Communications Research Centre Canada
An Agency of Industry Canada

Centre de recherches sur les communications Canada
Un organisme d'Industrie Canada

Engineering Study on ElectroMagnetic Compatibility (EMC) Between Land-Mobile, Fixed-Broadband Point-to-Multipoint and TV Broadcast Services

Version: Phase 1, Preliminary

Contributors:
CRC Broadcast Technologies Research
CRC Terrestrial Wireless Research

CRC Technical Note no: CRC-TN-2007-001

March 30, 2007

CAUTION
This information is provided with the
express understanding that
proprietary and patent rights will
be protected

Canadä

CRC

Communications Research Centre Canada
An Agency of Industry Canada

Centre de recherches sur les communications Canada
Un organisme d'Industrie Canada

Engineering Study on ElectroMagnetic Compatibility (EMC) Between Land-Mobile, Fixed-Broadband Point-to-Multipoint and TV Broadcast Services

Version: Phase 1, Preliminary

Contributors:
CRC Broadcast Technologies Research
CRC Terrestrial Wireless Research

CRC Technical Note no: CRC-TN-2007-001

March 30, 2007

Canada

CRC

Communications Research Centre Canada
An Agency of Industry Canada

Centre de recherches sur les communications Canada
Un organisme d'Industrie Canada

ENGINEERING STUDY ON ELECTROMAGNETIC COMPATIBILITY (EMC) BETWEEN LAND-MOBILE, FIXED-BROADBAND POINT-TO-MULTIPOINT AND TV BROADCAST SERVICES

Version: **Phase 1, Preliminary**
Published: **March 30, 2007**

Report Intended for:
Terrestrial Engineering (DTE)
Spectrum Planning and Engineering
Spectrum, Information Technologies and Telecommunications
Industry Canada

Contributors:
CRC Broadcast Technologies Research
CRC Terrestrial Wireless Research

Table of Contents

Engineering Study on EMC Between Land-Mobile, Fixed-Broadband Point-to-Multipoint and TV Broadcast Services

1 Introduction:

Industry Canada's Spectrum Planning and Engineering branch is in the process of redesigning its Automated Licensing System (ALS), a software tool used for the allocation of transmission systems licenses. To that effect, a number of recommended engineering studies need to be completed. The Communications Research Centre, with its Television Systems and Transmission (RTNT) and Wireless Applications & Systems Research (WASR) groups, used its expertise to perform this study on *EMC between Land-Mobile, Fixed-Broadband point-to-multipoint and TV Broadcast Services.*

The purpose of this study is to provide DGSE with information and data, pertinent to the impact of emerging telecommunications and broadcasting technologies, operating in the VHF and UHF bands, on television broadcasting. This study is considered a requirement to help define the appropriate parameters, conditions and models for the proper operation of the ALS.

This document, therefore, is a report on the first phase of an EMC Study between emerging telecommunications and broadcast technologies, and TV broadcast services. This study was requested by the Terrestrial Engineering group of the Spectrum Planning and Engineering (DGSE) branch of the Spectrum, Information Technologies and Telecommunications (SITT) sector of Industry Canada.

The report is divided in 5 sections as follows: Section 1, this section, presents the introduction to the Study; Section 2 describes the Study and the report in more details; Section 3 presents a review of current television broadcast systems, analog and digital; a review and description of emerging technologies that are likely to make use of the television broadcast band are described in Section 4; conclusions are presented in Section 5. Link budget calculations for the emerging broadcast technologies are given in Annex 1.

2 Description of the Study:

The study consists of two major sections, one on the current state of television broadcasting and the other one on emerging technologies that can make use of the same spectrum band as the television broadcasting services.

The first of those section, Section 3, deals with a brief description of the NTSC analog television broadcast system (subsection 3.1), followed by a more complete description of the current Advanced Television Systems Committee (ATSC) Digital Television (DTV) system (subsection 3.2). A third subsection presents current improvements to the ATSC DTV system such as Distributed Transmission Networks; and A-VSB which will allow new DTV services such as portable and mobile TV. The description mostly highlights the issues that may be involved and that should be considered in sharing the TV band with other services, licensed or unlicensed. The analog and digital TV subsections present the permissible signal levels in the form of required median signal strength as well as the tolerance to interference of each system that can be used as parameters for developing an appropriate model to be used in the development of the Automated Licensing System software.

The second major section, Section 4, provides information related to the emerging technologies that were studied. Each subsection presents a technology with information on the type of service offered by such technology; its availability and suitability for deployment in the VHF and UHF bands; and the type of modulation employed. Following are a number of spectrum related issues such as the availability of an uplink, or return channel for interactivity; the bands of operation, including bands outside the TV broadcast band; the required system bandwidth and emission mask information; the performance of the system are provided in the form of spectrum efficiency, Carrier-to-Noise ratio relative to modulation schemes, and supported bit rates; link budgets for the "good" reception case are provided for each system and those for the broadcast technologies are presented in Annex 1. The type of infrastructure required to support the technologies and the receiver availability and types are briefly mentioned since the technologies are evolving quite rapidly.

To support laboratory and field testing, a list of minimum required equipment is provided. It is important to note that to complement the study, a number of laboratory and field tests will be required to provide real-life data. It is to be noted though that depending on their suitability to being deployed in the television VHF and UHF bands, not all the presented technologies may require laboratory and field testing. Consideration will also have to be given to the emergence of yet newer technologies that may use these frequency bands. The IEEE 802.22 Wireless Regional Area Network (WRAN) is such a technology.

Bibliographical references used for the analysis of each technology are presented at the end of their respective subsection.

A brief description of the Quality of Coverage as well as a description of the usage scenario for each class is presented, in Annex 1, as a preamble to the presentation of the link budgets for each of the three broadcast technologies; namely, DVB-H, MediaFLO; and T-DMB.

3 Review of Existing Television Broadcast Systems:

3.1 NTSC

In NTSC transmission system, analog video and audio signals are used to modulate channel carriers. Vestigial sideband amplitude modulation is used for video, and frequency modulation for sound. The transmitted power is not evenly distributed over the 6-MHz channel bandwidth, but mostly concentrated around the carrier frequencies (mainly the video carrier). Accordingly, when compared to modern digital television transmission techniques, NTSC transmission is not spectrum efficient.

Analog television, was developed in the 1940's, and has undergone one transition in the past from black and white to color TV. Unlike the transition currently in progress from analog to digital TV, the former was backward compatible. At the end of the transition period from NTSC to DTV, the NTSC transmission is to be turned off.

Although a date (2009) has been set in the US for shutting down the NTSC transmission, no specific date has yet been set in Canada. Industry Canada and the CRTC have chosen so far a market driven approach. Going from analog to digital, however, may take place at different times in different regions of Canada. Highly populated areas like big cities and the areas closer to the US border will most likely be the first regions to switch from analog to digital TV. For remote areas, the transition may take longer.

It should be noted, however, that after the transition from analog to digital TV, some portions of the bands currently allocated to analog TV will be freed as explained later. To be able to reclaim those portions and use them for other services, it may be necessary to review the market driven approach and to set more restrictive dates for shutting down NTSC transmission in Canada.

- **Signal Level**

  In analog TV, the picture quality depends on the strength and the quality of the received signal. As such, six different picture grades (excellent, fine, passable, marginal, inferior, unusable) have been defined and different required signal to noise ratios (S/N) associated with each picture grade have been experimentally determined [1].

  Predicting the service area of an analog TV station (and the corresponding median field strength) is based on a set of assumptions made for some factors commonly known as the television planning factors. Such factors include the required picture grade, characteristics of the receiving equipment and environment, level of man-made noise, required location and time availability, etc. By making certain assumptions for such factors, three different service grades (namely grades A, B, and the city grade) have been defined for NTSC transmission.

  Planning and prediction of the coverage area for NTSC is based on grade B contour, which is the boundary of grade B service area. It is defined as the boundary of an area within which the level of the field strength, 10-meter above the ground, is sufficient to produce a "passable" picture for at least 50% of locations and 90% of time to a receiving installations considered typical of outlying areas. Table 3.1 shows the median field strength for grade B contour in different TV frequency bands [1, 2].

Table 3.1. Median field strength for NTSC grade B service contour for different frequency bands

	Low VHF channels 2 to 4 & 5 to 6	High VHF Channels 7 to 13	UHF Channels 14 to 69
Freq. band	54 – 72 & 76 – 88 MHz	174 – 216 MHz	470 – 806 MHz
Req. med. field	47 dBμV/m	56 dBμV/m	64 dBμV/m

- **Tolerance to Interference**

Table 3.2 shows the minimum required desired to undesired ratios (D/U) for an NTSC channel in the presence of an undesired co-channel or adjacent channel NTSC interfering signal [2, 3].

Table 3.2. Desired to undesired ratios (D/U) for NTSC co- and first adjacent channels

Channel Offset	D/U Ratio (dB)
– 1 (lower adjacent)	– 3
0 (co-channel)	+ 28
+ 1 (upper adjacent)	– 13

In the UHF band, which is continuous from 470 to 806 MHz, with the exception of channel 37 which is used for radio astronomy, the reception must also be protected against interference from undesired channels other than co- or first (upper and lower) adjacent channels.

Because of other interference mechanisms, such as inter-modulation, local oscillator effect, IF beat, etc., a desired channel operating on channel N may be interfered with by another channel operating on each of the channels N±2, N±3, N±4, N±5, N±7, or N±8. These are called "Taboo Channels" and a specific D/U is associated with each of them when they act as "undesired" channel [1].

References
[1] Television Engineering Handbook, revised edition, chapters 13 and 21. Copyright 1992, McGraw-Hill Inc. ISBN 0-07-004788-X
[2] Industry Canada, Spectrum Management, Broadcasting Procedures and Rules, BPR, Part IV, 1997
[3] FCC OET Bulletin No. 69, February 06, 2004.

3.2 ATSC-DTV

In DTV transmission system, the input of the transmission layer is a bit stream containing multiplexed packets of video, audio, and other corresponding data types which are to be sent down the channel. In the preceding layer (the transport layer), MPEG-2 is used to compress the signal and the compressed bit stream is transformed into Transport Stream (TS) packets, each one containing 188-bytes of binary data.

In ATSC-DTV transmission layer, the incoming TS packets undergo different processes such as randomization, Reed Solomon encoding, interleaving, segmentation, etc. and are then transformed into a multi-level analog signal (8-level in the case of 8-VSB) by undergoing a 2/3 trellis encoding. The multi-level signal is then grouped into data fields, each one starting with a data field sync followed by a payload equivalent to 312 data packets. After inserting a pilot frequency, the signal is used to modulate the channel carrier using suppressed-carrier vestigial sideband amplitude modulation.

DTV transmission is much more efficient than NTSC analog transmission. It can provide a bit rate of about 19.4 Mb/s, which is adequate for HDTV transmission in the same 6-MHz bandwidth used for NTSC channel.

To switch from NTSC to DTV transmission, there will be a transition period during which both NTSC and DTV will coexist. As such, a transition DTV allotment plan containing a DTV assignment paired with each of the present NTSC assignment has been adopted by Industry Canada. This plan was used as the basis for the DTV-only plan (that will become effective after the transition period). Efforts will be made to minimize the changes in switching from the transition to the DTV-only plan. Some changes, however, are unavoidable. A portion of the UHF-TV band, channels above 51, is to be freed for other services once the transition period is over. All the DTV assignments on channels above 51 must be reassigned into the core DTV spectrum.

- **Signal Level**

During the transition period from NTSC to DTV, a DTV channel will be provided for all existing NTSC services. The Canadian approach considers providing a DTV channel for all existing regular and low power NTSC services as well as all existing vacant TV allotments. Each DTV channel, however, will be assigned based on service replication of the coverage of the existing NTSC station. This means that the DTV coverage should extend to the grade B protected contour of the NTSC station. Table 3.3 shows the radius of the protected grade B contours of the NTSC services operating in different bands of frequencies.

Table 3.3. Radial distance of grade B contours for different classes of NTSC stations

NTSC Service	Grade B protected contours
Low VHF	89 km
High VHF	82 km
UHF Class A	25 km
UHF Class B	45 km
UHF Class C	70 km
Low Power	12 km

To provide the required coverage, the DTV station should be able to produce a minimum required signal level within the above distance limits. The value of such minimum signal level can be determined based on different factors (planning parameters) such as minimum required C/N, frequency of operation, receiving system characteristics, etc. The minimum required signal level for the three TV bands using the parameters assumed for the preliminary Canadian planning (used for the transition period) is given in table 3.4. Such minimum signal levels should be available at 50% of the locations and 90% of the time F(50, 90).

Table 3.4. Preliminary Canadian values for DTV minimum required field strength within grade B protected contour for use during the transition period

TV Band	Low VHF	High VHF	UHF
DTV Minimum Required Field Strength dBµV/m	35	33	39

The minimum required signal level for the three TV bands using the parameters adopted for use in the US is shown in Table 3.5. The same values are used during and after the transition period. Such minimum signal levels should also be available at 50% of the locations and 90% of the time F (50, 90).

Table 3.5. US values for DTV minimum required field strength within grade B protected contour for use during and after the transition period

TV Band	Low VHF	High VHF	UHF
DTV Minimum Required Field Strength dBµV/m	28	36	41

To the extent possible, Canadian values for DTV planning that will be used after the transition period, will be taken in close conformity with those used in the US.

Comparing with the minimum required field strengths for NTSC grade B (47, 56, and 64 dBµV/m for low VHF, high VHF, and UHF respectively), one can see that DTV requires significantly less minimum required field strengths for reception.

It should be noted, however, that while the minimum signal levels should be maintained within the protected contour (especially at its edge that is farthest from the transmitter), the maximum ERP and antenna height of the corresponding DTV transmitter should not exceed specific limits. For example, after the transition period in Canada, a DTV station working in the UHF band and covering an area of 89-km radius should not have an EHAAT (Effective Height Above Average Terrain) higher than 325-meters and an ERP more than 1-MW. If the same DTV station (having the same coverage area of 89-km) is working in the Upper-VHF band, then its maximum EHAAT and ERP would be limited to 300-meters and 14-kW.

- **Tolerance to Interference**

DTV is more robust than analog TV against interference and channel impairments. Table 3.6 shows Canadian and US desired to undesired (D/U) ratios for DTV-NTSC systems [1, 2]. The protection ratios for different channel relationships are based on a C/N of 19.5 dB for Canada and 15 dB for the US [3]. The Canadian parameters are for the transition period while the US parameters are for both the transition period and afterward. It should be noted, however, that at the request of the broadcasters, Canada will harmonize, as much as possible, the parameters used for DTV-only planning (after the transition period) with those used in the US.

Table 3.6. DTV and NTSC system protection ratios for Canada and the US

Type of Interference	Canadian values for D/U (for the transition period)	US values for D/U (during and after the transition period)
Co-Channel DTV into DTV	**19.5 dB**	**15 dB**
Co-Channel NTSC into DTV	**7.2 dB**	**2 dB**
Co-Channel DTV into NTSC	**33.8 dB**	**34 dB**

Considering the higher values of D/U required by NTSC, and also considering that the D/U ratio for Co-Channel NTSC into NTSC is 28 dB [3], one can see the robustness of DTV as compared to NTSC. The same conclusion may also be drawn by comparing the minimum required C/N of DTV with that of NTSC (> 41 dB for "Excellent" picture quality, 33 to 41 dB for "Fine" quality, 28 to 33 dB for "Passable" quality, etc.).

Another advantage over analog TV is that there are much less taboo channels with DTV transmission. Except the first lower and upper adjacent channels, there is less significant interference effect (as compared with NTSC) from other adjacent channels in DTV transmission. Such an advantage leads to a better frequency reuse and makes possible the repacking of the TV stations in narrower frequency bands. In the DTV-only planning, UHF channels 52 to 69 (698 – 806 MHz) will be freed and re-assigned to other services. Also, because of continuously increasing man-made noise in the low VHF band and its effect on TV operation, there have been concerns about limiting, or not using VHF channels 2 to 4 (54 to 72 MHz) for television, and possibly re-assigning it to other services. These frequencies are frequently used by home electronics equipment like cable or satellite set-top boxes, DVD players and recorders.

It should be mentioned, at this point, that recent CRC studies [4] and tests have shown some vulnerabilities for a variety of DTV receivers in the presence of interference on some adjacent channels other than the first lower and upper ones. The study is ongoing and the corresponding results may put some restrictions on the use of those adjacent channels for other services.

The use of error correction algorithms with DTV transmission, and adaptive equalizers in DTV receivers for echo cancellation, make DTV more robust than NTSC against channel impairments. While NTSC picture quality continuously degrades with the degradation of the signal, DTV is capable of reconstructing the original picture and sound (without any degradation) as long as channel impairments have not exceeded a specific maximum level. Slightly above such level (just in the order of one dB), the picture and sound will be lost. This is called "cliff effect" of DTV versus the graceful (and gradual) degradation of NTSC.

While creating a big advantage for DTV in general, such phenomena, however, causes a problem for DTV reception.

In NTSC, the quality of the picture is an indication of the quality of the signal. In DTV, however, since there is either a good picture or no picture, it is quite difficult to find the best (or even a good) location for the receiving antenna. This may create some problems for indoor and/or portable receptions or even for fixed reception at locations farther from the transmitter where the signal is weak. The receiving antenna may be located at a given location with a sufficient signal (slightly above minimum) which would give a good quality under normal conditions, but a slight degradation (e.g. due to the introduction of a new radiating device at a nearby location) can cause complete loss of reception.

The above issue may become more critical in the future as over the air (OTA) reception becomes more popular (due to the higher quality of DTV-OTA as compared to NTSC-OTA reception), and as portable and indoor OTA reception become more common by using portable computers as DTV receivers.

Other important issues to be considered are the RF performance of the DTV receivers' front end, and receivers' capability in handling static and dynamic echoes and multipaths. RF performance of the receiver's front end affects its tolerance against any interference caused by DTV or any other service that may be operating on the adjacent channels. Echo handling capability of the receiver affects its performance in high multipath environments and its tolerance to any additional interference. For example, a receiver working in a downtown canyon in which there are many reflections from stationary and/or moving objects, may be quite vulnerable to any additional interference. The vulnerability would be much higher if the interference could cause damages to DTV pilot frequency.

Concerning receiver's performance, there are no mandatory requirements, but only some recommendations, for the receiver manufacturers to follow. It is only the market and the competition that makes the manufacturers consider new and better designs. As a result, there are many models and generations of receivers in the market, each showing improvements, in some aspects, over the others. Some manufacturers may also choose to build low cost receiver with poor performance.

It should be noted, however, that in implementing recent developments and improvements to DTV, explained in the next subsection, and in coordinating DTV with other services that will eventually share the same bands, some characteristics have to be assumed for the receivers. Assuming good receivers' characteristics may make the above procedures much easier, but makes the situation very hard for those having previous generations of the receivers. On the other hand, assuming relaxed receiver characteristics may put too many restrictions on the coordination procedures and implementation of recent DTV improvements.

All the above issues are examples showing that DTV planning and coordination with other services involve many factors, some of which still under study and verification.

3.3 Recent developments

3.3.1 Distributed-Transmission

Distributed-transmission is a capability that is provided by DTV transmission systems. It can be regarded as a way of covering a large service area by a network of multiple transmitters that are all synchronized and transmitting the same program. The number of channels used by such a network can be far less than the number of its constituting transmitters, and when only one channel is used, the network becomes a Single Frequency Network (SFN).

Distributed transmission has been under study for years and such studies have led to the creation of a recommended practice (ATSC A/111) [5] and a standard (ATSC A/110) [6] for its use and for its synchronization. It has been allowed to be used in Canada (on a case by case basis), and in the US (under some specific conditions for now).

There are a number of benefits that could be exploited by using distributed transmission networks. Such benefits are helpful not only in DTV implementation and operation, but also in mitigating, to some extent, the limitations that now exist in the way of sharing the TV bands with other services.

When compared to a single central high-power high-tower transmitter approach, which has been the usual way of providing coverage in a large service area, a distributed transmission network can use less overall ERP and/or antenna heights for covering the same service area. In spite of this, the signal is more uniform and its average level is higher throughout the service area and at the edges of the coverage contour.

Exploiting such benefits, interference to other stations of any type of service would be lower, and tolerance to interference from other stations (and services) would be higher.

The use of distributed transmission is not limited to replacing a single central transmitter, but also to extend the DTV coverage or to fill the gaps in the service area by using the same channel as the main transmitter(s). Not using distributed transmission, separate channels must be used for such purposes. It can also be used to replace a multi-transmitter multi-frequency network that transmits the same program (for example TV Ontario or CBC) with a number of SFNs. By using such possibilities, channels are saved and there would be a better chance for accommodating other services in the TV bands.

As a trade off for all its benefits, distributed-transmission puts some restrictions on the use of DTV first adjacent channels in the same market area. Also, its implementation is more challenging in the presence of NTSC stations during the transition period. There exist, of course, some guidelines and procedures in the corresponding recommended practice [5] to mitigate such restrictions. As mentioned above, however, the values assumed for the receivers' characteristics directly affect the design procedures of distributed transmission networks.

Nowadays, broadcasters are showing some interest in using distributed transmission. Some networks of this type have already been implemented, and some are under development in Canada and the US. It should be noted, however, that in order to be able to exploit all the benefits of distributed transmission, DTV planning rules and regulations should undergo some modifications.

3.3.2 A-VSB

Advanced-VSB (A-VSB) is a new proposal for bringing extensibility and new functionality to the standard 8-VSB technology. It is making its way to create a new ATSC standard. CRC is currently preparing to test A-VSB in the field by setting up a large scale experimental multi-transmitter network in the Ottawa area.

While it is backward compatible with the 8-VSB standard, A-VSB can provide (in some subtle and complicated ways) more training sequences (more than that specified by the 8-VSB standard) in the transmitted signal. This results in faster equalization and adaptation in the new design receivers, giving them a better ability to work under very dynamic and fast varying channel conditions.

A-VSB also uses a portion of the channel capacity to embed a very robust (and low bit-rate) stream (called turbo stream) within the main data stream. Such embedded stream can be used for mobile reception by new design receivers. This is actually an in-band solution for over-the-air mobile TV, as the same 6-MHz bandwidth is used for simultaneous transmission of a high bit rate, and a robust low bit rate stream.

More efficient and recently developed codecs (such as H.264/AVC) can be used to increase the efficiency of such low bit-rate robust stream. It is, however, neglected by legacy receivers, or even by the new design receivers that select to receive the main stream. Depending on the mode of operation, the remaining bit-rate used for the main stream may still provide HDTV.

A-VSB can also provide necessary synchronization for SFN (single frequency network) operation. As mentioned earlier, a separate ATSC standard (ATSC A/110) has already been created (for SFN synchronization) to work in parallel with the ATSC 8-VSB standard (ATSC A/53). SFN synchronization, however, is one of the inherent properties of A-VSB.

A-VSB is a new technology in the direction of bringing enough robustness to DTV to serve mobile receivers. It can also provide all the advantages of distributed transmission, and in these ways, it can mitigate the limitations in the way of sharing the TV bands. It should be noted, however, that if adopted as an ATSC standard, it would require new and appropriate rules and regulations for protecting the mobile over-the-air TV service that it provides.

References:

[1] Industry Canada, Spectrum and Telecommunications Management, Broadcasting Procedures and Rules, Part 7: "Application Procedures and Rules for Digital Television (DTV) Undertakings". (BPR. Part 7, Issue 2, July 2004)

[2] Y. Wu, P. Bouchard, B. Caron, D. Tyrie, R. Trenholm. « Canadian Digital Terrestrial Television System Technical Parameters" IEEE Transaction on Broadcasting, Vol. 45, No. 4, December 1999. pages 353 to 364.

[3] FCC OET Bulletin No. 69, "Longley-Rice Methodology for Evaluating TV Coverage and Interference". February 06, 2004.

[4] Laboratory Evaluation of Five VSB Television Receivers iv DTV Adjacent Channel Interference – Laboratory Test Report and Calculations, co-authored with S. Lafleche, B. Ledoux, C. Nadeau and K. Salehian, Contract report to MSTV, Jan. 2007

[5] ATSC A/111 Recommended Practice, "Design of Synchronized Multiple Transmitter Networks", 3 September 2004

[6] ATSC A/110A Standard, "Synchronization Standard for Distributed Transmission"

4 Review and Description of Technologies in Development

4.1 DVB-H

The DVB-H (Digital Video Broadcasting for Handheld terminal) standard was adopted in 2004 by the European Telecommunications Standards Institute (ETSI). The standard is related to the Digital Video Broadcasting Terrestrial (DVB-T), standard which was designed to provide broadcast services to fixed, portable and mobile receivers. DVB-H is an extension designed to provide a service to handheld receivers.

Handheld receivers are small nomadic, battery powered devices with integrated antennas. These receivers can be carried on the bus, inside buildings and in cars. Specific signal reception challenges are changes in location, weak signal levels, Doppler when traveling and battery life.

DVB-H key features include:

- Time slicing to reduce the average power requirement in order to prolong battery life and to enable smooth and seamless handover;
- 4K mode which offers better performance than 8K mode in mobile channels and larger SFN cell size than the 2K mode.
- Signaling and cell identifier to support quicker signal scan and frequency handover;
- Forward Error Correction for an improvement in C/N performance and better performance in mobile channels;
- In-depth symbol interleaver for the 2K and 4K modes for improving robustness in mobile environment and impulse noise conditions.

The DVB-H signal is compatible with DVB-T, however the 4K mode can only be used in dedicated DVB-H networks.

- **Type of service:**
  DVB- H is designed to offer a broadcast service including audio and video streaming suitable for handheld and mobile receivers. The Forward Error Correction applied to the multi-protocol encapsulated data (MPE-FEC) improves the C/N performance and Doppler performance in mobile channels, also improving tolerance to impulse interference. DVB-H also provides signaling to enhance and speed up service discovery across cells. Time-slicing is utilized in order to reduce the average power consumption of the receiver; this feature allows smooth and seamless frequency handover. DVB-H can coexist with DVB-T in the same multiplex

- **Availability:**
  Hardware is currently available for 8 and 5 MHz BW channels.
  Results from field trials are available mostly from Europe and demonstrations services have been done in a number of countries worldwide.
  Commercial Services are expected to start in 2007 in Europe and Asia.
  Tentative trials are proposed for Canada.

- **Suitability for VHF and UHF:**
  Suitable for both frequency bands.

Impact of interference to and from DVB-H with respect to other services will need to be studied and tested in the lab and in the field. Information is available on protection ratios for PAL, SECAM, DVB-T, and Eureka 147 DAB.

- **Modulation:**
    - Uplink
      Telecom based OMA- BCAST
    - Downlink
      QPSK, 16QAM, 64QAM
      FFT 8K, 4K, 2K (4 K mode not compatible with DVB-T)
      Convolutional code (rate ½, 2/3, ¾, 5/6, 7/8) +Reed-Solomon RS (255,191)
      FEC + MPE-FEC
      Improvement of 7 to 8 dB in SNR Performance are possible with optional MPE-FEC and longer in-depth interleaver over two or four OFDM symbols (available in 2K or 4K modes)

- **Spectrum Issues**
    - **Uplink**
        - DVB-H uses Telecom network
    - **Band of Operation:**
        - DVB-H is designed to work in the following bands:
        - VHF-III (174-230 MHz, or a portion of it)
        - UHF-IV/V (470-830 MHz, or a portion of it)
        - L (1.452-1.492 GHz) US Modeo (1.670-1.675 GHz)
    - **Bandwidth**
        - DVB-H was developed in Europe for 8-MHz channels. Although specifications have also been devised for 5, 6, 7 MHz channels, existing hardware is mostly for 8 MHz channel in the UHF band and 5 MHz channel in L Band.
    - **Emission Mask**
        - Table 4.1.1 presents spectrum mask parameters for the 8MHz as well as the 6 MHz BW DVB-H systems.

Table 4.1.1 Breakpoints for spectrum mask for critical case

8 MHz Channel	6 MHz Channel	Relative Level
(MHz)	(MHz)	(dB)
-12	*-11*	-120
-6	*-5*	-95
-4.2	*-3.2*	-83
-3.8	*-2.8*	-32.8
+3.8	*+2.8*	-32.8
+4.2	*+3.2*	-83
+6	*+5*	-95
+12	*+11*	-120
Note Value in *italics* for 6 MHz Channel are derived from 8 MHz values		

- **Features**
  Table 4.1.2 presents the parameters for DVB-H systems for a 6 MHz channel. The 4K-Mode can only be used in dedicated DVB-H networks and is not

supported by DVB-T. It is however a good compromise between the 2K mode which provides good performance at high-speed but small-area SFN and the 8K mode with large SFN area and poor performance in mobile channels. It is expected that services for handheld receivers will use the 4K mode predominantly.

Table 4.1.2 Numerical Values for the DVB- H OFDM Parameters for 6 MHz channels

Parameter	2K	4K	8K
Number of Carriers	1705	3409	6817
Elementary Period	7/48		
Symbol Duration (Tu)	*298.6667μs*	*597.333 μs*	*1194.667 μs*
Carrier spacing 1/Tu	*3.348214 kHz*	*1. 953125 kHz*	*0.837054 kHz*
Signal Bandwidth	*5.71 MHz*	*5.71 MHz*	*5.71 MHz*
Maximum Distance between Transmitters	*12.8 km*	*24.8 km*	*50.3 km*

Note: *Values in italics are approximate values.*
The system is scaled from a 8 MHZ to a 6 MHz channel by changing the elementary period from 7/64 to 7/48.

o Guard interval ¼ , 1/8, 1/16, 1/32
Time interleaving: Typically 200-500 ms depends on MPE-FEC, up to 1000 ms
The in-depth interleaver available in the 2K and 4K mode improve performance in a mobile environment.

Time slicing reduces the average power consumption of the receiver and enables smooth and seamless service handover between cells. It consists in sending data in burst using higher instantaneous bit rate compared to the bit rate required if the data was transmitted using traditional streaming methods. Bursts of data have to be buffered at the receiver and the buffer needs to be large enough to contain all data requiring processing between two bursts. The position of the burst is signaled in term of the relative time difference between two consecutive bursts for the same service. The burst duration is in the order of several hundreds of milliseconds whereas the power-save time may amount to several seconds. Another benefit of time slicing is that the power-save period may be used to search for channels in neighboring radio cells offering the same service. This way a channel handover performed at the border between two cells can remain imperceptible for the user.

Although the MPEG-2 Transport stream is still used as the base layer, the IP data is embedded into the transport stream by an adaptation protocol, called the Multi-Protocol Encapsulation (MPE), defined in the DVB Data Broadcast Specification. On the level of the MPE an additional stage of forward error correction is added, this is the second main innovation of DVB-H. Its purpose is to lower the SNR requirements for reception by a handheld device. This technique results in a gain of 7 dB over DVB-T. MPE-FEC is calculated separately for each individual elementary stream. The MPE-FEC scheme consists of a Reed Solomon Code in conjunction with a block interleaver. The encoder creates a frame structure, the FEC frame consists of a maximum of 1024 rows and a constant number of 255 columns; every frame cell correspond to one byte, the maximum frame is ~ 2Mbit. The frame is separated in two tables: the application data table on the left (191 columns) and the RS data table on the right (64 columns). After applying the RS (255,191) code to the application data row by row, the RS data table contains the parity bytes of the RS code.

DVB- T designated carriers to be used for the purpose of signaling parameters related to the transmission scheme such as type of modulation (constellation pattern), guard interval, inner code rates, transmission mode, and frame number in superframe and cell identification. In DVB-H, additional Transmission Parameter Signaling (TPS) information is sent to indicate the use of time slicing and MPE-FEC.

- **Performance:**
  - Spectrum Efficiency 0.46 to 1.86 bps/Hz
  - C/N

Table 4.1.3 Required minimum C/N for DVB-H receivers

	QPSK ½ MPE FEC 3/4	QPSK 2/3 MPE FEC 3/4	16 QAM ½ MPE FEC 3/4	16 QAM 2/3 MPE FEC 3/4
Portable	7.5 dB	10.5 dB	13.5 dB	16.5 dB
Mobile	8.5 dB	11.5 dB	14.5 dB	17.5 dB
Net data rate GI 1/4	3.74 Mbps	4.98 Mbps	7.46 Mbps	9.95 Mbps
Net data rate GI 1/8	4.15 Mbps	5.53 Mbps	8.30 Mbps	11.06 Mbps
Note 8 MHz channel, Quality MPE FEC 5%, mobile Channel Model TU6 max speed 186 km/h at 698 MHz				

  - Bit rate
    Burst Size 0.5 to 2 Mbit

Table 4.1.4 Useful Bit Rate (Mbps) for 4K mode in 6 MHz channels

Modulation	Code Rate	Guard Interval			
		¼	1/8	1/16	1/32
QPSK	1/2	3.732	4.147	4.391	4.524
	2/3	4.976	5.529	5.855	6.032
	3/4	5.559	6.221	6.587	6.786
	5/6	6.221	6.912	7.318	7.540
	7/8	6.532	7.257	7.684	7.917
16-QAM	1/2	7.465	8.294	8.782	9.048
	2/3	9.953	11.059	11.709	12.064
	3/4	11.197	12.441	13.173	13.572
	5/6	12.441	13.824	14.637	15.080
	7/8	13.063	14.515	15.369	15.834
64-QAM	1/2	11.197	12.441	13.173	13.572
	2/3	14.929	16.588	17.564	18.096
	3/4	16.796	18.662	19.760	20.358
	5/6	18.662	20.735	21.955	22.620
	7/8	19.595	21.772	23.053	23.751

- **Link Budget:**

A link budget table for DVB-H is presented in Annex 1.

- **Infrastructure:**

  Single Frequency Network with ERP between 100 W to 100 kW will be required to provide a suitable service to handheld receivers with seamless handover and high signal availability.

- **Receiver:**

  Receivers are available from Nokia, Motorola, Siemens, Samsung, Sony Ericsson
  Models: LG - U900, KU950, Motorola - Nokia - Nokia N92, Nokia N77
  Samsung - SGH-P910, SGH-P920, SGH-P930, SGH-P940

  The 4 second time slice corresponds to a 4.5-5 second channel changing time. A 1550 mAhr battery is expected to provide roughly 3 hours of operation. Reception with single integrated antenna is possible in medium SFN (4K mode). The receiver should have a noise figure better than 5 dB, corresponding to a noise floor power level of -101.4 dBm (for 6 MHz channel)

  Gain for integrated antenna : VHF -25 dBi UHF -7 dBi

- **Requirements for tests needed to support the study:**

Equipment is available to perform laboratory tests as well as field tests. The major problem that may be faced for the field tests is the fact that most of the DVB-H equipment is built for 8 MHz bandwidth operation and thus may not be suitable for field testing in Canada because of the 6MHz bandwidth available in the television band spectrum. CRC has equipment for DVB-H operation that could be used for testing; this equipment supports all the DVB-H bandwidths. Channel simulators are also available to support lab testing.

In addition to the above, the following should be performed and considered:

- Literature survey
- Development of test method and procedures
- Laboratory tests
    - Sensitivity in fixed and mobile reception
    - Interference studies: co-channel and adjacent channel
    - (DVB-H into NTSC, DVB-H into ATSC, ATSC into DVB-H, NTSC into DVB-H)
    - Tests in 700 MHz UHF band
- Field tests (coverage quality and percentage, receiver robustness, SFN operation, etc...)
- Hardware available at CRC
    - One DVB-H signal generator (Rohde & Schwarz DVRG)
    - One DVB-H modulator (Rohde & Schwarz SFU)
    - DVB-H receivers
    - Channel simulator

- **Region of utilization:**

Figure 4.1.1 represents areas of the World where DVB-H service has either been launched or is undergoing trials.

Figure 4.1 DVB-H deployment around the World

References

[4.1.1]*Digital Video Broadcasting (DVB-H); Transmission System for Handheld Terminals (DVB-H)*, ETSI EN 302 304, November 2004.
[4.1.2]*Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television*, ETSI 300 744, November 2004.
[4.1.3]*Digital Video Broadcasting (DVB); DVB-H Implementation Guidelines*, ETSI TR 102 377, 2005.
[4.1.4]*Mobile Broadcast Bearer technologies: A Comparison*, Steve Turner Editor, bcmoforum.org, January 2007.
[4.1.5]*Mobile Broadcast Technologies, Link Budgets*, bmcoforum, January 2007.
[4.1.6]*Planning Parameters for Hand-Held Reception*, EBU, Tech 3317, Geneva, December 2006.
[4.1.7] *DVB-H: Digital Broadcast Services to Handheld Devices*, Gerard Faria, Jukka A. Henriksson, Erik Stare and Pekka Talmola, Proceedings of the IEEE, vol 94, No. 1, January 2006.

4.2 MediaFLO – Forward Link Only

MediaFLO is a broadcast service now being developed to move one step closer to realizing access to multimedia content anytime anywhere. The Telecommunication Industry Association (TIA) has completed the development of the following standards in working group TR 47.1. The Air Interface Standard TIA-1099 published in August 2006 along with the Minimum Performance Standard for the terminal, TIA-1102 and the FLO Transmitter, TIA-1103 published in November 2006. The Test Application Protocol standard TIA-1104 is soon to be published. With FLO technology multimedia content can be efficiently distributed to a large portable and mobile market place, in the order of millions of users.

- **Type of service:**

  Broadcast Service: suitable for portable (3 km/hr) and mobile (200 km/hr)
  Interactive Service: with 3G cellular return channel.

- **Availability:**

  Consumer equipment is not readily available. Several field trials are ongoing. China and Taiwan will commence field trials in March 2007

  Service expected to be available in 2007 in a number of USA cities.

- **Suitability for VHF and UHF:**

  VHF, UHF and L-Band possible. Currently designed for use in North America in the Lower 700 MHz operating in 6 MHz bandwidth. In the United States, Qualcomm has obtained TV channel 55 for nationwide distribution of MediaFLO to operators.

Table 4.2.1. FLO - Lower 700 MHz Channel Allocations

FLO RF Channel	Television Channel	FLO Transmit Band (MHz)	Band Center Frequency (MHz)
1	52	698-704	701
2	53	704-710	707
3	54	710-716	713
4	55	716-722	719
5	56	722-728	725
6	57	728-734	731
7	58	734-740	737
8	59	740-746	743

- **Modulation: Forward Link Only**

  QPSK, 16QAM, Layered
  Layered modulation [1] allows for a base component of a service to be delivered to handsets where low C/N is available while in higher C/N areas an enhanced component allows better quality reception.

Table 4.2.2. FLO – Modulation and Coding Operating Modes

Mode Number	Modulation	Turbo Code Rate
0	QPSK	1/3
1	QPSK	1/2
2	16-QAM	1/3
3	16-QAM	1/2
4	16-QAM	2/3
5	QPSK (OIS)	1/5
6	Layered Modulation ER 4	1/3
7	Layered Modulation ER 4	1/2
8	Layered Modulation ER 4	2/3
9	Layered Modulation ER 6.25	1/3
10	Layered Modulation ER 6.25	1/2
11	Layered Modulation ER 6.25	2/3

Spectrum Issues:

- **Band of Operation:**
  VHF to S-Band, 450 MHz to 3 GHz
  This frequency range provides for enough spectrum to allow for worldwide deployment

- **Bandwidth: Forward Link Only**
  5MHZ, 6MHz, 7MHZ, 8MHz
  Standard bandwidth accommodates worldwide television formats.

- **Emission Mask:**

Similar to the DTV mask in 6 MHz but less stringent. Under petition to the FCC by MSTV is additional constraints on the mask to limit interference to less than 2% of the TV audience in the 700 MHz band.

Features:

MediaFLO utilizes OFDM modulation with the following parameters

Table 4.2.3. FLO – OFDM Symbol Parameters

Parameter	Value
Number of sub-carriers	4096
FFT bandwidth	5.55MHz
Sub-carrier spacing	1.335 KHz
FFT duration	738.02 μs
Cyclic prefix	92.25 μs
Window interval	3.06 μs
OFDM symbol duration	833.33 μs
Chip duration	0.18 μs
Number of guard sub-carriers	96
Number of pilot sub-carriers	500

4K (4096) Symbol Carrier set
4K-Mode provides a good compromise between high-speed, small-area 2K SFNs and the slower, larger-area 8K mode; it provides great flexibility in the network design.

Performance:

- Bit Rate, Spectrum Efficiency, C/N.
  The following table provides the test results showing the data rate as a function of available C/N ratio and the spectrum efficiency considering the modulation and bandwidth.

Table 4.2.4 MediaFLO – Field Test Results [3]

Transmit Mode	Theoretical Data * Rate (Mbps)	Measured Data Rates (MHz)	Spectrum Efficiency (bs^{-1}Hz-1)	Target C/N (dB) 120 km/h
0	2.8	2.1	0.35	4.3
1	4.2	3.15	0.525	7.5
2	5.6	4.2	0.7	9.8
3	8.4	6.3	1.05	13.5
4	11.2	8.4	1.4	18.0
5	1.68	(OIS only)	-	-
6	5.6	4.2	0.7	6.5 (B**), 11.8 (E***)
7	8.4	6.3	1.05	10.7 (B), 15.5 (E)
8	11.2	6.4	1.4	15.0 (B), 20.0 (E)
9	5.6	4.2	0.7	5.5 (B), 13.5 (E)
10	8.4	6.3	1.05	9.5 (B), 17.3 (E)
11	11.2	8.4	1.4	13.3 (B), 22.0 (E)

*Physical Layer specification Reference [1]
** B=Base layer
*** E= Enhancement layer

- **Link Budget:**

  A link budget table for MediaFLO is presented in Annex 1.

- **Infrastructure:**

  Single Frequency Network – UHF Channel 55 allocated in the US.
  Multiple Frequency Network - Up to 8 RF Channel with 6 MHz channel occupancy

  - ERP - 50 kW Max. in UHF band

- **Receiver:**

Not commercially available although several manufactures have expressed an interest in producing them. Several units have been available for field trial purposes

- **Requirements for tests needed to support the study:**

New equipment would be required to perform lab tests but no inquiry has been done yet as to the availability of equipment for field testing. CRC has the signal generation equipment that can support MediaFLO through the acquisition of supplementary hardware as well as a software key. Channel simulators are also available to support lab testing.

The following actions should be performed and considered:

- Literature survey
- Acquisition of MediaFLO Standards documents; MediaFLO being a proprietary system
- Development of test method and procedures
- Laboratory tests
    - Sensitivity in fixed and mobile reception
    - Interference studies: co-channel and adjacent channel
    - (MediaFLO into NTSC, MediaFLO into ATSC, ATSC into MediaFLO, NTSC into MediaFLO)
    - Tests in 700 MHz UHF band
- Field tests (coverage quality and percentage, receiver robustness, SFN, etc...)
- Hardware available at CRC
    - One MediaFLO signal generator (Rohde & Schwarz DVRG)
    - One MediaFLO modulator (Rohde & Schwarz SFU, MediaFLO soft key + hardware will be required)
    - MediaFLO receivers to be acquired
    - Channel simulator

References

[1] Forward Link Only Air interface specification, Rev. 1, FLO Forum contribution to TR 47.
[2] Qualcomm Inc. Petition of declaratory ruling, Order, WT Docket No. 05-7, FCC 06-155 (rel. Oct. 13, 2006) ("Qualcomm Order")
[3] MediaFLO vs. DVB-H C/N performance. DVB Technical Module 28th September 2006

4.3 T-DMB

T-DMB uses MPEG-4 AVC (Advanced Video Coding), BSAC (Bit-Sliced Arithmetic Coding) or AAC and BIFS (Binary Format for Scenes) as the encoders for video, audio and contents-related data services. All of these encoded results are multiplexed into MPEG-2 TS packets. To increase the mobile reception capability of the audio, video and data contents, an additional channel coding scheme which includes RS (Reed-Solomon coding) and convolutional interleaving is used for the FEC(Forward Error Correction). Then the channel coded TS packets are transmitted through the Eureka-147 stream mode.

Standard adopted in 2004 (video service standard) in Korea, in 2005 by ETSI and in 2006 by ITU-R

- **Availability:**

  Service launched in Korea in December 2005, in Germany in summer 2006 (FIFA), with trials and demos in many other countries (France, UK, Mexico, China, Canada...)
  DMB is an extension of DAB which is present in other parts of the world (see map at the end of this document for details)

- **Band of Operation:** L-Band, VHF (not in Canada)

  T-DMB is based on DAB, which uses the following bands:
  VHF-III (174-230 MHz, or a portion of it – NOT in Canada)
  L-Band (1.452-1.492 GHz) in Canada

- **Type of service:**

  - Broadcast service including audio, video and data streaming suitable for portable (including handheld) and mobile receivers. Two channel coding levels (FEC + Reed Solomon codes) for an improvement video reception performance.
  - Multiplexed services, an ensemble can contain a mix of T-DMB along with other DAB-based services.

- **Modulation and channel coding:**

  - Transmission mode: one-way multicast COFDM
  - Modulation: DQPSK
  - FFT size: 256,512, 1024 and 2048
  - Error coding: Convolutional code (1/4,3/8,1/2) + Reed Solomon RS (204,188)

- **Bandwidth and capacity:**

  - Bandwidth : 1.536 MHz
    Capacity: typically 1.5Mbits/s (maximum of 1.728Mbits/s) for the whole channel
  - Typical bit rate per service DMB (kbp/s): 256, 384, 512 and 544

- **Features**
  - Video encoding: MPEG-4AVC/H.264
  - Audio encoding: MPEG-4 HE AAC v2 or BSAC

- Transport: MPEG-2 TS plus RS (204, 188, t=8)
- Time interleaving depth : 384 ms
- Frequency interleaving width: 1.536 MHz
- Inner FEC: Convolutional code with different rates
- Outer FEC: Reed Solomon RS (204, 188, t=8)
- Micro time slicing
- Spectrum efficiency: <= 1.216 bps/Hz
- Single frequency network operation
- Different transmission modes (see table 4.3.1)

Table 4.3.1 Parameters of DAB/DMB transmissions modes

System Parameter	Transmission Mode			
	I	II	III	IV
Number of Carriers	1536	384	192	768
Useful symbol duration	1ms	250us	125us	500us
Guard time duration	246us	62us	31us	123us
Total symbol duration	1246us	312us	156us	623us
Frame duration	96ms	24ms	24ms	48ms
Symbols per frame	76	76	153	76
Nominal frequency	375 MHz	1.5 GHz	3 GHz	1.5 GHz
SFN Transmitter separation	96 km	24 km	12km	48 km
Carrier spacing	1 kHz	4 kHz	8 kHz	2 kHz

- **Performance:**
  - Planning parameters (bmcoforum study, ref. 1)
    (Portable reception: class A, B and Mobile reception: class C, D)
    - Noise figure at VHF 225 MHz: 6 dB
    - Noise figure at L-band: 7 dB
    - Carrier to noise ratio C/N (see table 4.3.2)
    - (bandwidth 1.7 MHz for VHF and L-band, channel model TU6, receiver speed 199 km/h in Mode II)
    - Bit rate (see table 4.3.2)

Table 4.3.2: Minimum required C/N for T-DMB receivers

	Mode I/II protection level 3A
Class A,B	12 dB
Class C,D	13 dB
Net data rate	1.06 Mbits/s

- Field Strength

Table 4.3.3: Required median field strength at 1.5m, for a T-DMB service by coverage class

	VHF 225 MHZ	L-band 1470MHz	L-band currently 1470MHz
T-DMB	Mode I, PL-3A	Mode II, PL-3A	Mode II, PL-3A
-Acceptable out-door pedestrian -Acceptable mobile roof-top	54 dBuV/m	57 dBuV/m	61 dBuV/m
-Good mobile roof-top -Good outdoor pedestrian	61 dBuV/m	63 dBuV/m	67 dBuV/m
-Acceptable light indoor -Acceptable mobile in car	67 dBuV/m	66 dBuV/m	75 dBuV/m
-Acceptable mobile in car -Acceptable deep indoor -Good light indoor	72 dBuV/m	74 dBuV/m	83 dBuV/m
-Good deep indoor	79 dBuV/m	81 dBuV/m	90 dBuV/m

Note: For L-band , two cases are provided:

- Field strength for future devices or terminals: 0 dBi antenna gain and 3.5 dB NF
- Field strength for current devices or terminals: -5 dBi antenna gain and 7 dB NF

- **Performance:**
  - Planning parameters (EBU recommendations, ref. 2)
    - Noise figure at VHF band III: 7 dB
    - Noise figure at L-band 1.5 GHz: 7 dB
    - Carrier to noise ratio C/N (see table 4.3.4)

Table 4.3.4: Minimum required C/N for T-DMB receivers

	T-DMB in VHF Band III	T-DMB in L-Band 1.5 GHz
Class A, B (DQPSK, ½ Code rate)	16.6 dB	16.6 dB
Class C, D (DQPSK, ½ Code rate)	15 dB	15 dB

- **Link budget**

A link budget table for T-DMB is presented in Annex 1.

- **Emission Mask**

Since T-DMB would share frequency bands used by T-DAB, it is proposed to apply the same spectrum patterns (or masks) as are provided for T-DAB (see table 4.3.7).

Table 4.3.7: Out-of-band spectrum mask's table for a T-DAB or T-DMB transmission signal

	Frequency relative to the centre of the 1.54 MHz channel (MHz)	Relative level (dB)
Spectrum mask for T-DAB or T-DMB transmitters operating in non-critical cases	±0.97	-26
	±0.97	-56
	±3.0	-106
Spectrum mask for T-DAB or T-DMB transmitters operating in sensitive cases	±0.77	-26
	±0.97	-71
	±1.75	-106
	±3.0	-106
Spectrum mask for T-DAB or T-DMB transmitters operating in sensitive cases in certain areas where frequency block 12D is used	±0.77	-26
	±0.97	-78
	±2.2	-126
	±3.0	-126

- **Infrastructure:**
  - Type (Single transmitter, Distributed Transmitter Network, need for repeaters/translators, gap fillers)
  - Single Frequency Network (already operational in many countries for DAB transmission)
  - Korean DMB network (service in subways and in buildings)

  - ERP 100 W to 100 kW (available from various manufacturers)

  - Antenna (omni-directional, directional, variable height, vertical polarization)

- **Receiver:**

DMB services are made available through various kinds of handheld terminals such as mobile phones, laptops computers and in-car devices. The T-DMB function can be added to any kind of portable device with a screen.

1. Mobile phone

   T-DMB ready CDMA phones are commercially available and T-DMB embedded GSM/GPRS/WCDMA phones have also been developed and ready for commercial release.

   SAMSUNG SGH-P900, SAMSUNG SPH-B2300, LG LD1200,
   PANTECH PT-K1800
2. Vehicle DMB receiver

   Both Band III and Band III/L-Band dual mode car receivers are available.

Receivers with navigation function embedded were released in early 2006. The combination of TTI (Traffic and Travel Information) services of T-DMB and Telematics will provide real-time traffic and travel information customized to user's location.

MERCURY MD-1000 and MD-2000 , PERSTL DMR132G, HyonCorp HN3300T

3. Laptop& USB receiver

   Laptops with a T-DMB function and USB-type T-DMB receivers are available. With USB-type T-DMB receivers, users can enjoy T-DMB services through their own laptop and desktop PCS.

   Ubibro Technology Artemis T10, MNBT Leadia UD1000, LBS PLUS LPD-1000

Table 4.3.8: Required antenna gain in dBd (Band III and L-Band) for different reception classes

	Gain (dBd)		
	Band III VHF	1.5 GHz Band	Classes
Integrated antenna	-17 dBd	-4 dBd	A, B, D
External antenna	-13 dBd	-1dBd	A, B, D
Adapted antenna	-2.2 dBd	0	C

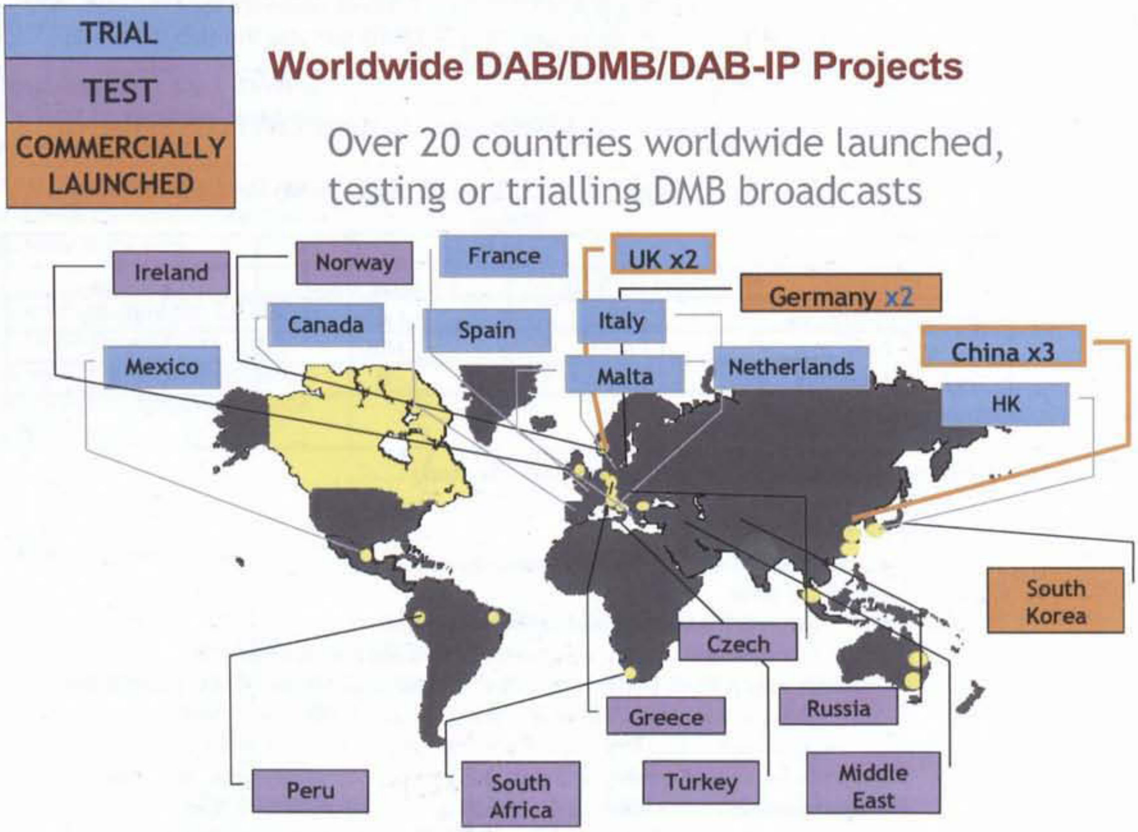
- **Requirements for tests needed to support the study:**

  - Literature survey
  - Development of test method and procedures
  - Laboratory tests
    - Sensitivity in fixed and mobile reception
    - Interference studies: co-channel and adjacent channel (DMB into NTSC, DMB into ATSC, ATSC into DMB, NTSC into DMB)
    - Tests in band III VHF and 700 MHz band UHF

  - Field tests (coverage quality and percentage, receiver robustness, SFN, etc...)
  - Hardware available at CRC
    - Availability: same as DAB + T-DMB media processor and T-DMB Ensemble Re-multiplexer
    - T-DMB encoder
    - T-DMB MUX
    - T-DMB modulator
    - T-DMB receivers
    - mobile channel simulator

- **Region of utilization:**

The figure below represents areas of the World where T-DMB service has either been launched or is undergoing tests or trials.



4.4 802.11: WiFi

WiFi products are based on the IEEE 802.11 standard. In order to bear the WiFi logo, products must be certified by the WiFi alliance and meet specific performance and interoperability requirements.

WiFi is currently available in three certified variants: 802.11b, 802.11g and 802.11a. The first is a direct-sequence spread spectrum (DSSS) technology while the two last types are OFDM technologies.WiFi is designed to be an unlicensed technology and is widely used in the 2.4 GHz, 5.2 GHz and 5.8 GHz unlicensed bands.

- **Type of service:**

  Fixed and nomadic with indoor support. WiFi equipment does not support hard or soft handoffs. Intra-network mobility is support, but not seamlessly.

- **Availability:**

  WiFi-certified products have become ubiquitous at both the consumer and enterprise level. The WiFi Alliance's web site lists over 260 sponsors, members, affiliates and adopters.[1]

  WiFi is currently built into virtually every portable computer and is now being integrated into many other consumer devices such as personal digital assistants, personal electronic devices, cell phones, MP3 players, cameras, video game consoles, etc.

  WiFi products that operate in a mesh topology in order to provide wide-area metro coverage for telecom operators are also available. Many of these products use two separate unlicensed bands to separate access and backhaul. Many of these systems have been deployed or are being planned for many cities throughout North America (see the region of utilization section for more details)

- **Suitability for VHF and UHF:**

  WiFi is not ideally suited for deployment within the current channelization scheme and regulatory framework of UHF TV bands for a number of reasons:

  - The bandwidth of an 802.11-based signal far exceeds the 6 MHz width of a TV channel. Both 802.11a and 802.11g systems occupy 16.54 MHz, which would require 3 contiguous channels to operate. 802.11b occupies 22 MHz, which would require 4 contiguous channels. The tendency for 802.11 technologies is towards greater channel bandwidths, with the proposed 802.11n standard occupying 40 MHz, which would be extremely impractical in TV bands where spectrum is at a premium.
  - Spectrum masks of 802.11-based technologies are quite relaxed and thus interference near band edges is a significant possibility.
  - The Medium Access Control (MAC) layer of 802.11 technologies is designed to operate in unlicensed bands where control of interferers is impossible. Carrier sense multiple access with collision avoidance

---

[1] http://www.wifialliance.com/our_members.php

(CSMA/CA) with back off is used rather than a system where transmit slots are assigned to each network user (via polling or other methods). As such, WiFi is less efficient at the MAC level than licensed technologies such as WiMAX. Unless some TV band spectrum is opened up for unlicensed used, WiFi cannot be considered particularly well-suited for operation in those bands.

- **Modulation:**

802.11b WiFi

WiFi products based on the 802.11b standard use Direct Sequence Spread Spectrum (DSSS) on top of the following modulations:

- Complimentary Code Keying (CCK)
- Quadrature Phase Shift Keying (QPSK)
- Binary Phase Shift Keying (BPSK)

802.11 a/g WiFi

WiFi products based on the 802.11a and 802.11g standards use a 52-subcarrier OFDM system. The subcarriers support the following modulation schemes:

- 64QAM (3/4 coding rate)
- 64 QAM (2/3 coding rate)
- 16QAM (3/4 coding rate)
- 16QAM (1/2 coding rate)
- QPSK (3/4 coding rate)
- QPSK (1/2 coding rate)
- BPSK (3/4 coding rate)
- BPSK (1/2 coding rate)

- **Spectrum Issues:**

  - **Band of Operation**

There are currently no commercial WiFi products designed to operate at UHF TV Band frequencies. CRC's WISELAB has designed and built frequency converters that allow 802.11 b/g products to operate in bands around 700 MHz, but such operation requires special experimental licensing and custom converters which are not commercially available.

Commercially available WiFi products operate in the following bands:

802.11b/g

WiFi products conforming to the 802.11b/g standard operate exclusively in 2400-2488 MHz unlicensed ISM band. Not all the band is available in all regions of the world however:

- Operation in North America and Europe is restricted between 2400 and 2483 MHz
- Operation in Japan is open in the full band up to 2488 MHz

802.11a

In Canada, WiFi products conforming to the 802.11a standard operate in three regions of the U-NII lower band (although more are being considered):

- From 5180 MHz to 5240 MHz
- From 5260 MHz to 5330 MHz
- From 5745 MHz to 5805 MHz

- **Bandwidth**

802.11b

802.11b WiFi systems utilize Time Division Duplexing (TDD) over a fixed bandwidth of 22 MHz, regardless of the modulation scheme used.

802.11 a/g

802.11a/g WiFi systems utilize Time Division Duplexing (TDD) over a fixed bandwidth of 16.54 MHz, regardless of the modulation scheme used. It should be noted that 802.11g systems are all backwards compatible with 802.11b and as such, their bandwidth will increase to 22 MHz when reverting to 802.11b compatibility mode.

- **Emissions Mask**

The following figures illustrate the emissions mask for both DSSS 802.11b systems as well as for 802.11/g[2]

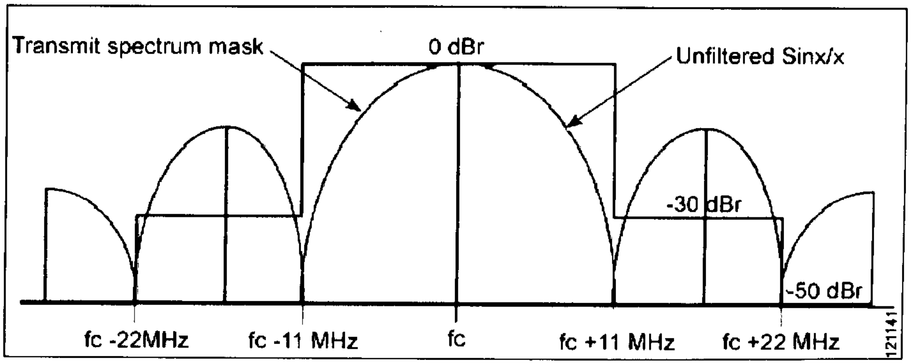


Figure 4.4.1 – 802.11b emissions mask

---

[2] **Channel Deployment Issues for 2.4-GHz 802.11 WLANs, Cisco Systems, 2004**

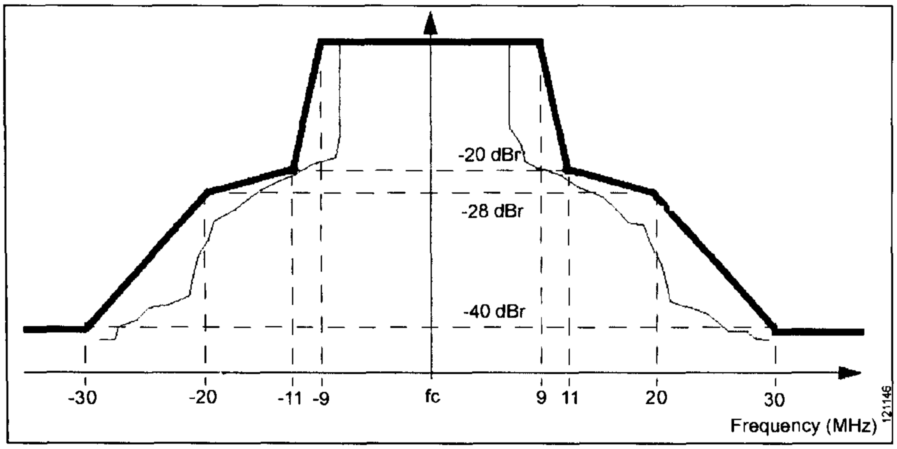


Figure 4.4.2 – 802.11g emissions mask

It should be noted that in both cases, RF energy is emitted at non-negligible levels significantly beyond the utilized channel. In the case of 802.11b, the RF emission level may be up to 50dB below the carrier anywhere beyond 22 MHz from the center frequency. This could mean out-of-band emissions at up to -14 dBm if the system operates at the maximal permitted EIRP of +36 dBm. Emissions are even higher within 11 MHz outside the channel and could reach +6 dBm for systems operating at maximal EIRP.

The interferer potential for an 802.11g system is even greater, with emissions at frequencies more than 30 MHz away from the carrier being only 40 dB below the transmitted carrier. At maximal EIRP, this could translate into out-of-band emissions at high as -4 dBm. At the edge of the occupied channel, emissions are only required to be attenuated by 20 dBm and could be as high as +16 dBm for systems operating at maximal EIRP.

Such emissions masks are obviously designed for operation in unlicensed bands where keeping hardware costs to a minimum is more important than avoiding out-of-band emissions. Using such masks in licensed bands will most likely cause interference problems with technologies in adjacent channels. Such interference issues can readily be observed between two Wi-Fi systems operating on adjacent channels at close range.

- **Performance:**
  - **EIRP**

Current Canadian regulation limits the maximum EIRP in the 2400-2483.5 MHz band to +36 dBm for point-to-multipoint systems. Point-to-point systems are allowed higher EIRPs as needed for satisfactory operation by using high-gain directional antennas, not increased transmitter power.[3]

EIRP limits for the bands in which 802.11a products operate are as follows[3]:

- For the band 5150-5250 MHz, the maximum EIRP shall not exceed 200 mW or $10 + 10 \log_{10}(B)$, dBm, whichever power is less. B is the 99% emission

---

[3] "Low-power, license-exempt Radiocommunications Devices", RSS-210, Industry Canada

bandwidth in MHz. The EIRP spectral density shall not exceed 10 dBm in any 1.0 MHz band.

- For the band 5250-5350 MHz and 5470-5725 MHz, the maximum conducted output power shall not exceed 250 mW or 11 + 10 $\log_{10}$ (B), dBm, whichever power is less. The power spectral density shall not exceed 11 dBm in any 1.0 MHz band. The maximum EIRP shall not exceed 1.0 W or 17 + 10 $\log_{10}$ (B), dBm, whichever power is less. B is the 99% emission bandwidth in MHz.

  In addition, devices with maximum EIRP greater than 500 mW shall implement transmit power control (TPC) in order to have the capability to operate at least 6 dB below the maximum permitted EIRP of 1 W.

  In addition to the above requirements, devices operating in the 5250-5350 MHz band with maximum EIRP. greater than 200 mW shall comply with the following EIRP elevation mask where θ is the angle above the local horizontal plane (of the earth) as shown below:

  - -13 dB (W/MHz) for $0^\circ \leq \theta < 8^\circ$
  - $-13 - 0.716\ (\theta\text{-}8)$ dB(W/MHz) for $8^\circ \leq \theta < 40^\circ$
  - $-35.9 - 1.22\ (\theta\text{-}40)$ dB(W/MHz) for $40^\circ \leq \theta \leq 45^\circ$
  - -42 dB (W/MHz) for $\theta > 45^\circ$

- (3) For the band 5725-5825 MHz, the maximum conducted output power shall not exceed 1.0 W or 17 + 10 $\log_{10}$ (B), dBm, whichever power is less. The power spectral density shall not exceed 17 dBm in any 1.0 MHz band. The maximum EIRP shall not exceed 4.0 W or 23 + 10 $\log_{10}$ (B), dBm, whichever power is less. B is the 99% emission bandwidth in MHz.

Fixed point-to-point devices for this band are permitted up to 200 W EIRP by employing higher gain antennas, but not higher transmitter output powers.

Manufacturer offers a broad range of WiFi products with varying transmit power levels and antenna gains. Manufacturers usually specify the maximum transmit power of a unit without reference to the modulation used. The transmit power for BPSK or QSPK modulations of a device can vary from the 16QAM or 64QAM transmit power, thus final EIRP also vary. The transmit power for a typical WiFi (802.11b/g) system implementation[4] can vary according the following table:

Table 4.4.1 – WiFi Transmit Power Levels

Modulation	Data rates (Mbps)	Selectable transmit power levels (dBm)
802.11g (OFDM)	54, 48, 24, 18, 12, 9, 6	15, 12, 9, 6, 2, -1
802.11b (DSSS)	11, 5.5, 2, 1	20, 17, 14, 11, 8, 5, 2, -1

---

[4] Cisco Aironet 1200 Series Access Point

In some cases, the customer's subscriber station will have a lower EIRP than the access point (base station). In such a case, the uplink from the subscriber to the access point will perform at a lower modulation than the downlink, which is common for point-to-multipoint access technologies (cable and ADSL are also asymmetrical).

- **S/N+I (Signal to Noise + Interference Ratios)**

Over-the-air S/N+Is calculated in table below are based on the same typical WiFi (802.11g/b) system as in previous section.

Table 4.4.2 – WiFi Modulation Schemes And Required S/N+I

Modulation	ToO (dBm)	Estimated S/N+I Required (dB)
802.11g		
64QAM(54 Mbps)	-72	23.8
64QAM(48 Mbps)	-72	23.8
16QAM(36 Mbps)	-73	22.8
16QAM(24 Mbps)	-77	18.8
QPSK(18 Mbps)	-80	15.8
QPSK(12 Mbps)	-82	13.8
BPSK(9 Mbps)	-84	11.8
BPSK(6 Mbps)	-90	5.8
802.11b		
CCK(11 Mbps)	-85	9.6
CCK(5.5 Mbps)	-89	5.6
QPSK(2 Mbps)	-91	3.6
BPSK(1 Mbps)	-94	0.6

ToO:
Thresholds of operation
SNR: Signal to noise ratio

Please note that the above SNR required column was calculated assuming a close to optimal implementation, 6 dB noise figure (NF) of the overall system.

$$\textbf{Estimated S/N+I Required}_{dB} = \textbf{ToO}_{dBm} - \textbf{KTB}_{dBm} - \textbf{NF}_{dB}$$

KTB: Noise floor due to thermal noise and receiver bandwidth

- **Data rate**

Maximum physical layer data rates in table below are based on the same typical WiFi (802.11g/b) system implementation as described in SNR section.

Table 4.4.3 – WiFi Modulation Schemes And Data Rates

Modulation	ToO (dBm)	Maximum Data Rate
802.11g		
64QAM(3/4 coding)	-72	54 Mbps
64QAM(2/3 coding)	-72	48 Mbps
16QAM(3/4 coding)	-73	36 Mbps
16QAM(1/2 coding)	-77	24 Mbps
QPSK(3/4 coding)	-80	18 Mbps
QPSK(1/2 coding)	-82	12 Mbps
BPSK(3/4 coding)	-84	9 Mbps
BPSK(1/2 coding)	-90	6 Mbps
802.11b		
CCK	-85	11 Mbps
CCK	-89	5.5 Mbps
QPSK	-91	2 Mbps
BPSK	-94	1 Mbps

Typical WiFi equipment has effective TCP/IP throughput of approximately half (or less) the maximum data rate due to high overhead that results from a design tailored to unlicensed use.

- **Link Budgets**

Fixed Rural Deployments Using WiFi (802.11g/b)

The information provided in tables of this section refers to downlink only, lower power uplink will limit the operational range of WiFi (802.11g/b) links or force uplink data to a lower modulation.

To visualize the increase in range achieved by a 700 MHz WiFi system in fixed rural deployments versus a 2.4 GHz implementation both are compared in the following tables. In fixed WiFi deployments at 2.4 GHz, 36 dBm EIRP is achievable with current WiFi devices.

At the client side of fixed WiFi deployments, smaller directional panel antennas are usually used. Assuming an 14 dBi 60° panel antenna at 2.4 GHz and an equivalent antenna at 700 MHz and considering a 5 dB link deployment margin, table 4.4.4 represents a rural area deployment using the maximum 2.4 GHz EIRP (+36 dBm). The actual necessary link margin depends on the required availability of the communication link. A fixed 5 dB of link deployment margin was assumed for simplicity of analysis. To meet a specific availability target in rural deployments, such as 99.95%, the required link margin would need to be adjusted accordingly.

Free space propagation is assumed for this table since in a rural environment roof-top antennas are typically used and free space propagation is closely approximated when no obstructions are present in the first Fresnel zone. An additional 10 dB of link margin is included in the calculations to take into account the effects of Earth's curvature on long links and other propagation factors.

Table 4.4.4: Rural Range Calculations (36 dBm EIRP)

Modulation	ToO + Margin Threshold (dBm)	Maximum Path Loss (dB)	Maximum Operational range (km)		Range increase at 700 MHz (km)
			2.4 GHz	700 MHz*	
802.11g					
64QAM(54 Mbps)	-57	107	2.2	7.6	5.4
64QAM(48 Mbps)	-57	107	2.2	7.6	5.4
16QAM(36 Mbps)	-58	108	2.5	8.6	6.1
16QAM(24 Mbps)	-62	112	4	13.6	9.6
QPSK(18 Mbps)	-65	115	5.6	19.2	13.6
QPSK(12 Mbps)	-67	117	7.0	24.2	17.2
BPSK(9 Mbps)	-69	119	8.9	30.4	21.5
BPSK(6 Mbps)	-75	125	17.7	60.7	43
802.11b					
CCK(11 Mbps)	-70	120	10	34.1	24.1
CCK(5.5 Mbps)	-74	124	15.8	54.1	38.3
QPSK(2 Mbps)	-76	126	19.9	68.1	48.2
BPSK(1 Mbps)	-79	129	28	96.2	68.2

*These calculations were achieved using equal gain client antennas at 2.4 GHz and 700 MHz (14 dBi). If two antennas with similar physical dimensions are used, the antenna gain at 700 MHz will be somewhat less than the 2.4 GHz antenna.

Due to WiFi medium access control (MAC) limitations, certain WiFi devices will not be able to operate at long ranges even though sufficient signal margin is available. Certain WiFi products have been tested to operate properly at distances of up to 60km with very high gain antennas at the receiver, while other have failed at under 3km despite having ample signal margin.

As we observe in above table, a 700 MHz WiFi implementation significantly increases the coverage area of a single access point versus a 2.4 GHz implementation.

Fixed Urban WiFi Deployments Including Outdoor to Indoor Connections

Table 4.4.5 considers the same 14 dBi client antenna at 2.4 GHz and 700 MHz and 5 dB of deployment margin assuming a 36 dBm EIRP. An additional 35dB of obstacle blockage is considered in the margin to account for attenuation by man-made structures. As mentioned previously, the actual necessary link margin required will depend on the required availability of the communications link. A fixed 5 dB of link deployment margin was assumed for simplicity of analysis. To meet a specific availability target in urban deployments, such as 99.95%, the required link margin would need to be adjusted accordingly. Typically, the required margin in fixed urban environments is less than in fixed rural deployments as urban links are much more subject to small rapid variations in power levels (which have little effect on the average received power) than deep fades, due to the typically shorter links in multipath-prone environments.

Table 4.4.5: Urban Range Calculations (36 dBm EIRP)

Modulation	ToO + Margin Threshold (dBm)	Maximum Path Loss (dB)	Maximum Operational range (m)		Range increase at 700 MHz (m)
			2.4 GHz	700 MHz*	
802.11g					
64QAM(54 Mbps)	-32	82	130	430	300
64QAM(48 Mbps)	-32	82	130	430	300
16QAM(36 Mbps)	-33	83	140	480	340
16QAM(24 Mbps)	-37	87	220	760	540
QPSK(18 Mbps)	-40	90	320	1080	760
QPSK(12 Mbps)	-42	92	400	1360	960
BPSK(9 Mbps)	-44	94	500	1710	1210
BPSK(6 Mbps)	-50	100	1000	3410	2410
802.11b					
CCK(11 Mbps)	-45	95	560	1920	1360
CCK(5.5 Mbps)	-49	99	890	3040	2150
QPSK(2 Mbps)	-51	101	1100	3830	2730
BPSK(1 Mbps)	-54	104	1580	5410	3830

*These calculations were achieved using equal gain client antennas at 2.4 GHz and 700 MHz (14 dBi). If two antennas with similar physical dimensions are used, the antenna gain at 700 MHz will be somewhat less than the 2.4 GHz antenna.

- **Infrastructure:**
  - **Type**

    Two different modes of operation are used:

    Infrastructure mode: Clients connect to an access point (AP) which is connected to the central network. In such a mode, client-to-client communication must go through the AP. A variant of this is mesh networking, where only some APs have a connection to the central network and other APs will relay traffic through each other in order to reach a network-connected AP.

    Ad-Hoc mode: Clients connect to each other in a peer-to-peer mode. There is no central traffic controller in this mode, and all clients within range of one another can communicate with each other. In its native form, relaying of information through a 3rd client is not supported.

  - **Antenna**

    Linear polarization (horizontal or vertical).

    Antenna gain varies upon model and antenna type.

- **Requirements for tests needed to support the study**

  There are currently no commercial WiFi products that can operate in VHF or UHF TV bands without external frequency converters.

- **Region of utilization:**

The unlicensed nature of WiFi products means that they are utilized extensively in ISM and U-NII bands throughout the industrialized world and are being adopted at a fast pace in the developing world.

It is beyond the scope of this document to list all the areas of utilization, but as an informative guide, the following map of deployed and planned U.S. metropolitan WiFi networks is included (red locations are active, blue locations are planned):[5]

San Francisco Still arguing over how much access will be free

Corpus Christi One of the largest active projects

Philadelphia Expected to be running in October, and will emphasize digital inclusion

Source: Free Press

Figure 4.4.3 – Planned and Deployed urban WiFi networks in the U.S.

Other references not explicitly listed in this section:

[1] Cisco Aironet 1200 Series Access Point Hardware Installation Guide, OL-8370-04
[2] Cisco Aironet 1200 Series Access Points – Data sheet

---

[5] Time Magazine, January 15th 2007, pp. 34-35

4.5 802.16: WiMAX

Fixed WiMAX is based on IEEE standard 802.16-2004 ratified in July 2004 which supports fixed and portable operation. Since then, 802.16-2004/Cor 1-2005, February 2006, was released which corrected errors, inconsistencies, and ambiguities in that standard.

Mobile WiMAX is based on IEEE standard 802.16e-2005 released on February 2006 and supports mobile operation.

- **Type of service:**

  Fixed, portable and mobile with indoor support.

  Fixed WiMAX equipment does not support hard or soft handoffs while mobile WiMAX equipment (802.16e) will.

- **Availability:**

  Manufacturers currently offer WiMAX-compliant products operating at 2.3, 2.5, 3.3-3.8, 4.9 and 5.8 GHz.

  Some manufacturers presently have development activity in the 700 MHz band due to completed U.S. auctions and offer pre-WiMAX, DOCSIS-based or other types of broadband wireless products in this band. The WiMAX Forum has not yet defined any profile (fixed or mobile) for this band. WiMAX equipment undergoes conformance and interoperability testing with other WiMAX products from different manufacturers. A product can be declared WiMAX when a certificate is issued for this particular model, tested upon a specific WiMAX profile. Standards-based, interoperable solutions allow economies of scale to be achieved and more products to be introduced in the marketplace. Since no WiMAX certified equipment operating in the 700 MHz band is currently being manufactured, pricing information is not available.

  However, manufacturers who currently offer broadband wireless products in the 700 MHz band include, but are not limited to:

Table 4.5.1 – BWA Products in the 700 MHz band

Company	Website	Product Name
Airspan Networks Inc	www.airspan.com	ASWipLL
Arris	www.arrisi.com	700 MHz base stations and CPEs
SOMA Networks, Inc.	www.somanetworks.com	FlexMAX
Vecima Networks Inc.	www.vecimanetworks.com	700 MHz BWIN
Vyyo	www.vyyo.com	V284i, V290i
WaveIP Inc.	www.waveip.com	GigAccess OFDM 700

Vecima Networks is a manufacturer that might offer a 700 MHz WiMAX products (possibly 802.16e-2005 compliant) next year, as part of their VistaMAX series, should demand arises for WiMAX in this band.

SOMA Networks' FlexMAX products support various frequency bands including the 700 MHz band and are commercially available. They have already won at least one contract in the United States to deploy their FlexMAX system in this band. SOMA's FlexMAX products are WiMAX upgradeable (software and possibly other upgrades) to the specific 700 MHz WiMAX profile when (or if) it's defined by the WiMAX Forum.

- **Suitability for VHF and UHF:**

  Due to present television spectrum regulations, there is no actual commercial WiMAX development in these bands. WiMAX channelizations of IEEE 802.16-2004 or 802.16e-2005 standards are, however, suitable for use in 6 MHz TV channels.

  WiMAX has profiles that support both TDD and FDD operation. TDD could operate in a single 6 MHz channel whereas FDD would require a second channel with a certain amount of spectral separation.

  Operation of WiMAX products in the lower UHF portion of the spectrum will significantly improve range and non line-of-sight (NLOS) performance in all demographics.

- **Modulation:**

  Fixed WiMAX
  Even though current fixed WiMAX products are all based on OFDM 256 FFT, the IEEE 802.16-2004 standard also support OFDMA 2048 FFT.
  - Uplink
    BPSK (OFDM only), QPSK, 16QAM, 64QAM (optional for OFDMA)
  - Downlink
    BPSK (OFDM only), QPSK, 16QAM, 64QAM (optional for OFDMA)

  Mobile WiMAX
  Mobile WiMAX products are based on scalable OFDMA (SOFDMA, corresponding FFT size for a given channel bandwidth)
  - Uplink
    QPSK, 16QAM with 64QAM (optional)
  - Downlink
    QPSK, 16QAM, 64QAM

- **Spectrum Issues:**
  - **Band of Operation**

    Fixed WiMAX

    IEEE 802.16-2004 allows for operation below 11 GHz.

    Current fixed WiMAX profiles, all based on OFDM 256 FFT, are as follows:

Table 4.5.2 – Current Fixed WiMAX Profiles

Frequency Band (MHz)	Duplexing	Channel Bandwidth (MHz)	IEEE Standard
3400-3600	TDD	3.5	802.16-2004
3400-3600	FDD	3.5	802.16-2004
3400-3600	TDD	7	802.16-2004
3400-3600	FDD	7	802.16-2004
5725-5850	TDD	10	802.16-2004

8

TDD: Time Division Duplexing
FDD: Frequency Division Duplexing

Certified fixed WiMAX equipments are presently available at 3.5 GHz in TDD and FDD operation for 3.5 MHz channel bandwidth. To date 28 fixed WiMAX certificates have been issued by the WiMAX Forum.

Mobile WiMAX

IEEE 802.16e-2005 allows for operation below 6 GHz.

Current mobile WiMAX profiles, all based on scalable OFDMA (SOFDMA), are as follows:

Table 4.5.3 – Mobile WiMAX Profiles

Channel Bandwidth (MHz)	FFT Size SOFDMA	2.3-2.4 GHz	2.305-2.320, 2.345-2.360 GHz	2.496-2.690 GHz	3.3-3.4 GHz	3.4-3.8 GHz
1.25	128					
3.5	512		TDD			
5.0	512	TDD	TDD	TDD	TDD	TDD
7.0	1024				TDD	TDD
8.75	1024	TDD				
10.0	1024	TDD	TDD	TDD	TDD	TDD
20.0	2048					

There are currently no certified mobile WiMAX products, but the first are expected to be available in the second half of 2007.

- **Bandwidth**

  Fixed WiMAX

  Even though current certified fixed WiMAX products (all based on OFDM 256 FFT) utilize channel bandwidths of 3.5, 7 and 10 MHz, IEEE 802.16-2004 allows for support of channel bandwidths from 1.75-20 MHz.

  - Uplink/Downlink

    1.75-20 MHz channel bandwidths in TDD or FDD operation.

    A single RF channel is necessary for TDD configurations while 2 channels (a channel pair) are required for FDD. In an FDD configuration, one channel is used for the uplink and the other for the downlink. Tx and Rx channel separation can vary by product implementation. Current certified fixed WiMAX products operating in the 3.5 GHz band in Canada utilize 100 MHz of channel separation due to spectrum regulations but this separation could be smaller.

  Mobile WiMAX

  Even though current mobile WiMAX products will utilize channel bandwidths of 3.5, 5.0, 7.0, 8.75, 10 MHz, IEEE 802.16e-2005 can support channel bandwidths from 1.25-20 MHz.

  - Uplink/Downlink

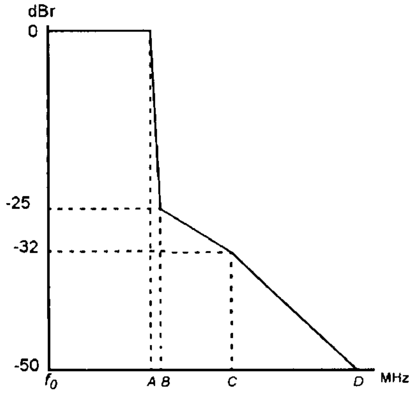
    1.25 to 20 MHz channel bandwidths in TDD or FDD operation.

    Note that all current mobile WiMAX profiles use TDD configuration.

- **Emissions Mask**

  For licensed bands, the 802.16-2004 standard (on which fixed WiMAX is based) refers to local regulations for out of band emissions or spectral masks for OFDM 256 FFT or OFDMA 2048 FFT (in TDD or FDD). Fixed WiMAX manufacturers must conform to local spectrum regulations upon design and manufacturing of there equipment.

  For license-exempt bands according to standard 802.16-2004, if a channel bandwidth of 10 or 20 MHz is used according to the WirelesssHUMAN air interface which includes the OFDM 256 FFT and OFDMA 2048 FFT (in TDD only) for license-exempt bands below 11 GHz, a specific transmit spectrum mask is defined as shown below[6].



---

[6] IEEE Std 802.16-2004 standard, page 631

Table 4.5.4 – Transmit spectral mask parameters

Channelization (MHz)	A	B	C	D
20	9.5	10.9	19.5	29.5
10	4.75	5.45	9.75	14.75

The transmitted spectral density of the transmitted signal shall fall within in the spectral mask as shown. The standard specifies that the measurements must be made using 100 kHz resolution bandwidth and a 30 kHz video bandwidth.

No changes were made regarding spectral masks in the 802.16-2004/Cor 1-2005 and 802.16e-2005 standards (upon which mobile WiMAX is based). They also refer to local regulations for licensed bands. As such, mobile WiMAX equipment (like fixed WiMAX equipment) is designed for local spectrum regulations as far as out of band emissions are concerned.

For the purpose of this report, the regulatory emissions mask of the 3.5 GHz band can be considered, where many certified fixed WiMAX products currently exist. The band 3475-3650 MHz is designated for fixed wireless access (FWA) in Canada and was licenced to many licensees in 2004 and 2005. This band is subdivided into 25 MHz blocks as described by the standard radio system plan, SRSP-303.4. Out of bands emission limits are specified in the radio standard specification, RSS-192, for this band. This document specifies that unwanted emissions must comply with the following emission mask:

(i) In any 30 kHz bandwidth, the unwanted emission spectral density that is relative to the inband spectral density shall be attenuated by at least:

(a) 10 dB at the band edge;
(b) 10 dB at the band edge to 25 dB at 200 kHz offset from band edge, linearly interpolated;
(c) 25 dB at 200 - 400 kHz offset from band edge;
(d) 25 dB at 400 kHz to 50 dB at 3.0 MHz offset, linearly interpolated; and
(e) 50 dB beyond 3 MHz offset, or see (ii), whichever is less stringent.

(ii) In any 1.0 MHz band that is removed from the assigned centre frequency by more than ±250% of the necessary bandwidth, the power of any emission must be attenuated below P_{mean} by at least $43+10\log_{10}(P_{mean})$ dB, or 70 dB, whichever is less stringent. P_{mean} is the mean output power of the transmitter in watts.

Please note that the necessary bandwidth is the width of the frequency band which is sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions for a given class of emission.

- **Performance:**
    - **EIRP**
    Current Canadian spectrum regulations (SRSP-303.4) for fixed wireless access (FWA) in the 3.5 GHz band (3.475-3.65 GHz) set the maximum EIRP of subscribers and base stations to +32 dBW (+62dBm) per RF channel. However, it is noted that higher EIRP may be permitted if technical justification is provided.

      Manufacturer offers a broad range of WiMAX products with varying transmit powers and antenna gains. Manufacturers usually specify the maximum transmit power of a unit without reference to the modulation used. The transmit power for BPSK or QSPK modulation of a device can vary from the 16QAM or 64QAM modulation, thus final EIRP also vary. Currently available fixed WiMAX base stations generally have transmit powers in the 20-30 dBm range with selected higher power units, again without specifying modulation. Fixed WiMAX customer premises equipment transmit power is generally in the 20-25 dBm range. Knowing this information and accounting for cable loss on the Tx and Rx side, EIRPs of 45 dBm are common (but can be greater).

      In many cases, the customer's subscriber station will have a lower EIRP than the base station. In such a case, the uplink from the subscriber to the network will perform at a lower modulation than the downlink, which is common for point-to-multipoint access technologies (cable and ADSL function in this way).

    - **SNR (Signal to Noise Ratios)**
    Received signal thresholds and SNRs calculated in table below are based on a typical certified WiMAX TDD system implementation using 3.5 and 7 MHz channel bandwidth.[7]

---

[7] Redline Communications, RedMAX Series Receiver Sensitivity Thresholds

Table 4.5.5 – Required SNR vs. Modulation

Modulation	Coding Rate	ToO (dBm)		Estimated SNR Required (dB)
		3.5 MHz	7MHz	3.5 MHz / 7 MHz
64QAM	3/4	-78	-75	24.5
64QAM	2/3	-80	-77	22.5
16QAM	3/4	-86	-83	16.5
16QAM	1/2	-88	-85	14.5
QPSK	3/4	-93	-90	9.5
QPSK	1/2	-95	-92	7.5
BPSK	1/2	-97	-95	4.5

ToO: Thresholds of operation
SNR: Signal to noise ratio

The above SNR required column was calculated assuming a close to optimal implementation with 6 dB overall system noise figure (NF).

$$\textbf{Estimated SNR Required}_{dB} = \textbf{ToO}_{dBm} - \textbf{KTB}_{dBm} - \textbf{NF}_{dB}$$

KTB: Noise floor due to thermal noise and receiver bandwidth

- **Net Payload Data rate**

  Typical net payload data rates in table below are based on the same typical WiMAX TDD system implementation as described in SNR section.

Table 4.5.6 – Net Payload Data Rates

Modulation	Coding Rate	Net Payload Capacity (Mbps)	
		3.5 MHz	7MHz
64QAM	3/4	10	21
64QAM	2/3	9	19
16QAM	3/4	7	14
16QAM	1/2	4	9
QPSK	3/4	3	7
QPSK	1/2	2	4
BPSK	1/2	1	2

- **Link Budgets**

  Rural Deployments Using Fixed WiMAX

  The information provided in tables of this section refers to downlink only, where a lower power uplink will limit the operational range of WiMAX or force uplink data to a lower modulation.

  To visualize the increase in range achieved by a 700 MHz fixed WiMAX system versus a 3.5 GHz implementation in rural deployments, both are compared in the following tables. Fixed WiMAX deployments at 3.5 GHz commonly use sector antennas of approximately 60° beam width and 17 dBi gain.

  At the client side (Rx side), smaller directional panel antennas are usually used. Assuming a 15 dBi 60° panel antenna at 3.5 GHz and an equivalent antenna at 700 MHz and considering a 5 dB deployment margin. The actual necessary link margin depends on the required availability of the communication link. A fixed 5 dB of link deployment margin was assumed for simplicity of analysis. To meet a specific availability target in rural deployments, such as 99.95%, the required link margin would need to be adjusted accordingly.

Table 4.5.7 illustrates the ranges of 3.5 GHz and 700 MHz fixed WiMAX products at 45 dBm EIRP. We are assuming free space propagation, a 15 dBi Rx antennas and still considering 5 dB of link deployment margin. An additional 10 dB of margin is included to account for earth's curvature diffraction effects in long links and other propagation effects.

Table 4.5.7: Rural Range Calculations (45 dBm EIRP)

Modulation	Coding Rate	ToO + Margin Threshold for 7 MHz BW (dBm)	Maximum Path Loss (dB)	Maximum Operational range (km)		Range increase at 700 MHz (km)
				3.5 GHz	700 MHz*	
64QAM	3/4	-60	120	6.8	34.1	27.3
64QAM	2/3	-62	122	8.6	43	34.4
16QAM	3/4	-68	128	17.1	85.8	68.7
16QAM	1/2	-70	130	21.6	108	86.4
QPSK	3/4	-75	135	38.4	192	153.6
QPSK	1/2	-77	137	48.3	241.7	193.4
BPSK	1/2	-80	140	68.2	341.4	273.2

*These calculations were achieved using equal gain client antennas at 3.5 GHz and 700 MHz (15 dBi). If two antennas with similar physical dimensions are used, the antenna gain at 700 MHz will be somewhat less than the 3.5 GHz antenna.

We notice that a 700 MHz WiMAX implementation significantly increases the coverage area of a single base station versus a 3.5 GHz implementation.

Urban Deployments Using Fixed WiMAX Including Outdoor to Indoor Links

Table 4.5.9 considers the same 15 dBi Rx antenna at and 5 dB of deployment margin as well as 45 dBm base station EIRP. An additional 35dB of obstacle blockage is considered in the margin to account for attenuation by man-made structures. As mentioned previously, the actual necessary link margin required will depend on the required availability of the communications link. A fixed 5 dB of link deployment margin was assumed for simplicity of analysis. To meet a specific availability target in urban deployments, such as 99.95%, the required link margin would need to be adjusted accordingly. Typically, the required margin in fixed urban environments is less than in fixed rural deployments as urban links are much more subject to small rapid variations in power levels (which have little effect on the average received power) than deep fades, due to the typically shorter links in multipath-prone environments.

Table 4.5.8: Urban Range Calculations (45 dBm EIRP)

Modulation	Coding Rate	ToO + Margin Threshold for 7 MHz BW (dBm)	Maximum Path Loss (dB)	Maximum Operational range (km)		Range increase at 700 MHz (km)
				3.5 GHz	700 MHz*	
64QAM	3/4	-35	95	0.4	1.9	1.5
64QAM	2/3	-37	97	0.5	2.4	1.9
16QAM	3/4	-43	103	1	4.8	3.8
16QAM	1/2	-45	105	1.2	6.1	4.9
QPSK	3/4	-50	110	2.2	10.8	8.6
QPSK	1/2	-52	112	2.7	13.6	10.9
BPSK	1/2	-55	115	3.8	19.2	15.4

*These calculations were achieved using equal gain client antennas at 3.5 GHz and 700 MHz (15 dBi). If two antennas with similar physical dimensions are used, the antenna gain at 700 MHz will be somewhat less than the 3.5 GHz antenna.

Rural or Urban Deployments Using Mobile WiMAX
Due to limited information provided by mobile WiMAX manufacturers at this stage, no typical mobile WiMAX link budget can be provided in this document.

- **Infrastructure:**
  - **Type**
    Point-to-multipoint (PMP) architecture comprises of base stations (BSs) with omnidirectional coverage (cells), which can use multiple sectors, and consumer premises equipments with directive (fixed) or omnidirectional (mobile) antennas.
  - **Antenna**
    Linear polarization (horizontal or vertical).

    Antenna gain varies upon model and antenna type.

- **Receiver:**

  Consumer premises equipments (subscriber stations) are available from various manufacturers.

- **Requirements for tests needed to support the study:**

  There are currently no commercial WiMAX products that can operate in the UHF TV bands.

- **Region of utilization:**

  A brief research on WiMAX service providers in Canada, conducted in January 2007, revealed that Canadian companies that had existing fixed WiMAX deployments in Canada included, but were not limited to:

Table 4.5.9 – Existing Fixed WiMAX Deployments in Canada

Company	Website	Frequency Band	Network Locations
ABC (Allen Business) Communications Ltd	www.abccomm.com	3.5 GHz	British Columbia
High-Speed FX Communications Inc.	www.highspeedfx.com	3.5 GHz	Ontario
I-NetLink Wireless	www.inetlink.ca	3.5 GHz	Manitoba
NETAGO Wireless	www.netago.ca	3.5 GHz	Alberta
Northwestel Inc.	www.nwtel.ca	3.5 GHz	B.C., Yukon
Sogetel Inc.	www.sogetel.com	3.5 GHz	Quebec

The same research revealed that Canadian companies planning WiMAX services in their respective Canadian markets included, but were not limited to:

Table 4.5.10 – Planned WiMAX Deployments in Canada

Company	Website	Frequency Band	Network Locations
Chatham Internet Access	www.ciaccess.com	3.5 GHz 2.3 GHz	Ontario
Comcentric Networking Inc.	www.cni.on.ca	3.5 GHz	Ontario
Mipps Inc.	www.mipps.net	3.5 GHz	-
Pathcom Wireless Inc.	www.pathcom.ca	3.5 GHz	West and North
RipNET Limited	www.ripnet.com	3.5 GHz	Ontario
Source Cable & Wireless Ltd.	www.sourcecable.ca	3.5 GHz	Ontario

Other pertinent references for WiMAX technology not mentioned explicitly in document.

[1] IEEE Std 802.16-2004, October 2004, http://standards.ieee.org/getieee802/download/802.16-2004.pdf

[2] IEEE Std 802.16e-2005 and IEEE Std and Std 802.16-2004/Cor1-2005, February 2006, http://ieeexplore.ieee.org/xpl/standardstoc.jsp?isnumber=33683

[3] WiMAX Forum Mobile System Profile, Release 1.0 Approved Specification (Revision 1.2.2), November 2006, http://www.wimaxforum.org/technology/documents/WiMAX_Forum_Mobile_System_Profile_v1_2_2.pdf

[4] The WiMAX Forum Certified™ program for fixed WiMAX, January 2007, http://www.wimaxforum.org/technology/downloads/WiMAX_Forum_Fixed_Certification_White_Paper_Jan_07.pdf

[5] Fixed, nomadic, portable and mobile applications for 802.16-2004 and 802.16e WiMAX networks, November 2005, http://www.wimaxforum.org/technology/downloads/Applications_for_802.16-2004_and_802.16e_WiMAX_networks_final.pdf

5 Conclusion

Industry Canada's Spectrum Planning and Engineering branch is in the process of redesigning its Automated Licensing System (ALS), a software tool used for the allocation of transmission systems licenses. To that effect, a number of recommended engineering studies need to be completed. The Communications Research Centre, with its Television Systems and Transmission (RTNT) and Wireless Applications & Systems Research (WASR) groups, having appropriate expertise, performed a preliminary study on *EMC between Land-Mobile, Fixed-Broadband point-to-multipoint and TV Broadcast Services*. This study is considered a requirement to help define the appropriate parameters for the proper operation of the ALS.

This document is the report on the first phase of an EMC Study between emerging telecommunications and broadcast technologies, and TV broadcast services. A description of the current analog and digital television broadcast systems was presented, and appropriate field strengths and interference parameters for grade B contour were provided. Improvements to the current ATSC DTV system that are meant to offer more and better services were described.

A number of licensed and unlicensed emerging technologies with the potential to operate in the television broadcast band were considered in this study. Given the tight schedule to perform this study, CRC has limited itself to five of those technologies which are deemed to be offered within a reasonably short period of time to provide new type of services such as wireless broadband access in rural and remoter areas, portable and mobile TV and multimedia; with and without return channel capabilities. The technologies fall into two categories, broadcast types like DVB-H, MediaFLO and T-DMB; and telecom types such as WiFi and WiMAX.

It is likely that the DVB-H and MediaFLO technologies will coexist in the near future as mobile and portable multimedia broadcasting technologies but their similarities may trigger a fierce fight for market shares. Nevertheless, their differences are significant enough to justify their analysis in the context of this study. T-DMB, if implemented in North America, will most likely be using L-Band, not VHF, and thus would not be a sharing the television band. WiFi, because of the way it was designed will not be used in the TV bands except for some trials. WiMAX on the other hand seem to generate a lot of interest in being deployed in the television bands; the potential market will be the key factor for its usage in these bands though.

Link budgets for all technologies presented were derived for a good performance scenario. The results show that higher filed strength levels are required across all technologies in order to allow for good quality portable and mobile reception. The extent to which these higher levels will impact fixed broadcast television operations under co-channel and adjacent channel conditions is yet to be determined and should be a subject in the next phase of the study.

Independent of the implementation issues of those technologies, the information that was presented in this report is considered preliminary in the sense that more work is required to provide a complete family of transmission parameters and conditions required for the ALS software. The studies that could be performed to augment the required information fall into two main categories. First, a more complete analysis that takes into consideration a number of other emerging technologies (WRAN, UltraWideBand (UWB) ...) that could not be considered in this study because of the very short time span over which this study took place. Second, at the very least, laboratory tests need to be performed and preferably followed by field tests to provide hard numbers to be used as the transmission parameters. To that effect, CRC has the capability to perform tests, in the lab and in the field that would help develop appropriate models of transmission parameters and conditions. Industry Canada's Spectrum Planning and Engineering branch is welcome to contact CRC for further discussions on a proposal for the next logical step of this study.

6 Annex 1: Broadcast Technologies Link Budgets

This annex contains a table listing the classes for the different scenarios possible with broadcast technologies such as fixed and mobile as well as the link budget calculations for the case of a good quality of coverage. These calculations can also be performed for the case of an acceptable quality of coverage by using the appropriate correction coefficient μ.

The quality of coverage is classified as follows, for a small area of 100m x 100m:

- "Good":
  - For Class A and B, if at least 95% of the receiving locations at the edge of the area are covered for portable reception;
  - For Class C and D, if at least 99% of the receiving locations within the area are covered for mobile reception;
- "Acceptable":
  - For Class A and B, if at least 70% of the receiving locations at the edge of the area are covered for portable reception;
  - For Class C and D, if at least 90% of the receiving locations within the area are covered for mobile reception;

The correction coefficient for the conditions presented above are as shown in table A-1.

Table A-1 Quality of Coverage and associated correction coefficient μ

Quality of Coverage	Class A and B	Class C and D
Good	95%, μ=1.64	99%, μ=2.33
Acceptable	70%, μ=0.52	90%, μ=1.28

The DVB-H implementation guidelines define four classes of usage as presented in table A-2.

Table A-2 Usage Scenarios for Link Budget

<table>
<tr><td colspan="2">Class A</td></tr>
<tr><td colspan="2">Outdoor reception where the portable receiver with an attached or built-in antenna is used. Reception is considered at 1.5 m above ground level, at a speed of 3km/h.</td></tr>
<tr><td colspan="2">Class B</td></tr>
<tr><td colspan="2">Indoor reception where the portable receiver with an attached or built-in antenna is used. The receiver is 1.5 m above floor level on the ground floor, in a room with a window in an external wall.</td></tr>
<tr><td>Class B1</td><td>Class B2</td></tr>
<tr><td>Light-indoor reception, for a portable receiver close to a window in a lightly shielded room.</td><td>Deep-indoor reception, for a portable receiver located further away from a window in a highly shielded room.</td></tr>
<tr><td colspan="2">Class C</td></tr>
<tr><td colspan="2">Mobile reception where the receiver is located in a moving vehicle and receives the signal from an external, outdoor antenna. Reception is considered at 1.5 m above ground level, at a speed of up to 130km/h.</td></tr>
<tr><td colspan="2">Class D</td></tr>
<tr><td colspan="2">Mobile reception where the receiver is located in a moving vehicle and receives the signal from an attached or built-in antenna. Reception is considered at 1.5 m above ground level, at a speed of up to 130km/h.</td></tr>
</table>

DVB-H Link Budget

Parameter	Value	Units
Frequency (f)	701	MHz
Wavelength (λ)	0.43	m
Absolute Temperature (T_0)	290	°K
Boltzmann's Constant (k)	1.38E-23	Ws/K
Bandwidth (B)	5.71E+06	Hz
Impedance (Z_i)	75	Ω
Rx Noise Figure (F)	6.0	dB
Receiver Noise Input Power (Pn)	-130.41	dBW

Equations

$Pn = F + 10\log_{10}(k\ T_0\ B)$

$Ps_{min} = C/N + Pn$

$Aa = G + 10\ \log_{10}(\lambda^2 / 4\pi)$

$\Phi_{min} = Ps_{min} - Aa$

$E_{min} = \Phi_{min} + 120 + 10\log_{10}(120\pi)$

$Cl = \sigma * \mu$

$E_{med} = E_{min} + Lp + Lo + Cl$

		Class A -- MPE-FEC 3/4			
		QPSK 1/2	QPSK 2/3	16QAM 1/2	16QAM 2/3
Carrier to Noise Ratio (C/N)	dB	7.5	10.5	13.5	16.5
Dipole Antenna Gain (Gd)	dBd	-9.2	-9.2	-9.2	-9.2
Isotropic Antenna Gain (G)	dBi	-7.00	-7.00	-7	-7
Antenna Aperture (Aa)	dBm²	-25.36	-25.36	-25.36	-25.36
Correction coefficient (μ)		1.6	1.6	1.6	1.6
Combined standard deviation (σ)	dB	5.5	5.5	5.5	5.5
Location correction factor (Cl)	dB	9.0	9.0	9.0	9.0
Penetration losses (Lp)	dB	0.0	0.0	0.0	0.0
Height losses (Lh)	dB	0.0	0.0	0.0	0.0
Other losses (man-made noise, polarisation mismatch, misc.) (Lo)	dB	3.0	3.0	3.0	3.0
Minimum Receiver Input Power (Ps_{min})	dBW	-122.91	-119.91	-116.91	-113.91
Minimum Equivalent Receiver Input Voltage into Z_i ($U_{s\ min}$)	dBμV	15.84	18.84	21.84	24.84
Minimum Power Flux Density (Φ_{min})	dBW/m²	-97.55	-94.55	-91.55	-88.55
Minimum Equivalent Field Strength (E_{min})	dBμV/m	48.22	51.22	54.22	57.22
Minimum Median Equivalent Field Strength (E_{med})	dBμV/m	60.2	63.2	66.2	69.2

		Class B1 -- MPE-FEC 3/4			
		QPSK 1/2	QPSK 2/3	16QAM 1/2	16QAM 2/3
Carrier to Noise Ratio (C/N)	dB	7.5	10.5	13.5	16.5
Dipole Antenna Gain (Gd)	dBd	-9.2	-9.2	-9.2	-9.2
Isotropic Antenna Gain (G)	dBi	-7.00	-7.00	-7	-7
Antenna Aperture (Aa)	dBm²	-25.36	-25.36	-25.36	-25.36
Correction coefficient (μ)		1.6	1.6	1.6	1.6
Combined standard deviation (σ)	dB	7.4	7.4	7.4	7.4
Location correction factor (Cl)	dB	12.2	12.2	12.2	12.2
Penetration losses (Lp)	dB	11.0	11.0	11.0	11.0
Height losses (Lh)	dB	0.0	0.0	0.0	0.0
Other losses (man-made noise, polarisation mismatch, misc.) (Lo)	dB	3.0	3.0	3.0	3.0
Minimum Receiver Input Power (Ps_{min})	dBW	-122.91	-119.91	-116.91	-113.91
Minimum Equivalent Receiver Input Voltage into Z_i ($U_{s\ min}$)	dBμV	15.84	18.84	21.84	24.84
Minimum Power Flux Density (Φ_{min})	dBW/m²	-97.55	-94.55	-91.55	-88.55
Minimum Equivalent Field Strength (E_{min})	dBμV/m	48.22	51.22	54.22	57.22
Minimum Median Equivalent Field Strength (E_{med})	dBμV/m	74.4	77.4	80.4	83.4

		Class C -- MPE-FEC 3/4			
		QPSK 1/2	QPSK 2/3	16QAM 1/2	16QAM 2/3
Carrier to Noise Ratio (C/N)	dB	8.5	11.5	14.5	17.5
Dipole Antenna Gain (Gd)	dBd	-4.2	-4.2	-4.2	-4.2
Isotropic Antenna Gain (G)	dBi	-2.00	-2.00	-2	-2
Antenna Aperture (Aa)	dBm²	-20.36	-20.36	-20.36	-20.36
Correction coefficient (μ)		2.3	2.3	2.3	2.3
Combined standard deviation (σ)	dB	5.5	5.5	5.5	5.5
Location correction factor (Cl)	dB	12.8	12.8	12.8	12.8
Penetration losses (Lp)	dB	0.0	0.0	0.0	0.0
Height losses (Lh)	dB	0.0	0.0	0.0	0.0
Other losses (man-made noise, polarisation mismatch, misc.) (Lo)	dB	3.0	3.0	3.0	3.0
Minimum Receiver Input Power (Ps_{min})	dBW	-121.91	-118.91	-115.91	-112.91
Minimum Equivalent Receiver Input Voltage into Z_i ($U_{s\ min}$)	dBμV	16.84	19.84	22.84	25.84
Minimum Power Flux Density (Φ_{min})	dBW/m²	-101.55	-98.55	-95.55	-92.55
Minimum Equivalent Field Strength (E_{min})	dBμV/m	44.22	47.22	50.22	53.22
Minimum Median Equivalent Field Strength (E_{med})	dBμV/m	60.0	63.0	66.0	69.0

		Class D -- MPE-FEC 3/4			
		QPSK 1/2	QPSK 2/3	16QAM 1/2	16QAM 2/3
Carrier to Noise Ratio (C/N)	dB	8.5	11.5	14.5	17.5
Dipole Antenna Gain (Gd)	dBd	-9.2	-9.2	-9.2	-9.2
Isotropic Antenna Gain (G)	dBi	-7.00	-7.00	-7	-7
Antenna Aperture (Aa)	dBm²	-25.36	-25.36	-25.36	-25.36
Correction coefficient (μ)		2.3	2.3	2.3	2.3
Combined standard deviation (σ)	dB	5.5	5.5	5.5	5.5
Location correction factor (Cl)	dB	12.8	12.8	12.8	12.8
Penetration losses (Lp)	dB	7.0	7.0	7.0	7.0
Height losses (Lh)	dB	0.0	0.0	0.0	0.0
Other losses (man-made noise, polarisation mismatch, misc.) (Lo)	dB	3.0	3.0	3.0	3.0
Minimum Receiver Input Power (Ps_{min})	dBW	-121.91	-118.91	-115.91	-112.91
Minimum Equivalent Receiver Input Voltage into Z_i ($U_{s\ min}$)	dBμV	16.84	19.84	22.84	25.84
Minimum Power Flux Density (Φ_{min})	dBW/m²	-96.55	-93.55	-90.55	-87.55
Minimum Equivalent Field Strength (E_{min})	dBμV/m	49.22	52.22	55.22	58.22
Minimum Median Equivalent Field Strength (E_{med})	dBμV/m	72.0	75.0	78.0	81.0

MediaFLO Link Budget

Parameter	Value	Units
Frequency (f)	701	MHz
Wavelength (λ)	0.43	m
Absolute Temperature (T_0)	290	°K
Boltzmann's Constant (k)	1.38E-23	Ws/K
Bandwidth (B)	5.42E+06	Hz
Impedance (Z_i)	75	Ω
Rx Noise Figure (F)	6.0	dB
Receiver Noise Input Power (Pn)	-130.64	dBW

Equations
$Pn = F + 10\log_{10}(k\ T_0\ B)$
$Ps_{min} = C/N + Pn$
$Aa = G + 10\ \log_{10}(\lambda^2 / 4\pi)$
$\Phi_{min} = Ps_{min} - Aa$
$E_{min} = \Phi_{min} + 120 + 10\log_{10}(120\pi)$
$Cl = \sigma * \mu$
$E_{med} = E_{min} + Lp + Lo + Cl$

		Class A			
		Mode 1	Mode 2	Mode 7	Mode 7
		QPSK 1/2	16QAM 1/3	QPSK 1/2 Base	QPSK 1/2 Enhanced
Carrier to Noise Ratio (C/N)	dB	6.0	8.0	9.0	13.5
Dipole Antenna Gain (Gd)	dBd	-9.2	-9.2	-9.2	-9.2
Isotropic Antenna Gain (G)	dBi	-7.0	-7.0	-7.0	-7.0
Antenna Aperture (Aa)	dBm²	-25.4	-25.4	-25.4	-25.4
Correction coefficient (μ)		1.6	1.6	1.6	1.6
Combined standard deviation (σ)	dB	5.5	5.5	5.5	5.5
Location correction factor (Cl)	dB	9.0	9.0	9.0	9.0
Penetration losses (Lp)	dB	0.0	0.0	0.0	0.0
Height losses (Lh)	dB	0.0	0.0	0.0	0.0
Other losses (man-made noise, polarisation mismatch, misc.) (Lo)	dB	3.0	3.0	3.0	3.0
Minimum Receiver Input Power (Ps_{min})	dBW	-124.6	-122.6	-121.6	-117.1
Minimum Equivalent Receiver Input Voltage into Z_i ($U_{s\ min}$)	dBμV	14.1	16.1	17.1	21.6
Minimum Power Flux Density (Φ_{min})	dBW/m²	-99.3	-97.3	-96.3	-91.8
Minimum Equivalent Field Strength (E_{min})	dBμV/m	46.5	48.5	49.5	54.0
Minimum Median Equivalent Field Strength (E_{med})	dBμV/m	58.5	60.5	61.5	66.0

		Class B1			
		Mode 1	Mode 2	Mode 7	Mode 7
		QPSK 1/2	16QAM 1/3	QPSK 1/2 Base	QPSK 1/2 Enhanced
Carrier to Noise Ratio (C/N)	dB	6.0	8.0	9.0	13.5
Dipole Antenna Gain (Gd)	dBd	-9.2	-9.2	-9.2	-9.2
Isotropic Antenna Gain (G)	dBi	-7.0	-7.0	-7.0	-7.0
Antenna Aperture (Aa)	dBm²	-25.4	-25.4	-25.4	-25.4
Correction coefficient (μ)		1.6	1.6	1.6	1.6
Combined standard deviation (σ)	dB	7.4	7.4	7.4	7.4
Location correction factor (Cl)	dB	12.2	12.2	12.2	12.2
Penetration losses (Lp)	dB	11.0	11.0	11.0	11.0
Height losses (Lh)	dB	0.0	0.0	0.0	0.0
Other losses (man-made noise, polarisation mismatch, misc.) (Lo)	dB	3.0	3.0	3.0	3.0
Minimum Receiver Input Power (Ps_{min})	dBW	-124.6	-122.6	-121.6	-117.1
Minimum Equivalent Receiver Input Voltage into Z_i ($U_{s\ min}$)	dBμV	14.1	16.1	17.1	21.6
Minimum Power Flux Density (Φ_{min})	dBW/m²	-99.3	-97.3	-96.3	-91.8
Minimum Equivalent Field Strength (E_{min})	dBμV/m	46.5	48.5	49.5	54.0
Minimum Median Equivalent Field Strength (E_{med})	dBμV/m	72.7	74.7	75.7	80.2

		Class C			
		Mode 1	Mode 2	Mode 7	Mode 7
		QPSK 1/2	16QAM 1/3	QPSK 1/2 Base	QPSK 1/2 Enhanced
Carrier to Noise Ratio (C/N)	dB	6.0	8.0	9.0	13.5
Dipole Antenna Gain (Gd)	dBd	-4.2	-4.2	-4.2	-4.2
Isotropic Antenna Gain (G)	dBi	-2.0	-2.0	-2.0	-2.0
Antenna Aperture (Aa)	dBm²	-20.4	-20.4	-20.4	-20.4
Correction coefficient (μ)		2.3	2.3	2.3	2.3
Combined standard deviation (σ)	dB	5.5	5.5	5.5	5.5
Location correction factor (Cl)	dB	12.8	12.8	12.8	12.8
Penetration losses (Lp)	dB	0.0	0.0	0.0	0.0
Height losses (Lh)	dB	0.0	0.0	0.0	0.0
Other losses (man-made noise, polarisation mismatch, misc.) (Lo)	dB	3.0	3.0	3.0	3.0
Minimum Receiver Input Power (Ps_{min})	dBW	-124.6	-122.6	-121.6	-117.1
Minimum Equivalent Receiver Input Voltage into Z_i ($U_{s\ min}$)	dBμV	14.1	16.1	17.1	21.6
Minimum Power Flux Density (Φ_{min})	dBW/m²	-104.3	-102.3	-101.3	-96.8
Minimum Equivalent Field Strength (E_{min})	dBμV/m	41.5	43.5	44.5	49.0
Minimum Median Equivalent Field Strength (E_{med})	dBμV/m	57.3	59.3	60.3	64.8

		Class D			
		Mode 1	Mode 2	Mode 7	Mode 7
		QPSK 1/2	16QAM 1/3	QPSK 1/2 Base	QPSK 1/2 Enhanced
Carrier to Noise Ratio (C/N)	dB	6.0	8.0	9.0	13.5
Dipole Antenna Gain (Gd)	dBd	-9.2	-9.2	-9.2	-9.2
Isotropic Antenna Gain (G)	dBi	-7.0	-7.0	-7.0	-7.0
Antenna Aperture (Aa)	dBm²	-25.4	-25.4	-25.4	-25.4
Correction coefficient (μ)		2.3	2.3	2.3	2.3
Combined standard deviation (σ)	dB	5.5	5.5	5.5	5.5
Location correction factor (Cl)	dB	12.8	12.8	12.8	12.8
Penetration losses (Lp)	dB	7.0	7.0	7.0	7.0
Height losses (Lh)	dB	0.0	0.0	0.0	0.0
Other losses (man-made noise, polarisation mismatch, misc.) (Lo)	dB	3.0	3.0	3.0	3.0
Minimum Receiver Input Power (Ps_{min})	dBW	-124.6	-122.6	-121.6	-117.1
Minimum Equivalent Receiver Input Voltage into Z_i ($U_{s\ min}$)	dBμV	14.1	16.1	17.1	21.6
Minimum Power Flux Density (Φ_{min})	dBW/m²	-99.3	-97.3	-96.3	-91.8
Minimum Equivalent Field Strength (E_{min})	dBμV/m	46.5	48.5	49.5	54.0
Minimum Median Equivalent Field Strength (E_{med})	dBμV/m	69.3	71.3	72.3	76.8

T-DMB Link Budget

Parameter	Value	Units
Frequency (f)	225	MHz
Wavelength (λ)	1.33	m
Absolute Temperature (T_0)	290	°K
Boltzmann's Constant (k)	1.38E-23	Ws/K
Bandwidth (B)	1.54E+06	Hz
Impedance (Z_i)	75	Ω
Rx Noise Figure (F)	7.0	dB
Receiver Noise Input Power (Pn)	-135.11	dBW

Equations

$Pn = F + 10\log_{10}(k\ T_0\ B)$

$Ps_{min} = C/N + Pn$

$Aa = G + 10\ \log_{10}(\lambda^2 / 4\pi)$

$\Phi_{min} = Ps_{min} - Aa$

$E_{min} = \Phi_{min} + 120 + 10\log_{10}(120\pi)$

$Cl = \sigma * \mu$

$E_{med} = E_{min} + Lp + Lo + Cl$

		Class A	Class B	Class C	Class D
		D-QPSK 1/2	D-QPSK 1/2	D-QPSK 1/2	D-QPSK 1/2
Carrier to Noise Ratio (C/N)	dB	16.6	16.6	15.0	15.0
Dipole Antenna Gain (Gd)	dBd	-17.0	-17.0	-2.2	-17.0
Isotropic Antenna Gain (G)	dBi	-14.9	-14.9	-0.1	-14.9
Antenna Aperture (Aa)	dBm^2	-23.3	-23.3	-8.5	-23.3
Correction coefficient (μ)		1.6	1.6	2.3	2.3
Combined standard deviation (σ)	dB	5.5	6.3	5.5	5.9
Location correction factor (Cl)	dB	9.0	10.4	12.8	13.7
Penetration losses (Lp)	dB	0.0	9.0	0.0	8.0
Height losses (Lh)	dB	19.0	19.0	12.0	12.0
Other losses (man-made noise, polarisation mismatch, misc.) (Lo)	dB	0.0	0.0	5.0	0.0
Minimum Receiver Input Power (Ps_{min})	dBW	-118.5	-118.5	-120.1	-120.1
Minimum Equivalent Receiver Input Voltage into Z_i ($U_{s\,min}$)	dBμV	20.2	20.2	18.6	18.6
Minimum Power Flux Density (Φ_{min})	dBW/m^2	-95.2	-95.2	-111.6	-96.8
Minimum Equivalent Field Strength (E_{min})	dBμV/m	50.6	50.6	34.2	49.0
Minimum Median Equivalent Field Strength (E_{med})	dBμV/m	78.6	89.0	64.0	82.7