DVB-T2 in relation to the DVB-x2 Family of Standards

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Abstract

DVB-T2 is a second-generation standard for terrestrial broadcasting aimed at broadcasting to fixed and portable receivers. DVB-T2-based HDTV services have started being broadcast in the UK and other countries are planning to start similar services in the near future.

This paper concentrates on the key features of the DVB-T2 system, illustrating how these build on the innovations introduced in the second-generation satellite transmission standard DVB-S2. A second-generation transmission standard, DVB-C2 has also been defined for cable systems and this system is also briefly described.

These three new standards form a distinct 'family of standards' with many features in common.

History

By the mid 1990's, the DVB organisation had defined three principal standards, DVB-S, DVB-T and DVB-C for distribution of TV over satellite, terrestrial and cable channels. Ten years later, the DVB organisation defined its first 'second-generation' DVB-S2 standard [1], in order to take advantage of the greatly improved capabilities of decoder-chip VLSI capabilities. This new satellite standard provided for a 30% increase in transmission capacity compared with DVB-S and was intended primarily for HDTV broadcasting. In DVB-S2, the forward error correction is based on advanced Low Density Parity Check Codes (LDPC) concatenated with BCH codes and these take the available performance close to the Shannon limit.

In 2006, it was widely recognised within DVB that, building on the improvements in DVB-S2, similar improvements might be achievable for terrestrial broadcasting and that such improvements could help the terrestrial platform in Europe migrate towards HDTV. Consequently, DVB launched a technical group to define the next-generation, DVB-T2 standard which was eventually published in June 2008 [2][3].

At the same time, the UK was busy planning for digital switch-over (DSO) which was to be completed by mid 2012. It was decided that, as part of the regional roll-out of DSO, one of the public service multiplexes would be converted to DVB-T2 in order to carry terrestrial HD services. This decision was taken on the understanding that a DVB-T2-based multiplex would be able to deliver at least 30% more capacity than a conventional DVB-T multiplex for the same coverage planning parameters. Additionally, with a timetable determined by the UK regional DSO schedule, the launch date for these new HD services was set to be December 2009.

These UK decisions helped to generate industry interest in the new standard and the short timescales helped to drive the standardisation process forward. More than 40 companies have actively participated in the development of the T2 specification through an intense schedule of meetings, telephone conferences, email exchanges followed by validation and verification exercises to test the interoperability of early implementations.

Towards the end of this process, DVB started the process of defining a second-generation, DVB-C2 modulation scheme for cable systems. This DVB-C2 standard built on many of the advanced techniques and data structures within the DVB-S2 and DVB-T2 standards leading to a coherent, 'family' of 'DVB-x2' second-generation standards. The DVB-C2 standard was published at the end of 2009 [4].

Requirements for DVB-T2

A set of commercial requirements were defined which acted as a framework for the T2 developments. These requirements included:

- T2 transmissions must be able use existing domestic receive antenna installations and must be able to re-use existing transmitter infrastructures. (This requirement ruled out the consideration of MIMO techniques which would involve both new receive and transmit antennas.)
- T2 should primarily target services to fixed and portable receivers
- T2 should provide a minimum of 30% capacity increase over DVB-T working within the same planning constraints and conditions as DVB-T
- T2 should provide for improved single-frequency-network (SFN) performance compared with DVB-T
- T2 should have a mechanism for providing service-specific robustness; i.e. it should be possible to give different levels of robustness to some services compared to others. For example, within a single 8MHz channel, it should be possible to target some services for roof-top reception and target other services for reception on portables.
- T2 should provide for bandwidth and frequency flexibility
- There should be a mechanism defined, if possible, to reduce the peak-to-average-power ratio of the transmitted signal in order to reduce transmission costs.

Technical features within T2

In order to provide a coherent family of standards where possible, T2 adopted two key technologies from DVB-S2. These were:

1) The system-layer architecture of DVB-S2; in particular, the packaging of data into 'Baseband Frames' (see below)
2) The use of the same Low Density Parity Check (LDPC) error-correcting codes as used in S2.

Most decisions in the design of T2 were directed by the requirement to maximise the data carrying capacity. Many options have been included in T2 in order that the overheads of the modulation scheme can be reduced to a minimum based on the requirements imposed by a particular transmission channel. For example, several options have been included for FFT sizes, guard-interval fractions, and pilot carrier modes as described below.

Forward Error Correcting (FEC) schemes and Baseband Frames

As shown in Figure 1, the data to be transmitted is packaged into Baseband Frames with an appropriate header for the frame that carries certain information about the data within the frame. The data is then protected by the DVB-S2 LDPC FEC by appending the LDPC check bits at the end. In order to mop up any residual errors after the LDPC decoding, the data is also protected by an additional short BCH code as shown in Figure 1.

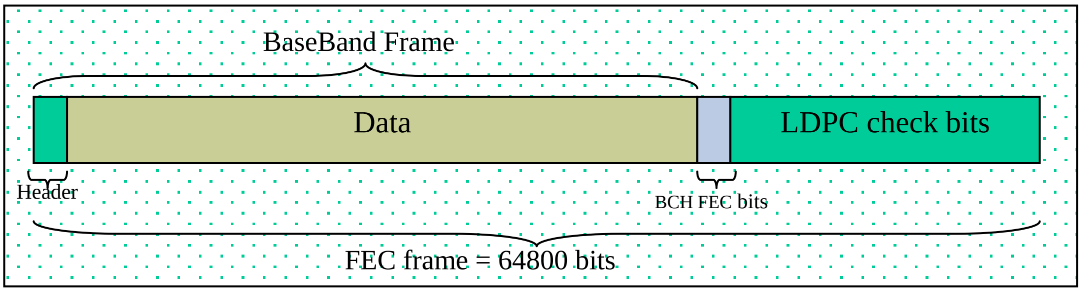

Figure 1 – Baseband Frame Structure

The total length of the FEC frame is 64,800 bits and this FEC frame is a fundamental unit within the T2 system. Within T2, the proportion of the frame that can be assigned to FEC parity bits ranges from around 15% to 50%. A shorter FEC frame of 16200 bits is also provided as an option in order to shorten the possible delay introduced by a T2 transmission system to low-data-rate services.

The data carried within the Baseband Frame will typically be a sequence of MPEG transport stream packets. However, the signalling fields in the Baseband Frame Header are fully compatible with the carriage of native IP packets using a new DVB protocol called ‘Generic Stream Encapsulation’.

The performance of the LDPC error-correcting scheme as used in a T2 system gives a significant improvement in performance compared with the error-correcting scheme used in DVB-T which uses a combination of convolutional coding and Reed-Solomon coding. This improvement can be as much as 3dB in the C/N ratio for a typical residual error rate and for a given FEC overhead, and this improvement can be converted into an approximate increase of capacity of 30% (e.g. by changing to a higher-order constellation mode).

Modulation

During the course of the T2 development, the performances of several variants of multi-carrier and single-carrier modulation schemes were compared. The decision was taken to use conventional guard-interval OFDM in T2 as is currently used in DVB-T.

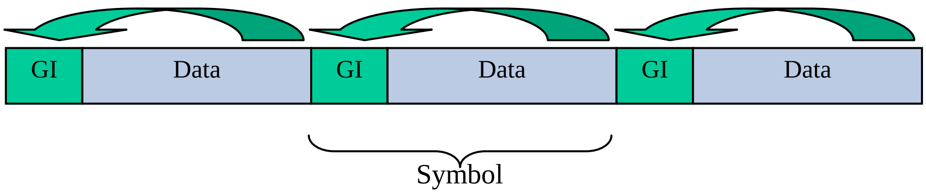

Figure 2 – The use of guard intervals

In GI-OFDM, each symbol consists of a large number of separate carriers with data modulating the amplitude and phase of each carrier. For example, DVB-T has ‘2K’ and ‘8K’ carrier modes. These numbers refer to the FFT size used to produce the multi-carrier signal. The numbers of actual carriers used to carry data are somewhat less than these values. Protection against corruption of the data on each carrier within each symbol, in the presence of multipath components on the transmission channel, is provided by copying the tail-end of each symbol to the beginning of the symbol as shown in Figure 2. The length of guard interval required depends on the transmission path and transmission network. Longer guard intervals are required in single-frequency networks where strong signal components can occur with a significant delay relative to the main signal path. The guard interval represents an overhead which reduces the data carrying capacity of the transmission channel. In DVB-T the maximum size of guard interval is ¼ of the 'data' portion of the signal shown in Figure 2. In order to increase the maximum length of the guard interval without increasing the guard-interval overhead, T2 has introduced 16K and 32K carrier modes. Increasing the number of carriers increases the symbol period in an OFDM system. Figure 3 illustrates simply how the guard-interval overhead can be reduced for a given absolute size of guard interval.

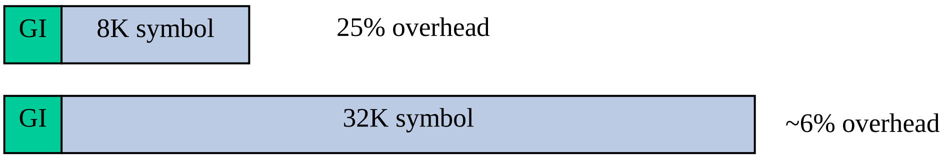

Figure 3 – DVB-T2 uses longer symbols to reduce the overhead associated with the guard interval

In T2, the maximum absolute value of guard interval that can be achieved is in the 32K mode with a fractional guard interval of 19/128. The guard interval then exceeds 500 μs which is sufficient to implement a large national SFN.

T2 offers a range of number-of-carrier modes (FFT sizes) and guard interval options. These are:

- FFT sizes: 1K, 2K, 4K, 8K, 16K, 32K
- Fractional guard intervals: 1/128, 1/32, 1/16, 19/256, 1/8, 19/128, 1/4

As mentioned above, in GI-OFDM the phase and amplitude of each carrier is modulated by data for each symbol period. In DVB-T, the highest modulation mode available is 64 QAM which can carry 6-bits per carrier per symbol (per data cell). In T2, the highest modulation mode is increased to 256 QAM which can carry 8-bits per data cell. Although this larger constellation is more sensitive to errors introduced by noise, the improved performance of the LDPC FEC enables this ~30% increase in data-carrying capacity to be maintained compared to DVB-T under typical conditions.

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For the new 16K and 32K carrier modes in T2, the out-of-band spectrum falls away much more rapidly than for the 2K mode in DVB-T. As shown in Figure 4, this is exploited in T2 by extending the number of data-carrying carriers closer to the normal spectrum mask that is applied to DVB-T signals in 8MHz channels.

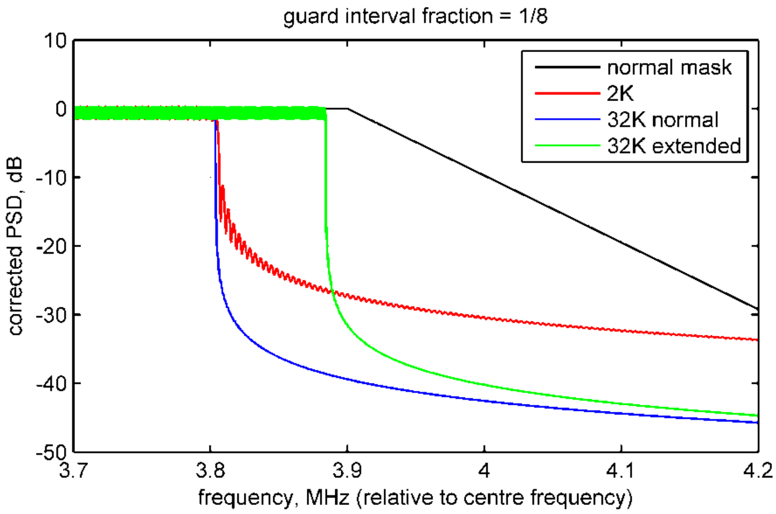

Figure 4 – Theoretical spectrum for DVB-T2 signals
(8 MHz channels)

This extended use of the available bandwidth provides for an extra 2% of data capacity compared with DVB-T.

Scattered Pilot Patterns

In OFDM systems, scattered pilots are OFDM (data) cells of known amplitude and phase that are used by the receiver to compensate/equalise for channel impairments as the channel changes in frequency and in time. In DVB-T, 1 in 12 OFDM cells are scattered pilots - which is an 8% overhead. This scattered pilot pattern is used for all guard-interval options in DVB-T, and so the pattern must be such that the demodulator is able to equalise channels which require a fractional guard interval of 1/4. However, this is a greater density of scattered pilots than is required to permit equalisation of channels which require a smaller fractional guard interval. Consequently, in order to minimise the overhead introduced by scattered pilots, T2 has 8 different scattered pilot pattern options. Each choice of guard interval has a small number of associated pilot patterns which might be selected depending on the time varying nature of the target transmission channel. Two example T2 scattered-pilot patterns are shown in Figure 5.

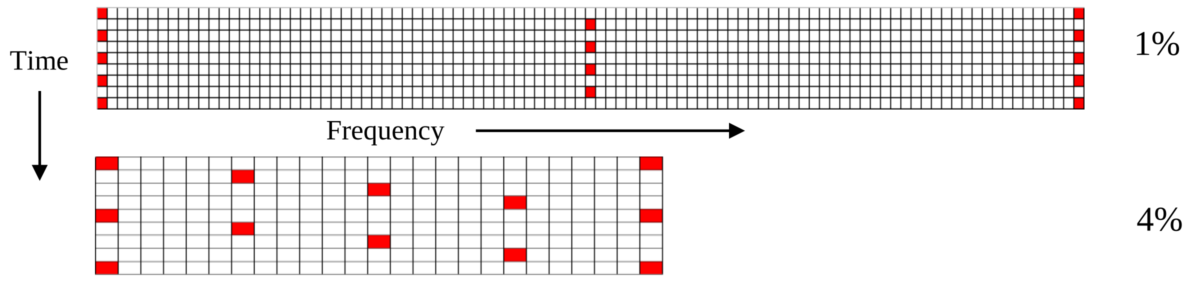

Figure 5 – Typical DVB-T2 scattered pilot patterns and their associated overhead

Service Specific Robustness and T2 frame structure

A commercial requirement for T2 was that it should be possible to apply different levels of robustness, in terms of modulation mode and FEC coding mode, to different services. This is achieved in T2 by grouping OFDM symbols together in frames and then assigning different services to different 'slices' within each frame as illustrated in Figure 6.

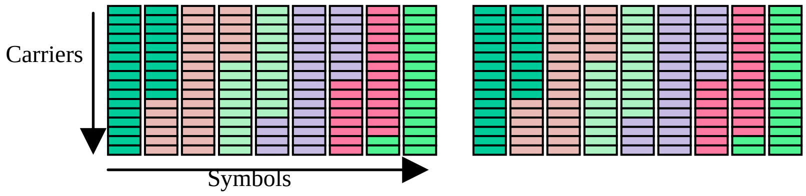

Figure 6 – Illustration of T2 frame structure
different colours indicate different services

The data channels provided by the slices shown above are referred to a 'Physical Layer Pipes' (PLPs). Each PLP has a separate modulation mode, FEC protection and time interleaving.

The start of the T2 frame is signalled by a short OFDM 'P1' symbol which is based on a 1K OFDM symbol with frequency shifted repeats at the front and rear of the symbol as shown in Figure 7. This structure allows easy detection of the P1 symbol whilst preventing any possible data imitation of P1 by any part of the signal within the main T2 frame.

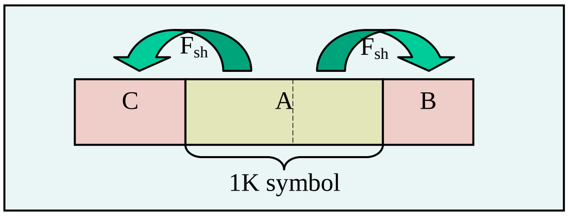

Figure 7 – Simple illustration of DVB-T2's P1 symbol

Only a proportion of the 1K carriers are occupied and these carry one of a set of carefully chosen data patterns to provide some signalling capability. This format of P1 symbol provides a) a simple and robust mechanism for rapid detection of T2 signals when a receiver scans through the appropriate spectrum band, b) a fast frequency lock mechanism for the receiver and 6-bits of signalling (e.g. for the FFT size used for symbols in the T2 frame).

A typical T2 frame duration is around 200 ms and the overhead required to signal the structure of the frame is typically less than 1%. This frame structure information is sent in a robust mode at the beginning of each frame in special 'P2' symbols.

Interleaving

T2 uses four stages of interleaving; 'bit', 'cell', 'time' and frequency interleaving. The target of the interleaving stages is to spread the content in the time/frequency plane in such a way that neither impulsive noise (disturbance of the OFDM signal over a short time period) nor frequency-selective fading (disturbance over a limited frequency span) would erase long sequences of the original data stream. Furthermore, the interleaving is matched to the behaviour of the error-control coding, which does not protect all data equally. Lastly, the interleaving is designed such that bits carried by a given transmitted constellation point do not correspond to a sequence of consecutive bits in the original stream.

The most significant step from DVB-T to DVB-T2 is the introduction of time interleaving, typically over 70ms, to provide protection against impulsive noise and short time-selective fading.

Rotated constellations

T2 uses the novel technique of 'rotated constellations'. Rotated constellations offer the potential for a significant improvement in robustness, particularly in the case of the challenging terrestrial channels that the signal must cope with. By rotating the constellation to a carefully chosen angle, each constellation point can have a unique mapping onto each axis, known as u_1 and u_2, as shown in Figure 8.

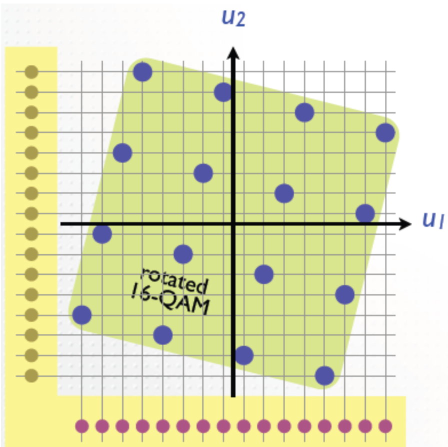

Fig. 8 – A rotated 16-QAM constellation

The data from each of the two axes u_1 and u_2 are separated in the modulator, and arranged to travel independently through the OFDM signal combined with u_2 and u_1 data from a different data cell (i.e. the values of the constellation points on each of u_1 and u_2 travel on different OFDM carriers and in different OFDM symbols). At the receiver, the u_1 and u_2 data are recombined to give the original rotated constellation. In this way, if one carrier or symbol is lost due to interference, some information is still available from the remaining axis value, albeit with a worse signal-to-noise ratio.

Initial simulation results show a significant gain in performance (of more than 5dB) may be achieved in difficult channels through the use of this technique.

Transmit Diversity

Although DVB-T supports Single-Frequency Networks (SFNs), the presence of similar-strength signals from two transmitters in a network causes a significant loss of margin because the resulting channel can have deep "notches".

DVB-T2 incorporates the option of using the Alamouti technique with a pair of transmitters. Alamouti is an example of a Multiple Input, Single Output (MISO) system, in which every constellation point is transmitted by each transmitter, but the second transmitter transmits a slightly modified version of each pair of constellations, and in the reverse order in frequency. The coding, together with a doubling of the pilot pattern, allows the two reception paths to be combined and decoded in an optimal way. Initial planning studies predict that a 30% increase in coverage may be obtained from some simple SFNs through the use of this technique.

Peak to average Power Ratio Reduction

OFDM systems can have a high peak-to-average power ratio and this can reduce the efficiency of the RF power amplifier. T2 includes the use of two techniques which can reduce the PAPR, and allow a reduction in peak amplifier power rating of around 20%. This could result in a significant saving in electricity costs.

The two techniques included in T2 are:

- 'tone reservation', where 1% of the carriers are reserved, and do not carry any data, but may be used instead by the transmitter to insert values which will counteract the peaks in the signal
- 'active constellation extension', where the values of certain of the edge constellation points are moved "outwards" in such a way as to cause a reduction in the signal peaks. Since edge constellation points are only ever moved outwards, this has no significant impact on the receiver's ability to decode the data.

Additional Features

Future Extension Frames

The T2 specification includes two additional features which may provide scope for future expansion. Firstly, the T2-frame structure includes provision for signalling some unused frames which can be used to carry as-yet-undefined signals. The contents of these "Future Extension Frames" (FEF) has not been specified, but by including appropriate signalling within the T2 specification, first generation receivers will know to ignore the FEF parts, which can therefore provide a backwards compatible upgrade path for the inclusion of new technologies in the future.

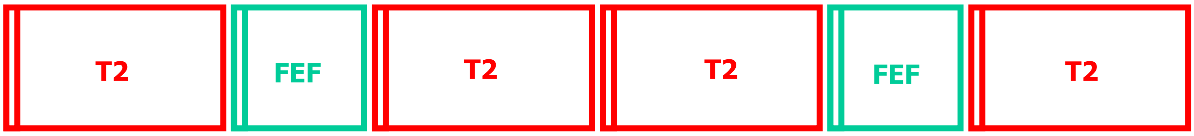

Fig 9 – The insertion of FEF parts in between T2-frames

One application already defined for these FEFs is for transmitter identification in single frequency networks and this is mentioned briefly below.

Time Frequency Slicing

T2 also includes the signalling required for the future implementation of Time Frequency Slicing (TFS). Whilst the basic specification is intended to be received with a single tuner and without the use of TFS, hooks have been included within the signalling to allow a future receiver, using 2 tuners to make use of TFS, which allows a signal to be spread across several (non-adjacent) RF channels. The receiver will hop from channel to channel to pick up the data for its required service. This allows several channels to be effectively combined, which means the size of the total multiplex is much larger than is possible with a single channel, and this in turn can provide a significant statistical multiplexing gain, as well as a frequency planning gain.

System Capacity

The capacity of the T2 system will depend on the exact choices of the many system parameters. These have deliberately been left to be configurable, with the parameter choices signalled within the T2 system. The choice of parameters will reflect the exact performance optimisations required, for example the trade-off between overhead and zapping time, or between capacity and ruggedness.

It will always be difficult to make direct comparisons with other systems, since the balance of parameter choices will be different. For example, in comparing with DVB-T, a T2 configuration providing equivalent Gaussian channel performance may be chosen, although it would be expected that the T2 system would be significantly more robust in difficult terrestrial channels in this case. This would lead to a significant increase in capacity compared with DVB-T. Alternatively, a system with slightly reduced Gaussian performance, but probably still better performance in difficult channels, might give an even greater increase in capacity.

A comparison aiming to achieve equivalent Gaussian performance is presented in Table 1, which shows the increase in capacity to be around 50% when comparing T2 (Option A) with the current UK DVB-T system. The actual mode chosen for use in the UK is slightly less robust but gives a data capacity of 40.1 Mbit/s. Taken together with H264 video compression coding, this capacity can carry 4 or possibly 5 HD services in a statistical multiplex.

	DVB-T (UK mode)	DVB-T2 (Option A)	DVB-T2 (UK mode)
Modulation	64QAM	256QAM	256QAM
FFT size	2K	32K	32K
Guard Interval	1/32	1/128	1/128
FEC	2/3 CC + RS (8%)	3/5LDPC + BCH (0.3%)	2/3LDPC + BCH (0.3%)
Scattered Pilots	8%	1%	1%
Continual Pilots	2.6%	0.53%	0.53%
Frame structure overhead	1%	0.53%	0.53%
Bandwidth	Normal	Extended	Extended
Data Capacity	24.1 Mbit/s	36.1 Mbit/s	40.1 Mbit/s

Table 1 – Comparison of DVB-T and DVB-T2 transmission capacity for estimated equivalent Gaussian channel performance and initial UK mode

Since the launch of services in December 2009, more than 50% of the UK population can now receive T2-based HD services and more than 1 million DVB-T2 receivers have been sold.

Modulator Interface Specification

In a single frequency network (SFN) it is essential that an identical signal is broadcast by every transmitter in the network and that the transmission timing is accurately controlled.   The framing of the T2 multiplex is more complicated than that for DVB-T and therefore a new distribution interface has been defined (DVB 'Blue Book' A136 and ETSI standard TS102 733) in which the T2 frames are constructed at a central ‘T2 gateway’ and these frames are then distributed (over IP or ASI) to all modulators/transmitters in the SFN.

Transmitter Identification

It would be very helpful to a network operator if standard mechanisms were available to test the correct operation of transmissions within an SFN where all transmitters are transmitting essentially the same data. A consequence of this is that it is not easy to distinguish and identify the contributions made by the various transmitters and to test that each transmitter is operating according to coverage planning predictions. Two techniques have been standardised (DVB ‘Blue Book’ A150 and ETSI TS 102 992) that would enable a professional receiver to identify the contributions from individual transmitters and to check the correct operation of the network. The first technique, unique pilot information is added to some auxiliary cells in the final symbol(s) of a frame. The second technique uses periodic Future Extension Frames to carry Generalised Orthogonal data sequences that are unique to a given transmitter and can be used to identify received power, relative timing and relative frequency of any particular transmitter.

Further developments based around T2

Work within DVB has started on defining a next-generation standard (currently referred to as DVB-NGH) for broadcasting to handheld / mobile devices. One of the options for NGH is to extend the DVB-T2 system with additional options/techniques to improve reception in the more difficult mobile reception conditions. Additional techniques include, for example, adding MIMO options to increase coverage or capacity.

DVB-C2

In 2007, work started looking at a second-generation DVB-C2 standard in order to increase the capabilities of cable systems in terms of capacity and flexibility. The standard was formally developed during 2008 and 2009. One of the goals of the development was to build, where possible and appropriate, on the successful features of the DVB-S2 and DVB-T2 standards.

Given that cable systems have traditionally used single-carrier QAM modulation, the rather surprising decision was made to base DVB-C2 on the use of COFDM. The use of COFDM was chosen for the following reasons:

- Flexible channel bandwidth: 6 MHz up to 64 MHz
- Easy implementation of narrowband or broadband notches
- Signal level adjustments of sub-bands easily possible
- Easier handling of cable-specific interference configurations
- Insensitivity regarding echoes up to a certain echo delay

Other features of C2 that are in line with DVB-S2 and/or DVB-T2 are:

- Support for Transport stream and Generic Stream Encapsulated (IP) streams
- LDPC + BCH FEC encoding with 64800 / 16200 length FEC frames
- A Systems Layer based on the use of Physical Layer Pipes and Baseband Frames

Several COFDM features were tailored for cable systems, namely:

- 4K FFT – based reception with the number of active carriers adapted for 8MHz or 6MHz systems

- 1024-QAM and 4096-QAM constellation options
- Two options for Guard Interval (1/64 and 1/128)
- Two different scattered pilot options and a new continual pilot pattern
- Fixed frame length of 448 symbols

New features in DVB-C2 include

- The concept that a receiver has a 'Receiving Window' (e.g. of 8 MHz) that can slide anywhere across the bandwidth of a transmitted C2 signal (e.g. of 24MHz bandwidth). Multiple PLPs are multiplexed into a 'Data Slice' where a Data Slice occupies only a fixed fraction of a decoder receiving window.
- A new frame-start symbol ('Preamble'), which contains a Header and frame structure signalling.

The theoretical performance of the C2 system options in comparison with the DVB-C system is shown in Fig. 10

Figure

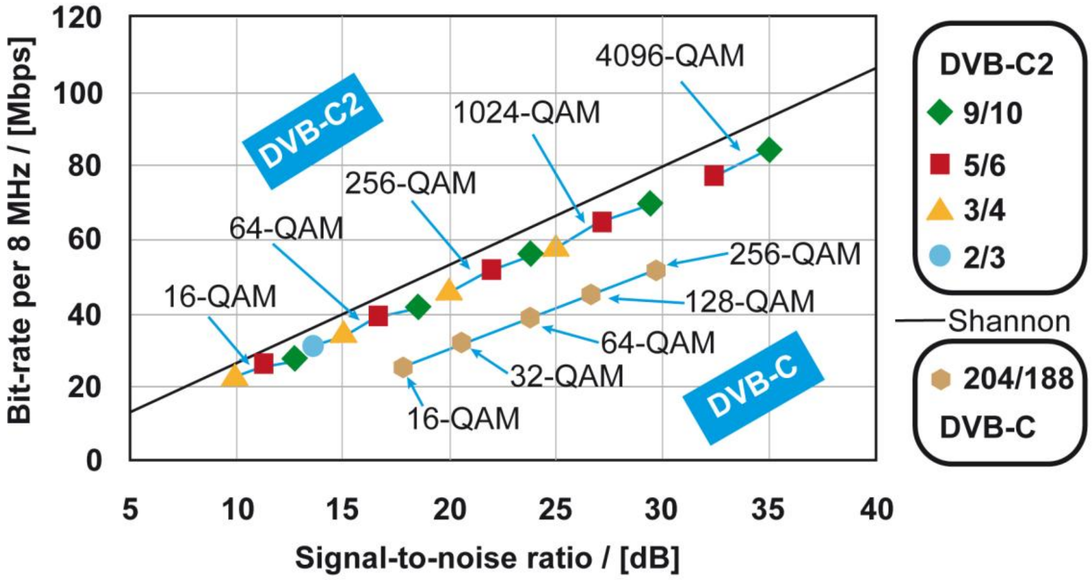

Figure 10: Performance of DVB-C2 in comparison with DVB-C for different FEC code rates and constellations.

Taking into account the gain of the broader channels (5%), the gain of 4096-QAM in relation to 1024-QAM (20%) and the gain due to the better FEC scheme (30%) the maximum total capacity gain for DVB-C2 is more than 60% above that of DVB-C.

Summary

The outline of DVB-T2, a second-generation terrestrial broadcasting system, has been described. DVB-T2 builds not only on the DVB-T standard but also on the second-generation DVB-S2 system whose fundamental technologies had already shown a significant capacity gain. In addition, DVB-T2 has several new features which specifically target the demands of the terrestrial transmission environment, and the range of basic parameters has been extended to allow much of the overhead from the transmission system to be eliminated. Taken together the result provides a very significant increase in capacity compared with first-generation systems, whilst simultaneously improving the ruggedness of the transmission system. These features make it an ideal system for the terrestrial broadcasting of High Definition Television.

DVB-T2 based HD services have now been broadcast in the UK for just over one year with more than 50% of the population covered to date with full coverage to be achieved by mid 2012.

The family of DVB second-generation standards has been extended in the new DVB-C2 specification which builds very much on the innovations within DVB-S2 and DVB-T2.

Innovation continues within DVB on a second-generation standard for broadcasting to mobiles and handheld devices. One of the options for this standard builds on framework set out in DVB-T2.

References

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[3] DVB-T2 Implementation Guidelines for a second generation digital terrestrial television broadcasting system (DVB-T2)’.
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