} H_{l,k} + n_{l,k},\ l = 1,2...,16$$

DBPSK demodulation

$$z_{l,k} = \boxed{y_{l,k} \bullet y^*_{l-1,k}} = |x_{l-1,k}|^2 H_{l,k} H^*_{l-1,k} (-1)^{s_l}$$

$$\cong |x_{l-1,k}|^2 |H_{l,k}|^2 (-1)^{s_l}$$

$$z_l = \sum_k z_{l,k} \quad \text{(k68個)}$$

Channel estimation for DVB-T (an OFDM system)

Scattered pilot

- The values of scattered pilot is:

<u>(continual pilot also 4/3, but TPS not because already repeated)</u>

$$\mathrm{Re}\{c_{m,l,k}\} = 4/3 \times 2\,(1/2 - w_k)$$

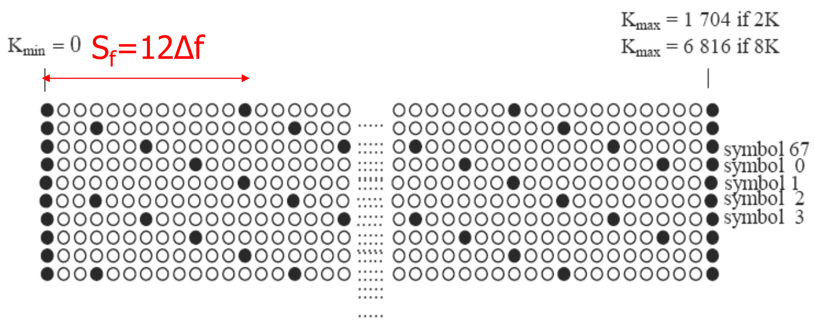
$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

- And the scattered pilot position is permuted as :

$$\{k = K_{min} + 3 \times (l \bmod 4) + 12p \mid p \text{ integer}, p \geq 0, k \in [K_{min}; K_{max}]\}$$

M:frame index   l:symbol index   k:carrier index

Scattered pilot



TPS pilots and continual pilots between K_{min} and K_{max} are not indicated

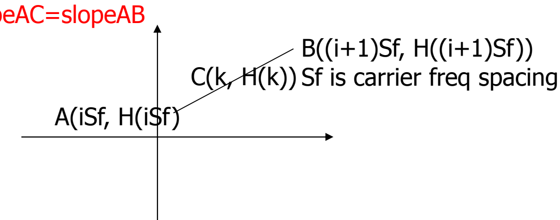
● boosted pilot

○ data

One-dimensional linear interpolation : inside 1 OFDM symbol

$$H[k] = H[i \cdot S_f] + \{H[(i+1) \cdot S_f] - H[i \cdot S_f]\} \cdot \frac{k - i \cdot S_f}{S_f} \quad \text{for } i \cdot S_f \le k \le (i+1) \cdot S_f$$

Simple but low accuracy.
Amplitude and phase should be interpolated separately
And note that 2π phase discontinuity
SlopeAC=slopeAB

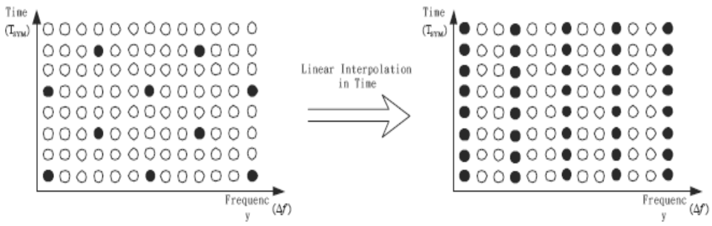


One-dimensional linear interpolation + multi OFDM symbol averaging

- very slow-varying channels
- By weak law of large numbers

Two-dimensional linear interpolation

- Interpolating cross OFDM symbols (vertical) first ($S_f=12\Delta f => S_f=3\Delta f$)
- Then interpolation inside OFDM symbol (horizontal)



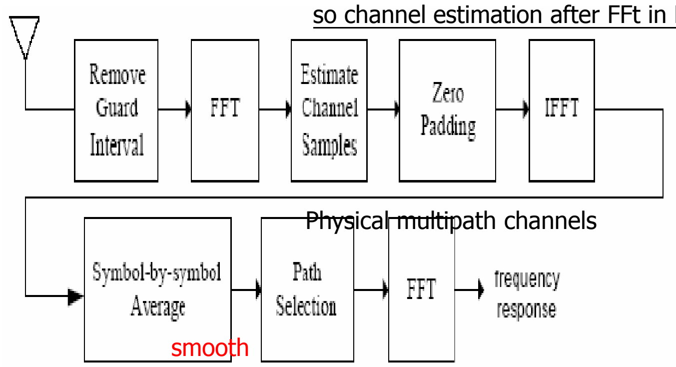
非DVB-T spacing

圖 3.23 時間軸上先做內插法的通道響應取樣訊號示意圖

Periodx12 in one domain
=>up sampling in the other domain

One-dimensional FFT interpolation

Pilot (insert pilot before IFFT in TX ,(p.30) so channel estimation after FFt in RX)



Pick strong paths
(weak paths dominated by interference and noise)

One-dimensional linear interpolation+ One-dimensional FFT interpolation

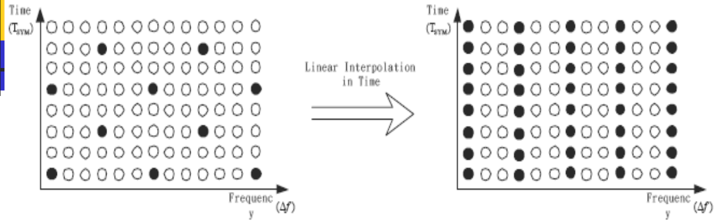
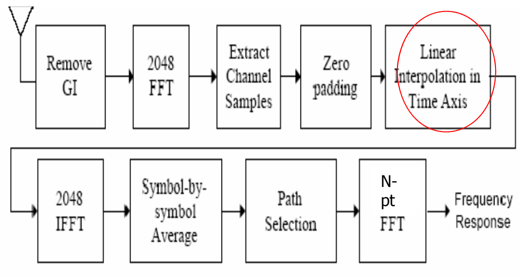
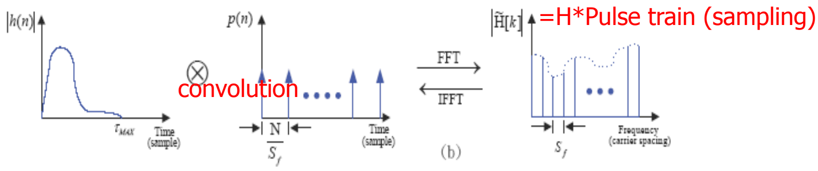


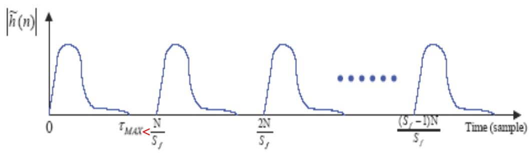
圖 3.23 時間軸上先做內插法的通道響應取樣訊號示意圖

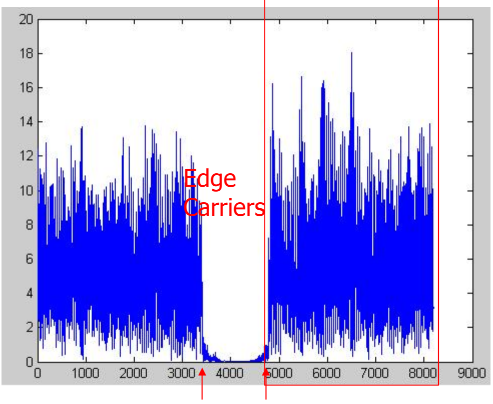


Extra:
compare previous page

S_f small=>delay spread T_{max} bigger)







OFDM power allocation-water filling (WF)

201704索豪聲WF

```
1  % This function calculates the power allocation using water filling
2  % algorithm
3  % The first input is the individual SNR
4  % The second input is the sum of power constraint
5  % The output is the vector of power allocation
6
7  function [P] = WF(SNR,Pt,Qo)
8  n = length(SNR);
9  %Qo=3/(qfuncinv(.01/4))^2;
10
11 SortSNR=sort(SNR);
12 for i=1:n
13     Power=1/(SortSNR(i)*Qo)+zeros(1,n);
14     for m=1:n
15         Power(m)=max(0,Power(m)-1/(SNR(m)*Qo));
16     end
17         if sum(Power)<Pt
18             o=n+1-i;
19             break
20         end
21
22 end
```

由小到大排列

$\eta = \frac{3}{P_{N_0}}[Q^{-1}(SER_t/4)]^{-2}$

In [Wan13] eq(4) 去除P_{N_0}

從最大的開始試

$(\frac{1}{SortSNR(i)*Qo})$=1/λ

sum(power)> P_t

試到第i個

sum(power)< P_t

有o個被power allocation到SNR大

$\frac{1}{\eta|H_{k,m}|^2}$=1/SNR

(floor)較低 水較深

$$P_{k,m}^{*} = \left[\frac{1}{\lambda_k} - \frac{1}{\eta|H_{k,m}|^2}\right]^{+}, \forall m \in A_k^{(i)}$$

In [Wan13] eq(16)

```
27 for t=n-o+1:n
28     tot=tot+1/(SortSNR(t)*Qo);
29 end
30
31 invth=(tot+Pt)/o;
32
33 P=zeros(1,n);
34 for i=1:n
35     P(i)=max(0, invth-1/(SNR(i)*Qo));
36 end
```

Line 27-36

sum(power)< P_t

=>sum(power)=P_t

$$P_{k,m}^{*} = \left[\boxed{\frac{1}{\lambda_k}} - \boxed{\frac{1}{\eta|H_{k,m}|^2}}\right]^{+}, \forall m \in A_k^{(i)}$$

In [Wan13] eq(16)

$$\sum_{o} P_{k,m}^{*}$$

=inveth*o-$\sum_o \frac{1}{\eta|H_{k,m}|^2}$

=(tot+P_t)-tot

=P_t