RECOMMENDATION ITU-R BT.1306-1

Error-correction, data framing, modulation and emission methods for digital terrestrial television broadcasting

(Question ITU-R 121/11)

(1997-2000)

The ITU Radiocommunication Assembly,

considering

a) that digital terrestrial television broadcasting (DTTB) are being introduced in the VHF/UHF bands by some administrations from 1997;

b) that DTTB should fit into existing 6, 7, 8 MHz channels intended for analogue television transmission;

c) that it may be desirable to support the simultaneous transmission of a hierarchy of nested quality levels (including high definition television (HDTV), extended definition TV (EDTV)) and standard definition TV (SDTV) within a single channel;

d) that it may be necessary for DTTB services to coexist with existing analogue television transmissions for a temporary period;

e) that many types of interference, including co-channel and adjacent channel, ignition noise, multipath and other signal distortions exist in the VHF/UHF bands;

f) that commonalities with alternative media, such as cable and satellite, could be advantageous at the level of outer coding scheme;

g) that it is necessary that the frame synchronization be capable of robustness in channels subject to transmission errors;

h) that it is desirable that the frame structure be adapted to different bit rate channels;

j) that both single carrier and multi-carrier modulation methods may be introduced;

k) that it is desirable that there be maximum commonality of characteristics between systems;

l) that it is desirable that there be maximum commonality between digital terrestrial television transmissions that are required to coexist with existing analogue television transmissions and those that are not;

m) that with the rapid evolution of digital technologies, digital terrestrial TV systems proposed at different times, open new attractive possibilities and services;

n) that the selection of modulation option needs to be based on specific conditions such as spectrum resource, policy, coverage requirements, existing network structure, reception conditions, type of service required, cost to the consumer and broadcasters, *recommends*

1 that administrations wishing to introduce DTTB should use one of the families of error correction, framing, modulation and emission methods outlined in Annex 1.

ANNEX 1

Table 1a) provides data for single carrier systems, Table 1b) provides data about multi-carrier systems, and Table 1c) provides data about multi-carrier systems with RF band segmentation. Specifications for Systems A, B, and C are found in Appendices 1, 2, and 3.

Selection guidelines for Systems A, B, and C are described in Appendix 4.

TABLE 1

Parameters for DTTB transmission systems

a) Single carrier systems

	Parameters	**6 MHz**	**7 MHz***	**8 MHz***
1	Used bandwidth	5.38 MHz (–3 dB)	6.00 MHz (–3 dB)	7.00 MHz (–3 dB)
2	Number of radiated carriers	1	1	1
3	Modulation method	8-VSB	8-VSB	8-VSB
4	Spectrum shaping function	Root raised cosine roll-off $R = 5.8\%$	Root raised cosine roll-off $R = 8.3\%$	Root raised cosine roll-off $R = 7.1\%$
5	Channel occupancy	See Rec. ITU-R BT.1206	–	–
6	Active symbol duration	92.9 ns	83.3 ns	71.4 ns
7	Overall symbol or segment duration	77.3 μs (segment)	69.3 μs (segment)	59.4 μs (segment)
8	Transmission frame duration	48.4 ms	43.4 ms	37.2 ms
9	Channel equalization			
10	Inner interleaving	12 (independently encoded streams interleaved in time)	24 (independently encoded streams interleaved in time)	28 (independently encoded streams interleaved in time)

TABLE 1 *(continued)*

a) Single carrier systems *(end)*

	Parameters	6 MHz	7 MHz*	8 MHz*
11	Outer channel Reed-Solomon (RS) code	RS (207,187, T = 10)	RS (207,187, T = 10)	RS (207,187, T = 10)
12	Outer interleaving	52 segment convolutional byte interleaved	52 segment convolutional byte interleaved	52 segment convolutional byte interleaved
13	Data randomization/ Energy dispersal	16 bit PRBS	16 bit PRBS	16 bit PRBS
14	Time/frequency synchronization	Segment sync, pilot carrier	Segment sync, pilot carrier	Segment sync, pilot carrier
15	Frame synchronization	Frame sync	Frame sync	Frame sync
16	Data equalization	Frame sync, PN.511 and 3 × PN.63	Frame sync, PN.511 and 3 × PN.63	Frame sync, PN.511 and 3 × PN.63
17	Transmission mode identification	Mode symbols in frame sync	Mode symbols in frame sync	Mode symbols in frame sync
18	Net data rate	19.39 Mbit/s	21.62 Mbit/s	27.48 Mbit/s
19	Carrier-to-noise ratio in an additive white Gaussian noise (AWGN) channel	15.19 dB(1)	15.19 dB	15.19 dB

b) Multi-carrier systems

	Parameters	6 MHz multi-carrier* (OFDM)	7 MHz multi-carrier (OFDM)	8 MHz multi-carrier (OFDM)
1	Used bandwidth	5.64 MHz	6.66 MHz	7.61 MHz
2	Number of radiated carriers	1 705 (2k mode)(2) 6 817 (8k mode)	1 705 (2k mode)(2) 6 817 (8k mode)	1 705 (2k mode)(2) 6 817 (8k mode)
3	Modulation method	QPSK, 16-QAM, 64-QAM, MR-16-QAM, MR-64-QAM(3)	QPSK, 16-QAM, 64-QAM, MR-16-QAM, MR-64-QAM(3)	QPSK, 16-QAM, 64-QAM, MR-16-QAM, MR-64-QAM(3)
4	Channel occupancy		See Rec. ITU-R BT.1206	See Rec. ITU-R BT.1206

TABLE 1 *(continued)*

b) Multi-carrier systems *(continued)*

	Parameters	6 MHz multi-carrier* (OFDM)	7 MHz multi-carrier (OFDM)	8 MHz multi-carrier (OFDM)
5	Active symbol duration	301.889 µs (2k mode) 1 207.556 µs (8k mode)	256 µs (2k mode) 1 024 µs (8k mode)	224 µs (2k mode) 896 µs (8k mode)
6	Carrier spacing	3 312.477 Hz (2k mode) 828.119 Hz (8k mode)	3 906 Hz (2k mode) 976 Hz (8k mode)	4 464 Hz (2k mode) 1 116 Hz (8k mode)
7	Guard interval duration	1/4, 1/8, 1/16, 1/32 of active symbol duration 9.43, 18.87, 37.74, 75.47 µs (2k mode) 37.74, 75.47, 150.94, 301.89 µs (8k mode)	1/4, 1/8, 1/16, 1/32 of active symbol duration 8, 16, 32, 64 µs (2k mode) 32, 64, 128, 256 µs (8k mode)	1/4, 1/8, 1/16, 1/32 of active symbol duration 7, 14, 28, 56 µs (2k mode) 28, 56, 112, 224 µs (8k mode)
8	Overall symbol duration	311.32, 320.76, 339.63, 377.36 µs (2k mode) 1 245.29, 1 283.03, 1 358.50, 1 509.45 µs (8k mode)	264, 272, 288, 320 µs (2k mode) 1 048, 1 088, 1 152, 1 280 µs (8k mode)	231, 238, 252, 280 µs (2k mode) 924, 952, 1 008, 1 120 µs (8k mode)
9	Transmission frame duration	68 OFDM symbols. One super frame consists of 4 frames	68 OFDM symbols. One super-frame consists of 4 frames	68 OFDM symbols. One super-frame consists of 4 frames
10	Inner channel code	Convolutional code, mother rate 1/2 with 64 states. Puncturing to rate 2/3, 3/4, 5/6, 7/8	Convolutional code, mother rate 1/2 with 64 states. Puncturing to rate 2/3, 3/4, 5/6, 7/8	Convolutional code, mother rate 1/2 with 64 states. Puncturing to rate 2/3, 3/4, 5/6, 7/8
11	Inner interleaving	Bit interleaving, depth 126, combined with symbol interleaving (frequency interleaving)	Bit interleaving, depth 126, combined with symbol interleaving (frequency interleaving)	Bit interleaving, depth 126, combined with symbol interleaving (frequency interleaving)
12	Outer channel Reed-Solomon (RS) code	RS(204,188, $T = 8$)	RS(204,188, $T = 8$)	RS(204,188, $T = 8$)
13	Outer interleaving	Bytewise convolutional interleaving, $I = 12$	Bytewise convolutional interleaving, $I = 12$	Bytewise convolutional interleaving, $I = 12$
14	Data randomization/ energy dispersal	PRBS	PRBS	PRBS
15	Time/frequency synchronization	Pilot carriers[(4)]	Pilot carriers[(4)]	Pilot carriers[(4)]

TABLE 1 *(continued)*

b) Multi-carrier systems *(end)*

	Parameters	6 MHz multi-carrier* (OFDM)	7 MHz multi-carrier (OFDM)	8 MHz multi-carrier (OFDM)
16	Transmission parameter signalling (TPS)(5)	Carried by TPS pilot carriers	Carried by TPS pilot carriers	Carried by TPS pilot carriers
17	Net data rate	Depending on modulation, code rate and guard interval (3.69-23.5 Mbit/s for non-hierarchical modes)(6)	Depending on modulation, code rate and guard interval (4.35-27.71 Mbit/s for non-hierarchical modes)(6)	Depending on modulation, code rate and guard interval (4.98-31.67 Mbit/s for non-hierarchical modes)(6)
18	Carrier-to-noise ratio in an AWGN channel	Depending on modulation and channel code. 3.1-20.1 dB(7)	Depending on modulation and channel code. 3.1-20.1 dB(7)	Depending on modulation and channel code. 3.1-20.1 dB(7)

c) Multi-carrier systems with radio-frequency band segmentation(8)

	Parameters	6 MHz multi-carrier (segmented OFDM)	7 MHz multi-carrier* (segmented OFDM)	8 MHz multi-carrier (segmented OFDM)
1	Numbers of segments (Ns)	13(9)	13(9)	13(9)
2	Segment bandwidth (Bws)	6 000/14 = 428.57 kHz	7 000/14 = 500 kHz	8 000/14 = 571.428 kHz
3	Used bandwidth (Bw)	Bw × Ns + Cs 5.575 MHz (Mode 1) 5.573 MHz (Mode 2) 5.572 MHz (Mode 3)	Bw × Ns + Cs 6.504 MHz (Mode 1) 6.502 MHz (Mode 2) 6.501 MHz (Mode 3)	Bw × Ns + Cs 7.434 MHz (Mode 1) 7.431 MHz (Mode 2) 7.430 MHz (Mode 3)
4	Number of radiated carriers	1 405 (Mode 1) 2 809 (Mode 2) 5 617 (Mode 3)	1 405 (Mode 1) 2 809 (Mode 2) 5 617 (Mode 3)	1 405 (Mode 1) 2 809 (Mode 2) 5 617 (Mode 3)
5	Modulation method	DQPSK, QPSK, 16-QAM, 64-QAM	DQPSK, QPSK, 16-QAM, 64-QAM	DQPSK, QPSK, 16-QAM, 64-QAM
6	Channel occupancy		See Rec. ITU-R BT.1206	See Rec. ITU-R BT.1206
7	Active symbol duration	252 μs (Mode 1) 502 μs (Mode 2) 1 008 μs (Mode 3)	216 μs (Mode 1) 432 μs (Mode 2) 864 μs (Mode 3)	189 μs (Mode 1) 378 μs (Mode 2) 756 μs (Mode 3)
8	Carrier spacing (Cs)	Bws/108 = 3.968 kHz (Mode 1) Bws/216 = 1.948 kHz (Mode 2) Bws/432 = 0.992 kHz (Mode 3)	Bws/108 = 4.629 kHz (Mode 1) Bws/216 = 2.361 kHz (Mode 2) Bws/432 = 1.157 kHz (Mode 3)	Bws/108 = 5.271 kHz (Mode 1) Bws/216 = 2.645 kHz (Mode 2) Bws/432 = 1.322 kHz (Mode 3)

TABLE 1 *(continued)*

c) Multi-carrier systems with radio-frequency band segmentation(8) *(continued)*

	Parameters	6 MHz multi-carrier (segmented OFDM)	7 MHz multi-carrier* (segmented OFDM)	8 MHz multi-carrier (segmented OFDM)
9	Guard interval duration	1/4, 1/8, 1/16, 1/32 of active symbol duration 63, 31.5, 15.75, 7.875 μs (Mode 1) 126, 63, 31.5, 15.75 μs (Mode 2) 252, 126, 63, 31.5 μs (Mode 3)	1/4, 1/8, 1/16, 1/32 of active symbol duration 54, 27, 13.5, 6.75 μs (Mode 1) 108, 54, 27, 13.5 μs (Mode 2) 216, 108, 54, 27 μs (Mode 3)	1/4, 1/8, 1/16, 1/32 of active symbol duration 47.25, 23.625, 11.8125, 5.90625 μs (Mode 1) 94.5, 47.25, 23.625, 11.8125 μs (Mode 2) 189, 94.5, 47.25, 23.625 μs (Mode 3)
10	Overall symbol duration	315, 283.5, 267.75, 259.875 μs (Mode 1) 628, 565, 533.5, 517.75 μs (Mode 2) 1 260, 1 134, 1 071, 1 039.5 μs (Mode 3)	270, 243, 229.5, 222.75 μs (Mode 1) 540, 486, 459, 445.5 μs (Mode 2) 1 080, 972, 918, 891 μs (Mode 3)	237.25, 212.625, 200.8125, 194.90625 μs (Mode 1) 472.5, 425.25, 401.625, 389.8125 μs (Mode 2) 945, 850.5, 803.25, 779.625 μs (Mode 3)
11	Transmission frame duration	204 OFDM symbols	204 OFDM symbols	204 OFDM symbols
12	Inner channel code	Convolutional code, mother rate 1/2 with 64 states. Puncturing to rate 2/3, 3/4, 5/6, 7/8	Convolutional code, mother rate 1/2 with 64 states. Puncturing to rate 2/3, 3/4, 5/6, 7/8	Convolutional code, mother rate 1/2 with 64 states. Puncturing to rate 2/3, 3/4, 5/6, 7/8
13	Inner interleaving	Intra and inter segments interleaving (frequency interleaving). Symbolwise convolutional interleaving 0, 380, 760, 1 520 symbols (time interleaving)	Intra and inter segments interleaving (frequency interleaving). Symbolwise convolutional interleaving 0, 190, 380, 760, symbols (time interleaving)	Intra and inter segments interleaving (frequency interleaving). Symbolwise convolutional interleaving 0, 95, 190, 380, symbols (time interleaving)
14	Outer channel code	RS (204,188, $T = 8$)	RS (204,188, $T = 8$)	RS (204,188, $T = 8$)
15	Outer interleaving	Bytewise convolutional interleaving, $I = 12$	Bytewise convolutional interleaving, $I = 12$	Bytewise convolutional interleaving, $I = 12$
16	Data randomization/ energy dispersal	PRBS	PRBS	PRBS
17	Time/frequency synchronization	Pilot carriers	Pilot carriers	Pilot carriers

TABLE 1 *(end)*

c) Multi-carrier systems with radio-frequency band segmentation(8) *(end)*

	Parameters	6 MHz multi-carrier (segmented OFDM)	7 MHz multi-carrier* (segmented OFDM)	8 MHz multi-carrier (segmented OFDM)
18	Transmission and multiplexing configuration	Carried by TMCC pilot carriers	Carried by TMCC pilot carriers	Carried by TMCC pilot carriers
19	Net data rate	Depending on number of segments, modulation, code rate, hierarchical structure and guard interval 3.65-23.2 Mbit/s per one segment	Depending on number of segments, modulation, code rate, hierarchical structure and guard interval 4.26-27.1 Mbit/s per one segment	Depending on number of segments, modulation, code rate, hierarchical structure and guard interval 4.87-31.0 Mbit/s per one segment
20	Carrier-to-noise ratio in an AWGN channel	Depending on modulation and channel code 5.0-23 dB(10)		Depending on modulation and channel code 5.0-23 dB(10)

* Provisional value

OFDM: orthogonal frequency division multiplex

PRBS: pseudo-random binary sequence

TMCC: transmission and multiplexing configuration control

VSB: vestigial side band

(1) Measured value. After RS decoding, error rate 3×10^{-6}.

(2) The 2k mode can be used for single transmitter operation, for single frequency gap-fillers and for small single frequency network. The 8k mode can be used for the same network structures and also for large single frequency network.

(3) 16-QAM, 64-QAM, MR-16-QAM and MR-64-QAM (MR-QAM: non-uniform QAM constellations), may be used for hierarchical transmission schemes. In this case two layers of modulation carry two different MPEG-2 transport streams. The two layers may have different code rates and can be decoded independently.

(4) Pilot carriers are continual pilots, carried by 45 (2k mode) or 177 (8k mode) carriers on all OFDM symbols, and scattered pilots, spread in time and frequency.

(5) TPS pilots carry information on modulation, code rate and other transmission parameters.

(6) The choice of modulation, code rate and guard interval depends on service requirements and planning environment.

(7) Simulated with perfect channel estimation, non-hierarchical modes. Error rate before RS decoding 2×10^{-4}, error rate after RS decoding 1×10^{-11}.

(8) Radio-frequency band segmentation allows use of appropriate modulation and error correction scheme segment by segment, and reception of a centre segment with narrow-band receivers.

(9) Multi-carrier systems with radio-frequency band segmentation uses 13 segments for television services while any number of segments may be used for other services such as sound services.

(10) Measured with prototype receivers. Error rate before RS decoding 2×10^{-4}, error rate after RS decoding 1×10^{-11}.

APPENDIX 1

TO ANNEX 1

System A Standard

BIBLIOGRAPHY

ATSC [September, 1995] Standard A/53. Digital television standard. Advanced Television Systems Committee.

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APPENDIX 2

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System B Standard

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APPENDIX 3

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System C Standard

BIBLIOGRAPHY

ARIB [May, 1999] ARIB B-10. Service information for digital broadcasting system. Association of Radio Industries and Businesses.

TTC [May, 1999] Digital terrestrial television broadcasting standard. Telecommunication Technical Council.

APPENDIX 4

TO ANNEX 1

System selection guideline

The process of selecting a suitable system may be thought of as an iterative one involving three phases:

– Phase I: an initial assessment of which system is most likely to meet the broadcaster’s main requirements taking into account the prevailing technical/regulatory environment.

– Phase II: a more detailed assessment of the “weighted” differences in performance.

– Phase III: an overall assessment of the commercial and operational factor impacting the system choice.

Given below is a fuller description of these three phases.

Phase I: Initial assessment

As a starting point, Table 2 may be used to assess which of the systems would best meet a particular broadcasting requirement.

TABLE 2

Guideline for the initial selection

Requirements		**Suitable systems**
Maximum data rate in a Gaussian channel for a given *C*/*N* threshold	Required	A
	Not required	A, B or C
Maximum ruggedness against multipath interference(1)	Required	B or C
	Not required	A, B or C
Single frequency networks (SFNs)	Required	B or C
	Not required	A, B or C
Mobile reception(1), (2)	Required	B or C
	Not required	A, B or C
Simultaneous transmission of different quality levels (hierarchical transmission)	Of primary importance	C
	Required	B or C
	Not required	A, B or C
Independent decoding of data sub-blocks (for example, to facilitate sound broadcasting)	Required	C
	Not required	A, B or C
Maximum coverage from central transmitter at a given power in a Gaussian environment(3)	Required	A
	Not required	A, B or C
Maximum ruggedness against impulse interference	Required(4)	A
	Not required(5)	A, B, or C

(1) Tradable against bandwidth efficiency and other system parameters.

(2) It may not be possible to provide HDTV reception in this mode.

(3) For all systems in situations with coverage holes, gap filler transmitters will be required.

(4) This comparison applies to B and C in the 2K mode.

(5) First results from Australia, testing the 8K mode, show significant improvements over the 2K mode and suggest the performance of System B and C in the 8K mode may be comparable to that of System A. However, further comparative tests of Systems A, B and C are required to verify relative performance.

Phase II: Assessment of the weighted differences in performance

After an initial assessment has been made on the basis of Table 2, a more thorough selection process will require comparative evaluation of the performance of the candidate systems. This is the case because the choice of selection parameters itself is not a simple "black or white" selection. In any given situation, any particular criterion will be of greater or lesser significance in the broadcasting environment under study which means that there has to be a means to identify a balance between small differences in performance and more important or less important selection parameters. In other words, it is clear that a small difference between systems against a critical parameter is likely to influence the choice more than large differences against relatively less important selection criteria.

The following methodology is recommended for this phase of system assessment:

Step 1 requires the identification of performance parameters that are relevant to the circumstances of the administration or broadcaster wishing to choose a DTTB system. These parameters might include the inherent performance capabilities of the digital system in itself, its compatibility with existing analogue services and the need for interoperability with other image communications or broadcasting services.

Step 2 requires the assignment of "weights" to the parameters in order of importance or criticality to the environment in which the digital TV service is to be introduced. This weighting might be a simple multiplier such as 1 for "normal" and 2 for "important".

Step 3 involves the accumulation of test data from (preferably both) laboratory and field trials. This data can be gathered direct by the parties involved in the evaluation or may be obtained from others who have undertaken trials or evaluations. It is expected that Radiocommunication Study Group 6 (formerly Study Group 11) will, in the near future, prepare a report providing full technical evidence on the different DTTB systems, which may be used where adequate test data is not available from other reliable sources.

Step 4 then requires the matching of test data with performance parameters and the determination of a "rating" against each parameter. The overall rating is used to choose a system that best matches the requirements. A tabular structure that uses a simple numerical rating and weighting scale has been found useful by some administrations. It is taken as a "given" that all candidate systems are able to provide a viable DTTB service. Accordingly, the differences between systems will be relatively small. It is desirable to avoid unnecessary exaggeration of the differences but, at the same time, take care to ensure that the selection process is matched to the needs of the intended service. A simple and compact numerical rating scale can be one way to achieve these goals.

The following scales are examples that might be useful:

Performance	Rating
Satisfactory	1
Better	2
Best	3

In this scale a 0 (or null) value is given for a system that does not provide satisfactory performance against a given parameter or for a parameter that is unable to be evaluated.

Importance	Weighting
Normal	1
Significant	2
Critical	3

The following is an example of a tabular structure that might be used for comparative assessment of various systems.

No.	Criterion	System performance			Weighting	System rating		
		A	B	C		A	B	C
1	Characteristics of transmitted signals							
A	Robustness of signal							
	Immunity of electrical interference							
	Efficiency of transmitted signal							
	Effective coverage							
	Reception using indoor antenna							
	Adjacent channel performance							
	Co-channel performance							
B	Resilience to distortions							
	Resilience to multipath distortions							
	Mobile reception							
	Portable reception							

Phase III: Assessment of commercial and operational aspects

The final phase is an assessment of the commercial and operational aspects to ascertain which of the systems is indeed the best solution overall. Such an assessment will take into account the required timescales to service implementation, cost and availability of equipment, interoperability within an evolving broadcasting environment, etc.

Compatible receiver

In the cases where it is necessary to receive more than one modulation system option, compatible receivers will be needed. The cost of such receivers, taking into account the progress in digital technologies, should not be significantly more than receivers for a single modulation system, but the advantages of such receivers could be important. They may open the door to attractive additional possibilities and services for the consumer and broadcaster as indicated by Table 2. Studies continue on this matter.