Office of the Director of
Telecommunications
Regulation

Selection of Appropriate Guard Interval for Irish Digital Terrestrial Television

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Foreword by the Director

The advent of Digital Terrestrial Television (DTT) means that new technology can be utilised to deliver new services to the public and provide greater choice to viewers. Digital television also allows additional information to be transmitted alongside the television signal so that further services such as home shopping and electronic banking can be facilitated

As Director of Telecommunications Regulation, I am responsible for the efficient use of the spectrum allocated for the purposes of television broadcasting and retransmission. As mentioned above, the advent of digital television makes more efficient use of the available spectrum so that additional programmes can be broadcast.

The technical parameters for the transmission of digital signals include a requirement to specify an appropriate guard interval to ensure that interference is minimised. When using a Single Frequency Network (SFN) configuration, such interference can be caused by signals originating from different transmitters in the SFN arriving at a receiver at different times. Interference can also arise in mountainous areas when a signal is reflected, thereby causing poor reception in such areas. By increasing the size of the guard interval, such interference can be reduced or eliminated. However, there is a corresponding reduction in the capacity available for transmission purposes. This is of considerable importance as it affects the amount of data and, at the extreme, the number of channels each multiplex can carry as well as the quality of the signal.

This needs to be viewed also against the options for broadcast network configurations that are outlined in the paper. I am happy to note that the preferred options would have little effect on DTT capacity.

I have commissioned this study to establish the guard interval required for digital television transmission in the context of the use of twelve main transmitters each supporting a regional single frequency network (on a different frequency to the main transmitter); and having regard to the difficult terrain, notably in Donegal and Kerry, where bare mountainsides may provide strong reflected signals. The work was carried out on behalf of my office by Teltec Ireland and supported by Radio Telefis Eireann.

I look forward to receiving responses to this document. Such responses will help inform our decision on the selection of the appropriate guard interval for use in Ireland.

Etain Doyle
Director of Telecommunications Regulation

Guard Interval Selection for Digital Terrestrial Television

Summary

The selection of the appropriate Guard Interval parameter for Digital Terrestrial Television (DTT) affords resilience against delayed, interference-causing signals in television reception.

Such delayed signals can arise as a result of local radio wave propagation conditions, e.g. multipath effects, where signals arrive at the receive location having been reflected off mountains, hills, etc. They may also be caused by signals originating from different transmitters in a Single Frequency Network (SFN) arriving at a receiver at different times.

A choice of Guard Interval is available, ranging from 1/32 to 1/4 of the duration of the basic digital television transmission symbol (group of data bits transmitted as a unit). For the 8k mode of the Digital Video Broadcasting-Terrestrial (DVB-T) system which is intended to be deployed in Ireland, this choice offers Guard Interval durations of 28µs, 56µs, 112µs and 224µs. This report indicates that no matter which ‘8k mode’ guard interval is used adequate protection from multipath interference due to an individual transmitter will be provided

Assuming the use of 64-QAM code rate 2/3 a guard interval of 1/32 would allow a transmission rate of 24.13 Mbit/s, whereas at the other extreme, a guard interval of 1/4 would allow a transmission rate of 19.91 Mbits/s. The maximum reduction in capacity (17.5%) as between a guard interval of 1/32 and 1/4 would result in the loss of one programme service per multiplex thereby reducing the total number of programme services available to the consumer.

If large area Single Frequency Network operation is adopted, then a Guard Interval setting of 1/8 should be considered. However, compared to the setting of 1/32, this would result in a reduction in capacity of 8.3% for the network leading to some reduction in the interactive/data capacity that could be carried on a multiplex.

Small area localised SFNs could be implemented with the Guard Interval set at 1/16 under certain conditions. The capacity reduction arising from a guard interval setting of 1/16 as opposed to a guard interval setting of 1/32 would amount to approximately 3% which is not considered material.

Where many DTT transmitters use the same frequency, but are not synchronised and as such do not make up a true Single Frequency Network, Guard Interval choice is not relevant. The issue is reduced to relative power levels of desired signal versus interference. In summary, the proposed Guard Interval settings for the possible DVB-T Network implementation configurations for Ireland are as follows;

Broadcast Network Configuration	**Capacity (64QAM rate 2/3) Mbit/s**	**Proposed Guard Interval**
Network with some small area localised SFNs	23.42	1/16
Network with large area SFNs	22.12	1/8

Section 1

Introduction and Background

1 Introduction and Background

1.1 Introduction and Scope

Digital Terrestrial Television (DTT) in Ireland will adopt the DVB-T standard as described in ETSI document EN 300-744 [1]. There are a number of parameters relating to the technical operation of DTT which may be varied according to the exact implementation of the standard. Included in those are:

- Number of carriers used,
- Guard Interval (GI) employed.

In Ireland, the decision has been made to use the ‘8k mode’ of DTT where the transmission data is COFDM (Coded Orthogonal Frequency Division Multiplex) modulated onto 6,817 carrier frequencies spread within the standard UHF television channel 8MHz bandwidth.

For 8k mode, the DTT specification document allows for a Guard Interval choice of 1/32, 1/16, 1/8 or 1/4 times the duration of the basic transmission symbol. This represents permitted Guard Interval durations of 28μs, 56μs, 112μs and 224μs respectively.

It is assumed that DTT services are to be provided by a number of main transmitters each serving distinct geographical regions. In each of those regions, areas of poor coverage will be served by local fill-in lower power DTT transmitters.

Guard Interval specification is examined from two perspectives in this paper:

- an assessment of the implications for Guard Interval choice due to multipath radio propagation effects from individual transmitters. This is of particular concern where the transmitter service area contains mountains and hills.

- the implications for Guard Interval selection when DTT transmitters are used as fill-ins in areas where poor coverage is afforded by the regional main transmitter. Where such fill-in transmitters are synchronised and operate as a Single Frequency Network, there are implications for Guard Interval choice.

In addition, it is noted that the Guard Interval is not a factor in certain network configurations. Where DTT transmitters operate on the same carrier frequencies, but do not operate as a synchronised SFN, Guard Interval is irrelevant. Issues related to such an implementation of DTT are pointed out.

The study assumes that DTT services are to be provided on UHF, Bands IV and V.

Terms of Reference
The terms of reference provided to Teltec Ireland were as follows:

"To provide advice to the ODTR on the appropriate 'Guard Interval' (GI) to be used for Irish Digital Terrestrial TV (DTT), by region. This advice should be based on an assessment of the GI implications of:

- the use of twelve main transmitters each supporting a regional single frequency network (on a different frequency to the main transmitter); and
- the difficult terrain, notably in Donegal and Kerry, where bare mountainsides may provide strong reflected signals.

The advice should be based on an appropriate computer model, verified by field trial data for the most difficult terrain."

Document Structure
The document is structured as follows:

- Section 1 sets out the background to the examination of the appropriate Guard Interval along with a consideration of associated issues. Questions arising from the discussion paper are also suggested in order to focus the discussion**.**

- Section 2 is the report of the consultants, Teltec Ireland, and comprises the report and supporting annexes

1.2 Background

The 1996 Act[1] which established the ODTR provided for the regulation of all transmission platforms by the Director. Responsibility for licences granted for the operation of cable, MMDS and the national television transmission network was transferred to the Director by virtue of the Act. Specifically, the Director is responsible for the efficient use of the radio spectrum.

In August 1997, the Director commissioned a report entitled "The Future Delivery of Television Services in Ireland" (ODTR 98/06) from National Economic Research Associates (NERA) and Smith System Engineering (Smith) in order to provide information on future options for broadcasting transmission. The report focused on the spectrum management and economic issues pertaining to such transmission and particular emphasis was given to Digital Terrestrial Television. It was suggested that the ODTR consider a guard interval of either 1/8 or 1/16 in the context of a Single Frequency Network.

In July1998, the Director published "The Future of TV Transmission in Ireland - The Way Forward"(ODTR 98/20). This paper dealt with the regulatory and licensing

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[1] Telecommunications (Miscellaneous Provisions) Act, 1996

issues associated with the delivery of television services and the introduction of digital services.

1.3 Other Issues

Apart from the technical issues which are covered in detail in Section 11 of this report, there are other factors which impinge on the choice of guard interval for DTT in Ireland. These include consideration of international developments, capacity implications, spectrum efficiency, and the cost of implementing a large area SFN network.

International Developments
The United Kingdom are currently building a ‘2k mode’ DTT Multiple Frequency Network using a guard interval of 1/32, which for ‘2k mode’ is of only 7µs duration. Ireland, in common with Sweden and most other European countries, plans to introduce ‘8k mode’ DTT services. At the shortest 1/32 guard interval, 8k mode services have a guard interval duration of 28µs. “The Future Delivery of Television Services in Ireland” (ODTR 98/06) suggested a guard interval of either 1/8 or 1/16 in the context of a Single Frequency Network.

Regional variations
It is possible that different Guard Intervals could be selected for regions served by different main transmitters on different frequency channels. Such an arrangement would add costs to link network distribution and complicate the multiplex equipment required. Each region would require its own multiplexing equipment which could be housed centrally (in Dublin) or at a local studio or main transmitter site. For such a regional variant the choice of guard interval would be dependent on the transmitter network configuration in the region. If, in the future, local/regional DTT services transmitted from a single site (or closely spaced SFN network) were to be introduced a guard interval of 1/32 might be more appropriate.

Capacity Implications
Assuming the use of 64-QAM code rate 2/3 a guard interval of 1/32 would allow a transmission rate of 24.13 Mbit/s, whereas at the other extreme, a guard interval of 1/4 would allow a transmission rate of 19.91 Mbits/s. The maximum reduction in capacity (17.5%) as between a guard interval of 1/32 and 1/4 would result in the loss of one programme service per multiplex thereby reducing the total number of programme services available to the consumer. The capacity reduction arising from a guard interval setting of 1/8 as opposed to a guard interval setting of 1/32 would be approximately 8.3% and would result in a reduction in the interactive/data capacity that could be carried on a multiplex.
The capacity reduction arising from a guard interval setting of 1/16 as opposed to a guard interval setting of 1/32 would amount to approximately 3% which is not considered material.

Planning in Ireland for DTT is being carried out on the basis of using a 64-QAM code rate 2/3. Other code rates are possible but there is a trade off between the additional capacity arising from a higher code rate and the signal strength required and interference protection required.

Network Configuration and Cost implications

The Coded Orthogonal Frequency Division Multiplex (COFDM) modulation system used by the DVB-T standard permits the operation of multiple transmitters on the same channel thus overcoming some of the spectrum constraints currently faced by analogue television in many countries. Such a system is described as a Single Frequency Network. However the digital information carried on all the transmitters must be the same and the transmitters must be synchronised. This has implications for the equipment at the transmitter site and for the method of delivery of signal to the site.

The option of a nation-wide SFN is not open to most European countries as the distances between potentially interfering co-channel transmitters result in delayed signals which cannot be overcome by the largest guard interval and in any case many countries operate regional programme variants. Within Europe transmission providers are therefore considering Multiple Frequency Networks (MFN) with Single Frequency Networks (SFN) used for local gap fill transmissions. At country boundaries, where spectrum is in demand by television services from two nations, large area SFN's are being implemented. This is the case in the south of Sweden and Denmark.

The ODTR is of the opinion that there will not be enough spectrum to provide dedicated MFN channels to each transposer in areas of the country requiring a large number of analogue television transposers. SFNs could be used to best advantage in such areas. The technical report considers the factors affecting the choice of guard interval for such a network configuration. In particular the distance between such transmitters should not be such that the signal from one transmitter would arrive outside the guard interval of the signal from another transmitter at the viewer's aerial. In general SFN operation has the added advantage that the viewer does not require a directional aerial to successfully receive programme services as all transmitters in effect add constructively. A type of receiver has been designed in Italy that will even cope with signals arriving slightly outside the guard interval duration. It is hoped that set top box and integrated DTV manufacturers will implement this design within the next few years.

Despite the improved efficiency, there are additional capital costs associated with SFN implementation. The extra equipment required due to synchronised SFN operation includes an SFN generator to insert the megastream timing signal into each multiplex at each regional SFN timing centre. An SFN interface adapter is required at each transmitter site to interpret the timing information. The timing reference can be obtained from a GPS receiver, which is required at all the SFN generator and transmitter sites.

A further network configuration can therefore be considered, co-channel non-synchronous transmitters. In such a network the choice of guard interval is independent of the distances between transmitter sites. However such a network must be planned to ensure that at least one signal adequately protected from co-channel

DTT interference is available at a viewer's receiver. Whilst this type of network is not as expensive to install, it has the disadvantage of requiring the viewer to use a directional aerial.

RTE have estimated the cost of establishing the DTT transmission network at £40 million. A further £28 million will be required to upgrade the network distribution system. A regional SFN would cost approximately 10-15% more than an unsynchronised network. The extra capital cost of installing regional SFN's is estimated at £3 million for 60 transmitter sites. The current analogue UHF national plan calls for over 120 transmitter and transposer sites. SFN link distribution costs would also be greater than those of an MFN.

It is not expected that lower power transposers could economically operate in an SFN but would, due to their very small terrain shielded service area, be operated co-channel with a parent transmitter.

1.4 Questions arising

The ODTR is concerned that a reliable DTT network should be established in Ireland with the protection of the consumer interest of paramount importance. It is not clear at present whether it would be practical to commence DTT service with one guard interval and change at a later date. However, the ODTR believes that it would be difficult for a transmission provider to change the network configuration or alter multiplex capacity after DTT service has begun.

Question 1.4.1
What are the views of respondents on the broadcast network configuration that should be utilised for the delivery of DTT?

Question 1.4.2
Do you agree with the planning assumption regarding the use of a 64 QAM Code Rate 2/3 for DTT in Ireland? If not please give reasons for your answer.

Question 1.4.3
Do you agree with the methodology used to arrive at the selection of the proposed guard interval? If you do not agree please provide reasons for your answer.

Question 1.4.4

Based on the technical evaluation carried out, the other considerations outlined earlier and assuming a network with some small area localised SFN's, it is proposed that a guard interval of 1/16 be selected thus providing an extra margin of ruggedness. Where a network with large area SFNs is assumed then it is proposed that a guard interval of 1/8 be selected.

Broadcast Network Configuration	**Proposed Guard Interval**
Network with some small area localised SFNs	1/16
Network with large area SFNs	1/8

Do you agree that the Guard Intervals shown above are appropriate for the broadcast network configurations shown? If you do not agree please provide reasons for your answer.

The Director invites views from interested parties by Friday 11th June 1999. Comments should be submitted in writing to:

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All comments are welcome, but it would make the task of analysing responses easier if comments reference the relevant question numbers from this document. In the interests of promoting openness and transparency, the ODTR will make copies of responses to this paper available for inspection at its offices during working hours, excluding information that the Director considers to be of a commercially sensitive nature. Where confidential material is included in responses it should be clearly marked as such and included in an Annex to the response.

This document does not constitute legal, commercial or technical advice. The Director is not bound by it. The consultation is without prejudice to the legal position of the Director or her rights and duties to regulate the market generally.

Section 11

Report on the selection of the Appropriate Guard Interval for Irish Digital Terrestrial Television

Prepared on behalf of The Office of the Director of Telecommunications Regulation

By

Teltec Ireland

2.1 Introduction

The Guard Interval parameter of digital terrestrial television, as specified by the DVB-T standard (EN 300-744, [1]), affords resilience against delayed, interference-causing signals or echoes in television reception.

Such delayed signals when caused by multipath radio wave propagation are responsible for the ‘ghosting’ effect sometimes observed in analogue television reception. Such ghosting effects primarily occur in mountainous areas, where the signal arrives at the receiving antenna by more than one path.

An additional source of ‘artificial’ echoes arises when signals originating from different transmitters in a Single Frequency Network (SFN) as defined in the DVB-T standard arrive at a receiver at different times.

In official DVB-T implementation guidelines (TR 101 190, [2]), it is pointed out that natural or multipath related echoes rarely occur later than 7µs after the main signal has been received. It is stated, however, that in mountainous areas, echoes with longer delays are possible.

Where delayed signals at a receiver occur due to reception from more than one transmitter in a Single Frequency Network, the timing of signals’ arrival at the receiver depends on the distances to the transmitters, and consequently transmitter spacing.

In both cases the Guard Interval parameter, when set appropriately, protects against interference caused by the delayed signals’ arrival.

2.2 Guard Interval

For DVB-T, the signal for transmission is organised as frames. Each frame consists of 68 Orthogonal Frequency Division Multiplexed symbols. For the 8k mode of the standard, to be implemented in Ireland, each symbol is made up of a set of 6,817 carriers.

The Guard Interval represents a cyclic extension of the symbol, in simplistic terms a section of the start of the symbol is appended to the end, before the next symbol commences. For the 8k mode of DVB-T, the basic transmission symbol period is 896µs. For such a DTT system, the available Guard Interval options are as follows:

Fraction of symbol	Guard Interval duration
1/32	28µs
1/16	56µs
1/8	112µs
¼	224µs

A particular Guard Interval choice affords protection against interference from delayed signals' arrival up to that time. In fact, within the Guard Interval, delayed signals can contribute to gain enhancement at the receiver.

Because the Guard Interval reduces the amount of time available for data transmission, its setting has an effect on the DVB-T net deliverable bit rate. Lengthening the Guard Interval decreases the bit rate. For 8k mode, when each carrier is modulated using 64-QAM, the table below indicates the net bit rate in Mbits/s for various combinations of Guard Interval settings and error protection code rates (TR 101 190 [2]).

Error protection code rate	Guard Interval			
	1/32	1/16	1/8	1/4
1/2	18.10Mb/s	17.56Mb/s	16.59Mb/s	14.93Mb/s
2/3	24.13Mb/s	23.42Mb/s	22.12Mb/s	19.91Mb/s
3/4	27.14Mb/s	26.35Mb/s	24.88Mb/s	22.39Mb/s

For example, with an error protection code rate set at 2/3, a 1/32 Guard Interval choice yields a net deliverable bit rate of 24.13Mbits/s. This decreases to 23.42Mbits/s and 22.12Mbits/s for 1/16 and 1/8 Guard Interval settings respectively.

In terms of actual program quality, an indicative figure for the bit rate necessary to provide very good picture quality for normal program material is approximately 4-5Mbits/s. Pop video and talking heads type programs can be transmitted with video rates of just 2-3Mbits/s, while certain program types e.g. sports coverage where superior picture quality is required, may run to 7Mbits/s [6]. For the 2/3 error protection code rate setting, the choice of a Guard Interval of 1/ 4 rather than 1/32 means a multiplex reduction in capacity of 4.22Mb/s; this would entail a loss in network capacity equivalent to one program.

2.3 Network Configurations

The current Irish analogue television broadcasting transmission network as deployed by RTE can be considered to be made up of three types of installation;

- Main regional transmitters, e.g. Mullaghanish, Truskmore. These are fed from a distribution network (usually digital microwave),
- Sub-regional transmitters, e.g. Knockmoyle, Holywell Hill. These are fed off-air from a main regional transmitter,
- Minor transposers, e.g. Malin, Crossbarry. These may be fed off-air, either from the main transmitter or from a sub-regional transmitter.

It is likely that the existing RTE analogue network will form the basis of the network for DTT transmission [3].

In the proposed national transmitter network configuration for digital broadcasting, it has previously been decided that the main regional transmitters will operate on independent UHF channels as a Multi-Frequency Network (MFN).

It is then intended that all subsidiary transmitters in a region should operate on a single frequency assigned to the region, thus increasing spectrum usage efficiency. The subsidiary transmitters may be fed off-air from the main transmitter. These sub-regional transmitters may be synchronised in re-broadcasting the programme material, in which case large area synchronised Single Frequency Networks will exist. If they are not synchronised, then they cannot be regarded as Single Frequency Networks, they are simply unsynchronised co-channel DTT transmitters.

Heretofore, DTT planning has been done on the basis of fixed domestic reception using directional UHF receive antennas. These are assumed to have a directional discrimination characteristic of –16dB outside of the +/-60 degree main lobe. Transmission polarisation enables the achievement of up to 15dB of discrimination between vertically and horizontally polarised received signals.

2.4 Interference between main regional transmitters

For television broadcasting, signals originating from transmitters on different channels will not cause interference, as long as channels are assigned with due regard for adjacent channel interference susceptibility. This applies to the main regional transmitters in the MFN.

2.5 Multipath propagation effects for individual transmitters

In the case of signals originating from a transmitter, the arrival of many delayed signals at a receiver location can occur owing to multipath propagation. In general, propagation paths longer than the shortest will have suffered higher attenuation, due to free space propagation losses, as well as scattering and absorption losses.

For such cases, the potential for interference will be limited to those paths where the signal strength from additional paths is attenuated by less than 20dB below the main path. This is the recommended threshold for DVB-T signals interfering with co-channel DVB-T signals. [4]

For this study, using sophisticated propagation modelling software developed at TCD in conjunction with a digital terrain database for Ireland, actual propagation conditions for a variety of typical individual transmitter DTT scenarios have been simulated.

Primary coverage estimates have been established using prediction software based on a modified Okamura-Hata propagation model which incorporates diffraction effects using Epstein-Peterson modelling. The accuracy of such modelling has been verified through comparison with field survey measurements.

The significant multipath signal paths are distinguished through identification of all those locations in an intended transmitter coverage area from where there is visibility (line of sight) of both transmitter and receiver. Such locations can serve as scatterers of the transmitted signal. The signal delay and attenuation suffered though travelling via this indirect path between the transmitter and receiver is quantified. Comparison of the estimated power in any reflected path with the primary initial signal allows identification of geographical areas where significant multipath components (i.e. within 20dB of the main signal) can present at the receiver. The simulation software indicates delay times associated with such signals

Multipath propagation effects have been modelled for a variety of geographical regions in Ireland, including highly irregular mountainous terrain areas of Cork and Donegal, less difficult mountainous terrain in the Wexford/Carlow/Kilkenny area and flat terrain in the midlands. Simulation of a variety of actual transmitters has shown that where significant delayed reflections occur, they do not occur later than 28μs. This is within the shortest Guard Interval available. The actual extent of areas where propagation conditions exist which give delayed signals past 20μs is negligibly low. In fact, the incidence of propagation conditions where interfering signals fall outside 16μs typically represents < 0.1% of all locations within the intended coverage area.

On this basis, the Guard Interval necessary to overcome any multipath related interference for individual transmitter situations could be specified with confidence at the lowest setting, 28μs.

2.6 Single Frequency Network operation

In the case of signals originating from a synchronised co-channel multi-transmitter network (SFN), delayed signals at a receiving location may occur due to the reception of signals from more than one transmitter. The signal to interference ratio will depend both on the relative position and relative power of the transmitters.

The recommendation given in the Implementation Guidelines (TR 101 190, [2]) for DVB-T is that Guard Interval selection should be based on the distance between the transmitters. The spacing between transmitters in a SFN should not be greater than the propagation time permitted in the Guard Interval. For a Guard Interval setting of 1/32, the maximum distance would be 8.4km, for 1/16 the distance would be 16.8km and for 1/8 Guard Interval the distance would be 33.6km.

Guard Interval	Delay	Extra Travel Distance (km)
1/32	28µs	8.4
1/16	56µs	16.8
1/8	112µs	33.6
¼	224µs	67.2

Note that in some areas which may be under consideration for SFN operation (West Cork/Kerry and Donegal) the separation distances between the prominent transmitters are in the region of 35-40 km.

However, this must be considered in conjunction with field strength ratios, which may be affected by the relative effective radiated powers (ERPs) of the transmitters in directions to the reception points.

Station 1	Station 2	Distance (km)
Castletownbere	Bantry	39
Castletownbere	Cahirciveen	35
Letterkenny	Fanad	37
Moville	Fanad	42

As indicated in the table, the spacing between some current RTE sub-regional transmitters in West Cork/Kerry and Donegal exceeds 33.8km. In these cases, it would be difficult to implement synchronous SFNs using a Guard Interval of less than 1/8 without taking measures to ensure that field strengths were maintained with sufficient difference, where signals arrive separated in time by greater than the Guard Interval.

However, in virtually all such cases, directional receive antennas combined with polarisation discrimination (where applicable), the relative ERPs, free space loss and terrain shielding will permit the desired/undesired signal ratio to be maintained above 20dB. Once below the threshold of interference, a signal is not of consequence even if it falls outside the Guard Interval time.

In certain situations, for some localised smaller regions, it may be deemed advantageous to operate a number of DTT transmitters as a Single Frequency Network. In these cases, it may be possible to assign a Guard Interval setting less than 1/8. Where transmitters do not share coverage areas, or where transmitters of shared coverage areas are within 8.4km of each other, then such a localised network may be operated as a SFN with a Guard Interval setting of 1/32. Such an implementation may be useful for city coverage, where the reception gain enhancement aspects of SFN operation may be desired.

In general, where SFN operation over wide areas is anticipated, then Guard Interval should be 1/8. The cases where the path differences exceed 33.8km are few in number and it should be possible to achieve the required 20dB signal to interference ratio in these instances. Small, localised SFNs may be implemented with a lesser Guard Interval.

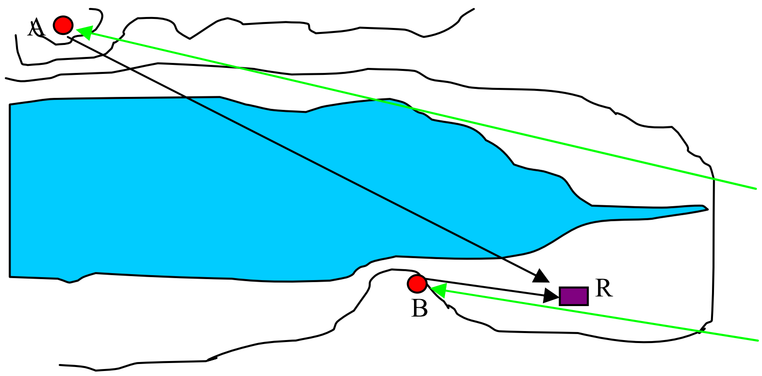
Professional DTT equipment capable of supporting SFN operation will be more complex and expensive than that for unsynchronised operation. The main transmitter sites will each require GPS-based time synchronisation equipment as well as SFN adapters for each multiplex. For 12 such main transmitter sites, each carrying six multiplexes, this equipment can be expected to cost in the region of £1.5million. For each sub-regional DTT transmitter, additional costs in the region of £25,000 would be incurred to cover the costs of GPS and SFN synchronisation equipment. For the complete network, the extra cost associated with implementing Single Frequency Networks is thus likely to run to approximately £2million. Additionally, any subsidiary SFN transmitters unable to receive their input signal directly off-air from the local main transmitter may require to be fed via microwave links. To carry six DVB-T multiplexes, 155Mbit/s links will be necessary at an approximate cost of at least £150,000 each for radio frequency equipment only.

2.7 Unsynchronised co-channel DTT transmitters

In the case of signals originating from unsynchronised co-channel multi-transmitter networks, all signals other than that from the wanted transmitter must be regarded as noise/interference. Where such transmitters operate on the same carrier frequency, the 'DVB-T interfering with DVB-T' threshold of 20dB must be upheld.

While in many cases, directional and polarisation discrimination may allow the receiver to respond to one or other of the transmitters preferentially, it is possible that the directional discrimination of a domestic TV receiver antenna may not be sufficient to provide usable signal level differences in certain situations.

In the diagram, the sub-regional transmitter at A and a fill-in transmitter at B are fed off-air from the main transmitter (not in diagram). Each of these rebroadcasts the signal, which is picked up by the receiver at R, with an antenna that does not offer sufficient directivity to discriminate between the two signals.



Plan View

Irrespective of the choice of Guard Interval, there exists the possibility that a combination of co-channel DTT transmitters, will result in unacceptable interference at a receive location. In such extreme cases it may be necessary to assign an alternate UHF channel to one of the transmitters.

2.8 On-channel DTT repeaters and gap-fillers

In relation to analogue television distribution, fill-in transposers normally receive signals off-air and re-radiate the signals on different channels. For such a distribution method, it is desirable not to have more than one such off-air link. That is, ideally each local transposer obtains its feed signal from a main transmitter, which is fed from a microwave link. This ensures that the signals radiated from the transposers are subject to minimum degradation due to noise.

In practice however, it is not always possible to achieve this. Some transposers in the current RTE analogue network have off-air feeds from another transposer, while a few have two-transposer daisy-chain feeds to them.

Many existing smaller analogue transposer sites have been constructed so as to minimise the visual impact of the installation. Small antenna support structures are used, often wooden telegraph poles. There is no shielding or isolation between the receiver and transmitter antennas, other than what is achieved by directional patterns. However, due to the close spacing of the antennas, and near field effects, directional patterns are unlikely to be effective in providing isolation.

Feeding a fill-in DTT rebroadcast transmitter off-air, from another DTT transmitter on the same frequency will be difficult unless a high degree of receive/transmit antenna isolation can be achieved. Directional and polarisation discrimination may be available, but as already stated it may be difficult to achieve a sufficient level difference at typical small rebroadcast sites, especially as the fill-in booster receiver will have to be protected from its own transmitter output. On this basis, unless other feed systems are used, two channel sets may be required for each main region (in addition to the main transmitter channel set).

The EU ACTS VALIDATE project has examined the possibility of implementing both professional and domestic on-channel, off-air gap-filler repeaters in DTT systems [5]. Professional units would fill gaps in the coverage of main transmitters caused by shadowing from terrain or large buildings, while domestic gap fillers installed within a house would improve portable television reception. Again however, achieving adequate isolation between the receive and transmit antennas is crucial.

For such on-channel off-air repeaters (gap-fillers), the delay between a signal from the feeder transmitter and the gap-filler transmitter may be constant, but will include a delay which will depend on the repeating time of the gap-filler. As the signal processing in the gap-filler units may contain filters based on SAW[2] devices, this delay could be sufficient to require long Guard Intervals unless the relative signal levels at the receiver are greater than 20dB. As their use implies significant shadowing of the main signal, the requirement for such relative levels of signal/interference should be met in the vast majority of cases. On this basis, gap-filler time delay implications may be excluded as a factor influencing Guard Interval choice.

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[2] SAW filter; Surface Acoustic Wave filter, a highly selective filter commonly found in TV tuners to reject unwanted signals due to adjacent channels.

2.9 Conclusions

Guard Interval may be set at 1/32 for the 8k mode implementation of DVB-T for use on UHF channels in Ireland where sub-regional synchronous SFN operation is not anticipated.

- For such a choice, multipath signals owing to individual transmitters will not cause interference.
- Where sub-regional transmitters transmit unsynchronised DTT, Guard Interval is not relevant.

Where large area synchronous SFNs are proposed, implementation may be difficult using a Guard Interval of less than 1/8, unless coverage from potentially mutually interfering sites is planned to ensure an interference free signal is available at receive locations.

- This may be achieved through free space or terrain related loss of one signal compared to another, due to longer path length, as well as from directional and polarisation discrimination of transmissions.
- It would be difficult to implement a nation-wide DTT network with sub-regional SFNs unless the same Guard Interval is applied throughout. In such a situation, Guard Interval specification criteria of one region will have undesirable capacity reduction implications for the entire network.
- It may be deemed advantageous to operate small localised SFNs in a small number of areas. For such cases, where the DTT transmitters' separation distances are within the necessary limits, then localised SFNs can operate with a Guard Interval setting equal to 1/32. For such cases, there will be no capacity reduction implication for the network.
- Additionally, in deciding whether SFNs should be implemented, the higher cost of such (including the necessary links to the transmitters) will need to be considered in comparison with the cost of implementing a co-channel unsynchronised DTT network.

References

[1] ETSI EN 300-744 Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television.

[2] ETSI TR 101-190 Digital Video Broadcasting (DVB); Implementation guidelines for DVB terrestrial services; Transmission aspects.

[3] ODTR 98/20 The Future of TV Transmission in Ireland. The Way Forward.

[4] CEPT Chester 97 The Chester 1997 Multilateral Co-ordination Agreement relating to Technical Criteria, Co-ordination Principles and Procedures for the introduction of Terrestrial Digital Video Broadcasting (DVB-T)

[5] ACTS AC106 VALIDATE Project Final Report. Verifying the DVB-T specification. Preparing for the launch of services.

[6] RTE Presentation to the Institution of Engineers of Ireland 4 April 1999. The Transmission of Broadcast Signals on Telecommunications Networks. Presented by Paul Myhal

Glossary of acronyms

ACTS	Advanced Communication Technologies and Services
CEPT	Conférence Européenne des Administrations des Postes et des Télécommunications
COFDM	Coded Orthogonal Frequency Division Multiplex
DTT	Digital Terrestrial Television
DVB-T	Digital Video Broadcasting – Terrestrial
ERP	Effective Radiated Power
ETSI	European Telecommunications Standards Institute
EU	European Union
GI	Guard Interval
MFN	Multi Frequency Network
ODTR	Office of the Director of Telecommunications Regulation
RTE	Radio Telefís Éireann
SAW	Surface Acoustic Wave
SFN	Single Frequency Network
UHF	Ultra High Frequency

Appendix II

Multipath estimation

For the purposes of this study, radio propagation estimation has been carried out using software which implements a modified Okamura Hata prediction model. Terrain shadowing effects are accounted for through incorporation of the Epstein Peterson diffraction algorithm. Terrain detail information has been supplied from a 100 metre resolution digital terrain model.

The significant multipath signal paths are distinguished through identification of all locations in an intended transmitter coverage area from where there is visibility of both transmitter and receiver. Such locations serve as reflectors of the transmitted signal. The signal delay and attenuation suffered though travelling via this indirect path between the transmitter and receiver is quantified. Comparison of the estimated power in any reflected path with the primary initial signal allows identification of geographical regions where significant multipath components (i.e. within 20dB of main signal) can occur at the receiver. The simulation software indicates delay times associated with such signals.

Simulations have been carried out for a variety of transmitter sites, at both 500MHz and 800MHz. Figures 1 to 3 serve to illustrate typical simulation results observed.

In Figure 1, the results of a typical analysis are presented. An estimate of the likely multipath effects experienced in the coverage area of the Mullaghanish RTE site are presented. The vertical and horizontal gradations are at 10km intervals. The colour scale indicates time delay (in microseconds) after which no significant multipath reflected components are received. In Figure 2, the results for the Cairn Hill RTE site are presented. The vertical and horizontal gradations are at 10km intervals. The colour scale indicates time delay (in seconds) after which no significant multipath reflected component will be received. Finally, Figure 3 shows the results for a transmitter at Fanad in Co. Donegal.

For all cases, it can be seen that no significant multipath components occur later than 28µs after the primary signal has been received.

Figures 1 to 3 serve to illustrate typical simulation results observed. In all cases, the background yellow colour indicates areas where it is predicted that there will be no significant delayed signals arriving at the receiver. Coloured areas indicate locations where it is predicted that there will be some delayed signals arriving at the receiver which are of significant amplitude. The colour coding indicates the delay associated with the reflections in such areas. For reflections to cause interference, they must exceed the Guard Interval time. It can be seen that there are no areas where reflections occur which exceed the minimum Guard Interval setting of 28µs.

Multipath effects will not represent a problem for DTT, even with the shortest Guard Interval setting.

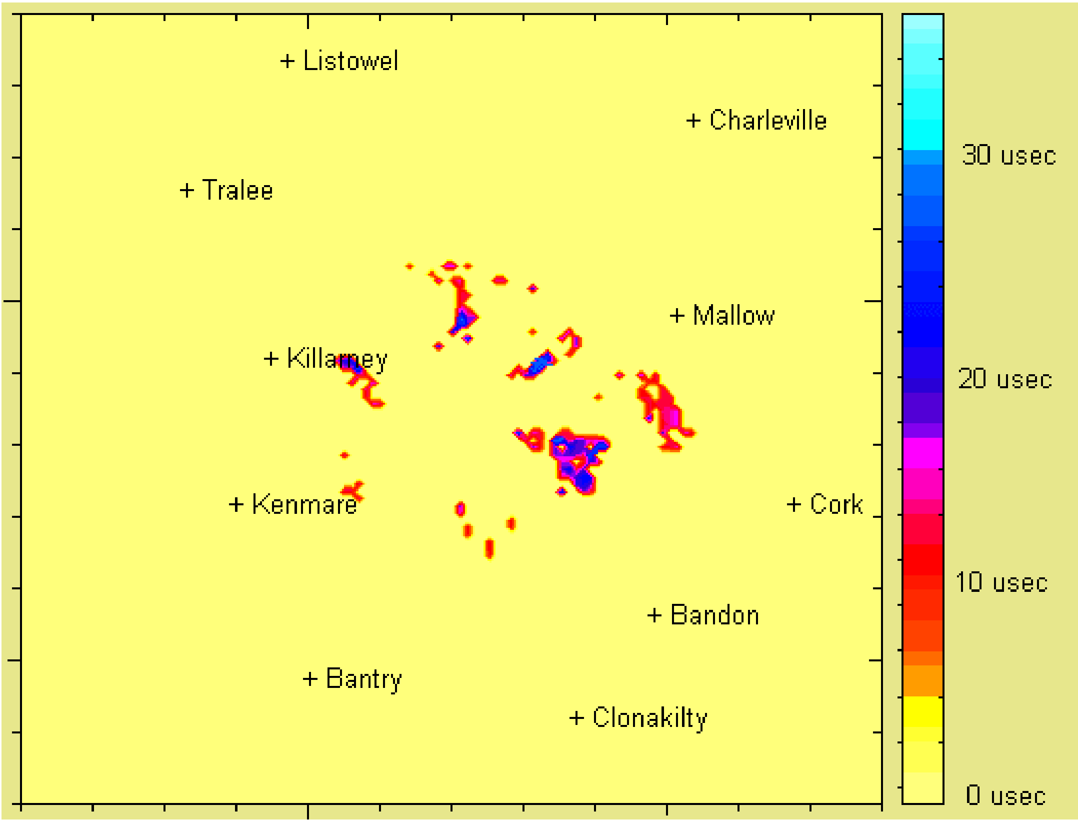

Figure 1 Estimated multipath characteristics for Mullaghanish coverage area. 110km x 120km region. Coordinates; bottom left E060000 N030000, top right E180000 N140000. Transmitter at E081700 N121300. Colour bar units in microseconds.

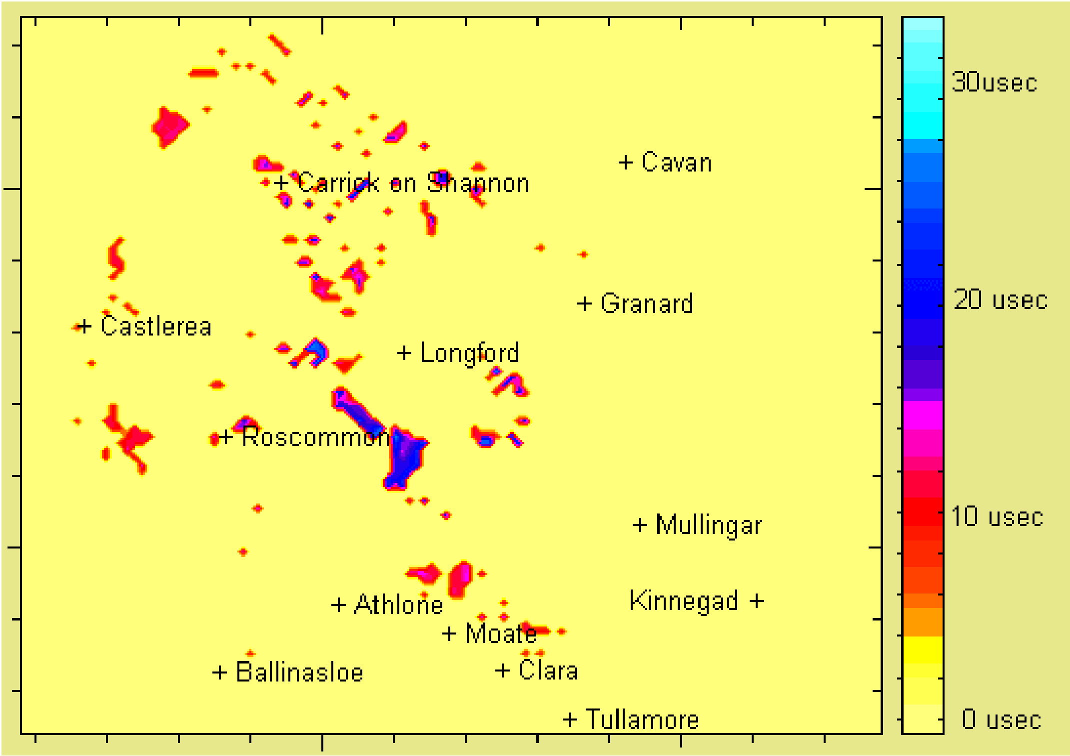

Figure 2 Estimated multipath characteristics for Cairn Hill coverage area. 120km x 100km region. Coordinates; bottom left E158000 N224000, top right E278000 N324000. Transmitter at E218500 N284200. Colour bar units in microseconds.

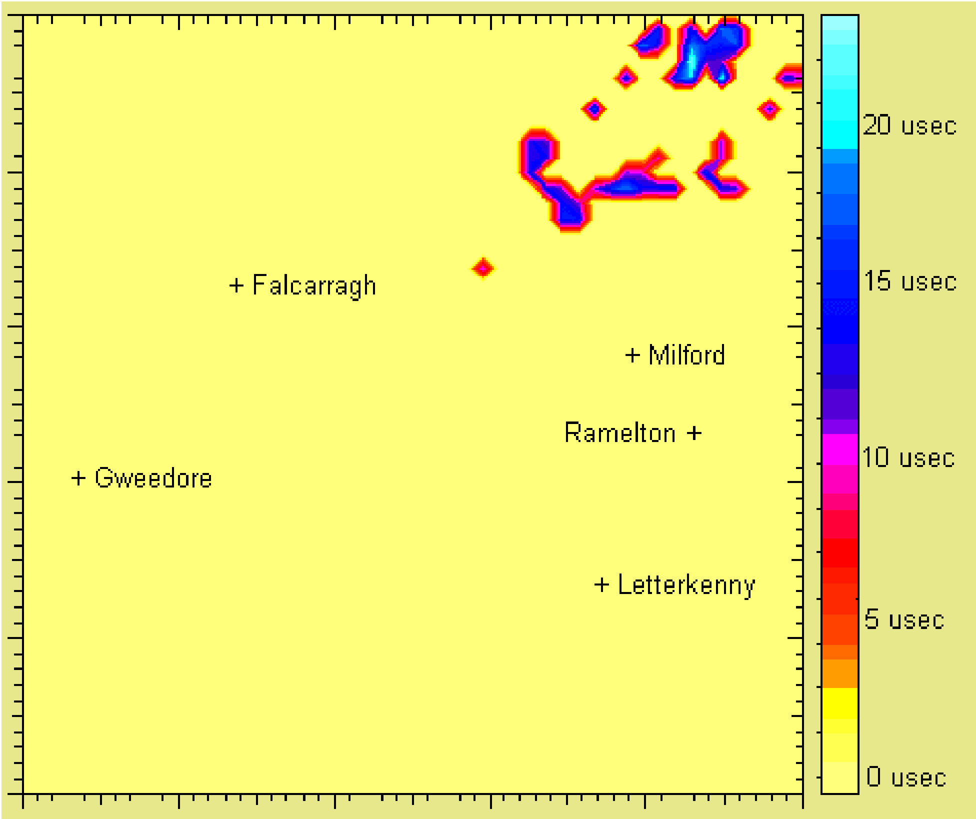

Figure 3 Estimated multipath characteristics for Fanad transmitter coverage area. 50km x 50km region. Coordinates; bottom left E180000 N400000, top right E230000 N450000. Transmitter at E221800 N441800. Colour bar units in microseconds.