TM-T2 Report to TM 75

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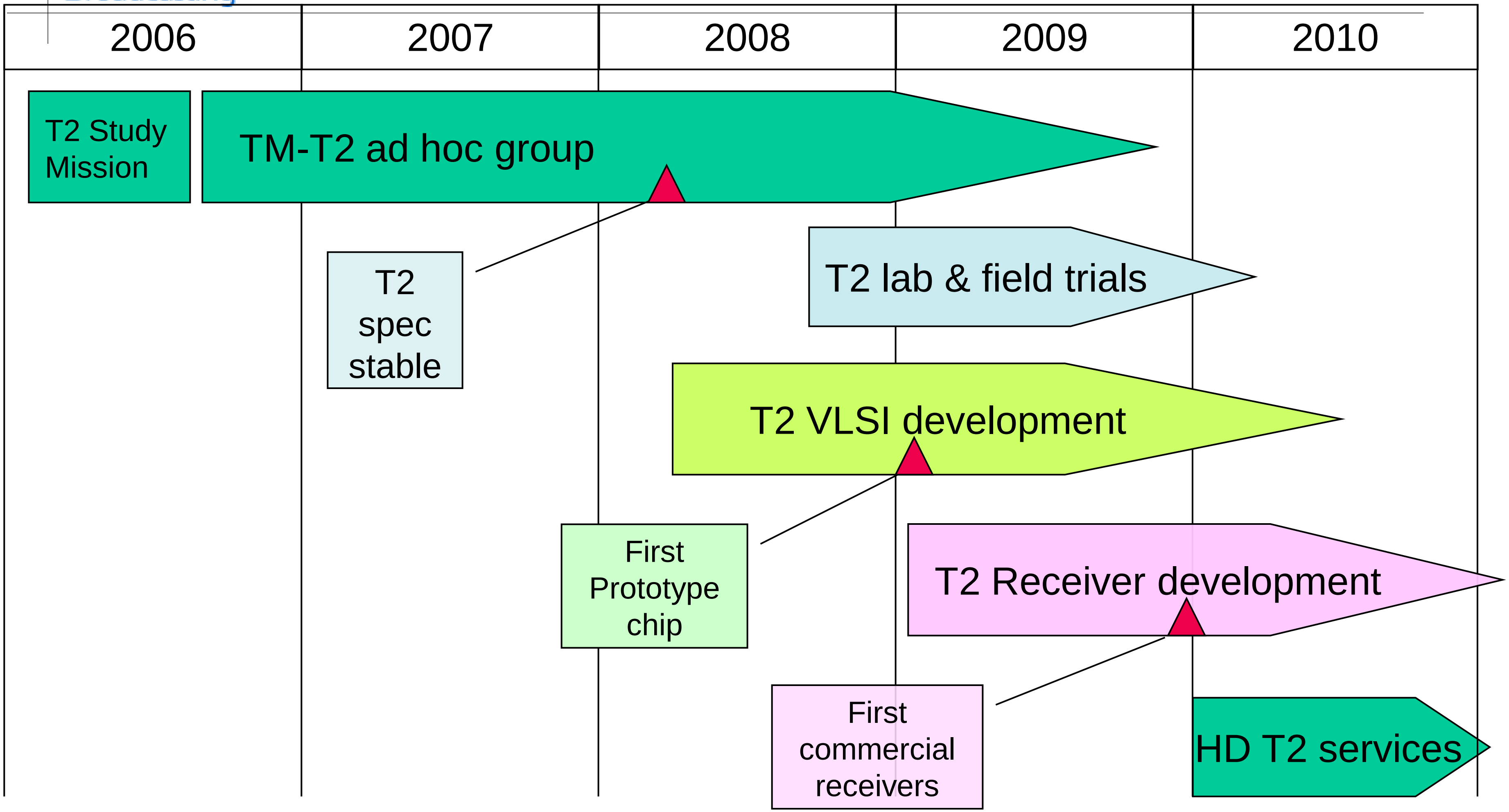
BBC Research & Innovation

Introduction

- Since last TM report:
  - One meeting, T-Systems, Darmstadt, 4-6 March, 65 participants
  - More than 20 telephone conferences
  - Many hundreds of emails on T2 reflector
- Goals
  - To prepare T2 physical layer specification for this TM
  - For specification to be stable – so that receiver chip design can start
    - Accepting further polishing of documents will be required.
- Achievements
  - All technical details relating to physical layer specification have been decided
    - Only one minor decision remains - to be resolved by end March
    - Technical innovation frozen – only changes allowed will be bug fixes
  - Draft of specification written
    - Concentrated first on getting technical details correct
    - ETSI references etc. still to be added
- Actions requested from TM
  - Decision from TM on strategy for handling documentation process from here

T2 Timeline


2006
2007
2008
2009
2010
T2 Study Mission
TM-T2 ad hoc group
T2 spec stable
T2 lab & field trials
T2 VLSI development
First Prototype chip
T2 Receiver development
First commercial receivers
HD T2 services

Commercial Requirements for T2

- Key requirements include
  - Must be able to use existing domestic receive antenna and existing transmitter infrastructure
    - Intended primarily for services to fixed and portable receivers
  - Should provide minimum of 30% capacity increase over DVB-T
    - Within same spectrum planning constraints
  - Should provide for improved SFN performance
  - Should have mechanism for providing service-specific robustness
  - Should provide for bandwidth and frequency flexibility
  - Should provide means to reduce peak-to-average power ratio
- Initial analysis of specification against requirements written for CM-AMT
  - Doc. tmxxxx

T2 physical layer specification overview

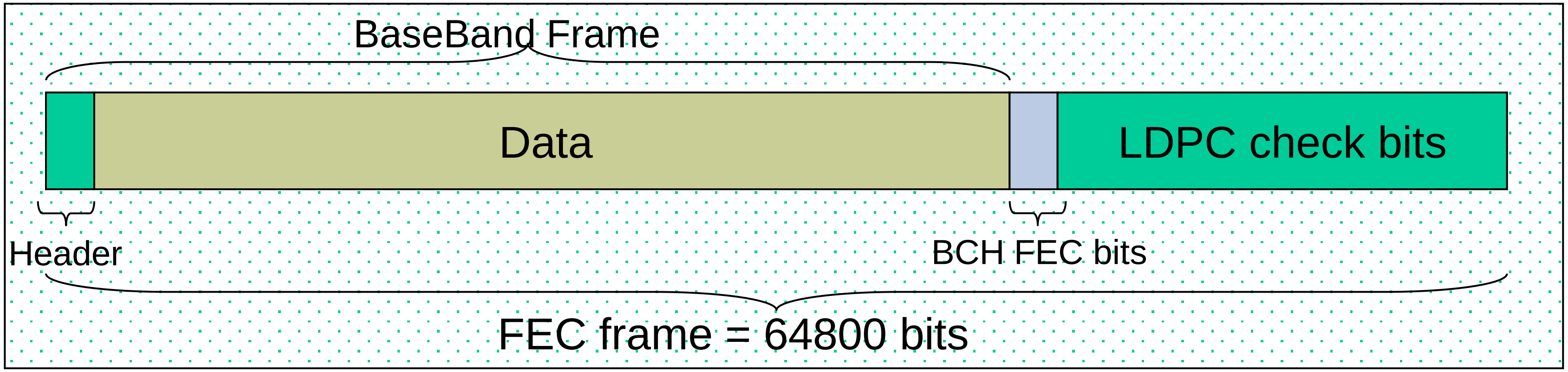
Key features: Compatibility with S2

- General DVB principles
  - DVB should aim to provide a coherent family of standards (where possible)
  - There should be easy translation between standards
    - e.g. between S2 and T2
  - Don’t re-invent solutions when they already exist within other DVB standards

- T2 adopted two key technologies from S2
  - Packaging of data into BaseBand Frames
  - S2 LDPC error correcting codes

Key features: BB Frames and LDPC

- Data packaged into BaseBand Frames
- BaseBand Frames protected by the S2 LDPC FEC
  - With an additional small BCH code to mop up any residual errors after LDPC decoding



- This FEC frame, of length 64800 bits, is a fundamental unit within T2
  - Code rates: 1/2, 3/5, 2/3, 3/4, 4/5, 5/6
  - A shorter FEC frame of 16200 bits also provided for low data rate services

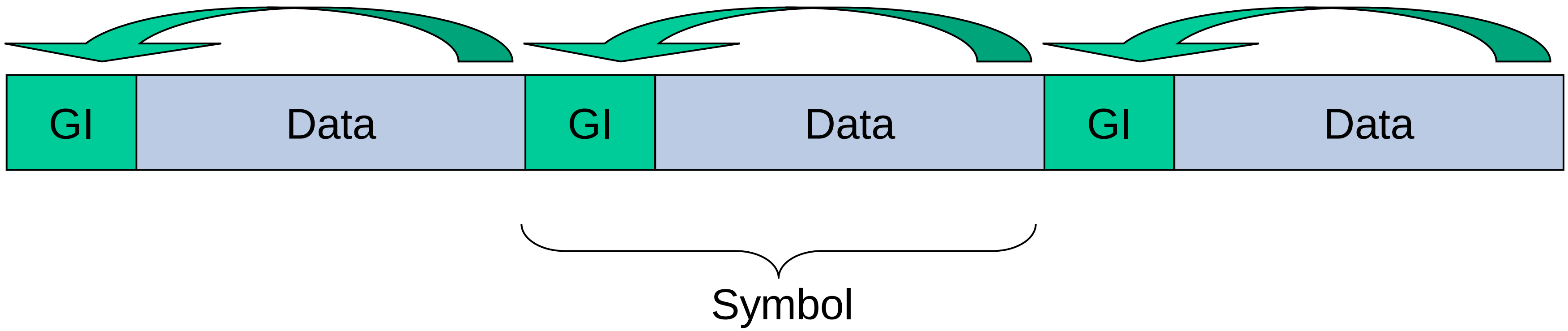
T2/S2 System Layer - details

- Mechanisms for jitter removal and synchronisation inherited from S2
  - Null packet deletion/re-insertion from Transport Streams
  - Input Stream Synchronisation (ISSY) mechanism

- Baseband Header
  - Carries some information about data within stream and information about synchronisation mechanisms
  - 2 types of BB header within T2
    - Fully S2-compatible mode
    - New high-efficiency mode (saving more than 1% overhead)
  - Compatible with TS or GSE

Key Features: Modulation (1)

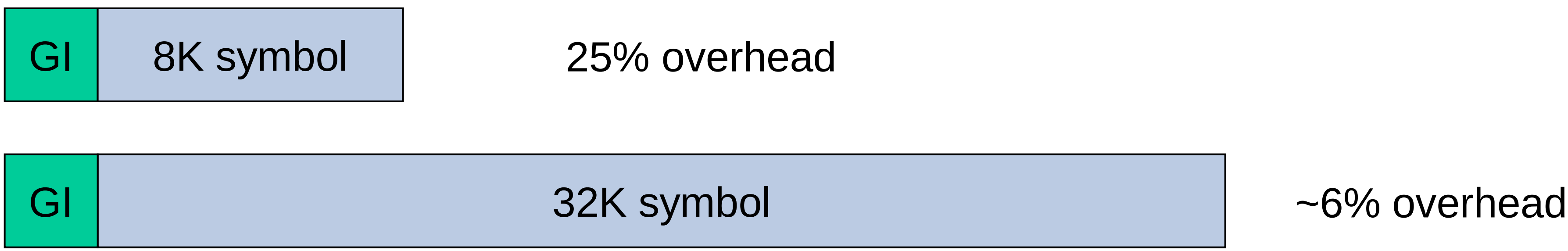
- T2 uses conventional Guard-Interval OFDM (GI-OFDM)
  - as in DVB-T



- Each symbol carries data on a large number of separate carriers
  - 1K, 2K, 4K, 8K, 16K, 32K options are available in T2
    - 16K and 32K: to give improved SFN performance
    - 1K for bandwidth and frequency flexibility
  - Increasing the number of carriers increases the symbol period

Key Features: Modulation (2)

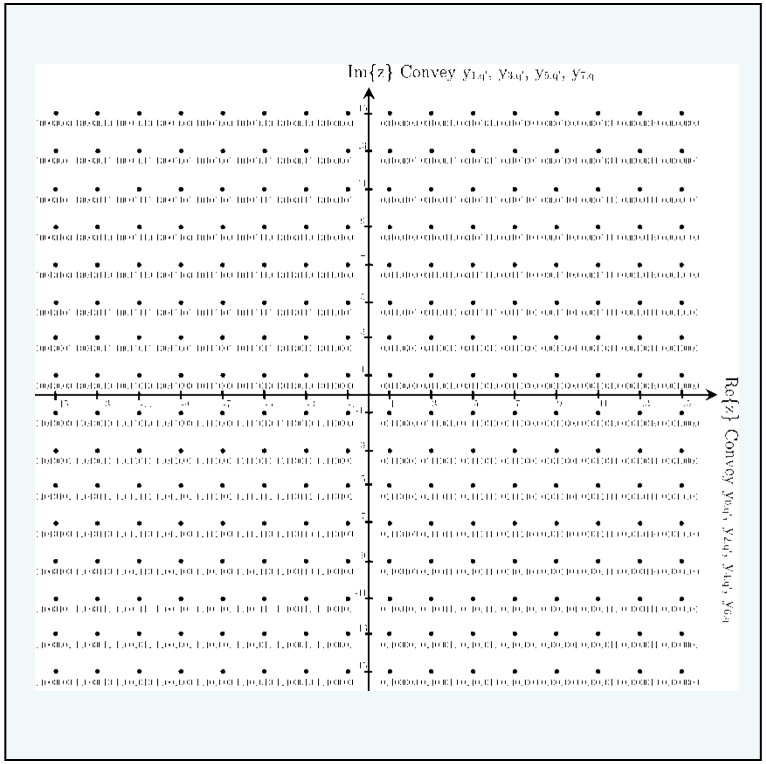
- Increasing the symbol period
  - Can reduce guard interval overhead for given size of SFN
  - Can increase SFN capability for a given fractional GI



- T2 extends guard interval range to allow reduced overhead and additional flexibility
  - GIs in T2: 1/128, 1/32, 1/16, 19/256, 1/8, 19/128, 1/4

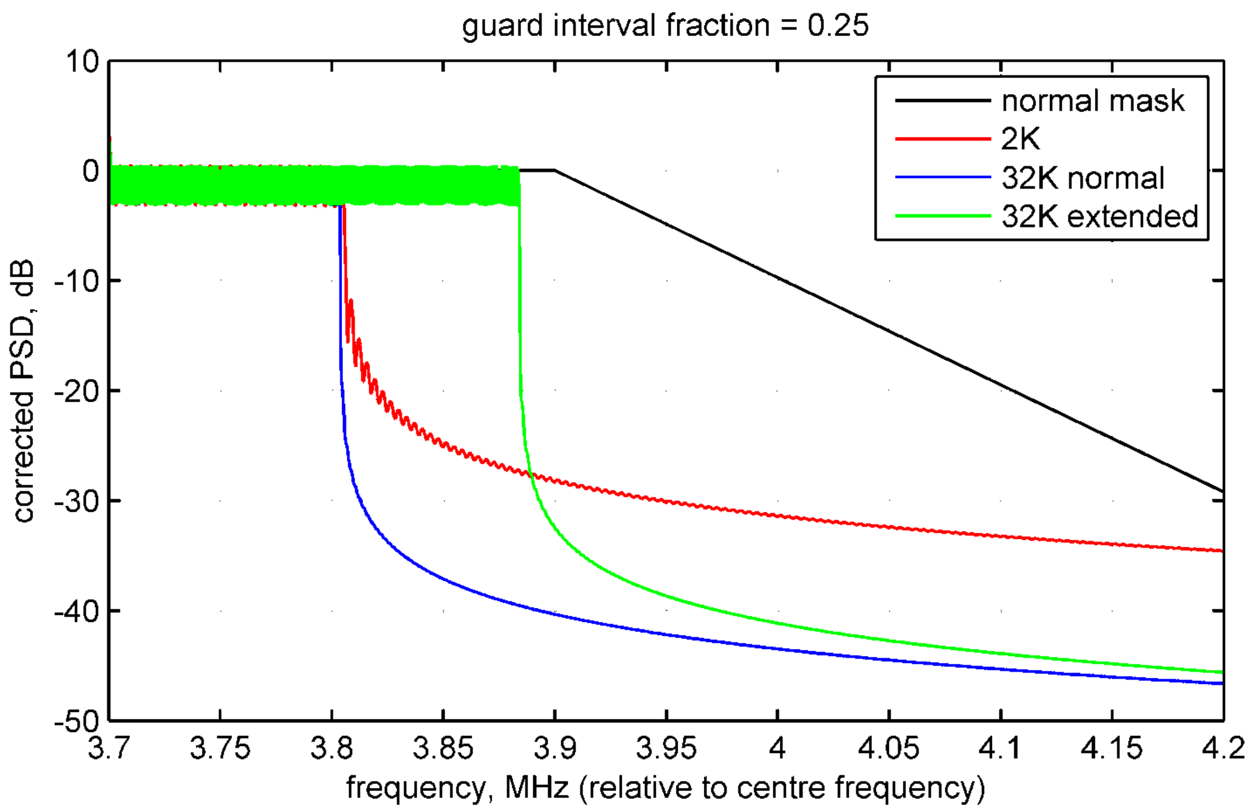
Key Features: Modulation (3)

- T2 includes 256 QAM mode
  - Carries 8 bits/ data cell
    - (c.f 6 bits / data cell for 64 QAM)
  - Enables greater capacity, exploiting improved FEC performance of LDPC
  - Studies show that typical tuner phase noise should not be a problem



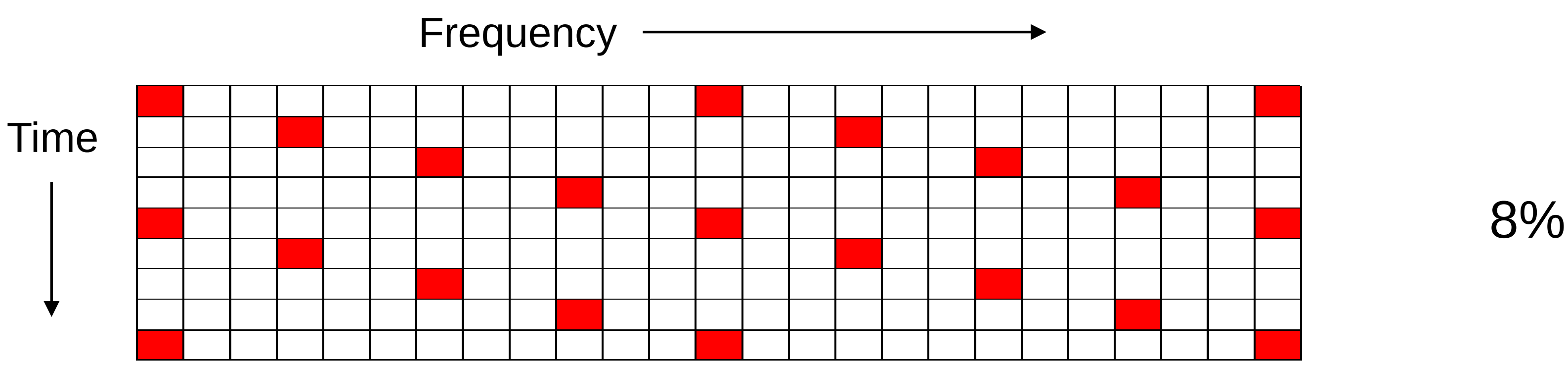
Key Features: Extended bandwidth mode

- Out of band spectrum for 32K mode falls away more quickly than spectrum for 2K mode
  - Allows 2% extra bandwidth/capacity whilst remaining within normal spectrum mask



Scattered Pilot Patterns (1)

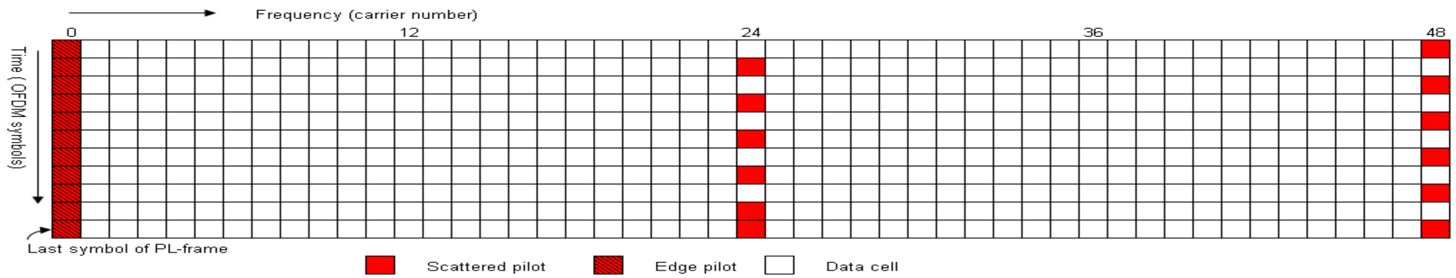
- Scattered pilots are OFDM cells of known amplitude and phase
  - Receiver uses these to compensate for effects of channel changing in frequency and time.
- In DVB-T, 1 in 12 OFDM cells is a scattered pilot
  - 8% overhead
  - Independent of guard-interval fraction



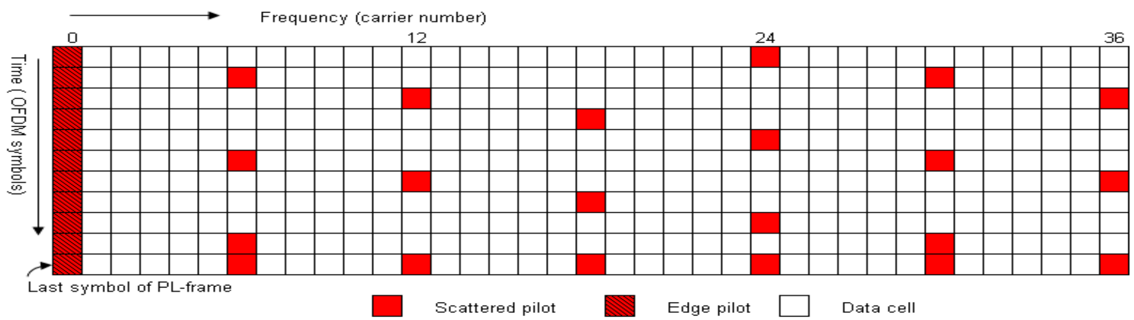
Scattered Pilot Patterns (2)

- T2 has 8 different scattered pilot pattern options
  - Aim: to minimise pilot pattern overhead for a given fractional guard interval; e.g. ….

Time



2%



4%

- Pilot cells are boosted by up to 7 dB depending on density
  - Improves signal to noise on channel estimate
- Pilot pattern modulated by pseudo-random sequence
  - Can be used for improved time synchronisation algorithms
- Pilot pattern modified for edge carriers and for last symbol of frame

Scattered Pilots: Details

Table 50 Parameters defining the scattered pilot patterns

Pilot pattern	Separation of pilot bearing carriers (*x*)	Number of symbols forming one scattered pilot sequence (*y*)
PP1	3	4
PP2	6	2
PP3	6	4
PP4	12	2
PP5	12	4
PP6	24	2
PP7	24	4
PP8	6	16

Table 51 Scattered pilot pattern to be used for each allowed combination of FFT size and guard interval in SISO mode

FFT	Guard interval						
	1/128	1/32	1/16	19/256	1/8	19/128	1/4
32K	PP7	PP4 PP6	PP2 PP8 PP4	PP2 PP8 PP4	PP2 PP8	N/A	N/A
16K	PP7	PP7 PP4 PP6	PP2 PP8 PP4 PP5	PP2 PP8 PP4 PP5	PP2 PP3 PP8	PP2 PP3 PP8	PP1 PP8
8K	PP7	PP7 PP4	PP8 PP4 PP5	PP8 PP4 PP5	PP2 PP3 PP8	PP2 PP3 PP8	PP1 PP8
4K, 2K	N/A	PP7 PP4	PP4 PP5	PP4 PP5	PP2 PP3	PP2 PP3	PP1
1K	N/A	N/A	PP4 PP5	PP4 PP5	PP2 PP3	PP2 PP3	PP1

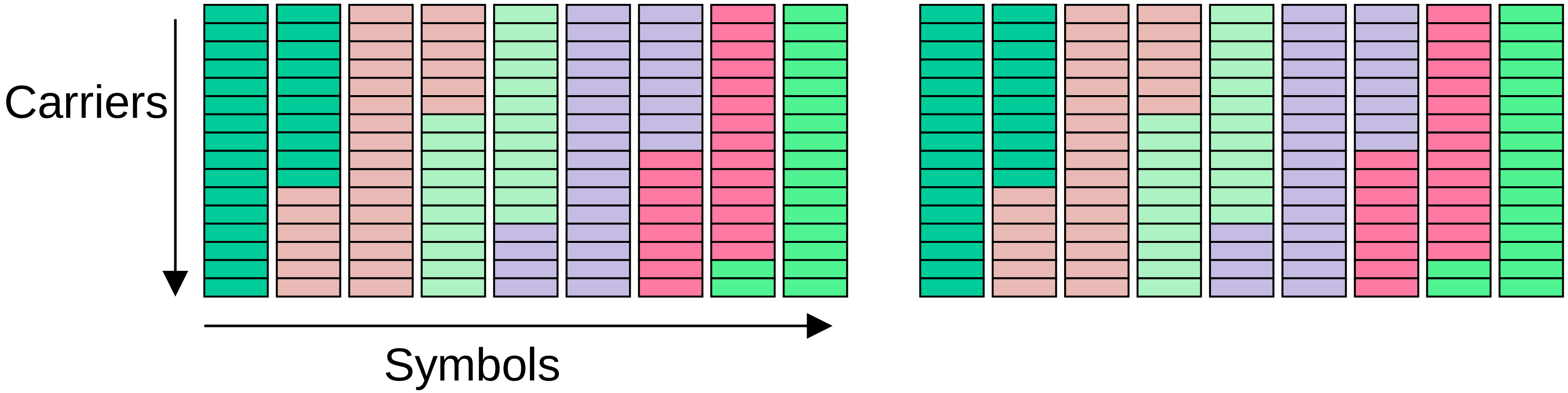
- No pilot mode also attractive - if receiver implements ‘CD3’ feedback equalisation
  - PP8 included (1% overhead) included so that receiver not forced to implement CD3

Continual Pilots

- Continual pilots are used in addition to scattered pilots
  - Used for fine frequency lock of receiver
  - Used to remove Common Phase Errors in channel equalisation
  - 2.5% overhead in DVB-T
- T2 : percentage of CPs depends on FFT size
  - ~2.5% for 1K, 2K
  - ~0.7% for 8K, 16K, 32K
  - % overhead further reduced as ~50% of continual pilot locations coincide with scattered pilot locations
  - Positions of CPs chosen not to collide with PAPR reserved tones

Key features: Service Specific Robustness

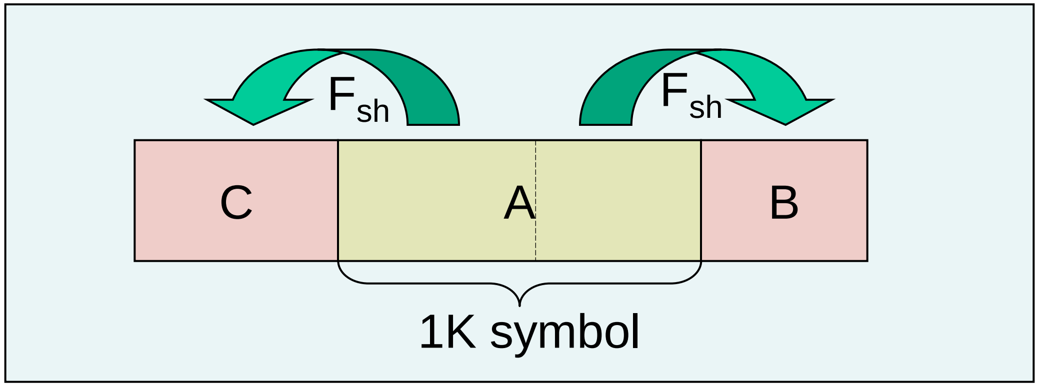
- Each service can be given its own modulation mode (e.g. 256QAM, 16 QAM) and FEC coding rate (e.g. rate 3/5, rate 3/4)
  - Different applications: roof-top reception/portables



- Each service is given a slice of data cells within a frame
  - Each slice is part of a *Physical Layer Pipe* for that service
  - Also enables power saving in the receiver
  - Slices can be sub-divided into sub-slices within frame in order to give more time diversity

Key features: Frame Structure

- Start of frame is signalled by a short P1 symbol
  - Based on 1K OFDM symbol with frequency shifted repeats at front and rear of symbol

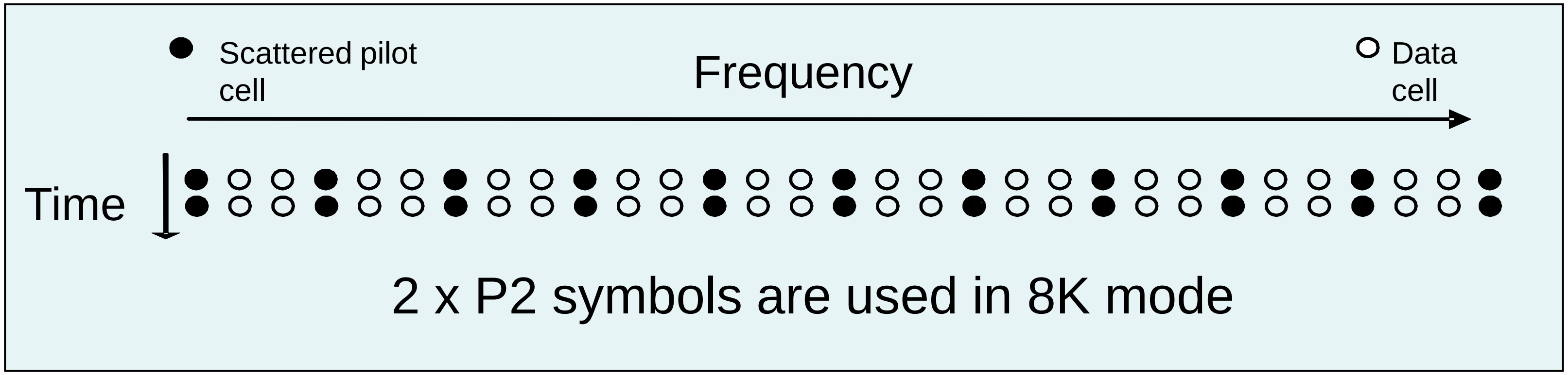


- Only a proportion of 1K carriers occupied
  - Carrying carefully chosen data patterns
- Lengths of segments carefully chosen

- This format of P1 symbol provides
  - Simple and robust mechanism for rapid detection of T2 signal
  - Fast frequency lock mechanism
  - 7 bits of signalling (e.g. for FFT size in main frame)

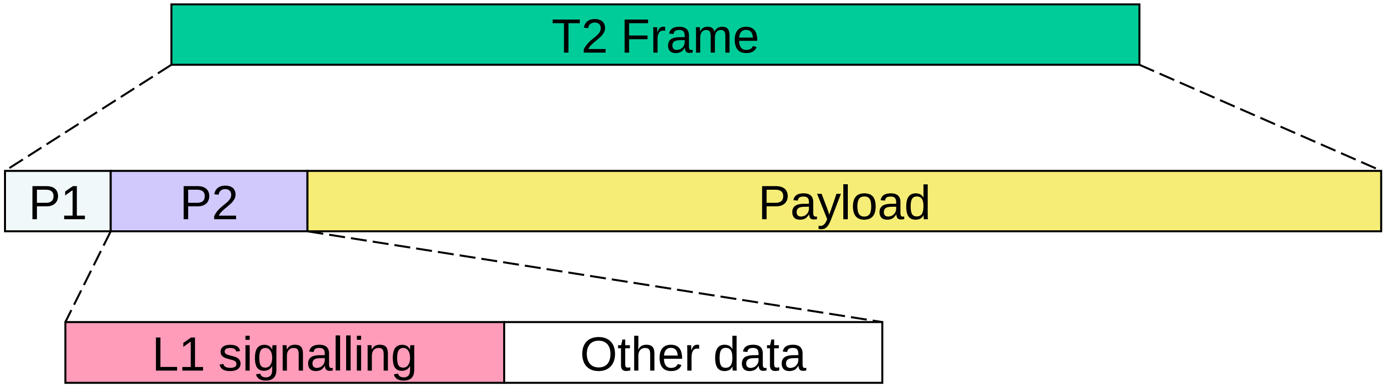
Frame Structure (2)

- Structure of frame must be signalled at beginning of frame
  - Start address and length of individual PLPs
  - This data is carried in P2 symbols which follow P1 symbol
    - Number of P2 symbols depends on FFT size
  - Frame structure data must be carried robustly
    - Use strong FEC and modulation modes within P2
  - Channel equalisation must be rapid and robust
    - Use a greater density of scattered pilots



Frame Structure (3)

- Typical frame duration: 150 -250 ms
  - P1 & P2 overhead typically less than 1%



- L1 signalling carries frame structure data
  - L1 data must be carried more robustly than payload data
  - L1 data split into 2 parts: L1-pre (very robust); L1-post (quite robust)
  - L1 data protected by LDPC (16200-size LDPC with shortening and puncturing)
- Other data carried in P2 can include common PSI/SI data for services carried in payload

Digital Video Broadcasting

Frame Structure (4)

- Typical use – single PLP
  - Complete transport stream is contained within single PLP
    - Including all PSI/SI

- Typical use – multiple PLP
  - Each PLP carries a transport stream
    - or a stream of transport packets (with minimum PSI for contained service)
  - Frame structure for all PLPs is contained in L1 data - which is
    - carried in P2 symbols at beginning of frame
    - And normally carried 'in-band' with each PLP – for that PLP (to reduce need to decode P2 symbols)
  - PSI/SI information common to a group of PLPs (e.g. ESG) is carried in a 'Common PLP'
    - This Common PLP is always carried at beginning of frame
    - Decoder must be able to decode Common PLP + PLP(n)

- PSI/SI additions/modifications
  - T2 PLP Information Table (T2PIT)
  - T2_system_descriptor (to be found within NIT)

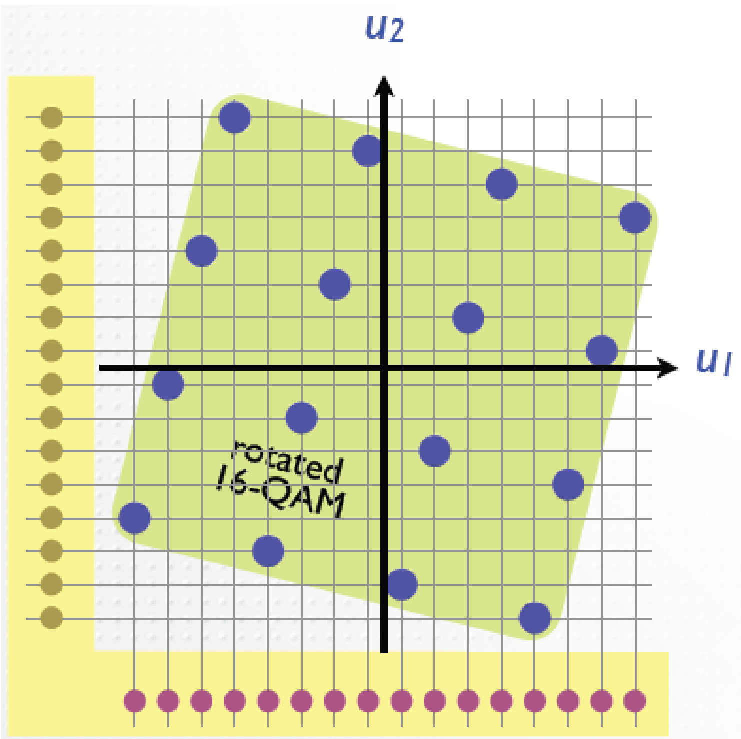
Interleaving (1)

- LDPC works well only for randomly distributed bit errors
  - Must avoid regular patterns of errors and bursts of errors
  - Must randomise mapping of bits from FEC block into constellation points
- T2 uses three main interleavers – applied per PLP
  - Bit Interleaving within an FEC block
    - Randomises errors from single errored data cells
    - Based on a row/column block interleaver - with a 'twist'
  - Time Interleaver
    - Disperses data cells from FEC blocks of a given service throughout slice (/subslices) for that service
  - Frequency Interleaving
    - Causes randomisation of possibly-damaged adjacent data cells within an OFDM symbol
    - Provides robustness against a frequency-selective channel
    - T2 uses twin interleavers (based on DVB-T interleaver)

Interleaving (2)

- Time Interleaver
  - Disperses data cells from FEC blocks of a given service throughout a slice (/subslices) within a frame
  - Provides robustness against impulsive noise
  - Based on row/column block interleaver
  - Depth of interleaving is adjustable per PLP (in units of FEC blocks)
  - Max size = 500Kcells (equiv. to ~10Mbit in receiver)
  - Is preceded by additional data cell-interleaver (for additional safety)
  - For low bit rate services, time interleaving can extend over more than one frame

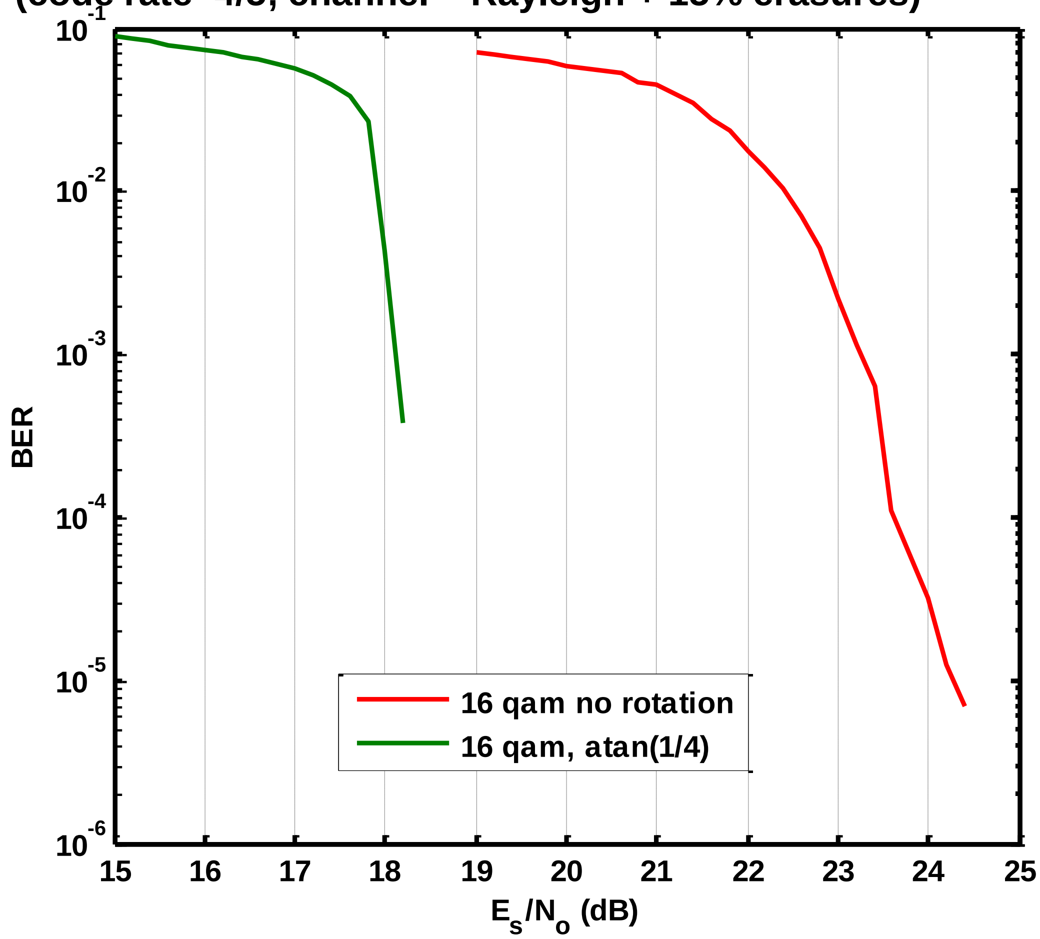
Rotated Constellations (1)



- Map data onto a normal QAM (x,y)
- Rotate constellation (axes now (u_1,u_2))
- Ensure u_1 and u_2 travel in different cells
  - So that they fade independently
  - Gather together in receiver
- Each of u_1,u_2 carries all of the info of original x,y
  - So can decode (less ruggedly) if one is erased completely

Rotated Constellations (2)

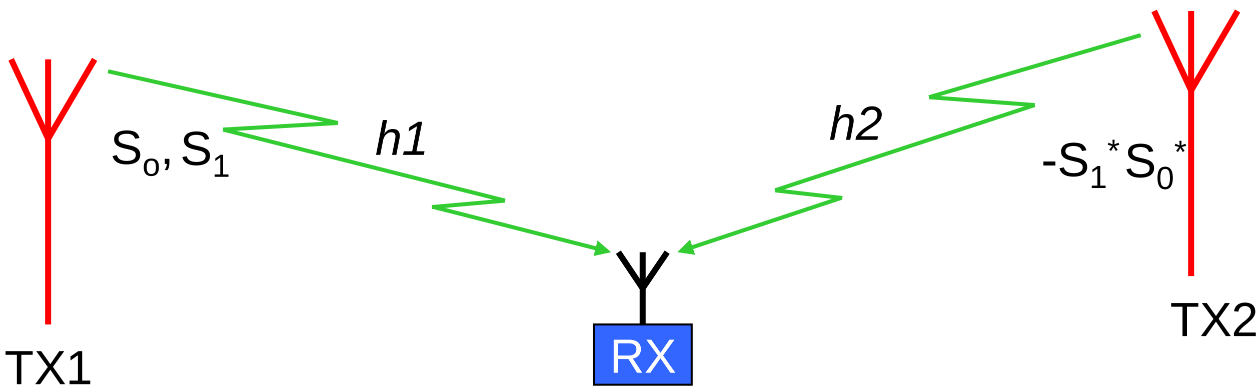
Comparison of performance for rotated/non-rotated constellations (code rate=4/5; channel = Rayleigh + 15% erasures)



- Rotated constellations provide significantly improved robustness against loss of data cells
  - Can achieve gains of up to 5 dB on difficult channels
    - e.g. 15% cell loss channel
  - Can translate into increased bit rate by choosing less robust FEC with lower overhead

Transmit Diversity (1)

- T2 includes Alamouti coding mode for simple SFNs
  - While Tx1 transmits pair of data cells S_0,S_1, Tx2 transmits $-S_1^*,S_0^*$
  - Also involves modification of pilot patterns to measure *h1 and h2*
  - This prevents possibility of 'flat fading' at receiver

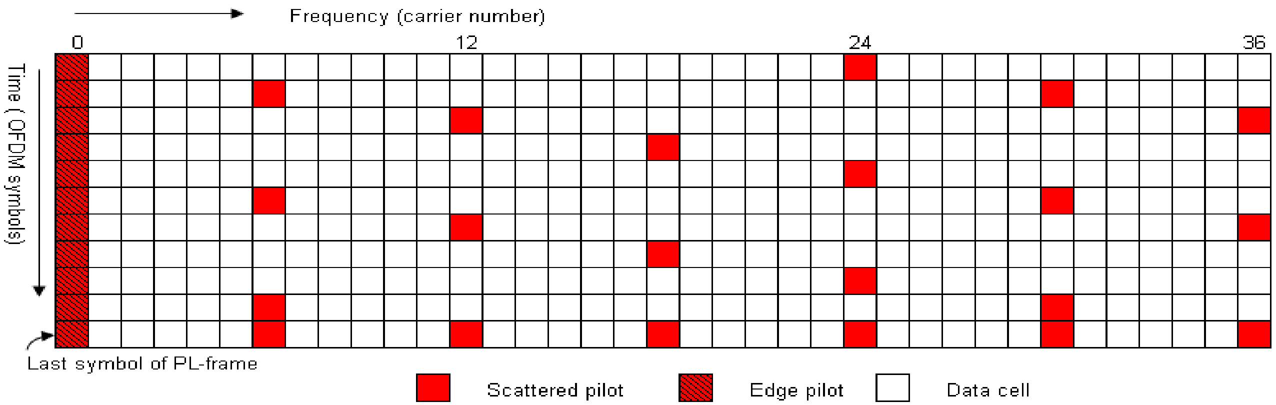


- Initial planning studies predict 30% increase in coverage area for simple SFNs

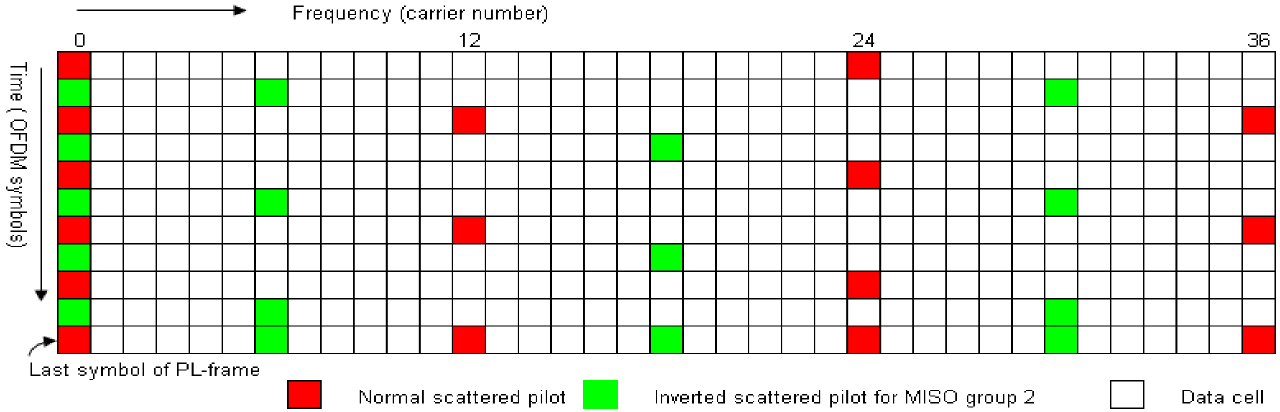
Transmit Diversity (2)

- Scattered pilot patterns are modified (for second transmitter) to enable measurement of channels h1 and h2; e.g. -

Transmitter 1

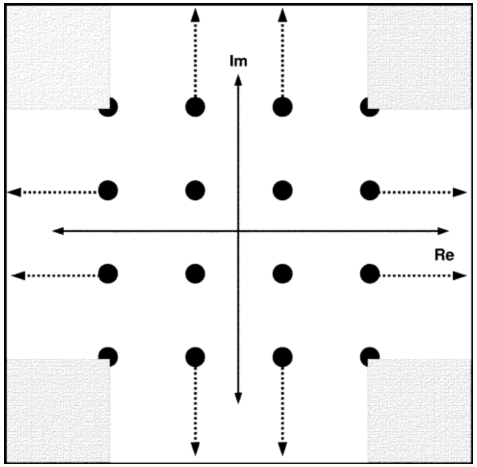


Transmitter 2



Peak to Average Power Reduction

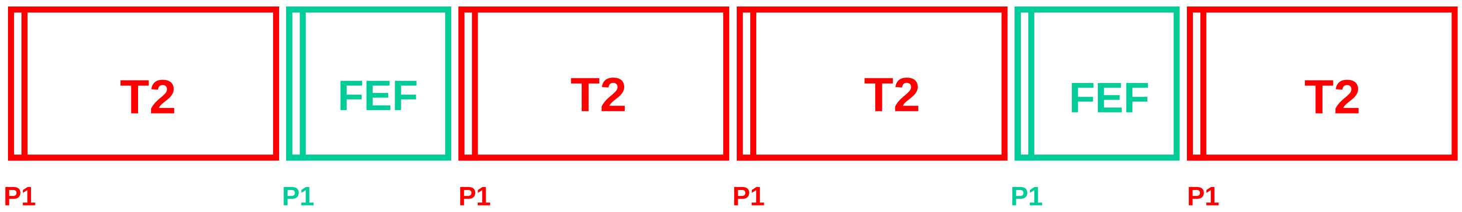
- T2 uses a combination of 2 PAPR reduction techniques
  - Tone reservation
    - 1% of carriers reserved for arbitrary modulation to counteract any peaks
  - 'ACE'
    - Constellation distortion to counteract peaks



- Reduction in peak to average power allows amplifier peak power requirement to be reduced by 20%

Additional Features

- Future Extension Frames (FEFs)
  - Provide a mechanism for future compatible enhancements – e.g. MIMO
  - Only requirement is for FEF to start with P1 symbol



- Time Frequency Slicing
  - Multiplex of signals is spread across several linked frequencies
    - Can give significant Stat Mux gain (20%) and frequency planning gain (5dB)
  - T2 signalling and system is compatible with Time Frequency Slicing system provided receivers have 2 tuners

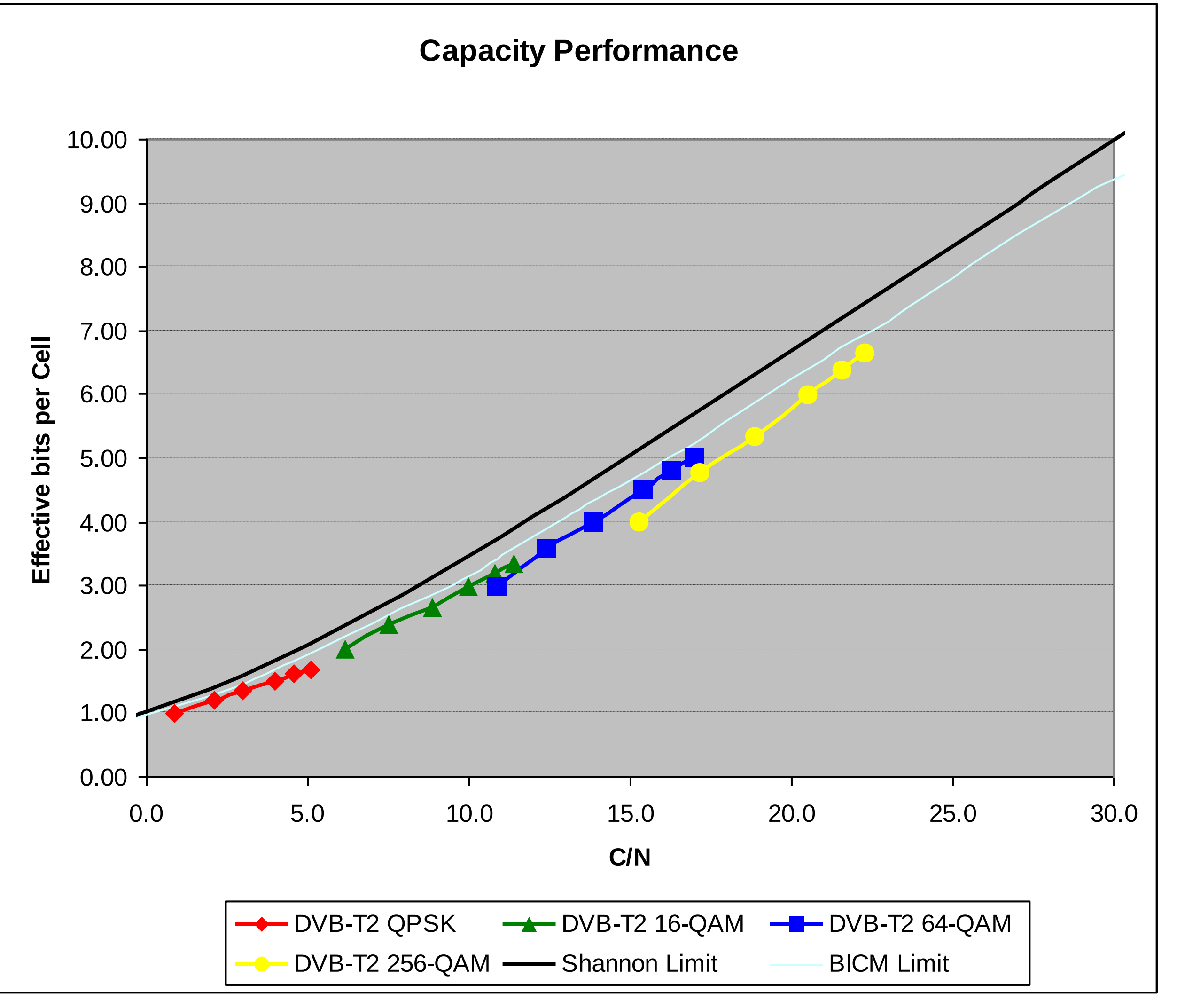
- Transmitter identification
  - A low-level signal (-40dB) can be added to transmitted signal to identify transmitter
    - Provides capability for professional receiver to identify faults within SFN
  - Not yet defined

Remaining Technical Issue

- S2 rate 3/5 LDPC
  - It is apparently 'well known' that the performance of this particular code is not optimum
    - In terms of performance and receiver/memory complexity
  - Worthwhile improvements can be made by modifying the code
    - ~ 0.5dB
  - Options
    - Supplement FEC code set with alternative 3/5 code
    - Swap 3/5 code
    - Carefully optimise mapping of bits to constellations for this particular S2 code rate
      - i.e. include additional constellation 'mappers' for this code
  - Decision process
    - Technical comparisons in progress
    - Decision to be taken by March 27th
      - Then, inclusive text currently in specification will be removed

Modulation and Coding performance

- Capacity limits for simple Gaussian noise channel
  - With LDPC can get close to theoretical limit
- Typically 30% gain in capacity compared with DVB-T codes.

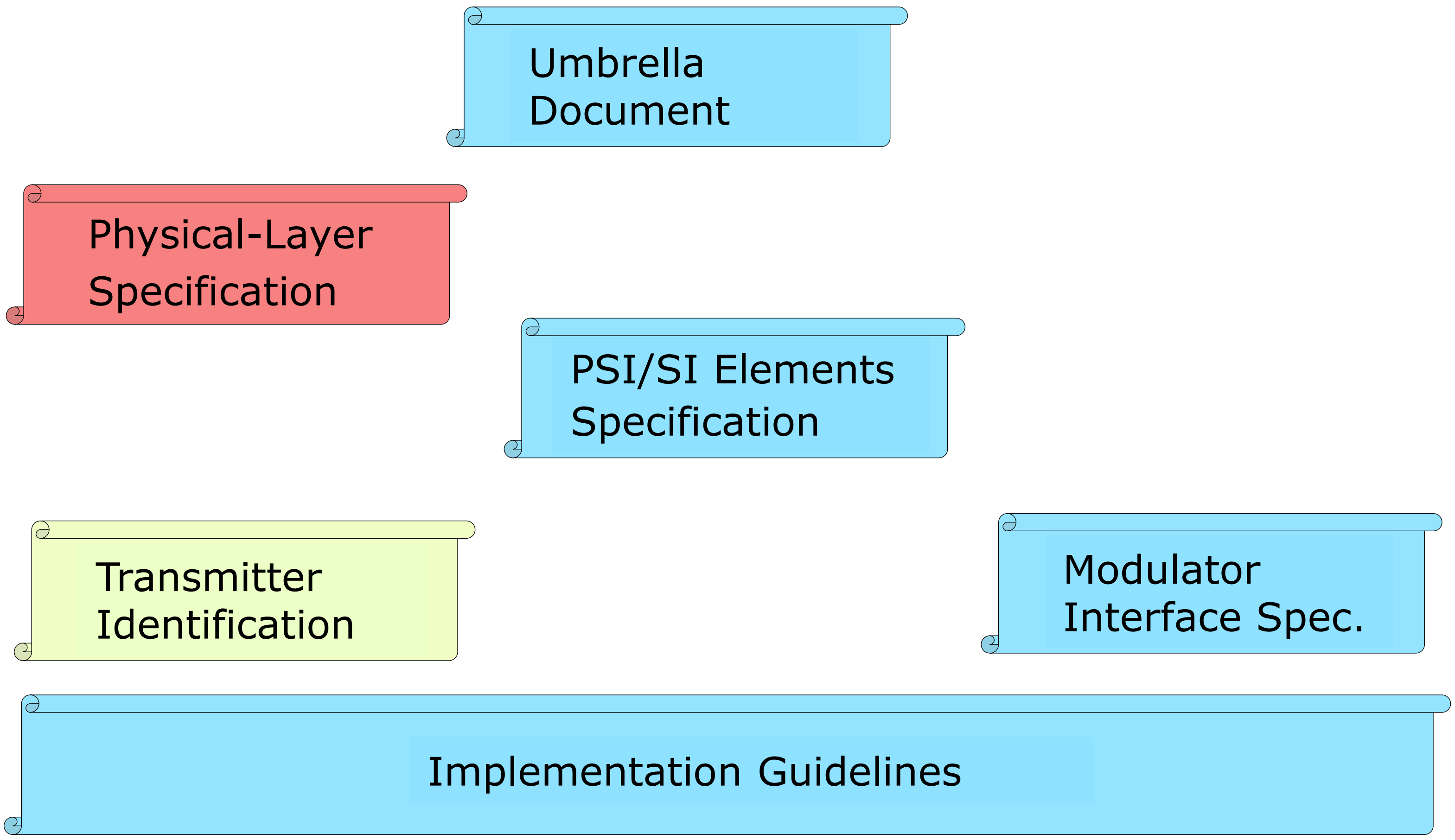


UK Capacity estimate (unverified)

	Current UK mode	T2
Modulation	64QAM	256QAM
FFT size	2K	32K
Guard Interval	1/32	1/128
FEC	2/3 CC + RS (8%)	3/5LDPC + BCH (0.3%)
Scattered Pilots	8%	1%
Continual Pilots	2.6%	0.35%
P1/P2 overhead	0%	0.7%
Bandwidth	Standard	Extended
Capacity	24 Mbit/s	35.4Mbit/s

Capacity = DVB-T + 47%

Specification Documentation



Status of Specification

- Physical Layer specification has been drafted and reviewed for release to this March TM meeting
  - One minor technical issue still to be resolved by March 27
- Some polishing and ETSI-fication of physical layer specification still required
  - But specification is complete and stable
    - No further technical enhancements will be made
  - VLSI design can be started with confidence in stability of spec.
- PSI/SI specification document
  - Draft agreed with GBS
- Other documents not yet started
  - Umbrella document
  - Modulator interface
  - Transmitter Identification
  - Implementation Guidelines

Summary of Techniques (1)

- S2 LDPC (Rates: ½, 3/5, 2/3, ¾, 4/5, 5/6)
- Compatible S2 system layer (Baseband Frames)
- Classical GI-OFDM
  - FFT sizes: 1K, 2K, 4K, 8K, 16K, 32K
  - GI sizes: 1/128, 1/32, 1/16, 19/256, 1/8, 19/128, ¼
  - Bandwidths 1.7, 5, 6, 7, 8,10 MHz
- 8 Scattered Pilot patterns
- Continual pilots for common phase error rejection and fine frequency control
- Time interleaving at physical layer to improve impulse noise robustness
- Time slicing at physical layer
  - Different PLPs can have different levels of robustness
  - Enables power saving
- Sub-slicing within frame
  - Increases time diversity/interleaving depth without increasing de-interleaver memory

Summary of techniques (2)

- P1 symbol for frame sync. and for rapid T2 signal detection
- P2 symbol carrying frame construction data and PSI/SI information
- Three main levels of interleaving
  - Bit interleaving, Time interleaving and Freq. interleaving
- Rotated constellations
- MISO capability (Alamouti-based transmit diversity)
- Peak-to-average-power reduction via tone reservation and constellation distortion
- Future Expansion Frames
- Signalling and compatibility with future implementations of Time Frequency Slicing
- Low-level transmitter identification signalling

Conclusion

- Huge amount of work has been done in last 8 months
- T2 Physical Layer Specification completed in time to enable launch of HD services in 2009/2010
- Specification meets requirements set by Commercial Module
- Specification is compatible with future extensions
  - Time Frequency Slicing
  - Future Extension Frames (for future definition)
- 30% improvement in capacity should be easily achieved
  - Up to ~45% might be possible if all techniques verified
- T2 is a new and exciting specification
  - Stemming from excellent and intense international collaboration involving very high-calibre contributions
- How best to now handle Physical Layer Specification ?

Future Work and Meetings

- Future work
  - Polishing of Physical Layer specification
  - Completion of specification for new PSI/SI features
  - Definition of Modulator interface
  - Definition of transmitter identification signal
  - Write Implementation Guidelines
  - Full system simulations

- Future meetings
  - May 13-15 Toronto
  - June 24-25 Helsinki
  - Sept. 2-3
  - Dec. 2-3 Madrid / Seoul (?)