DVB-T
Terrestrial Standard

DVB-T Standard

- Terrestrial DB is more difficult than cable DB or satellite DB because of the variations in the transmission path
  - multipath fading: reflections off buildings and terrain
  - preference for vertical polarization
- Typical terrestrial receiver:
  - Yagi-Uda rooftop antenna (multiple dipole directors)
  - gain: $G \sim 10$ dB
    - High gain reduces effect of echoes from buildings or hills
  - still some echoes (multipath) and other periodic interference

DVB-T Antenna

- A good rooftop antenna (typically with gain of 7 to 10dB) would guarantee satisfactory service quality within the coverage of the terrestrial transmission
- Reception of the rooftop antenna can be modelled as stationary reception
- The directivity of the antenna can be used to cancel echo coming from different direction.

Portable Receiver Problems

- Specific problems:
  - Receiver may be moved during reception, changing the reception conditions (fading)
  - Portable receivers have ‘whip’ or ‘rod’ (dipole, monopole) antenna that has poor directivity
- Result: a specific *a priori* known dominant direct signal path (line-of-sight) cannot be assumed
  - Portable sets are often much closer to ground than rooftop antenna, hence they receive multipath signal with lower (but variable) strength.
  - Polarization direction more stable

Requirements for DVB-T (I)

- Should be similar to DVB-S and DVB-C [to be discussed tomorrow], to share same STB receiver technology
- Maximize number of programmes to be broadcast, to compete with DVB-S
- Channel bandwidth should remain 8 MHz, to fit with standard UHF spectrum allocations
  - now also 6 and 7 MHz for non-European DVB
- Large coverage area for stationary reception with rooftop antennas
  - coverage for portables as a bonus [but not the objective of the standard]
  - growing demand for mobile TV support

Requirements for DVB-T (II)

- Single frequency network (SFN): transmit shared data from synchronized neighbouring transmitters on the same carrier and bandwidth
  - why?
  - leads automatically to COFDM
- STB receivers should be low-cost for mass uptake
- Hierarchical modulation should be supported

Single Frequency Network

- What? (Terrestrial) broadcast network that transmits the same TV program in different areas (micro/macrocells) at the <u>same</u> carrier frequency
  - Transmitter towers have a limited range over which their signal can be received
  - In order to broadcast to a large area, many transmitter towers in different locations are necessary
- SFN not possible with analogue transmission
  - interference between towers operating at the same frequency leads to loss of quality of service (QoS)

Statistical Multipath Propagation Models for DVB-T

Terrestrial Propagation Model

- SFN resolves interference, but not noise
- Need a statistical model for non-line-of-sight (NLoS) propagation:
  - Simplest model: Nakagami-Rice distribution: LoS path with constant phase + additive white Gaussian noise (AWGN)

Terrestrial Propagation Model

- EN 300744 input-output model:

$$y(t) = \frac{\alpha_0 x(t) + \sum_{k=1}^{N} \alpha_k e^{j2\pi\theta_k} x(t - \tau_k)}{\sqrt{\sum_{k=0}^{N} \alpha_k^2}}$$

α_0 = attenuation in direct (LoS) path

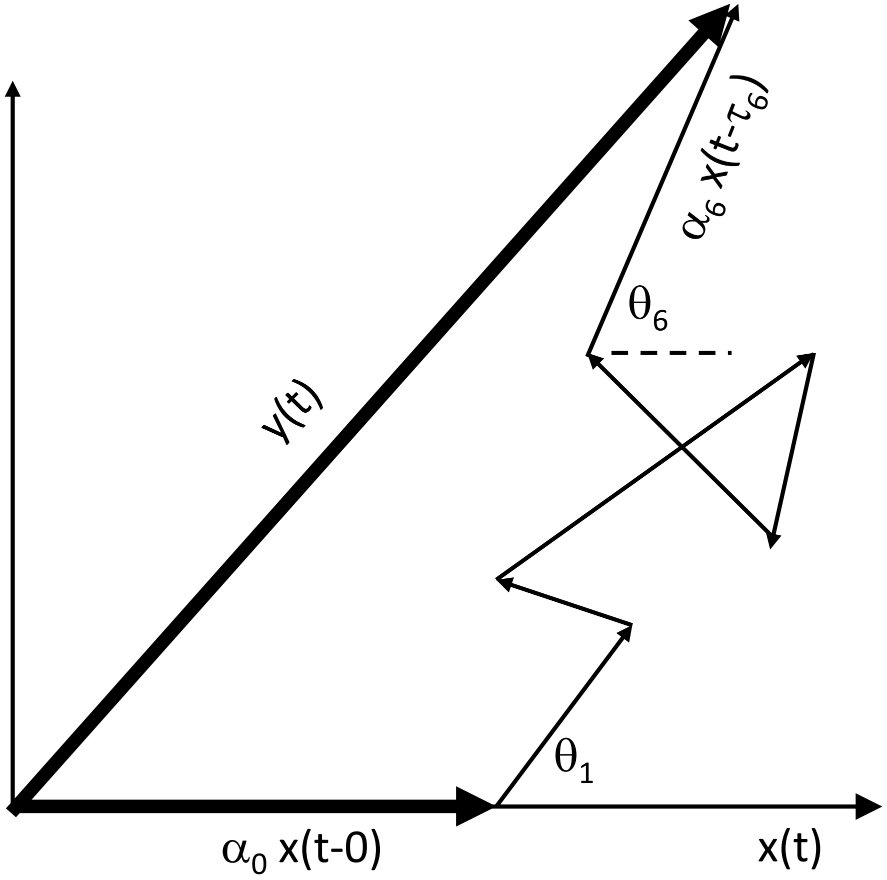
N = number of indirect (NLoS, multipath) components = 20

α_k = attenuation in k^{th} indirect (non-line-of-sight) path

θ_k = phase rotation in path k relative to phase of direct path

τ_k = time delay in path k relative to arrival along direct path

Random Walk Model



Terrestrial Propagation Model

- EN 300744 input-output model:

Ricean factor: $K = \frac{\alpha_0^2}{\sum_{k=1}^{N} \alpha_k^2} = \frac{\text{power in direct path}}{\text{power in indirect paths}}$

In practical DVB for Ricean channel: to get quasi error-free (QEF) reception, the C/N must be increased by 0.3…1.1 dB compared to pure LoS.

Terrestrial Propagation Model

- Rayleigh propagation channel model: no LoS:

$$y(t) = \frac{\sum_{k=1}^{N} \alpha_k e^{j2\pi\theta_k} x(t - \tau_k)}{\sqrt{\sum_{k=0}^{N} \alpha_k^2}}$$

  - Typical for highly build-up areas (inner cities)
  - In practical DVB for Rayleigh channel: to get QEF reception, C/N must be increased by 7…9 dB (= × 5…8) compared to pure LoS
    - Power increase is reduced when using hierarchical modulation

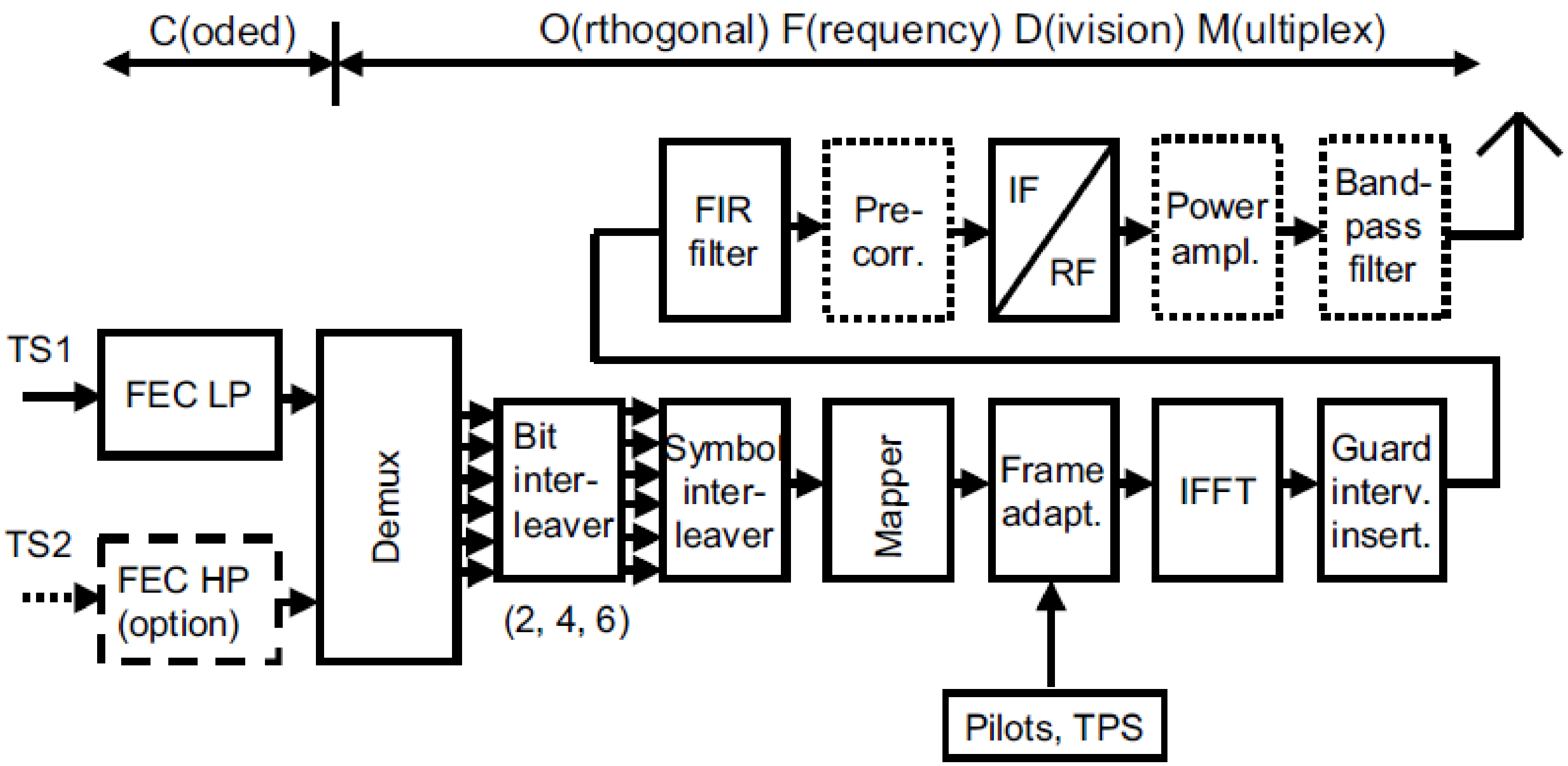
Power Budget Calculation

- Example: indoor portable digital TV on ground floor: loss compared to rooftop Yagi antenna
  - Rayleigh channel: + 8 dB
  - Loss of omnidirectional antenna gain: + 10 dB
  - Decrease height (10m $\rightarrow$ 1.5m): + 12 dB
  - Wall penetration: + 7 dB

  - Total insertion loss: + 37 dB

(worst case)

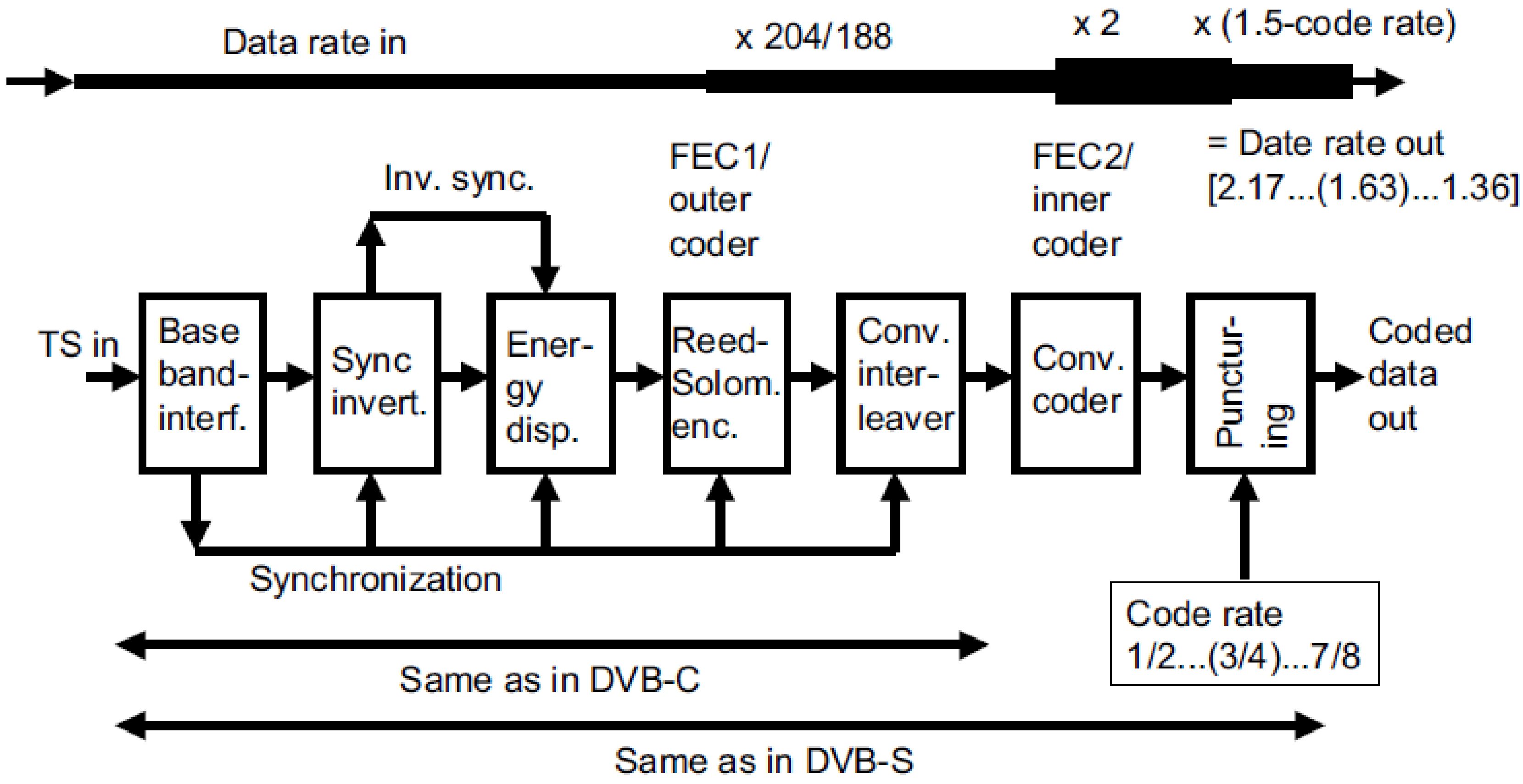
Block diagram of the DVB-T modulator



DVB-T Modulator

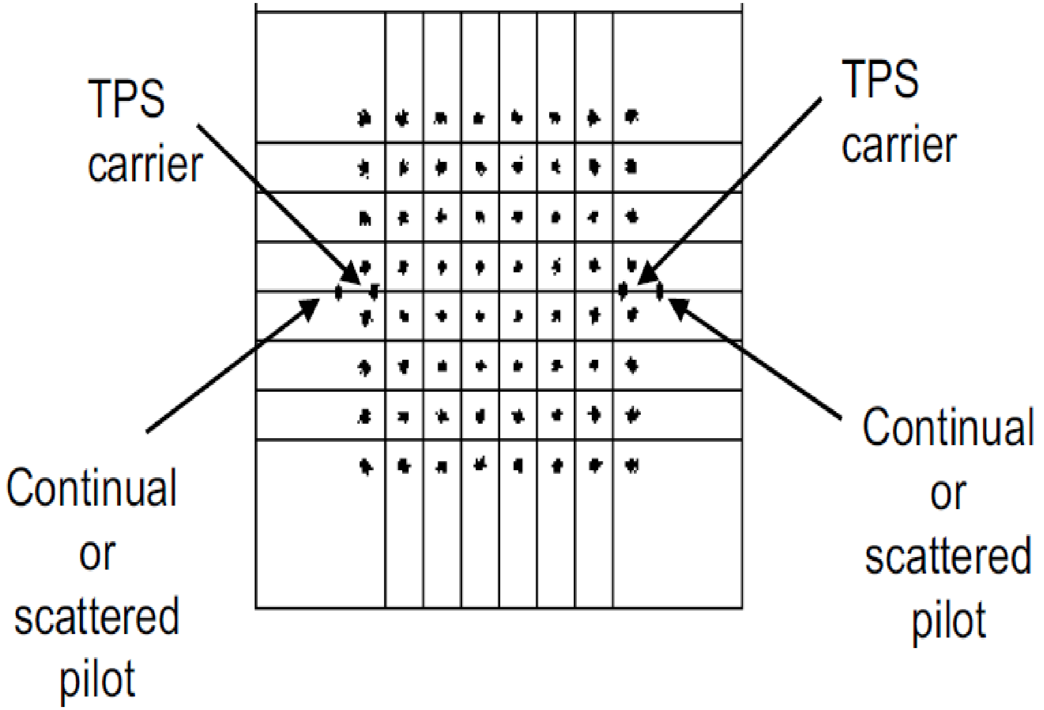
- Two MPEG-2 transport stream inputs are possible which then provides for the so-called hierarchical modulation.
- Hierarchical modulation was originally provided for transmitting the same TV programs with different data rate, different error correction and different quality in one DVB-T channel.
- Not every COFDM carrier in DVB-T is a payload carrier. There is also a large number of pilot carriers and special carriers.
- These special carriers are used for frequency synchronization, channel estimation and channel correction, and for implementing a fast information channel.

DVB-T Modulator (FEC details)



Types of Carrier in DVB Carriers

- DVB-T contains the following types of carrier:
  - Inactive carriers with fixed position (set to zero amplitude)
  - Payload carriers with fixed position
  - Continual pilots with fixed position
  - Scattered pilots with changing position in the spectrum
  - Transmission Parameter Signalling (TPS) carriers with fixed position



The System Parameters of DVB-T

- IFFT sampling frequencies
  - For 8MHz Channel: 9.142857143 MHz.
  - From this basic parameter, all other system parameters can be derived
- DVB-T signal bandwidths
- Spectrum occupied by the 8/7 and 6 MHz DVB-T channel
- Data rates
- Signal levels of the individual carriers

Data Rate calculation process

- The gross data rate is then the result of the symbol rate, the number of actual payload carriers and the type of modulation

$$symbol\_rate_{COFDM} = \frac{1}{symbol\_duration + guard\_duration};$$

$$\text{gross\_data\_rate} = \text{symbol\_rate}_{\text{COFDM}} \bullet \text{no\_of\_payload\_carriers} \bullet \text{bits\_per\_symbol};$$

$$\text{net\_data\_rate} = \text{gross\_data\_rate} \bullet 188/204 \bullet \text{code\_rate};$$

General Classification of DVB-T Receiver

	Stationary	Portable	Mobile
Integrated Digital TV set (IDTV)	X		
Set Top Box (STB)	X		
Portable TV		X	
Personal Digital Assistant (PDA)		X	X
Home-PC extension	X		
Notebook-PC Extension		X	X
Car receiver			X

DVB-T Upgrades

DVB-T2

- Update of DVB-T standard; approved June 2008
- is a completely new DVB-T-Standard which no longer has anything in common with the conventional DVB-T standard.
- Just like DVB-T, DVB-T2 was mainly promoted by the BBC
- Exploits extra available spectrum made available by switch-off of analogue services.
  - Requires viewers to buy new but affordable STBs
- The error protection used is the FEC defined in DVB-S2

Roll-out of DVB-T2

- Key drivers:
  - increased capacity
  - improved robustness
  - downward compatibility: use existing receiving antennas.
- Uses COFDM with improved error coding
- DVB-T2 is 30% to 50% more efficient in use of spectrum than DVB-T.
- Supports reception on laptops, in-car receivers, other portable devices.
- DVB-T2 first used in UK
  - Ofcom (= UK radio agency regulator) decided to use DVB-T2 and H.264 for terrestrial HDTV from Autumn 2009 onwards.

DVB-T2: capacity, SNR and FEC

- .

  $C = 1/3 \cdot B \cdot SNR$;
  where C = channel capacity (in bits/s);
  B = bandwidth (in Hz);
  SNR = signal/noise ratio (in dB);

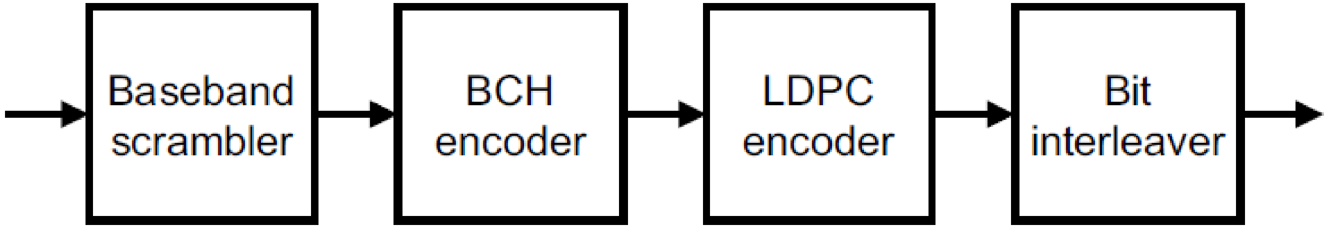


Fig. 37.1. DVB-T2-Error protection (BCH = Bose-Chaudhuri-Hoquenghem, LDPC = Low Density Parity Check Code)

DVB-T and DVB-T2 Comparison

	DVB-T	DVB-T2
FEC	Convolutional Coding + Reed Solomon 1/2, 2/3, 3/4, 5/6, 7/8	LDPC + BCH 1/2, 3/5, 2/3, 3/4, 4/5, 5/6
Modes	QPSK, 16-QAM, 64-QAM	QPSK, 16-QAM, 64-QAM, 256-QAM
Guard Interval (T_g/T_S)	1/4, 1/8, 1/16, 1/32	1/4, 19/256, 1/8, 19/128, 1/16, 1/32, 1/128
FFT size	2k, 8k	1k, 2k, 4k, 8k, 16k, 32k
Scattered Pilots	8% of total	1%, 2%, 4%, 8% of total
Continual Pilots	2.6% of total	0.35% of total

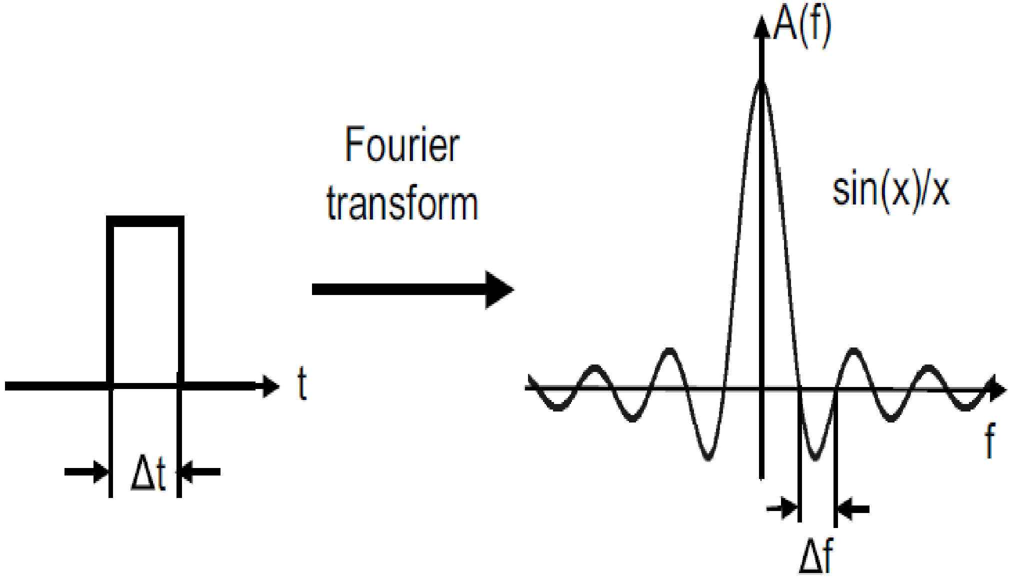
~ 25% extra capacity

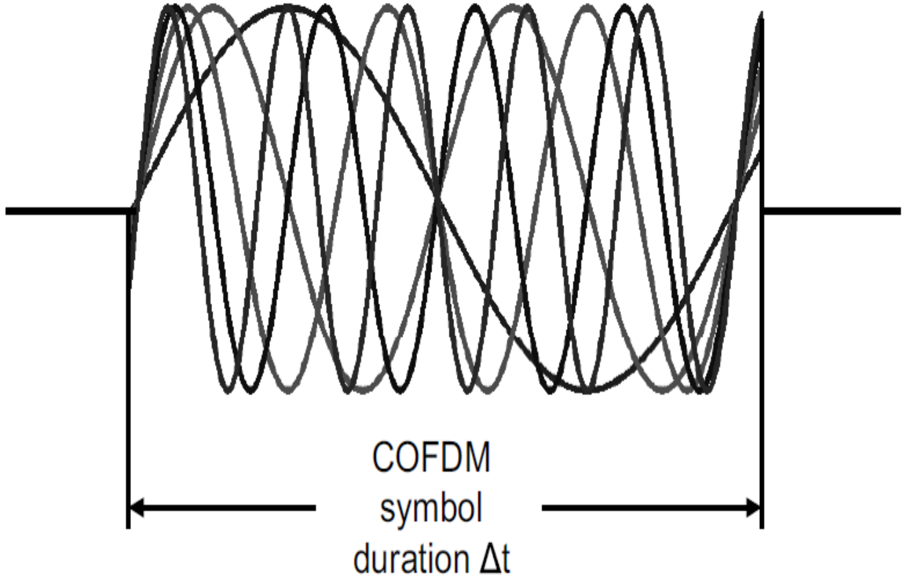
OFDM

COFDM

- COFDM – Coded Orthogonal Frequency Division Multiplexing
- Coded – error protection and distribution of data between different frequency carriers
- FDM – as in analogue
- Orthogonal (in signal space) – the subcarriers do not interfere with each other, despite spectral overlap

Fourier Transform of rectangular pulse





COFDM diagram

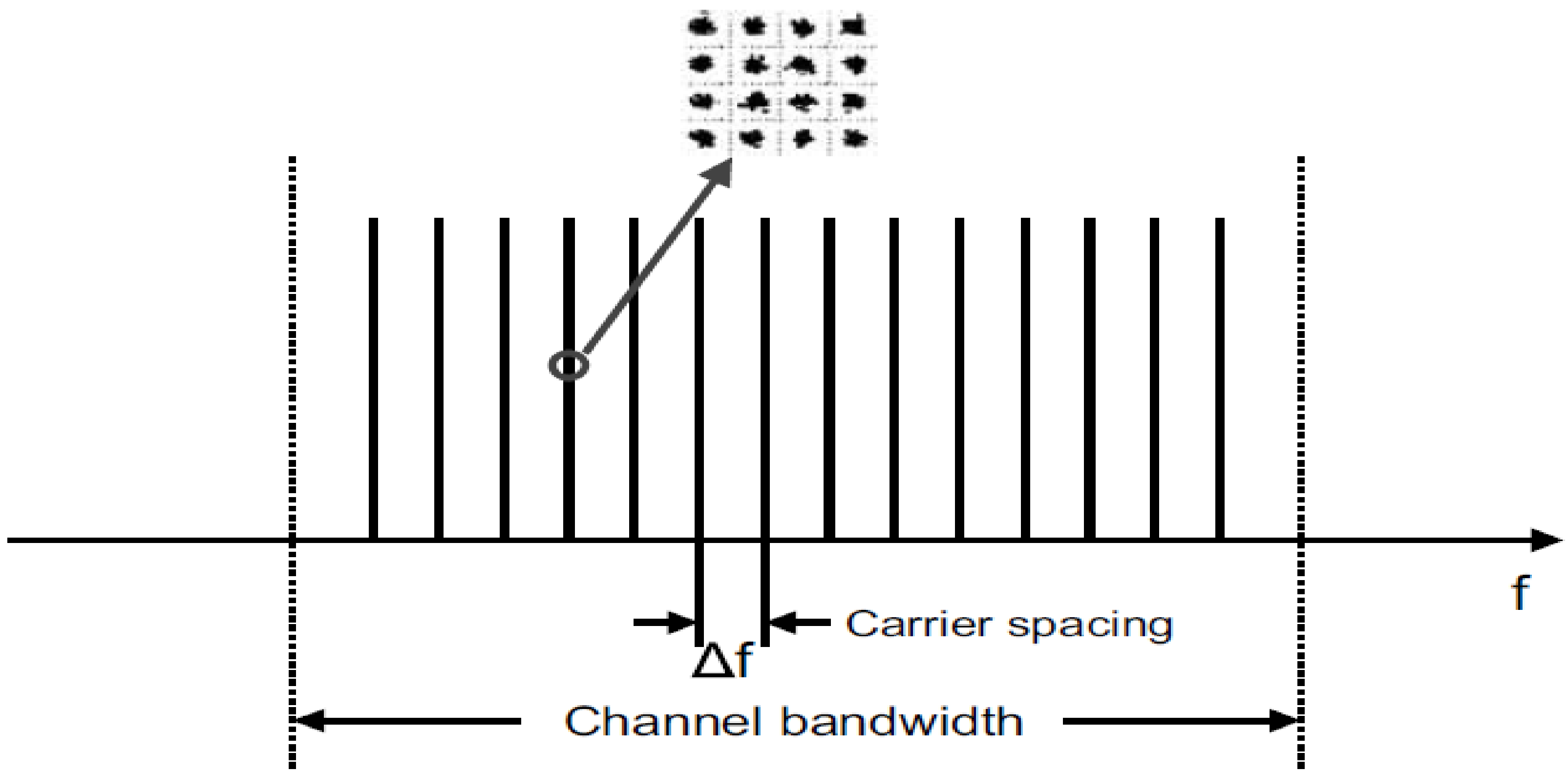


Fig. 19.6. Coded Orthogonal Frequency Division Multiplex (COFDM)

OFDM Bandwidth

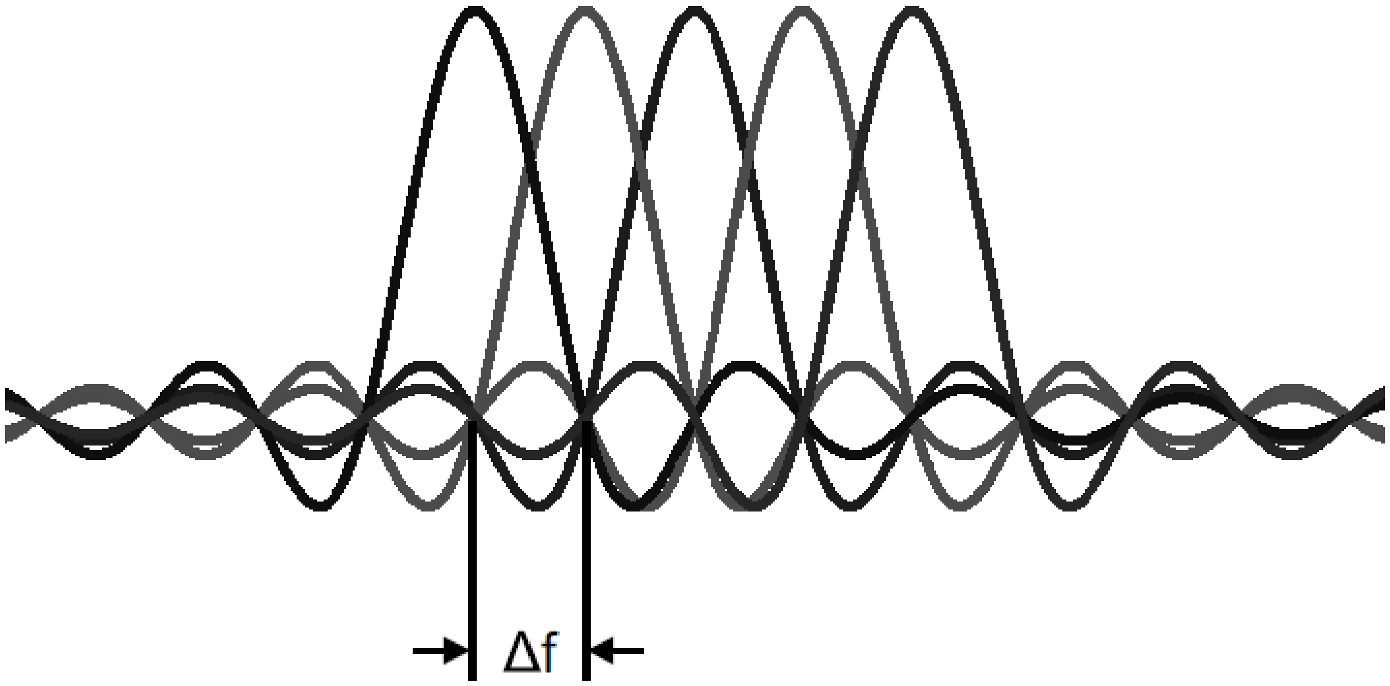
- Instead of one single carrier frequency for modulating all data, use many subcarriers each carrying a small different portion of data
- In COFDM, same overall bandwidth is kept when using multi-carrier system
  - single carrier would require a high symbol rate, hence large bandwidth
  - multiple carriers in OFDM each carry lower symbol rate, only needing a low bandwidth
  - the lower the symbol rate required, the longer each symbol can be, solving the multi-path problem

Interference?

- Typical OFDM systems have 2K or 8K subcarriers.
- Does existence of many subcarriers at closely spaced frequencies cause interference?
  - Normally, yes
  - Not so when designing for orthogonality.

Orthogonality

Orthogonality condition: $\Delta f = 1/\Delta t$



Orthogonality

- All subcarriers are spaced apart by a constant interval Δf (few kHz).
- Carrier signals contain information by symbol mapping (amplitude and phase shift keying).
- In time domain (TD), modulated carrier can be decomposed into short sections of quasi-sinusoids that are ‘cut out’ rectangularly.

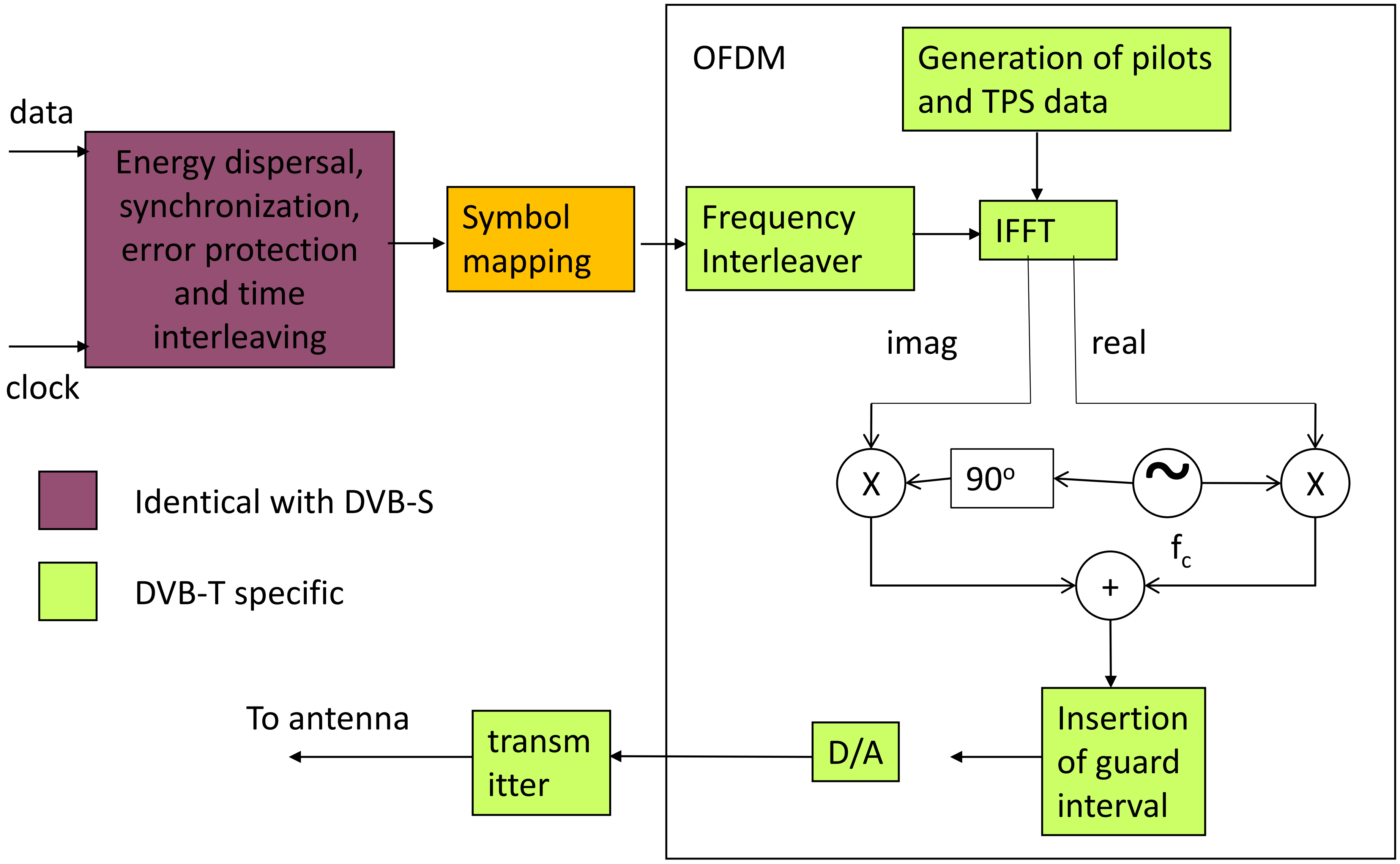
Orthogonality

- Rectangular TD block corresponds to sinc in FD, a sinc function centered at the carrier frequency.
- For many subcarriers: give symbols correct length such that all nulls of all but one of the shifted sinc functions exactly coincide.
- Result: no interference at f_i.

Transmission

- The requirement for a single frequency network can best be met by using orthogonal frequency division multiplexing (OFDM)
- To make the system as similar as possible to satellite systems the same error protection scheme is used, including interleaving
- OFDM modulation with error protection scheme is known as Coded Orthogonal Frequency Division Multiplex (COFDM)

Encoding



data
clock
Energy dispersal, synchronization, error protection and time interleaving
Symbol mapping
OFDM
Generation of pilots and TPS data
Frequency Interleaver
IFFT
imag
real
X
90o
X
fc
+
Insertion of guard interval
D/A
transmitter
To antenna
Identical with DVB-S
DVB-T specific

Frequency Interleaving

- Convolutional interleaving (in time) is used in DVB-S, DVB-C and now DVB-T for error protection to randomise burst errors.
- Because OFDM uses multiple subcarriers, frequency interleaving can be used.
- Transport Stream (TS) contains several programs, channels and services (video, audio, data).
- Instead of dedicating one (or several) available carrier(s) in a multi-carrier system to a set of channels, the data for all channels is spread over all carriers.
  - Reduces effects of frequency selective fading.

IFFT

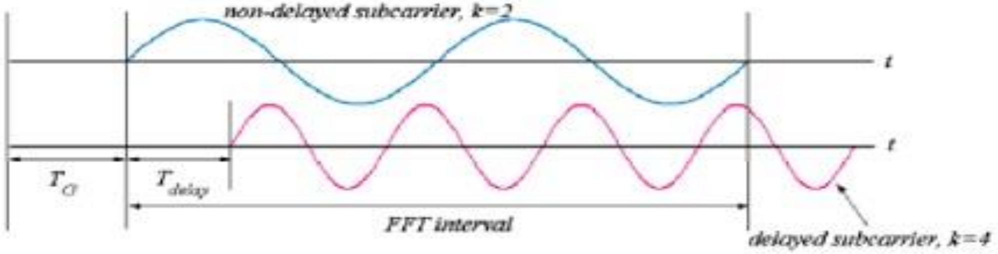
- After frequency interleaving in 2K mode, there are 1512 complex numbers that represent data symbols to be transmited on each of the subcarriers.
- We could use 1512 QPSK modulators – expensive!
- We use the IFFT on each set of symbols to give a set of complex time-domain samples.
- These are then quadrature modulated in the standard way: QPSK; 16-QAM, …, 2^n-QAM
  - requires *n* bit interleavers (1 per symbol of ‘parallel’ bits)
- Additional 193 non-data carriers are used for synchronization, signalling, control,
- Remainder carriers: used as pilots

Guard Interval

- Also known as the cyclic prefix.
- To solve multi-path problem: need to make symbol longer than maximum expected delay (lecture 2).
- ‘Symbol’ contains 2048 time domain samples, modulated onto a carrier.
- Cannot simply ‘stretch’ the symbol to be longer, because this would lose data.

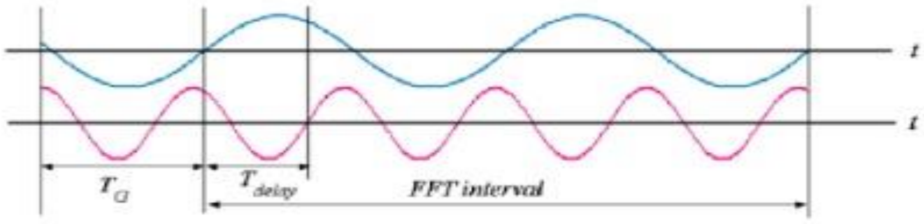
Cyclic Prefix for Guard Interval

zero-valued guard interval

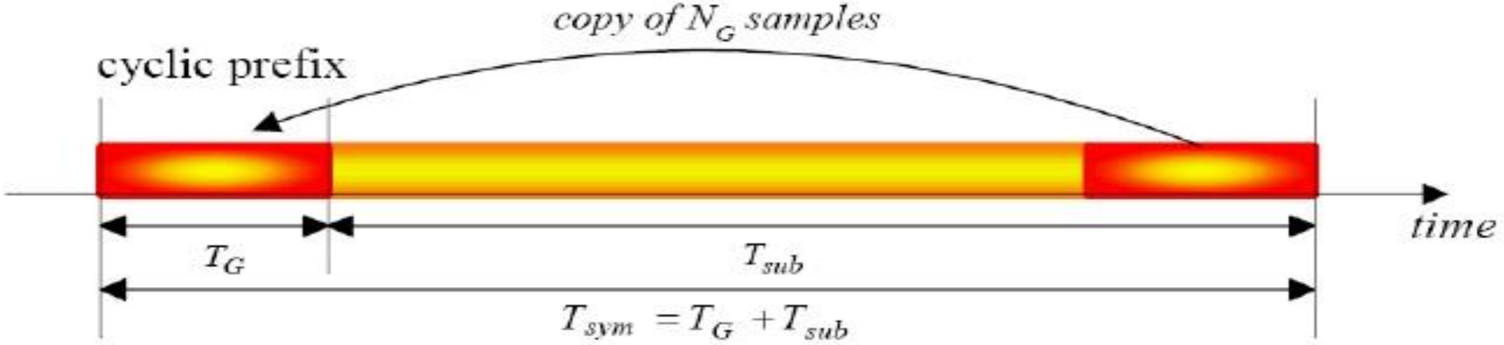


no ISI but ICI

cyclic prefix



no ISI and ICI



Practical Lengths of Guard Interval

- Typical values for DVB-T on SFN:
  - T_g = 62.5 μs to achieve 63% UK population coverage
  - T_g = 125 μs to achieve 77% UK population coverage
  - T_g = 250 μs to achieve 91% UK population coverage
  - T_g = 500 μs to achieve 97% UK population coverage
- T_g = 200 μs requires radius of 60 km per transmission tower in national coverage and needs most complex type of COFDM (8K mode)

Design of OFDM for DVB-T

- Parameters: DVB transmitter spacing d, guard interval T_g, symbol duration T_S, OFDM carrier count N, subcarrier modulation scheme (K), channel capacity C
- $d_{max} \rightarrow T_g \rightarrow T_S \rightarrow T_U \rightarrow \delta f \rightarrow N \rightarrow C_{min}$
- Example:
  - $d_{max} = 60$ km $\rightarrow T_g = d_{max} / c = 200\ \mu s$
  - Typically, $T_S = 5\ T_g \rightarrow T_U = T_S - T_g = 800\ \mu s$
  - $\delta f = 1 / T_U = 1.25$ kHz
  - $N = \Delta f / \delta f = 6000$ (UHF: $\Delta f = 7.5$ MHz) $\rightarrow$ 8K mode
  - For 64-QAM: $b = 6$ bits/symbol $\rightarrow\ C = b\ N / T_S = 36$ Mbps

Design of OFDM for DVB-T

- T_U is often decided based on the fixed IDFT sampling frequency f_s = 64/7 = 9.143 MHz:

  e.g. for 8K mode: $T_U = \frac{8192}{64/7} = 896\ \mu s$

- NB: not all carriers can be used; they must fit within TV bandwidth Δf (in practice: $\Delta f \approx$ 7.6 MHz chosen)
  - Leads to N_{eff} = 6817 (in 8K) or 1705 (in 2K) effective data subcarriers for this Δf (check!)
- Exercise: re-design network for metropolitan TV coverage (d_{max} = 5 km). What are the consequences for the OFDM mode, hardware and spectral requirements?

Why f_s = 64/7 MHz?

- Sampling frequency depends on TV channel bandwidth
- For TV bandwidth of 7 MHz instead of 8 MHz:

  $f_s = (64/7) \times (7/8) = 8$ MHz
- For bandwidth of 6 MHz: $f_s = 48/7 = 6.86$ MHz
  - NB: effective data bandwidths are reduced, because smaller effective number of data carriers
- <u>Exercise</u>: find T_U , δf, etc. for these different f_s

Pilot Signals

OFDM Carriers Utilization

- In 2K mode: 1512 carriers used to carry payload (MPEG data)

- Use of remaining 2048-1512-193 = 343 carriers:
  - Continual pilots linked to fixed position
  - Scattered pilots linked to changing position
  - TPS carriers with fixed position

Pilot Signals

- Pilot signal = unmodulated sinusoidal reference ‘signal’ (marker): information = ‘present/absent’
  - Reference signal for all OFDM carriers
  - Unmodulated carrier is easier to detect than modulated
  - Acts as phase reference: detects any frequency shift
- Scattered pilots: at different, but known frequencies in every symbol
  - used for synchronisation

Types of Pilot Signals (I)

- Continual (or boosted) pilots
  - Present in each symbol at the same carrier position
  - Frequency positions chosen so that no periodicities occur, to enable frequency coarse adjustment (synchronization) of local oscillator in receiver
    - Based on maximum-length (*m*-) sequences with pseudo-random noise properties
    - E.g., in 2K mode: 45 pilots at 0, 48, 54, 87, …, 1704
    - In 8K mode: 177 pilots at 0, 48, 54, 87, … 6816
  - Boosting because of importance of synchronization: carrier amplitude $\times$ (4/3)

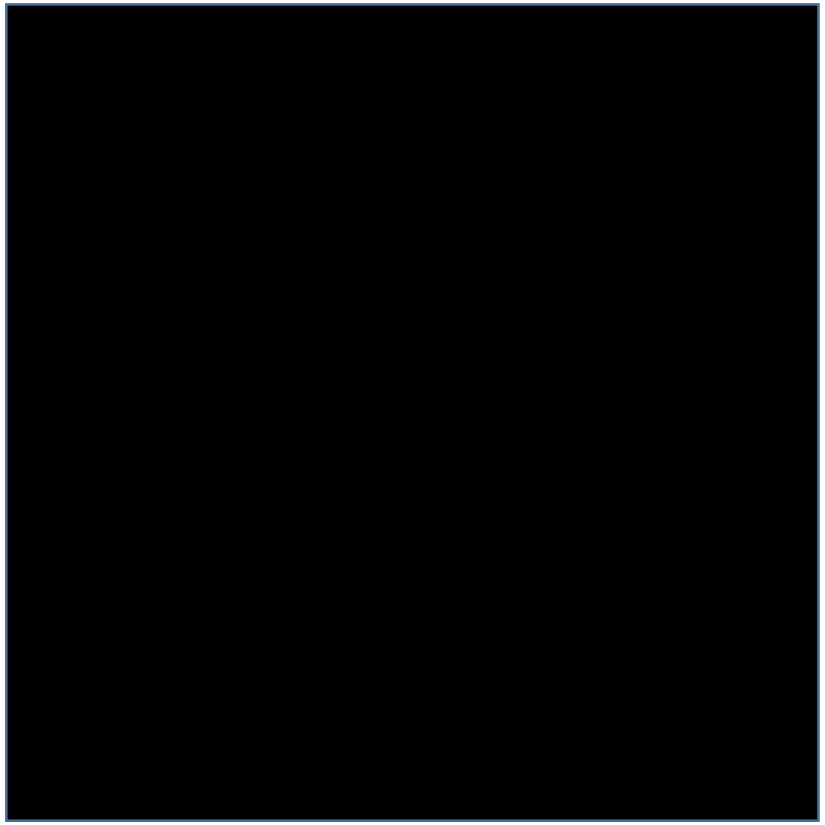
Types of Pilot Signals (II)

- Scattered pilots
  - Scattered across transmission frame according to fixed known plan
  - Large number of pilots per symbol enables fine adjustment of receiver
  - Also contributes to synchronization of oscillator
  - Enables channel estimation in time-varying conditions (spectrogram)

Types of Pilot Signals (III)

- TPS pilots = Transmission Parameter Signalling pilots.
  - Contain additional information to help with temporal synchronisation
  - TPS data include special information needed for signal demodulation, similar to FIC in DAB:
    - type of modulation used (QPSK, 16-QAM, 64-QAM)
    - duration of the guard interval (multiple of 2^{-n})
    - channel code rate (1/2, 2/3, 3/4, 5,6, 7,8)
    - OFDM variation and cell identifier (combats interference in SFN)
  - TPS data transmission is crucial
    - repeated many times, to ensure it is received without errors.
      - One TPS bit in 2-PSK per symbol for 17 (in 2K) or 68 (in 8K) symbols per frame
    - transmitted at boosted power level (e.g. double power)

Hierarchical Modulation

Hierarchical Modulation (I)

- DVB-T fails abruptly when the C/N ratio falls below threshold (‘fall-off-the-cliff’, ‘brick wall’ effect)
  - Compare: in analogue systems: degradation is gradual and therefore more acceptable.
- In city areas that are on lower ground, there may be no reception possible at all in these regions.
  - Remedies:
    - Increase transmitter power.
    - Use different modulation scheme or lower code rate.
    - Install extra transmitters.
  - However, any of these solutions uses the available channel capacity less efficiently, possibly for just a few customers

Hierarchical Modulation (II)

- Solution: hierarchical modulation:
  - Principle: splits TV channel (programme) into two parts
  - Each program is transmitted twice (‘modulation multiplex’):
    - lower bit rate channel (few Mbps) + high error protection: can still be received with poor C/N.
    - higher data rate channel + low error protection: can be received and used, provided C/N is higher.
  - Example:
    - QPSK with a low code rate for error protection at lower bit rate for most robust channel
    - 64-QAM with high code rate and higher bit rate for least robust (most fragile) channel.
- Hierarchical coding was ultimately not included in DVB-T standard