Australian
Broadcasting
Authority

DIGITAL RADIO STUDY GROUP

Digital Radio Technology Update

This paper has been prepared to assist the Digital Radio Study Group in its consultation with stakeholders. It is hoped that interested parties will comment on the issues raised and the information presented in the paper.

This working document does not represent Government policy or a Government view in relation to the possible implementation of digital radio in Australia.

Australian Broadcasting Authority
September 2003

Published by the Australian Broadcasting Authority
201 Sussex Street
Sydney NSW 2000

September 2003

Contents

Executive Summary

Background

On 6 May 2003, the Minister for Communications, Information Technology and the Arts announced the formation of a Digital Radio Study Group (the DRSG) to inquire into and report on the status of major digital radio technologies currently available internationally. The DRSG comprises representatives of the Australian Broadcasting Authority (the ABA), the Australian Communications Authority (the ACA) and the Department of Communications, Information Technology and the Arts (DCITA).

As a first step in its inquiry the DRSG has undertaken research into developments in digital radio technologies and the various approaches taken overseas in implementing such technologies. This report outlines developments in relation to digital radio technologies, while the DRSG's companion report, *Stocktake of Implementation Strategies for Digital Radio*, provides an overview of international experiences.

Scope

The general promise of digital technology is error-free performance with superior performance and flexibility in the quality and range of content that can be offered compared to its analog counterpart. Initial developments in digital radio technology were particularly driven by the promise of CD-quality sound.

Several of the digital radio technologies that have been developed are designed to reproduce the key characteristics of analog radio. These digital radio systems share the following key technical characteristics of analog radio:

- the provision of audio information and entertainment (eg music, news, current affairs and talkback);
- reliable indoor and mobile reception;
- use of terrestrial transmitters (noting that some satellite and hybrid satellite-terrestrial systems are also considered); and,
- service delivery through free-to-air cheap and ubiquitous receivers on a point to multipoint basis.

In recent years other digital technologies have demonstrated the potential to deliver audio information and entertainment services. The increased content and sound quality options these digital technologies offer across a range of platforms could see them play a significant role in a future digital radio environment.

The DRSG has chosen to take a wide view of digital radio. It has examined all systems that are designed to replicate the characteristics of analog radio, including Eureka 147, Digital Radio Mondiale (DRM), In-Band On Channel (IBOC), ISDB-TSB and (to a lesser extent) DVB-T. The DRSG has also examined other digital systems that are capable of delivering audio entertainment and information, including Worldspace satellite, US based Satellite Digital Audio Radio Services (SDARS) and other emerging technologies such as Internet audio streaming combined with wireless technologies such as Wi-Fi and 3G.

Spectrum Issues

The availability of sufficient radiofrequency spectrum is a key threshold issue for the implementation of digital radio technologies. Each digital radio system has its own specific spectrum requirements in terms of which spectrum bands it is designed to operate in[1] and the bandwidth required for each digital radio channel. Some digital radio systems can operate in the same channel as current analog radio services. Other systems would require new channels in the same bands as existing analog radio or television services or new channels in bands which are currently used for non-broadcasting services. This report identifies general spectrum management issues for Australia and also identifies the issues raised by each digital radio system.

Current Usage and Availability

Service types and uses of spectrum (ie broadcasting, mobile radiocommunications, point-to-point radiocommunications, defence, amateur, etc) are allotted to specific spectrum bands by the International Telecommunication Union (ITU) on an international basis At a national level the Australian Communications Authority (ACA) attempts wherever possible to follow these arrangements. Spectrum bands that are being considered for use by digital radio are the MF Band, HF Band, VHF Bands I, II and III, UHF Bands IV and V and the 1.5 GHz, 2.3 GHz and 2.6 GHz Bands[2]. The body of the report provides greater detail on the suitability, or otherwise, of these bands for use by digital radio in Australia.

In Australia these bands are shared with other broadcasting services (analog radio and analog and digital television), radiocommunications services and, in some cases, secondary services such as amateur radio, wireless microphones and monitoring equipment. Australia is fortunate that its relative geographical isolation allows it to manage spectrum with relatively limited international coordination in most bands considered for digital radio. Nevertheless, Australia should minimise deviation from international standards and usages to benefit from the economies of scale brought by global markets. The relatively small size of the Australian market makes it unlikely that affordable digital radio equipment will be manufactured to operate in parts of the radiofrequency spectrum other than those proposed for use in major consumer markets.

[1] Often the bands that receivers are manufactured for are a subset of the bands the system has been designed to operate in.

[2] Current international arrangements for ITU Region 3, and the Australian arrangements that mirror the ITU Region 3 arrangements, do not provide for Broadcasting Satellite services in the 2.3 GHz and 2.6 GHz bands in Australia.

Options for making spectrum for digital radio services available in Australia include:

- finding spectrum adjacent to existing services in some bands;
- shifting existing services to different bands;
- shuffling services within a band to clear sufficient spectrum for digital radio services; and
- limiting the number of future analog radio or analog and digital television services licensed in relevant bands.

Digital Radio Technologies

Eureka 147

Eureka 147 is a digital radio system developed in Europe. One of the strengths of Eureka 147 is that it is a mature technology with established standards implemented widely, in Canada, the UK, Germany and other parts of Europe. Eureka 147 is a broadband system requiring a 1.5 MHz channel, that can offer five simultaneous CD quality services at 224 kilobits per second (kbit/s) or considerably more services at lower quality. In the UK, digital radio operators are currently providing a mixture of five to six stereo services at 128 kbit/s or 160 kbit/s; three to six mono services at 64 kbit/s or 80 kbit/s and some data services.

Eureka 147 can be received by mobile, portable and fixed receivers and can be used in a wide range of applications such as wide-area or local delivery of audio and data services for mobile, portable and fixed reception. It can be delivered terrestrially, via satellite; hybrid (satellite with complementary terrestrial) and cable networks. Although Eureka 147 was designed to operate over a wide spectrum range from 30 - 3000 MHz, it has only been commercially implemented in two spectrum bands, VHF Band III and L-Band.

As an older technology, however, its audio compression techniques are less efficient than more recently developed digital radio technologies. This means that fewer audio programs can be transmitted within a given bandwidth. The price of Eureka receivers is still seen as being relatively expensive, however this is expected to change as production numbers increase.

Eureka 147 uses spectrum currently used for analog and digital television, defence services and radiocommunication services. Though the future return of analog television spectrum may present an opportunity for Eureka 147, finding sufficient spectrum in the meantime poses challenges because of current use by other services. If Eureka was to be implemented in Australia, there is in general more capacity in the L- Band than in VHF Band III. However, the L-Band is a less attractive proposition than the VHF band, due to its inferior propagation properties in urban areas.

This shortage of VHF spectrum suitable for wide coverage poses problems for both augmentation and conversion models of digital radio introduction using Eureka 147, as L-Band Eureka 147 would require numbers of new transmission sites within each major city and may not be an economically viable way to provide wide area coverage in regional areas, where many L-Band transmitters would be required to replicate the coverage of a single VHF Band III transmitter. Meanwhile, the supply of VHF spectrum currently available in advance of analog television switch-off is extremely limited. Only 6 MHz of VHF Band III channel 9A, is available in each of the five major cities and in many of the existing radio markets that are adjacent to them. Trials currently proposed for Sydney should assist in determining whether this spectrum can support two or three Eureka multiplexes. To avoid or minimise the potential for interference to or from adjacent television services, Eureka 147 transmissions on VHF channels may be constrained to operate from the same sites as VHF television transmissions.

The World DAB Forum (which is an international, non-governmental organisation whose members have an interest in establishing Eureka 147 as a commercial marketing success) and DRM recently announced their intention to form a strategic alliance. This alliance offers the potential for common DRM/Eureka 147 receivers to be developed and augurs a potential increase in market 'reach' for both Eureka 147 and DRM. In particular, DRM is designed for wide coverage reception using MF, LF and HF spectrum and this offers one possible solution to the shortage of suitable wide-coverage VHF Band III spectrum that would confront Eureka 147 in regional Australia.

Digital Radio Mondiale (DRM)

Digital Radio Mondiale is a narrowband digital radio system designed for use in the low frequency (LF) medium frequency (MF) and high frequency (HF) terrestrial broadcasting bands below 30 MHz. DRM was originally designed as a greenfields solution in that it requires a clear frequency to operate effectively. It was designed to augment existing services by operating with the existing channel spacing employed for amplitude modulated (AM) broadcasting and for HF broadcasting worldwide. It can carry audio and/or data with the flexibility to trade-off between audio quality, data capacity and signal robustness. More recently, work has been undertaken to develop a version of the DRM system designed to facilitate conversion of analog services by permitting simulcasting in analog and digital modes. Under this system, it is proposed that the analog and DRM transmissions would occupy the same bandwidth as an ordinary AM-MF service. This variant of DRM is still under development and it is not possible to evaluate its claims.

DRM is a comparatively new technology which requires further technical development and testing before it can be properly considered for implementation in Australia. Currently, it is unclear when its receivers will be available. The feasibility and practical implications of its simulcast operation has also yet to be established. DRM operates on lower bit rates and therefore offers lower audio quality compared to most other digital radio systems. The availability of spectrum for additional services in the AM-MF band is limited in Australia due to the operation of existing analog services. Options for the introduction of DRM in MF spectrum include identification of remaining available channels or the freeing up of some existing MF-AM channels for DRM.

Implementation of DRM in the HF Band is also problematic. HF propagation relies on sky wave propagation through the ionosphere, the state of which changes throughout the day. HF broadcasters are often required to transmit the same signal at different frequencies, or to regularly change transmitting frequency, in order to increase the probability of reception in the intended target area. Use of the HF broadcasting bands is also subject to international coordination and recent ITU studies have shown these bands are already heavily congested.

In Band On Channel (IBOC)

IBOC is a narrowband system which is designed to allow for the implementation of digital radio in two phases. The first is a *Hybrid phase*, which supplements an existing AM or FM analog radio signal with a digital signal carried alongside the transmission of the analog signal. The second is an *All-Digital phase* in which the analog signal is removed and the digital signal reconfigured to optimise system ruggedness and maximise coverage areas. In the *Hybrid phase*, the analog and digital services need to be identical as the IBOC receiver is designed to use the analog service as a “fallback” signal when the digital signal drops out at the edge of coverage. IBOC has two system variants, IBOC-AM for use in the MF-AM band and IBOC-FM for use in the VHF-FM band.

The IBOC system design enables broadcasters to maximise the use of existing infrastructure thereby minimising upgrade costs and, from a consumer perspective, allowing a progressive migration from analog to digital. Its receiver design avoids abrupt reception failures common in digital systems at the edge of the coverage area.

IBOC’s system design, however, is relatively immature and is still being standardised. Its operational range and quality also needs to be further tested before it can be properly considered in terms of its suitability for Australia. IBOC-AM was designed to work in the US, which has adopted a 10 kHz channel spacing for the MF-AM band. A 9 kHz design, which would suit Australian conditions has not yet been developed. The MF-AM band in the US is very congested with night-time operation limited by interference. As a consequence the US Federal Communications Commission (FCC) has not approved night-time operation of IBOC-AM. Although the MF band in Australia is comparatively less constrained, IBOC-AM would need to be extensively tested in Australian conditions to confirm its ability to operate at night. Broadcasters converting to IBOC-AM would need to revert to mono operation for the analog service as the IBOC-AM system is not compatible with standard analog AM stereo.

The audio quality of IBOC (in particular the AM variant) is currently under review by system developers. Compared to other digital radio systems IBOC-AM would offer much lower quality audio. The greater data capacity of IBOC-FM accommodates a stereo digital audio service in addition to the existing stereo analog service.

There are fewer operational concerns with IBOC-FM as the same channel arrangements are used in Australia and the US. Like the MF-AM band, the VHF-FM band in the USA is “interference-limited”. In Australia, analog VHF-FM services are typically planned with noise being the limiting criterion for coverage. IBOC-FM would need to be extensively tested in Australian conditions to confirm that it does not significantly compromise the current coverage of analog VHF-FM radio services.

Integrated Services Digital Broadcasting- for Terrestrial Sound Broadcasting ISDB-TSB)

ISDB-TSB was developed in Japan and is part of a family of ISDB systems which delivers television and radio services. The technical characteristics of ISDB offer flexibility in that it is designed for fixed, portable and mobile delivery of television and radio services and can operate in variable width channels. The technology is similar to DVB-T technology (discussed below) but uses band segmentation. ISDB-TSB has the capacity to provide one to about seven "CD" quality services in channels of 429 kHz or 1.286 MHz depending on the level of robustness chosen by the broadcaster. ISDB-TSB has been designed to operate in VHF Bands II and III and UHF Bands IV and V. It also offers greater content options such as delivering low bit rate video programs. ISDB-TSB is designed for low power consumption of receivers to allow portable battery operated devices to be manufactured.

While the potential capabilities of ISDB-TSB have been described it has not yet reached the stage of an operational deployment. There are currently no ISDB-TSB transmissions or consumer receivers although trial services may commence in 2003.

DVB-T

The DVB project[3] has developed a number of related digital broadcasting systems for cable, satellite and terrestrial delivery of television services. These are known as DVB-C, DVB-S and DVB-T respectively. While all these systems were primarily designed for television broadcasting they can and do provide radio (audio-only) programs.

The satellite delivered DVB-S services that principally provide free to air television services to remote areas in Australia or provide Pay-TV services, already provide a number of radio services. Additionally, the free to air DVB-T digital television services offered by the ABC and SBS both carry radio programs. The ABC broadcasts Digradio which is also available on the internet. SBS provides its two main radio channels.

This report focuses on DVB-T rather than DVB-S or DVB-C, as the latter two can only provide service to fixed receivers. DVB-T on the other hand is sufficiently flexible to allow it to be optimised for delivery to portable and mobile receivers.

Current implementations of DVB-T services for digital television in Australia are planned for and target fixed reception. Consumer grade mobile DVB-T receivers are likely to be produced with the aim of providing mobile television and multi-media services.

DVB-T is a proven technology for digital television, and has been implemented in many countries. It is capable of operating over a wide range of frequencies providing broad scope for the identification of suitable spectrum. In many areas of Australia, there is limited VHF or UHF spectrum available pending the completion of the transition to digital television. As part of the television Digital Channel Planning process, two 7 MHz channels have recently been made available from most high power television

[3] The DVB project is an industry led consortium of broadcasters, manufacturers, network operators, software developers, regulatory bodies and others in over 35 countries which has its objective the design of global standards for the global delivery of digital television and data services.

transmission sites in Australia. These channels have been considered for short-term trialling of datacasting technologies following the decision not to proceed with the long-term allocation of datacasting transmitter licences.

Challenges with implementing DVB-T for digital radio centre on the need for good mobile and portable reception and its large bandwidth usage. DVB-T is not optimised for mobile reception and no mobile or portable hand held receivers are available. The high data rates and wide bandwidth needed to operate the system not only increases power consumption but also makes the design of battery-powered devices difficult. The large bandwidth use required for DVB-T means that many services must be multiplexed together for efficient use of the spectrum and there is a risk that such multiplexes may not be fully utilised thereby leading to inefficient spectrum use.

However, experience here and overseas suggests that platforms designed primarily for digital television are likely increasingly to carry audio-only entertainment and information as well, whether on a subscription or free-to-air basis.

Worldspace Satellite

Current Worldspace services aim to provide radio and data services to underserved regions through portable battery operated devices in less developed countries including areas where infrastructure such as mains power may not be available.

Worldspace digital radio technologies consist of two satellite transmission systems for operation in L-band at approximately 1.5 GHz. The first of these two systems is operational and provides coverage to Asia, Africa, the Middle East and potentially parts of Europe through two geostationary orbiting satellites to relatively simple portable radio receivers. The two operational satellites are named ‘Afristar’ and ‘Asiastar’. A third satellite was intended to cover Central and South America, however the launch of this satellite has been delayed indefinitely. This system uses a single carrier modulation technique (ie it does not use COFDM) and is therefore not optimal for mobile reception. The second system has not yet been implemented. It is similar to the first system for the satellite component but has some enhancements, including the ability to operate in a hybrid satellite/terrestrial mode through the use of terrestrial repeaters.

Current Worldspace satellites occupy the band 1467 - 1492 MHz and use this spectrum across three beams on each satellite. The band 1427 - 1535 MHz is used for several types of radiocommunications services which include point-to-point microwave links throughout Australia. Telstra also operates the Digital Radio Concentrator System (DRCS) and a replacement high capacity version (HCRC) in this band. To utilise this band for a satellite delivered digital radio service would require the filing of a satellite notification to the ITU and successful coordination with countries that respond to the filing. The impact of the satellite service on existing services would also need to be assessed.

US based Satellite Digital Audio Radio Services (SDARS)

Two similar satellite delivered subscription radio services providing approximately 100 audio channels each have commenced operation in the US. These are XM radio commencing in November 2001 and Sirius, which commenced July 2002. The 100 audio channels are typically divided into 60 music channels and 40 voice channels. Both services operate in a frequency band around 2.3 GHz, that is part of the radiofrequency spectrum known as ‘S-Band’. The only country that has implemented a service using this allocation is the USA. Both systems use COFDM transmissions enabling the use of terrestrial in-fill transmitters on the same frequencies as the satellite transmissions.

Adjacent band interference is a major concern particularly for the repeater stations. Interference may also pose a problem to reception of the SDARS from out-of-band emissions from devices such as Wireless LAN type technologies (eg Wi-Fi) and cordless telephones.

Unlike 1.5 GHz satellite systems, there is no appropriate 2.3 GHz Broadcasting Satellite Service allocation that could be used in Australia by 2.3 GHz systems like Sirius or XM radio. To obtain the same band allocation as used by Sirius and XM Radio, an ITU World Radio Conference would have to modify the table of allocations. Use of the 2310 - 2360 MHz band would also require the displacement of existing spectrum licence holders, which have a 15 year term. The 2.3 GHz band used by XM Radio and Sirius in the US, is therefore unlikely to be available for deployment of these systems in Australia. To operate either the Sirius or XM Radio systems in Australia in a different band (eg 1.5 GHz) would require modification of receivers at unknown cost.

Other Emerging Technologies

The Internet is sometimes touted as a future competitor to digital radio in the provision of digital audio entertainment and information. ‘Internet radio’ or audio streaming via the Internet to PCs has been available for some time. Radio content available on the Internet is already being included in ratings statistics in the UK when considering the number of people accessing digital radio (alongside Eureka 147 and digital television broadcasts).

Audio streaming uses techniques such as ‘buffering,’ in which audio or audiovisual files are continuously downloaded into a ‘reservoir’ before being played, to counter the inherent unreliability of the Internet as a source of continuously streamed content. There are various streaming software packages available allowing the content to be heard without paying a subscription fee, and therefore radio can be broadcast free to air. Audio-on-demand is featured on a number of larger radio sites, giving the listener access to programs up to seven days after the live broadcast (depending on the copyright agreements entered into by broadcasters and record companies etc). Additional content, both text and picture based, is available and directly linked to individual programs allowing interactivity for competitions and live feedback/text conversations with presenters. Though the Internet makes radio services from all over the world available, it suffers from lack of mobility, low sound quality, cost of bandwidth and limitations on the number of PCs to which services can be streamed simultaneously.

The mobility problem may be partially addressed by Wi-Fi systems. Wi-Fi refers to systems that transmit and receive data on mobile platforms within a short distance of a cell or base station. Wi-Fi increases somewhat the mobility of Internet services but is envisaged as a wireless local area network (LAN) rather than a mobile entertainment platform per se.

Only launched this year in Australia, and still in its early stages, 3G is a mobile telephone service that allows access to additional content such as video and picture messaging services; the ability to see the person one is talking to; walled garden websites (the ability to see specific sections of a larger website available on the Internet); enhanced wireless application protocol (WAP) services such as maps and horoscopes, local guides (eg what's on), news, weather and sporting results; short video on demand clips and a modem to connect to email. It offers ubiquitous mobile coverage but is subject to severe constraints on bandwidth. As yet, 3G is not capable of streaming live audio broadcasts and after contacting representatives from Hutchison, Optus and Telstra it is clear that they are not prioritising further development of this application for Australian audiences in the near future.

In future there is likely to be increasing migration of Internet applications to mobile platforms such as telephones and Personal Digital Assistants (PDAs), although whether these applications will ultimately include streamed audio entertainment is unclear. Indeed, there are indications a more likely hybrid in the short term could be mobile telephones that contain digital radio receivers.

Tabular Comparison of Digital Radio Systems

The following table summarises the key aspects of the digital radio systems considered in this report.

Parameter	Eureka 147	IBOC-AM	IBOC-FM	DRM	ISDB-TSB	DVB-T	Worldspace	SDARS
Bands	VHF-III, L-Band	MF	VHF-FM	LF, MF, HF	VHF, UHF	VHF-III, UHF	L-Band	S-Band
Origin	Europe	US-prop		Europe	Japan	Europe	Prop	US-prop
Terrestrial	Yes	Yes		Yes	Yes	Yes	Enhance-ment	Enhance-ment
Satellite	Possible	No		No	Possible	No	Yes	Yes
Hybrid	Possible	No		No	Possible	No	possible	Yes
Wideband Narrowband	Wideband 1.5 MHz	Narrowband 18/20 kHz*	Narrowband 200 kHz	Narrowband 9-18 kHz	Wideband 0.4 or 1.3 MHz	Wideband 7 MHz	Wideband 1.6 MHz	Wideband 12.5 MHz
Modulation System	COFDM QPSK	COFDM	COFDM	COFDM 16-QAM, 64-QAM	COFDM DQPSK, QPSK, 16-QAM, 64-QAM	COFDM (QPSK, 16-QAM, 64-QAM)	Sat - Single carrier Ter - COFDM	COFDM
Max data rates	1.2 Mbit/s	~ 20-40 kbit/s	~ 98 kbit/s	~ 24 kbit/s	0.3–5.3 Mbit/s	4-27 Mbit/s	1.5 Mbit/s	
Multiplex of services	Yes	No		No	Yes	Yes	Yes	Yes
Audio Coding method	MPEG-1 Layer II and MPEG-2 Layer II	PAC	PAC	MPEG-4 HE AAC	MPEG-2 Layer II, MPEG-2 AAC, AC-3	MPEG-1 Layer II and MPEG-2 Layer II AC-3	MPEG-2.5	Sirius uses PAC XM uses CTaacPlus
Bit rate for Audio Quality	"CD" at 192-224 kbit/s	"FM" at 20-40 kbit/s	"CD" at 98 kbit/s	"Mono FM" at 24 kbit/s	MPEG-2 AAC: "CD" at 144 kbit/s	"CD" at 192-224 kbit/s	~ 16-128 kbit/s	
Infrastructure	FM/TV and infill sites	AM sites	FM sites	AM sites	FM/TV sites	FM/TV sites	Sat and infill	Sat and infill
Standardisa-tion	Extensive	Developmental, limited standards		High	Some	High	Little	Little
Receiver availability	Yes	No		No	No	Yes	Yes	Yes
On-air	Yes	Tests		Tests	Tests	Yes	Yes	Yes

* IBOC-AM would need to be modified for Australia which uses 18 kHz occupancy, 9 kHz channel width for MF-AM services rather than the 20 kHz occupancy, 10 kHz channel width used in the USA.

Introduction

Background

On 6 May 2003, the Minister for Communications, Information Technology and the Arts announced the formation of a Digital Radio Study Group to report on the status of major digital radio technologies currently available internationally.

The Study Group is comprised of representatives from the Department of Communications, Information Technology and the Arts, the Australian Broadcasting Authority (ABA) and the Australian Communications Authority (ACA) and is tasked with examining initiatives currently being developed and implemented overseas, in terms of digital radio technology and approaches to service delivery.

Specifically, the Study Group is to inquire into and report to the Minister on:

- The implementation of the alternative digital radio technologies, including Eureka 147, IBOC, Digital Radio Mondiale (DRM) and digital satellite and hybrid satellite/ terrestrial services, in overseas markets.
- The relative merits of the alternative technologies in terms of the range and types of services that can be delivered, the particular advantages and disadvantages of each technology in the Australian environment, and any implications for spectrum planning, clearing or efficiency in the Australian context.
- The implications of the alternative technologies with respect to technical standards or regulatory considerations.
- The Study Group is to report by 28 November 2003.

The DRSG has divided its workload into two phases. The first phase is a fact gathering exercise, which describes the current technical features and developments of digital radio technologies. It also describes approaches taken overseas in implementing such technologies. The second phase is concerned with identifying a range of technical and regulatory issues that may impact on the implementation of the various digital radio technologies in Australia. Material gathered in the first phase will be used as the basis for analysis.

This report is one of two prepared under the first phase of the DRSG work plan. It provides an update on existing and emerging digital radio technologies. DCITA has also prepared a report for phase one advising on overseas approaches to implementing various digital radio technologies.

Scope of the Report

This report primarily examines digital radio technologies, which possess the key technical characteristics and market impact of analog radio. The technical characteristics are:

- Provision of content consisting of high quality stereo (“FM” - like) and lower quality mono (“AM” – like) audio information and entertainment;
- Providing reliable indoor and mobile reception;
- Use of terrestrial transmitters to serve a city or a region, allowing customisation of the service to local needs but also permitting a wide range of coverage in sparsely settled areas;
- Service delivery through free-to-air or cheap and ubiquitous receivers on a point-to-multipoint basis.

Several digital systems in existence or under development reproduce these key characteristics. These include:

- Eureka 147;
- The Ibiquity IBOC (In Band On Channel) systems for AM and FM radio;
- ISDB-T; and
- DRM

Digital systems that are capable of delivering audio entertainment and information have also been considered in this report to the extent that there has been publicly available information to consider. This group of technologies do not share all of analog radio’s key characteristics but have the potential to impact on the analog radio market. They have been included in this report on that basis and because the path to digitalisation in the radio industry remains unclear. It may well be that such technologies form a key part of a future digital audio information and entertainment environment which may have significantly different characteristics from the current analog radio industry. The group of digital radio systems included in this category and also covered in this report include:

- Satellite radio systems such as Sirius, XM Radio and Worldspace;
- Digital television systems, such as DVB-T;
- Internet services, including Internet radio and evolving wireless internet services.

How Digital Radio Works

Music and other analog radio content is typically extremely information-rich. It comprises 'a potentially unlimited range of values which progresses continuously through time'[4]. Digital broadcasting systems rely on a series of short cuts to reduce this to a manageable number of pieces of binary code, or 'bits,' per second. A bit consists of a single binary instruction, 0 or 1. These techniques include:

- *Sampling* – digital audio systems take large numbers of samples or snapshots of what is occurring each second (eg audio to be recorded on a compact disc (CD) is sampled 44 100 times in one second).
- *The 'quantising' of those samples*. The sample is then broken down into a finite series of values – thus, instead of an infinite range of values, the qualities of the sound, such as volume or pitch, are expressed as a finite series of steps or levels.

Once the sound has been sampled and quantised, it can be coded into binary form for transmission and reception. Even once sounds have been encoded into a finite number of bits, however, the amount of information that is to be transmitted is still challenging (a stereo CD track requires a bit rate of 1.4112 megabits per second (Mbit/s)). Engineers have therefore developed a further series of shortcuts, called *'audio compression'*, which reduce the amount of digital data required to be transmitted by stripping out redundant information or removing non-critical data.

There are a variety of audio compression techniques, which have evolved over many years. Improvements are continually being made, allowing the newer techniques to achieve similar audio quality as older techniques, but with lower bit rates and therefore greater efficiency.

Compressed digital audio can be conveyed to end listeners in a variety of ways, digital radio being just one. Others include, for example, the Internet, Wi-Fi and 3G mobile phones. In a digital radio system the compressed digital audio is transmitted directly to the end user not via wires, but by electromagnetic radio waves. This presents a key challenge to the system design as a radio transmission can suffer impairments such as interference from other signals and from noise sources, both man-made and naturally occurring (eg atmospheric noise). Whether the receiver is stationary or mobile is also an important design criterion as the characteristics of the radio channel will vary with time for mobile reception. Consequently, special 'modulation'[5] techniques are needed to ensure the receiver can accurately decode the signal after transmission through the radio channel.

The choice of modulation technique and coding/error protection is a key consideration in digital radio system design as they affect the performance of the system in the presence of noise and interference. All digital radio systems use digital modulation

---

4 Jock Given, 'Turning Off the Television: Broadcasting's Uncertain Future' UNSW Press, 2003, at pg. 85.

5 Modulation is the process used to transform the audio data to a form suitable for transmission.

techniques and many digital radio systems provide broadcasters with a choice of the modulation technique. Modulation techniques that have higher data transmission rates are generally more prone to interference than those modulation techniques with lower data rates. There is therefore a trade off between the data rate and the robustness of the system.

While some digital systems modulate just one carrier frequency, most digital radio systems modulate a large number of carriers using a technique known as Coded Orthogonal Frequency Division Multiplexing (COFDM). Hundreds or sometimes thousands of carrier frequencies are modulated with the digital audio signal(s) being spread (using a coding technique) across the available radio channel bandwidth. The use of COFDM assists in coping with the challenges of mobile reception and enables the use of single frequency networks where the same frequency or channel can be used at multiple transmission sites without mutual interference.

Additional coding methods are used to provide the receiver with the ability, within limits, to correct errors in the received and demodulated signal. Often such methods involve an amount of redundancy in the transmitted signal. In a number of systems the broadcaster can trade-off this redundancy/error protection for greater data throughput, which could be used for either greater audio quality or extra data services.

COFDM returns the greatest benefit in wider bandwidth systems where the large number of carriers provide some immunity to signal fading**.** Moreover, the wider bandwidth also provides a greater data carrying capacity and the ability to carry multiple audio signals or programs within the one radio channel. The multiplexing of signals together for transmission has infrastructure implications, as signals need to be distributed to a common point for multiplexing prior to broadcast. This is significantly different to the analog transmission approach of one transmitter per program.

Satellite transmission of digital radio signals faces unique challenges. It must overcome the problems of relatively low signal levels at the surface of the Earth and the potential for the signal to be blocked by local obstructions. These challenges have led to the use of multiple satellites in some systems and the use of terrestrial repeaters for more urbanised areas.

Overview of Digital Radio Systems

This chapter addresses areas of commonality across most or all of the digital radio systems discussed in this report.

Digital Audio Coding Techniques

Generation of a Digital Radio Signal

Figure 1 is a block diagram of a conceptual digital radio generator, based on the Eureka 147 model. Each audio or data service is coded individually at the source level, error protected and time interleaved in the channel coder. The services are then multiplexed in a main service channel multiplexer, according to a pre-determined, but adjustable, multiplex configuration. The multiplexer output is combined with multiplex control and service information to form the transmission frames. Finally, the signal is modulated, typically with Orthogonal Frequency Division Multiplexing (OFDM). The signal is then transposed to the appropriate radio frequency band, amplified and transmitted.

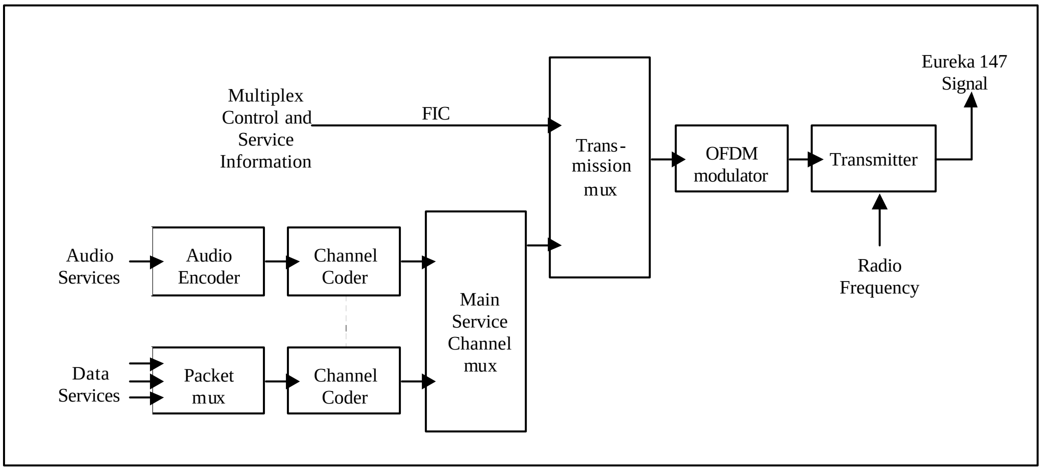

Figure 1: Digital Radio Signal Generation (based on Eureka 147)

Reception of a Digital Radio Signal

Figure 2 shows a conceptual receiver. The digital radio ensemble is selected in the tuner, the output of which is fed to the demodulator (typically OFDM demodulator), and channel decoder to eliminate transmission errors. Multiplex control and service information is passed to the user interface for service selection and to set up the receiver appropriately. The main service channel data is further processed in an audio decoder to produce the left and right audio signals, or in a data decoder as appropriate.

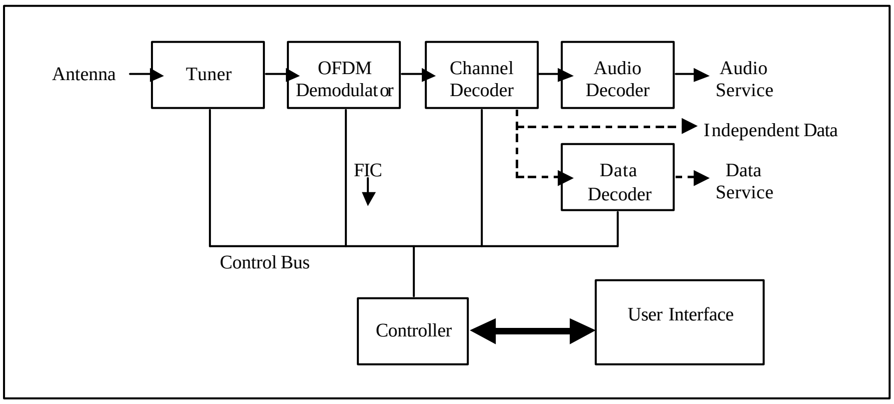

Figure 2: Digital Radio Signal Reception (based on Eureka 147)

Audio Compression

Digital radio systems reduce the audio source data rate by means of digital audio compression techniques, typically a low data rate sub-band coding system enhanced by a psychoacoustic model (see figure 3). Due to the specific behaviour of the inner ear, the human auditory system perceives only a small part of the complex audio spectrum. Only those parts of the spectrum located above the masking threshold of a given sound contribute to its perception, whereas any acoustic action occurring at the same time but with less intensity and thus situated under the masking threshold will not be heard because it is masked by the main sound event.

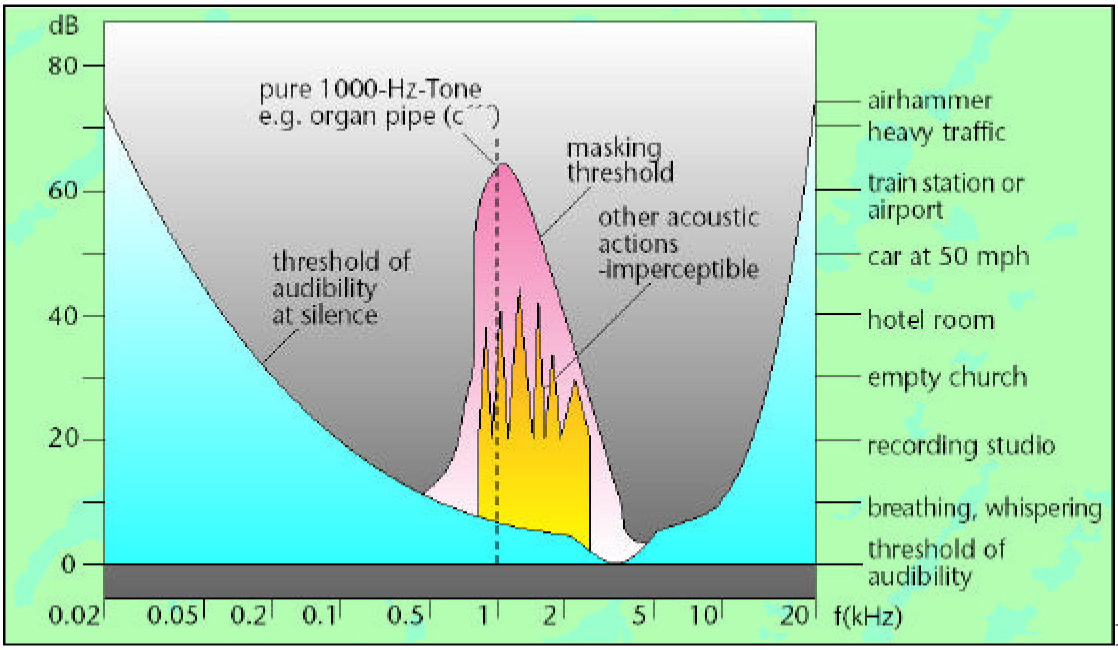

Figure. 3: Psychoacoustic Masking

To extract the perceptible part of the audio signal the spectrum is split into a number of equally -spaced sub-bands. In each sub-band, the signal is quantised in such a way that the quantising noise matches the masking threshold. Digital Radio standards do not generally prescribe the audio encoder - only the format of the coded bit stream and actions to be taken by the decoder. This approach has the advantage of allowing for future improvements in the encoder (ie further data rate reductions) without the need to change existing decoders (ie receivers). This approach, however, means that different encoders, although compliant with the standards, may afford different audio qualities.

Data Services

Program Associated Data

Each audio program contains a variable amount of Program Associated Data (PAD) which is used to convey information together with the sound program. Typical examples of PAD applications are dynamic range control information, a dynamic label to display program titles or lyrics, speech/music indication and text with graphic features.

Independent Data Services

In addition to PAD, general data may often be transmitted as a separate service, typically in the form of a continuous stream or in packet mode, where individual packet data services may have much lower capacities and are bundled in a packet sub-multiplex. Typical examples of Independent Data Services are a Traffic Message Channel, correction data for Differential GPS, paging and an electronic newspaper.

Conditional Access

Digital Radio systems may include Conditional Access (CA). Usually, the CA can be applied to any or all of the services within an ensemble. The CA system includes three main functions: scrambling/unscrambling, entitlement checking and entitlement management. The scrambling/unscrambling function makes the service incomprehensible to unauthorised users. Entitlement checking consists of broadcasting the conditions required to access a service, together with encrypted codes to enable unscrambling for authorised receivers. The entitlement management function distributes entitlements to receivers.

Service Information

The following elements of Service Information (SI) can generally be made available to the listener for program selection and for operation and control of receivers:

- basic program service label (ie the name of a program service);
- program type label (eg news, sports, classical music);
- dynamic text label (eg the program title, lyrics, names of artists);
- program language, time and date, for display or recorder control;
- switching to traffic reports, news flashes or announcements on other services;
- cross-reference to the same service being transmitted on another frequency or channel or via AM or FM and to other services;
- transmitter identification information (eg for geographical selection of information).

Essential items of SI that are used for program selection need to be made immediately available to the receiver. Information that is not required immediately when switching on a receiver, such as a list of all the day's programs, may be carried separately as a general data service (Auxiliary Information Channel).

Channel Coding and Time Interleaving

The data representing each of the program services is subjected to energy dispersal scrambling, convolutional coding and time interleaving. For energy dispersal scrambling a pseudo-random bit sequence is added to the data in order to randomise the shape of the transmission and thus efficiently use power amplifiers. The convolutional encoding process involves adding redundancy to the data in order to help the receiver detect and better eliminate transmission errors. In the case of an audio signal, some parts of the audio frame are less sensitive to transmission errors than others and accordingly, the amount of redundancy added might in some digital radio systems be reduced for these.

Main Service Multiplex

The encoded and interleaved data is fed to the main service channel (MSC) multiplexer where the data is gathered in sequences. The net data rate can vary depending on the convolutional code rate, which can differ from one application to another. The MSC multiplex can also be reconfigured from time to time. The precise information about the contents of the MSC multiplex is generally transmitted to the receiver using a highly protected and frequently repeated data stream to ensure its ruggedness, as the receiver needs this data to access the services.

Transmission Frame

In order to facilitate receiver synchronisation, the transmitted signal is designed according to a frame structure with a fixed sequence of symbols.

Audio Compression Standards

A number of audio compression standards have been developed since the early 1990s. Basically, each standard is a snapshot of the state of compression technology at the time the standard was formalised. The standard gives some certainty to digital radio systems implementers and equipment manufacturers. Research into compression technologies does not stop, though, and newer, better systems are continually being developed.

MPEG-1

The Motion Picture Experts Group (MPEG) is an international body that has developed a family of standards for the compression of digital video and audio services. MPEG-1 was developed for coding progressive scan video, typically non-broadcast video, at a transmission rate of about 1.5 Mbit/s. MPEG-1 had three audio compression systems or layers. Layer I is for high data rates (up to approx. 400 kbit/s) and has generally been used for high quality storage. Layer II is for medium data rates (up to approx. 256 kbit/s) and has been used for Eureka 147, the DVB digital television system and ISDN and digital cable television systems. Layer III is for low data rates (up to approx. 128 kbit/s) and has been widely used for ISDN and Internet audio services. Layer III is much better known as MP3.

MPEG-2

MPEG-2 was developed for coding higher data rate digital video, typically for broadcast television services. MPEG-2 is backward-compatible with MPEG-1 and supports the three MPEG-1 audio layers as well as adding low sampling frequency and discrete multi-channel sound enhancements.

In addition to the three MPEG-1 audio layers, a non-backward compatible, MPEG-2 AAC (Advanced Audio Coding) standard was developed as an extension of MPEG-1 Layer III.

MPEG-4

MPEG-4 takes a different approach to MPEG-1 and MPEG-2 and addresses speech and video synthesis, fractal geometry, computer visualisation, and an artificial intelligence approach to reconstructing images. MPEG-4 uses a tool-based approach to create audio at very low data rates (2 - 64 kbit/s). The tools include: text-to-speech, music synthesis, speech coders, surround sound, audio coding and the ability to mix and change the received audio.

MPEG-4 AAC is the MPEG-4 audio coding tool. It incorporates MPEG-2 AAC with additional tools increasing the effectiveness of MPEG-2 AAC at lower data rates, and adding scalability and error resilience characteristics.

A German Company, Coding Technologies GmBH, increased the efficiency of MPEG-4 AAC using their Spectral Band Replication technology to develop aacPlus (also known as CTaacPlus). This technology was subsequently incorporated into the MPEG standards system as MPEG-4 High Efficiency AAC or MPEG-4 HE AAC.

PAC

The IBOC digital radio system was developed using the Perceptual Audio Coder (PAC) compression technology originally developed by Lucent. PAC also utilises advanced signal processing and psycho-acoustic modelling to interpret human hearing and eliminate redundancies and irrelevancies in the audio signal. Recent developments may lead IBOC to change from PAC to some other audio coding system.

Audio Quality

The more advanced audio coding systems require a lower data rate to achieve the same quality service, but at the cost of increased complexity and increased coding/decoding delay.

Quantitative measures, such as signal-to-noise, frequency response or distortion cannot fully describe the quality of an audio compression system. Subjective listening tests are currently the only way to assess such systems, but unfortunately some material will sound fine to some people and terrible to others. Such systems should not be assessed by individuals - subjective tests with critical material and many listeners are needed to give a reliable indication of performance. There are newer objective perceptual measurement methods which use psychoacoustic models and subjective test data, but they are still not as reliable as subjective tests.

Subjective listening tests have been conducted by various organisations in an attempt to quantify the reduction in data rate for a given audio quality. While the tests clearly show that the more advanced audio coding techniques result in a significant data rate reduction over older systems, there is still a deal of conjecture as to what data rate is necessary to provide a given audio quality.

Each part of the broadcast chain has an impact on the quality of the delivered program. When data rate reduced systems are used one after the other (cascaded), the quality deteriorates. If several parts of the chain are only “just good enough” in isolation, the final result may not be “good enough” to transmit. Cascading of coding systems should be avoided wherever possible. When cascading is unavoidable, some coding “headroom” should be built in to each part of the system, for example by using a data rate that is more than “just good enough”.

In the early 1990s the ITU produced recommendations BS.774 and BO.789 which defined service requirements for digital radio to vehicular, portable and fixed receivers using terrestrial transmitters in the VHF/UHF bands and for broadcasting-satellite service (sound) in the frequency range 1 400 - 2 700 MHz.

The ITU recommended digital broadcasting systems be “capable of providing high-quality stereophonic sound of two or more channels with subjective quality indistinguishable from high-quality consumer digital recorded media (“CD quality”) to vehicular, portable and fixed receivers”.

Modulation

Most digital radio systems use an OFDM multi-carrier scheme. This scheme meets the exacting requirements of high bit- rate digital broadcasting to mobile, portable and fixed receivers, especially in multi-path environments where signals may arrive at the receiver from different directions with varying time delays. As all OFDM systems include a coding layer for improved error protection, the term Coded Orthogonal Frequency Division Multiplexing (COFDM) is usually used.

Before transmission the information is divided into a large number of bit-streams with low data rates each. These are then used to modulate individual orthogonal carriers using an appropriate modulation scheme. For example, Eureka 147 uses differential quadrature phase shift keying (DQPSK), in such a way that the corresponding symbol duration becomes larger than the delay spread of the transmission channels. By inserting a temporal guard interval between successive symbols, channel selectivity and multi-path propagation will not cause inter-symbol interference.

Output Spectrum

The large number of orthogonal carriers can be easily generated by a Fast Fourier Transformation (FFT) process. The spectrum of the signal is approximately rectangular and Gaussian noise-like. Figure 4 shows an example of a typical COFDM transmitter output spectrum.

With multi-path propagation, some of the carriers are amplified by constructive signals, while others suffer destructive interference (frequency selective fading). Therefore, the

COFDM system provides frequency interleaving by a re-arrangement of the digital bit-stream among the carriers, so that successive source samples are not affected by selective fade. In stationary receivers, this diversity in the frequency domain is the prime means to guarantee unimpaired reception; the time diversity due to time interleaving provides further assistance to a mobile receiver. Consequently, multi-path propagation is a form of diversity of which digital radio takes advantage, in stark contrast to conventional analog FM or narrowband digital systems, where it can completely destroy a service.

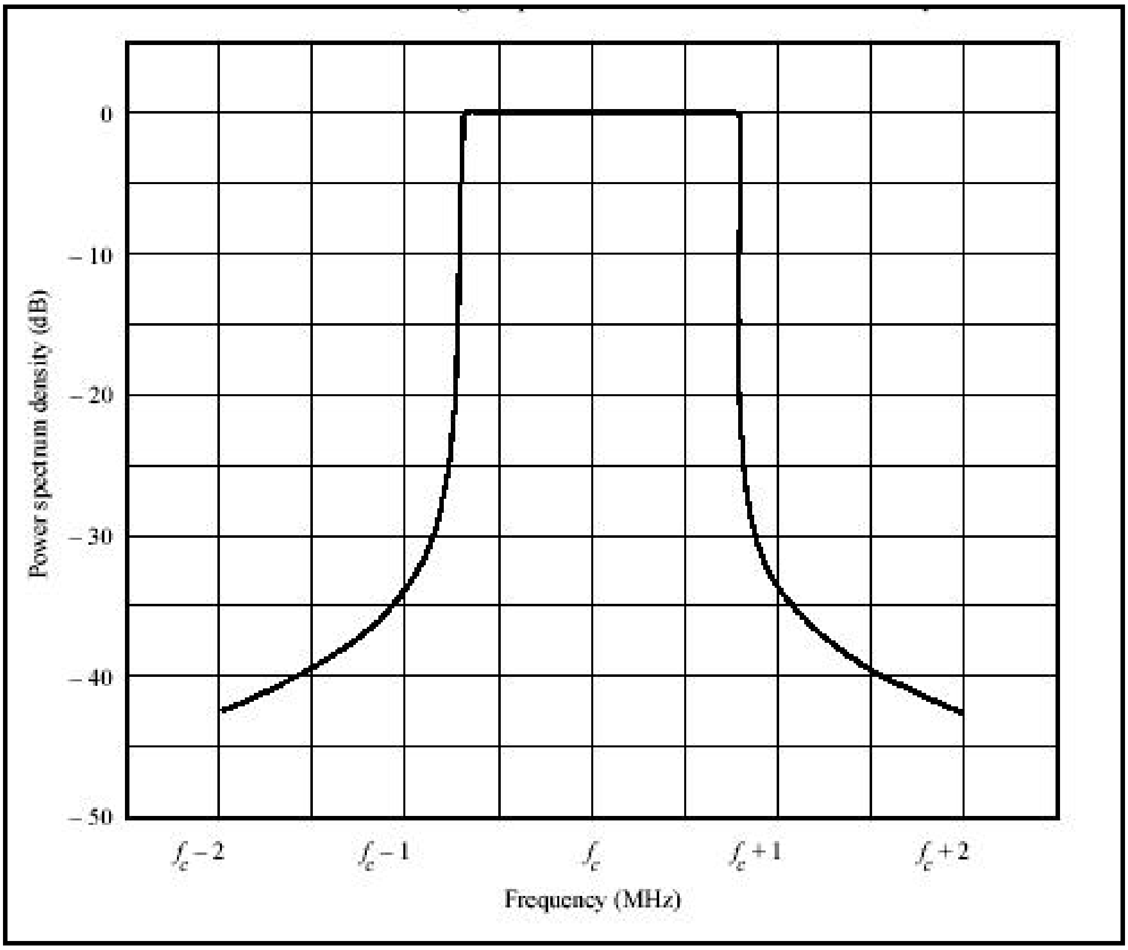

Figure 4: Theoretical Output Spectrum for digital radio (Eureka 147 Mode II)

Infrastructure Requirements

Infrastructure Models

Digital radio systems fall into three broad categories: Narrowband, Wideband and Satellite.

Narrowband digital radio systems (such as DRM and IBOC) provide a digital audio service in a similar bandwidth and spectrum as current AM and FM analog services. These systems can use very similar infrastructure to current analog systems providing similar coverage.

Wideband digital radio systems (such as Eureka 147 and ISDB-TSB) multiplex a number of audio and data services into a wideband signal in a different spectrum band to the analog radio services. Consequently, wideband systems will often have different infrastructure requirements to current analog radio services with resulting impact on licence areas and coverage.

Satellite digital radio systems (such as Worldspace, Sirius and XM Radio) provide national and international coverage in relatively wide bandwidths. They provide limited opportunity for localised programming, although local insertion of program material or advertising is possible at terrestrial repeater sites.

Siting

The coverage area of broadcasting services in the VHF and UHF bands is primarily determined by the transmitted power and height above the surrounding terrain. Consequently, services in these bands (ie FM radio, analog and digital television services and wideband digital radio services) will typically be transmitted from the tops of hills, buildings or towers.

In general, new wideband services are also likely to be co-located with existing FM radio or television services given the cost of developing new sites and the increasing difficulty in getting local council planning approval for new transmission sites.

Many higher power national and commercial FM services are currently co-located with television services and, if these services have complementary VHF or UHF wideband digital radio services, would be best suited using the same site. Conversely, most community and low–power FM services have their own transmission sites, which are often not co-located with television transmission facilities. If the digital radio system is to operate in a TV frequency band, co-siting with TV services will give the best spectrum productivity.

AM broadcasting services, on the other hand are generally sited at low flat sites, which would be unsuitable for wideband digital radio services, but would be suitable for narrowband digital radio services in the MF band using either the DRM or IBOC-AM standards.

Program multiplexing and distribution

Wideband digital radio systems which multiplex services need all program material to be sent to a common location for multiplexing and distribution to transmission sites. This is may not be a major concern in Europe where there is often a separation between network and service providers. In Australia though, broadcasters generally have control of their own service from the studio to the transmitter.

In some cases, particularly for high power commercial and national FM services, a common multiplex and transmission facility may be practicable. In the case of low power community services, a common multiplex and transmission infrastructure does not appear to be practicable without a major rearrangement of licence areas (eg. aggregation of smaller licence areas into larger licence areas).

Relationship to licence areas

The implementation of digital radio services will be complex if based on duplicating existing analog licence areas. Licence area boundaries do not always reflect actual service coverage, as other factors are taken into account when they are determined, eg the social and economic links between inhabitants and between the major urban centres in the area, governmental functions and responsibilities. The boundaries may be defined by adjacent licence areas (ie minimising overlaps), target markets and the nature of licence area definitions (ie the smallest element of a licence area definition is a Census collection district which could be quite large geographically).

There are many instances where a particular location will be able to receive radio services that have different licence areas and are transmitted from different sites, particularly where there is a mix of AM and FM, local and regional services.

In metropolitan areas, it may be possible to use a mixture of wide-area and local-area multiplexes that may also operate as Single Frequency Networks (SFNs). In regional areas, this would be spectrum inefficient in areas where there are insufficient services to fill a multiplex. Either efficiency could be compromised to allow multiple lower power local services or coverage and licence area requirements will be compromised with wider coverage spectrum efficient multiplexes.

Spectrum: Usage and Current Availability in Australia

Current Usage

Australian radio broadcasting services are predominantly delivered using two analog modulation systems.

Amplitude Modulation (AM) broadcasting services have a nominal bandwidth of 18 kHz and operate in the medium frequency band (MF). There are approximately 260 licensed AM broadcasting services with transmission powers ranging from 50 W to 50 kW.

Frequency Modulation (FM) broadcasting services have a nominal bandwidth of 200 kHz and operate in the very high frequency Band II (VHF Band II). There are approximately 1600 licensed FM broadcasting services with transmissions ranging from very low power to 250 kW effective radiated power (ERP).

The Australian AM and FM emission standards for radio broadcasting services are defined in Appendices 1 and 2 of the ABA Technical Planning Guidelines[6].

Other radio services are also delivered by other means, including direct-to-home satellite; HF (short wave) broadcasts; narrowcasting services and Narrowband Area Services (NAS).

Spectrum Bands

Digital radio services may potentially be implemented in one or more spectrum bands with each band having different coverage properties and existing usage (eg navigation aids, broadcasting services, point-to-point radiocommunications, land mobile, radar, etc).

The coverage of a digital radio service depends not only on its system characteristics and radiated power, but also on the spectrum band used and, in particular on the propagation or way the signal travels from the transmitter to the receiver. In different spectrum bands a digital radio emission may propagate by “bouncing” off layers of the atmosphere; follow the curvature of the earth; or travel directly from one point to another. The emission may pass through or around obstacles in one band that would completely block the emission in another band. In some bands coverage may also vary on an hourly, daily, seasonal or multi-year basis as radiation from the sun affects the height and density of the atmospheric layers. This is mostly apparent at lower frequencies which are refracted by the atmosphere while higher frequencies tend to pass through, or are attenuated by, the atmosphere.

6 http://www.aba.gov.au/tv/licensing/tpg/toc.htm

Other factors that change with the spectrum band used are the amount of information or data that can be transmitted; the size and nature of the transmission and reception antennas and the effect of interference from the sun, system noise and man-made source such as power lines and electrical motors.

Satellite systems are feasible in frequency bands in the vicinity of 1 - 3 GHz. Below 1 GHz, too much power must be transmitted to overcome man-made noise and the size of the antennas on the satellite are too large for practical use. Above 3 GHz, the gain of a practical omni-directional receive antenna[7] is too low to provide a reasonable service without a significant increase in satellite transmit power.

The International Telecommunication Union (ITU) manages the international co-ordination of radiocommunication services. The ITU has divided the world into three regions. Region 1 covers Europe (including Russia), the Middle East and Africa, Region 2 covers the Americas and Greenland and Region 3 covers Asia and Oceania.

ITU conferences allocate different service types (eg fixed, mobile, broadcasting etc) to frequency bands for each Region. Such allocations are specified in the ITU's Table of Frequency Allocations. However actual spectrum usage in countries within a Region may vary for a variety of reasons. Such departures from the Region's allocation are typically specified in 'footnotes' to the ITU Table of Frequency Allocations. Each national administration typically publishes its own frequency allocation table, which may contain local variations from the ITU table. Australia's is prepared by the Australian Communications Authority (ACA) and is known as the Australian Radiofrequency Spectrum Plan.

In its identification of appropriate frequency bands for digital radio at WARC-92 the ITU took into account the bands which could be accessed in the short term. These were VHF Bands I, II and III, UHF Bands IV and V and the 1.5 GHz, 2.3 GHz and 2.6 GHz Bands.

The principal coverage and usage issues for these bands in Australia are summarised in the following sections.

Low Frequency (LF)

The LF band is 30 - 300 kHz. In Europe (ITU Region 1) the band 148.5 - 283.5 kHz is allocated to the broadcasting service, but there is no corresponding allocation for the broadcasting service in ITU Region 3 (which includes Australia). Broadcasting in the LF band can provide extended coverage from a single transmitter, using ground wave propagation. These services are also referred to as "long-wave" services.

Medium Frequency (MF)

The MF band is 300 - 3000 kHz. Parts of the MF band, including 526.5 - 1606.5 kHz in ITU Regions 1 and 3, and 525 - 1705 kHz in ITU Region 2 are used for AM broadcasting services. The band 1606.5 - 1705 kHz is used in Australia for MF-NAS services. The MF wave transmission occurs by means of ground wave and sky wave. Mainly the ground wave propagation is used for coverage. Ground wave propagation is

[7] While higher gain can be obtained from directional antennas, such antennas are not suitable for mobile reception.

slightly less effective in the MF band in comparison to the LF band. Sky wave transmission is generally not intentional and may cause interference to distant services. This sky wave transmission mode necessitates international coordination of broadcasting services in the MF band. These services are also referred to as "medium-wave" services.

High Frequency (HF)

The HF band is 3 - 30 MHz. A number of bands have been allocated to the broadcasting service within the HF band. These allocations include frequency bands from 2.3 - 27 MHz. The HF broadcasting allocations are generally used for national or international broadcasting on a worldwide basis. These services are also referred to as "short-wave" services.

Under favourable propagation conditions HF transmissions can cover very large distances, using sky wave propagation as the intended transmission mode. As reception depends on the frequency of the transmission and the state of the ionosphere (part of the atmosphere), broadcasters operating on HF are often required to transmit the same signal at different frequencies, or to regularly change transmitting frequency, in order to increase the probability of reception in the intended target.

Very High Frequency (VHF)

The VHF Band is 30 – 300 MHz. Within the VHF Band there are three bands used for broadcasting as outlined below.

Very High Frequency (VHF) Band I

VHF Band I includes frequencies from 45 - 70 MHz and has, in part, been used to provide channel 0, 1 and 2 analog television services (amongst other non-broadcasting uses). VHF Band I transmissions generally follow the curvature of the earth but may also bounce off the atmosphere, particularly in the summer months. Services in VHF Band I are also particularly susceptible to interference from man-made noise.

Very High Frequency (VHF) Band II

VHF Band II covers 87.5 - 108 MHz and is generally used for FM broadcasting although it has also been used for television broadcasting in Australia. VHF Band II transmissions have lower anomalous seasonal propagation problems than VHF Band I but are still susceptible to interference from man-made noise.

Very High Frequency (VHF) Band III

VHF Band III covers 174 - 230 MHz and is generally used for television broadcasting. The spectrum from 230 - 240 MHz is used for radiocommunication services, particularly by defence, but has been identified as being possibly suitable for digital radio services, particularly in Europe.

VHF Band III transmissions follow the curvature of the earth and are well suited to the provision of terrestrial digital radio services over large coverage areas (possibly up to a radius of 100 KM). VHF Band III has lower man-made noise and does not suffer from a number of the anomalous propagation characteristics, which are a problem in Bands I and II.

Ultra High Frequency (UHF) Band IV and V

The UHF Band is 300 – 3000 MHz. Within the UHF Band there are two sub-bands that are generally used for terrestrial analog broadcasting. UHF Band IV covers 470 - 582 MHz and UHF Band V covers 582 - 820 MHz. They are generally used for television broadcasting, although only the spectrum above 526 MHz has been used for television in Australia. UHF Band IV and V transmissions travel more or less in straight lines with greater curving or diffraction evident at the lower frequencies. While the UHF bands are not generally affected by man-made noise and anomalous propagation to the same extent as VHF transmissions, they do not cover as wide an area as they tend to be attenuated by local terrain obstructions such as buildings, hills and trees.

L-Band

The L-Band covers 1 – 2 GHz and is part of the UHF Band. The sub-band 1452 - 1492 MHz has been identified by the ITU as suitable spectrum for terrestrial and satellite delivered digital radio services. It is currently used for fixed point-to-point and point-to-multipoint services, including Telstra's Digital Radio Concentrator System (DRCS) service in regional and remote areas of Australia. The band was allocated to the broadcasting service and the broadcasting satellite service (sound) in all three ITU regions at the ITU World Radio Conference in 1992 (with a few countries opting out – including the USA). The assignment of new services in this band has been constrained by the ACA, pending consideration on the possible future use of the band by terrestrial or satellite digital radio services. L-Band frequencies are characterised by higher propagation losses than the lower frequency bands.

S-Band

The S-Band covers 2 – 4 GHz and overlaps the UHF and SHF (3 - 30 GHz) Bands. Two sub-bands 2310 - 2360 MHz and 2535 - 2655 MHz have been identified by the ITU as suitable spectrum for satellite delivered digital radio services for certain countries. The lower band is available in the USA, Mexico and India, and the upper band in Korea (Rep. of), India, Japan, Pakistan, and Thailand. Australia does not have allocations for the broadcasting service and the broadcasting satellite service (sound) in these bands.

Eureka 147

Background

System Overview

Eureka 147[8] is a digital radio system developed in Europe for reception by mobile, portable and fixed receivers with a simple non-directional antenna. It can be used in terrestrial, satellite, hybrid (satellite with complementary terrestrial), and cable broadcast networks and has been designed to operate at any frequency from 30 - 3000 MHz. In practice, Eureka 147 is being implemented in two spectrum bands, VHF Band III and L-Band. [1]

System Development

Eureka[9] was established in 1985 by 17 countries and the European Union to encourage a bottom-up approach to technological development and to strengthen the competitive position of European companies on the world market. It supports the competitiveness of European companies through international collaboration, in creating links and networks of innovation. The 147th Eureka technical project was to develop a digital radio system, hence Eureka 147. DRM is also a Eureka project.

The Eureka 147 Consortium[10] was founded in 1986 with 16 partners from Germany, France, The Netherlands and the UK. The Eureka 147 standard was defined in 1993 with ITU Recommendations released in 1994 and an initial ETSI standard released in 1995. Eureka closed the Eureka 147 project on 1 January 2000.

The first Eureka 147 prototype equipment was demonstrated in 1988 with third generation equipment widely used for test purposes from 1993. The first consumer-type Eureka 147 receivers developed for pilot projects were released in 1995. The first Eureka 147 services commenced transmitting in the UK and Sweden in 1995. Eureka 147 was officially launched at the Berlin IFA (a major consumer electronics show) in 1997.

The WorldDAB Forum[11] was formed in 1995 to encourage international cooperation and coordination for the introduction of Eureka 147 onto the consumer market. The technical work previously carried out by Eureka 147 now takes place within the Technical and Commercial Committee of the WorldDAB forum. In August 2003, DRM and WorldDAB announced they would collaborate in the development of their systems.

---

8 Eureka 147 is also known as DAB, Eureka DAB, S!147 (S! is the logo for Eureka projects) and ITU System A . T-DAB and S-DAB may also be used to distinguish between terrestrial and satellite versions of Eureka 147.

9 Further information on Eureka at www.eureka.be

10 Further information on Eureka-147 consortium at http://www.eureka.be/ifs/files/ifs/jsp-bin/eureka/ifs/jsps/projectForm.jsp?enumber=147.

11 Further information on WorldDAB forum at http://www.worlddab.org/dab

Australian Consideration of Digital Radio[12]

In 1994, the Australian Broadcasting Authority (ABA) convened a Digital Radio Broadcasting Task Force, which reported in October 1996. In August 1995 the Federal Government established the Digital Radio Advisory Committee. Its report "Digital Radio Broadcasting in Australia" was presented in August 1997. In 1998 the Federal Government formed a Digital Radio Planning and Steering Committee to examine planning issues and formulate legislative proposals to facilitate the introduction of digital radio services in Australia. A specialist Technical Working Group of the committee prepared an "Australian Notional Terrestrial Allotment Plan for L-Band" in February 2000.

The Communications Laboratory of the Department of Communications, Information Technology and the Arts (DCITA), in conjunction with Optus and the then National Transmission Agency (NTA) conducted a series of satellite trials of Eureka 147 between June 1996 and January 1997. The Communications Laboratory and NTA conducted terrestrial L-Band trials in Canberra from January 1997. The DR2000 group (2DAY, 2KY, 2WS, ABC classic and Racing Radio) commenced Eureka 147 terrestrial trials on L-Band in Sydney in June 1999 and is still operating. Commercial Radio Australia (formerly Federation of Australian Radio Broadcasters) is currently planning further terrestrial trials of Eureka 147 in Sydney in the VHF band.[13]

Advantages/Disadvantages

Advantages

- Eureka 147 is a mature technology that has been implemented in the UK, Germany and Canada and extensively tested in other parts of Europe and in other countries including Australia.
- Eureka 147 is defined by international ITU recommendations, European ETSI, Cenelec and IEC standards and national standards (ie British receiver standards).
- Many ancillary aspects of the Eureka 147 system, such as multimedia delivery, distribution interfaces and user interactivity are also formally defined in ETSI standards.
- Eureka 147 can be implemented for a range of applications such as wide-area or local delivery of audio and data services for mobile, portable and fixed reception. It can be delivered terrestrially, via satellite, cable or a mixture of terrestrial and satellite.
- Eureka 147 is designed to be used across a wide spectrum range, from 30 - 3000 MHz, but has only been implemented using VHF Band III and the 1452 - 1492 MHz segment of the L-Band.
- Eureka 147 uses a wideband COFDM modulation system which provides a robust transmission which is multi-path resilient and can provide high availability coverage.

---

[12] DCITA DAB reports at http://www.dcita.gov.au/Article/0,,0_1-2_10-3_485-4_10720,00.html#Index

[13] CRA http://www.commercialradio.com.au/

- Eureka 147 can be implemented using on-channel repeaters in SFNs or low power gap fillers and extenders. SFNs may also provide "network gain" giving improved service availability over single channel services.
- Eureka 147 can accommodate a varying number of audio services of differing quality with associated data. The audio quality can range from simple mono speech to CD quality. An increase in quality requires higher data rates for each audio service, hence reducing the number of services that can be delivered. Data can also be delivered independently of the audio services.
- Eureka 147 uses mature technologies such as MPEG-1 Layer II and MPEG-2 Layer II audio coding systems and COFDM modulation, which are also used in the DVB-T video broadcasting standard. This should lead to cheap single chip solutions for receivers.
- Eureka 147 has been extensively standardised by European standards organisations and it would be fairly straightforward for these standards to be adopted as Australia standards by Standards Australia.
- A growing number of Eureka 147 receivers are now available for portable, in-car and in-house reception.

Disadvantages

- The MPEG-1 Layer II and MPEG-2 Layer II audio coding systems are now somewhat dated and sub-optimal compared to new systems. While programs using newer coding systems could in theory be accommodated as independent data, receivers would need to be adapted or replaced to receive these services.
- While a range of receivers is available, they are still generally seen as being too costly for general public acceptance, particularly when compared to the very cheap AM and FM radios that many listeners currently use. This is an issue for all digital radio systems and, as Eureka 147 services expand, the cost of receivers is expected to drop.
- Eureka 147 requires services to be multiplexed together before transmission. All audio programs and data services in a given Eureka 147 channel will therefore have similar coverage and reception quality. If Eureka 147 were implemented as a conversion service for existing broadcasters, this would require broadcasters who currently manage their own transmission facilities to use a common transmission provider.
- The standard capacity of Eureka 147 multiplexes means that conversion would require existing services to be grouped into blocks of 5 or more services per multiplex, all of which would then cover the same area. In a conversion model, this would pose challenges for many current radio broadcasting markets, which are typically served by a mixture of narrowcasting, community, commercial and national services using AM and FM frequencies with different or overlapping licence and coverage areas giving local, medium or wide-area coverage. Conversely, the requirement for multiplexing could over time reduce the number of transmission sites and result in more consistent coverage of services.

- Eureka 147 uses spectrum that is often used for analog and digital television services (VHF Band III), defence services (top of VHF Band III) and radiocommunication services (L-Band). If a conversion model is used for the introduction of digital radio finding sufficient spectrum for the conversion of all analog radio broadcasting services to digital will not be easy, particularly as L-Band will require more transmitters to provide wide-area coverage and adequate reception in urban areas.

System Description

Like almost all digital radio systems, Eureka 147 uses standard audio compression techniques and COFDM. As Eureka 147 was the first standardised digital radio system, the audio compression techniques used in all Eureka 147 implementations are now some-what dated. Refer to the Overview section of this report for further information on coding and modulation techniques.

A Eureka 147 transmission has an emission bandwidth of 1.536 MHz, which is capable of providing a range of useful data rates depending on the level of protection. The multiplex contains audio programs; program associated data and, optionally, other data services. Each audio program or data service is independently error protected with a variable coding overhead, the amount of which depends on the requirements of the broadcasters (transmitter coverage and reception quality). A specific part of the multiplex contains information on how the multiplex is configured, so that a receiver can decode the signal correctly, and, possibly, information about the services themselves, the links between different services, and conditional access information for subscription services.

Eureka 147 is a mature system with 29 standards and related documents published by the European Telecommunication Standards Institute (ETSI). The ITU has included details of the Eureka 147 system in its Digital Sound Broadcasting (DSB) Handbook and Recommendations BS.1114 and BO.1130.

Modes of Operation

Eureka 147 provides four transmission mode options that allow for a wide range of transmission frequencies, between 30 and 3000 MHz, and network configurations. For the nominal frequency ranges, the transmission modes have been designed to provide good mobile reception by overcoming multi-path echoes, which occur when the signal bounces off buildings and other objects and receivers must deal with multiple and slightly out of phase versions of the same signal.

Mode I is most suitable for a terrestrial SFN in the VHF range, because it allows the greatest distances between transmitters. Mode II is most suitable for hybrid satellite/terrestrial transmission up to 1.5 GHz and local radio applications that require one terrestrial transmitter. Mode II can also be used for a medium-to-large scale SFNs in the L-Band by inserting, if necessary, artificial delays at the transmitters and/or by using directive transmitting antennas. Mode III is most appropriate for cable, satellite and complementary terrestrial transmission, since it can be operated at all frequencies up to 3 GHz for mobile reception and has the greatest phase-noise tolerance. Mode IV is most suitable for medium-to-large scale SFNs in the L-Band while still accommodating mobile reception at reasonable highway speeds (up to approximately 120 km/h). However, it is less resistant to degradation at higher vehicle speeds than this.

Table 1: Eureka 147 Transmission Parameters

System Parameter	**Transmission Mode**			
	I	**II**	**III**	**IV**
No. of radiated carriers	1536	384	192	768
Nominal Maximum transmitter separation for SFN	96 km	24 km	12 km	48 km
Nominal frequency range for mobile reception	≤ 375 MHz	≤ 1.5 GHz	≤ 3 GHz	≤ 1.5 GHz
Speed/Coverage trade off	No	No	No	Yes
Frame Duration	96 ms	24 ms	24 ms	48 ms
Total Symbol Duration	1246 µs	312 µs	156 µs	623 µs
Useful Symbol Duration	1000 µs	250 µs	125 µs	500 µs
Guard Interval Duration	246 µs	62 µs	31 µs	123 µs
Null Symbol Duration	1297 µs	324 µs	168 µs	648 µs

Audio and Data Capacity

General aspects of Audio Compression and Modulation are covered in the Overview section of this report.

Total Data Capacity

Audio and data services are carried in the main service channel (MSC) of the Eureka 147 multiplex. This channel supports a gross data rate of 2.304 Mbit/s. However, the net data rate (ie the actual capacity available for use) depends on the protection level applied to services. For audio-only services the net capacity of the ensemble varies between 783 (highest protection) and 1728 kbit/s (lowest protection). The corresponding range for data-only services is 576 and 1728 kbit/s. At a median protection level the available net capacity for both audio and data services is 1.152 Mbit/s.

Within the MSC each audio or data service is carried in a sub-channel. Up to 63 sub-channels can be supported, each of which is treated individually as far as error protection is concerned.

Data Services

Each audio program contains PAD with a variable capacity (minimum 667 bit/s, up to 65 kbit/s) which is used to convey information together with the sound program. Typical examples of PAD applications are dynamic range control information, a dynamic label to display program titles or lyrics, speech/music indication and text with graphic features.

Additionally, general data may be transmitted as a separate service. This may be either in the form of a continuous stream segmented into 24 ms logical frames with a data rate of n x 8 kbit/s (n x 32 kbit/s for some code rates) or in packet mode, where individual packet data services may have much lower capacities and are bundled in a packet sub-multiplex. A third way to carry independent data services is as a part of the Fast Information Channel (FIC) that carries multiplex control and service information. Typical examples of independent data services that could use the FIC are a Traffic Message Channel, correction data for Differential GPS and paging.

Some elements of Service Information (SI) data can also be made available to the listener for program selection and for the operation and control of receivers. For example, the name of a program service; the program type, title and language; transmitter identification and controls for switching to traffic reports, news flashes or announcements.

Number of audio services in a multiplex

Eureka 147 uses MPEG-1 Layer II and MPEG-2 Layer II audio compression standards and permits full data rate coding at the sampling frequency of 48 kHz and half data rate coding at the sampling frequency of 24 kHz. Half data rate coding is not fast enough to capture all of the information in a speech signal so this sampling rate is only used where some distortion.

Eureka 147 is capable of processing mono, stereo and dual-channel (eg bilingual) programs. A range of encoded data rate options are available (8, 16, 24, 32, 40, 48, 56, 64, 80, 96, 112, 128, 144, 160 or 192 kbit/s per monophonic channel). In stereophonic or dual-channel mode, the encoder produces twice the data rate of a mono channel. The range of possible options can be utilised flexibly by broadcasters depending on the quality required and the number of sound programs to be broadcast.

A stereophonic signal may be conveyed in the stereo mode, or - particularly at lower data rates - in the joint stereo mode. This mode, typically used at 144 - 224 kbit/s, uses the redundancy and interleaving of the two channels of a stereophonic program to maximise the overall perceived audio quality.

The degree of error protection (and hence ruggedness) can also be varied to meet the needs of the broadcasters. In the case of audio services, five protection levels (1 to 5) have been specified in order to cater for a variety of applications. Level 5 affords the lowest protection and is designed for cable systems. It allows a high number of program services, but does not have the strong error protection necessary for operation in multi-path environments. Protection Level 3 is better suited to mobile operation. To allow more flexibility in accommodating sub-channels, Protection Levels 4 and 2 have also been introduced with somewhat weaker and stronger performance than Protection Level 3 (respectively). Protection Level 1 is suited to applications with a very high sensitivity to transmission errors while Protection Level 4 is intended for less demanding applications (for example services addressed to fixed receivers).

Table 2 outlines the typical number of services that can be delivered for a selection of audio data rates for different levels of error protection.

Table 2: Example of possible number of programs

Audio data rate (kbit/s)	Protection level (increasing protection)				
	5	4	3	2	1
24*	N/A	64	48	36	24
32	54	41	36	29	24
64	27	20	18	14	12
128	13	10	9	7	6
192	9	7	6	5	4
224	7	6	5	4	3
256	6	5	4	3	3

* At most audio data rates, Eureka 147 uses Unequal Error Protection - an error protection procedure which allows the bit error characteristics to be matched with the bit error sensitivity of the different parts of the audio frame. At the lowest data rate, 24 kbit/s, Eureka 147 uses Equal Error Protection –an error protection procedure which ensure a constant protection of the bit stream.

Audio Quality

General aspects of Audio Quality are covered in the Overview section of this report.

ITU-R Recommendation BS.1115 specifies use of MPEG-1 Layer II at 256 kbit/s (stereo mode), for broadcast applications requiring CD quality. This recommendation is based on subjective listening tests undertaken in 1992. At the time, MPEG-1 Layer II at 192 kbit/s (joint stereo mode) was also tested but was found to only marginally meet the audio quality requirement. Additional tests in 1993 failed to reveal sufficient improvement in the codec to warrant inclusion of this lower data rate in the ITU recommendation.

Further listening tests were performed in 1995, as part of the US Electronic Industries Association's (EIA) evaluation of digital radio systems. A range of audio coding systems were tested including MPEG-1 Layer II at 224 and 192 kbit/s (joint stereo modes). The findings of this work indicate the MPEG-1 Layer II codec at 224 kbit/s is capable of meeting the basic audio quality criteria specified by the ITU-R. The lower rate of 192 kbit/s again failed to meet the required quality.

Is CD quality what listeners want? - the UK Experience

The UK Radio Authority[14] guideline for licensees defines a minimum data rate for all program services on a multiplex, dependent on whether each is at the time predominantly speech or music, mono or stereo [8]. The data rate minima which apply to sound program services are given in Table 3.

[14] Following the recent enactment of the UK Communications Act 2003 the new regulator, Ofcom, will carry out functions formerly undertaken by the UK Radio Authority.

Table 3: UK Radio Authority data rate minima for sound program services

music services, stereo	128 kbit/s
music services, mono	64 kbit/s
speech services, stereo	128 kbit/s
speech services, mono	64 kbit/s

However, the Radio Authority hopes that the flexibility to use higher data rates for better audio quality will be used creatively to maximise digital radio's appeal to the public. The guidelines also stress that there is no expectation or preference that services would normally be confined to the specified minimum data rates.

A general range of expected values would be, for example:
speech programs, mono: 64-96 kbit/s
music programs, stereo: 128-256 kbit/s

At the 2003 Australian Broadcasting Authority Conference, Mr Clive Morton from Broadcast Australia [9] stated:

> "Firstly, it is questionable whether the audience really wants that extra quality step up from what can be delivered at a lower data rate equivalent to "FM" quality. Secondly, audio compression techniques and performance have come a long way in recent years and still have further to go … subjective tests are currently running to assess performance at 112kbit/s using a new breed of encoder-multiplexers. The Canadian Research Centre is working on compression techniques and psychoacoustic testing so as to further reduce the required data rate, and anticipates high quality stereo data rates at or close to 64kbit/s."

At the same conference, Jeff Astle from the UK commercial multiplex operator DigitalOne reported that in the UK, on average 10 stations were provided per multiplex at data rates of approximately 64 kbit/s for speech and 128 kbit/s for music.

Conversely, there have been concerns raised by "early adopters" and "sound purists" that UK broadcasters, for commercial reasons, are compromising audio quality to maximizing the number of available services. In a submission to the Radio Authority, Dr David Robinson of the University of Essex summarised subjective listening test data that suggested that MPEG Layer II audio at 128 kbit/s was, on average, worse than FM (see table 4). [10, 11]

Table 4: Comparison of MPEG-Layer II with FM

MPEG layer II stereo data rate (kbit/s)	**Audio quality**	
	Compared to FM on average	**Compared to FM at worst/best**
256	Much better	Very rarely worse than FM; usually much better
192	Better	Rarely worse than FM; sometimes much better
160	Similar	Sometimes worse; sometimes better
128	Worse	Sometimes much worse; sometimes better

Dr Robinson's submission also included data from a website [12] which monitors Eureka 147 ensembles around the world which claimed that many more UK broadcasters were using 128 kbit/s than internationally and in a regulatory environment where the only restraint on data rate is the imposition of an absolute minimum, and whole multiplexes are licensed to a single operator, very few broadcasters will choose to provide better than minimum audio quality.

The UK Magazine "What Hi-Fi" had an article on 12 November 2002 entitled "BBC advice: stick to FM for quality". The BBC Reception Advice service response to a complaint about the BBC reducing the data rates at which digital stations are broadcast was: "The pursuit of more channels within the current allocation of multiplex capacity has led to a reduction in subjective quality of output, DAB no longer delivers quality that can be considered hi-fi when compared with domestic CD reproduction. Therefore, for the foreseeable future, FM will remain the medium more likely to please you."

The BBC later claimed that the response was a personal view of the Reception Advice operator, not a BBC view claiming "We've not compromised sound quality: the vast majority of digital-radio listeners will hear an improvement in sound quality, with a significant reduction in interference."

The BBC has been altering data rates to accommodate new services aiming to strike a balance between improved programming choice and sound quality. Some Radio 3 transmissions have been reduced to 160 kbit/s from 192 kbit/s, while Radio 4 broadcasts have been cut to 128 kbit/s, and even 80 kbit/s for some mono services.

Manufacturers of Eureka 147 equipment aren't impressed with the reduction in quality, particularly those manufacturers promoting premium equipment.

Spectrum Issues

Eureka 147 Channel Plans

In 1995, the introduction of terrestrial Eureka 147 was discussed by the European Conference for Posts and Telecommunications (CEPT) in Wiesbaden [2]. In cooperation with representatives of regional and international organisations such as the EBU, the European Commission and the ITU a total of 73 channels to be used for future and current digital audio broadcasting services was agreed. Each channel is 1.536 MHz wide with appropriate guard bands between each channel and at the edge of each band.

The European CEPT channel plan encompasses four frequency bands, namely VHF Bands I, II and III and L-Band. Allotments were made to allow the implementation of two Eureka 147 ensembles in any given country or area in Europe. The majority of these allotments were in VHF Band III and the lower part of the L-Band (1452 MHz - 1467 MHz). Allotments in the 230 - 240 MHz sub band of VHF Band III are subject to coordination with national defence users and the L-Band was divided into terrestrial and satellite segments. Further consideration of L-Band allotments was made at a second CEPT conference at Maastricht in 2002.

A second channel plan has been developed for Canada that covers only the L-Band. This plan also provides for 23 channels, but with different guard bands to the CEPT Plan.

Comparing the characteristics of the two plans, the Canadian channel plan provides an interchannel guard band some 18% greater than the CEPT channel plan. Maximizing the spacing between adjacent channels is desirable, as this contributes to improved adjacent channel isolation which results in less stringent implementation constraints. In contrast, the CEPT channel plan trades off a larger inter-channel guard band for increased guards at the band edges to facilitate sharing with other services operating near the band edges.

To facilitate receiver tuning and minimize scan times, manufacturers will assume, or at least prioritise, the use of certain centre frequencies as defined by the CEPT and/or Canadian channel plans. The use of 'non-standard' frequencies could result in the need for manual tuning or, alternatively, require the receiver to undertake a complete scan of the band(s) based on the 16 kHz grid spacing. The latter is likely to take considerably longer and could be seen as a distinct disadvantage. Although manufacturers have been encouraged to incorporate the Canadian channel plan in their designs, it remains unclear what level of support will be afforded to the plan and whether there are cost implications for manufacturers in supporting both channel plans.

For Australia, there is a further complication if VHF Band III is used for digital radio. In this scenario, adoption of the Canadian channel plan would result in a 'mixed' frequency table arrangement (ie use of the CEPT channel plan at VHF Band III and the Canadian channel plan at L-Band). In view of these uncertainties, adoption of the Canadian channel plan would appear justified only if significant benefits, in terms of improved adjacent channel isolation, were shown to be associated with the wider channel spacing of this plan. In the absence of any published data, the Communications Laboratory undertook measurements of the adjacent channel isolation afforded by the two channel plans, using a limited range of transmitting and receiving equipment available at that time. The results of these tests indicate no significant difference in adjacent channel performance [3].

Australian Notional Terrestrial Allotment Plan

In 1998 and 1999 a Technical Working Group (TWG) of the Australian Digital Radio Planning and Steering Committee (established by the Federal Government in June 1998) developed a 'notional' Terrestrial Allotment Plan for the L-Band [4]. The frequency allotment process was based on a number of assumptions which included:

- Based on the Eureka 147 system;
- Each multiplex to be shared by five services of 224 kbit/s each, thereby enabling each broadcaster to provide the equivalent of a "CD quality" audio service (ie protection level 3 assumed);
- Replacement of service for the current AM and FM broadcast services with some consideration of additional capacity to allow for new services;
- Implemented in the L-Band spectrum with consideration to be given to use of VHF Band III for regional and remote services, subject to spectrum availability;

- Reservation of sufficient spectrum to accommodate six Eureka 147 channels for possible nation-wide satellite delivered digital radio services, preferably in the relatively 'clean' mid-band gap.

Guided by these principles, the Technical Working Group developed technical criteria to assist in the frequency allotment process. Amongst the key planning criteria adopted by the Working Group were:

- Planning to be based on a target service availability, for both location and time, of 95%;
- Adoption of the CEPT plan for VHF Band III and the L-Band.

The report consisted of a number of channel allotment exercises to estimate the amount of spectrum that could be allotted for Eureka 147 services in the L-Band. The conclusions were tentative. There appeared to be little immediately available capacity in the VHF Band III spectrum, only the 6 MHz of channel 9A in the major capital cities, enough for three multiplexes only. The lightly used parts of the L-Band would not be quite sufficient to accommodate all existing analog services at near-CD quality. The report showed that substantial additional capacity in L-Band could be made available if incumbent fixed services could be cleared. If this were done potential exists for full conversion of existing services using L-Band alone over time.

Planning Parameters

The planning parameters that could be used for the implementation of Eureka 147 services in Australia (and were assumed for the Australian Notional Terrestrial Allotment Plan) draw on a number of ITU and European sources:

- The ITU DSB Handbook;
- EBU 'Technical bases for T-DAB services network planning and compatibility with existing broadcasting services', Document BPN 003 Rev. 1, May 1998;
- Chester 97, 'The Chester 1997 multilateral coordination agreement relating to the technical criteria, coordinating principles and procedures for the introduction of terrestrial digital video broadcasting (DVB-T)', 25 July 1997;
- ITU-R Recommendation BT.1368 - "Planning criteria for digital terrestrial television services in the VHF/UHF bands", 14 April 1998.

Availability of Spectrum in Australia

Refer to the section on Spectrum Usage for general discussion of Australian spectrum availability and propagation properties.

VHF Band I

While the Eureka 147 system is capable of operating in VHF Band I and there have been some preliminary digital radio allotments in this band in Europe, current receivers do not operate in this band and there do not appear to be any actual proposals to implement Band I digital radio services.

Band I is currently used for analog television services in Australia. There are two high power and three low power channel 0 (45 - 52 MHz) services, seven high power and three low power channel 1 (56 - 63 MHz) services and ten high power and 17 low power channel 2 (63 - 70 MHz) services in Australia.

Digital television services are not being planned in this band (because of the relatively high level of man-made noise). The band could therefore be used for other purposes post analog television switch off.

VHF Band II

In Australia, as in most parts of the world, VHF Band II is extensively used for FM radio services. To fit Eureka 147 into this spectrum would require significant reorganisation or closure of FM services to clear sufficient spectrum for the 1.5 MHz wide Eureka 147 channels. Therefore, VHF Band II does not appear to be a viable candidate for the short or medium term introduction of digital radio services.

As for VHF Band I, current Eureka 147 receivers do not operate in this band and there do not appear to be any actual proposals to implement Band II Eureka 147 services.

Australia also has a number of VHF Band II television services which limit the spectrum for analog FM services, and consequently, future digital radio services, in areas adjacent to the transmissions. There are 11 channel 3 (85 - 92 MHz) services, two channel 4 (94 - 101 MHz) services and one channel 5 (101 - 108 MHz) service.

In the long term, subject to receiver availability issues being addressed, VHF Band II may be suitable for terrestrial digital radio services following the closure of FM radio services.

VHF Band III (Broadcasting)

In Australia, the VHF Band III spectrum from 174 - 230 MHz is used for broadcasting PAL-B analog television services and DVB-T digital television services. The spectrum is divided into eight 7 MHz wide channels with channels 9A and 12 only made available for television services in the 1990s.

Many channel 10 and 11 analog television services operate on an old channel alignment that results in channel 9A being limited to 6 MHz. Consequently, channel 9A cannot be used for a digital television service in areas where channel 10 is on the old alignment, unless the analog television service shifts up in frequency by 1 MHz.

In the five major Australian cities of Adelaide, Brisbane, Melbourne, Perth and Sydney, channels 7, 9 and 10 (on the old channel alignment) are used for high power analog television transmissions and channels 6, 8, 11 (on the new alignment) and 12 are used for high power digital television services. This leaves only 202 - 208 MHz and 215 - 216 MHz unused. This may be sufficient spectrum for three Eureka 147 channels in the 202 - 208 MHz portion, although there is some question whether the first of these Eureka 147 channels may cause unacceptable interference to the sound carriers of the lower adjacent analog television service, particularly if the Eureka 147 and television services are not co-sited. Trials proposed by Commercial Radio Australia (CRA) in channel 9A in Sydney will provide more data on the potential for interference. Shifting the analog television service on channel 10 up by 1 MHz should provide adequate spectrum for a fourth Eureka 147 channel.

As noted above, to avoid interference to television services, the Eureka 147 services would frequently be constrained to operate from television rather than radio sites, potentially leading to the loss or merger of some existing terrestrial radio markets.

Although VHF Band III may not be used for television services in large cities directly adjacent to metropolitan areas, (ie Sunshine Coast, Gold Coast, Newcastle, Wollongong, Latrobe Valley and Ballarat) the use of VHF for Eureka 147 services in these markets will also be constrained by the VHF television services in the adjacent metropolitan area or near adjacent regional areas.

The VHF Band III spectrum is also extensively used for analog and digital television services outside of the metropolitan licence areas. Table 5 summarises the number of VHF Band III television services across Australia which are currently licensed or allotted for future digital television services.

Table 5: Australian VHF Television Channels

Ch	Number of Analog Services	Number of Digital Services
6	66	13
7	46	12
8	87	14
9	63	10
9A	4	18

Ch	Number of Analog Services	Number of Digital Services
10 old	63	N/A
10 new	4	11
11 old	56	N/A
11 new	9	14
12	6	23

Table 6 lists the television areas where there are only one or two unoccupied VHF Band III channels. It is important to note that in some of these areas the use of the nominally available channels will still not be possible because of its use in an adjacent area.

Table 6: Australian VHF Television Channels

Area Served	Unoccupied VHF Channel
Adelaide	9A
Batemans Bay/Moruya	6, 8
Bathurst	8
Brisbane	9A
Broome	12*
Cairns	7, 9A
Canberra	8, 10
Carnarvon	None*
Hobart	9

Area Served	Unoccupied VHF Channel
Kalgoorlie	9*
Manning River	10, 11
Melbourne	9A
Perth	9A
Port Hedland	9*
Sydney	9A
Upper Murray	6, 9
Western Victoria	8, 9
Wide Bay	11, 12

* - Depending on commercial broadcasters decision with regard to the implementation of an additional section 38B digital television service.

Current legislation for the conversion of television services from analog mode to digital mode specifies a minimum simulcast period from the official start of digital television services in each licence area. Consequently, the earliest date that analog services may close in the five major cities is December 31 2008 and mid to late 2011 in regional markets. The simulcast period is subject to review by the end of 2006. Consideration could be given to making some of the spectrum freed by the closure of analog television services available for digital radio services.

VHF Band III (Defence Use)

The Australian Radiofrequency Spectrum Plan (ASRP) [5] allocates the spectrum 230 - 240 MHz for fixed and mobile services on a primary basis. This allocation is consistent with ITU Region 1, 2 and 3 allocations. In addition, in ITU Region 3 the spectrum 230 - 235 MHz is also allocated for aeronautical radionavigation services on a primary basis. Within Australia the frequency range 230 - 240 MHz is subject to an AUS1 footnote which states: *"This band is designated to be used principally for the purposes of defence. The Department of Defence is normally consulted in considering non-defence use of this band."*

It is noted that the ARSP does not include an allocation to the broadcasting service in the 230-240 MHz band. Also this band is outside the Broadcasting Services Bands.

The 225-400 MHz band has been harmonised for military command and control use throughout NATO for tactical and mobile communications. NATO agreed that the sub-band 225-240 MHz could be used for civil purposes subject to national approval. The UK has been able to allocate the spectrum from 225 –230 MHz for Eureka 147 services following discussions with the Ministry of Defence.

If consideration of the use of the frequency range 230 - 240 MHz is pursued, consultations between the ABA, ACA and Defence would need to be undertaken, and changes to the ARSP and the definition of Broadcasting Services Bands may also need to be addressed.

L-Band Spectrum

The 1452 - 1492 MHz band was allocated worldwide (Regions 1, 2 and 3), except in the United States, for sound broadcasting-satellite services (BSS)[15] and complementary sound terrestrial broadcasting services (BS) on a primary basis. The United States has allocated this band to fixed and mobile services on a primary basis. These arrangements are reflected in the ARSP. However, the 1452 - 1492 MHz band is not included in the defined Australian Broadcasting Services Bands.

To reserve options for, amongst other things, digital radio services, the Australian Communications Authority (ACA) has produced the "1.5 GHz Band Plan" [6] which constrains new assignments in the frequency range 1452 - 1492 MHz.

The Australian Notional Terrestrial Allotment Plan contained a detailed assessment of the impact of fixed link and Telstra Rural and Remote Area Telecommunication

[15] Under Resolution 528 (which is called up by footnote 345 of the Radio Regulations), until a broadcasting satellite (sound) planning conference is convened broadcasting-satellite systems may only be introduced in the 1467-1492 MHz range;

Services on the availability of L-Band Spectrum for digital radio services and concluded that the vacant parts of the L-Band would not be quite sufficient to accommodate all existing analog services at near-CD quality. The report showed that there was substantial additional capacity in L-Band that could be made available through clearance of incumbent fixed services and if this were done the potential exists for full conversion of existing services using L-Band alone over time.

Fixed Point-to-Point Service

1.5 GHz band fixed services are typically low capacity point-to-point systems used for the transmission of voice, video and data information. Current fixed service licensees include telecommunication carriers, public and private utility operators, and network broadcasters (the latter for studio-to-transmitter links). Almost all the licensed services are in Metropolitan areas. The number of these fixed services has been fairly static since the Australian Notional Terrestrial Allotment Plan was prepared and the conclusions drawn in the report with respect to fixed service spectrum are still valid.

Telstra's Rural and Remote Area Telecommunication Services

Telstra uses L-Band spectrum to deliver basic telecommunication services to rural and remote areas of Australia. The DRCS service is a point-to-point and point-to-multipoint system that is deployed where other service delivery mechanisms are considered impractical or too costly to implement. The DRCS service is essentially a low-traffic density wireless local loop system, providing radio-based access between customer terminals and a parent telephone exchange. DRCS 'hub' stations utilize an omni-directional antenna to communicate with the surrounding population of outstations (ie customer terminals) and, where necessary, the next hub/repeater section in the network. The customer stations are fitted with directional antennas, the type depending on the distance from the serving hub station. DRCS hub stations may be daisy chained directly, or through a repeater backbone similar to the regular point-to-point fixed service.

Telstra is gradually replacing its DRCS network with a High Capacity Radio Concentrator (HCRC) network, satellite technology and CDMA wireless local loop technology (subject to successful trials and development). The HCRC upgrading is consistent with the existing allocations and DRCS channelling and no further significant network growth or additional spectrum demand is anticipated for these services. As there should be no net change in Telstra's usage of the L-Band spectrum following the closure of the DRCS services the conclusions of the Australian Notional Terrestrial Allotment Plan are unlikely to be affected.

Defence

Defence also uses a number of frequencies at various locations around Australia (in both metropolitan and regional/remote areas) the 1452 - 1492 MHz band for aeronautical mobile telemetry and other purposes.

Eureka 147 via Satellite

While L-Band is attractive for satellite delivered and hybrid satellite-terrestrial digital radio services, at present there are no satellite digital radio services using Eureka 147. The Wiesbaden channel plan reserved specific L-Band channels, which were to be used for terrestrial and for satellite services. As the demand for terrestrial services has increased and satellite Eureka 147 services have failed to appear, the amount of spectrum reserved for satellite services has been questioned.

Spectrum Efficiency

Eureka 147 uses digital audio compression and modulation techniques to achieve spectrum efficiency equivalent to or higher than that of conventional FM radio. The efficiency of spectrum use is increased by the use of SFNs.

In terms of the number of programs per kHz the spectrum efficiency is comparable with FM achieving one program per 200 kHz and Eureka 147 achieving one program per 256 to 307 kHz (for FM or near CD quality respectively). However, Eureka 147 co-channel and adjacent channel protection requirements are also much better than those for FM. For example, Eureka 147 services can operate on adjacent channels where as FM radio services covering the same area must be spaced 800 kHz (ie 4 channels) apart.

Spectrum efficiency can be maximised by using a single frequency network with repeaters reusing the same frequency. Low power on-channel gap fillers and extenders, which may operate outside of an SFN, are possible if there is sufficient signal isolation.

In practice, spectrum efficiency will not be optimal if co-ordination with other services (ie co-location with television services and multiplexing of different licence area services) compromises network design.

Spectrum efficiency requires that services be grouped together to ensure each Eureka 147 multiplex is fully occupied. In practice this will necessitate the re-alignment and/or aggregation of licence areas. The implications of such adjustments need to be considered, particularly with regard to community and open narrowcast services which could be most affected by this process.

Propagation Properties

General aspects of Propagation Properties are covered in the Spectrum Usage section of this report. The two bands in which Eureka 147 are likely to be implemented are VHF Band III and L-Band.

VHF Band III

VHF Band III is well suited to the provision of terrestrial digital radio services over large coverage areas. The frequencies are still sufficiently low for good reception in moving vehicles of Eureka 147 Mode 1 transmissions. VHF Band III has less man-made noise than VHF Bands I and II and does not suffer from a number of the anomalous propagation characteristics which are a problem in VHF Band I.

L-Band (1452 - 1492 MHz)

L-Band can be used for both terrestrial and satellite digital radio services. L-Band may be used to provide the following types of coverage, assuming average terrain conditions:

- small local coverage areas up to a radius of approximately 35 - 40 km using a single, moderate power transmitter;
- larger local area coverage ranging up to a radius of approximately 60 km using a single main transmitter of moderate power and augmented by a number of gap-fillers and coverage extenders;
- large area coverage (> 60 km radius) can be achieved by the use of single frequency networks employing a number of moderately spaced synchronized transmitters;
- coverage along corridors or motorways using repeaters employing highly directional antennas (ie, coverage extenders).

The higher frequency, shorter wavelength of an L-Band transmission means that it is severely affected by local obstructions to a degree that is not encountered at VHF Band III. Conversely, the much smaller transmit antennas lend themselves to small cellular networks with discretely placed antennas. Also, the much smaller receive antenna would be attractive for small portable applications.

Present indications are that L-Band is less attractive to radio broadcasters than VHF. One reason is the different ways that VHF and L-Band signals propagate over distance. While a single VHF transmitter at Artarmon could serve all of Sydney, a network of five or six L-Band transmitters would be needed to provide equivalent coverage. Arguably this could increase opportunities for provision of local services.

Commercial Radio Australia has also expressed concern that the higher building penetration losses of L-Band transmissions make it less attractive than VHF Band III for indoor reception. There have been a number of studies to assess how different buildings attenuate L-Band transmissions and, while they show that attenuation can be large, they show that L-Band can be used to provide indoor reception with a well designed terrestrial retransmission network. Canadian authorities consider L-Band to be suitable for terrestrial digital radio services and are using only L-Band for their Eureka 147 services. In the USA, S-Band has been used for terrestrial digital radio repeaters and GSM phones have been implemented at 1800 MHz in Australia and elsewhere and can provide adequate indoor reception.

Infrastructure Requirements

General issues concerning Eureka 147 infrastructure requirements are in the Overview of Digital Radio Systems chapter of this report. Eureka 147 is a wideband technology requiring services to be multiplexed before transmission. The use of VHF and UHF bands means Eureka 147 services will be typically transmitted from high sites such as the tops of hills, buildings or towers.

In general, new Eureka 147 services are also likely to be co-located with existing FM radio or television transmission services given the cost of developing new sites and the increasing difficulty in getting local council planning approval for new transmission sites.

Receiver Issues

Receiver Capability

Eureka 147 receivers have been developed for a broad range of applications including reception in the home, portable, by car, the personal computer (PC) and hand-held.

In the United Kingdom and Germany, Eureka 147 is being implemented in two spectrum bands, VHF Band III and L-Band. In Canada, Eureka 147 is being implemented in the L-Band.

Home/Portable

Eureka 147 home radios currently on the UK market are separate components that plug into existing hi-fi systems or are stand-alone. Whilst some manufacturers have developed Eureka 147 - only tuners, others have developed combined Eureka 147/FM/AM units. Manufacturers have also catered for the possibility of receiving text, so the displays are large enough for data transmitted along with the radio program.

Car

Most Eureka 147 in-car radios consist of 3 parts: the digital radio black box (stored in the boot, under the seat or behind the dashboard, a compatible head unit and a compact digital aerial (for L-band services). All in-car Eureka 147 receivers combine Eureka 147, FM and AM. Some manufacturers also have receivers that are complete all-in-one digital radios without a separate black box and which fit into standard mounting frames.

Personal Computer

Eureka 147 PC Receivers plug into the computer and allow you to listen to your preferred digital radio programs and access data services whilst working on the computer. The receiver's functions are directly controlled from the computer screen.

Hand-held

Eureka 147 hand-held receivers are becoming a reality, as several companies have been developing smaller lower-powered chips to allow the creation of the truly portable digital radios. Initial hand-held Eureka 147 radios, however, have poor battery performance, needing to be recharged after only a few hours use.

Cost and Availability of Receivers

The WorldDAB Forum March 2003 *Digital Radio Product Guide* for Eureka 147 provided the following in relation to the cost and availability of receivers:

- Acoustic Solutions, Acram, Cambridge, Cymbol, Kiiro, Goodmans, PURE, Sony TAGMclaren, Technics and Terratec manufacture home / portable receivers. The retail cost ranges from EUR 205 – 3675.
- Alpine, Blaupunkt, Clarion, Grundig, JVC, Kenwood, Panasonic, Pioneer and Siemens manufacture car receivers. The retail cost ranges from EUR 160 – 1400.
- Terratec and Modular Technology manufacture receivers for personal computers. The retail cost ranges from EUR 160 – 439.

- PersTel, Zoopad, Ministry of Sound and PURE manufacture hand-held receivers. The retail costs range from EUR 227 – 350.

United Kingdom

Uptake of digital radio has been slow because very few sets were in the shops and those that were available were very expensive. Sales picked up over Christmas 2002, due largely to the fact that a much cheaper £100 digital radio was made available in a promotional deal between the manufacturer and DigitalOne.

In the UK, there are 3,000 digital radio retailers, including many of the biggest electrical chains, as compared to 600 in June 2002.

The Digital Radio Development Bureau (DRDB) in the UK, a joint company set up by the BBC and commercial radio companies, reported in June 2003 that there are around 175,000 digital radio sets in the market – up by 25,000 since the beginning of 2003. The DRDB has set a target of between 350,000 and 500,000 digital radio set sales by the end of 2003.

Germany

While Eureka 147 has been transmitted in Germany since the mid-1990s the future implementation of Eureka 147 services is still being debated. Government officials, representatives of receiver and car manufacturers and broadcasters met in mid 2003 to discuss how to speed up the digital transition. Key to the decision are plans by the government to revamp its subsidy program to cover broadcasters' transition costs for digital radio.

Actual Eureka 147 sales figures are difficult to find: Blaupunkt reported sales of more than 18,000 Woodstock DAB52 radios between May and December 2002. It was the second best selling car receiver (of both Eureka 147 and non-Eureka 147 models) in its price range in Germany between May and September 2002.

Canada

In the autumn of 2002, RadioShack Canada became the first retail chain in Canada to carry a line of Eureka 147 products for the home and portable markets. Eureka 147 products will be available in approximately 250 Radio Shack stores. While the initial receivers are hand-held portable devices (with and without MP3 capability) additional products included boom boxes, other hand-held portable devices, and Eureka 147 computer attachments.

Size of Current Markets

United Kingdom

There are two national multiplex operators in the UK, BBC and DigitalOne, and ten commercial local/regional multiplexes. The UK audience is estimated at over 17 million people [16] (but this UK audience is also served by digital audio services on free-to-air and subscription television[17]).

16 Digital Radio Development Bureau, www.drdb.org

17 'Digital radio comes of age with millions of listeners', The Independent p 9 - 9 May 2003

The WorldDAB Forum reported in January 2003 that the commercial coverage currently reaches 85% of the population whilst the BBC reaches 65% of the UK, increasing to 85% by the end of 2004.

Germany

Germany has a potential market of more than 80 million people, 38 million households and 42 million cars, according to the WorldDAB Forum. Approximately 70 per cent of the population area is covered, and most of the 16 German Federal States have launched services. There are approximately 150 stations on the air.

Canada

Canada has 72 licensed digital stations in five markets: Toronto, Montreal, Vancouver, Windsor and Ottawa. The stations operating in the first four cities provide a service to 10 million potential listeners or about 35 per cent of population, according to the WorldDAB forum.

Technical Standards

International Standards

ETSI Standards [14]

Eureka 147 standards are formalised by ETSI and are available for download. The current list of ETSI standards relating to Eureka 147 are in Table 7. The main ETSI standard for Eureka 147 is EN 300 401.

Table 7: ETSI Standards relating to Eureka 147

Number	Title
EN 300 401 V1.3.3 (May 2001)	Digital Audio Broadcasting (DAB); DAB to mobile, portable and fixed receivers (THIRD EDITION)
EN 300 797 V1.1.1	Digital Audio Broadcasting (DAB); Distribution interfaces; Service Transport Interface (STI)
EN 300 798 V1.1.1	Digital Audio Broadcasting (DAB); Distribution interfaces; Digital baseband In-phase and Quadrature (DIQ) Interface
EN 301 234 V1.2.1	Digital Audio Broadcasting (DAB); Multimedia Object Transfer (MOT) protocol
EN 301 700 V1.1.1	Digital Audio Broadcasting (DAB); Service Referencing from FM-RDS; Definition and use of RDS-ODA
EN 302 077 V1.1.1	Electromagnetic compatibility and Radio spectrum Matters (ERM); Harmonised EN for Terrestrial Digital Audio Broadcast (TDAB) equipment used in the sound broadcasting service.
ES 201 735	Digital Audio Broadcasting (DAB); Internet Protocol Datagram Tunnelling
ES 201 736 V1.1.1	Digital Audio Broadcasting (DAB); Network Independent Protocols for Interactive Services
ES 201 737 V1.1.1	Digital Audio Broadcasting (DAB); DAB Interaction Channel through GSM / PSTN / ISDN / DECT
ETS 300 799	Digital Audio Broadcasting (DAB); Distribution interfaces; Ensemble

Number	Title
	Transport Interface (ETI)
TR 101 495 V1.1.1	Digital Audio Broadcasting (DAB); Guide to DAB Standards; Guidelines and Bibliography
TR 101 496-1 V.1.1.1	Digital Audio Broadcasting (DAB); Guidelines and Rules for Implementation and Operation
TR 101 496-2 V.1.1.2	Digital Audio Broadcasting (DAB); Guidelines and Rules for Implementation and Operation
TR 101 496-3 V.1.1.2	Digital Audio Broadcasting (DAB); Guidelines and Rules for Implementation and Operation
TR 101 497 V1.1.1	Digital Audio Broadcasting (DAB); Rules of Operation for the Multimedia Object Transfer Protocol
TS 101 498-1 V1.1.1	Digital Audio Broadcasting (DAB); Broadcast Web Site Application, Part 1:User Application Specification
TS 101 498-2 V1.1.1	Digital Audio Broadcasting (DAB); Broadcast Web Site Application, Part 2: Basic Profile Specification
TS 101 499 V1.1.1	Digital Audio Broadcasting (DAB); MOT Slide Show; User Application Specification
TS 101 735 V1.1.1	Digital Audio Broadcasting (DAB); Internet Protocol Datagram Tunnelling
TS 101 736 V1.1.1	Digital Audio Broadcasting (DAB); Network Independent Protocols for Interactive Services
TS 101 737 V1.1.1	Digital Audio Broadcasting (DAB); DAB Interaction Channel through GSM / PSTN / ISDN / DECT
TS 101 756 V1.1.1	Digital Audio Broadcasting (DAB); Registered Tables
TS 101 757 V1.1.1	Digital Audio Broadcasting (DAB); Conformance Testing for DAB Audio
TS 101 758 V2.1.1	Digital Audio Broadcasting (DAB); DAB Signal Strengths and Receiver Parameters
TS 101 759 V1.1.1	Digital Audio Broadcasting (DAB); DAB Data Broadcasting Transparent Data Channel
TS 101 860 V1.1.1	Digital Audio Broadcasting (DAB); Distribution Interfaces; Service Transport Interface (STI); STI Levels
TS 101 993 V1.1.1	Digital Audio Broadcasting (DAB); A Virtual Machine for DAB: DAB Java Specification
TS 102 818 V1.1.1	Digital Audio Broadcasting (DAB); XML Specification for DAB Electronic Program Guide (EPG)

Receiver Standards

European receiver standards have been developed by CENELEC, IEC and national standards bodies (eg UK). A list of relevant receiver standards is in Table 8.

Table 8: Receiver Standards for Eureka 147

Reference	Title
CENELEC EN 50255	Digital Audio Broadcasting system - Specification of the Receiver Data Interface (RDI)
CENELEC EN 50248	Characteristics of DAB receivers
CENELEC EN 50320	The DAB Command Set for receivers

Reference	Title
IEC 62105	Digital Audio Broadcasting System - Specification of the Receiver Data Interface (RDI)
IEC 62104	Characteristics of DAB Receivers

ITU Publications and Recommendations

The International Telecommunications Union has a number of publications and Recommendations relating to Eureka 147 and digital radio in particular. The "DSB Handbook - Terrestrial and satellite DSB to vehicular, portable and fixed receivers in the VHF/UHF bands" is an aggregation of ITU input documents and data. Relevant recommendations are in Table 9.

Table 9: ITU Recommendations relevant to Eureka 147

Reference	Title
BS.1115	Low data rate audio coding
BS.774-2	Service requirements for DSB to vehicular, portable and fixed receivers using terrestrial transmitters in the VHF/UHF bands
BS.1114-3	Systems for terrestrial DSB to vehicular, portable and fixed receivers in the frequency range 30-3 000 MHz
BO.789-2	Service for DSB to vehicular portable and fixed receivers for broadcasting-satellite service (sound) in the frequency range 1 400-2 700 MHz
BO.1130-4	Systems for digital satellite broadcasting to vehicular, portable and fixed receivers in the bands allocated to BSS (sound) in the frequency range 1 400-2 700 MHz

Australian Standards Development

As for digital television, standards for digital radio in Australia could be developed and managed by Standards Australia through its CT-2 committee which addresses Broadcasting and related services.

If Eureka 147 is adopted for use in Australia without modification then Standards Australia could publish the relevant ETSI standards as Australian Standards.

Standards Australia may need to develop an Australian receiver standard to suit the particular broadcasting environment in Australia. Such a standard could draw heavily on international receiver standards.

References

1. "Eureka 147 - Digital Audio Broadcasting", Eureka 147 Project, August 1997 http://www.worlddab.org/public_documents/eureka_brochure.pdf
2. "Final Acts of the CEPT T_DAB Planning Meeting (3)", Maastricht 2002, CEPT, http://www.ero.dk/52EB3135-F356-49FF-A970-B32D2C745921?frames=0
3. Communications Laboratory Technical Note 99/01, 'The impact of European and Canadian L-Band channel spacings on adjacent channel operation", 20 April 1999.

4. “Digital Radio Broadcasting - Australian Notional Terrestrial Allotment Plan”, Technical Working Group of the Digital Radio Planning & Steering Committee, February 2000
5. “The Australian Radiofrequency Spectrum Plan”, Australian Communications Authority, 2002 http://www.aca.gov.au/radcomm/frequency_planning/band_plans/spectrum.htm http://www.aca.gov.au/radcomm/frequency_planning/spectrum_plan/spectrum.htm
6. “1.5 GHz Band Plan”, Australian Communications Authority, 1996 http://www.aca.gov.au/aca_home/legislation/radcomm/band_plans/1-5.htm
7. Communications Laboratory, Report No. 97/3, “Digital Radio Broadcasting - Capacity of the Eureka 147 Multiplex”, April 1997
8. “Notes of Guidance”, UK Radio Authority http://www.radioauthority.org.uk/publications-archive/word-doc/regulation/codes_guidelines/dabnog0103.doc
9. http://www.aba.gov.au/conf03/presentations/morton.pdf
10. http://www.digitalradiotech.co.uk/ofcom_article.pdf
11. Soulodre,G. A.; Grusec, T.; Lavoie, M.; and Thibault, L. (1998)., Subjective Evaluation of State-of-the-Art Two-Channel Audio Codecs., Journal of the Audio Engineering Society, vol. 46, no. 3, Mar., pp. 164-177.
12. “DAB Ensembles Worldwide”. http://www.wohnort.demon.co.uk/DABIT/index.html
13. 1“BBC advice: stick to FM for quality”, What HI-FI, 12 November 2002, http://www.whathifi.com/newsMainTemplate.asp?newssectionID=2&storyID=109
14. ETSI
15. CENELEC
16. IEC
17. http://www.itu.int/itudoc/itu-r/bookshop/manuels/81036.html

Digital Radio Mondiale

Background

System Overview

The DRM system is a digital radio system designed for use in the low frequency (LF), medium frequency (MF) and high frequency (HF) terrestrial broadcasting bands below 30 MHz.

System Development

The DRM system was initially proposed by a small group of international (ie HF) broadcasters and equipment manufacturers. Development of the system was formalised in 1998 with the formation of the DRM consortium. The consortium membership has since expanded to include some 81 organisations, also representing national broadcasters, research institutes, regulatory agencies and regional broadcasting unions.

In April 2001 the system was endorsed by the ITU as a standard for digital radio in the bands below 30 MHz. In the same year the DRM system specification was finalised and adopted as a Technical Standard by ETSI.

In June 2003 the DRM consortium initiated the first regular DRM transmissions. Amongst broadcasters to commence regular services were Deutsche Welle, Radio Netherlands, the BBC World Service, Voice of America, Swedish Radio International and Christian Vision.

Like Eureka 147, DRM is a project of the pan-European research organisation, Eureka project (DRM is Eureka project number 1559). In August 2003, DRM and WorldDAB announced they would collaborate in the development of their digital radio systems.

Despite these recent developments there remains some uncertainty regarding the timeframe for availability of consumer receivers. Recent reports indicate timeframes ranging from mid 2004 through to mid 2006 for the introduction of DRM-capable receivers to the marketplace.

Advantages/Disadvantages

Advantages

The principal advantages of the DRM system are:

- ability to deal with the wide-ranging propagation conditions encountered in the LF, MF and HF broadcasting bands, through appropriate selection of transmission mode;
- potential for significant improvement in the audio quality and signal reliability of broadcasting services operating below 30 MHz;

- ability to carry audio and/or data with flexibility to trade-off between audio quality, data capacity and signal robustness;
- compatible with the existing channel spacing employed for amplitude modulated (MF-AM) broadcasting and for HF broadcasting worldwide, thus providing scope for wide-spread adoption of the system;
- provides scope for further improvement in audio quality or data carrying capacity through use of wider channel bandwidths, where frequency planning allows for such operation;
- the potential for introduction of additional digital based services in the MF-AM band once analog services have ceased operation; and
- existing sites and, in some cases infrastructure, can be used for the transmission of digital services.
- has arguably the most efficient audio coding of all digital radio systems (ie MPEG-4 AAC.

Disadvantages

The principal disadvantages of the DRM system are:

- feasibility and practical implications of simulcast operation, in which the digital signal is transmitted adjacent in frequency to the current MF-AM analog signal, have yet to be established;
- the ability of the system to operate in simulcast or digital mode in the current Australian MF-AM planning environment, without undue interference to existing analog services, has yet to be established;
- availability of spectrum for additional services in the MF-AM band is limited due to the operation of existing analog AM services;
- given the requirement for international coordination, current high levels of congestion in the bands and the varied propagation conditions, use of the HF bands for digital services within Australia is problematic at best;
- uncertainty regarding the timeframe for availability of consumer receivers;
- the DRM system has limited data capacity compared to broadband digital radio systems.

System Description

The DRM system is designed for use in the LF, MF and HF terrestrial broadcasting bands below 30 MHz. These frequency bands are characterised by two forms of signal propagation, known as sky wave and ground wave propagation. The DRM system is designed to cope with the severe propagation conditions, characteristic of long distance HF sky wave propagation, as well as the less demanding ground wave propagation usually associated with MF and LF broadcasting.

The coding and channel modulation scheme used by the DRM system is a COFDM variant that uses Quadrature Amplitude Modulation (QAM) on each of the individual

COFDM carriers. Two primary QAM constellations are available: 64-QAM and 16-QAM.

Modes of Operation

To cater for the different propagation conditions encountered in the LF, MF and HF bands, four modes are defined which provide varying degrees of signal robustness for a given signal bandwidth. The four modes are:

Mode A: Primarily intended for ground wave coverage with minor fading conditions (likely to be used for the LF and MF bands);

Mode B: Intended for time and frequency selective channels with longer delay spread (likely to be used for MF and HF bands);

Mode C: Similar to Mode B, but with higher tolerance to Doppler spread (likely to be used only for the HF band); and

Mode D: Similar to Mode B, but with tolerance to both severe delay and Doppler spread (likely to be used only for the HF band).

Two channelling arrangements are currently employed for the provision of MF-AM services worldwide. In Regions 1 and 3 the nominal channel spacing in the band is 9 kHz, while in Region 2 the nominal channel spacing is 10 kHz. A channel spacing of 10 kHz is employed worldwide for broadcasting in the HF bands. The DRM system is designed to operate:

- in an all-digital mode, with 9 or 10 kHz bandwidths, in order to comply with current planning arrangements;
- within half these bandwidths (4.5 kHz or 5 kHz) in order to allow for simulcast operation with current analog AM signals and
- within twice these bandwidths (18 kHz or 20 kHz), to provide for larger transmission capacity where and when the planning constraints allow for such operation.

In Australia the nominal channel spacing for MF-AM services is 9 kHz. However, the permitted bandwidth of radio frequency (RF) emissions is 18 kHz (ie twice the nominal channel spacing) in order to allow for relatively high quality audio transmission.

To date, frequency sharing studies conducted by proponents of the system in both simulcast and all-digital mode, have assumed an RF emission bandwidth of 9 kHz for the MF-AM broadcasting service. The introduction of DRM services in to the Australian MF-AM band, based on these current planning parameters, may require the RF emission bandwidth of analog AM services to be restricted. Further studies would be required to establish the feasibility of sharing with MF-AM services in the case where the RF emission bandwidth of the analog service exceeds 9 kHz.

In addressing the issue of sharing with current analog MF-AM services, consideration will also need to be given to the performance of current domestic receivers. DRM sharing, in both simulcast and all-digital modes, is prefaced on a relatively narrow AM receiver pass band, commensurate with 9 kHz channel operation. As noted above, Australia has adopted a wider emission bandwidth to allow for higher quality audio transmission. Analog receivers with relatively wide RF pass band, that are capable of benefiting from this greater transmission bandwidth, are likely to be more susceptible to interference from the DRM service.

Simulcast mode

A number of simulcast modes are detailed in the DRM system specification. Simulcast modes are available in conjunction with double-sideband AM analog operation and with single sideband (SSB) analog operation. In the MF-AM broadcasting band, analog signals are transmitted using double-sideband amplitude modulation.

In the simulcast mode the analog transmission occupies an RF bandwidth of 9 kHz while the digital signal occupies either 4.5 or 9 kHz[18] in the immediate upper or lower adjacent channel. Implementation of this simulcast mode requires that the RF emission bandwidth of the AM signal be restricted to 9 kHz.

To date, only limited tests[19] have been conducted in to the feasibility of simulcast operation. Aspects of this mode of operation that require careful consideration include:

- The level of the digital signal relative to the analog signal, necessary to minimise interference to the analog service;
- Whether the necessary ratio of digital to analog signal level is sufficient for the digital service to achieve the same coverage as the analog service;
- The ability of current analog receivers to provide sufficient rejection of the digital signal; and
- Determination of appropriate planning parameters, including the identification of any sharing constraints with the MF-AM service, for the various simulcast modes.

DRM digital mode

When operating in the MF-AM band in all-digital mode the DRM service can occupy a bandwidth of 9 kHz or 18 kHz. Studies have established that it is possible to replace an existing analog AM service with a 9 kHz DRM digital service without adversely impacting on existing analog services. Although some reduction in the power of the DRM service is required, the resultant coverage of the DRM service is comparable to that of the existing analog service. Importantly, this assessment assumes an RF emission bandwidth of 9 kHz for the existing analog services.

[18] Other simulcast modes are possible in which the digital signal also occupies the second adjacent channel above or below the analog service. In these modes the digital signal occupies a bandwidth of 18 kHz.

[19] ITU-R Input Document 6E/199-E ‘The status of DRM simulcast results and future plans about the DRM simulcast feasibility within the MF and HF broadcasting bands’, 7 March 2002.

Audio and Data Capacity

The DRM system is capable of both audio and data transmission. This capability is inherent in the system design and enables the broadcaster to trade-off between signal robustness, audio quality and data capacity. The system allows for flexible allocation of the available data capacity between audio and data applications.

In the context of audio broadcasting, there are extensive facilities for the transmission of program related data. At the basic level the name of the broadcaster or station can be transmitted and displayed in the same way as with RDS (Radio Data System) or RBDS (Radio Broadcast Data System) on FM transmissions. Additional features provide for text, which could carry information about the program content. However, the carriage of large amounts of text or other program related data would reduce the capacity available for audio data, which can impact on the quality of the audio service.

The carrying capacity of the system varies considerably depending on the desired signal robustness and available bandwidth. For digital operation within a 9 kHz channel in the MF-AM band, data rates of the order of 20 - 25 kbit/s can be expected. In the case of simulcast operation, the digital bandwidth is further restricted and the available data rate may be as low as 8 to 10 kbit/s.

Audio Quality

The DRM system employs a subset of the MPEG-4 audio coding scheme. A data rate of 24 kbit/s using MPEG-4 AAC (Advance Audio Coding) with Spectral Band Replication (an additional audio enhancement also included in the MPEG standard) is claimed to deliver audio quality comparable to that of monophonic FM.

In situations where the available data rate is restricted, such as in simulcast operation or where high signal robustness is required, the DRM system can employ CELP (Code Excited Linear Prediction) based encoding. This subset of the MPEG-4 standard is intended for speech encoding and allows for reasonable quality at data rates below 10 kbit/s.

Spectrum Issues

Frequency Band Usage

The DRM digital system is intended for use in the LF, MF and HF broadcasting bands below 30 MHz.

Availability of Spectrum in Australia

LF spectrum is not currently allocated for broadcasting in Australia (ITU Region 3).

The MF band (526.5 - 1606.5 kHz) is allocated in Australia to AM broadcasting services. Identifying additional channels in this band for DRM operation with reasonable night-time coverage in metropolitan, regional or even remote areas of Australia will be difficult due to the night-time propagation characteristics of MF radio waves and to general congestion in the MF band. It is relevant to note that night-time operation of any new service is subject to international co-coordination, particularly with regional countries that may be affected by a proposed new service. It is more likely that additional channels can be identified for day-time operation.

The MF-AM broadcasting band in Australia is smaller than in the USA[20]. The Australian band is 526.5 - 1606.5 kHz. The band 1606.5 - 1705 kHz is used in Australia for MF-NAS services and is therefore unlikely to be suitable for high power, full bandwidth MF broadcasting systems. The MF spectrum above the MF-NAS services is allocated to Fixed, Mobile, Radiolocation and Radionavigation services.

The HF bands are mostly known for long distance international broadcasting, using sky wave propagation. The lower-frequency end of the HF band is also suited to coverage of large countries and for use in tropical zones. Both applications rely on sky wave propagation and thus depend on the state of the ionosphere, which changes throughout the day. As reception depends on the frequency of the transmission and the state of the ionosphere, broadcasters operating on HF are often required to transmit the same signal at different frequencies, or to regularly change transmitting frequency, in order to increase the probability of reception in the intended target area.

From the viewpoint of coverage, there are also significant differences between MF and HF propagation. These differences are such as to make the concept of same coverage at MF and HF difficult at best.

Use of the HF broadcasting bands is also subject to international coordination. Recent ITU-R studies have shown these bands are already heavily congested. For frequencies above 5.9 MHz, a seasonal coordination procedure has also been implemented by the ITU-R to ensure equitable access to the bands by all administrations wishing to provide HF broadcasting services.

Spectrum Efficiency

Compared to analog AM, the co-channel and adjacent channel protection requirements for DRM are significantly less. This should provide scope for additional digital services once analog services have been cleared.

As the DRM system utilises COFDM modulation, it is potentially suited to SFN operation. Although only limited tests have been conducted of SFN operation, this capability has been widely demonstrated during the past several years with COFDM based systems in other spectral bands. Care is required during network planning, however, to ensure the delay difference between transmitted signals in the service area are within the system design limits. The identification of suitable transmission sites and the potential for night-time interference are issues that also need to be addressed in the planning of SFN services.

Infrastructure Requirements

Existing AM sites could be used for transmitting DRM digital services. In some cases it may also be feasible to share transmission facilities (ie antenna radiating system), however this will depend on the frequency separation of the analog and digital services and the RF bandwidth of the radiating system. Broadcasters may use their existing

20 A similar number of channels are available, due to different channel spacing.

transmission systems for simulcast operation provided the RF bandwidth of the transmission system is adequate.

Both digital and simulcast operation require that careful attention be given to phasing, matching and antenna coupling networks, since these can often introduce undesirable effects in the frequency and phase response of the DRM signal, which can adversely impact on the spectrum of the transmitted signal.

In principle, existing analog transmitters can be modified to transmit DRM signals, however, depending on the age of the transmitter and the type of signal amplification (linear/non-linear) in use this may not be economical. Field tests of the DRM system to date have employed existing transmitters that have been adapted to transmit the DRM signal.

Receiver Issues

Cost and Availability of Receivers

Although some operators have recently commenced regular DRM broadcasts, there is uncertainty regarding the timeframe for availability of consumer receivers.

The publication *Diffusion EBU 2003/1* reported that the DRM working program to finalize the electronic chipset anticipates that receivers will be on the consumer market by late 2005.

A Digital Radio Mondiale (DRM) Publication, 5th Edition, June 2003 indicated that early DRM receivers, including "production-ready" consumer receivers, have been showcased at major industry events such as IBC in Amsterdam, IFA in Berlin and NAB in Las Vegas. The report stated that it is expected that commercial DRM capable receivers be introduced to the marketplace within the next two to three years.

For DRM's commercial rollout to succeed, it will be necessary that four vital industry elements – universal standardization, regulatory acceptance, DRM programming by key broadcasters and the availability of DRM-capable equipment (especially receivers) emerging simultaneously.

The Diffusion EBU 2003/1 report indicated that receiver manufacturers in Eureka 147 countries (mainly Europe and Canada) will install Eureka 147 and DRM in their digital receivers and in other countries DRM may be the only option chosen to bring digital radio to markets.

Capabilities

With the availability of consumer receivers still someway off, it is difficult to predict the range of capabilities that receiver manufacturers will choose to support. Nevertheless, from the viewpoint of facilitating the transition to the new technology, it is reasonable to expect that receivers will be multi-mode and that digital reception will be provided as an extension to the AM and FM capability widely available in current consumer radio receivers.

The DRM system specification provides for carriage of audio and audio program related data, as well as dedicated data applications. The standard also provides for a wide range of advance service related features (for example automatic frequency switching by receivers), however the range of features supported will be up to individual manufacturers. It is likely that a subset of the full capability embodied in the DRM specification will be implemented initially, in order to minimise receiver cost.

Size of current markets

The potential market for DRM receivers is considerable, as HF broadcasting is used worldwide. MF DRM broadcasting may be more regionalized, however the market for MF DRM receivers also has significant potential.

Technical Standards

The ITU has endorsed the DRM system for digital radio use in the LF, MF and HF broadcasting bands below 30 MHz. The IEC, the international standards body dealing with electrical and electronic technologies, has also approved the DRM system specification as an international standard.

At a regional level ETSI has formalised two DRM related standards. One addresses the system specification and the other details requirements related to the carriage of data applications by the DRM system.

References

1. Technical Specification document on DRM published by European Telecommunications Standards Institute - ETSI 101 980 V1.2.2 (2003 – 04) – ETSI Website: http://www.etsi.org.
2. ITU-R Recommendation BS.1514-1, 'System for digital sound broadcasting in the broadcasting bands below 30 MHz'.
3. International Telecommunication Union, 'CPM report on technical, operational and regulatory/procedural matters to be considered by the 2003 World Radiocommunication Conference', Geneva 2002.
4. Michel Penneroux, 'DRM Commercial Challenge', Diffusion EBU 2003/1, pp30 – 33.
5. Michel Penneroux, 'Digital Radio Broadcasts to be launched at WRC-03', ITU News 5/2003, pp19 – 22.
6. Pierre Vasseur, 'DRM Transmitter Technology', DRM Symposium, Las Vegas, April 2001.
7. Markus Zumkeller, 'The new standard for digital radio broadcasting below 30 MHz', DRM Symposium, Las Vegas, April 2001.
8. Digital Radio Mondiale Publication, 'The year of DRM's Inaugural Broadcasts', 5th Edition, June 2003.
9. ITU-R Input Document 6E/199-E 'The status of DRM simulcast results and future plans about the DRM simulcast feasibility within the MF and HF broadcasting bands', 7 March 2002
10. DRM Website: http://www.drm.org.

In-Band-On-Channel (IBOC)

Background

System Overview

The design objective of the In-Band-On-Channel (IBOC) system was to provide for high quality digital audio and information services, that will operate in either of the existing MF-AM or VHF-FM bands, using the same frequency and planning criteria as the existing analog services.

The IBOC system design permits implementation in two separate phases. The initial *Hybrid* phase provides a digital service, that supplements the existing analog service. Both of these services broadcast identical audio programming, using the existing frequency assignment; thereby providing simultaneous analog and digital services, to the same coverage area.

Listeners may continue to use standard analog receivers to receive the analog audio service, or may purchase digital receivers to receive the digital audio and the information services. This enables listeners to progressively replace their analog receivers, with a digital receiver that provides high quality services.

After a suitable introductory period, broadcasters can implement the final *All-Digital* phase, which removes the analog signal and modifies the digital system configuration to optimise system ruggedness, and maximise coverage area.

IBOC has two system variants, IBOC-AM for use in the MF-AM band and IBOC-FM for use in the VHF-FM band. These variants provide similar functionality, although the technical details of each system vary.

The IBOC-AM system has been designed to work specifically in the US which has adopted a 10 kHz channel spacing environment. In Australia (as in the rest of the world) the channel spacing for AM is 9 kHz. It is possible to modify the system for 9 kHz channel spacing, however at this time there are no immediate plans to modify the technical specifications.

System Development

In the USA, the terrestrial MF-AM and VHF-FM bands have traditionally been used for radio broadcasting. These systems use analog techniques to provide audio broadcasting services, through an existing terrestrial transmission network, consisting of approximately 4 800 AM stations and 8 600 FM Stations. (June 2003)

Planning for the introduction of terrestrial digital radio services began in the USA in the early 1990's. In November 2001, after extensive research by a range of commercial groups, the Ibiquity Digital Corporation proposed to the Federal Communications Commission (FCC), a digital radio system called IBOC. Ibiquity was formed in August 2000 after merger of USA Digital Radio and a division of Lucent Technologies that had previously proposed different IBOC systems. Lucent Technologies developed the audio coding system known as PAC, which is proposed for IBOC. This system uses the existing broadcasting MF-AM and VHF-FM bands, to provide a digital radio service on the same frequency as the existing analog service.

The Ibiquity IBOC systems are being promoted under the trade name “HD Radio”.

Advantages/Disadvantages

Advantages

The IBOC system has the following advantages:

- a system design that can inherently simulcast both analog and digital services, using the current frequency assignment (ie does not require additional spectrum);
- a system design that enables broadcasters to maximise the use of existing infrastructure; thereby minimising upgrade costs;
- a system design that enables listeners to progressively migrate from analog to digital;
- a system design that offers improved audio quality, and a range of information services;
- a receiver design that avoids abrupt reception failures, common in some digital systems at the edge of the coverage area;
- a system design that offers the broadcaster flexibilities to trade-off audio quality and the data-rate of the information services;
- at the end of the simulcast period, the robustness of the signal is significantly increased, providing options to reduce transmitter power for the same coverage area;
- IBOC-FM may provide auxiliary audio services, such as surround sound, or multiple audio channels.

Disadvantages

The IBOC system has the following disadvantages:

- the final system design is not yet complete, the audio quality of the IBOC-AM is currently under review by the system developers;
- the IBOC-AM system has been designed for 10 kHz channel spacing, as used in the USA. A 9 kHz design for Australian conditions has not yet been developed or tested. A 9 kHz design would also result in a reduced data capacity and consequently audio quality compared to the 10 kHz version;
- the MF-AM band in the USA is very congested, with night-time operation limited by interference. As a consequence the FCC has not yet approved night-time operation of IBOC-AM. Although Australian MF band conditions are less constrained, testing in Australian conditions is required to confirm night-time operation;

- the IBOC system is not compatible with standard analog AM stereo. Consequentially, broadcasters converting to IBOC-AM will need to revert to mono operation on the analog service;
- there is little or no scope for the introduction of additional services when using the *Hybrid* mode as both the MF-AM and VHF-FM bands are fully utilised in many parts of Australia., however the *All-Digital* mode may allow additional services through reduced interference protection requirements;
- the IBOC system has limited data capacity compared to broadband digital radio systems;
- there are no consumer receivers currently available.

System Description

Modes of Operation

The IBOC system has two modes of operation, Hybrid and All-Digital mode.

In the *Hybrid* mode, IBOC provides simultaneous analog and digital services. The digital service is achieved by placing digital carriers adjacent to the analog signal. The digital carriers provide a data service with a coverage area similar to the analog service, but configured so as not to cause interference to the analog service. Note that the analog and digital services need to be identical as the IBOC receiver is designed to use the analog service as a "fallback" signal when the digital signal drops out at the edge of coverage.

In the *All-digital* mode, IBOC only provides a digital service. The analog audio is removed and replaced with digital carriers that are configured to provide for maximum robustness, and therefore maximum coverage area.

Channel Spacing/Bandwidth

MF-AM services in ITU Region 1 and 3, including Australia, operate with 9 kHz channel spacing, using a channel bandwidth of 18 kHz. Services in Region 2, including the USA, operate with 10 kHz channel spacing, using a channel bandwidth of 20 kHz.

The IBOC-AM system has been designed for the USA's 10 kHz channel spacing environment only. It would be possible to modify the technical specifications of IBOC-AM for 9 kHz channel spacing, however there are no immediate plans to do so.

VHF-FM services in the USA and Australia, both operate with 100 kHz[21] channel spacing, using a channel bandwidth of 200 kHz. The IBOC-FM system has been designed for use with 100 kHz channel spacing.

[21] The ABA specifies FM stations on a channel spacing of 200 kHz, although a few stations are permitted to operate with frequency offsets of +/- 100 kHz.

Modulation

The IBOC system has been designed to operate within the channel bandwidths of the existing MF-AM and VHF-FM bands. The channel bandwidth in the MF-AM band is 20 kHz (18 kHz for Australia), and 200 kHz in the VHF-FM band. Given that channel bandwidth ultimately defines the achievable digital data-rate; the channel bandwidth of the MF-AM and VHF-FM bands therefore limits the maximum data-rates achievable by the IBOC system.

The IBOC system uses segmented COFDM digital modulation, where the digital spectrum is divided into a number of individual segments, where each segment is configured to independently carry data at different data-rates and robustness 22.

This enables the digital receiver to provide a 'soft' reception failure at the edge of the coverage area, thereby avoiding the abrupt reception failure, common in some digital systems.

Services

The IBOC system design provides an audio service and a number of data or information services, with each service carried by an independent data stream within the IBOC modulation system. Each of the data streams is individually assigned characteristics according to their hierarchy of importance.

This enables broadcasters to uniquely configure their system and trade-off audio quality, data-rate and robustness according to the relative importance of each service.

Receiver Operation

It is the general nature of digital radio systems that they deliver consistent audio quality services throughout their coverage area, however at the edge of the coverage area, or when subject to short term interference, reception can fail abruptly. This annoying affect, often referred to as the 'cliff effect', is very disconcerting for the listener.

The IBOC transmission system and receiver design use a number of techniques to reduce the impact of the 'cliff effect', to provide 'soft failure' at the edge of the coverage area.

In the IBOC *Hybrid* mode, the digital receiver normally uses the digital audio service, however, when the digital data stream becomes corrupt at the edge of the digital reception area, or when subject to interference, the receiver 'blends' to the analog service to ensure that the audio service is maintained.

In the IBOC *All-Digital* mode, the analog audio is not available, however, the audio encoder provides two data streams of the same audio source, one data stream provides the basic audio quality, with both data streams required to provide the full audio quality. The IBOC modulation system transmits both streams, but with differing levels of robustness. When reception failure occurs in the IBOC receiver at the edge of the coverage area, the least robust data stream will fail first, thereby reducing the quality of

[22] Robustness is the ability of the data service to withstand impairments such as noise and interference. For a given bandwidth, a data service that has a high data rate, usually has a lower robustness, than a service with a low data rate.

the decoded audio, with the basic data stream providing extended coverage well beyond the standard coverage area.

In both the *Hybrid* and *All-Digital* modes, the quality of the audio service is reduced at the edge of the coverage area. This provides a ‘soft’ reception failure at the edge of the coverage area, rather than an abrupt reception failure.

Audio and Data Capacity

General aspects of Audio Compression and Modulation are covered in the Overview section of this report.

The following tables list the services and data rates available for each variant and mode of IBOC.

IBOC-AM

IBOC-AM provides the following services:

- Analog audio service – “AM” quality (Hybrid mode only)
- Digital audio service – “FM” quality.
- Limited information services.

Hybrid mode has two options, MA 1 and MA 2, selected according to the operational mode of the audio encoder. *All-Digital* mode has two options, MA 3 and MA 4, again selected according to the operational mode of the audio encoder. See note 1 below for details of the operational modes of the audio encoder.

The characteristics of each option is defined in the following table:

Mode	Service	Data-rate kbit/s (USA Note 2)	Data-rate kbit/s (AUS Note 2)
All modes	System control data - note 1	0.4	0.36
Hybrid			
MA 1	Analog audio – “AM” quality		
	Digital audio – “FM” quality, Core data - single stream.	20.2	18.2
	Digital audio – “FM” quality, Enhanced data, shared with the Information service.	16.2	14.6
MA 2	Analog audio – “AM” quality		
	Digital audio – “FM” quality, Core data - dual stream.	40.4	36.4
	Digital audio - “FM” quality, Enhanced data, shared with the Information service.	16.2	14.6
All-Digital			

Mode	Service	Data-rate kbit/s (USA Note 2)	Data-rate kbit/s (AUS Note 2)
MA 3	Digital audio - "FM" quality, Core data - single stream.	20.2	18.2
	Digital audio - "FM" quality, Enhanced data, shared with the Information service.	20.2	18.2
MA 3	Digital audio - "FM" quality, Core data - dual stream.	40.4	36.4
	Digital audio - "FM" quality, Enhanced data, shared with the Information service.	20.2	18.2

Note 1: System control data provides station identification and control information for the digital receiver. It is applicable to all modes of operation, and requires a fixed low data rate.

Note 2: As highlighted elsewhere in this report the IBOC-AM system has initially been developed for the USA broadcast environment, using 10 kHz channel spacing. A variant of IBOC-AM for Australian conditions, using 9 kHz channel spacing, appears possible, but has not been developed as yet. An Australian variant would have a lower data rate, as shown in the table, and is expected to have a correspondingly reduced audio quality to "near FM" quality.

IBOC-FM Hybrid mode

The IBOC-FM Hybrid mode provides the following services:

- Analog audio service - "FM" quality;
- Digital audio service - CD quality;
- Information services - at various data rates.

There are 4 options for this mode, designed to enable the broadcaster to trade-off the occupied spectrum of the analog audio and the data rate of the information service. That is mode MP1 has the best analog audio quality, ranging to mode MP4 with the worst analog audio quality. The data rate and quality of the digital audio remains constant for all modes.

The characteristics of each option is defined in the following table:

Mode	Service	Data-rate kbit/s
All modes	System control data	0.9
MP 1	"CD" quality audio (Single audio stream)	98.4
	No Information service	0
MP 2	"CD" quality audio (Single audio stream)	98.4
	Information service - Low data rate	12.4

Mode	Service	Data-rate kbit/s
MP 3	"CD" quality audio (Single audio stream)	98.4
	Information service - Medium data rate	24.8
MP 4	"CD" quality audio (Single audio stream)	98.4
	Information service - High data rate	49.6

IBOC-FM All-Digital mode

The IBOC-FM All-Digital mode provides the following services:

- Primary Digital audio service – "FM" or "CD" quality;
- Secondary Digital audio service – "FM" or "CD" quality;
- Information services - at various data rates.

Options for the Primary and Secondary services are independently configured.

The characteristics of each option is defined in the following table:

Mode	Service	Data-rate kbit/s
Primary		
All modes	System control data	0.9
MP 5	"CD" quality audio	98.4
	Information service	24.8
MP 6	"CD" quality audio (Very robust)	98.4
	No information service	0
MP 7	"Near FM" quality audio	24.8
	Information service	132.2
Secondary		
All modes	System control data	0.9
MS 1	Information service only	103.9
MS 2	"CD" quality audio	98.4
	Information service	30.3
MS 3	"CD" quality audio	98.4

Mode	Service	Data-rate kbit/s
	Information service	5.5
MS 4	"Near FM" quality audio	24.8
	Information service	128.7

Audio Quality

General aspects of Audio Quality are covered in the Overview section of this report.

Audio encoder

The IBOC system has been designed to use the latest generation audio coders, which provide a number of functions optimised for low data rate digital audio services, that operate in adverse reception conditions typically of the MF-AM and VHF-FM broadcast bands.

These audio coders support multi-descriptive audio coding, where the audio encoder provides a number of hierarchically related, but independent data streams. Data from the audio encoder is divided into two data streams. *Core* data and *Enhanced* data. *Core* data, provides the base component of the audio data stream and can be independently decoded, to provide basic quality audio. The *Core* data stream is passed through the modulation system, with the highest level of protection from transmissions errors. The *Enhanced* data stream, supplements the *Core* data, and adds to the quality of the decoded audio. The *Enhanced* data stream is passed through the modulation system with a medium level of protection.

The audio encoder *Core* data stream may be further divided into a single data stream or into a dual data stream. The single data stream requires a high level of protection but a lower data rate, whereas the dual data stream requires a higher data rate with a lower level of protection.

All of the above techniques are used in the IBOC receiver to provide graceful degradation of the audio signal when the digital receiver is at the edge of the coverage area, or is subject to interference.

The audio encoder may also be configured to share data between more than one service. The encoder may operate at a fixed rate, for a given audio quality; or can be configured to operate at a variable rate, tied to the complexity of the encoded digital audio. Highly complex audio requires a higher data rate than simpler passages. The audio encoder dynamically measures audio complexity and adjusts data rate accordingly, without compromising the quality of the encoded digital audio. This ability to vary the audio data rate could potentially allow greater throughput for data services when the audio is less complex.

Ibiquity Digital Corporation, the proponents of IBOC, has selected the PAC [23] audio encoder system. However this encoder is still under development and is not yet available but Ibiquity claim that the performance of PAC is similar to MPEG-4 AAC. The IBOC transmission tests have been conducted using the MPEG-2 AAC encoder [1].

On May 15, 2003, the Digital Audio Broadcasting sub-committee of the National Radio Systems Committee temporarily suspended its standard setting process for IBOC, and has requested Ibiquity to review the audio quality of the PAC audio encoder at low data rates [2][3].

Subjective Audio Quality

The audio coders within the IBOC system provide for differing grades of audio quality, ranging from, "AM" quality, "FM" quality to "CD" quality, with each quality grade, requiring a correspondingly higher data-rate.

Preliminary estimates indicate that current MPEG-4 AAC audio coders, are achieving "near FM" quality at approximately 20 kbit/s, "FM" quality at approximately 36 kbit/s and "CD" quality at approximately 64 kbit/s. The audio quality targets for the IBOC system are IBOC-AM: "FM" quality and IBOC-FM: "CD" quality.

Spectrum Issues

Frequency Usage

The IBOC systems have been designed for use in the USA radio broadcasting bands. The MF-AM band in the USA is 525 - 1705 kHz, and the VHF-FM band is 88 - 108 MHz.

Availability of Spectrum in Australia

The MF-AM broadcasting band in Australia is smaller than in the USA[24]. The Australian band is 526.5 - 1606.5 kHz. The band 1606.5 - 1705 kHz is used in Australia for MF-NAS services and is therefore unlikely to be suitable for high power, full bandwidth MF broadcasting systems. The MF spectrum above the MF-NAS services is allocated to Fixed, Mobile, Radiolocation and Radionavigation services.

Propagation Properties

IBOC-AM

The IBOC-AM system has been designed for use in the AM band. There are significant differences in signal propagation characteristics in the MF-AM band between day-time and night-time operation, due to the increase in sky wave propagation during night-time operation.

Testing conducted in the USA demonstrated that the performance of IBOC-AM during day-time operation was as expected, however night-time operation was less than expected due to the severe interference from adjacent channel services, caused by the increase in sky wave propagation. The Federal Communications Commission in the

[23] Developed by Lucent Technologies.
[24] A similar number of channels are available, due to different channel spacing.

USA has approved the IBOC-AM system for day-time operation only, pending further study under night-time operation [4].

The MF-AM broadcasting environment in Australia is substantially different to the USA Detailed Australian testing would be required to assess how IBOC-AM would operate at night in Australian conditions.

IBOC-FM

The propagation properties of IBOC-FM are similar to VHF-FM, therefore performance of IBOC-FM system will be similar to VHF-FM.

Spectrum Efficiency

The IBOC systems are inherently efficient in the use of spectrum as no new spectrum bands or channels need to be identified for the introduction of digital services.

SFN operation etc

The IBOC system, operating in the *All-Digital* mode is suitable for operation in an SFN network. Although this mode has not been tested, it is expected that the COFDM system could be adapted for SFN operation.

Infrastructure Requirements

Transmission infrastructure

The total spectrum bandwidth occupied by IBOC systems operating in Hybrid mode, is approximately 50% greater than existing analog systems, broadcasters will need to ensure that the bandwidth of their transmission systems is adequate.

AM Stereo

The CQUAM modulation system used for Australian analog AM stereo is not compatible with IBOC-AM. Consequentially, stations converting to digital with IBOC-AM will need to revert to mono operation on the analog service.

ACS services

ACS services provided by FM services can continue to be used with IBOC-FM Hybrid mode, as these two services are compatible.

Receiver Issues

Cost and Availability of Receivers

Receivers are not currently available. With the uncertainty regarding possible changes to the audio coding system, the earliest receivers will not be available before first quarter 2004.

Receiver Capability

With the availability of consumer receivers still someway off, it is difficult to predict the range of capabilities that receiver manufacturers will choose to support.

Size of Current Markets

No information available.

Technical Standards

The IBOC technical standard is proprietary, however there is an FCC requirement that a formal standard be prepared. The ITU recommendation BS.1114-3 identifies IBOC-FM as a possible system for use in the 30 - 3 000 MHz range, and ITU recommendation BS.1514-1 identifies IBOC-AM as a possible system for services below 3 MHz.

References

1. Ibiquity, Third report to the National Radio Systems Committee "AM IBOC DAB Laboratory and Field, Testing", January 4, 2002; Section II.A Audio Quality
2. Radio Magazine, 1 June, 2003 An IBOC roadblock, www.beradio.com/
3. Radio World Newspaper, 18 June 2003, Impact of IBOC pause disputed. www.rwonline.com/
4. Federal Communications Commission, "Digital Audio Broadcasting systems and their Impact on the Terrestrial Radio Broadcast Service." FCC 02-286, First Report and Order, October 11, 2002.

ISDB-TSB

Background

System Overview

Integrated Services Digital Broadcasting – for Terrestrial Sound Broadcasting (ISDB-TSB) is a narrow band model of the ISDB-T wide band system. The ISDB-T system is similar to DVB-T technology used in Australia for digital television, in that it uses COFDM to transmit digital video and sound. A key difference between ISDB-T and DVB-T is that in ISDB-T the wide band signal is divided into 13 band segments and that different modulation parameters can be used in band segments of the one service, providing the ability to trade off robustness and data rate depending on the importance of the information being carried in different band segments. A further difference is that ISDB-T can make use of time interleaving of the digital signals for improved mobile reception. (Eureka 147 also uses time interleaving but DVB-T does not). The ISDB-TSB system also allows for the use of MPEG-4 video coding which lends itself to mobile small screen video applications[25].

While ISDB-T services use 13 band segments in a 5.6 MHz bandwidth[26], ISDB-TSB services will use either 1 or 3 band segments, and have a bandwidth of 429 kHz or 1286 kHz. Three different operating modes are specified, along with 4 modulation schemes, a range of error correction rates and guard interval options. These different options result in a wide range of data rates: 281 - 1787 kbit/s for a single segment service; and 842 - 5361 kbit/s for a triple segment service. As services are most likely to be tailored for mobile reception, the data rates selected will be at the lower end of these ranges.

An ISDB-TSB receiver (ie a single or triple segment receiver) can also receive the centre segment of an ISDB-T service if the ISDB-T service is configured to allow this.

System Development

The ISDB-TSB system for digital radio has been developed in Japan, and is part of a family of ISDB systems. The first, ISDB-S, is a satellite system that delivers HDTV services to Japan. ISDB-S services commenced in December 2000 and now have over 4 million viewers. ISDB-T television services are expected to commence in Tokyo in December 2003. A target of 2006 has been set for nationwide coverage of ISDB-T services. Much of the focus is on the television variant of ISDB-T and as a result, few details are available on the implementation status of ISDB-TSB digital radio services.

---

25 ISDB-T can use MPEG-2 and MPEG-4 video coding.
26 In a 6 MHz channel, as used in Japan. The standards also allow for 7 and 8 MHz spacing.

Advantages/Disadvantages

Advantages

- Advanced system designed for fixed, portable and mobile delivery of television and radio services.
- Designed for low power consumption of receivers to allow portable battery operated devices to be manufactured.
- Allows use of efficient video coding (MPEG-4).

Disadvantages

- System not yet implemented (initial ISDB-T services expected to commence Dec 2003).
- No receivers currently available.

System Description

Modes of operation

As mentioned earlier, the ISDB-T system uses COFDM modulation together with band segmentation. For ISDB-TSB either one or three band segments are used. Four modulation schemes are specified (DQPSK, QPSK, 16-QAM and 64-QAM).

Individual segments can have independent properties forming up to 2 hierarchical layers. The band segments within each layer are able to adopt different modulation schemes, coding rates, and time interleaving lengths. Data transmitted on a robustly specified segment may still be recovered if the other segments fail. However, ISDB-TSB single-segmented transmission does not offer this layering and thus cannot make use of partial reception. For example in a triple segment ISDB-TSB, the centre segment could be made more robust with DQPSK and the outer two segments could be less robust and carry more data (eg for video) using 16-QAM.

Three modes are specified in the standard, which equate to different numbers of carriers, carrier spacing, and symbol duration for each mode. In a number of ways modes 1 and 3 are similar to the 2k and 8k modes of DVB-T respectively and the choice between the modes trade off performance parameters in the same way. For example, mode 3 has longer symbol duration and is therefore better for SFNs and multi-path performance. Mode 1 on the other hand gives better high-speed mobile performance due to immunity to Doppler frequency shift. Mode 2 offers a compromise between the other two modes.

In addition to the choice of three modes there are also options for different guard intervals and different error coding rates.

Bandwidth and Capacity

ISDB-TSB schemes are designed with channel plans to be used worldwide ie 6, 7 or 8 MHz. However, as no country outside Japan has adopted the system, it is possible that receivers will only be manufactured for the 6 MHz channel spacing. The system divides each channel into 14 segments. One segment is left unused to provide a guard band between channels, thus there are 13 useable band segments for each channel. In a 6 MHz system these band segments are 429 kHz wide. In a 7 MHz system they would be 500 kHz wide. In this paper, segment widths and data rates will refer to the 6 MHz system.

Audio and Data Capacity

The different modulation schemes, code rates and guard intervals result in a wide range of useable data rates: 281 - 1787 kbit/s for a single segment service; and 842 - 5361 kbit/s for a triple segment service. Services are most likely to be tailored for mobile reception and will therefore use the parameters that give the most robust reception. Accordingly, the data rates selected will be at the lower end of these ranges.

One example [2] of a service configuration is as follows. For a single segment service using DQPSK, 1/16 guard interval and ½ FEC, the available data rate is 330 kbit/s, which could be used for one stereo audio program at 144 kbit/s, text (such as EPG) 16 kbit/s, still images or video at 64 kbit/s, data at 32 kbit/s and control information at 64 kbit/s. If 16-QAM is used, the example suggest providing 2 stereo audio programs and using 256 kbit/s for video with the other components mentioned in the first example in an available data rate of 660 kbit/s. Presumably, in the example of a 330 kbit/s single segment service, two audio programs of 144 kbit/s could be transmitted, however, if the control information is fixed at 64 kbit/s (which seems a lot) then a minimum data rate for two “near CD” quality audio only services would be 352 kbit/s, and could require a change to 2/3 FEC giving a useable data rate of 440 kbit/s.

It should be noted that the use of 16-QAM instead of DQPSK doubles the data rate, however, 6dB more field strength is required for good reception which translates to a requirement for 4 times the transmitted power to provide the same coverage as a DQPSK system.

Audio Quality

Either MPEG-2 Layer II, MPEG-2 AAC or AC-3 (Dolby Digital 5.1 surround sound) audio coding techniques may be used. The MPEG-2 AAC system can produce “near CD” quality audio with a data rate of 144 kbit/s.

MPEG-4 video coding is also specified, allowing video with low data rates for small screen sizes such as 144 or 288 lines (SDTV has 576 lines). At the lowest resolution data rates of less than 64 kbit/s are needed.

Spectrum Issues

Frequency band usage

ISDB-T and ISDB-TSB are designed for use in the Japanese VHF and UHF bands, which are:

Band	Frequency Range	Current use in Japan
VHF Band II	76 - 90 MHz	FM Radio broadcasting
VHF Band II	90 - 108 MHz	TV broadcasting
VHF Band III	170 - 222 MHz	TV broadcasting
UHF Band IV	470 - 585 MHz	TV broadcasting
VHF Band V	585 - 770 MHz	TV broadcasting

From available information on trials conducted to date, it appears there may be an intention for the ISDB-TSB services to operate in the VHF bands (ie below 222 MHz) and for ISDB-T services to operate in the lower UHF band. To make room for the new ISDB-T services, a number of analog television services are being relocated to the higher UHF frequencies.

Satellite Spectrum

ISDB-T is not designed for use via satellite transmission. An ISDB-S system for satellite transmission to fixed receivers is available.

Availability of Spectrum in Australia

Current

Of the Japanese broadcasting bands 76 - 87.5 MHz and 470 - 520 MHz are not used for broadcasting in Australia. These bands in Australia are predominately used for land mobile services.

The remainder of the Japanese bands are used in Australia for FM radio and analog and digital television broadcasting. There may be limited spectrum opportunities in these bands. Such opportunities include the unused UHF channels that have been planned for datacasting. The highest frequency of the Japanese bands corresponds to Australian television channel 62 (upper edge of channel 62 is 771 MHz).

Future

The digital television conversion process for Australia features a simulcast period when, both analog and digital television services operate in parallel. At the end of the simulcast period the vacated analog channels (and potentially some more - subject to planning) could be made available for other uses such as datacasting or digital radio. The simulcast period is set at eight years with a review to take place to consider whether this needs to be revised. Currently, the end of the simulcast would see additional spectrum becoming available in capital cities on 1 January 2009 and in regional areas during 2011.

Spectrum Efficiency

The ISDB-TSB system has a variety of available data rates. For a robust service it would appear that two “near CD” quality stereo audio programs can be provided in one 429 kHz band segment, which is crudely equivalent to an average of one service per

215 kHz. For less robust systems at higher data rates spectrum efficiency can increase to one program per 39 kHz (ie using 64-QAM). With 16-QAM the efficiency is around one program per 61 kHz.

An advantage of COFDM technology is it allows low co-channel and adjacent channel protection requirements. The effect is being able to align channels close to each other, which is in itself can improve spectrum efficiency.

The system is able to cope very well with echoes produced by long signal delays, which makes is very suitable for SFNs. Single frequency networks enable using one frequency to service large areas, which can improve spectrum efficiency.

Propagation Properties

ISDB-TSB is designed for use in the VHF and UHF bands and is subject to noise, attenuation and interference like current FM and television services. ISDB-T is robust in cases of noise, multi-path delays, co-channel and adjacent channel interference.

Infrastructure requirements

ISDB-T and ISDB-TSB would be most suited to transmission from existing television sites as the services would be operating in the television bands and this would provide the greatest spectrum productivity and provide the greatest opportunity to identify available spectrum. In less spectrum congested areas, ISDB-TSB services could operate from other sites.

At common transmission sites there are theoretically a number of ways multiple services could be combined for transmission. In the analog world this combining is done after the output stage of the transmitter. This may also be possible for ISDB-TSB but further clarification will be required on whether a one segment guard band would be required. A guard band may be a necessity as each service places a pilot carrier signal just above the highest carrier. In a triple segment transmission the lowest carrier of the two highest segments form the pilot carrier for the lower segments. Therefore, to combine two services without a guard band the lowest carrier of the higher frequency service may interfere with the pilot carrier of the lower frequency service. To avoid this problem the services could be combined at the data layer and transmitted using a common transmitter. This will allow the lower carriers of each segment to become the necessary pilot carriers and will ensure proper synchronisation of the carriers.

Receiver Issues

Cost and availability of receivers

Receivers are not currently available. With ISDB-T services due to start in December 2003 it would be expected that receivers should be available at the same time. Note that it is not clear whether both sound and television services will start in 2003 or whether it is just television that is to commence first.

Capabilities

ISDB-TSB has commonality and interoperability with other systems, which adopt MPEG-2 technology such as ISDB-S, ISDB-T, DVB-S, and DVB-T. The system structure is fully compliant with MPEG-2 systems architecture. For instance, an ISDB-TSB receiver is able to receive the middle segment from an ISDB-T television broadcasting service (providing the television service is configured appropriately). This middle segment could contain the television sound program and perhaps a low data rate video version of the television program, to enable portable reception.

The multi-carrier ISDB-T system uses very low modulating frequencies. This is a major factor affecting power consumption on a device. The result is that ISDB-TSB receivers can be made small and lightweight. This is particularly beneficial for portable/personal radio receivers and will allow incorporation of ISDB-TSB receivers into mobile phones, PDA and similar devices.

Size of current markets

Japan has a population of 127 million (July 2002 estimate), which will allow large-scale production of affordable ISDB-TSB receivers.

Technical Standards

Standards are available in Japanese only at this point in time. The standards are produced by the Association of Radio Industries and Businesses (ARIB). Relevant standards Include:

Number	Title
ARIB STD-B29	Transmission System for Digital Terrestrial Sound Broadcasting
ARIB STD-B30	Receiver for Digital Terrestrial Sound Broadcast

References

1. http://www.nhk.or.jp/strl/open99/de-2/shosai-e.html
2. http://www.nhk.or.jp/strl/publica/bt/en/pa0006.html
3. ITU DSB handbook
4. ABA planning manual
5. DRAFT REVISION OF RECOMMENDATION ITU-R BS.1114-2 http://www.ibiquity.com/about/pdf/DraftRev_ITU-R_BS1114-2.doc
6. MPEG-AAC http://www.iis.fraunhofer.de/amm/techinf/aac/index.html

DVB-T

Background

The DVB project has developed a number of related digital broadcasting systems, for cable, satellite and terrestrial delivery of television services. These are known as DVB-C, DVB-S and DVB-T respectively. While all these systems were primarily designed for television broadcasting, they can and do also provide radio (audio-only) programs.

DVB-S services that principally provide free-to-air satellite television services to remote areas in Australia or provide Pay-TV services, already provide a number of radio services. Additionally, the free-to-air DVB-T digital television services offered by the ABC and SBS both carry radio programs. The ABC broadcasts "Dig" radio which is also available on the internet whilst SBS provides its two main radio channels. In the UK the Freeview DVB-T service provides up to 16 radio channels.

This chapter focuses on DVB-T since it is more radio like than DVB-S or DVB-C as the latter two can only provide service to fixed receivers. DVB-T on the other hand is sufficiently flexible to allow it to be optimised for delivery to portable and mobile receivers.

Current implementations of DVB-T services in Australia are planned for, and target fixed reception. These services transmit a net data rate of 19.3 - 23.0 Mbit/s using 64-QAM modulation. It is possible to introduce greater robustness by using QPSK modulation. This would enhance mobile reception but reduce data rates to as little as 4.3 Mbit/s (in the case of QPSK), although a data rate of 6.4 Mbit/s (also QPSK) would also give a very reliable service. Such data rates could provide 16 to 25[27] stereo radio services.

Additionally, recent technological advances such as the incorporation of diversity reception into chipsets have improved mobile reception for DVB-T services even at the higher data rates intended. At the IBC2002 conference mobile reception of a 64-QAM service with a diversity receiver was demonstrated.

Consumer grade mobile DVB-T receivers are likely to be produced with the aim of providing mobile television and multi-media services. Such developments could take place with the German market in mind from major car radio manufacturers such as Blaupunkt, Kenwood and Alpine. Analog TV tuners are available from these manufacturers as an option for in-car DVD players, and the next logical step is to provide a digital tuner option. However, currently in Europe the focus for digital radio is on the Eureka 147 system and there may be some commercial sensitivities in promoting DVB-T as a digital radio competitor. Additionally, as Eureka 147 has been designed with mobility in mind, it has a number of features that cater for mobility better than

27 Assuming a data rate of 256 kbit/s for each audio program, and overheads for service information in the range 51 to 258 kbit/s.

DVB-T. In particular the fact that DVB-T does not implement the time interleaving technique (unlike Eureka 147 and ISDB-T) will mean that DVB-T will be less robust than if it did. Tests in Japan on the ISDB-T system with and without time interleaving demonstrated up to a 10 dB improvement in performance with time interleaving.

In mid 2003 DVB set up an ad-hoc group within its technical committee structure to examine the issues surrounding mobile reception. An evaluation of DVB-T by this group concluded that while DVB-T was suited to mobile applications, the reception by small portable battery operated devices was highlighted as an area for further work. A 'Call for Technology' was released in January 2003, and inputs were to be evaluated in the first half of 2003 and a draft standard prepared.

Advantages/Disadvantages

Advantages

The advantages of using DVB-T for delivering digital radio services include:

- proven technology, established in many countries world-wide;
- digital radio services are already broadcast to fixed receivers in the UK and Australia;
- capable of operating over a wide range of frequencies, giving good scope to identify suitable spectrum
- two 7 MHz wide channels already identified as suitable for use from most television transmission sites throughout Australia;
- existing infrastructure, especially at television broadcast sites, can be used for transmission;
- capable of operating in single frequency networks for greater spectrum efficiency and seamless coverage between areas;

Disadvantages

The disadvantages of using DVB-T for delivering digital radio services include:

- although DVB-T is capable of being used for mobile reception with particular modulation parameters, it is not optimised for mobile reception, as it does not have a time interleaving capability;
- no mobile or portable hand held receivers are currently available;
- high data rates and wide bandwidth increases power consumption, making design of battery powered devices difficult;
- large bandwidth means many services must be multiplexed together for efficient use of the spectrum, in some scenarios multiplexes may not be fully utilised.

Audio and Data Capacity

The use of DVB-T for digital radio would present some interesting opportunities, as delivery of video is also possible, as is the provision of Dolby Digital (AC-3) surround sound. New consumer audio formats such as SACD (super audio compact disc) and DVD-A (DVD-audio) are now available with surround sound material, which could potentially lead to demand for surround sound digital radio services.

As indicated above a DVB-T channel can deliver between 16 and 89 stereo audio programs depending on the transmission mode and thus the robustness of the transmission (assuming a data rate of 256 kbit/s).

Permissible digital audio coding formats are MPEG Layers 1 or 2. Dolby Digital (AC-3) is an optional format, meaning only some receivers can decode it. MPEG audio data rates range up to 256 kbit/s, and Dolby Digital surround sound requires 384 kbit/s.

DVB-T is also capable of providing high quality standard definition and high definition video. The capability to decode high definition video is optional. In addition to the usual standard definition video format of 576i (720 horizontal pixels by 576 lines interlaced scanning), it is also possible to provide lower resolution video with several modes, the lowest being 352 horizontal pixels by 288 lines. Such a lower resolution mode would reduce the required data rate and be suited to viewing on small screens integrated into portable devices.

Spectrum Issues

The DVB-T system was designed to operate within existing broadcasting service band allocations, including VHF Bands I and III, and UHF Bands IV and V, and within existing TV channels (with 6, 7 and 8 MHz channel spacing catered for).

Due to extensive use of VHF Band II for FM radio services throughout Australia, this band is impractical for DVB-T and hence, is not given further consideration.

Due to relatively high levels of man-made noise in VHF Band I no country appears to have implemented DVB-T services in this band. This does not mean it is not possible to use this band. Providing sufficient field strength is available to overcome the noise, it should in theory, be possible to implement a system in this band. If deployment of services in Band I were to be seriously considered, it is recommended that testing be carried out in a number of different areas/regions in Australia to evaluate the effect of man-made noise on the robustness of DVB-T transmissions.

Australia has adopted the 7 MHz channel spacing for DVB-T, consistent with the analog television channel spacing.

Frequency Band Usage

Australia has implemented DVB-T for the delivery of digital television services in VHF Band III and UHF Bands IV and V as has Germany. The UK on the other hand has only implemented DVB-T in the UHF band. As a result no receivers are available or likely to be available in the foreseeable future with tuners for capable also of operation in VHF Bands I and II.

Satellite Spectrum

Not applicable to DVB-T.

Availability of Spectrum in Australia

Current

In most areas in Australia, there are five analog television services (six in most capital cities and eight in some areas adjacent to capital cities where licence areas overlap.) Planning for digital television services has seen seven digital channels planned for most areas, with the five analog broadcasters being assigned one digital channel each at each transmission site. In most areas there are two unassigned 7 MHz channels (usually in UHF Band IV or V). These channels have been considered for short-term trialling of datacasting technologies following the decision not to proceed with the long-term allocation of datacasting transmitter licences. If policy and legislation allowed, these two unassigned channels could be used for the delivery of digital radio services. In some areas additional channels may be available. For example in the capital cities channel 9A is not available due to the analog channel 10 operating on an old channel spacing. If the analog channel 10 service were shifted by 1 MHz in frequency an additional channel, suitable for a 7 MHz wide DVB-T service could be available in most capital cities, noting that consideration of any use of channel 9A in regional areas would need to be taken into account in confirming channel availability. Without a shift of the analog channel 10 service, a 6 MHz wide DVB-T could operate, but the wisdom of mixing channel bandwidths in a region is questionable, because receivers designed for one channel bandwidth may not necessarily be able to access channels of another bandwidth.

Planning for DVB-T radio would not need to consider some of the planning issues that were relevant for digital television, such as aiming to keep channel allotments within the bandwidth of existing antennas. This may allow some additional channels to be planned, probably in the upper parts of UHF Band V in some areas where the spectrum is not required for analog and digital television repeaters.

Future

The digital television conversion process for Australia features a simulcast period when, both analog and digital television services operate in parallel. At the end of the simulcast period the vacated analog channels (and potentially some more - subject to planning) could be made available for other uses such as datacasting or digital radio. The simulcast period is set at eight years with a review to take place to consider whether this needs to be revised. Currently, the end of the simulcast would see additional spectrum becoming available in capital cities on 1 January 2009 and in regional areas during 2011.

Spectrum Efficiency

The spectrum efficiency in terms of audio programs per kHz is dependent on the operating mode/modulation chosen. If the most robust mode was selected then just 4.3 Mbit/s would be available. Assuming 256 kbit/s for each stereo audio program, which is typical for television audio, would allow 16 audio programs (allowing 258 kbit/s for service information). This is equivalent to 437 kHz per program. The slightly less robust mode that provides a net data rate of 6.4 Mbit/s would allow 25 audio programs with 51 kbit/s for service information). The resulting efficiency then improves to 280 kHz per program. Assuming the data rates used for fixed reception of digital television, ie 19.3 or 23 Mbit/s would permit 75 to 89 audio program to be delivered, with efficiency at approximately 80 - 90 kHz per program.

The use of single frequency networks allows for efficient use of the available spectrum. DVB-T services can be implemented in single frequency networks, although this is at increased cost in comparison to multi frequency networks.

Propagation Properties

VHF Band I

Services in VHF Band I, particularly at the lower end of frequencies, are susceptible to interference from man-made noise and anomalous seasonal propagation due to "sporadic-E" and "F2 layer" propagation. The spectrum may be suitable for lower power services, which may cover a relatively wide area, but the anomalous propagation may limit the usefulness of higher power services.

Propagation losses due to vegetation are low for VHF bands.

VHF Band III (174-230 MHz)

VHF Band III has good propagation characteristics that would be suited to the provision of terrestrial digital radio services over large coverage areas (possibly up to a radius of 100 km). VHF Band III frequencies have lower man-made noise than Band I and do not suffer from a number of the anomalous propagation characteristics, which are a problem in Band I such as sporadic E and F2 layer propagation. It is for these reasons that VHF Band III is also favoured for terrestrial television broadcasting.

Propagation losses due to vegetation are low for VHF bands.

UHF Bands IV and V (520-820 MHz)

The propagation characteristics for UHF Bands IV and V are well suited to small to medium coverage terrestrial digital radio services. Wide coverage digital radio services would be possible in these bands as is evident from the wide coverage television services using these bands, however, very high radiated power levels are required.

The lower UHF frequencies have an advantage over the higher frequencies for a number of reasons. At higher frequencies, greater signals levels are required for adequate reception due to increasing noise generated by the internal electronic circuitry of the receiver ('receiver noise'). Additionally, propagation losses due to terrain, man-made obstructions and vegetation also increase with frequency.

Doppler effect

The Doppler effect is an effective change in frequency with the relative speed of the receiver compared to the transmitter. Using the 8k mode, the Doppler effect limits the maximum receiver speed to approximately 60 km at the higher UHF frequencies. While the 2k mode would allow higher speeds, suitable for reception at highway speeds, it would limit the use of SFNs and increase the potential for destructive interference due to long echoes.

Consequently, the use of DVB-T will require a compromise between maximum receiver speed and network coverage and design.

Infrastructure Requirements

As with other wide bandwidth systems for digital radio such as Eureka 147, ISDB-T and SDARS, programs need to be multiplexed together at a central point before distribution to transmitter sites for transmission. New ownership arrangements for the multiplexer and transmission sites will be required.

As digital radio services delivered by DVB-T will be operating within the television frequency bands, the greatest spectrum availability and spectrum productivity will be for the case where the digital radio services share television transmission sites and operate with similar coverage. However, television and radio services often have different licence areas, so either changes to licence areas will be required or reduced spectrum productivity will be necessary to constrain the DVB-T digital radio services within existing radio licence areas.

Additionally, for very small licence areas such as those for low power local community radio services it would be inefficient to allow each of those broadcasters a 7 MHz channel to transmit a single radio service when such a channel is capable of transmitting between 16 and 89 programs.

As discussed earlier, there are two unassigned television channels that have been planned for most areas of Australia. It should be noted, however, that these channels are in some cases limited by power restrictions which constrain the coverage, and in a number of cases, due to spectrum shortages, it will be necessary to operate the channels in an SFN over wide areas. In particular, the same two channels have been reserved for datacasting at each of the Sydney, Newcastle and the Central Coast transmission sites and will need to be operated in an SFN and thus will need to carry identical programming across both Sydney and Newcastle. Similarly the available channels in the Brisbane region are common across an area stretching from Gympie, and the Sunshine Coast in the North to the Gold Coast and Currumbin in the South. Additionally, one of these Brisbane region channels is also common to the Northern Rivers/Richmond-Tweed region, and would also serve towns such as Lismore in NSW.

Receiver Issues

Capability

Currently available receivers for DVB-T are suitable for fixed or portable indoor reception where mains power is available. There are no currently available receivers designed for in-vehicle operation, or portable battery powered operation.

Chipsets are now available that incorporate diversity reception and it is understood that several of the set top boxes on the market in Germany incorporate these chipsets to facilitate improved indoor reception (ie with rabbit ear type antennas).

Receivers available in the Australian market (and most overseas markets) can only tune to channels in VHF Band III or UHF Bands IV or V. No receivers appear to be currently available that are capable of tuning to VHF Band I channels.

Cost and Availability of Receivers

Mains powered DVB-T set top boxes are available in Australia from $299 to $999.

Size of Current Markets

Due to the wide-spread adoption throughout much of the world of DVB-T for television applications, the volume of receivers and chipsets being manufactured is potentially very large which should lead to further levels of chip set integration and lower prices. These lower prices could make the use of DVB-T attractive for the delivery of digital radio services.

Technical Standards

Standards are available that are suitable for digital television use of DVB-T these are embodied in ETSI standards and have been adopted and modified by Standards Australia. Relevant standards Include:

Number	Title
ETSI EN 300 744 V1.4.1	Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television.
ETSI EN 300 468 V1.5.1	Digital Video Broadcasting (DVB); Specification for Service Information (SI) in DVB systems.
ETSI TR 101 154 v1.4.1	Digital Video Broadcasting (DVB); Implementation guidelines for the use of MPEG-2 Systems; Video and Audio in satellite, cable and terrestrial broadcasting applications.
ETSI TR 101 190 v1.1.1	Digital Video Broadcasting (DVB); Implementation guidelines for DVB terrestrial services; Transmission Aspects.
ETSI TR 101 211 v1.5.1	Digital Video Broadcasting (DVB); Guidelines on implementation and usage of Service Information (SI).
Standards Australia AS 4599-1999	Digital Television – Terrestrial Broadcasting – Characteristics of digital terrestrial television transmissions.
Standards Australia AS 4533.1-2000	Digital Television – Requirements for receivers Part 1: VHF/UHF DVB-T television broadcasts.

As noted above, the DVB project is examining what modifications may need to be made to the standards to facilitate mobile and portable reception by battery-powered devices. Adoption by Standards Australia of any new or revised standards may be desirable if DVB-T (or a related future standard) is to be adopted for digital radio delivery in Australia.

Worldspace Satellite

Background

System Overview

Worldspace Corporation has developed two satellite transmission systems for operation in L band at approximately 1.5 GHz. In ITU terminology, the two systems are known as System D_S and System D_H. The first system is designed solely for satellite delivery of services, and the H reflects that the second system is a hybrid satellite/terrestrial delivery system. System D_S, is operational and provides coverage to Asia, Africa, the Middle East and potentially parts of Europe through two geostationary orbiting satellites to relatively simple portable radio receivers. The two operational satellites are named ‘Afristar’ and ‘Asiastar’. A third satellite was intended to cover central and south America, however the launch of this satellite has been delayed indefinitely. System D_S uses a single carrier QPSK modulation which is not as well suited to mobile reception as COFDM systems.

The second system, System D_H has not yet been implemented. It is based on System D_S for the satellite component with some enhancements. The receiver design provides for simultaneous reception of the single carrier QPSK satellite signal and terrestrial repeaters using COFDM and is claimed to provide mobile reception. Due to the use of COFDM the terrestrial repeaters should be able to provide good mobile reception and will also provide coverage to areas shaded from the satellite. The use of single frequency networks (SFNs) for the terrestrial repeaters will also be possible. Mobile reception of the satellite outside coverage areas of the terrestrial repeaters will be less reliable as errors and signal dropouts are likely to occur, particularly at higher speeds.

The aim of the current Worldspace services is to provide radio and data services to underserved regions through portable battery operated devices in less developed countries including areas where infrastructure such as mains power may not be available. Many of the programs are available free to air, however, there is also premium content available on a subscription basis.

According to a recent article [3], Worldspace is also proposing a service targeted at Europe using the satellite that had been intended for the Americas. It is likely the System D_H would be used. The high latitudes of Europe mean that the angle of arrival of signals from a satellite will be quite low, leading to greater shading and blocking of the signal by buildings and other obstacles. Because of this, a large number of repeaters will be necessary and as a result the initial roll-out will focus on three countries in France, Germany and Italy. A second satellite to provide diversity of signals (as used in the US SDARS services) may improve the reliability of the satellite signal. The projected launch date for the first satellite is late 2005.

Advantages/Disadvantages

Advantages

Advantages of the Worldspace digital radio systems are:

- relatively inexpensive digital receivers;
- wide (ie continental) coverage;
- lower cost satellites than other satellite digital radio systems.

Disadvantages

Disadvantages of the Worldspace digital radio systems are:

- satellite component not specifically designed for mobile reception;
- satellite signal can be blocked by buildings and other obstacles;
- poor in-building coverage from satellite;
- requires terrestrial repeaters in the hybrid mode to overcome the above three issues;
- as for Eureka 147, the required frequency band (L-Band) is currently encumbered with fixed point-to-point and point-to-multipoint services;
- limited capacity for localised services, although local insertion of program material or advertising is possible at terrestrial repeater sites.

Audio and Data Capacity

Permissible audio data rates range from 16 to 128 kbit/s. The net payload is 1.536 Mbit/s. One reference [4] talks about each satellite beam providing 'more than 40 satellite radio stations and a variety of multimedia services'. From this it would appear that on average those 40 radio stations are using just 32 kbit/s.

The Worldspace system D_S uses a variation of MPEG-2 Layer III called MPEG-2.5 that allows for quarter rate sampling (at 12, 11.025 and 8 kHz). Layer III for audio and JPEG for image data. Layer III means that greater coding efficiency is available (in comparison to Layer I or Layer II used for Eureka 147 and DVB-T) at the expense of greater complexity in the encoder and greater coding delay.

The Worldspace system can also be used to provide data to remote locations, and one application Worldspace suggests is for multinational companies to deliver data to remote field sites. Additionally, a subscription service is being offered in Kenya that provides downloads of web content in a 'push' delivery model. The content is cached on the computer hard drive for later viewing and is updated periodically.

Spectrum Issues

The Worldspace satellites occupy the band 1467 - 1492 MHz utilising this spectrum across three beams on each satellite. In System D_H, terrestrial repeaters can be operated in the same band as the satellite, but not on the same channel. Worldspace has indicated that terrestrial repeaters could (if suitable receivers were available) be operated in any band including S band and VHF bands.

ITU Frequency Band Allocations

The ITU table of allocations allocates the band 1452 – 1492 MHz to both the Broadcasting Service (BS) and the Broadcast Satellite Service (Sound) (BSS(S))[28] in all three ITU regions on a primary basis. The band is also allocated to the Fixed and Mobile services. However, the USA has an alternative allocation only allowing Fixed and Mobile services in this band. Additionally in Region 2 (the Americas) Mobile Aeronautical Telemetry has priority over other uses of the band.

Availability of Spectrum in Australia

Current

As indicated above the band 1452 - 1492 MHz is allocated in Australia for use by broadcasting and broadcasting satellite services on a shared basis with Fixed and Mobile services. This allocation is within the band 1427 - 1535 MHz used for low capacity Fixed Service point-to-point microwave links throughout Australia and for Telstra's Digital Radio Concentrator System (DRCS) and a high capacity version of it (HCRS) throughout the more remote parts of the country. Defence also use the band for Mobile Aeronautical Telemetry in various parts of Australia.

The band has seen little increase in assignments to these services as the then SMA (now ACA) introduced an embargo on new assignments which was replaced by the *1.5 GHz Band Plan* in December 1996 which limits new assignments. The purpose of the embargo and subsequent Band Plan was, amongst other things, to preserve spectrum options for digital radio.

Future

To utilise this band for a satellite delivered digital radio service would require an operator to finance and successfully launch a satellite with an L band package. This cost may run to hundreds of millions of dollars. Given the high cost of such an activity, no prospective operator is likely to embark on such a path unless they had obtained guaranteed access to spectrum. The international process to achieve that is to submit a satellite system filing to the ITU and to successfully complete coordination with countries that respond to the filing. Additionally at a national level the impact of the satellite service on existing Fixed and Mobile services would need to be assessed and consideration may need to be given to relocating Fixed and Mobile services to other spectrum.

Spectrum Efficiency

The net data payload is 1.536 Mbit/s over a bandwidth of 1.584 MHz. The gross data rate is 3.68 Mbit/s. Assuming an average data rate of 32 kbit/s this equates to 48 streams of programming. This is crudely equivalent to an average of one service per 33 kHz.

---

28 Under Resolution 528 (which is called up by footnote 345 of the Radio Regulations), until a broadcasting satellite (sound) planning conference is convened broadcasting-satellite systems may only be introduced in the 1467-1492 MHz range;

Propagation Properties

Due to the limited power budget available on satellites, satellite delivered radio signals at 1.5 GHz essentially can only be received when the receiver is within line-of-sight of the satellite. If the signal is blocked by obstructions, reception may be blocked. The Worldspace System D_S is designed for reception by stationary (but portable) receivers. The stationary nature allows the use of antennas with some directionality and gain. Such antennas can be positioned and pointed relative to obstacles to achieve optimal reception.

Infrastructure Requirements

The operating Worldspace services using system $D_{S,}$ operate using a single satellite in geostationary orbit for each region. Each satellite has three antenna beams covering different areas although there is some overlapping of the coverage of each beam. The proposed service for Europe may operate with two geostationary satellites to provide signal diversity.

Due to the use of QPSK modulation the satellites do not need to be as powerful as those used for SDARS. EIRP figures for the Worldspace satellites appear to be in the 75 - 200 kW range. Power flux densities across the service area are in the range -113 to –121 $dBW/m^2/MHz$. The ability to make use of a lower power satellite reduces the cost of introducing the system relative to other satellite systems

The Worldspace satellites have been designed with on-board processing capabilities allowing programming to be up-linked from multiple locations and multiplexed in the satellite, as opposed to the usual approach of backhauling all programming to a central site and multiplexing the signals there before up-linking to the satellite.

Licence area implications

If implemented in Australia, a satellite system would most likely cover the whole continent, due to the practicalities of designing satellite antennas for this relatively low (in satellite terms) frequency. As such, it may not therefore be a direct substitute for analog terrestrial radio, which typically has small regional or city-wide licence areas with local content or local inserts.

Receiver Issues

Capability

Worldspace receivers are supplied with an integrated or detachable satellite antenna. Line-out connections are available for connection with a home 'hi-fi' system. Additionally data adapters are available for connections to a personal computer, or a PC card satellite tuner is also available. Optional extras include high gain antennas, antenna extension cables, and low noise amplifiers and 'interference filters'. The interference filters appear to assist in reducing interference from existing terrestrial services using the band such as fixed links.

Cost and Availability of Receivers

The most reliable information about costs and availability of receivers is on the Worldspace website. The website lists prices for System D_S receivers as ranging from USD$125 to $250. There are ten models of receivers, however, it appears that stock of four models currently have nearly sold out.

There are no receivers available for System D_H.

Size of Current Markets

Information on the size of markets is not currently available.

Technical Standards

Although the Worldspace systems are included in ITU-R Recommendations, they are essentially proprietary standards and hence no regional or country based standards are available. However, there would be technical specifications provided to manufacturers building receivers on which standards could be based.

References

1. ITU DSB Handbook
2. www.worldspace.com
3. Ref: Satmagazine.com June/July 2003 pages 20-23
4. http://www.worldspace.com/about/corpbrochure0801.pdf

US based Satellite Digital Audio Radio Services (SDARS)

Background

Two satellite delivered subscription radio services providing similar suites of approximately 100 audio channels each have commenced operation in the US. These are XM radio commencing in November 2001 and Sirius, which commenced July 2002. The 100 audio channels are typically divided into 60 music channels and 40 voice channels. The licences were auctioned in April 1997 with the FCC issuing licences in October 1997. The licensees were given 6 years to have the system fully operational. XM Radio paid nearly US$90 million and Sirius paid over US$83 million for their licences.

Under the FCC rules, the service category is Satellite Digital Audio Radio Service (SDARS). Both services operate in a frequency band around 2.3 GHz, that is part of the radiofrequency spectrum known as 'S-Band'.

Both systems use COFDM transmissions enabling the use of terrestrial in-fill transmitters.

Advantages/Disadvantages

Advantages

Advantages of the SDARS digital radio systems are:

- wide (ie continental) coverage, especially to mobile receivers;
- large bandwidth allocations allow approximately 100 audio programs to be transmitted by each system.

Disadvantages

Disadvantages of the SDARS digital radio systems are:

- satellite signal can be blocked by buildings and other obstacles;
- poor in-building coverage from satellite;
- requires terrestrial repeaters to overcome the above two issues;
- frequency band (S-Band) not available in Australia;
- requires two to three high cost, powerful satellites.

Audio and Data Capacity

Publicly available information on the audio and data capacity of these systems is limited primarily because they are proprietary systems.

The audio coding system used by the Sirius system is Perceptual Audio Coding (PAC) version 4. The technology is owned by Ibiquity and is also proposed for use in the US IBOC terrestrial digital radio systems. Sirius uses a variable data rate together with statistical multiplexing to make the most efficient use of the available bandwidth. Different data rates are used depending on the type of program material; talk programs use fewer bits than music programming. Various news articles and internet discussion forums on Sirius and XM radio talk about data rates ranging from 8 – 64 kbit/s.

There does not appear to be any significant data component of either service, other than program-associated data that could give the song title and artist.

The XM Radio system uses CTaacPlus, which is a combination of Advanced Audio Coding, the work of AT&T, Dolby, Fraunhofer and Sony – and Spectral Band Replication from Coding Technologies. CTaacPlus has also been adopted for Digital Radio Mondiale (DRM).

Various forums and articles available on the internet appear to point to XM Radio having superior sound quality to the Sirius system. It is not clear whether this is solely due to the different audio coding systems or partly due to interference.

Spectrum Issues

Frequency Band Usage

The ITU table of allocations by way of footnote 393 allocates the band 2310 - 2360 MHz to the Broadcast Satellite Service (Sound) (BSS(S)) and complementary terrestrial sound broadcasting service on a primary basis in the USA, Mexico and India. See also spectrum allocation footnote 396. The only country that has implemented a service using this allocation is the USA. (A bilateral agreement between Mexico and the USA shows Mexico has at least reserved the right to operate its own satellite system). The ITU table of allocations also allocates the band 2300 - 2450 MHz to the Fixed, Mobile and Radiolocation services on a primary basis and to the Amateur service on a secondary basis[29].

According to the FCC rules (part 25) the band 2320 – 2345 MHz is used for SDARS with each of the two licensees being allocated 12.5 MHz. Sirius is licensed to operate in the band 2320 - 2332.5 MHz and XM Radio is licensed to operate in the band 2332.5 – 2345 MHz. The FCC rules allow for part of each licensees spectrum allocation to be used for telemetry beacons by reducing the bandwidth of the satellite down link.

Permission to operate terrestrial repeaters has only been granted to the SDARS licensees on a temporary basis and is subject to a condition that the repeaters do not cause interference to a Wireless Communications Service (WCS), the Multipoint Distribution Service (MDS), and the Instructional Television Fixed Service (IFTS). [Ref: FCC order DA 01-2383, 15 October 2001]. The WCS bands (2305 - 2320 MHz and 2345 - 2360 MHz) are immediately adjacent to the SDARS bands, and thus adjacent

[29] Under footnote 150 of the Radio Regulations the band 2400 - 2500 MHz is also designated for Industrial, Scientific and Medical applications (eg. microwave ovens). Under the Low Interference Potential Devices or the Spread Spectrum Devices Class Licences users are authorised to operate a range of devices in this band (eg. RLANs, some cordless telephones).

band interference will be a major concern particularly for the repeater stations. Interference to MDS and IFTS is likely to be less of an issue as there is a fair degree of frequency separation. MDS bands are 2150 - 2162 MHz and 2596 - 2680 MHz. IFTS is also 2596 - 2680 MHz.

Interference may also pose a problem to reception of the SDARS from out-of-band emissions from devices operating in the 2.4 GHz ISM (Industrial Scientific and Medical) band, 2400 - 2483 MHz. Interference sources could include ISM devices (eg microwave ovens) as well as the use of Wireless LAN type technologies and cordless telephones.

Availability of Spectrum in Australia

Current

The band 2302 - 2400 MHz is used for MDS (Multipoint Distribution Systems) on a spectrum licensed basis. Additionally, Australia does not have an allocation for BSS(S) use in the 2.3 GHz band used for XM Radio and Sirius.

The only BSS(S) allocation for Australia is at L band. To operate either the Sirius or XM Radio systems in this band would require availability of a satellite system and modification of receivers at unknown cost. See discussion under receivers.

Future

To obtain the same band allocation as used by Sirius and XM Radio allocation, would require an ITU World Radio Conference to modify the table of allocations. In the lead up to such a WRC decision considerable work on sharing studies and bilateral negotiations with other countries in our region would be required. The next WRC is tentatively scheduled for 2007 – however possible revision of that allocation is not included on the agenda for the 2007 Conference. Use of the 2310 - 2360 MHz band would also require the displacement of existing spectrum licence holders, which have a 15 year term. In summary, it is highly unlikely that operation of a satellite system in S-Band over Australia would be possible.

Spectrum Efficiency

Each operator delivers approximately 100 radio services nationwide in 12.5 MHz, which is crudely equivalent to an average of one service per 125 kHz.

Propagation Properties

The use of multiple satellites and terrestrial repeaters provide a level of redundancy such that only one of the satellites or a repeater needs to be in view of the receiver. When two satellites are in view, this provides a degree of signal diversity, which adds to the robustness of the reception. Additionally, one or both systems incorporate a 10 second memory buffer, which allows for service to continue despite temporary loss of signal when a vehicle passes under a freeway overpass bridge or behind a building.

Infrastructure Requirements

The two licensees have adopted different system architecture. Sirius operates three satellites in a Highly Elliptical Orbit (HEO) that is geo-synchronous. The satellites are spaced eight hours apart on the same orbit and two satellites are active at any given moment. In comparison, XM Radio operates two satellites in Geostationary – satellite orbit (GSO) with one positioned above the East coast and the other above the West coast.

Coverage of these satellite systems extends across the whole of the contiguous states of the US (ie excludes Alaska, Hawaii etc).

For each system, all programming is uplinked from the one location using frequencies around 7 GHz. Each system also needs to have a satellite operations centre to control the satellites and keep them correctly positioned in each orbit.

The XM Radio satellites are claimed to be the most powerful in commercial use. EIRP figures appear to be in the 2 – 10 MW range. Power flux densities across the service area are in the range –119 to –110 dBW/m^2/MHz.

In addition to the satellites, terrestrial repeaters are used to fill-in coverage where the satellite signal is shadowed by buildings or other obstructions. According to a January 2002 internet news article, XM Radio had over 800 repeaters. These repeaters can be up to 40 kW EIRP.

Licence area implications

If implemented in Australia, these satellite systems would most likely be implemented to cover the whole continent, and would therefore not fit well with the current approach of small regional or city-wide licence areas for most radio services.

Receiver Issues

Receiver Capability

The majority of the available receivers for XM Radio and Sirius services are for in car use, however there are also a few models available for in home use. There currently appear to be no battery powered portable receivers. Receivers usually have AM and FM reception capability in addition to reception of either S-DARS services. Most receivers for cars also have in-built CD players. Add on modules with an FM modulated output can be added to existing car radios. There are also head units (ie AM/FM/CD units) that are either ‘XM ready’ or ‘Sirius Ready’ to which an additional satellite tuner module to be added later.

Receivers do not currently appear to be available that can receive both XM Radio and Sirius. However, the FCC rules require that the receivers should be able to receive all licensed S-DARS systems that are operational or under construction (FCC Part 25.144 (3)(ii)).

Cost and Availability of Receivers

Alpine, Audiovox, Clarion, Delphi, Delco, Motorola, Panasonic, Pioneer, Sanyo, and Sony are manufacturing receivers for XM radio. Clarion, Kenwood, Panasonic, Audiovox, Milennia and Jensen are manufacturing receivers for Sirius.

Antenna prices

In addition to the receiver costs a suitable antenna is also required. A range of antennas for cars, trucks and boats are available. For Sirius, car antennas range from USD $50 to $80, for trucks up to $100 and a marine/boat antenna is available for $195. For XM Radio, car antennas range from USD $40 to $90, for trucks up to $150 and a marine/boat antenna is available for $140.

Sirius receiver prices

'Sirius ready' AM/FM/CD in car head units range in price from USD$170 to $600. These units do not include the satellite tuner. The add-on tuners to 'Sirius ready" receivers cost USD$160. Sirius ready AM/FM/CD/DVD/TV in car units range in price from USD $2000 to $2800.

The minimum cost of antenna, tuner and AM/FM/CD head unit for the Sirius system is therefore USD $380.

XM Radio receiver prices

'XM ready' AM/FM/CD in car head units range in price from USD$ 250. 'XM Ready' AM/FM/Cassette models are also available from USD $100. These units do not include the satellite tuner. The add-on tuners to 'XM ready' receivers cost USD$150 to $250.

The minimum cost of antenna, tuner and AM/FM/CD head unit for the XM Radio system is therefore USD $440, or for an AM/FM/Cassette system the minimum cost is USD $290.

Subscription fees

The monthly subscription for XM Radio is USD$9.95 and for Sirius USD$12.95 (Sirius subscribers can take out a second subscription for USD$6.99). For Sirius a one off activation fee of $5 (online) or $15 (not online) also applies.

Modification of receivers to suit Australia

The 2.3 GHz band used by XM Radio and Sirius in the US, is unlikely to be available for deployment of these systems in Australia. The 1.5 GHz band is more practical for an Australian satellite delivered radio service. If either of the XM or Sirius system were to be implemented in the 1.5 GHz band, then modification of the receivers would be required, adding to the above mentioned costs.

Size of Current Markets

XM Radio

On 1 July 2003 XM Radio announced that it had 692,253 subscribers[30].

XM Radio receivers are available as options of a wide range of new cars. XM is currently available on 25 of General Motors' 2003 models, XM will be available on 44 of GM's most popular Cadillac, Chevrolet, GMC, Pontiac, Buick and Saturn models beginning later this year. Honda is making XM available on the Honda Accord, Honda Pilot and Acura RL, Acura TL and Acura MDX models. Toyota, Isuzu, Infiniti, Nissan,

---

30 From the XM website http://www.xmradio.com/newsroom/screen/pr_2003_07_01.html

Audi and Volkswagen will offer XM to their customers. The luxury division of Nissan North America is also installing XM radios as an option in their cars. XM is available on the 2003 Infiniti FX 45 crossover vehicle, the Q45 luxury sedan, the M45 performance sedan, the G35 sport sedan, G35 sport coupe and I35 performance luxury sedan.

Consumers can also purchase after market car, home and portable audio receivers, at Wal-Mart, Best Buy, Circuit City and other major retailers nationwide.

Sirius

As of 14 May 2003 Sirius claimed to have 68 000 subscribers (a growth of nearly 40 000 for the first quarter of 2003). Sirius has set itself a target of 300 000 subscribers by the end of 2003.

Technical Standards

As the both XM Radio and Sirius are proprietary systems, there are no standards available. However, there would be technical specifications provided to manufacturers building receivers on which standards could be based.

Other Emerging Technologies

Background

The Internet is sometimes touted as a future competitor to digital radio in the provision of digital audio entertainment and information. ‘Internet radio’ or audio streaming via the Internet to personal computers has been available for some time. Radio content available on the Internet is already being included in ratings statistics in the UK when considering the number of people accessing digital radio (alongside Eureka 147 and digital television broadcasts). Audio streaming uses techniques such as ‘buffering’, in which audio or audiovisual files are continuously downloaded into a ‘reservoir’ before being played, to counter the inherent unreliability of the Internet as a source of continuously streamed content.

There are various streaming software packages available allowing the content to be heard without paying a subscription fee, so radio can be broadcast free-to-air. Audio-on-demand is featured on a number of larger radio sites, giving the listener to access programs up to seven days after the live broadcast (depending on the copyright agreements entered into by broadcasters and record companies etc.). Additional content, both text and picture based, is available and directly linked to individual programs allowing interactivity for competitions and live feedback/text conversations with presenters.

Content competition is high and quality ranges from highly synthesised, well engineered and designed websites to those that a school child can create in their own home. Internet ‘broadcasters’ do not require a licence or a scarce channel to become established so barriers to entry are low.

Although the Internet makes radio services from all over the world accessible, compared to analogue radio, it still suffers from lack of mobility, low sound quality, high cost of bandwidth and limitations to the number of personal computers to which services can be streamed simultaneously.

Looking ahead, the continuing development of wireless/mobile telecommunications may create further opportunities for services that do not resemble established digital radio models to enter the digital radio market. Two emerging wireless/mobile technologies are 3rd Generation Cellular technology (3G) and Wireless Broadband Internet technology or IEEE 802.11 (Wi-Fi). Neither of these are ‘radio only’ technologies but have been developed with the telecommunications and Internet industries in mind. In the case of 3G, there is potential for the technology to complement, rather than to compete with more ‘traditional’ point-to-multipoint digital radio technologies such as Eureka.

3G

3G is the newest technology available to consumers in mobile telecommunications. It is a mobile telephone service allowing access to additional content such as video and picture messaging services; the ability to see the person one is talking to; the ability to see specific sections of a larger website available on the Internet ("walled garden websites"); short video on demand clips; connection to email and information services (eg maps and horoscopes, local guides, news, weather and sporting results). 3G content can be localised due to the service owners' already existing regional set-up. 3G provides ubiquitous and continuous mobile coverage however it is restricted by severe limitations of bandwidth (ISDN-level data rates).

In Australia spectrum suitable for delivery of 3G services was allocated in a price based allocation process in 2000. Spectrum licensees have exclusive property rights to the spectrum and hence, quality of content can be recorded and maintained.

3G is in its early stages in Australia (officially launched April 2003) and is largely used as a platform to receive phone calls and media rich, short messages within communities. 3, the Hutchinson 3G Australia Pty Ltd service, attracted 43 650 subscribers in the first three months of the services becoming available.

As yet, 3G is not capable of streaming live audio broadcasts and after contacting representatives from Hutchinson, Optus and Telstra it is clear that they are not prioritising further development of this ability for Australian audiences in the near future. However, it is possible that arrangements with radio broadcasters could be set up to enable streamed radio services. In the shorter term, however, 3G may have potential to be used in conjunction with digital radio broadcasting, for example as a back channel increasing interactivity with audiences.

On the Isle of Man, UK, trials have taken place experimenting with the use of 3G alongside Eureka 147 technology. Audiences were able to listen to Eureka 147 broadcasts via a Eureka 147 receiver and could vote for their favourite program or track, request further track information, create personal playlists and listen to audio on demand using 3G technology as a back channel creating a truly interactive radio environment. At the time of writing, the results of this 'proof of concept' had not been publicly released.

Although 3G may have potential in the long term for carrying streamed audio in its own right, it is a platform developed for telecommunications and 'information at a glance'. As 3G receivers become ubiquitous, there may be the possibility of incorporating a digital radio receiver chip into handsets allowing them to become receivers without using bandwidth to stream audio and associated content.

Wi-Fi

Wi-Fi is a broadband wireless protocol that links lap tops or other devices within an area to one another and to a telecommunications 'hub', thereby creating something akin to a wireless local area network. Wi-Fi enabled computers send and receive data indoors and out; anywhere within the range of a cell or base station. A wireless LAN transceiver or 'base station' can connect a wired LAN to one or many wireless devices through a chip inserted into the device (eg a laptop or handheld computer). Wi-Fi can expect broadband capability in ideal environments such as local hotspots (eg close to the Wi-Fi access point) and the technology is portable within that cell. Wi-Fi handheld receivers/devices are yet to be fully developed and deployed however advances in reducing the size and increasing battery power are constantly emerging.

Wi-Fi allows connection to the Internet and worldwide content can therefore be viewed/heard. One of the strengths of the Wi-Fi system is that Internet content is already widely accepted and in demand.

Wi-Fi has some (as yet unrealised) potential to permit the access of streamed services by portable devices such as hand-held computers, albeit within the wireless LAN area. In Australia a subscription fee must be paid to access the Wi-Fi cell.

Glossary Of Terms

Amplitude Modulation (AM): Modulation in which the amplitude of a carrier wave is varied in accordance with the amplitude of the modulating signal.

Audio bit stream: A sequence of consecutive audio frames.

Audio Frame: A frame of a duration of 24ms (at 48 kHz sampling frequency) or of 48 ms (at 24 kHz sampling frequency), which contains a Layer II encoded audio signal ISO/IEC 11172-3 [3], ISO/IEC 13818-3 [14], corresponding to 1152 consecutive audio samples. It is the smallest part of the audio bit stream, which is decidable on its own.

Audio mode: Audio coding systems typically provides single channel, dual channel, stereo and joint stereo audio modes. In each mode, the complete audio signal is encoded as one audio bit stream.

Auxiliary Information Channel (AIC): All or part of sub-channel 63, used to carry information redirected from the Fast Information Channel.

Bel: A measure of voltage, current, or power gain. One bel is defined as a tenfold increase in power. If an amplifier increases a signal's power by 10 times, its power gain is 1 bel or 10 decibels (dB). If power is increased by 100 times, the power gain is 2 bels or 20 decibels. 3 dB is considered a doubling.

Broadcasting Services Bands (BSB): In Australia, the BSB are the AM, FM and television bands managed by the ABA.

Channel: A portion of the broadcast spectrum assigned to a particular broadcasting station.

Channel encoding: The process used to add redundancy to each of the logical channels to improve the reliability of the transmitted information.

Coded Orthogonal Frequency Division Multiplexing (COFDM): Is a form of digital modulation in which the data is transmitted over an ensemble of closely spaced carriers. Each carrier is modulated at a low data rate and occupies a corresponding narrow bandwidth.

Compression: Reduction of the size of digital data files or data streams by removing redundant information (lossless) or removing non-critical data (lossy).

Convolutional coding: The coding procedure, which generates redundancy in the transmitted data stream in order to provide ruggedness against transmission distortions. Convolution Coding is a form of Forward Error Correction.

Data service: A service, which comprises a non-audio primary service component and optionally additional secondary service components.

Decibel (dB): A measure of voltage, current, or power gain equal to one tenth of a Bel. See Bel.

Delay spread: The difference in signal arrival times at the receiver when a signal is received via different transmission paths.

Digital: Circuitry in which data carrying signals are restricted to either of two voltage levels, corresponding to logic 1 or 0. A circuit that has two stable states: high or low, on or off.

Digital Sound Broadcasting (DSB): Term often for used to refer to digital radio broadcasting.

Doppler spread: The difference in frequency between a received and emitted signal because of relative motion between transmitter and receiver. Sky wave propagation also can cause frequency shift when more than one signal is received via different transmission paths.

Dual channel mode: The audio mode in which two audio channels with independent programme contents (eg. bilingual) are encoded within one audio bit stream. The coding process is the same as for the Stereo mode.

Effective Radiated Power (ERP): The power radiated from an antenna, is equivalent to the product of the transmitter power and the gain of an antenna, less any losses.

Energy dispersal: An operation involving deterministic selective complementing of bits in the logical frame, intended to reduce the possibility that systematic patters result in unwanted regularity in the transmitted signal.

Ensemble: The transmitted signal, comprising a set of regularly and closely spaced orthogonal carriers. The ensemble is the entity, which is received and processed. In general, it contains programme and data services.

Equal Error Protection (EEP): An error protection procedure, which ensure a constant protection of the bit stream. (Specific to Eureka 147)

Fading: The variation in received signal level due to changes in the propagation medium and the radio transmission path, with time.

Fast Information Channel (FIC): A part of the transmission frame, comprising the Fast Information Blocks, which contains the multiplex configuration information together with optional service information and data service components. (Specific to Eureka 147)

Forward Error Protection (FEC): See Convolutional Coding.

Frequency Interleaving: A reordering of the message bits to distribute them in frequency (over different OFDM sub-carriers) to mitigate the effects of signal fading and interference.

Frequency Modulation (FM): Modulation in which the frequency of a carrier wave is varied in accordance with the amplitude of the modulating signal.

Gaussian: When many independent random factors act in an additive manner to create variability, data will follow a bell-shaped distribution called the Gaussian distribution (also called a Normal distribution).

Ground wave propagation: A propagation mechanism whereby the radio signal is guided along the earth's surface. This mode of operation is generally useful for broadcasting at frequencies in the range 150 kHz to 3 MHz.

High Frequency (HF): Frequencies in the range 3 - 30 MHz.

Hybrid transmission: A service which uses both satellite and terrestrial transmissions to provide coverage.

Hybrid reception: The IBOC Hybrid mode caters for switching of reception between the analog and digital modes depending upon the quality of reception.

International Telecommunication Union (ITU): Is an agency of the United Nations responsible for coordinating the operation of telecommunication networks and services and for promoting the development of communications technology. The work of the ITU is distributed across three sectors – Radiocommunication, Standardisation and Development.

The Radiocommunication Sector of the International Telecommunication Union (ITU-R): Determines the technical characteristics and operational procedures for radiocommunication services. The Sector also plays an important role in the international coordination of radiofrequency spectrum usage.

ITU Regions: For the purpose of international frequency allocation, the ITU-R has divided the world into three regions (1, 2 and 3). In broad terms, Region 1 encompasses Europe, the Middle East and Africa. Region 2 includes the Americas. Region 3 encompasses Oceania and most of Asia. Australia is situated in ITU Region 3.

Joint stereo mode: The audio mode in which two channels forming a stereo pair (left and right) are encoded within one bit stream and for which stereophonic irrelevance or redundancy is exploited for further bit reduction.

Logical Channel: A signal path that conducts transfer frames from Layer 1 with a specified grade of service.

Low Frequency (LF): Frequencies in the range 30 - 300 kHz.

Main Service Channel (MSC): A channel which occupies the major part of the transmission frame and which carries all the digital audio service components, together with possible supporting and additional data service components. (Specific to Eureka 147)

Masking: Property of the human auditory system by which an audio signal cannot be perceived in the presence of another audio signal.

Medium Frequency (MF): Frequencies in the range 300 - 3000 kHz.

MSC data group: A package of data used for one application in the Main Service Channel. MSC data groups are transported in a series of one or more packets.

Multiplex: To intelligently combine two or more data streams or signals into a single stream or single for transmission.

Multiplexer (MUX): Device for combining two or more electrical signals into a single, composite signal.

Multiplex Configuration Information (MCI): Information defining the configuration of the multiplex. It contains the current (and in the case of an imminent re-configuration of the forthcoming) details about the services, service components and sub-channels and the linking between these objects. It is carried in the FIC in order that a receiver may interpret this information in advance of the service components carried in the Main Service Channel. It also includes identification of the ensemble itself and a date and time marker. (Specific to Eureka 147)

Narrowcasting Service: Uses the BSB to provide a service to a narrow audience in either an open or subscription mode. Low power open narrowcasting (LPON) service licences are issued by the ACA for operation within the VHF Band II sub-band 87.5 - 88.0 MHz.

Narrowband Area Service (NAS): Broadcasting/narrowcasting service licensed by the ACA to transmit one-way radio transmission to at least four NAS receivers and use a bandwidth not exceeding 4 MHz. These services usually operate outside the broadcasting services bands.

Null symbol: The first Orthogonal Frequency Division Multiplex (OFDM) symbol of the transmission frame.

Orthogonal Frequency Division Multiplexing (OFDM): A parallel multiplexing scheme that modulates a data stream onto a large number of orthogonal sub-carriers that are transmitted simultaneously.

OFDM symbol: The transmitted signal for the portion of time when the modulating phase state is held constant on each of the equi-spaced, equal amplitude carriers in the ensemble.

Packet mode: The mode of data transmission in which data are carried in addressable blocks called packets. Packets are used to convey MSC data groups within a sub-channel.

Programme Associated Data (PAD): Information, which is related to the audio data in terms of contents and synchronization.

Protection level: A level specifying the degree of protection, provided by the convolutional coding, against transmission errors.

Psychoacoustic model: A mathematical model of the masking behaviour of the human auditory system.

Quadrature Amplitude Modulation (QAM): Is a form of digital modulation in which the data is conveyed in both the phase and amplitude of the modulated carrier.

Quantising: The process of converting an analog signal into discrete (digital) levels.

Quantising noise: Noise that results from the stepped/discrete waveform. It is equivalent to the difference between the original analog signal and the quantised signal.

Robustness: The ability of a logical channel to withstand channel impairments such as noise, interference and fading.

Service component: A part of a service, which carries either audio (including PAD) or data. The service components of a given service are linked together by the Multiplex Configuration Information. Each service component is carried either in a sub-channel or in the Fast information Data Channel.

Service Information (SI): Auxiliary information about services, such as service labels and programme type codes.

Service: The user-selectable output, which can be either a programme service or a data service.

Single Frequency Network: A network of digital radio transmitters sharing the same radio frequency and closely synchronised in time to achieve large area coverage.

Sky wave propagation: A propagation mechanism whereby the radio signal is propagated by reflection or refraction from the earth's ionosphere. This mode of operation is useful for long distance broadcasting at frequencies in the range 3 to 30 MHz.

Stereo mode: The audio mode in which two channels forming a stereo pair (left and right are encoded within one bit stream and for which the coding process is the same as for the dual channel mode.

Stuffing: One or more bits, which may be inserted into the audio bit stream. Stuffing bits are ignored by the audio decoding process. The purpose is to fill up a data field when required.

Sub-band: A subdivision of the audio frequency range. In the audio coding system, 32 sub-bands of equal bandwidth are used.

Sub-channel: A part of the Main Service Channel, which is individually convolutionally encoded. (Specific to Eureka 147).

Synchronization channel: A part of the transmission frame providing a phase reference.

Time Interleaving: A reordering of the message bits to distribute them in time (over different OFDM symbols) to mitigate the effects of signal fading and interference.

Transmission frame: The actual transmitted frame, specific to the four transmission modes, conveying the Synchronization channel, the Fast Information Channel and the Main Service Channel. (Specific to Eureka 147)

Transmission mode: A specific set of transmission parameters (eg. number of carriers, OFDM symbol duration).

Ultra High Frequency (UHF): Frequencies in the range 300 - 3000 MHz.

Unequal Error Protection (UEP): An error protection procedure, which allows the bit error characteristics to be matched with the bit error sensitivity of the different parts of the bit stream. (Specific to Eureka 147)

Very High Frequency (VHF): Frequencies in the range 30 - 300 MHz.