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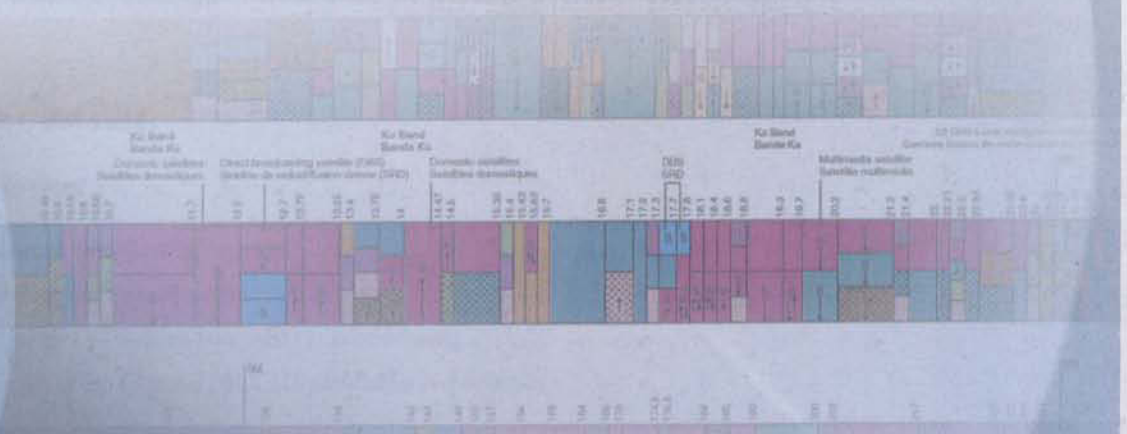

Spectrum R&D Program

FY 2004/2005

Canada

CRC

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Spectrum R&D Program FY 2004/2005

1 - Introduction

This report provides a summarized version of the final reports and presentations produced as a result of the various R&D projects undertaken by CRC under the Spectrum R&D program, sponsored by SITT/DGSE during the fiscal year 04/05. A summary description, including the context of the project, the work done and the results achieved, as well as a list of the main publications produced as a result of the work is presented for each R&D project. These summaries have been grouped under key topics for ease of reference.

The SITT funding for the Spectrum R&D program in FY 04/05 was $410K while CRC provided $520k in O&M and the equivalent of 20 FTEs for a total program funding of $2,550k.

2- Broadcast projects

B-15 Advanced techniques in DTV

DGSE: J. Dadourian CRC: Bernard Caron and VPBT staff

This multi-year project continued during FY 04/05 to confirm the spectrum allocation rules for DTV and support the harmonized implementation of new broadcast services. CRC continued its work on the Distributed Transmission Systems for DTV. A number of outdoor field tests were carried out using the experimental Single Frequency Network (SFN) implemented in downtown Ottawa with three low-power transmitters. The results indicate that this provides better coverage than a single higher power transmitter. Measurements were conducted for indoor reception from a lower power transmitter in downtown Montreal, and reception was found to be poorer than expected, likely due to the large amount of multipath. The tests will be repeated with newer generation DTV receivers. Further tests are planned in Ottawa for FY 05/06 for indoor reception. Work was also done on the use of multiple receive antennas to improve indoor reception. The use of maximum ratio combining from these antennas was simulated and it appeared to be a very promising technique.

DTV Single frequency network measurements in Ottawa

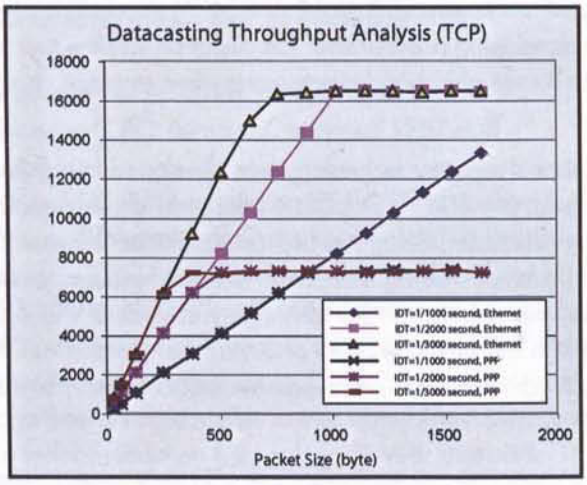
CRC contributed to the extension of the ATSC DTV standard to include SFN operation by developing a Transmitter Identification scheme that will help identifying the source of in-band interference when common channels are used.

A novel on-channel repeater technology was developed in collaboration with the Korean laboratory ETRI. It includes a baseband digital equalization with relatively short processing delay that improves isolation between the receive and transmit antennas, making installation of these repeaters easier. Laboratory tests have shown that, with this technology, a clean 8-VSB signal can be re-generated with a processing delay of 5.5 mseconds, and can withstand moderate multi-path distortion and moderate adjacent channel interference (NTSC and DTV).

Studies were initiated on the applicability of Distributed Transmission in an existing allotment plan (TVO network) by examining the availability of common channel(s) that could possibly be used by a group of low power stations.

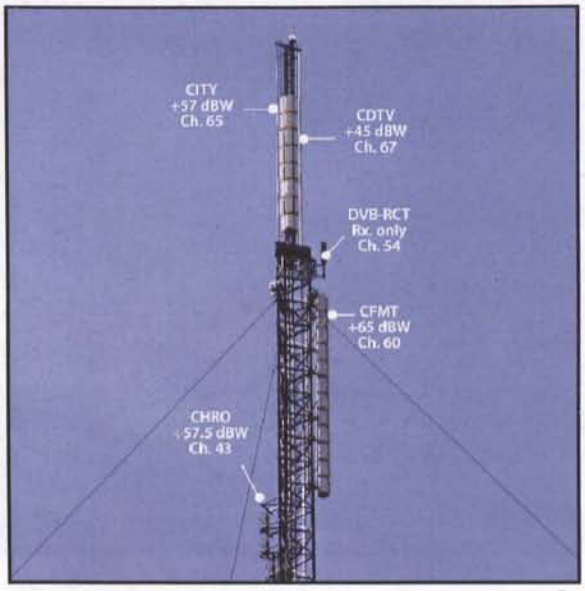
Some tests were performed on DTV receivers to investigate the impact of the presence of unlicensed devices operating in the TV bands as proposed by the FCC. It was found that the level of out-of-band emission suggested by the FCC for these devices would impact the TV reception and should therefore be reduced.

CRC developed a testbed for IP data transmission over DTV to: help understand the behavior of IP data transmission over DTV datacasting networks; assess the quality of network services; and provide valuable information for broadcasters who intend to implement IP datacasting over DTV. It was found that the IP packet size is critical in maximizing the datacasting throughput over DTV. In order to have access to the full datacasting downstream capacity in the case of a bi-directional TCP link, the capacity on the return link needs to be at least 115 kbit/s. It was found that DTV datacasting experiences a very fast transition to outage, within 1 dB. It is envisaged to add a layer of error protection at the IP level to improve the robustness of data reception in presence of channel impairments such as noise and multipath, especially for streaming data such as UDP/IP which do not have inherent error recovery mechanism.



DTV-ATSC Datacasting performance

Work continued on the implementation of a DTV return channel at the Manotick experimental DTV station, south of Ottawa. The receive antenna had been installed the previous year. An Internet access point is now operational at the station. An 8 MHz version of the DVB-RCT equipment for the return channel was received and tests took place in a laboratory environment to qualify the equipment performance. Field tests are planned with a 6 MHz version, to be delivered later.



Antennas on the Manotick tower

CRC contributed to the development of a special Issue of IEEE Proceedings on Broadcasting dealing with digital television. CRC's contribution covered the Synchronized Distributed Transmission and Single Frequency Networks.

The results of the work are detailed in the following publications:

[1] D. Prendergast, M. Guillet and B. Caron, "Broadband Internet Multimedia Service Return Channel using DTV for Rural and Remote Access," Proceeding of the "World Wireless Congress", May 24-29, 2004, San Francisco CA.

[2] X. Wang, Y. Wu, and B. Caron, "Transmitter Identification Using Embedded Pseudo Random Sequences," IEEE Transactions on Broadcasting, vol. 50, no. 3, Sept. 2004.

[3] Prendergast, D., Wu, Y., Salehian, K., Caron, B., "Digital video broadcasting return channel terrestrial (DVB-RCT) and on channel repeaters (OCR) for broadband internet multimedia service to rural and remote access", IBC 2004: International Broadcasting Convention, Amsterdam, Sept. 9-14, 2004, p. 121-131.

[4] Wang, X., Wu, Y., Chouinard, J.-Y., "Modified channel estimation algorithms for OFDM system with reduced complexity", ICSP'04: 7th International Conference on Signal Processing, Beijing, China, Aug. 31-Sept. 4, 2004, v. 2, p.1747-51.

[5] Wu, Y., Salehian, K., Gagnon, R., Lafleche, S., Ledoux, B., Wang, X., Caron, B. "Implementation of an experimental DTV distributed coherent translators network in Canada", International Broadcasting Convention, Amsterdam, Netherlands, Sept. 9-14, 2004

[6] Prendergast, D., Caron, B., Wu, Y., "The implementation of a return channel for ATSC-DTV", IEEE 54th Annual Broadcast Symposium, Washington, DC, Oct. 13-15, 2004.

[7] Salehian, K., Wu, Y., Caron, B., "An experimental ATSC-DTV distributed- transmission network", IEEE 54th Annual Broadcast Symposium, Washington, DC, Oct. 13-15, 2004.

[8] Wang, X., Wu, Y., Caron, B., Chouinard, J.-Y. "Robust data transmission using the transmitter identification sequences in ATSC DTV signals", ICCE 2005 : International Conference on Consumer Electronics, Jan. 8-12, 2005, Las Vegas, NV, (CD-ROM section 10.1-4)

[9] Wang, X., Wu, Y., Chouinard, J.-Y., "Robust data transmission using the transmitter identification sequences in ATSC DTV signals", IEEE Transactions on Consumer Electronics, v. 51, n. 1, Feb. 2005, p. 41-7.

[10] W. Li, H. Liu and G. Gagnon, "Performance Assessment of IP Traffic over ATSC Interactive Datacasting Systems", IEEE Transactions on Consumer Electronics, Vol. 51, No. 1, pp.54-62, February 2005.

[11] Salehian K., Wu Y., and Caron B., "Design Procedures and Field Test Results of a Distributed-Translator Network, and a Case Study for an Application of Distributed-Transmission", Submitted to the NAB 2005 Las Vegas, April 2005.

[12] Wang, X., Wu, Y., Chouinard, J.-Y., "Transmitter identification in distributed transmission network and its application in position location and a new data transmission scheme", NAB Broadcast Engineering Conference, Las Vegas, NV, Apr. 16-21, 2005.

[13] Wang, X., Ho, P., Wu, Y., "Robust channel estimation and ISI cancellation for OFDM systems with suppressed features", IEEE Journal on Selected Areas in Communications, vol. 23, n. 5, May 2005, p. 963-972.

[14] Semmar, A., Chouinard, J.-Y., Wang, X., Wu, Y., "UHF DTV band channel characterization for mobile reception", CCECE 2004: Canadian Conference on Electrical and Computer Engineering, Niagara Falls, ON, May 2-5, 2004, v.3, p. 1339-1342.

[19] S Lu, A. Semmar, X. Wang, Y. Wu, J-Y. Chouinard, and P. Fortier, "Implementation and Field Test of a New Channel Estimation Technique for DVB-T System," Proceedings of Canadian Conference on Electrical and Computer Engineering, Niagara Falls, Ontario, Canada, May 2-5, 2004.

B-16 Delivery of multimedia content in broadcasting

DGSE: J. Dadourian CRC: A. Vincent, L. Thibault, R. Voyer and staff

This project was the continuation of work done in previous years on mobile multimedia broadcasting and video quality for multimedia services. The work continued on the investigation of advanced video coding and development of multimedia broadcasting based on the DAB technology.
A new video compression algorithm based on the Curved Wavelet Transform was developed which outperforms the existing DCT-based coding schemes. This is achieved by analyzing the image content to identify edges and lines so that proper filtering and wavelet encoding can be done along these curves rather than in the usual horizontal and vertical directions. This is complemented by motion-compensated temporal filtering. These coding schemes are well suited for multimedia since they are efficient and inherently scalable.

Portions of decoded images at 0.2 bpp, (a) original image, (b) the improved coder , (c) JPEG2000

Computer simulations were conducted to compare various means of improving the performance of error protection for DAB/DMB data services transmission so that these data services start to fail (BER: 10-8 to 10-10) only when the audio service starts to fail (BER: 10-4). The proposed DAB-FEC and DVB-FEC, which include interleaving, give similar results and meet the requirement in the case of the typical urban channel at medium and high vehicle speed but not for the rural channel model. Increasing the interleaving depth will tend to improve the performance in the rural channel case for high vehicle speed. Adding the outer error correcting coding does not bring any substantial improvement at low speed such as walking speed.

The DAB multiplexer testbed continued to be developed to support development in the area of mobile multimedia broadcasting. The flexible software-

based platform allows many typical DAB services to be generated and multiplexed on a single PC platform for transmission of live or pre-recorded sources. The testbed was augmented to include a basic Digital Multimedia Broadcasting (DMB) chain to allow for an enhanced streaming mode including an additional error protection for MPEG-2 transport packets. Besides the implementation of the DVB Reed-Solomon forward error coding, an interleaver, synchronization, and packet mode encoding components were developed. An MP4 video stream was successfully transmitted over the augmented testbed, proving its functionality. During this work, some limitations in the DMB specification were identified. An implementation of the MPEG-4 SL video codec and the BSAC audio codec will be required once they become available to prove the complete functionality of the testbed and the compatibility with the commercial Korean DMB receivers.

DAB multiplexer testbed at CWTA in 2004

The results of the work are detailed in the following publications:

[1] D. Wang, L. Zhang, A. Vincent, "Curved Wavelet Transform for Scalable Video Coding," ISO/IEC JTC1/SC29/WG11, MPEG2004/m10535, March 2004, Munich, Germany.

[2] D. Wang, L. Zhang, A. Vincent, and Filippo Speranza "Curved wavelet transform for image coding" IEEE Trans. Image Processing, submitted and accepted.

[3] D. Wang, L. Zhang and A. Vincent, "Curved wavelet transform and overlapped extension for image coding," Proceedings of International Conference on Image Processing 2004 pp. 1273-1276, Singapore, Oct. 24-27, 2004.

[4] L. Zhang, D. Wang, and A. Vincent, "Adaptive SPIHT for image coding based on curved wavelet transform," Proceeding of Image and Video Communications and Processing 2005, SPIE Vol. 5685, 18-20 Jan. 2005, San Jose California USA.

[5] D. Wang, L. Zhang, and A. Vincent, "Wavelet video coding using a new method to reduce GOP-boundary artifacts," submitted to IEEE Transactions on Broadcasting, December 2005.

[6] D. Wang, L. Zhang, and A. Vincent, "Improvement of JPEG2000 Using Curved Wavelet Transform," 2005 IEEE International Conference on Acoustics, Speech, and Signal Processing, Philadelphia, PA, USA, March 18-23, 2005.

[7] L. Zhang, D. Wang, and A. Vincent, "Adaptive Zero-Tree Structure for Curved Wavelet Image Coding" Optical Engineering, submitted and accepted.

[8] Dr. L. Zhang and L. Thibault, "Advanced Forward Error Correction for DMB", Spectrum Research Report Research Project B-16 – FY 2004-05, June 2005.

[9] D. Wang, L. Zhang, and A. Vincent, "Recursive wavelet filters for video coding," Visual Communications and Image Processing 2005, Beijing, China, July 12-15, 2005.

[10] D. Wang, L, Zhang, A. Vincent, "Curved Wavelet Transform for Image and Video Compression", US and EU patent applications.

B-17 In Band On Channel (IBOC) Digital Radio Technologies

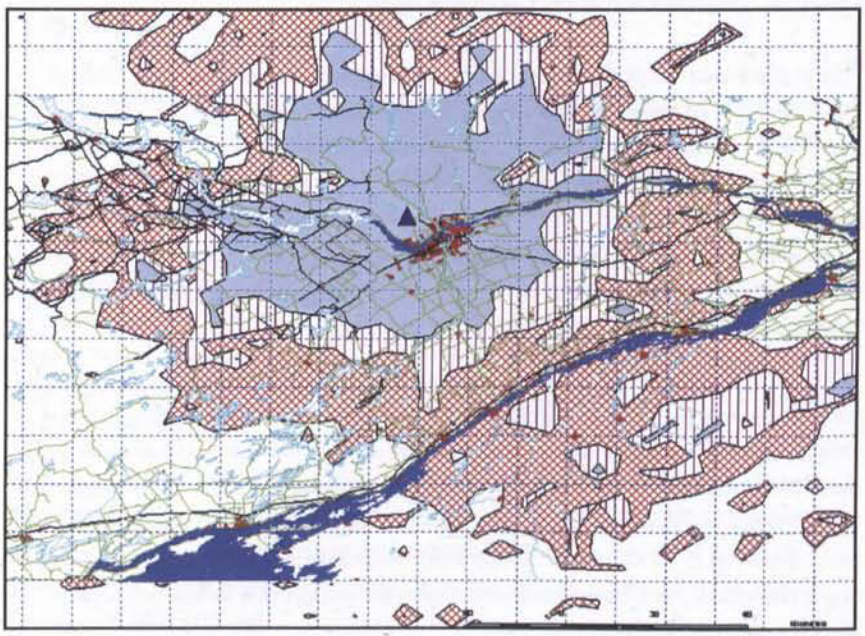
DGSE: J. Dadourian CRC: R. Voyer, A. Carr, D. Camiré

This new project was established in FY 04/05 to assess the impact of IBOC on the FM band. In the USA, the radio broadcasters decided to standardize and operate digital radio broadcasting within their FM channel allocation (in band on channel) using a technology called HDRadio. The FCC has authorized the use of this technology and a number of HDRadio transmitters have been installed. Relevant technical information on IBOC was gathered and assembled into a compendium. It contains over a hundred individual documents, including CRC reports, system specifications, test reports, FCC filings, white papers, technical articles, and it also addresses the results of system tests and field trials in the US.

New functionalities were added to the CRC-COVLAB coverage analysis software in order to simulate an IBOC system and to study interference scenarios to and from existing FM stations. A detailed search functionality was added to allow any FM broadcasting station in Canada (IC database) or the USA (FCC database) to be imported based on call sign, frequency range and/or search radius for interference calculations. A 'weighing factor' was also added to the FM receiver model to allow consideration of co-channel, first, second and third adjacent channel interference from analog and digital sources. The coverage analysis software already allows for hybrid FM IBOC

digital emission and both analog and digital reception.

An initial study was conducted on the use of coverage extenders for the IBOC signal. Limitations were identified for the use of these extenders based on technical aspects that may hinder their effectiveness.



Simulated FM IBOC Coverage around Ottawa

The results of the work are detailed in the following publications:

[1] B. McLarnon, BDMComm, "Coverage Extension for the FM IBOC System", V1.4, January 2005.
[2] B. McLarnon, BDMComm, "An IBOC System Compendium", V1.6, February 2005.
[3] M.-P. Lussier, VPBT 05-05/06 "CRC-COVLAB Technical memo: Station search and import tool for the IC database", April 2005.
[4] M.-P. Lussier, VPBT 06-05/06 "CRC-COVLAB Technical memo: Station search and import tool for the FCC database", April 2005.

3- Satellite projects

FB-09 Investigation of close-in antenna pattern suppression techniques

DGSE: R. Trenholm CRC: M. Cuhaci, J. Shafar

This project was a continuation of an investigation started in FY 02/03 on the possibility of reducing the size of the Ku-band receive antenna for the StarChoice Direct-to-Home service in presence of small orbital spacing with a Mexican satellite (1.9°). The use of multilayer frequency selective surface structures was proposed. In FY 03/04, extensive computer simulations were conducted to determine the parameters for a 3rd order Chebichev filter using these surface structures. The actual filter was designed and fabricated along with the test setup to carry out the filter measurement.

In FY 04/05, work was done on generalizing the use of this filter in cascade as well as verifying experimentally the performance of the resulting close-in antenna pattern suppression. Some discrepancies were found between the simulated results and the actual measured performance. The differences were traced back to the simulation software. New simulation software was used showing greater concordance with measured results. Four new surfaces were designed, fabricated and tested and the results are in line with the trends observed in the simulations.

Early measurement setup with 2-layer filter

Modified filter holder with 4-layer filter

Further work was needed to achieve the required close-in antenna pattern suppression. The four surfaces need to be overlaid with a specific separation. The angular response of the multistage filter needs to be investigated and the exact tilt angle needs to be found to achieve the desired angular response. This work is currently carried out in FY 05/06.

The results of the work are detailed in the following report:

[1] "Angular filter design, fabrication, test", Jafar Shaker, CRC Technical Note No. VPTWS-04-08-31, August 2004.

FB-10 Study of an offset dual-fed parabolic antenna

DGSE: R. Trenholm CRC: A. Petosa, D. Lee

This study is the continuation of work started in FY 03/04 and characterises the performance of the dual feed StarChoice Ku-band receive-only dish in order to validate the modelling approach toward ITU-R regulatory specifications in assuming independent antennas. A survey of commercial reflector technology and radiation pattern measurements was done to determine the theoretical and practical limitations on the maximum beam separation achievable with a dual-fed reflector. Of particular interest is the level of coupling between the two feeds as to whether they can be treated independently with respect to the radiation patterns in comparing it with those of a single-fed antenna.

As a result of the measured antenna patterns, it was found that the second feed has only a minor impact on the broadening of the half-power antenna beamwidth (0.1°) but has a significant deterioration in the sidelobe level performance in the azimuth plane, due to the added aperture blockage of the second feed (10 dB).

The StarChoice offset-fed antenna

The dual-feed arrangement

The results of the work are detailed in the following report:

[1] Study of an Offset Dual-Fed Parabolic Antenna, Aldo Petosa and David Lee, CRC Technical Note No. VPTWS-TM-05-03-17, March 2005.

FB-12 Impact of reduced orbital spacing in the Region 2 BSS Plan

DGSE: V. Mimis CRC: M. Caron, R. Paiement

The objective of this project was to study the impact of implementing reduced orbital spacing between satellites in the Region 2 BSS Plan on the future flexibility and growth of BSS services. DBS operators in the US would like to reduce the current 9° orbital spacing between the US satellites to 4.5° to increase the number of orbital positions. As a result, the FCC issued a petition for rulemaking in early 2004 which resulted in comments from the industry asking for protection of existing DBS systems while accepting a reduction to 4.5° spacing without undue requirements for negotiation with existing systems. This is now in the hands of the ITU-R to resolve at the international level.

Since the BSS plan was based on analog technologies, the interference criteria used in planning the orbit utilization are dated considering that all DBS systems now use digital modulation. The key element driving the interference discrimination among orbital positions is the antenna at the DBS terminal. The antenna size of 45 cm diameter was assumed as typical in the study. Current digital modulation systems typically giving 1.5 bit/(s*Hz) in spectrum efficiency with C/(N+I)= 12 dB, as well as newer DBS modulation standards such as DVB-S2 which increases this spectrum efficiency by a factor of up to 3 to 4.5 bit/(s*Hz) but requires a higher protection against interference and noise, i.e., C/(N+I)= 18 dB, were considered. The study was done assuming an orbital arc fully populated with the given orbital spacing (9°, 4.5°, 3° and 2.25°).

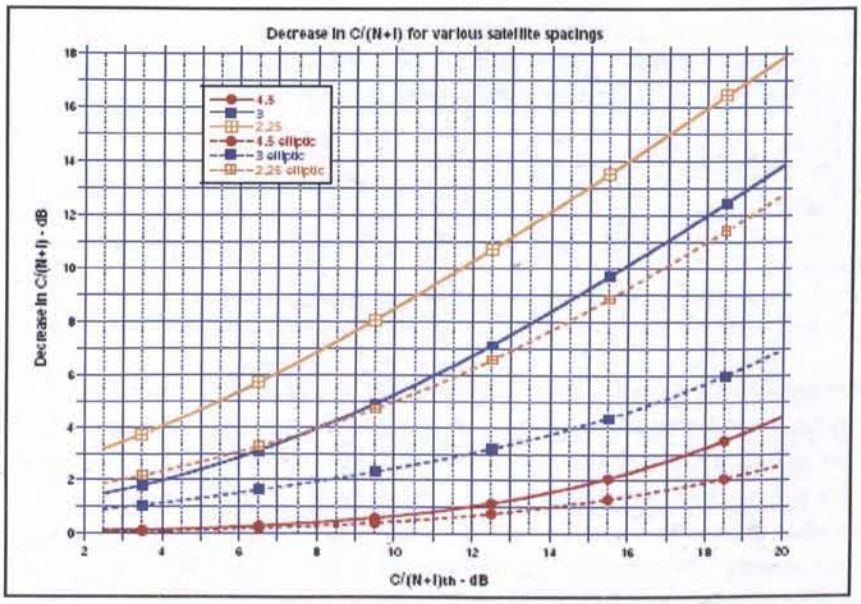
The results show that the increase in interference is minimal for a 4.5° separation. The results show that the cost in decrease of C/(N+I) increases with the required threshold C/(N+I). The impact on the existing DBS systems could also be limited for smaller than 9° orbital separation if elliptical reflectors were used at the user terminals operating with the new interstitial systems since it would allow a reduction of the EIRP at the new orbital positions resulting from the increased antenna gain and a better angular discrimination of the receive antenna toward the existing DBS satellites. However we noted that using an elliptical antenna offers little benefit for a 4.5° satellite spacing scenario at low to moderate required threshold C/(N+I) and a slight increase in user terminal antenna size would be as beneficial in this case.

The study did not consider multiple satellite beam systems currently in use but it is clear that closer spacing would be more costly in terms of increase

interference in these situations. The study provides data to DGSE to trade-off orbital and spectrum efficiency in their positioning considering this potential change of regulation, and quantify the impact on the Canadian systems.

The results of the work are detailed in the following report:

[1] On reducing the orbital spacing of DBS satellites, Mario Caron and Richard Paiement, CRC Technical Memorandum No. VPSAT #14/05, August 22, 2005.



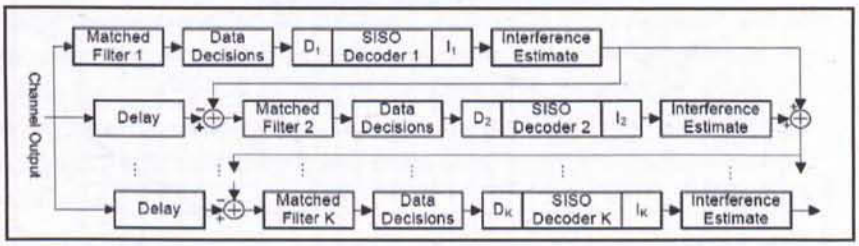
Decrease in C/(N+I) for various satellite spacing

FB-13 Study of More Efficient Multi-User Access Detection Techniques for Provision of Satellite Internet Access

DGSE: R. Trenholm CRC: K.Gracie, J. Lodge

With the growth in IP transmission over satellite, an increasing amount of the return-link traffic will be in the form of fairly short "randomly" transmitted packets that are sent in a random access fashion. If not handled properly and collisions occur on the return link, latency of several seconds may result. Joint multi-user detection and decoding to reduce latency and increase throughput of the return link for IP over satellite was investigated. A review of multi-user detection techniques, mostly for terrestrial applications (e.g., CDMA) was made to compare their relative performance, complexity

and latency. Turbo multi-user detection delivers the best performance given appropriate FEC coding and sufficient iterations, however, good synchronization recovery is critical. Latency can be controlled by the choice of detection scheme, high computational capacity and the use of small data blocks. Multi-user detection can be added after the fact to reduce problems linked with packet collisions but the best performance is achieved if multi-user detection is inherent to the system design with specific customization of the system.



Serial Interference Cancellation for multi-user detection

For satellite transmission, multi-user detection can be used advantageously on the return link to the satellite. It could also eliminate the feedback channel that signals packet collisions usually needed with random access schemes. This will result in more efficient use of the spectrum and will support larger number of users because of its ability to detect and decode overlapping return packets. An example application is the COSPAS-SARSAT system where multi-user detection techniques can be used to increase the probability of detection of multiple rescue distress signals arriving at the same time and on the same frequency in the 406 MHz band. An enhanced SARSAT detector was developed which resulted in reduced beacon detection delay.

Turbo multi-user detection schemes were investigated in the presence of Gaussian noise to find the best trade-off between improved performance and reasonable computational complexity. The initial results were for a rather complex decoding process and synchronization. Further research will be needed to reduce this complexity if these techniques are to find broad applicability. Multi-user detection is an algorithm that SDR systems should be able to support.

The results of the work are detailed in the following reports:

[1] Multiuser Detection Techniques and their Application to Satellite Communications, Ken Gracie, CRC Report, January 4, 2005.

[2] Multiuser Detection Techniques: Research Results and Future Trends, Ken Gracie, CRC Report, August 2, 2005.

4- Terrestrial Wireless projects

4.1- Ultrawideband Technologies

E-09 Characterization of Ultrawideband (UWB) emissions

DGSE: S. Hanna CRC: W. Lauber, P. Charlebois

Ultra Wideband uses extremely short pulses (typically less than a nano-second) transmitted at very low average power levels (typically only a few microwatts, <–41.3 dBm/MHz resulting in 500 _V/m at 3 m) to carry high data rates over short distances (<10 m). The pulses can be 'shaped' to produce the required spectrum (e.g., like the masks proposed by the FCC in its first R&O in Feb. 2002) to minimize interference to other services using the same frequency range (3.1 to 10.6 GHz).

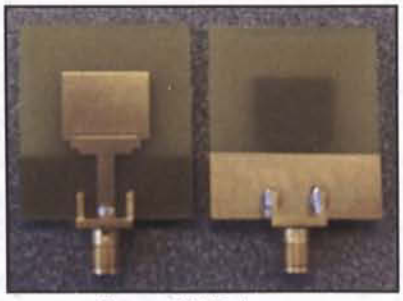
During the first year, CRC developed a flexible "burst CW" UWB signal generator centred at 6 GHz for interference and propagation studies and purchased a "monocycle generator" from Time Domain (PulsON 200) (bandwidth of 3.2 GHz centred at 4.9 GHz) and a calibrated TEM Sensor from FARR Research Inc. This project continued for a second year in support of DGSE's development of a regulatory framework and standards for the introduction of UWB technology and, in particular, to enable the measurement of UWB emissions.

With the two UWB signal generators and the calibrated sensor, various UWB waveforms were used to study the pulse distortion caused by the transmit and receive antennas spaced between 15 and 100 cm. Some resonance related to the physical size of the Time Domain antenna was found at 6.5 GHz and the gain was found to be 2.5 dBi. The antenna of the FARR sensor also experienced some resonances above 7.5 GHz and gave a gain of 9 dBi. Two new antennas to be used with the CRC UWB source were measured. One was an adaptation of a Korean antenna centered at 6.5 GHz with a 2.4 GHz bandwidth. A broad resonance was found around 4.7 GHz and the gain was measured at –1.8 dBi. The other was the 'Vivaldi' antenna which gave a gain of 6 dBi and produced broad resonances at 4.2, 5.5 and 6.6 GHz. These lab measurement results were confirmed with anechoic chamber measurements.

FARR UWB Antenna

Vivaldi UWB Antenna

Time Domain Antenna



Korean UWB Antenna

The results show that resonances in the frequency band of the UWB signal do not distort the signal. However the return loss must be less than -10 dB across the band of the signal. Ideally the transmission loss should look like a bandpass response around the signal spectrum, i.e., it should reject the out-of-band signals and allow the in-band signals. The Time Domain antenna has these characteristics but not the two new antennas. Field tests confirmed that the UWB propagation in line-of-sight corresponds to the free space path loss model.

The results of the work are detailed in the following report and publications:

[1] Ultra Wideband Antenna and Propagation Measurements, Dan Ball, Paul Charlebois, Jean Bertrand & Wilfred Lauber, CRC Technical Memorandum No. VPTWS-TM-05-01-24, January 2005.

[2] Dan Ball, Paul Charlebois, Wilfred Lauber, "Ultra Wideband Signal Sources for Interference Measurements", Paper presented at ICU 2005, 2005 IEEE International Conference on Ultra-Wideband, Zurich Switzerland, Sept. 2005.

[3] Wilfred Lauber, Siva Palaninathan, "Ultra-Wideband Antenna Characteristics and Pulse Distortion", Paper submitted to ICUWB 2006, 2006 International Conference on Ultra-Wideband, Waltham Ma, Sept. 2005.

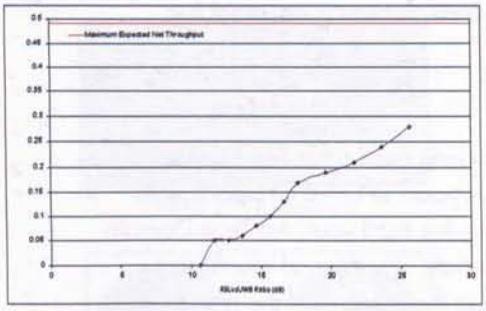
T-15 Measurements of potential interference caused by UWB devices on handheld devices

DGSE: S. Hanna CRC: L. Boucher

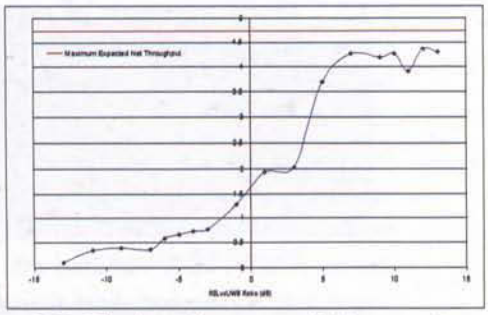
This project was a continuation of the work done during the two previous years on measurements and analysis of the impact of UWB emissions onto existing handheld wireless technologies. For this third year, the Time Domain source (PulsON 200) was used with appropriate filtering and amplification to reproduce a high field strength level at the antenna of the handheld wireless device to isolate it from the effect of the equipment thermal noise limitations. The measurement results showed that, under these very stringent conditions, all the wireless devices tested were affected to varying degrees with protection ratios between the wanted signal and the UWB signal varying from −12 dB to +20 dB. It was found that some wireless devices could not function under these severe test conditions independent of the received level of their wanted signal. The results were presented in terms of throughput performance of the wireless device as a function of the ratio between the wanted signal level and the UWB signal level at the output of the receiving antenna (D/U or protection ratio). An interpretation of these results can lead to the amount of receiver desensitization by UWB interference as a function of the distance of the UWB device, just meeting the FCC Part 15 UWB emission limit in the given band from the receiver under test.

Results are available for the following wireless types of devices:

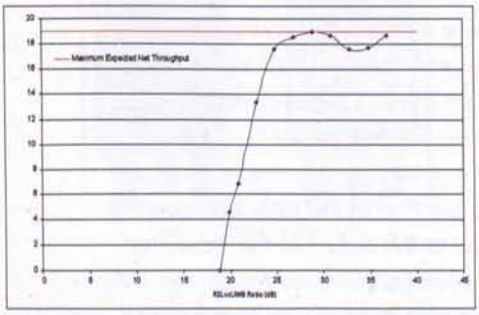
AMPS (800 MHz)	Bell Samsung	*Qualitative testing: system operation in presence of various levels of UWB signal.*
GPS (1.6 GHz)	Garmin Street Pilot	
GSM (TDMA) (1.9 GHz)	Fido Motorola V60i	
CDMA (1.9 GHz)	Bell Samsung	
GPRS (1.9 GHz)	Fido Merlin G100	
Bluetooth (2.4 GHz)	Motorola Cards	*Quantitative testing: measurements establishing required protection ratio (or UWB received level) as a function of system throughput.*
802.11 (FHSS) (2.4 GHz)	Breezecom	
802.11b (DSSS) (2.4 GHz)	Cisco Aironet 350	
802.11g (OFDM) (2.4 GHz)	Cisco Aironet 1200	
802.11a (OFDM) (5 GHz)	D-Link	
Point-to-point Microwave (5 GHz)	Tsunami	



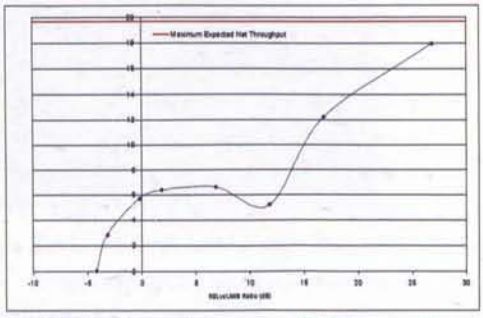
Bluetooth throughput versus UWB protection ratio



802.11b throughput versus UWB protection ratio



802.11g throughput versus UWB protection ratio



802.11a throughput versus UWB protection ratio

The results of the work are detailed in the following report:

[1] Technical Study on UWB Interference - Using the Time Domain Prototype UWB Source, Prepared by CRC – WASR/WISELab, March 03, 2005.

T-17 Spectral Density Shaping, Interference Mitigation, Detection, Identification and Location of UWB Signals

DGSE: S. Hanna CRC: J. Lodge, M. Sablatash

This project continued from the previous year in support of DGSE for the development of a regulatory framework and standards for the introduction of UWB technology for short-range wireless communication. CRC participated in the discussions of the ITU-R CNO TG 1/8 held by DGSE and the RABC meetings and contributed to 6 Canadian documents submitted to the ITU-R TG 1/8 on various aspects of UWB interference into other communication systems.

Means of mitigating interference into UWB systems by narrowband communication systems using sub-band decomposition, removal of sub-bands where interference occurs and reconstruction based on wavelet methods were described. Mitigation of interference from UWB signals into narrowband communication systems by pulse shaping, choice of modulation techniques and power spectral density shaping or whitening were also described. The effects of pulse repetition frequency of UWB PPM signals were shown on the location of discrete components in the power spectral density function. A study of path loss models for UWB indoor and outdoor propagation was carried out.

The results of the work are detailed in the following publications:

[1] M. Sablatash and M. Sellathurai, "Methods for interference mitigation by and into UWB communication systems, including techniques based on multi-band techniques and on wavelets," Proc. 22nd Biennial Symposium on Communications, Queen's University, Kingston, May 31-June 3, 2004, pp. 463-465.

[2] Mathini Sellathurai and Michel Sablatash, "Methods for interference mitigation by and into UWB communication systems," Proc. Sixteenth International Conference on Wireless Communications, Coast Plaza Hotel, Calgary, Alberta, Canada, 12-14 July, 2004, vol. 2, pp. 401-411.

4.2- Spectrum monitoring and interference studies

T-02 Digital Analysis System for the Integrated Spectrum Observation Centre

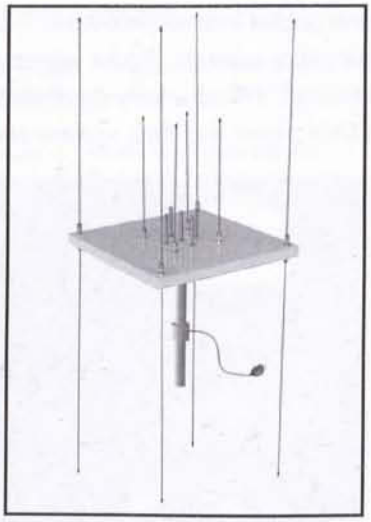
DGSE: D. Paskovich CRC: M. Dufour, F. Patenaude

The purpose of this multi-year project is to develop and deploy the next generation of spectrum monitoring tools for the Integrated Spectrum Observation Centre. The Spectrum Explorer® (SE) software has been enhanced in the areas of direction-finding measurement and calibration, Automatic Modulation Recognition (AMR), systems signal parameter extraction, frequency measurement accuracy, short duration signal measurements and new hardware support.

The implementation of the Spectrum Explorer® in the Integrated Spectrum Observation Center of IC should be rather straightforward with the addition of a data transfer interface. This will be carried out in FY 05/06. The possibility of using the Rhode&Schwarz FSP and FSL series spectrum analyzers as the RF front end of the Spectrum Explorer® was analyzed. Because of the competitive price of this equipment, the faster frequency sweep, the capability of broadband measurements, the extent of the frequency range (10 kHz to 40 GHz) and the better precision in signal amplitude measurement (0.5 dB), the integration of these spectrum analyzers will be a welcome improvement to the Spectrum Explorer®. It was found that the data architecture of these spectrum analyzers is essentially compatible with that of the Spectrum Explorer®. The integration work will be done in FY 05/06.
The communication signal analyzer has been improved with the inclusion of a larger number of signal types for the modulation classifier. Two GPS devices and their USB interface were successfully integrated to the Spectrum Explorer. An automatic calibration method including software routines and switching of the noise source in the direction-finding antenna was added to the system. This feature can now be used reliably.

Investigation continued on the design of a direction-finding antenna that would cover the range 100 MHz to 1 GHz. It was found that two antennas optimized for their specific frequency range would be required to cover this frequency range. The aim is to achieve a direction-finding precision of better than 5° rms. Some preliminary work was done on the development of direction-finding techniques using amplitude comparison rather than phase comparison for frequencies above 2 GHz.

Spectrum Explorer®



VHF/UHF Direction-finding antenna

T-23 Effects of aggregate interference from wireless local area networks into terrestrial weather radars operating in the band 5600-5650 MHz

DGSE: M. Guillemette CRC: A. Brandao

The goal of the project is to determine, through field experimentation and measurements, to what extent RLAN operation in the 5 GHz UNII bands creates interference to weather radars in the 5.6 GHz band. The ITU-R conducted studies on this topic and the results were incorporated in Rec. M.1652. It was concluded that dynamic frequency selection (DFS) with a sensing threshold of –62 dBm will mitigate aggregate interference from RLAN into radiolocation service if a continuous 10-minute monitoring period is provided for the 5600-5650 MHz band. However, the FCC opted not to impose this requirement, resulting in the need to determine the potential interference of RLAN into the Canadian weather radars.

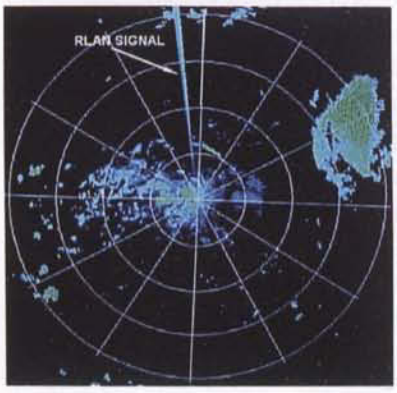
Measurements were conducted using IEEE 802.11a RLAN devices and the CWSR98 weather radar located in Franktown, Ontario. RLAN interference appears as azimuthal streaks on the radar map (especially for low elevation radar sweeps). The RLAN transmissions are incoherent with radar pulses and it appears to the radar receiver as uncorrelated additive noise equivalent to the average RLAN power, independent of the modulation, baud rate

and packet inter–arrival time. This noise adds to the thermal noise floor of the radar receiver. Radar operators can therefore rely on their computed nominal SNR sensitivity thresholds for estimating the maximum aggregate RLAN power that their systems can tolerate.

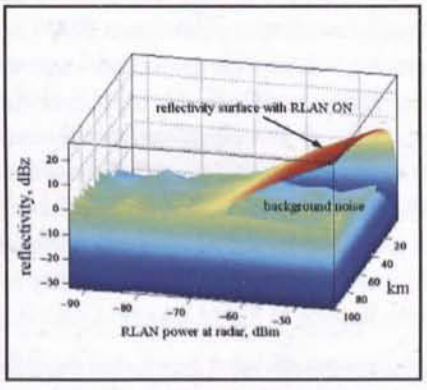
Doppler weather radar station in Franktown, ON, Canada

An experimental aggregate RLAN power of –79 dBm in 1.13 MHz (-67 dBm in 18 MHz) was found to be the threshold value at which reflectivity degradation starts to happen on the CWSR98 weather radar. The field experimental results were obtained with the RLAN transmitters radiating 38 dBm EIRP and located at 10.6 km from the radar station, at 15 m and 7 m above ground while the radar tower height was 18 m. As for the DFS capabilities, in this setting, the radar signal was detected easily above the DFS sensing threshold at the RLAN site.

As a result of this work, it was concluded that RLAN has a potential to generate interference to meteorological radars operating co-channel in the band 5600-5650 MHz. This confirms the need for interference mitigation



LAN signal appearing as streak



Reflectivity surface vs. RLAN radiated power vs. radar range

techniques such as the use of DFS and a 10-minute continuous monitoring requirement. The DFS sensing threshold of –62 dBm appears to be sufficient to identify the presence of radars in the band and avoid interference.

The results of the work are detailed in the following publications:

[1] Brandao, A., Sydor, J., Brett, W., Scott, J., Joe, P., Hung, D., "5 GHz RLAN Interference on Active Meteorological Radards", IEEE VTC2005-Spring, Stockholm, Sweden, May 30-June 1,2005.

[2] Joe, P., Scott J., Sydor J., Brandão A. and Yongacoglu, A., "Radio Local Area Network (RLAN) and C-Band Weather Radar Interference Studies", 32nd AMS Radar Conference on Radar Meteorology, Albuquerque, New Mexico, Oct 24-29, 2005.

T-24 Evaluation of the Interference Potential of PLC Systems in the Frequency Range 1-80 MHz

DGSE: J.C. Brien, H. Khomusi CRC: W. Lauber, M. Zhang

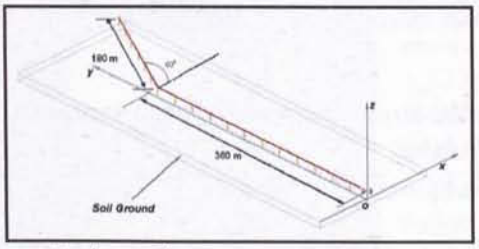
High data rate Power-Line Communications (PLC) or Broadband over Power-Line (BPL) is a new way of bringing the Internet into homes. In the past few years, methods have been developed for the signals to bypass transformers and travel on Low and Medium Voltage (MV) power-lines up to about 35 KV. However, because the signals travel on the local distribution lines and on the in-house wiring, all of these wires could form a large radiating antenna from which the signals could radiate. Some studies have predicted large increases in the background noise levels especially at HF which could wipeout the reception of low level signals.

The project consisted in evaluating the proposed PLC technologies and their system architecture. A computer model of a typical medium voltage overhead three-phase power line wiring configuration was developed to characterize a real power line wiring structure with several combinations of devices, such as transformers, other conductors in the vicinity and line turns. In this study, several PLC Cases were developed by varying the locations of the signal source and adding more transformers or PLC devices.

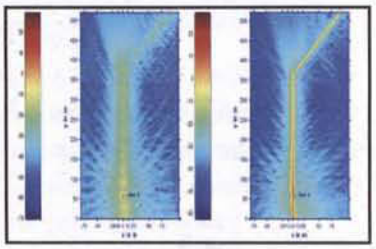
Various scenarios of impedance discontinuities resulted from this numerical modeling and their analysis provided a good understanding for the unintentional radiation expected from real PLC systems. The electric field distributions in both near and far field zones were obtained to investigate the radiation characteristics of PLC systems. The modeling results showed that only a small percentage of frequency components radiate effectively from the power lines. The return loss for most frequencies was very high (from 0 to about -5 dB) whereas a value of less than −20 dB is needed to radiate efficiently. Hence, most of the time, powerlines are not a good antenna.

Based on the modeling results, analyses with respect to the FCC Part 15 field strength limits were performed to identify the amount of energy radiated

from these PLC systems in terms of the field strength levels produced. Early findings indicated that in order to meet the Part 15 emission limits, the maximum power that a BPL system would be able to inject on power lines is about 0.5 mW. More work will need to be done on this to come up with more scientifically sound numbers.



Medium Voltage Power Line Geometry



Near-field distribution at 30 MHz, 2 m above ground and at power line height

As a final note, the interest for BPL seems to be moving from the use of power lines to indoor broadband distribution such as Power-Plug technologies. Even in this case, interference could be created to neighbors who are Radio Amateurs or people who are trying to receive short wave broadcasting.

The results of the work are detailed in the following report:

[1] Evaluation of the Interference Potential of PLC Systems, Ming Zhang and Wilfred Lauber, CRC Technical Memorandum No. VPTWS-TM-05-02-09, February 2005.

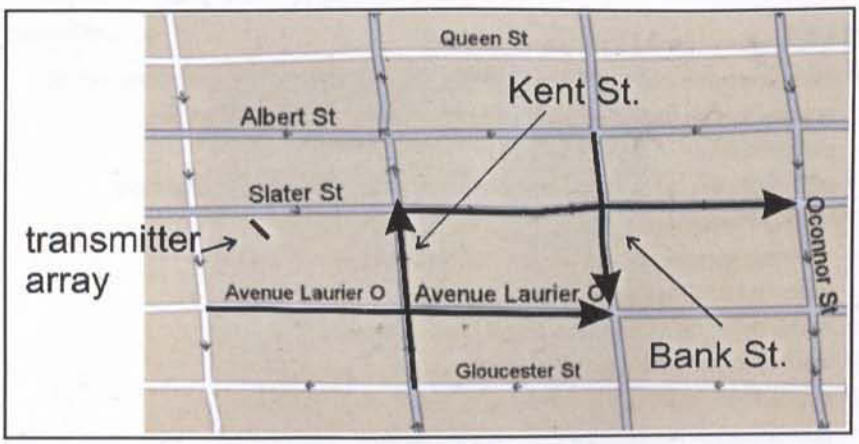
4.3- Improvement of spectrum usage

T-16 Multi-element antennas for mobile communications

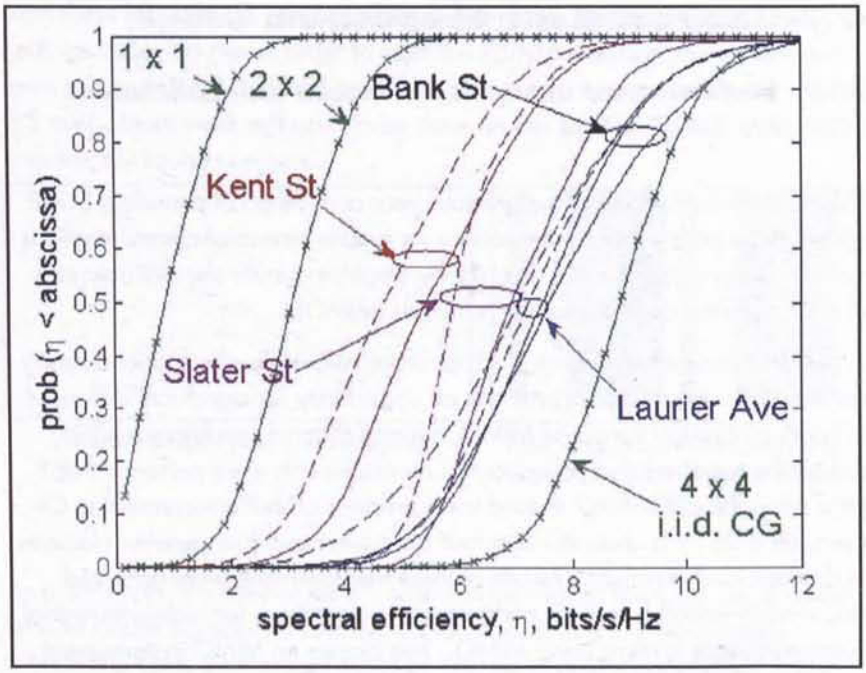
DGSE: P.Vu CRC: T. Willink

This project continued from the previous year and aimed at providing DGSE with realistic performance expectations for mobile terrestrial communications systems which exploit spatial diversity by employing multi-element antennas at the transmitter and/or receiver terminals (MIMO).

In rich scattering environments, such as urban microcells, the spatial diversity resulting from the multipath provides an opportunity for significant increases in capacity through the use of MIMO, but real channel conditions tend to reduce the expected channel capacity. Measurements were performed at 2 GHz using the CRC MIMO testbed in an urban microcell environment in Ottawa, on a 25 MHz channel using four transmitter and four receiver elements in different configurations. Results of these measurements were analyzed and used to establish realistic performance expectations for mobile terrestrial communications systems using MIMO. Two classes on MIMO systems were investigated: space-time coding and spatial multiplexing.



Measurement routes in downtown Ottawa



Transmission channel performance

The following conclusions were reached:

- measurements obtained using single element antenna systems are not ad equate to obtain the information required to assess real system performance
- real channels have lower potential than 'ideal' multipath channels
- MIMO transmission capacity varies over local area
- antenna spacing at the transmitter and receiver affect the potential throughput
- body/antenna interaction affect real systems
- theoretical capacity is not a good metric for performance
- space-time coding & spatial multiplexing have different performance trends
- eigenbeamforming for spatial multiplexing has limited practical applicability in mobile environments when considering realistic effects such as channel estimation errors

As a result, MIMO system performance is quite significantly different than that predicted by theory for ideal multipath channels but substantial increase in system capacity is usually achievable.

The results of the work are detailed in the following report:

[1] Measurement-based analysis of MIMO system performance in urban microcells, T.J. Willink, CRC Report No. CRC-RP-2005-002, September, 2005.
[2] G. Downes, T.J. Willink, C. D'Amours, "Capacity limitations of real MIMO channels and their impact on system performance", WIRELESS 2005, Calgary, AB, July 2005.
[3] G. Downes, T.J. Willink, C. D'Amours, "Performance prediction of urban MIMO channels", Canadian Conf. on Elec. and Computer Eng., Ottawa, ON, May, 2006.
[4] G. Downes, "Characterisation and performance prediction of narrowband MIMO channels", MASc Thesis, School of Information Technology and Engineering, University of Ottawa, submitted Feb. 2005.

T-21 Cognitive Radio as a means to improve Spectrum Efficiency

DGSE: C. Cook CRC: John Sydor

This project undertook the examination of the technical attributes of a cognitive radio system so that it can undertake spectrum management and interference control, especially in high reuse environments typical of the license-exempt bands. The experimental work done on the MILTON 5 GHz system was used to examine cognitive radio techniques and address such issues as the recognition and identification of other users of the same spectrum, deferral to priority users, and the efficacy of some currently proposed spectrum etiquettes.

24-petal MILTON Hub antenna

The following Cognitive Radio features were tested as part of a network management system for the MILTON rosette and its subscriber terminals deployed west of Ottawa since September 2004. Specifically they were:

1) Power Spectrum Density (PSD) Monitoring and Measurement Capability. Both subscriber and hub terminals collected PSD information in the bands 5250-5350 and 5725-5825 MHz and relayed the results via the MAC system of Milton to a Network Management System. This technique is used to monitor the RF spectrum use (white spaces). Peak power measurements were needed to identify the type of users (802.11a, MILTON). PSD monitoring can be done during pauses in the uplink bursts and when the terminal does not expect MAC messages. PSD network signaling represents a small overhead. RF sensing linearity (dynamic range) is important for proper PSD information processing. Sensing integration time may need to be rather long (seconds to minutes) because of the bursty nature of the transmissions.

2) Packet Tagging and Identification for co-channel interference control. Uplink and downlink packets are tagged with the identity of the transmit station using a commonly demodulated header to allow identification of the source of co-channel interference and allow cognitive radio processor, when coupled with the PSD monitoring technique, to under take appropriate corrective action. This interference could then continuously be tracked and correlated with systemic changes occurring in nearby cells such as RF power increase or sporadic changes such as 5 GHz backscatter caused by snow fall. More information could be included in the packet tagging (e.g., transmit EIRP, antenna configuration, GPS location, IP address of the base station) for easier mitigation of the interference through direct action or negotiation between interfering base stations. This is being considered by 802.16h.

3) Uplink power control using Packet Tagging information. With the help of two previous techniques, more equitable sharing of the spectrum resource could be achieved by power balancing across the network (i.e., reducing the power of the identified interfering nodes by appropriate amounts while still maintaining positive link margins). In TDD systems, isolation of the identified interferers to specific time slots to avoid interference would also be possible.

This work led to a number of recommendations to the IEEE 802.22 and IEEE 802.16h standards committees which are involved with developing cognitive radio and spectrum coexistence standards.

The results of the work are detailed in the following documents:

[1] "Notes on an Emission Data Exchange Mechanism for License-Exempt 802.16 Cognitive Radio Networks", http://www.wirelessman.org/le/le_sg/contrib/C80216le-04_03.pdf.

[2] "Interference Resolution and Control in High Frequency Reuse Environments using Cognitive Radio", http://crc.ca/en/html/milton/home/berkeley_nov2004.pdf

T-22 Technology Developments to Improve Access to the Radio Frequency Spectrum

DGSE: M. Christensen, J. MacEachern CRC: Nur Serinken

The objective of this project was to provide a capability to improve access to RF 'white spaces' in both time and frequency dimensions. An OFDM based radio test-bed was developed for testing modulation strategies that would use segmented modulation and demodulation techniques in order to provide flexibility and frequency agility needed for adaptive and non-contiguous use of radio spectrum.

New protocols to improve channel access were investigated. Collision sense techniques are not sufficient to exploit time gaps in the networking protocols for coexisting wireless devices. The devices should synchronize and announce/reserve intention of accessing the channel. New techniques exhibiting lower complexity and/or latency were developed using Bayesian signal processing principles for detection and synchronization to 802.11a preamble to achieve increased channel capacity. When combined with suitable channel access techniques, accurate and fast detection of the 802.11a preamble would increase the channel capacity. These techniques can be applied to communication systems operating below 1 GHz. It is planned to use these signal processing principles for the detection of spectrum holes. Iterative equalization techniques will be investigated to increase the resilience of the system to adjacent channel interferers.

The results of the work are detailed in the following publications:

[1] Pacheco, R., Ureten, O., Hatzinakos, D. and Serinken, N., "Bayesian Frame Synchronization Using Periodic Preamble for OFDM Based WLANs", IEEE Signal Processing Letters, vol. 12, no.7, pp. 524-527, 2005.

[2] Ureten, O., Pacheco, R., Serinken, N. and Hatzinakos, D., "Bayesian Frame Synchronization for 802.11a WLANs: Experimental Results", Proc. IEEE Canadian Conf. on Electrical & Computer Engineering, pp.884-887, Saskatoon, 2005.

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