DAB

— from Digital Radio towards Mobile Multimedia

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The purpose of this article is to inform EBU Members of recent progress with Digital Audio Broadcasting (DAB) – in terms of its market rollout in Europe, its system developments within the WorldDAB Forum, the preparations for the ITU Regional Radio Conference RRC-04/05 and its potential for any future developments.

One of the main messages of the article is that DAB has the potential to transform the traditional audio-based radio medium into a fully-fledged multimedia system, particularly suited to bringing digital information to the general public, anywhere and anytime. It is vital for the success of DAB to work in harmony and synergy with some other systems, particularly those in the communication and Internet sectors [1].

Digital Radio has already become a reality in many European countries. It is now possible to enjoy Digital Radio via various platforms of which DAB, i.e. Eureka-147 or EU-147, is one. Other Digital Radio platforms in Europe may include DVB-T, satellite DVB, cable DVB, Wi-Fi, mobile telephony and the Internet. Digital Radio Mondiale (DRM) is likely to be commercially introduced shortly. It is clear that DAB has to share the market and compete with these other Digital Radio delivery systems.

DAB rollout has been slower than most of us – the enthusiastic engineers who helped to develop and promote it – were hoping. But it has been quite steady and has clearly now reached a point of no-return; DAB is unstoppable!

DAB technology was developed by the Eureka-147 DAB Project, which was set up in 1987. The Project ended in 1999 as a stand-alone organization and merged with the WorldDAB Forum (formerly the EuroDAB Forum [2]). Since 2000, the WorldDAB Forum has been responsible for the technical maintenance of the EU-147 standard. The Forum is now a central body for ensuring international promotion and marketing of the DAB system worldwide as well as lobbying the international bodies such as the European Commission, European Parliament and the CEPT for frequency spectrum management issues. The Forum counts almost 90 member organizations from 30 countries and includes partners from manufacturing industries, public and commercial broadcasters, multiplex and network providers, programme makers, regulatory and governmental bodies, etc.

The Asia DAB Committee [1], based in Singapore, is a non-profit association working hand-in-hand with the WorldDAB Forum to promote, facilitate, support and harmonize the implementation of DAB projects and services in Asia. It currently has 21 member organizations from the Asia-Pacific Region.

1. The author has been a passionate promoter of DAB since its beginnings in the late 1980s and was heavily involved in the development and standardization of the EU-147 DAB system in the 90s as the Project Director of the WorldDAB Forum (see an earlier article published in Spring 1999 [2]). Being from an engineering background, he has since retained his interest in the technical aspects of DAB development.
2. The EuroDAB Forum was founded in 1994 to promote EU-147 DAB in Europe and beyond. The EBU was one of of its founding members and hosted the EuroDAB Project Office at its headquarters in Geneva. In 1997, EuroDAB was replaced by the WorldDAB Forum which subsequently moved its Project Office to London.

Whereas international cooperation is ensured by the WorldDAB Forum, the rollout of DAB services in practice is in the hands of national broadcasters and national governments. Now that all major broadcasters and consumer electronics manufacturers have adopted it, DAB seems to have begun moving beyond the "early adopter" stage. From the technology perspective, the value of DAB lies in better sound quality, more efficient use of frequency spectrum and the ability to carry additional data (non-audio) services, either associated with the main radio programme, or not.

The implementation of DAB has been affected by the increasingly difficult political and economic situation in many countries. Many radio broadcasters have been facing financial problems and have had insufficient funding available to invest in the DAB transmitter network infrastructure, new production facilities and multimedia programming. The Public's attention recently has been more focused on the auctioning of telecom spectrum and the bursting of the Internet bubble than on DAB rollout. Today, DAB has to face competition from other digital broadcasting systems, along with new communication, Internet and storage technologies that can also provide some types of audio and radio services. Consumers are overwhelmed by buzz words such as DVD, ADSL, Internet, Wi-Fi, digital music players, memory sticks, digital video and photo cameras, advanced mobile phones, PDAs ...

On the other hand, analogue FM and AM radio services still enjoy huge popularity. They can still satisfy the expectations of millions of keen listeners interested in listening to the news, music, radio drama and reportages. Unless DAB is able to offer significantly better quality, a bigger choice of programmes, additional attractive multimedia (data) services and non-expensive receivers, there is only minor incentive for listeners to switch from FM to DAB.

National DAB developments and implementations

According to WorldDAB statistics, over 300 million people globally are now within reach of DAB terrestrial transmissions (see *Fig. 1*). More than 585 different DAB programme services are currently available around the world, with more than half of these in the UK alone.

Furthermore, as well as all European countries, other non-European countries including Canada, Singapore, Taiwan and Australia have launched operational or pilot services. Countries such as China and India have

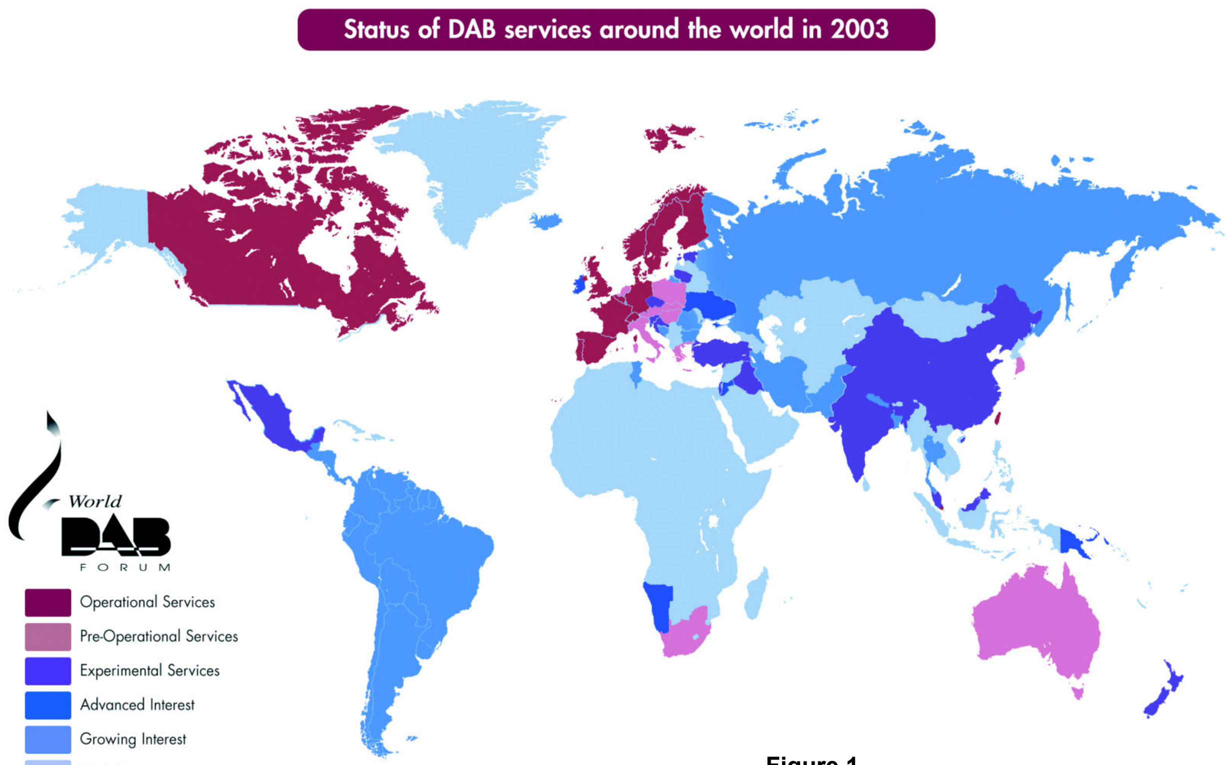

Figure 1
Current DAB coverage around the world

begun experimental services, and Mexico and Paraguay among other countries have expressed their advanced interest in DAB [3].

Commercial DAB receivers have been in the market since summer 1998. There are now more than 35 different DAB receivers commercially available, some with affordable prices of around or even less than €100. These receivers are of several types including DAB car radios, hi-fi tuners, portable and kitchen radios, hand-held radios, PC cards and others. According to WorldDAB estimates, some 500 000 DAB receivers will have been sold worldwide by the end of 2003.

The above figures are really impressive but may be misleading as they do not tell what percentage of all listeners have actually switched to DAB and listen to Digital Radio on a regular basis.

In the following sections, some European examples of "success stories" are given [4]:

United Kingdom

It is widely accepted that the UK has co-ordinated the implementation of DAB Digital Radio in a sensible way. A wide variety of Digital Radio services are now available across the UK. The BBC simulcasts its five national analogue radio stations on its DAB multiplex, as well as BBC World Service. In addition, it has now launched five new digital-only national stations:

- **BBC FIVE LIVE Sports Extra** – a part-time sports service;
- **6 Music** – targeted at sophisticated music listeners over 25;
- **1Xtra** – playing contemporary black music for a young audience;
- **BBC 7** – featuring comedy, drama, readings and dedicated children's programmes;
- **BBC Asian Network** – formerly only a regional analogue service.

In addition, the BBC runs: (i) **BBC Vision Radio** (teletext for radio), (ii) **BBC Travel** (a TPEG service) and (iii) **Test BBC Guide** (a pilot electronic programme guide).

Commercial radio in the UK also has a national multiplex, run by Digital One. It broadcasts eight Digital Radio stations – including simulcasts of the three independent national analogue stations:

- **Classic FM**;
- **Virgin Radio**;
- **talkSPORT**;
- **Planet Rock** – classic rock channel;
- **Core** – fresh hits and chart music;
- **Oneword** – a channel devoted to plays, books and comedy;
- **Life** – the national digital station of Capital Radio in London;
- **3 PrimeTime** – radio aimed at the over 50s.

In addition, Digital One runs a data service, the **Digizone**, which is an interactive service featuring games for downloading from the Cartoon Network, background material to support the classics on Classic FM and an interactive service for Core's young listeners.

There are currently 37 local and regional multiplexes in the UK with 9 more still to come. By the end of 2002 there were some 300 national, regional and local radio stations broadcasting digitally in the UK. Approximately half of these are unique to DAB Digital Radio. By the end of 2003, there are expected to be some 400 services of which more than half will be exclusively digital.

3. Country Progress Report and coverage maps are available on the WorldDAB website: **http://www.worlddab.org**

4. Please note that my intention in this article is not to give a comprehensive survey on DAB rollout in different countries. For more information on this, see the earlier article by Delphine Josse [3].

Consumers have seen their listening choice double with the advent of DAB Digital Radio. Simulcasts of analogue favourites in improved quality sound sit alongside a whole new generation of radio stations formulated to reflect the wide and varied tastes of radio listeners. By the end of 2004, 85% of the UK population will be covered by BBC and commercial DAB terrestrial transmissions. Many DAB digital services are also available via digital satellite and digital terrestrial television.

Denmark

Denmark was the first country in Europe with 100% DAB Digital Radio coverage by October 2003, just one year after public broadcaster Danmarks Radio launched its range of DAB services. A total of eight DAB Digital Radio programmes are being broadcast. These include:

- **DR Nyheder** – news, sport, weather and financial;
- **DR Demokrati** – political comment and debate;
- **DR Plus** – speech-based radio.

This choice is stimulating many people to buy a DAB Digital Radio. It is an indication of the consumer's desire for the unique programmes available via Digital Radio.

Germany

Germany offers two examples of truly European content for radio [5]:

- **Dasding** (literal translation: "The Thing")

  This is a comprehensive commercial-free youth programme and multimedia project (radio, TV and Internet) of *Südwestrundfunk* (SWR), the second largest broadcasting corporation within the ARD framework (Association of Public Broadcasting Corporations in Germany). It is a programme from young people for young people. In the youngest multimedia editorial office in Germany, young journalists aged 14 to 24 make Dasding for listeners of their own age group. The programme covers information in all areas, from a debate in parliament to Berlin's love parade, from share prices to lovesickness – all in the language young people speak. Dasding also serves educational purposes by giving young people a chance to gain practical experience in broadcasting. The young journalists may only work with Dasding for a certain time; afterwards they are encouraged to pursue further education before eventually returning to broadcasting.

- **Funkhaus Europa**

  Since May 1999, Funkhaus Europa – an all-day cosmopolitan radio programme – has covered "Everyday Life in Europe" and "Multicultural Co-existence in North-Rhine-Westphalia". In order to do that, it offers special programmes for immigrants living in Germany, in their native language as well as in German, designed to facilitate integration. In the current affairs programmes, "Cosmo" and "Piazza", the focus is on topics that are currently being talked about, thought about, argued about or simply smiled about in Europe. It is part of both magazines' profile to report about all the day's topics in Germany and its neighbouring countries – from a "European viewpoint" – and to offer different assessments from different cultures. Finally, Funkhaus Europa is the World Music radio station in North-Rhine-Westphalia.

  Funkhaus Europa also exchanges programmes with other European public broadcasters such as RAI, Radio France and the BBC. The editorial team at Funkhaus Europa is made up of editors, presenters and freelance writers from over thirty different countries.

5. The second example given is not digital yet but will eventually be.

DAB rollout

As the preceding examples demonstrate, DAB Digital Radio offers the opportunity for new styles and types of audio and other data services to be made available on the move, anywhere within the transmission area. New services are a principal *raison d'être* for Digital Radio and of great benefit to the listeners and users.

Since the introduction of regular DAB services in the UK, Sweden and Denmark (in September 1995), DAB rollout in many other countries has been less successful. Almost 10 years later, many countries are still facing multiple barriers to the successful rollout of DAB services. In some countries, DAB has been implemented by the public broadcasters only, with the commercial broadcasters lagging well behind. In one country, which successfully deployed an extensive DAB network covering almost 90% of the population, a large proportion of the DAB services had to close down recently, as the cost of simulcasting was too high.

A number of broadcasters have started experimental DAB transmissions but have soon had to discontinue them because public interest was low due to the relatively high cost of receivers – which exceed the purchasing power of the average consumer. Yet other countries have simply replicated their FM services, with no value-added data services. In such countries, the DAB market has grown very slowly because the improved audio quality of DAB has not, on its own, been a sufficient incentive for listeners to buy an (expensive) DAB receiver.

With the exception of some successful countries, broadcasters do not promote sufficiently their new DAB services, so the general public is not sufficiently informed of the benefits of Digital Radio. Some public broadcasters do not wish to make significant investments in the network infrastructure from fear that they will be forced by their regulators to share the multiplex with their commercial competitors. And some broadcasters are using any spare capacity on their DVB-T networks to provide Digital Radio services, thus avoiding having to build two completely different digital networks.

Other rollout problems have been caused by the DAB receiver manufacturers. Not only were they late in bringing their products to market, often these first-generation receivers did not perform according to the specification, therefore causing a lot of complaints from early adopters. Today, happily, there is a good selection of portable and hand-held DAB radios on the market (a selection is shown in *Fig. 2*) – although the range of integrated car radios, line-fitted in new vehicles, is still insufficient. As current DAB radios generally have a very small display, many multi-media applications carried by the DAB multiplex cannot be displayed properly, unless a DAB-enabled PC is used.

International standardization

The radio medium needs an internationally agreed standard allowing the users to take their radio set with them to use in any country worldwide. The EU-147 system is such an open internationally-agreed system. It was first specified by the European Telecommunications Standardization Institute (ETSI) in 1995. This standard has been the subject of several revisions. The latest version of the DAB standard is given in ETSI document EN 300 401 v1.3.3 (2001-05) entitled *Radio Broadcasting Systems: Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers*.

The EU-147 system is also a worldwide standard under ITU Recommendation ITU-R BS.1114-2: *Digital System A*. This Recommendation contains an Appendix giving a notional description of the system. The purpose of the ITU standardization process was to create a worldwide system where a common receiver would be able to decode broadcast transmissions regardless of their location.

EN 300 401 is still the central DAB standard. It defines the characteristics of the transmission signal, including audio coding, data services, signal and service multiplexing, channel coding and modulation. This documents has been complemented in recent years by several other ETSI standards, technical reports and rules of operation, totalling some 50 different documents [6]. These documents define the implementation of DAB receivers, transport of data services and data applications, linkage to FM RDS and the Internet, and multiplex formats for distribution and transmission.

6. For a complete list of DAB standardization documents see **http://www.worlddab.org/irc.aspx?sub=10**

The technical work has not stopped there; further developments are being carried out within the WorldDAB Technical Committee and several of its Task Forces. These are covered in the next section.

Figure 2
A selection of current DAB receivers

Recent system developments

Digital Radio is likely to turn from a simple audio-only service (merely simulcasting existing analogue programmes) into a far more interactive and rich experience across several platforms including DAB – and using scrolling text and on-demand functionalities. This section describes some of the technical developments being carried out by the WorldDAB Forum. The challenge is to restrict these developments to only those for which an international consensus of broadcasters, manufacturers and other players could be reached.

Multimedia Object Transport (MOT)

The MOT protocol allows the standardized transport of audio-visual information, such as still pictures and web pages. It can be used in the PAD and packet mode. MOT is particularly suitable for two applications: Broadcast Web Site (BWS) and Slide Show (SLS).

The basic principle of the MOT data carousels [4] is that each file to be broadcast is divided into segments of equal length and then the segments for all files are repeated cyclically in the broadcast stream. Each segment is tagged with an identifier to say which file it belongs to and a segment number to identify which segment of the file it is. Segmenting the file in this way means that the system will still work in an error-prone channel because, even for large files, the minimum amount of data that must be received without error is just a segment rather than the whole file. If a segment is received in error, the receiver can just wait for the next time that segment is broadcast, and the file identifier and segment number allow the receiver to correctly reconstruct each file.

This on its own, however, is not sufficient; with a "sea" of segments, the receiver can reconstruct the files but cannot know either how to access them or how to manage them. What is needed is a "table of contents" for the carousel that contains a list of all the files contained within the carousel. With suitable version control applied to this "table of contents", it is possible to detect any changes to the carousel simply by examining the version of the table of contents. If a file is changed, the version number for the file will change. This will, in turn, change the "table of contents" and a simple comparison before and after the change will allow the receiver to determine exactly what has changed, and to perform any cache management as appropriate.

In MOT, the "table of contents" function is handled by the MOT Directory Object and its operation is illustrated in *Fig. 3*. If we replace the file "animals/lion" with a new file called "animals/tiger", the carousel would then appear as shown in the right-hand diagram in *Fig. 3*.

The receiver can tell that the carousel has changed because the Directory Object has a new version, and by comparing the old and new Directory Objects, it can immediately determine that the file "animals/lion" has been replaced by "animals/tiger".

The MOT Directory Object serves two functions:

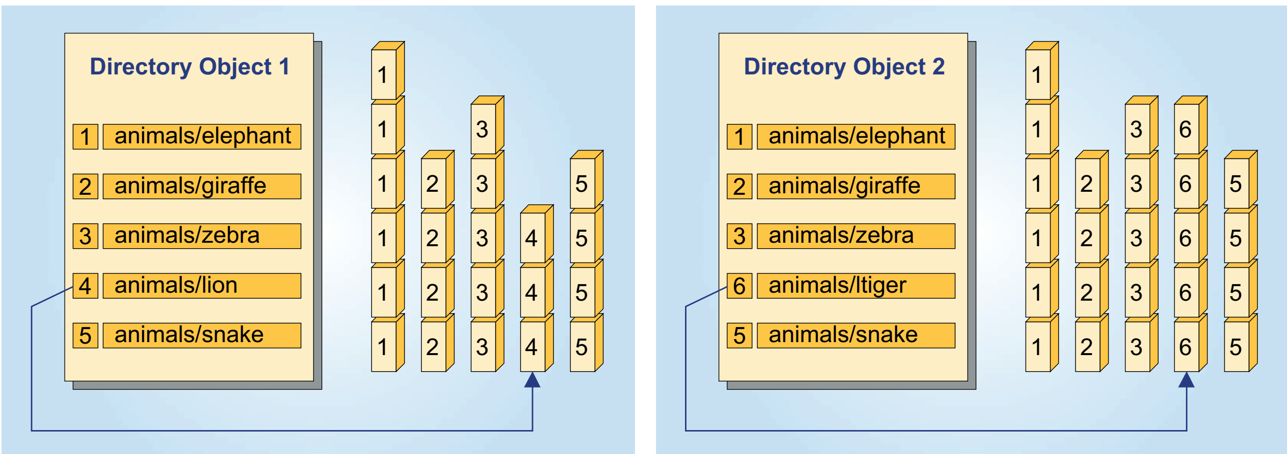

Figure 3
MOT Directory Object handles the "Table of Contents" for DAB services

- it provides reliable management of the files so that any changes to the carousel are understood by the receiver;
- it provides a name and other information for each file so that it may be accessed by an application.

Dynamic Label

This application carries text information and control characters with a length of up to 128 characters in the PAD channel. It requires a simple alphanumeric text display of 2 lines, with 32 characters in each. If the length of the text to be displayed is longer than 64 characters, the text can be incremental or scrolling.

Broadcast Web Site

BWS is a local interactive service; the user selects information already received by a browser. This "radio web" service allows access to a limited number of web sites, as chosen by the broadcaster ("walled garden"). BWS can be rendered either by a PC or a car navigation platform using a ¼ VGA display (320 x 240 pixels). HTML version 3.2 and a storage capacity of 256 kB are required.

Slide Show

This application involves sequences of still pictures (JPEG or PNG). The order and presentation time of this service are generated by the broadcaster. The transmission time depends primarily on the file sizes of the pictures and the chosen PAD data rate. For example, a CD cover coded as JPEG 320 x 240 requires a transmission time of 22 seconds (PAD or packet mode data rate of 16 kbit/s is assumed). No local interaction is required.

A visual component, associated with audio, would potentially greatly help radio advertisers to increase advertising revenue. For example, instead of just talking about the new model that Volvo has released, it would be good if we could see some pictures of the car while we hear about its great features [5].

Electronic Programme Guide (EPG)

The DAB Electronic Programme Guide (EPG) allows programme providers to signpost on a receiver screen their key music positions, programme schedules and benchmark features, and to set up opportunities for the user to record or auto-retune the radio to their station.

Schedules can be sent to the receiver several days in advance of the broadcasts, allowing the opportunity to highlight and lock listeners into new on-air activities early on. They can also be updated frequently to reflect last-minute changes to the on-air output.

Experience of TV EPGs shows that they can build up station loyalty and increase the time spent watching. It is expected that the EPG will also become a standard feature on many DAB digital radios, as it has become a worldwide technical standard that can be freely adopted by receiver manufacturers. The DAB EPG was the result of a 2-year task force made up of broadcasters and receiver manufacturers working together within the WorldDAB Forum.

As in TV, the DAB EPG will be useful for helping the user to find, preview, select, listen and record radio programmes, particularly if there are many, possibly several hundred, radio programmes in a given area [7]. The EPG will be used to provide programme listings information for both audio and data services and as a mechanism for the user to select services, programmes and related content. A key requirement is that the EPG must work on a range of receivers with differing display capabilities, resources and back-channel capabilities. To achieve this, a flexible multilayer structure has been defined. The EPG data is broken down into *service information* (ensembles and services) and *programme information* (schedules, programmes, groups and events).

7. Currently there are 320 DAB radio programmes on air in the UK, including 50 in London.

Additionally, programmes and events can be linked together into groups (e.g. for grouping programmes together into serials or series).

DAB EPG will be useful to promote new programmes and to attract new listeners. It should also enable future technologies such as Personal Media Recording (the DAB equivalent of PVR) to be introduced. Manual or automatic time-shifting of the programme will be possible for the user to choose what they want to listen to and when.

An EPG standard "XML Specification for DAB Electronic Programme Guide" is being developed by WorldDAB [6]. Work is still continuing into the transportation and compression of the EPG data. EPG is currently being broadcast experimentally on eight multiplexes in the UK.

DAB Virtual Machine (DAB Java)

Analogous to DVB Multimedia Home Platform (MHP), but suitably scaled down to fit into a narrow-band DAB channel, DAB Java provides a flexible and extendible platform (middleware) for all new DAB data services. DAB Java is standardized by ETSI [7]. The platform enables the rapid implementation and deployment of new business ideas by enabling the applications (and applets) to access DAB resources. Future data services for DAB will be realized more efficiently – in terms of time to market and platform independence – if based on DAB Java. This approach should enable DAB to be integrated readily into large-scale Java-based software environments, e.g. vehicles using widely accepted standards.

The concept of Virtual Machine has been chosen to allow for execution of any DAB applications, independent of the hardware-specific configuration. The DAB Java Framework is divided in three basic modules or packages: (a) a DAB-specific extension of the Java API; (b) a runtime support for the DAB applications execution environment and (c) a DAB I/O package for signalling the DAB Java extension over the DAB signal.

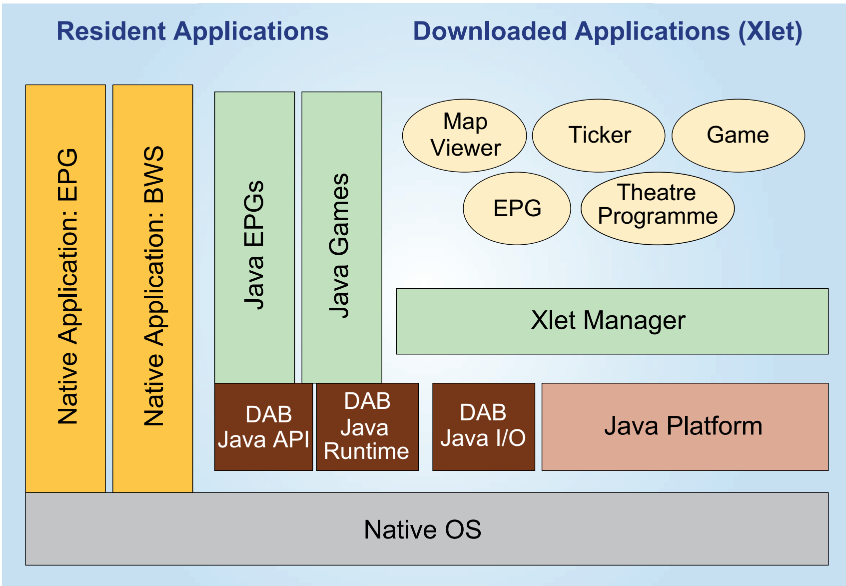

Figure 4
The architecture of DAB Java

End-to-end reference implementations have been successfully developed to demonstrate the benefits and new possibilities of DAB Java. These implementations include an EPG application, a BWS application, a stock market ticker and some local interactive games. The BBC has developed an interactive Java-based DAB application called "Composer Biographies". Bosch has demonstrated the integration of DAB Java in an OSGi-based telematics system (GPS device).

Fig. 4 shows the basic architecture of DAB Java.

The development and implementation of DAB Java requires close cooperation between content, service and network providers and terminal manufacturers.

DAB receiver interfaces

In order to introduce new applications in a mature market with millions of DAB receivers deployed, it is essential to allow legacy receivers to connect to new application decoders via an agreed interface. To this end, The WorldDAB Forum has developed a specification for the Receiver Data Interface (RDI) [8]. Nevertheless, as RDI has some technical limitations (e.g. flexibility, fixed bandwidth), it has been decided to develop a new interface. The WorldDAB Forum and the DRM Forum have agreed to cooperate in defining a generic physical

USB interface for all Digital Radio receivers. Furthermore, a generic low-level driver interface based on the Digital Command Set for Receivers (DCSR) specification will be developed, taking account of copy protection and digital rights management issues.

Conditional Access

The DAB system already includes a comprehensive conditional access (CA) system (see Chapter 9 of EN 300 401). Further work is now underway to develop a simple, yet reliable, system to be used in commercial receivers using a common scrambling algorithm and a common receiver interface, at the same time allowing the use of different commercial CA systems such as Simulcrypt and Multicrypt.

MPEG-1/2 Layer II audio enhanced by SBR

Spectral Band Replication (SBR) is a process – proposed by Coding Technologies and now standardized within MPEG-4 Audio – designed to improve the spectrum efficiency of audio compression systems by reducing the bitrate for the same audio quality, while retaining backwards compatibility. Some initial studies indicate that an improvement in coding efficiency of around 30% could be achieved using SBR.

EBU Project Group B/AIM (Audio In Multimedia) is carrying out studies on the error sensitivity of SBR-enhanced Layer II audio, and compatibility with non-SBR receivers. Some preliminary results show that the inclusion of SBR in the DAB system does not significantly degrade the C/N performance of the DAB system, neither in terms of Threshold of Audibility (ToA) nor Point of Failure (PoF).

Studies are continuing on balancing the benefits and drawbacks of SBR. The matters to be addressed involve the increase of complexity (and thus cost) of the receiver and the related IPR issues. No decision has been taken by the WorldDAB Forum to date about the viability of including SBR in the DAB standard and recommending its incorporation into commercial DAB receivers.

File caching in the receiver

The WorldDAB Forum has now established a specification for using an optional caching facility in the receiver. The user will benefit from a so-called "rewind radio", which will allow listening to the latest programme at any time. The caching device will also allow the user to use the DAB receiver as a kind of PVR (Personal Video Recorder) device for time-shifted playout of audio events (with or without associated data). It should be pointed out that the use of caching may change the way how people access and enjoy radio listening. It potentially widens the programming possibilities offered by the broadcaster but also introduces new technical and operational problems (copyright, EPG, etc).

Figure 5
RS200L DAB module from RadioScape

In September 2003, RadioScape – which specializes in Digital Radio software – launched a new module called RS200L, shown in *Fig. 5*. One of the features of this module is the inclusion of Rewind Radio that enables about ten minutes of audio to be stored on a RAM chip. This can be used to listen to a news clip again, or to time shift by pausing and resuming the radio broadcast. The module has been designed using the DRE200 chip from Texas Instruments, which is probably one of the world's best selling receiver chips for the EU-147 standard. This chip has now been superseded by a new version DRE310 [10] that can decode more than one channel simultaneously and includes time-shifted radio, announcement support, service linking (FM/DAB ensemble switching), TII (Transmitter Identification Information) and support for MP3 / Windows Media Audio CDs.

TopNews

TopNews is the commercial name for Bosch / Blaupunkt's system that allows broadcasters (and multiplex providers) to download the news and other audio files or objects coded in MP3 to the receiver [11] via a suitable DAB data channel (e.g. MOT, MSC packet mode). The user is appropriately informed of the existence of these audio objects and can access them whenever convenient. The broadcaster is responsible for the content and needs to update it regularly. There is no need for a return link to the service provider. This "audio anytime" system is particularly attractive for in-car applications.

IP datacasting in DAB

The DAB system is capable of carrying IP packets (datagrams) using IP/UDP protocol [12]. As these packets travel unidirectionally from a service provider to many users simultaneously, this is a form of IP Multicasting, i.e. pushing the same content to several users concurrently. The IP datagrams are tunnelled through a DAB packet mode Service Component (SC). This is done by encapsulating the IP datagram in an MSC data group on packet mode transport level. It is not necessary to establish a connection between the transmitter and the user prior to the transmission of data.

For connection-oriented point-to-point transport, TCP has to be used (rather than UDP). TCP requires an interaction channel for the return flow of acknowledgements.

Abbreviations

AAC	(MPEG-2/4) Advanced Audio Coding
ADSL	Asynchronous Digital Subscriber Line
API	Application Programming Interface
AVC	(MPEG-4) Advanced Video Coding
BER	Bit-Error Ratio
BWS	Broadcast Web Site
C/N	Carrier-to-Noise ratio
CA	Conditional Access
CEPT	European Conference of Postal and Telecommunications Administrations
COFDM	Coded Orthogonal Frequency Division Multiplex
DAB	Digital Audio Broadcasting (Eureka-147)
DCSR	Digital Command Set for Receivers
DIM	DAB Information Module
DMB	Digital Multimedia Broadcasting
DRM	Digital Radio Mondiale
DVB	Digital Video Broadcasting
DVB-C	DVB - Cable
DVB-H	DVB - Handheld
DVB-IPI	DVB - Internet Protocol Infrastructure
DVB-S	DVB - Satellite
DVB-T	DVB - Terrestrial
EPG	Electronic Programme Guide
ETSI	European Telecommunication Standards Institute
FM	Frequency Modulation
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
HTML	HyperText Markup Language
I/O	Input/Output
IEC	International Electrotechnical Commission
IP	Internet Protocol
ISO	International Organization for Standardization
ITU	International Telecommunication Union
JPEG	Joint Photographic Experts Group
MHP	(DVB) Multimedia Home Platform
MOT	Multimedia Object Transfer
MPE	(DVB) MultiProtocol Encapsulation
MPEG	(ISO/IEC) Moving Picture Experts Group
MSC	(DAB) Main Service Channel
OSGi	Open Services Gateway initiative
PAD	Programme-Associated Data
PDA	Personal Digital Assistant
PMR	Personal Media Recording
PNG	Portable Network Graphics
PoF	Point of Failure
PVR	Personal Video Recorder
RAM	Random-Access Memory
RDI	Receiver Data Interface
SBR	Spectral Band Replication
SFN	Single-Frequency Network
SLS	SLide Show
T-DAB	Terrestrial - Digital Audio Broadcasting
TCP	Transmission Control Protocol
TDC	(DAB) Transparent Data Channel
TII	Transmitter Identification Information
TMC	Traffic Message Channel
ToA	Threshold of Audibility
TPEG	Transport Protocol Experts Group
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunication System
USB	Universal Serial Bus
VGA	Video Graphics Array
X-PAD	eXtended Programme-Associated Data
XML	eXtensible Markup Language

Further work will need to be carried out, similar to that performed by the DVB-IPI project, in order to specify the discovery and selection of data services by the user.

The DVB Project has developed a data broadcasting standard that describes the encapsulation of IPv4 and IPv6 datagrams in the MPEG-2 transport stream. This system is commonly called MultiProtocol Encapsulation (MPE) or Data Piping [13] and includes dynamic address resolution, multicast group membership and other supporting procedures and protocols. The overhead due to encapsulation is reasonably low, i.e. below 3%.

IP datacasting is an interesting option for DAB systems that are required to work with IP-enabled devices such as mobile phones and PDAs. The IP layer could be used as a common communications layer between the two systems. IP datacasting over DAB will reliably bring data content – such as moving pictures, audio, web pages, computer programmes and software upgrades – to each user (or a group of users) and will thus expand significantly the market opportunities of DAB. IP datacasting will pave the way towards the personalization of broadcast services.

TPEG transport in DAB

It is well known to all broadcasters that radio is an ideal (and the cheapest) medium to inform travellers about road conditions and traffic jams – provided that such information is timely and relevant, in the correct location. Currently, analogue FM radio uses a well-established RDS-TMC (Traffic Message System) system. However, the TMC is essentially limited to inter-urban road events and every decoder must have a location database to interpret any message received.

TPEG was developed by the EBU to overcome these limitations. TPEG delivers very rich location referencing information with every message, so that receivers do not need a location database. Thus, navigation systems which are now becoming a standard commodity in vehicles can “machine read” the location content and localise an event directly onto the map display. A text-only device (such as a PDA) is able to present locally found names, such as a railway station name and a platform number, directly to an end user as a text message. Such a message can be rendered in the language of choice of the end user. TPEG can filter the information to avoid receiver overload, so that end users can select messages on any number of criteria, such as the type of location, mode of public transport, direction of travel, event, etc.

TPEG can be transported within the DAB system in the Transparent Data Channel (TDC) in a stream-like format; bytes come out in the same order they go in [14]. The TDC specification allows TPEG data to be carried in three modes: packet mode, stream mode and X-PAD. Nevertheless, this approach – which is specified in the present version of the DAB standard – introduces several problems in terms of reception reliability and interpretation. It has therefore been proposed that TPEG could be transported as one of the multimedia applications in the MOT data channel. This would offer some advantages: MOT is already implemented in most receivers and enables efficient object compression, power saving and delta updates and has a much lower overhead than TDC.

Advanced demodulation technique for COFDM

The Communications Research Centre (CRC) in Canada has developed an advanced COFDM demodulation technique [15] which reduces the Doppler effect in mobile reception, thereby allowing vehicle speeds up to 140 km/s while achieving a target bit error rate (BER) of 10^{-4}. Canadian DAB broadcasters use L-Band (1452 to 1492 MHz) and would like to use Transmission Mode IV (instead of Mode II) because it allows for a larger separation distance between co-channel transmitters than in the case of Mode II. However, Mode IV in L-Band limits the speed to less than 100 km/h, so this new CRC technique could help. Further studies are required to investigate whether this technique could be useful for the VHF band and whether the chip manufacturers could accommodate it readily into their chip designs.

Spectrum issues and the switch to digital

Sufficient spectrum availability is critically important for the successful rollout of DAB. If DAB is to replace FM one day, all existing radio stations that use FM and a large number of new services (which could not be accommodated on FM because of the lack of Band II spectrum), together with some new data and multimedia services (associated or not with the mainstream programmes), should find its place on DAB. It is clear that scarcity of the available channels is a big problem for DAB, as all national, regional and local service requirements need to be satisfied (particularly in densely populated zones).

Terrestrial digital broadcasting offers a series of benefits compared with terrestrial analogue broadcasting, not least it being a more efficient use of frequency resources. This opens the way for new opportunities including more services and, with appropriate transmitter network design, portable indoor and mobile reception.

Since the adoption of the Wiesbaden 1995 plan ("Special Arrangement as revised in Maastricht 2002"), where each country obtained at least one national DAB multiplex in Band III (174 to 230 MHz), further efforts have been made to improve the spectrum availability for broadcasting services in the VHF and UHF bands used in the European Broadcasting Zone. Currently these bands are also used by analogue TV. Indeed, a new frequency plan is under preparation to plan these bands for both T-DAB and DVB-T services in the future. In accordance with ITU Resolution 1185, a Regional Radio Conference (RRC 04/05) will be held in May 2004 to produce a digital terrestrial broadcasting plan for bands III (174 to 230 MHz) and IV/V (470 to 862 MHz).

European administrations consider that the introduction and market penetration of digital transmission techniques will represent a longterm transition process where analogue and digital transmissions may have to be broadcast in parallel over a significant period of time.

It is unlikely that there will be common time scales for all countries to migrate from analogue-only to all-digital services. Moreover, the key parameters of the regulatory framework for DVB-T and T-DAB are being defined at the national level, with considerable variation between countries as a result of distinct market and cultural conditions.

There will be two phases of the transition process during which bilateral and multilateral coordination will be required. The first phase is the transition from analogue-only to mixed analogue and digital, which might be achieved in a relatively short time scale. Several European countries have already reached this initial transition phase. The second phase is a transition from mixed analogue/digital to all-digital configurations, which is likely to take many years. Through the whole transition period there will be a need to protect both existing and planned broadcasting stations, in both the analogue and digital broadcasting formats. The two phases will overlap within the planning area, as each individual country will need to develop its own timetable which will be subject to revision to meet changing circumstances both within the country and in neighbouring countries.

Therefore, it can be expected that the transition to digital services will be done on an area-by-area basis. The size of these areas could range from the coverage area of a single transmitter to a very large geographical area. Whilst it currently seems unlikely that several countries will convert to digital simultaneously, it will be necessary for the administrations concerned to agree on the appropriate mechanism and dates.

For DAB, a single-frequency network (SFN) is the most suitable network. In such a network, distributed emission is implemented whereby the required coverage is provided through the use of multiple transmitters operating on the same frequency and carrying the same programmes.

For the initial planning purposes, the adopted reception mode is *mobile reception* for a location probability of 99%. Nevertheless, frequency planning should be flexible to allow reception requirements to evolve over time (e.g. starting initially with mobile reception and later becoming *portable indoor reception* which requires higher field strengths due to building attenuation). This could be achieved by future network re-engineering within the planned allotment area. In the preparation of the plan, it is necessary to determine the interference potential for allotment requirements by means of reference networks. Allotment planning provides flexibility for establishing the real transmitter networks and for further development of DAB services (e.g. portable indoor reception).

As the DAB market matures, there will be ever-growing demand for more radio channels. Given that the spectrum is a very limited resource, it is unlikely that more spectrum could be allocated to DAB in the future. Nevertheless, spectrum efficiency could be significantly improved by using a more efficient source-coding technology. However, caution should be applied here, as very diverse codecs already exist and the technology is rapidly evolving. In addition, introducing a new codec may pose a problem of backward compatibility and overall system ruggedness.

Synergies with other systems

DAB and GSM

DAB is an efficient broadcasting (i.e. one-to-many) system that is capable of providing reliable digital services in real time to all users located in a coverage zone. It is especially suitable for providing reception to mobile and portable receivers and in areas where a direct line of sight between the transmitter and the receiver is not possible.

On the other hand, GSM and its successors (GPRS and UMTS) are more suitable for delivering on-demand media services to individual clients or relatively small groups of clients. These telecom systems are technically able to provide services to several users at the same time, provided that the number of simultaneous users (or, in other words, the total bandwidth capacity) does not exceed a certain level, or else the network collapses rapidly. The use of telecom services in the "one-to-many" scenario is much more expensive for the user than the use of DAB (or DVB) broadcast systems [16].

It may be advantageous for both broadcasters and telecom operators to provide concurrently a combination of both one-to-many and one-to-one applications. For example, a traffic/travel information service may consist of two parts: a basic part and a value-added part. The former would be carried over the broadcast network to everybody (possibly for free), whereas the latter would be available on-demand over the telecom network and would be paid for according to an agreed tariff.

Collaboration between the broadcasting and telecom industries should be carried out only if there is clear evidence that both entities could benefit from it (i.e. a win-win situation). Neither broadcasting nor telecom assets and achievements should be destabilized and compromised. It is imperative that DAB should be fully integrated in the new convergent media landscape as it can deliver content cost-efficiently, and both industries could benefit from this [16].

As an example of such synergy, Nagra-Futuris has created an IT infrastructure for hosting end-to-end interactive services based on the existing GSM and DAB technologies [17]. The system provides back-channel communication, conditional access, data warehousing, integrated billing/clearing and interfacing to external M-commerce providers. The system allows for deployment of interactive services and dynamic insertion of programme-related data. The mobile terminal device is a combination of a mobile phone and a DAB receiver. It contains a DAB Identification Module (DIM).

The EBU has identified many attractive interactive applications and business opportunities based on DAB/GSM synergy. Such synergetic services [18] may help telecom operators to generate more traffic and offer new content-rich services (games, live and on-demand video/audio clips, etc.).

Synergies between GSM and DAB networks may be useful in the case of DAB single-frequency networks (SFN) at L-Band [5]. To set up an SFN network at L-Band, the transmitter locations must not be any further than 18 km apart using Transmission Mode II, in order to maintain network timing and to benefit from the network gain of an SFN. Therefore an ideal SFN at L-Band could emulate the infrastructure of mobile phone networks, but with lower masts and powers.

Synergies with DRM

Digital Radio Mondiale (DRM) is another new Digital Radio development designed to be deployed in the frequency bands below 30 MHz to replace existing AM services. This system has been successfully standardized within the ITU and ETSI, and is now being implemented in the commercial market. DAB and DRM are complementary as they target different markets: DRM targets larger coverage zones and international audiences, whereas DAB is mainly intended for local, regional and national audiences. Future listeners will be interested in **all** services provided by *Digital Radio*. To this end, future radio sets should enable users to receive any Digital Radio service without concern for the transmission system. In terms of the technologies used, both systems are not too dissimilar; for example, both use COFDM and similar channel-coding strategies. To this end, common integrated circuits are being developed and integrated DAB/DRM receivers could soon appear in the market. A common interface for external devices is also being developed. In August 2003, DRM and World-DAB announced that they would collaborate in the development of their systems [19].

Synergies with digital television

Although the DVB systems (i.e. DVB-S, DVB-C and DVB-T) were primarily designed for television broadcasting, they can and do provide radio (audio-only) programmes. DVB-T is a proven technology for digital television and has been implemented in many countries. As with DAB, DVB-T is sufficiently flexible to provide delivery to portable and mobile receivers. However, the high data rates and wide bandwidth needed for DVB not only increases power consumption but also makes the design of battery-powered devices difficult. The large bandwidth requirement of 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 utilized, thereby leading to inefficient spectrum use.

Experience suggests that DVB-T platforms designed primarily for digital television are increasingly likely to carry audio-only entertainment and information as well. Most current implementations of DVB-T services for digital television target fixed reception. Consumer-grade mobile DVB-T receivers are likely to be produced with the aim of providing mobile television and multimedia services.

From the technical perspective, DAB and DVB-T both use the same modulation system: OFDM. Therefore it will not be surprising to see common DAB / DVB-T chips developing rapidly. Frontier Silicon has announced that it is planning to develop a single-chip DVB-T / DAB decoder termed “Logie”, for which it has already signed a number of customers [20].

Future developments of DAB

Future DAB technical developments will probably go in two directions:

a) flexible multimedia services, including moving pictures;
b) multichannel audio.

DAB as carrier of multimedia

State-of-the-art audio/video compression technology has moved forward dramatically over the past few years, culminating in a new highly-optimized algorithm currently referred to as H.264 [21] for video, and AAC [22] for audio. These new algorithms have been jointly developed by the ISO (MPEG) and ITU international standards committees and were ratified in 2003. H.264 achieves significant improvement [8] in compression performance compared with MPEG-based technologies.

The immediate benefits to users of the new algorithms include the ability to store and deliver substantially more content for a given storage size and transmission bitrate capacity.

The compression performance improvements brought by H.264 come at a significant cost in complexity. Estimates of the increased computational complexity suggest that H.264 *encoding* is at least 5 - 10 times more

8. Formal verification tests on AVC, carried out by the Joint VideoTeam (JVT) Test and Video Group in December 2003, showed that AVC achieved a coding efficiency improvement of between 1.5 and 2 times (depending on the bitrate and content) compared to MPEG-4 Visual (ISO/IEC 14496-2).

complex than MPEG-2 encoding and that H.264 *decoding* is 2 - 4 times more complex than MPEG-2 decoding. In addition, the recursive nature of the H.264 algorithm does not lend itself to conventional parallel architectures.

The WorldDAB Forum plans to set up a Task Force to develop a mobile multimedia broadcasting system using the DAB transport mechanism which is known for its high error resilience and robustness [23]. A similar system called Digital Multimedia Broadcasting (DMB) using MPEG-2 was proposed by Bosch in the mid 1990s. The new mobile multimedia broadcasting system would be based on the DAB standard but would provide the necessary hooks to accommodate advanced audio/video coding plug-ins (such as MPEG-4/AVC or H.264), as they develop. One of the objectives is to avoid a diversity of different systems being developed [24] which all use the DAB transport mechanism but may use a variety of non-agreed application layers. It is intended to avoid revising the standard each time a new application decoder appears on the market. As these advanced codecs become more and more efficient and better methods of compression are invented, they need a better channel bit error ruggedness to perform correctly. This is due to the fact that in highly bit-efficient codecs, every bit is very significant so any bit loss may cause catastrophic failure of the received content.

DAB has already been shown to be capable of providing a robust transport for multimedia and video. Frontier Silicon demonstrated MPEG-4 video playback running on its Chorus multimedia processor at the Mediacast 2003 show. The advanced capabilities of the Chorus DAB processor also include playback of MP3 and other digital audio formats [25].

Several Asian countries (Korea, Taiwan, China) are considering using the DAB transport platform to launch “DMB” services handling mobile TV and multimedia for handheld devices [24]. Korean manufacturers (Samsung, PersTel, TBK Electronics and FreeSat) and broadcasters (KBS, MBC and SBS) have joined forces to produce some impressive end-to-end demonstrations of the “DMB” approach. They intend to commence experimental services by the end of 2004. Some concerns have been expressed in Europe about matters relating to licensing (royalties) and standardization of the Korean “DMB” system.

It should be observed that an alternative broadcast system for mobile multimedia applications is being developed in the framework of the DVB Project: DVB-H (the “H” stands for handheld). Some EBU research establishments are in the process of looking into the technical and operational merits of DVB-H and DAB. Notwithstanding the results of such a study, it should be remembered that the ultimate choice may not necessarily be taken on purely technical grounds. History teaches us that the best technology does not always win – as business interests may sometimes be more important (e.g. VHS versus Betamax).

DAB as carrier of multichannel audio

Many EBU broadcasters would like to see *multichannel audio* introduced not only in satellite and cable systems but also in terrestrial DAB and DVB-T systems. Towards this end, the EBU Broadcast Management Committee (BMC) has set up a Focus Group B/MCAT (MultiChannel Audio Transmission) which is due to start its work in February 2004 [9]. The EBU Village at IBC 2003 in Amsterdam staged a very successful demonstration of some pre-recorded multichannel material (such as the well-known production of ORF’s New Year Concert from Vienna) as well as some live broadcasts over the Astra satellite prepared by *Bayerischer Rundfunk*.

Some argue that multichannel audio is more appropriate for television, particularly as an adjunct to enhanced TV or HDTV, and less so for radio. The DVB system has recently been extended to accommodate not only

9. The studio and production aspects of multichannel sound are being studied by EBU Project Group P/AGA (Advisory Group on Audio).

MPEG-2 multichannel audio but, optionally, Dolby Digital (AC3) and Digital Theater System (DTS) as well, with the proviso that further hooks for other systems such as AAC may follow [26][27].

Others believe that multichannel audio could enhance the users' experience of radio significantly and make DAB even more popular, not only in the home environment but also (or especially) in the car. Many consider that multichannel DAB could be branded as the future "high definition" radio and could differentiate DAB from FM in order to drive new business models and make it more attractive for the general public.

There are several possible scenarios how multichannel audio could be brought into the DAB system efficiently and in a backwards-compatible manner. For example, one possible solution (not necessarily the best) would be to code the basic stereo in the existing MPEG 1/2 Layer II standard and the "surround" component in AAC. The downside is that multichannel sound requires more spectrum – which is a very scarce resource indeed – along with new production facilities; it also increases the production costs.

At IBC 2003, Microsoft, Capital Radio, NTL Broadcast and RadioScape announced that they plan to conduct a trial broadcast of 5.1 multichannel audio signals over DAB in the central London area [28]. This trial started in October 2003 and involves live IP datacasting over L-Band frequencies of Widows Media Audio 9 Professional (WMA Pro) content, coded at 128 kbit/s.

Conclusions

This article has attempted to show that, although it is often perceived that the rollout of DAB services in Europe has been very slow, the progress has in fact been steady and in some areas quite significant. The DAB technical specification has been refined and it is becoming a truly multimedia system. Perhaps the most noticeable progress has been made in the receiver market and in the development of new multimedia services. In terms of frequency planning, a major international conference is due to be held in Geneva later this year.

The objective of the DAB community is to make DAB even more accessible and popular. We need to create a mass market for DAB receivers. We should be able to translate our excellent technical work into listener-focused benefits that are convincing for programme makers. We should address – with more vigour – the critical questions of how DAB could increase listening to "my" station, how it could make "me" more money and which new things will excite "my" audience.

Radio is at a crucial period in its development. It needs to reposition itself to become a modern communications medium, attracting existing and new radio users, and particularly young people. DAB is but one pipeline helping multimedia radio to develop and prosper. DAB will surely face many challenges and vigorous competition from digital television, wireless networks and broadband. But the author is confident that DAB will ultimately succeed in all European countries and many others worldwide.

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He started his professional career as an R&D engineer at Radio-Television Slovenia. Since 1985, he has been with the EBU Technical Department and has been involved in a variety of engineering activities covering satellite broadcasting, frequency spectrum planning, digital audio broadcasting, audio source coding and the RF aspects of various audio and video broadcasting system developments, such as Digital Video Broadcasting (DVB) and Digital Audio Broadcasting (DAB).

During his years at the EBU, Mr Kozamernik has coordinated the Internet-related technical studies carried out by B/BMW (Broadcast of Multimedia on the Web) and contributed technical studies to the I/OLS (On-Line Services) Group. Currently, he is the coordinator of several EBU R&D Project Groups including B/AIM (Audio in Multimedia), B/VIM (Video in Multimedia) and B/SYN (Synergies of Broadcast and Telecom Systems and Services). He also coordinates EBU Focus Groups on Broadband Television (B/BTV) and MultiChannel Audio Transmission (B/MCAT). Franc Kozamernik has represented the EBU in several collaborative projects and international bodies, and has contributed a large number of articles to the technical press and presented several papers at international conferences.

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I devote this paper to Professor Henri Mertens. He passed away in December 2003. Professor Mertens was my mentor when I joined the EBU Technical Centre in Brussels in 1985. He was a great promoter of Digital Radio. As early as 1985, he set up a first study group within the EBU (i.e. V4/RSM) which looked into different modulation and coding technologies suitable for digital radio (which later became known as DAB). I consider him as a pioneer of Digital Radio.

Franc Kozamernik

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