Review of the Terrestrial Wireless Systems Branch of the Communications Research Centre

Prepared by:

Performance Management Network Inc.

Prepared for:

Terrestrial Wireless Systems Branch
Communications Research Centre Canada

March 28, 2002

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Table of Contents

Executive Summary

This review of the Terrestrial Wireless Systems Branch has been undertaken in order to assist CRC management to determine the extent to which the programs and activities of the Branch are appropriate and effective in meeting public and private sector needs for expertise in terrestrial wireless communications systems. The review also identifies opportunities to improve the performance of the Branch and its effectiveness.

The Terrestrial Wireless Systems Branch (TWS) was formed in 1998, during a major reorganization of CRC, to provide a greater focus on this important telecommunications field. TWS undertakes research, technology development and testing, and provides advice to government and private industry related to terrestrial wireless communications systems. In support of this mission, the Branch has four research groups that conduct programs related to:

- broadband wireless high speed communications;
- terrestrial radio communication technologies;
- integrated high speed electronics for wireless systems; and
- wireless applications and systems research, which incorporates WISELab, for the testing and evaluation of new wireless concepts, prototypes and products.

In 20001-2002, TWS had a total budget of $5.4 million, which is almost 10% of CRC's total budget. These resources are used to support up to 47 full-time equivalent staff, with a salary budget of $3.0 million, and $2.4 million in operating funding. Of the 46 FTEs, 32 are supported by A-base funding and the other 14 from special funds from DND, revenues and other sources. A-base funding provides about 25% of resources for operational expenditures, with the remainder provided by DND, Spectrum, Information Technology and Telecommunications Branch of Industry Canada and other sources.

The review addressed three major issues related to relevance, quality, and alternatives and examined a number of questions, which addressed specific aspects of each issue. Detailed analysis and discussions on the various questions can be found in the main body of this report.

It is clear that, overall, the Branch is appropriately and effectively positioned to fulfill the role of a government research laboratory in the field of terrestrial wireless systems. Based on the responses of clients and knowledgeable stakeholders interviewed, the Branch is providing valuable and important services to clients, through the generation of results of a technical or strategic nature difficult or impossible to achieve without the contribution of the Branch. Clients rate the quality of research, services and equipment highly. However, there is concern that extensive loss of qualified staff over the past three years has left the Branch less able to meet client needs.

An overview of the evidence and conclusions for each issue, followed by recommendations for change is provided below.

Issue 1: To what extent are the programs and activities carried out within the Terrestrial Wireless Systems Branch relevant and effective in terms of the appropriate role of government laboratories?

Based on a review of recent literature and the 1996 federal review of government S&T entitled "Science and Technology for the New Century", it is clear that the Canadian government expects its scientific laboratories to fulfil a dual role in support of both public interest and economic growth and wealth creation. There is increased interest in the use of S&T to support efficient, effective government. In fact, recent reports by the Council of Scientific and Technology Advisors clearly identify the important role of government S&T in providing scientific and technical advice for policy formulation and decision making. This is reflected in the CRC mission statement. These two roles can be complementary, particularly in the case of standards, regulations and testing. In the case of terrestrial wireless systems, an effective national telecommunications system serving the interests of the public needs to be supported through an efficient, effective, and accessible Canadian wireless communications system based on internationally accepted standards, and private wireless communications systems developers and suppliers need appropriate scientific knowledge and technical assistance which help them develop, test and provide quality communications systems. Policy studies for the government support the development of national spectrum utlization regulations and guidelines compatible with international systems. A review of Branch projects shows that TWS has had success in informing government policy on spectrum utilization through the provision of relevant advice, and in achieving useful outcomes for many public and private clients.

TWS has also had a substantial longstanding role in supporting the wireless telecommunications needs of DND, another major public sector client.

TWS also contributes directly to several of the business lines of its parent department, Industry Canada. For example, there is a clear linkage between the work of the Branch on broadband wireless communications and connectedness. While this has always been true, it is particularly relevant to the recent federal Broadband Taskforce objectives to bring broadband services to all Canadians. CRC has responded by creating a major new corporate Remote Broadband Access Initiative to support the development and implementation of a broadband telecommunications system to serve those Canadians who might otherwise be missed by commercial interests. TWS is expected to be a major contributor to that initiative. TWS also supports the Innovation business line, as Branch R&D projects with both the public and private sectors contribute to innovative products and practices, particularly in the areas of broadband wireless advances. In some cases in the private sector, projects with the Branch result in increased efficiencies and cost savings, as well as increased sales and greater competitiveness. The Branch also contributes to the Marketplace business line through support to the radiowave spectrum regulatory system. By contributing to having scientifically based Canadian spectrum usage policies and regulations that are consistent with international approaches, the Terrestrial Wireless Systems Branch is supporting an orderly, efficient marketplace. As an example, recent Branch contributions to the development of a Spectrum Utilization policy for the 50 – 70 GHZ bands supports orderly implementation of new technology and the development of innovative communications products and services to meet Canadian needs.

A review of Branch programs and projects, analysis of clients and collaborators, and feedback from the client survey, staff and expert interviews show that the Branch has the expertise and capability to fulfill these complementary roles, supporting both public and private interests within the Canadian and international broadcasting community. Clients and partners value its expertise and research capabilities, as well as services, such as the provision of information, advice, and strategic intelligence. Some of those interviewed would like the Branch to make a greater effort to make them aware of technical developments and other emerging issues on a regular basis.

Another need in the wireless communications community is for highly qualified personnel with experience in higher frequency communications systems. The Branch works with the university community to support the training of graduate students, who then move on to perform valuable work with a range of public and private sector organizations. Some of these graduate students are hired by CRC following completion of their studies. Over the past few years, a number of the skilled staff of the Branch have also left to fill these needs in other organizations.

Relevance - Recommendations

The first specific recommendation that follows identifies specific aspects of a more proactive approach by the Branch to identify and meet the needs of clients and stakeholders.

Communications, Networking and Awareness Building

The Branch should move to address the expressed desire by some clients for increased access to strategic knowledge of technical developments and emerging issues, and to extend its reach to a greater proportion of the community which can benefit from its knowledge and expertise. Communicating with the broader stakeholder community about Branch initiatives and emerging issues should become a higher priority, and the Branch should develop mechanisms to accomplish this objective. The review of the Broadcast Technologies Research Branch identified a number of possible mechanisms that seem appropriate for the Terrestrial Wireless Systems Branch as well. They include:

- regular workshops possibly aligned to the specific needs of various stakeholder groups;
- a periodic newsletter with information about Branch projects and strategic intelligence from international meetings;
- articles on Branch capabilties and current projects in wireless systems community technical journals and trade journals: and
- a well publicized web page with basic information about the Branch priorities, as well as similar information as in the newsletter described above.

The Branch should also try to develop its relationship with associations or groups associated with the Canadian wireless communications community (such as the Radio Advisory Board of Canada, or the) which could serve as a partner to disseminate strategic information from the Branch about emerging technical and regulatory issues.

It is likely that a combination of approaches will be more effective than a single one.

Maintain Multiple Complementary Roles

It is clear that the Terrestrial Wireless Systems Branch is uniquely positioned to meet needs of both the public and private sectors within the Canadian wireless communications community and that insight into the needs of one group contributes to the Branch's ability to meet the needs of the other. The Terrestrial Wireless Systems Branch should continue to maintain a balance among its various roles, developing new knowledge and expertise and providing advice and services to meet both public and private sector needs in a complementary manner. The provision of high quality technical support for Canadian wireless communications policies, standards and regulations in the public interest also helps provide the private sector with an efficient and effective regulatory infrastructure within which to work.

Issue 2: To what extent does the quality of research, advice and services provided by the Terrestrial Wireless Systems Branch meet the needs of clients and collaborators?

The issue of the appropriateness of the quality of research and services was reviewed through a number of complementary methods. Based on the client survey results and in-depth interviews, the large majority of clients and collaborators are generally highly satisfied with the quality of research and technical services provided by the Branch, and have confidence in the results obtained. Clients and informed stakeholders also agree that existing services are highly relevant to their needs and more generally to the needs of the public and private sector wireless communications community. The clients who were surveyed were asked to rate their satisfaction with the Branch's contribution to a specific project. The average rating was 8.2 out of 10. This is a high rating, indicating a positive relationship between the Branch and the clients surveyed.

While interviewees generally gave high ratings for the capabilities of Branch staff (overall rating, 8.3 out of 10), a number stated that the quality of research and the breadth and depth of scientific and technical capability is now lower than it had been. Many noted that there has been a significant loss in the past several years of highly qualified staff, leading to a loss of important research and testing capabilities in the Branch. However, it should be noted that the Branch now has a full complement of staff, and that new employees are rapidly gaining experience, and are beginning to contribute to effectively meeting client needs.

For those interviewees who worked with other communications laboratories, the Branch also compared reasonably favourably. In some cases, other identified organizations were large national laboratories much better funded than the Branch, so in that respect clients noted that the comparison may not be fair. On average, clients rated the quality of Branch equipment and facilities, quality of personnel, and overall responsiveness to client needs slightly better than these comparable organizations.

Quality – Recommendations

The major concern under this issue is developing and maintaining a pool of experienced research staff and managers.

Hiring and Retention of Qualified Staff

The Terrestrial Wireless Systems Branch should treat the hiring and retention of qualified professional staff as a priority. Hopefully, now that the overheated technology sector of the economy has returned to a more normal level, employees will consider working in the Branch more favourably, and will be more likely to stay. To ensure that clients have access to as broad and qualified a group of researchers as possible, other avenues should be explored, such as working with university professors on sabbatical, secondments from other organizations, and increased use of graduate and post-graduate students.

Issue 3: Are there alternatives to the present design and delivery of programs and services within the Terrestrial Wireless Services Branch that can better meet the needs of the public and private sectors?

Several specific questions were examined under this issue, loosely linked to Branch management issues.

The degree to which TWS operates as a cohesive unit, with all research groups contributing to a common goal was examined. The Branch was formed in 1998 from several separate groups, and continues to operate as a collection of four research groups, each with its separate research capability, client group and stakeholders. While the four group managers meet regularly with the Vice President to plan and manage their research programs within the overall Branch plan, there is limited need at present for collaboration among the groups. The new CRC Remote Broadband Access Initiative may provide an opportunity for the research groups to develop an integrated approach to addressing some research needs.

The ways in which TWS ensures that research programs are well aligned with client needs was also examined. In a review of recent Branch reports, there was little evidence in of the Branch undertaking major needs analysis studies, and Branch Business plans do not demonstrate linkages between research priorities and strategic and operational needs of clients and stakeholders. However, because of the high levels of external funding of both salaries and operational resources by major clients, there is a significant level of direct client influence on almost all Branch research initiatives.

An analysis was also undertaken of the adequacy of Branch resources to meet client needs. A-base resources available for operational needs is very low across CRC, because of a decision made in the early 1990s in the face of major resource cuts, to maintain as many staff positions as possible and cut more deeply into operational funding. Comparing TWS to Broadcast Technologies Research Branch and Radio Sciences Branch shows that TWS has about twice as many operational resources per staff person. However, many of those resources are provided by DND for the Radio

Communications Technologies Research Group for DND projects. SITT also provides significant levels of operational funding, which cover on part of the costs of their research projects. Another factor is that some research areas require high levels of operational funding. For example, a single foundry run for the Integrated Electronics groups cost about $85 – 100K, which would be a major drain on operational funding, and is only possible with funding support from major clients. There is a concern that in some cases, the Branch may be diverting efforts from traditional clients to those who can make a larger contribution towards research costs. In spite of the fact that the commercial terrestrial wireless sector has grown appreciably over the past four years, with the addition of new applications and the opening of additional higher frequency bands, the A-base resources provided to the Branch have remained constant. There may be an opportunity for new funding for TWS arising from the Remote Broadband Access or other similar initiatives.

The review also found that what seemed to be similar or complementary research is being carried out in separate initiatives at TWS and other CRC Branches. Examples include MIMO transmission and receiving (Multiple Input / Multiple output) and adaptive antennas. It may be appropriate to determine to what extent the research is complementary and if so, develop mechanisms for collaboration or networking.

The review found that WISELab was still in the development phase, and continues to seek a major client base from the private sector or within CRC. To date there has been one project to test a CRC product. Interviews with researchers from other Branches indicate that they have not yet seen the benefit of utilizing the testing or research capabilities of WISELab. However, WISELab is well positioned to contribute to the Remote Broadband Access Initiative and to support SITT needs.

The review also investigated the role of the CRC Business Office in dealings with TWS clients. During the client survey, several clients were concerned that Branch scientists were involved in business negotiations that would have been more properly handled by the business office. As one client said, "let the researchers focus on what they do best and leave the business negotiations to those who have training and experience in that area". Following this practice would also lessen any concern about conflict of interests by researchers negotiating fees from which they would receive compensation.

Alternatives - Recommendations

Ensure that relevance of TWS research priorities and linkages to client needs are described in all public documents

The Terrestrial Wireless Systems Branch should take advantage of every opportunity to communicate to clients and stakeholders the manner in which TWS research priorities and projects are aligned with government and stakeholder needs in the area of terrestrial wireless systems research and development. In particular, publically available Branch documents such as the annual business plan and the annual progress report should describe the strategic and operational objectives of the Branch in terms of client and stakeholder needs, and identify how research results will contribute to meeting the needs of the Canadian public and private sectors and provide social and economic impacts.

Develop mechanisms to encourage discussion among CRC groups working in complementary areas

To reduce concern about research groups operating in isolation and not identifying opportunities for effective partnerships or collaborations, CRC should develop methods to determine when research is complementary and encourage collaborations where appropriate. Holding seminars on selected research topics and encouraging discussions among research groups should be considered.

Provide support for awareness and utilization of WISELab measurement and testing capabilities

CRC and Branch management should develop mechanisms to encourage increased awareness and utilization of WISELab capabilities both within CRC and among CRC public and private sector clients and stakeholders. Further studies of client needs may be appropriate to direct the development of WISELab capabilities.

Involve CRC Business Office in all client negotiations

In order to reduce any complaints about conflict of interest among researchers, minimize business related problems with clients and ensure that CRC receives appropriate compensation for revenue producing projects and intellectual property, the CRC Business Office should be brought in early to all significant negotiations with clients for revenue producing projects.

1.0 Introduction

1.1 Background

Beginning in 1998, the Communications Research Centre Canada (CRC) began a series of in-depth, independent reviews of its research branches, in order to provide senior management and the CRC Board of Directors with objective information about the extent to which programs and strategies are relevant and are achieving objectives, and to provide recommendations for improving program delivery, effectiveness and objectives achievement. The information in the review studies also provides accountability for the effective use of public funds and assists management in improving overall program performance.

Previous studies examined the Broadcast Technology Research Branch (1999) and the Radio Science Branch (2001). This review focuses on the Terrestrial Wireless Systems Branch (TWS).

Government policy with respect to the role of government research laboratories has evolved considerably since the early 1990s when CRC became a separate operating agency within Industry Canada. CRC management is interested in the extent to which the activities and objectives of the Terrestrial Wireless Systems Branch are relevant and effective in meeting the present needs of government and Industry Canada. In making this assessment, it is important to determine who the beneficiaries of Branch activities are, and what benefits they receive.

Since the mid 1990s, as one aspect of performance management, the federal government has asked departments and agencies to ensure that they monitor client perspective on the quality of services and interactions, and the benefits that the clients receive. CRC is no exception, and this review provides an opportunity to gather client feedback on a number of aspects of TWS, including the capabilities of Branch staff, quality of research and facilities, advice and services, and client relations.

This review of TWS builds on the experience gained in the two previous reviews and employs similar methodological approaches to those that were found to be appropriate in the earlier studies.

1.2 Study Issues

The study issues for this review are closely linked to the Treasury Board issues of relevance, objectives achievement and alternatives. Based on input from CRC management and their requirements for information to demonstrate accountability and support decision-making, these general issues have been aligned to address specific points of interest to CRC. Each issue has a number of research questions to explore various aspects of the issue.

Issue 1: To what extent are the programs and activities carried out within the Terrestrial Wireless Systems Branch relevant and effective in terms of the appropriate role of government laboratories?

1.1 Is there a continuing need in government and the private sector for the research and testing carried out within the Terrestrial Wireless Systems Branch?

1.2 Who benefits from the Terrestrial Wireless Systems Branch programs?

1.3 What are the immediate and longer term impacts and effects of the work carried out within the Terrestrial Wireless Systems Branch?

1.4 How effectively is the Terrestrial Wireless Systems Branch meeting Canadian public and private sector needs for information and advice about existing and emerging knowledge, technologies and systems?

1.5 To what extent is the Terrestrial Wireless Systems Branch meeting its objectives and contributing to the mission of CRC?

1.6 Is the Terrestrial Wireless Systems Branch within CRC filling an appropriate role for government?

Issue 2: To what extent does the quality of research, advice and services provided by the Terrestrial Wireless Systems Branch meet the needs of clients and collaborators?

2.1 In what manner does the Terrestrial Wireless Systems Branch contribute to meeting Canadian and international needs for new knowledge?

2.2 Do clients and collaborators have confidence in the quality of research, advice, testing and other services provided by the Terrestrial Wireless Systems Branch?

2.3 Are Branch collaborations and services meeting the needs of clients?

2.4 Are the capabilities of Terrestrial Wireless Systems Branch staff and the quality of facilities appropriate to the needs of clients and collaborators?

2.5 What is the nature and extent of collaboration with other CRC branches and with other organizations?

Issue 3: Are there alternatives to the present design and delivery of programs and services within the Terrestrial Wireless Services Branch that can better meet the needs of the public and private sectors?

3.1 To what extent do managers and staff of the Terrestrial Wireless Systems Branch have a clear understanding of Branch objectives, strategy and their role in achieving them?

3.2 What mechanisms are in place to ensure that Branch programs and activities are well aligned to the needs of clients and stakeholders?

3.3 To what extent does the Branch have adequate resources to meet client needs?

3.4 What lessons can be learned to improve the efficiency and effectiveness of the Terrestrial Wireless Systems Branch?

1.3 Methodology

This section presents a summary of the methodological approach used to gather evidence to reach credible conclusions on the study issues and questions. (A detailed description of the approach can be found in the **Planning Report for the Review of the Terrestrial Wireless Systems Branch** that was used as the basis for this study.) The methodological approach is based on the use of several complementary analytical methods to gather multiple lines of evidence to arrive at credible findings and conclusions for each research question and issue. For each question, there is at least one major source of evidence with additional supplementary sources as appropriate. Each of the methods used was adjusted to the specific information sources and requirements for each research question.

Based on the information provided in the preliminary document review, interviews and preparation of the Branch profile, and the experience gained in undertaking the previous two Branch reviews, the following methods were used to collect evidence for the study:

- CRC and Branch document and file review and analysis;
- coauthorship analysis (organizational type and location) of TWS Branch publications for the past four years (1998 to 2001);
- interviews with managers and senior staff from the Terrestrial Wireless Systems Branch and other CRC branches that collaborated on Branch projects (list provided as **Annex A**);

- survey of a sample of 42 partners, collaborators and clients of the Branch (face-to-face and telephone interviews using a standardized questionnaire, shown in **Annex B**), names taken from a list provided by the Branch[1] (**Annex C**);
- in-depth interviews with informed stakeholders within CRC, the federal government and others (names included in **Annex A**); and,
- case studies of four major Branch projects, one from each research group, (attached as **Annex D**).

In addition, an integration and analysis phase focused on gathering and examining pertinent evidence from the various sources in order to provide credible conclusions on each specific research question and issue. Where appropriate, results from this review of TWS are compared to those found in the previous reviews of the Broadcast Technologies Branch and the Radio Science Branch.

In reviews of this nature, each particular methodological approach has specific strengths and limitations. Careful combining of methods can minimize the limitations of each approach and provide more credible conclusions than available from a single source.

Table 1, following page, provides a summary of the strengths and limitations of each of the methodological approaches employed.

1.4 Report Outline

This report is organized as follows:

- **Section 2** provides a description of the Terrestrial Wireless Systems Branch;
- **Section 3** addresses Review Issue 1 related to the relevance of TWS to the needs of clients and stakeholders;
- **Section 4** deals with Review Issue 2, which examines the degree to which the quality of TWS research and services meet the needs of clients; and,
- **Section 5** covers Review Issue 3, which examines alternatives to the present design and delivery of TWS to more efficiently and effectively meet client needs.

[1] The list of clients and collaborators of each TWS research group provided for the review is found in **Annex C.** The list includes the name of the individual, the name and category of the organization, a description of the interaction and identifies whether the person was surveyed or not.

Table 1: Strengths and Limitations of Review Methods

Method	Strength	Limitation
Document Review	Provides factual background information to support other sources.	Usually does not relate directly to review issues. Must be complemented with other methods.
Publication Analysis (coauthors)	Provides factual information about scientific outputs of Branch, collaborators and intended audience.	Captures evidence of nature of scientific outputs and collaboration partners (part of Issue 1), but not relevance of activities and outputs.
Branch Staff Interviews	Staff input is essential to provide background and context. Have detailed knowledge about projects and extent of networking.	Input is combination of fact and perception. Needs to be confirmed from other sources (i.e., for project success, compared to client perspective).
CRC Collaborator Interviews and Client Survey	Important source of partner and client perspective on relevance, benefits arising from working with Branch, quality of services.	Clients chosen from list provided by Branch - may not be representative. Numbers too small to form definite conclusions. Perception is not fact - comments may not reflect reality, cannot be proven.
In depth Interviews	Experienced, well-informed individuals provide important strategic perspective unavailable elsewhere.	Not representative of stakeholder group, perspectives are personal, possibly biased.
Case Studies	Provide in depth probing of roles, relationships and outcomes and impacts of specific projects.	Not representative or generalizeable, usually choose successful projects to demonstrate nature and extent of benefits which can occur.

2.0 Description of Terrestrial Wireless Systems Branch

2.1 Communications Research Centre

CRC is the Canadian government's primary communications research organization. It was originally formed in 1969 as an agency of the Department of Communications, having evolved from previous military communications objectives to a new civilian role. In 1993, CRC was made part of Industry Canada, the federal government's major industrial and economic development agency. The primary mission of CRC is:

> ***to be the federal government's centre of excellence for communications research and development, ensuring an independent source of advice for public policy purposes.***

This reflects the alignment of CRC programs to providing support for policy making and regulations, development and management of standards, support for defence needs and enabling government initiatives related to economic and social development.

The complementary mission of CRC, related to support for the private sector is:

> ***to help identify and close the innovation gaps in Canada's communications sector by:***
>
> - ***engaging in industry partnerships;***
> - ***building technical intelligence; and***
> - ***supporting small and medium sized high technology enterprise.***

2.2 Description of the Branch[2]

2.2.1 Mission and Objectives

The mission of the Terrestrial Wireless Systems Branch is:

> ***to advance the understanding of and develop the concepts and technologies for fixed, mobile and personal wireless communications systems, and develop enabling technologies for telecommunications, in fulfillment of the CRC mandate.***

[2] For a more complete description of the Branch, please see the "Planning Report for the Review of the Terrestrial Wireless Systems Branch".

The Branch was formed in 1998, during a major reorganization of CRC. TWS undertakes research, technology development and testing, and provides advice to government and private industry related to terrestrial wireless communications systems. Originaly the Branch had six research groups. Following reorganization and consolidation, the Branch now has four research groups which conduct programs related to broadband wireless high speed communications, terrestrial radio communication technologies, wireless applications and systems and integrated electronics for wireless systems. TWS also has a **W**ireless and **I**nternetworking **S**ystems **E**xperimentation **Lab**oratory (WISELab). These research groups are described in greater detail below.

Broadband Wireless Research (BBW) was created at the time of the formation of the Branch in 1998. The group has two main objectives:

- to study propagation of radio signals in the microwave and millimeter bands and develop technologies to use these bands for high speed communications applications; and,
- to develop applications involving the transition from wireline to broadband wireless telecommunications.

Within these broad objectives, the group focuses on the development of systems to deliver high speed wireless data to clients in homes. Present research is focussed on two areas. The first is exploiting the 5GHz licence exempt (LE) frequency bands through the development of prototype broadband wireless Ethernet bridges and wireless switches. The second is development of Broadband Wireless Networks, particularly for "last mile" distribution of wireline high speed communications via a low cost high capacity wireless network using the 5.2 GHz LE band, particularly in rural and suburban areas where conventional alternatives are not effective. The group also supports development of national and international policies and regulations and industrial standards which facilitate the use of the technology being developed.

This work is primarily of interest to the broadband wireless communications sector. Industry Canada's Spectrum, Information Technology and Telecommunications Branch (SITT) also has an interest.

Radio Communications Technology Research (RCT) was an existing research group, which was transferred to TWS in 1998. The group objectives are to:

- increase the efficiency of spectrum use;
- increase the rates of data transmission for mobile communications;
- enhance communications security; and,
- improve spectrum monitoring capability.

To accomplish these objectives, the group conducts research and development in wireless communications technologies in the HF, VHF, UHF and higher frequency bands, focussing

on adaptive signal processing and adaptive array techniques, such as multiple-input multiple-output systems (MIMO). The group also conducts research on signal processing techniques to increase the quality and security of voice communications and radio signature analysis to aid in spectrum monitoring and enforcement. The group's research has both military and civilian applications, with the major clients being DND. Private sector firms providing military communications equipment and Industry Canada's SITT.

Wireless Applications and Systems Research (WASR) is a new group which was created soon after the formation of the Branch. The group has two complementary programs, **Systems Research** and **Wireless Applications** (WISELab). WISELab was created soon after the formation of the Branch in 1998, and Systems Research was formed in 2001.

The objectives of **Systems Research** are to conduct R&D on new technologies and higher frequency bands to support the development of new policies, regulations and standards, and facilitate frequency coordination. This work is primarily in support of the needs of government and industry for effective use of radiowave spectrum within an effective regulatory framework. Specific clients include Spectrum Engineering and the Radio Advisory Board of Canada (RABC).

The objectives of **Wireless Applications** are to support the testing and evaluation of new wireless concepts, prototypes and products. This program has responsibility for the further development and utilization of WISELab, a high speed wireless communications testbed. This work is in support of public sector regulatory and private sector measurement needs as well as CRC R&D needs. WISELab is targeted to meet the needs of clients from CRC Research Branches, Spectrum Engineering, and industry.

Integrated Electronics Research (IE) group is also made up of two research groups which existed before the formation of the Branch, and were transferred to the Branch in 1998. The group objectives are to develop novel microwave, millimetre wave and digital integrated circuits, and advanced integrated electronics packaging and interconnect design techniques for communications and image processing applications. Research programs are focused on the development of monolithic microwave integrated circuits (MMICs), miniature hybrid microwave integrated circuits (MHMICs), low temperature cofired ceramic (LTCC) package technology, low loss micro-machined devices (MEMs), and VLSI circuits. Artificial neural networks form another research area separate from the main program. DND is a major client, with the Canadian Space Agency as another client. The group has continuing relationships with several Canadian universities and international research laboratories. Some Canadian telecommunications firms also receive support from the group.

As well as performing R&D, the Branch also administers on behalf of CRC, the Defence Communications R&D Program, which has a total budget of about $5.3 million distributed across CRC R&D branches and research services. The objective of the program is to provide improved operational capability to the Canadian Forces (CF) and to maintain scientific knowledge and expertise in wireless communications to assist DND and CF in decision making.

2.2.2 Branch Outputs

The research, development, testing, and advisory activities carried out by these four research groups result in a number of outputs, including the following:

- new knowledge;
- new and improved standards and test procedures;
- research and test results;
- technical advice and assistance;
- new and improved products and services; and,
- trained highly qualified personnel.

2.2.3 Resources

In the 2001-2002 Operational Plan, Terrestrial Wireless Systems Branch has a total budget of $5.4 million, which is almost 10% of CRC's total budget. These resources are used to support up to 47 full-time equivalent staff (FTE), with a salary budget of $3.0 million, and $2.4 million in operating funding. **Table 2** below, provides a breakdown of the sources of funding and utilization of resources, based on the 2001-2002 Operational Plan. A-base funding provides about 25% of operational resources. Of the 46 FTEs, 32 are provided from A-base funding and the other 14 from contract revenues, grants and special funds, including DND.

Table 2: Terrestrial Wireless Systems Branch Resources (2001-2002) [1]

	FTEs[2]		O&M FUNDING ($000s)					
	A-Base	Other[4]	A-Base	Spectrum	DND	IP	Other[5]	Total
VPTWS[3]	3.4	0.6	93	0	0	44	50	187
BBW	6.7	0.0	90	0	0	88	145	323
RCT	5.2	10.8	133	17	897	38	227	1,312
IE	10.6	2.0	162	0	75	20	0	257
WASR	6.2	0.8	70	140	0	0	65	275
TOTAL	**32.1**	**14.2**	**548**	**157**	**972**	**190**	**487**	**2,354**

1. Based on information provided by Branch, December 31, 2001
2. Salary budget is $2.97 million, including $1.93 million CRC A-base, $910K DND vote netting and $130K other funding sources
3. Includes VP and Branch administration and support
4. Includes project paid employees
5. Contracting-in revenues have been adjusted for the 25% corporate levy

2.2.4 Reach

According to Branch documentation, Terrestrial Wireless Systems Branch has a wide variety of Canadian and international public and private sector partners, collaborators and clients with whom they interact. Within the public sector, they include the following:

- Canadian communications regulators (Industry Canada Spectrum, Information Technologies and Telecommunications Branch (SITT));
- Department of National Defence (DND);
- Canadian Space Agency (CSA);
- Canadian and international universities;
- international telecommunications organizations; and,
- foreign government research agencies.

In the private sector, the Branch works primarily with Canadian wireless communications systems manufacturers and providers.

The total number of organizations with which the branch has significant interactions is estimated to be 30 to 40. However, taking account of multiple interaction partners in some organizations such as Spectrum Engineering, DND and universities, the total number of interaction partners rises to approximately 50.

2.2.5 Intended Results

The intended results of branch activities and interactions vary by type of partner or client. For public sector partners, intended results include:

- technically informed communications policy and regulatory decision making within Canada;
- improved use of the communications radio frequency spectrum;
- Canadian influence in international telecommunications policy and regulatory bodies; and,
- technically informed decisions about the development and use of advanced communications systems by DND and CSA.

For private sector partners intended results focus on the improved competitiveness of the Canadian wireless communications services and equipment manufacturing firms and sectors.

2.2.6 Terrestrial Wireless Systems Branch Performance Framework

As shown in the previous sections, this review has followed the practice used with the reviews of the Broadcast Technologies and Radio Science Branches, which made use of the

performance framework approach to describe the Branch. This approach describes the essential components of a program in terms of five broad categories. They are:

- activities (what program staff and management do);
- outputs (direct products of program activities);
- reach (individual organizations and groups directly and indirectly involved in or "reached" by program activities, includes co-delivery agents);
- direct outcomes (direct results of interaction between program and those reached, includes knowledge transfer, attitudinal and behavioural changes); and,
- ultimate impacts (follow direct outcomes, usually longer term, should link directly to program objectives).

These five categories can be further condensed into three groups – resources (activities, outputs), reach (reach) and results (direct outcomes, ultimate impacts) – which address the three basic performance questions of:

- **HOW** are we going to allocate resources to provide activities and outputs, which achieve program objectives?
- **WHO** do we need to work with and influence to achieve program objectives? and,
- **WHAT** is the logical result of doing these things with these people and organizations?

Following this model, a performance framework was developed for the Branch, shown below as **Exhibit 1**. As can be seen, the Branch performance framework presents a strategic view of the main elements of the Branch operations, its target clients and partners as well as intended immediate and longer-term results. This framework will be used in this review as the basis for comparing aspects of the actual performance of the Branch to the intended performance.

Exhibit 1: Terrestrial Wireless Systems Branch Performance Framework

Mission Statement: To advance the understanding of and develop the concepts and technologies for fixed, mobile and personal wireless communications systems, and develop enabling technologies for telecommunications in support of the CRC mandate.

Resources: 47 full time equivalent employees, $5 million in total funding ($2.5 million A base, $2.5 million external)

HOW?	WHO?	WHAT do we want?	WHY?
Resources	**Reach**	**Results**	
Activities / outputs	**Users / clients / co-deliverers / beneficiaries**	**Direct/Intermediate outcomes**	**Ultimate impacts**
Research, Development and Testing ▸ Broadband Wireless ▸ Radio Communications Technologies ▸ Wireless Systems ▸ Integrated Electronics **Development and Operation of Test Facilities** ▸ WISELab ▸ Integrated Electronics Publications / Test Results Advice / Assistance **Management** ▸ DND Communications R&D Program ▸ Contracts ▸ Projects ▸ Staff	Federal Government: ▸ Spectrum Management ▸ DND ▸ CSA ▸ CIDA Universities ▸ Canadian ▸ Other Centres of Excellence ▸ CITR International Regulatory Agencies ▸ ITU-R International Agencies ▸ NATO wireless communications labs ▸ Other national labs Telecommunications Firms ▸ Terrestrial Wireless Sector ▸ Communications Devices Sector ▸ Wireless services providers	Increased human resources capacity in wireless communications Technically aware policy and regulatory decision making Improved use of wireless communications technology by government agencies Canadian influence in international standards development Awareness, use of Canadian wireless communications expertise, capability Increased interoperability, capacity, availability and robustness of military wireless communications Improved wireless related decision making in DND New and improved wireless communications products, processes and systems	Improved use of spectrum Technically effective, efficient public communications policy, regulations Improved government decision making in use of communications technology Canadian influence in international regulatory system Canadian policies and regulations aligned with international requirements Increased competitiveness of Canadian terrestrial wireless communications sector More informed, appropriate decisions by public and private sector terrestrial wireless communications stakeholders

3.0 Program Relevance

Issue 1: To what extent are the programs and activities carried out within the Terrestrial Wireless Systems Branch relevant and effective in terms of the appropriate role for government laboratories?

Six specific questions related to program relevance have been identified in order to examine various aspects of this issue. These include:

- continuing need for Branch research and testing facilities;
- nature of clients and beneficiaries of Branch;
- impacts and effects of Branch programs and activities
- Branch effectiveness in providing information and advice on emerging trends;
- Branch contribution to CRC mission; and,
- appropriateness of Branch activities and programs for a government research agency.

Each question is examined in detail in the following sections, followed by a general summary and recommendations. Analysis of this issue will include reference to the description of TWS found in the preceding section, and the Branch performance framework found in Exhibit 1, which identifies the various types of TWS activities and services and their characteristics, from R&D to communication and awareness building.

3.1 Is there a continuing need in government and the private sector for the research and testing carried out within the Terrestrial Wireless Systems Branch?

3.1.1 Context

The question of continuing need represents one of the basic questions that must be answered about all government programs. In this case, there are many aspects to the question, linked to the multiple roles TWS is expected to perform in support of both the public and private sectors. Need should be considered from at least three perspectives: those of the nation; the wireless communications community at large; and individual public and private sector organizations.

This question was examined using evidence from four major sources. These include TWS documents and files, the client survey, expert interviews, and CRC staff interviews. Of particular importance was the input from Branch major public and private sector clients, namely Industry Canada SITT Branch, DND and representatives of the Canadian wireless communications sector.

As well as being examined in this section, continuing need for TWS is examined in several following sections. In particular, Section 2.2 considers the beneficiaries of Branch's activities and programs, Section 2.3 examines the impacts and benefits that result from client's

interactions with the Branch, and Section 2.6 reviews the appropriate role for government research agencies.

3.1.2 Detailed Findings

Document Review

For many years, going back to the origins of CRC as a defence telecommunications organization, the Canadian Department of National Defence has relied on CRC to provide essential research, development and applications support for military needs in telecommunications. This has carried on through the recent reorganization to the present. In fact, TWS is a major participant in this relationship. Through the Defence Communications R&D fund, DND pays for the salaries of 12.5 of the total 46 Branch staff members, or over 25%. In addition, as shown in Table 2, in 2001-2002, DND provided almost one million dollars towards the total $2.35 million in TWS O&M funds, or about 40%. While most of the resources go to the Radio Communications Technology Group, some also goes to the Integrated Electronics Group. This level of funding is a clear indicator of the importance that DND places on the activities carried out within this Branch on its behalf.

Similarly, the level of funding from SITT is an indicator of the relevance of Branch capabilities to its needs. Based on TWS records, SITT is providing over $150,000 to TWS this year, which is about 25% of the total SITT project funding available. This is once again a clear indication of the need by SITT for TWS services. In 2001-2002, almost 90% of SIIT funding to TWS went to WISELab.

Client Survey

The issue of continuing need for the Branch's capabilities by individual organizations was addressed by several questions in the client survey. While not asked directly if they would continue to work with the Branch, the positive statements by a large majority of respondents regarding the importance and value of their relationship with the Branch is a good indicator that the Branch continues to meet many of their needs. In fact, several small private sector firms stated that they wanted an increased level of support from TWS.

Survey respondents were asked to rate the relevance of the Terrestrial Wireless Systems Branch capabilities to their organizational needs on a scale of 1 to 10, with 1 being not at all relevant and 10 being extremely relevant. For the 38 respondents who answered the question, the average rating was 8.2, a high rating. In some cases, respondents from organizations with a broad product mix or mandate, were responding only in terms of that part of their business to which Branch capabilities were a good fit. Less than 10% of respondents gave ratings of 6 or less, another indicator of a good fit between clients and the program. This is not surprising, as any clients who found TWS capabilities not very relevant to their needs would soon leave.

Survey respondents were also asked why they worked with the Branch. As the question was open ended, with no list of prepared options, there were a variety of responses. The most frequent related to the strong technical capabilities of TWS, as reflected in the high level of capabilities and expertise of staff, and the facilities and equipment. Other respondents stated that the capabilities of the Branch matched their needs.

Evidence from the survey suggests that for many clients, the Branch provides unique services otherwise unavailable in Canada. Respondents were asked to consider, for specific projects identified by the Branch, what effect not having access to the Branch would have had. Of 37 respondents, 29, or almost three quarters, stated that there would have been major negative effects. Of the remaining 8, 7 said that minor effects would result. For one particularly unsuccessful project, there was no impact of TWS participation. Negative effects of not having access to TWS that were mentioned by survey respondents include the following:

- project would not have gone ahead without Branch participation, Branch role critical to success;
- project would be less complete, information less reliable;
- loss of credibility due to absence of Branch participation;
- major delays; and,
- increased costs.

CRC Staff Interviews

Evidence from interviews with individuals from other CRC Branches shows that some researchers from other Branches have positive, rewarding collaborations with TWS researchers in areas of common interest. In some cases, relationships are informal, such as information exchange and advice. In others, often where a subcontract is involved, a more formal collaboration is formed.

In-depth Interviews

It is clear from discussion with representatives from SITT and other informed stakeholders that the Branch is playing an important role in the development of Canada's policies and guidelines on the use of spectrum. The private sector also supports the role of TWS in developing policies, as those policies provide the framework within which the private sector wireless broadband sector operates. The case studies for the Broadband Wireless group and WISELab provide examples of TWS support to the development of spectrum utilization policies. This role will be discussed in more detail in later sections.

Discussions with researchers at Canadian universities involved in TWS projects also show that they value their relationship with TWS researchers. In a number of cases, the Branch provides opportunities for graduate students to work on real life problems and have access to facilities and equipment not available in the university laboratories. In other cases, TWS expertise is a valuable complement to university capabilities.

3.1.3 Summary

All evidence presented above indicates strongly that the Canadian public and private sectors both have a clear and continuing need for the research capabilities and facilities of the Branch. Document review shows the significant funding support provided by DND and SITT, an indicator that TWS is addressing their needs. Clients and stakeholders have spoken of the importance they place in having access to the expertise within the Branch. This applies to the Canadian federal government, private sector wireless communications firms, Canadian universities and international telecommunications organizations. In terms of the relevance of the Branch to meeting their needs, those surveyed gave a rating of 8.2 out of 10, a high rating. The public and private sector wireless broadband communications community will continue to require access to the expertise and technical knowledge in the Branch, as higher frequencies come into use.

In addition, the branch is ideally suited to provide support to universities in the training of highly qualified personnel (HQP), to meet the growing need in this area, within both CRC and other public and private organizations in Canada.

3.2 Who benefits from the Terrestrial Wireless Systems Branch programs?

3.2.1 Context

An analysis of the number and types of individuals and organizations benefiting from Branch activities is central to the issue of program relevance. The question will be analyzed in terms of direct and indirect beneficiaries. Although detailed information is not available, some attempt will also be made to discuss the level of support to the various client groups, at least qualitatively.

It must be kept in mind that TWS was formed in April 1998. Two research groups, Integrated Electronics and Radio Communications Technologies, were transferred more or less intact from an earlier organizational structure. They brought with them the relationships they had before the reorganization. The Broadband Wireless group was formed when the Branch began, and had to build relationships with clients and partners. The fourth group, WISELab, was formed even later than the other three. These facts have an impact on the number and type of clients and collaborators.

The Terrestrial Wireless Systems Branch performance framework shown in Exhibit 1 is a useful reference for this issue, as it identifies the intended beneficiaries and impacts of the work of the Branch. Note that the TWS performance framework identified beneficiaries in both the public and private sectors. In examining this question, several methodological approaches provided information of value. Primary sources were Branch documentation and coauthorship analysis of publications.

3.2.2 Detailed Findings

Document Review

Several sources were used to identify the clients and collaborators of the Radio Science Branch. One came from the lists of clients and collaborators of the four research groups within the Branch, which were provided as the basis for the interviews and surveys (Annex B). A summary of this information is shown in **Table 3**, which describes the number of different types of clients and collaborators for each TWS research group.

Table 3: Terrestrial Wireless Systems Branch Clients, Collaborators and Partners*

Branch Research Group	Canadian University	Canadian Industry	Canadian Government	International University	International Industry	International Government
Broadband Wireless	1	4	7	0	0	2
Integrated Electronics	6	3	9	1	2	3
Radio Communications Technology	5	8	11	3	3	6
Wireless Applications and Systems	1	5	9	0	0	1
Total	13	20	36	4	5	12

*Taken from client lists provided by Branch

Assuming that a complete or representative list of clients and collaborators was provided, this table shows that the types of clients and partners, with which the Branch works directly, closely parallel those identified in Exhibit 1.

The publications for the four groups within TWS have also be examined to shed light on collaborations. In particular, coauthorships were analyzed to determine from which type of organization coauthors are. For this review, coauthors for refereed publications, published conference proceedings and ITU presentations for the period from 1998 to the present for the Broadband Wireless, Integrated Electronics, Radio Communications Technologies and Wireless Applications and Systems groups respectively were analyzed. (This analysis focuses on formal research linkages only, and does not attempt to examine productivity of the four groups in terms of publications.)

The coauthorship analysis presents a somewhat different picture than that shown in Table 3. By and large, the publication analysis shows that most scientific collaborative relationships are with Canadian and international university researchers. In the case of the Radio Communications Technology group, a few are with researchers in defence related government research organizations in other countries. For the Integrated Electronics

Group, some are with government research laboratories in Japan. As is the case for all CRC Branches, many of the publications with Canadian universities are associated with publishing the results of university graduate student research projects carried out at TWS, often with TWS researchers as cosupervisors.

A summary of the number of publications for each of the four research groups is presented in **Table 4**, below. The number of researchers in each research group is a amajor factor in quantifying and assessing ouputs.

Table 4: Number of Publications for each Research Group per Year

Year	Broadband Wireless	Radio Communications Technology	Integrated Electronics	Wireless Applications and Systems	Total
1998	2	8	8	0	18
1999	0	8	15	0	23
2000	3	13	18	6	42
2001*	4	7	8	3	22

* preliminary data

3.2.3 Summary

The following list of clients, collaborators and other beneficiaries of TWS research has been developed, based on the various analyses described above. It identifies the various types of public and private sector organizations supportd by TWS, and the types of activities and projects for each:

- Industry Canada Spectrum, Information Technology and Telecommunications Branch (testing and advice related to Canadian government spectrum utilization policies and regulations, spectrum allocation);
- Canadian and other national defence organizations (research and development of wireless communications systems, advanced waveforms, telecommunications components);
- Canadian universities (wireless communications related research);
- Canadian wireless broadband telecommunications firms (transfer of technology, technical support for system development, development of components, testing and measurements);
- international wireless telecommunications firms (waveform and modem development and utilization);
- other government and international research groups (wireless R&D, high frequency component R&D);

- international wireless communications standards bodies International Telecommunication Union-Radiocommunication Sector (ITU-R) (development of international wireless broadband standards); and,

- international industry standards development organization - IEEE. (development of industry standards for outdoor wireless broadband local area networks (LANs).

While the relative effort towards each group varies according to the specific projects and initiatives underway at any particular time, it is clear that, on a yearly basis the single largest client of the Branch is the Department of National Defence, followed by SITT. Canadian universities constitute the next largest group. The level of effort in collaborating with and doing contract work for Canadian and foreign private sector firms is smaller. Among the four TWS research groups there is some effort devoted to working with foreign government research organizations, international wireless standards and regulatory agencies and foreign universities. Much of the work for DND, SITT and the private sector is performed on a cost recovery basis under contract. In other cases, most resources come from the internal Branch budget.

Based on this analysis, the largest beneficiary is the Canadian public sector, namely the Government of Canada, through support to DND and SITT, the national telecommunications spectrum management organization. Other public sector beneficiaries include Canadian and foreign universities, foreign defence organizations and foreign research organizations. Individual private sector beneficiaries, that is Canadian and foreign wireless telecommunications firms, are much fewer in number and receive much less direct support from TWS, although the sector as a whole benefits extensively from the support provided to the development of spectrum policies and regulations and industrial standards.

3.3 What are the immediate and longer term impacts and effects of the work carried out within the Terrestrial Wireless Systems Branch?

3.3.1 Context

This section will examine the nature of program outcomes, impacts and effects of TWS activities and interactions with clients, collaborators and other beneficiaries. While the focus will be on direct benefits to partners, indirect impacts will also be considered where possible. The primary sources of information are document review, client survey, and case studies.

The Terrestrial Wireless Systems Branch performance framework is once again a useful reference, as it provides a strategic perspective on the intended impacts of the work of the Branch. As shown in Exhibit 1, results are considered on two levels, direct outcomes and ultimate impacts. Note that both public and private sector benefits are identified.

3.3.2 Detailed Findings

Document Review

One source of information about private sector benefits is the revenues received by the Branch from the use of Branch intellectual property. In these cases, private sector firms have paid for technology developed by the Branch, or developed products based on TWS technology, and have paid a fee to TWS. An examination of Branch revenues from 1999-2000 and 2000-2001 shows relatively low revenues from this source. The largest single source of revenue is the licensing of Wireless Ethernet Bridge (WEB) technology developed by the Broadband Wireless group. There are also some revenues from technology developed by the Radio Communications Technology group in the mid 1990s, before the Branch was formed.

Client Survey

The client survey gathered information on the benefits and impacts resulting from specific interactions between the Branch and those surveyed. Respondents were asked to focus on a single project and identify whether specific results had occurred or will occur as a result of the project. Respondents were also asked to rate the involvement of the Branch in achieving the results on a scale of 1 to 10, with 1 representing not at all involved and 10 being completely responsible for the result. **Table 5** contains a summary of the survey data.

Of the 42 individuals interviewed, a number were involved in projects that were not sufficiently completed to be able to respond to this question. Those who said that the result will occur are made up of two groups. In some cases, projects have not been fully completed but they could anticipate the result, in others the project has been completed and the result has not yet occurred, but is likely to occur in the future. This was particularly true of commercial results such as new products, increased sales and competitiveness.

Table 5: Project Results Identified in Survey

Result *	Has Occurred (#)	Will Occur (#)	Importance of Branch Role
Solution to technical problem	23	2	7.8
New knowledge	30	0	7.6
Increased scientific / technical capability	16	0	7.5
Reduced development time	10	0	7.8
New / improved product	14	5	7.4
New / improved process	2	3	7.0
Cost savings / greater efficiency	6	2	7.0
Increased competitiveness	3	6	6.7
Increased sales	3	4	5.3
New / improved policies / regulations	6	4	7.1

* from a prepared list read to respondents

The list of possible results in Table 4 includes a progression from immediate technical results to longer-term, consequential commercial or public benefits. The list begins with the most immediate and likely results, being new knowledge and solutions to technical problems as well as increased scientific or technical capability being developed in or transferred to the client organization during the project. These results can be found for all types of projects with all types of clients. Increased technical capability within the client organization is a particularly desired result, as it leaves the organization in a better position to make its own technical decisions without continuing support. As can be seen, this group of results occurred most frequently.

The next group of results relating to products and processes occur further downstream from research and experimentation. In the case of TWS, products in particular tend to be associated more with DND and private sector organizations. This is the reason for the reduced occurrence of these results.

The next three types of results (cost savings / greater efficiency, greater competitiveness, increased sales) are clearly private sector benefits, and are unlikely to be found in public sector projects. This is the reason for the lower frequency. In addition, the length of time between R&D and the achievement of commercial results is probably responsible for the larger number of results that are expected to occur compared to those that have already occurred. The rating for the Branch's role is somewhat lower due to the increased involvement from the client organization for these downstream benefits to occur and the concomitant reduced role for TWS.

The final category reflects a different stream of results, namely public sector impacts. It is related to one of the main roles of the Branch, namely involvement in the development of

new and improved national and international policies, regulations and guidelines linked to spectrum usage. About 20% of the clients who identified some results had projects related in some way to this fundamental role of the Branch.

Respondents were also asked to identify other results beyond those named on the list. Few did. One university-based respondent identified the training of highly qualified personnel (HQP) as an important result of working with TWS. Two other respondents, one from DND and one from the private sector, stated that in addition to a specific product, working with the Branch resulted in their group having increased credibility within NATO.

In addition to providing information about the results from a specific project, respondents were also asked to provide a more general sense of the value of the Branch to their organization. They were asked to rate the importance of the Branch to their organization's success on a scale of 1 to 10, with 1 being of no importance and 10 being of major importance. The average rating of the 33 respondents who answered the question was 6.8, with 11 giving a rating of 6 or below. This is not unexpected, for several reasons. Some clients and partners have several lines of business and those related to Branch capabilities may be a relatively small portion of the total. Some scores were relativelky low because a number of the people interviewed were collaborators with the Branch, or in fact were conducting contract research on behalf of the Branch and not in a true client relationship. For these cases, the collaborators or contract researchers often considered that they were major contributors to the success of the project.

Case Studies

The four case studies (Annex D) probed more deeply into specific projects by TWS research groups with selected partners and attempted to capture the impacts of specific projects on the participants and the broader community. The individual case studies support the evidence from the client survey, identifying benefits at the partner organization level as well as the broader community level.

These case studies show the various ways research can influence both public and private sectors. In the case of the development of wireless Internet application systems for use in the 5GHz unlicenced band, the Branch researcher developed both new technology which can be manufactured and sold by the private sector for use in the 5GHz band, but also contributed to the development of government and industry standards governing use of devices under these circumstances. In another case, WISELab provided research data and analysis to support development of government policies for use of a new 50 – 70GHz band. The project to develop a NATO standard waveform for high capacity communications also benefited both the public sector through support to international security arrangements and the private sector through support for sales of military telecommunications equipment to NATO.

3.3.3 Summary

Evidence from the client survey and other sources show that TWS clients and partners benefit through access to research, technical information, advice and assistance provided by the Branch through collaborative and in-house R&D as well as participation in national and international conferences and international standards and regulatory forums.

Clients receive important technical benefits from projects with the Branch. These include new knowledge, solutions to technical problems, increased scientific and technical capability, new and improved products and processes, and reduced development time. These technical impacts often result in economic and organizational benefits, including cost savings, and in the case of private sector firms, increased competitiveness and sales. Public benefits include new and improved policies and regulations arising from interactions with the Branch. In the case of DND, benefits include improved decision making related to telecommunications policies and procurement, and increased reputation and influence within the NATO and broader international defence community.

Exhibit 2 summarizes the various types of impacts and benefits that clients and the broader wireless communication community receive, based on information from the case studies. The Exhibit is consistent with the information in Table 4 from the client survey, which also identifies impacts.

Exhibit 2: Impacts of Branch Programs

Project Incrementality (influence)	Direct User Impacts	Industry Sector / Public Sector Impacts	Economy / Societal Impacts
Major x project would not have been undertaken without Branch involvement x conducted some critical R&D that otherwise would not have been done **Minor** o Participated in project as one of a number of participants (contribution was helpful, but not essential)	**Technical results** x new or improved product x new or improved process x advancement of knowledge x increased technical capabilities o improved quality control x new skills internally p increased efficiency / improved productivity x technology transfer **Policy/Legislative results** o policy behavioral changes o agreement / accord s legislative / regulation s acceptance of standards **Commercial results** s increased sales p increased market share o increased profitability o cost savings **Organizational effects** p increase in jobs o diversification p expansion s strategic alliances / partnerships o achievement awards / recognition	**Industry** o production process efficiencies x increased science and technology information p increased sales o cost savings p changes to industry structure o spin-off companies x training of technological problem-solvers x establishment of operational standards **Public Sector** x increased decision making capability	o reduced consumer costs o protection of environment o improved energy efficiency x improved public regulatory capability x effective use of radiowave spectrum x public access to latest communications technology x increased public security p increased employment

o has not occurred
x has occurred
s occurs sometimes
p potential in future

3.4 How effectively is the Terrestrial Wireless Systems Branch meeting Canadian public and private sector needs for information and advice about existing and emerging knowledge, technologies and systems?

3.4.1 Context

In Section 2.1, the extent of the need for the types of activities and services provided by the Terrestrial Wireless Systems Branch was examined. These discussions will not be repeated here. Rather, this examination will focus narrowly on the question of the effectiveness of the Branch in meeting public and private sector needs for information and advice. Provision of information and advice to the wireless broadband community on existing and emerging technological and regulatory issues falls into one of the defined categories of services that can be provided by TWS. In fact, this objective is embedded in the CRC mission statement, where an independent source of advice for public policy purposes and building technical intelligence in support of the private sector are specifically mentioned. In a previous review, the Broadcast Technologies Research Branch was found to be very effective in sharing information obtained from participation in ITU meetings with the client and stakeholder community, and clients were very appreciative of the information. Incremental costs for this activity are relatively low and the number of recipients of the information can be quite large, including some outside the range of the more focused services. Access to strategic intelligence is highly valued in all organizations, and of particular importance in high technology sectors such as wireless communications. The role of the Branch in providing information and advice on emerging international trends in both standards and technology should be considered as part of its core mandate.

The primary source of information used to examine this question is the client survey which provides the perspective of representatives of the Canadian public and private wireless communications sector. Document review and expert interviews also contributed.

3.4.2 Detailed Findings

Document Review

The WISELab Group, in cooperation with the Industry Canada New Wireless Services and Technologies Directorate, publishes the "New Technology Bulletin" bimonthly. This report, which is available on the CRC WISELab website, provides an overview of new wireless technologies. WISELab has also recently provided several reviews of technologies and trends to clients and stakeholders. These included a review of new and emerging wireless technologies and technological trends for DND, and a review of worldwide trends, and available experimental data regarding the use of licence exempt 50-70 GHz bands by the U.S. and several other countries for the RABC and SITT. In addition, Branch personnel make presentations to RABC and SITT as part of their ongoing program.

Client Survey

The client survey gathered information directly related to this question. Respondents were asked whether the Branch helped make their organization aware of new developments and emerging trends. Of those answering this question, a bare majority (19) said yes and 18 said no. Of those who said yes, most stated that the information exchange was very informal, and occurred as part of the ongoing relationship. Several respondents who said no, volunteered that they wished the Branch would provide that service. Those respondents who said that the Branch did keep them informed were next asked to rate both the importance of that help and how well the Branch does at keeping them aware. As usual, a scale of 1 to 10 was used in both cases, with 1 being not at all important/very low and 10 being extremely important/extremely well, respectively. In the case of the importance of the information, the average rating was 7.5, with 3 of the 19 respondents giving a rating below 7. In some cases, respondents stated that there was no expectation that the Branch had a specific role in providing strategic intelligence. In terms of rating how well the Branch does at providing help, the average rating was 6.8, with 6 of the 17 who responded giving a rating below 7.

The rating for how well the Terrestrial Wireless Systems Branch did at providing strategic intelligence is significantly lower than that for the Broadcast Technologies Branch, and somewhat higher than that for the Radio Science Branch in previous reviews. For comparison purposes, the average rating for the Broadcast Technologies Branch was 7.9, and for the Radio Science Branch, 6.4.

Other information collected in the survey supported the conclusion that TWS is not very proactive in sharing information with individual clients. When asked to identify ways in which the Branch could improve services, several respondents stated that the Branch could do a better job of communicating with the community and sharing intelligence.

CRC Staff Interviews

Information from CRC staff from other branches suggests that some researchers in other CRC branches would also value hearing more about Branch projects and initiatives, as well as receiving strategic intelligence gathered from international standards meetings and other sources. This information would help them understand when interests coincide and joint projects would be appropriate. This sharing will likely become of increasing importance as CRC moves forward to respond to the federal government priority for nation-wide broadband services through the Remote Broadband Access initiative.

Indepth Interviews

Discussions with informed stakeholders revealed that the Terrestrial Wireless Systems Branch is at a disadvantage compared to the Broadcast Technologies Research Branch in sharing information. The Broadcast Technologies Research Branch has excellent relationships with several industry associations that are the natural vehicle for sharing and

disseminating information. The wireless broadband sector has a different structure, and TWS has not established similar relationships. One individual mentioned the Canadian Wireless Telecommunications Association, and their publication Wireless Telecom, as vehicles which TWS could make use of to share information more broadly among the wireless communications community. The RABC is another possible mechanism that could be used to disseminate relevant information.

3.4.3 Summary

Evidence from the document review, client and expert interviews shows that the Terrestrial Wireless Systems Branch does not do a particularly good job of sharing information on emerging trends in wireless broadband technology with the broader client community. The exception is the WISELab group, which has several specific activities in support of this objective. Ratings from the client survey for how well the Branch keeps clients aware of emerging trends are below those for the Broadcast Technologies Research Branch (average of 6.8 compared to 7.9). The Terrestrial Wireless Systems Branch has a more difficult task, as it is a relatively new Branch that is still building relationships with stakeholders. TWS is at an earlier stage in identifying appropriate mechanisms, such as industry or technology associations, through which to disseminate knowledge.

Evidence also suggests that the Branch is not proactive in this area. Many respondents noted that when they ask for information it is generally provided, however, they observed, with some exceptions, that Branch staff do not see it as their role to actively disseminate knowledge about emerging technological and regulatory trends.

3.5 To what extent is the Terrestrial Wireless Systems Branch meeting its objectives and contributing to the mission of CRC?

3.5.1 Context

The Terrestrial Wireless Systems Branch will be examined in terms of its relationship to both the public and private sector aspects of the CRC mission statement (discussed in Section 2). The analysis will not include new evidence, but will draw to a large extent on evidence and discussion from previous research questions in Section 3 related to the issue of relevance.

3.5.2 Detailed Findings

Evidence presented in Section 3.2 on beneficiaries and Section 3.3 on outcomes and impacts is pertinent to this question. The role of the Branch in providing SITT with technical information and advice to support wireless broadband policy and regulations, and spectrum allocation is directly aligned with the first section of the CRC mission statement. The Branch also provides DND with information and advice on policy options with respect to strategies and procurement, and conducts research leading to product and system development. The Branch's contribution to the development of international policies and regulations, and

industrial standards on spectrum use is also an important factor in helping ensure that government policies and regulations are consistent with international standards and vice versa.

In terms of its role as a centre of excellence, many clients say that the Branch is a unique source for many topics in the broadband wireless research field within Canada. TWS has the technical expertise, equipment and facilities, credibility and reputation required for a number of the projects. Loss of access to the Branch's services would have caused major negative impacts for many of their projects, ranging from time delays and greater costs to inability to proceed.

As discussed in Section 3.2, the Branch devotes fewer resources to meeting the second CRC mission related to support to the private sector. With particular reference to building technical intelligence, Section 3.4 found that, with some exceptions, TWS researchers are often not proactive in providing strategic intelligence on emerging technologies to clients, in particular the private sector. While those discussions will not be repeated here, the Branch could play a larger role in this area, which is directly linked to CRC's mission to build and share technical intelligence.

Evidence also shows that, to a limited extent, the Branch works with and supports small and medium sized Canadian wireless broadband and other telecommunications sector firms in a number of ways. From Annex C, approximately 20% of the projects identified for this study were with Canadian and foreign private sector firms. However the level of effort is considerably lower than 20%, perhaps half of that. Not all private sector firms are in the SME category.

3.5.3 Summary

It is clear that, broadly speaking, the strategies and priorities of the Terrestrial Wireless Systems Branch are aligned to the CRC mission statement, and that the Branch is helping achieve the CRC mission, primarily in terms of providing scientific expertise and advice in support of achieving federal government objectives related to spectrum utilization for broadband wireless services and wireless telecommunications capabilities linked to national security. The Branch is less active in communicating or disseminating technical intelligence, and supporting small and medium wireless broadband firms. All major projects and initiatives can be shown to provide development of new knowledge, public policy advice, or support to the Canadian military or to the Canadian wireless communications industry.

3.6 Is the Terrestrial Wireless Branch within CRC filling an appropriate role for Government?

3.6.1 Context

This question is, to a large extent, a comparison between the present strategic positioning of the Branch and government policies on the role of government research agencies. To address the question, this study examined a number of policy documents and studies, and reviewed the discussion in Sections 2.2 and 2.3 on beneficiaries and benefits as well as relevant information from in expert interviews.

3.6.2 Detailed Findings

Document Review

In its 1996 review of government S&T entitled "Science and Technology for the New Century", the government identified three interrelated goals as the focus of future federal S&T activities. They are:

- the application and commercialization of S&T to create jobs and economic growth;
- using S&T to improve the quality of life and social well being of Canadians; and,
- achieving and maintaining excellence in the advancement of knowledge.

These three objectives can be restated in terms of using S&T to support industrial development and economic growth, including support for individual private firms, using S&T for public good through improved policies and services to the public, and continued creation and development of knowledge, particularly to support the achievement of the first two goals.

As well as these three goals, the government identified a number of operating principles in its 1996 review. One of specific interest to CRC and the Terrestrial Wireless Systems Branch is: positioning Canada competitively within emerging international regulatory, standards and intellectual property regimes.

Another source of information about the appropriate role for the federal government can be found in the reports of the Council of Science and Technology Advisors (CSTA). CSTA, a group of representatives of the S&T advisory councils of Federal science-based departments and agencies, was formed in the late 1990s as part of the 1996 federal S&T strategy. CSTA produced several reports including one on scientific advisory processes and the utilization of advice entitled "Science Advice for Government Effectiveness (SAGE)" and another on the roles of government in performing S&T and its capacity to deliver entitled "Building Excellence in Science and Technology (BEST)". The SAGE report provides guidance on how to ensure that government decisions are appropriately informed by sound scientific advice, while the BEST report makes an important statement by defining excellence as a composite of quality, relevance and useful outcomes. This is an important point, since much

S&T literature describes excellence strictly in terms of quality without reference to relevance or utilization.

CSTAs perspectives on the role of science in government decision making and the definition of quality are both directly relevant to the Terrestrial Wireless Systems Branch, which seems to have had success in informing government policy on spectrum utilization through the provision of relevant advice, and in utilizing TWS capability to achieve useful outcomes for many clients.

As a research agency within Industry Canada, CRC also has a responsibility to contribute to the objectives of its parent department. Industry Canada has five strategic priorities or lines of business. These include:

- Connectedness;
- Innovation;
- Investment;
- Trade; and
- Marketplace.

Terrestrial Wireless Systems Branch makes significant contributions to three of the five Industry Canada Business lines. There is a clear linkage between the work of the Branch on broadband wireless communications and connectedness. While this has always been true, it is particularly relevant to the recent federal Broadband Taskforce objectives to bring broadband services to all Canadians. CRC has responded by creating a major new corporate Remote Broadband Access Initiative to support the development and implementation of a broadband telecommunications system to serve those Canadians who might otherwise be missed by commercial interests.

TWS also contributes to the Innovation business line. As shown previously in Exhibit 1, TWS R&D projects with both the public and private sectors contribute to innovative products and practices, particularly in the areas of broadband wireless advances. In some cases, in the private sector, projects with the Branch result in increased efficiencies and cost savings, as well as increased sales and greater competitiveness.

The Branch also contributes to the Marketplace business line through support to the radiowave spectrum regulatory system. By contributing to having well thought out Canadian spectrum usage policies and regulations that are consistent with international approaches, the Terrestrial Wireless Systems Branch is contributing to an orderly, efficient marketplace. As identified in the case study on development of a Spectrum Utilization policy for the 50 – 70 GHZ bands, setting policies and regulations supports orderly implementation of new technology and the development of innovative communications products and services to meet Canadian needs.

Branch documents also identify a role in achieving the Industry Canada Trade objective through international collaborations with India, Japan and Taiwan.

3.6.3 Summary

Based on an examination of the federal government objectives for S&T, the objectives and capabilities of the Terrestrial Wireless Systems Branch are well positioned to support a number of roles appropriate for a government research agency. These include research and development, technical support, testing and advice to:

- the Canadian and international wireless communications standards and regulatory community, in support of the public interest and social well-being of Canadians;
- the Canadian military , in support of national security; and,
- the national and international private wireless communications sector, in support of an innovative wireless broadband communications industry, wealth creation and economic growth.

In particular, the Branch is recognized as a neutral, credible source of scientific data and analysis on wireless communications issues and can be relied upon to present a technically accurate, unbiased perspective.

The Terrestrial Wireless Systems Branch performs a number of complementary roles in support of both public and private sectors. First and foremost, the Branch provides support to the Canadian .wireless communications policy and regulatory system through its relationship with SITT. This is linked to the recent focus on provision of scientific advice to better inform government decision making. More specifically, the Branch, through its support to the development of national and international spectrum utilization policies and regulations is also directly contributing to the government objective of ensuring an economic, legal and regulatory environment conducive to innovative activity.

The Branch also provides extensive support to meet Canadian military needs for wireless telecommunications R&D and technological development. This is a role that is performed in most countries by public sector R&D organizations, rather than the private sector.

TWS has relatively few resources directed towards the application and commercialization of technology for the creation of jobs and economic growth. In most cases, firms do followon work linked to economic objectives.

3.7 Relevance – Summary

Based on the 1996 Federal review of government S&T entitled "Science and Technology for the New Century", and recent reports of the Federal Council of Science and Technology Advisors, it is clear that the Canadian government expects its scientific laboratories to fill a dual role, in support of both public interest and economic growth and wealth creation. This

is reflected in the CRC mission statement. These two roles can be complementary, particularly in the case of standards and regulations. In the case of the Terrestrial Wireless Systems Branch, the social and cultural well being of the public needs to be supported through an efficient, effective, and accessible Canadian wireless communications system. This system should be based on internationally accepted standards, and the private communications systems developers need appropriate scientific knowledge and technical assistance, which help them develop and provide quality communications systems. Policy studies support the role of government S&T as providing technical support to the development of national regulations and guidelines compatible with international systems. This is as true of wireless communications as of other areas of commerce. The Branch is well positioned to fulfill this role for the Canadian public and private sector radio communications.

The need for Branch capabilities in wireless communications is once again being recognized. As the lower frequencies are being fully utilized, allocations of new higher frequency allocations are being required, and the characteristics of wireless propagation at these higher frequencies need to be studied.

A review of Branch programs and projects, analysis of clients and collaborators, and feedback from the client survey, staff and expert interviews show that the Branch has the expertise and capability to meet these complementary roles, supporting both public and private interests within the Canadian and international wireless communications community. However, the Branch has not been as active in sharing its knowledge with the broader community as some clients and stakeholders would like. In addition to its working on specific projects to meet client needs, clients and partners of the Branch would like it to provide other types of services, such as the provision of information, advice, and strategic intelligence. Some of those interviewed would like the Branch to make a greater effort to make them aware of technical developments and other emerging issues on a regular basis.

Another need in the wireless communications community is for highly qualified personnel with experience in wireless communications systems. A number of the skilled staff of the Branch have been hired away in recent years to fill these needs in other organizations, particularly in the private sector. In this manner, the Branch has contributed to technology transfer and development of highly qualified personnel for the sector. The Branch also works with the university community to support the training of graduate students, which provides additional resources for Branch research and development projects, while helping develop trained personnel. Some of these students are hired by CRC following completion of their studies.

3.8 Relevance - Recommendations

The recommendations that follow identify specific aspects of a more proactive approach by the Branch to identify and meet the needs of clients and stakeholders, and the need to maintain a balanced program focussed on both public and private sector needs.

3.8.1 Communications, Networking and Awareness Building

The Branch should move to address the expressed desire in the wireless communications community for improved access to strategic knowledge of technical developments and emerging issues. Communicating with the broader stakeholder community about Branch initiatives and perspectives on emerging issues should become a higher priority, and the Branch should develop mechanisms to accomplish this objective. The review of the Broadcast Technologies Research Branch identified a number of possible mechanisms that seem appropriate for the Terrestrial Wireless Systems Branch as well. They include regular workshops, possibly aligned to the specific needs of various stakeholder groups; a periodic newsletter with information about Branch projects and strategic intelligence from international meetings; and a web site with basic information about Branch priorities and projects, as well as similar information as in the newsletter described above.

The Branch should also try to identify an association or group associated with the Canadian wireless communications community which could serve as a partner to disseminate strategic information from the Branch to the wireless telecommunications community about emerging technical and regulatory issues. The Canadian Wireless Telecommunications Association, which has a quarterly publication, or the Radio Advisory Board of Canada are potential candidates.

It is likely that a combination of approaches will be more effective than a single one.

3.8.2 Maintain Multiple Complementary Roles

It is clear that the Terrestrial Wireless Systems Branch is well positioned to meet needs of public and private sector stakeholders within the Canadian wireless communications community and that insight into the needs of one group contributes to the Branch's ability to meet the needs of the other. The Branch should continue to maintain a balance among its various roles, developing new knowledge and expertise and providing advice and services to meet both public and private sector needs in a complementary manner. The Branch should ensure that it is providing support to the private as well as the public sector. The provision of high quality technical support for Canadian wireless communications policies, standards and regulations in the public interest also helps the private sector by providing an efficient and effective regulatory infrastructure within which to work.

4.0 Quality

Issue 2: To what extent does the quality of research, advice and services provided by the Terrestrial Wireless Systems Branch meet the needs of clients and collaborators?

The wording of this issue is intentional as it applies to the Terrestrial Wireless Systems Branch. While it is not always recognized among researchers nor in the management and reward systems governing public sector R&D organizations, research quality is not an end in itself, but rather the means to an end. In the case of CRC, the mandate is to perform relevant research to meet the technical needs of public and private sector stakeholders and clients. This issue is also related to the question of the appropriate strategic mix of activities. These include on one hand, research in-house and with collaborators to build knowledge and increase scientific and technical capability and, on the other, development work, contract research, testing, product and process development, and advice, which apply and utilize existing knowledge. Resource allocation needs to be carefully balanced between building and utilizing capability. This concept is clearly included in the government goals for S&T, which were discussed in Section 3.6, which include both building new knowledge and also utilizing current capability to provide advice for public policy decision making and contributing to economic growth and social well-being. The quality of research and capabilities of staff should be sufficiently high to meet the needs of the identified client group, but utilization of capability to achieve results is the real objective, as shown in the Branch performance framework in Exhibit 1. It should be noted that there is a range of requirements for research quality among clients and stakeholders, with those of scientific collaborators being in most cases the highest.

In the case of services, the concept of quality is expanded beyond facilities, equipment, staff expertise and capabilities, to include elements of 'client friendliness' such as responsiveness and ability to meet deadlines. The issue of quality will be examined from this broader perspective of the relationship between quality of research and services and the needs of clients and collaborators.

As the needs of clients are the basis for examining quality for this issue, the primary source of evidence to address these questions is the client survey, with some information taken from documentation, staff and expert interviews.

4.1 In what manner does the Terrestrial Wireless Systems Branch contribute to meeting Canadian and international needs for new knowledge?

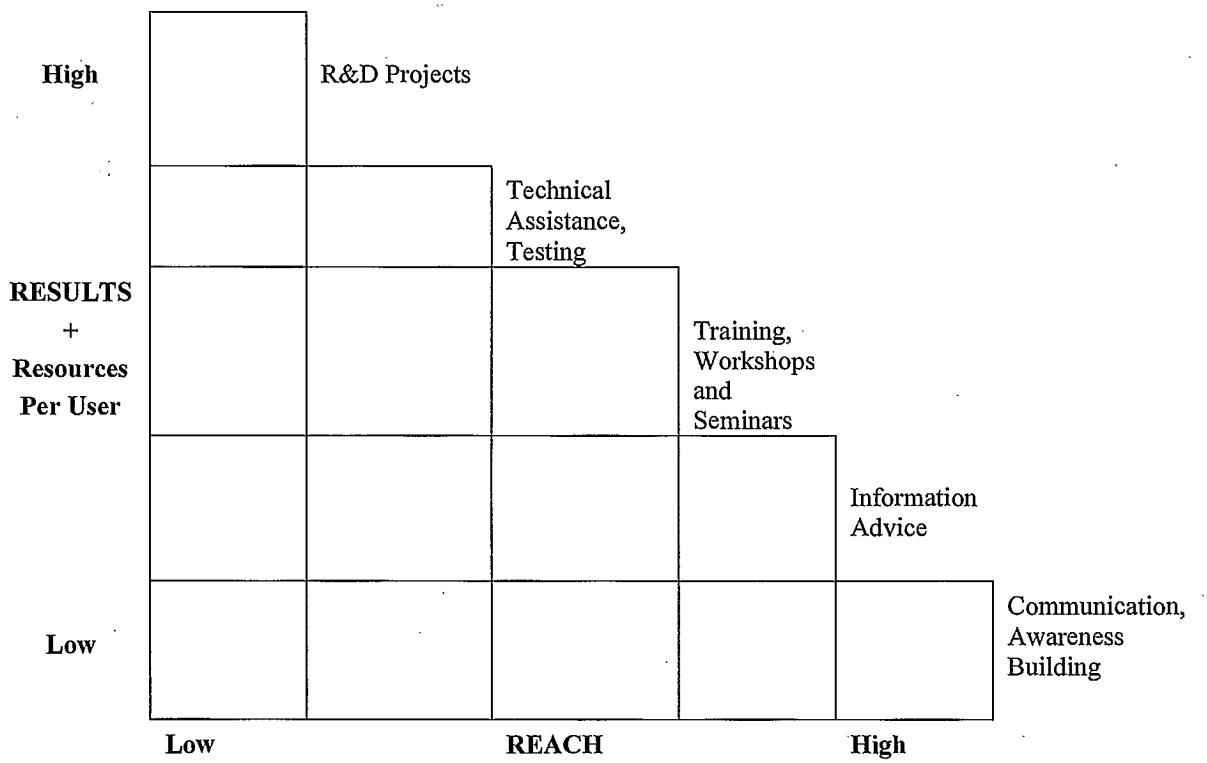
4.1.1 Context

This question can be considered as a more specific examination of one of the outcomes of Terrestrial Wireless Systems Branch activities and projects. It is also linked to the discussion in Section 3.4 on the effectiveness of the Branch in meeting Canadian needs for information about existing and emerging knowledge.

Research organizations need to acquire new knowledge before sharing it with the outside world. Knowledge acquisition can occur through knowledge creation or learning about new developments from others. It is also important to remember that "new knowledge" can mean different things to different people. If someone learns something they didn't know before, it is new to them, even if it is known to others. Knowledge transfer involves some form of interaction with the recipient, and most research organizations make use of a balanced mix of approaches. One primary method for those organizations with a mandate to support particular communities is through direct contact with target client groups through collaborations, contract research and advice. In addition, every research organization, except for those involved in commercially or defence confidential research, disseminate research results to the larger research community through a range of more widespread methods including seminars, workshops, conference presentations and publications.

In fact, the types of services which a research organization provides to its clients and collaborators can be classified in terms of the level of effort or resources required for each "service" provided and the extent of "reach" or number of clients or recipients reached by each service. **Exhibit 3** presents a summary of the main types of services and their characteristics.

Exhibit 3: Types of Activities and Services



The '*clustering*' of services or activities by level of results, cost per client, and reach can provide new perspective.

Source: The Three Rs of Performance: Core Concepts for Planning, Measurement, and Management, Performance Management Network Inc., 1997, p. 120.

Level of Resources, Reach and Results

As shown in Exhibit 3, an R&D project is typically very resource intensive and has only one or a few participants. Using this classification, an R&D project has a high cost per client or user, and a small reach (one or a few clients). In this case, knowledge is generally created. At the other extreme from R&D projects is knowledge dissemination, community awareness building and communication through publications, newsletters or via a website, which has a relatively low cost per recipient and can reach a large part of the target client group. In this case, there is sharing of existing, albeit often leading edge knowledge. While not "new" to those researchers keeping up with their field of research, it is likely new to many who are in the technology development and applications and user part of the community. Between these extremes in types of activities undertaken by research organizations are:

- in-depth technical assistance and testing to existing protocols;
- training and workshops; and,
- directed information dissemination, such as conference presentations or presentations to associations.

The type of knowledge transferred and the results or impacts expected from these different types of services also varies, with the largest and most direct impact per client or recipient expected from those services which have the highest cost per user. For this reason, the direct impact of publications on most individual clients is not expected to be high. However, the integrated effect of a small impact on a large number of recipients can be very large. Consideration of the outcomes of these different types of services requires careful examination of the number of people being reached, the impact on each one of the knowledge being received and integration of both factors.

The question of the contribution of TWS to needs for new knowledge will be addressed through an examination of Branch publications, complemented by information obtained from staff and client interviews. The analysis of the Branch publications in refereed journals, published conference proceedings and ITU reports found in Section 3.2 is also relevant to this question.

4.1.2 Detailed Findings

Document Analysis

In addressing this issue, publications from TWS were examined in terms of intended audience. There are a number of types of publications. These include:

- refereed papers in specific journals either targeted to specific audiences or for widespread distribution;
- published proceedings from conferences, which can be targeted or of general interest;

- publications for international radio organizations, such as ITU-R and URSI;
- contractor reports, containing the results of contract research projects;
- CRC research reports, which contain technical results of Branch research; and
- presentations of research results, reviews of scientific and technological knowledge in specific areas.

Each of these different types of publications has an audience, which may or may not be similar to others.

Publications in refereed journals present new knowledge developed by TWS to the widest audience. While they include Canadians, these audiences are typically international in scope. These publications contribute to the advancement of worldwide knowledge, and can be considered as part of Canada's contribution to the international supply of fundamental and applied knowledge. While the audience for these publications is broad, the subject matter covers issues of interest to TWS, its co-authors and stakeholders, and the research results published are linked to Canadian priorities. This is true of all published reports from the Branch.

While published proceedings from conferences can have a similar audience, they are often more focused on a particular problem or subject which is the theme of the conference. For example, last year, TWS had published conference proceedings in the IEEE International Symposium on Personal, Indoor and Mobile Radio Conference Microwave Theory and Techniques Symposium. This conference and publications have a more focused audience than many journals. The actual publications from these conferences were of interest and benefit to those interested in efficient utilization of spectrum for broadband wireless applications, a topic of great importance to Canada, as well as other countries.

Documents written for the ITU-R are also part of Canada's contribution to the international radio science community. These publications and contributions present the results of research and analysis relevant to the needs of these organizations, and serve Canada's interests as well, by keeping areas of importance to Canada on the agenda of these international regulatory bodies. The research data are used as the basis for setting international guidelines for use of radio spectrum, an area of international importance. It is in Canada's interest to be a credible contributor to scientifically based, internationally agreed upon regulations and protocols for the use of radio spectrum. SITT also participates in these international meetings and collaborates with the Terrestrial Wireless Systems Branch on presenting scientifically and technically sound Canadian positions.

Contracting-in reports contain the results of specific projects that an organization has contracted with TWS to undertake. In some cases, these reports are confidential, and are available only to the organization that funded the research. In these cases, the direct effects

of the research are available only to the contracting organization. However, in almost all projects, the Branch benefits through an increase in staff knowledge and expertise, and Branch reputation.

CRC research reports typically contain technical data and analysis which may not be suitable for a refereed publication or presentation at a conference, but is worthy of being captured and presented in report form. These publications are available for distribution to anyone with an interest in the subject.

Client Survey

As expected, almost all Branch project with clients result in new knowledge being created and shared with the client or collaborator. This was confirmed by the analysis in Section 3.3, where new knowledge was the outcome from projects most often mentioned by respondents. However, Section 3.4 identified weaknesses in the Branch's dissemination of information to clients and the larger community.

4.1.3 Summary

Contributing to meeting the needs of Canadian public and private sector organizations for new knowledge related to terrestrial wireless technologies is central to the mission of the Terrestrial Wireless Systems Branch. This knowledge is both created and learned from collaborating interacting with others. A number of methods of providing new knowledge to clients and the wider broadband wireless community are used. As shown by the publication analysis and client survey, these include the following:

- Conducting R&D for or with the client to develop new knowledge and sharing the results;
- Disseminating the results of research through a range of refereed publications, conference proceedings, contractor and internal technical reports, newsletters and web site material;
- Presenting results to clients and the research community through conferences, workshops and seminars; and,
- Providing scientific and technical advice to clients in support of public policy and private sector decision making.

4.2 *Do clients and collaborators have confidence in the quality of research, advice, testing and other services provided by the Terrestrial Wireless Branch?*

4.2.1 *Context*

This is a basic question to be addressed during all reviews of research organizations. While the narrow interpretation of the question relates only to client confidence in the quality of Branch research and abilities, it will be examined from a number of related perspectives, including client perspective on the quality of Branch staff, publications, and reports.

This question focuses on the perspective of existing clients and collaborators. Some of the clients are long term, particularly those of the Radio Communications Technology group and the Integrated Electronics group, which existed long before 1998, and transferred to the newly created Branch. Some of the clients and collaborators of these groups who were interviewed, have relatively long-term, established relationships with the research groups, which are continuing. These clients and collaborators continue to work with the Branch, so they must have confidence. For other newer clients, the answer is less obvious. Evidence was collected in the client survey to address this question from several perspectives, and this will be presented in the following section.

4.2.2 *Detailed Findings*

Client Survey

A number of survey questions relate to client perspectives on the quality of Branch research and services and on the qualities of Branch staff.

While respondents were not asked directly for their opinion about the quality of research, they were asked to identify the strengths of the Branch. The single most frequent response was the scientific and technical capability of the Branch, embodied in the competence and expertise of staff and the quality of equipment and facilities. Respondents were also asked why they worked with the Branch. Again, the most frequent response was related to the scientific and technical capabilities of the Branch staff aligned with the needs of the clients. In many cases, the Branch is the primary source of technical assistance for clients in the area of broadband wireless research, HF communications or high frequency microwave components. In others, the Branch is a full partner in collaborative research. These responses provide further evidence of the confidence clients and partners place in Branch research capabilities, advice and technical services.

In probing the quality of services, respondents were asked to focus on a specific project, and rate a number of specific features of the Branch, in terms of their satisfaction. The rating was on a scale of 1 to 10, with 1 being extremely low, and 10 being extremely high. **Table 6**, which follows, presents a summary of the results.

Table 6: Client Satisfaction with Branch Fractures

Branch Feature	Satisfaction with Feature*
Branch's understanding of your needs	8.2 (N=39)
Quality of equipment and facilities	8.4 (N=25)
Availability of facilities	8.0 (N=25)

* average rating of all respondents to this question, using a rating of 1 – 10, with 10 being extremely satisfied
N is the number of people surveyed who responded to this question

These data need to be interpreted carefully. Firstly, as mentioned previously, the sample of respondents was chosen by the Branch, and most had successful projects. As such, they are predisposed to be positive and supportive. In spite of this caution, the average ratings are all very high and indicate a high degree of satisfaction and confidence with these features of the Branch from this sample of clients.

An additional set of questions related to the quality of various Branch features asked respondents to identify other research organizations that they found comparable in some way to the Branch. Twenty-one respondents identified at least one other organization with capabilities similar to the part of the Branch with which they worked. They were asked to identify the other organization and compare TWS to it for a number of features. The other organizations identified are listed below in two categories, Canadian and foreign:

Canadian
- Defence Research Establishment Ottawa (DREO);
- CRC Satellite Branch
- Institut de la recherech electonique du Québec (IREQ);
- National Research Council of Canada (no longer);
- Institut national d'optique (INO);
- SPAR, now EMS;
- University of Manitoba;
- Queens University;
- Concordia Univesity;
- Nortel;
- ALCATEL; and
- Nanowave.

Foreign
- Harris;
- AMC;
- Defence Evaluation Research Agency, U.K.;
- QinetiQ, U.K.;
- DSTO, Australia;
- NASA;
- Los Alamos;

- Sandia;
- USAF; and,
- Research organizations in other NATO countries.

It can be seen that there is a wide variation in size and type among the named organizations. DREO and NRC are both federal government laboratories in Ottawa, near CRC. Others are Canadian universities. Yet others are foreign government or private sector research organizations.

Table 7 below contains the average ratings for those respondents who compared the Branch to another organization. The scale used was 1 to 10, with 1 being the Branch is much poorer and 10 being the Branch is much better than the comparable organization. A rating of 5 was used to denote equality. It is important to note that care must be taken in interpreting the average ratings due to the small number of respondents.

Table 7: Comparison of Terrestrial Wireless Systems Branch to Other Comparable Organizations

Feature	Average rating*
Quality of personnel	5.0 previously, now 4.8 (N=18)
Quality of facilities and equipment	5.1 (N=14)
Responsiveness	5.3 (N=15)
Overall	5.4 (N=12)

* On a scale of 1-10 with 1 being much worse than other organization, 5 being equal to other organization and 10 being much better than other organization

Most clients rated the Branch as equal to or slightly better than comparable organizations. Note that the Branch received the highest relative rating for responsiveness and overall comparability. It is interesting to compare the Branch's rating for responsiveness to those found in previous reviews for the Broadcast Technologies Branch (7.8) and the Radio Science Branch (5.8). The Broadcast Technologies Research Branch in particular was perceived by clients to be highly client oriented and responsive to their needs. This data indicates that TWS could do better in terms of being responsive to client needs.

While the ratings for quality of personnel and facilities and equipment may seem low, they are probably realistic. The Branch is being compared with a range of research organizations. In some cases, with other similar research organizations of the Canadian federal government in Ottawa, or with Canadian universities. In other cases, the comparable organizations are foreign world class laboratories, with considerably more resources, staff and facilities.

The quality and capabilities of staff are critical to the quality of research and testing. This aspect of the question is discussed further in Section 4.4. However, in giving their ratings for the quality of Branch researchers, many interviewees expressed concern that overall Branch capabilities have dropped recently due to the Branch's inability to retain qualified staff in the face of private sector hiring pressures and retirement. This is reflected in the ratings shown in Table 6 above, where several respondents stated that overall quality of

Branch personnel is significantly lower now than it was a couple of years ago. There is further discussion of this issue in Section 4.4.

In support of their level of confidence in the Branch, several interviewees gave specific examples of how the high quality of Branch research and staff contributed to the success of their project. In more than one case, the interviewee stated that the technical competence and capability of a Branch senior scientist was the critical element in the successful completion of a major project. In another case, research results presented to the ITU-R were immediately accepted and contributed to a greater appreciation of the Canadian position on policies for use by broadband wireless of spectrum. This was considered by the interviewee to be testimony to the quality and credibility of the TWS researcher.

Case Studies

In the case study on the development of a broadband wireless system for use in the 5 GHz LE bands, more than one interviewee stated that the credibility of the TWS researcher and the quality of the experimental results and presentation were major factors in the successful development of IEEE industrial standards and national and international spectrum utilization policies and regulations. Similarly, the confidence of RABC and SITT in the quality of research carried out at WISELab was a factor in the acceptance of their results and the development of Canadian policies for use of the LE 45 - 70 GHz bands.

4.2.3 Summary

Evidence collected from all sources clearly shows that major clients, partners, and collaborators have confidence in the quality of research, testing, and other services provided by the Branch. When compared to other similar laboratories, the Branch was considered by clients to be broadly comparable in terms of quality of staff, test equipment and facilities, and somewhat better in terms of responsiveness, and overall. However, the Terrestrial Wireless Systems Branch was rated lower in terms of responsiveness in this review than the Broadcast Technologies Branch or the Radio Science Branch had been in similar earlier reviews. As well, there was considerable concern among some interviewees about recent loss of qualified staff, leading to an inability to respond adequately to client needs.

4.3 Are Terrestrial Wireless Systems Branch collaborations and services meeting the needs of clients?

4.3.1 Context

This question has to some extent been covered by the analysis provided in Sections 3.1, 3.4, and 4.1). Each of these sections addresses the question from a different perspective. For example, the wish by many clients for more proactivity on the part of the Branch in providing information on emerging broadband wireless and other relevant issues was discussed in Section 3.4. The information and analyses provided previously will not be

repeated here. However, there is some additional information from the client survey that will be examined.

4.3.2 Detailed Findings

Client Survey

In an attempt to determine the extent to which existing services were adequate, the client survey asked respondents if there were additional services which the Branch could provide to better meet their needs. The large majority of clients were unable to identify additional services or capabilities, an indication that, for the most part, client needs are met. One respondent did suggest that the Branch should improve the documentation of software code being written, to facilitate transfer to clients. Several private and public sector clients of the Integrated Electronics group said that they had trouble getting access to the researchers in the group due to excess workload. Another private sector respondent asked that the Integrated Electronics group expand its capabilities and provide microwave component fabrication services to help small firms.

4.3.3 Summary

Based on evidence from the client survey, the Terrestrial Wireless Branch is meeting many of the scientific and technical needs of the existing clients. A few respondents identified additional services or asked for improved access to Branch researchers.

4.4 Are the capabilities of Terrestrial Wireless Systems Branch staff and the quality of facilities appropriate to the needs of clients and collaborators?

4.4.1 Context

Once again, the generally positive response of Branch clients and experts to many of the other questions under Issue 1 and in Section 4.2 and 4.3 immediately preceding are relevant to answering this question in the affirmative. However, the client survey addressed this question directly, and those results will be presented and discussed here, together with some input from the in depth interviews.

4.4.2 Detailed Findings

Client Survey

One obvious way to examine the relationship between the capabilities of Branch staff and the quality of facilities is to ask the clients. Survey respondents were asked to rate their satisfaction with several specific features of staff related to capabilities and service. Once again, a scale of 1 to 10 was used, with 1 being not at all satisfied and 10 being very satisfied. Those results are shown in **Table 8.**

Table 8: Client Perspective on TWS Branch Staff – Client Survey Results

Staff Feature	Average Rating
Scientific / technical competence	8.7
Responsiveness	8.2
Ability to meet deadlines	7.8
Overall quality	8.3

These results are very similar to those found in last year's review of the Radio Science Branch, and are broadly indicative of a satisfied client group, with confidence in the technical capabilities and supportiveness of Branch staff. However, there is useful information in some of the comments that accompanied these responses.

A number of respondents observed that for the Branch research group they worked with, the overall depth and breadth of scientific and technical capability has suffered in the recent past due to the significant loss of knowledgeable staff to the private sector and to retirement. To examine this issue in more detail, data was collected from each of the research groups on the number of staff who have left the Branch since its formation in April, 1998, and the total number of years of CRC experience which were lost with those departures. The results are presented in **Table 9** and **Table 10,** below.

Table 9 - Number of Staff Lost from TWS, by Year since Formation

Research Group	1998-99	1999-2000	2000-2001	2001-2002	Total
Broadband Wireless	0	2	2	0	4
Integrated Electronics	0	0	2	0	2
Radio Communications Technologies	5	5	1	2	13
Wireless Applications and Systems	0	0	1	0	1
TWS Branch	**5**	**7**	**6**	**2**	**20**

Table 10 - Number of Years of CRC Experience in Staff Departures in TWS, by Year since Formation

Research Group	1998-99	1999-2000	2000-2001	2001-2002	Total
Broadband Wireless	0	6	3.5	0	9.5
Integrated Electronics	0	0	12	0	12
Radio Communications Technologies	49	32	3	47	131
Wireless Applications and Systems	0	0	10	0	10
TWS Branch	**49**	**38**	**28.5**	**47**	**162.5**

Of the 20 departures, 2 were due to retirement. The Branch lost the entire complement of the Narrow Band Wireless Research Group (shown in Tables 8 and 9 as 0part of Radio Communications), with expertise of great importance to both DND and private sector firms

providing military wireless communications equipment. The Broadband Wireless group also had significant losses relative to the group size (4 out of 7).

It is understandable that clients and collaborators are concerned about loss of expertise and its effects on scientific capabilities within the Branch. It is impossible to lose this number of years of experience without having an effect on the quality of the research program.

It is however important to note that since these losses, the Branch has had considerable success in replacing the lost expertise with new resources. The new staff are learning rapidly, and bringing new skills and energy to complement those already in the Branch.

4.4.3 Summary

Results from the client survey indicate that clients and collaborators are generally satisfied with the capabilities of TWS staff and the qualities of equipment. However, there has been concern about the significant loss of experienced staff to the private sector over the past two or three years, and its effect on the ability of the Branch to deliver quality services in an effective manner. Recently, the Branch has been able to replace these departures with new employees, who are gaining experience rapidly and beginning to contribute effectively.

4.5 What is the nature and extent of collaborations by the Branch with other CRC Branches and with other organizations?

4.5.1 Context

In 1998, there was a major reorganization of CRC into five branches, each with a Vice President. The branches are:

- Terrestrial Wireless Systems;
- Broadband Network Technologies;
- Broadcast Technologies Research;
- Satellite Communications; and,
- Radio Science.

The nature and extent of collaborations between the Terrestrial Wireless Systems Branch and the other four CRC Branches and corporate groups is examined in this section. Project work which is done by TWS on behalf of external clients is not included in this analysis. Collaborations between the Branch and organizations external to CRC, including universities, other government laboratories, and private sector laboratories are also examined. Primary sources of information for the analysis include document review, publication analysis and staff interviews.

4.5.2 Detailed Findings

Document Review

Analysis of the Activity Reports for TWS for the past three years identified several collaborations with other branches of CRC and other organizations, which are listed below.

Within TWS Branch

- development of a C-band MIC driver for Broadband Wireless by the Integrated Electronics Group.

Internal to CRC

- development of prototype antennas and related advice from the Advanced Antenna group and development of models for outdoor 5.2 GHz propagation by the radiowave propagation Group in Radio Science Branch in support of the Broadband Wireless WEB and "MILTON" project;
- development of high speed modem by Caron Group within the Satellite Branch for incorporation into the Broadband Wireless WEB and "MILTON" project;
- collaborative research on space wave modelling and rain attenuation on fixed mmwave radio links with the Radiowave Propagation group of Radio Science Branch by the Radio Communications Technologies group;
- collaboration with Propagation Group, Radio Science Branch on attenuation effects of the interaction between wind and tree leaves at 50 – 70 GHz by WISELab;
- development of group demultiplexer/demodulator for VPSAT Advanced SATCOM program by Integrated Electronics; and ,
- collaboration on neural network classifier for spectrum monitoring with VPSAT by Integrated Electronics.

External

- with the Spectrum, Information and Telecommunications Technologies Branch at Industry Canada and the Radio Advisory Board of Canada, development of spectrum utilization policies and regulations for 5 GHz and 40 – 70 GHz licence exempt bands;
- with representatives of the wireless communications industry, development of IEEE 802.16.4 international wireless licence exempt communications standards by Broadband Wireless Group;

- with OCRI, deployment and testing of a high speed WEB link between Glebe High School and the OCRI Media Centre;
- with CresTech, DND, US DoD, NASA, Mount Allison University and the University of Western Ontario, measurement of Leonid meteor shower by Radio Communications Technologies Group;
- with UWO, research on position determination of radio transmitters by multiple baseline interferometry by Radio Communications Technologies Group;
- with University of Ankara and University of Manitoba, development of radio transmitter identification techniques by Radio Communications Technologies Group;
- with Lucent, development of frame synchronization techniques for broadband mobile wireless by Radio Communications Technologies Group;
- with DREO, miniaturization of EHF T/R modules for phased arrays by Integrated Electronics Group;
- with Defence Evaluation and Research Agency U.K., research on **D**oppler **A**nd **M**ultipath **SO**u**N**ding (DAMSON) by the Radio Communications Technologies Group;
- with the Canadian Microelectronics Centre and OCRI, development of remote MMIC measurement and testing facility, by Integrated Electronics Group;
- with the Centre for Development of Telematics (C-DOT), India for MMIC and VLSI research, development and training by Integrated Electronics;
- with Carleton University/CITR, development of Microwave microelectromechanical systems (MEMS) and high performance macrocells for narrow and wideband receivers using VLSI technology by Integrated Electronics Group.

A review of the client and project list discussed in Section 3.2 (also see Annex B) reveals a few projects with partners internal to CRC and a significant number of collaborations with external colleagues. In almost all cases, these have already been identified in the list above. These include projects with universities here in Canada (UWO, Manitoba, RMC, etc.) and abroad (Ankara), as well as some with foreign defence related research organizations.

A review of joint authorships of Branch publications, previously discussed in Section 3.2 also revealed a number of collaborations between Branch staff and individuals in Canadian and foreign universities. Although a number of contracts have been performed for the Canadian and foreign private sector, no joint papers have been published with the private sector.

The Integrated Electronics Group in particular has had the most collaborations with Canadian university research groups, usually involving graduate students. This is a deliberate strategy of the group to broaden its research network. Several researchers from this group have adjunct professorships at Canadian universities (Carleton and Laval). These relationships assist in fostering such collaborations.

The Radio Communications Technologies Group also has a number of collaborations involving Canadian and foreign universities and foreign defence related research organizations. The international collaborations are reflective of the international scope of their work on behalf of DND.

It is interesting to note that, except for the Integrated Electronics Group, there are almost no joint authorships of published papers or conference proceedings with staff from other CRC branches.

Staff Interviews

Evidence from staff interviews corroborates the evidence from the annual reports and publication analysis, as most collaborations between the Branch and other CRC branches are informal and occur between staff members as required to exchange information. In fact, revenue generation pressures discourage collaborations, unless in the form of a subcontract or directly linked to Branch objectives, as helping another branch can mean using A-base resources to help achieve the objectives of the other branches. Many of the collaborations with other CRC Branches occurred through subcontracts. Some of the university collaborations are actually contracts with university professors to conduct research on behalf of TWS.

Interviews with staff from other CRC branches confirmed that most branches are relatively independent and work primarily with external clients and partners in their area of expertise, not together. Collaborations do occur on an as needed basis, if they meet the needs of both parties.

4.5.3 Summary

Several TWS research groups, namely Integrated Electronics and Radio Communications Technologies have a significant level of collaboration with university and other public sector laboratories.

However, there is less evidence of formal collaborations with other CRC branches. Most interactions are informal, and involve development of components for or by TWS research groups, often through subcontracts which provide funding. The Branch does have a number of formal collaborations with Canadian and foreign universities, as well as foreign government research laboratories. The adjunct professorships of Branch staff are

instrumental in the university-based collaborations, and help provide access to basic research knowledge.

4.6 Quality - Summary

The issue of the appropriateness of the quality of research and services was reviewed through a number of complementary methods. Based on the client survey results, and in-depth interviews, the large majority of clients and collaborators are generally highly satisfied with the quality of research and technical services provided by the Branch, and have confidence in the results obtained. Clients and informed stakeholders also agree that existing services are highly relevant to the needs of the wireless communications community. When clients were asked to rate their satisfaction with the Branch's contribution to a specific project, the average rating was 8.2 out of 10. This is a high rating, indicating a positive relationship between the Branch and the clients surveyed. However, as stated previously, some interviewees from Spectrum Engineering and other CRC branches were concerned about a mismatch between the Branch's focus on longer-term research and their needs for support for shorter-term applied and developmental projects. In the past, this has at times led to the Branch's unwillingness to meet their requests for assistance.

However, the Branch focus on longer-term research is consistent with the direction being taken by CRC, following last fall's recommendations from CRC's Board of Directors and the support of the DM.

A number of clients thought that the quality of research and the breadth and depth of scientific and technical capability is now lower than it has been due to the large number of vacancies, now approaching 25%, and inability to retain qualified professional staff. Many noted that there has been a significant loss in the past several years of highly qualified staff, leading to a loss of important research and testing capabilities in the Branch. However, it should be noted that the Branch now has a full complement of staff, and that new employees are rapidly gaining experience, and are beginning to contribute to effectively meeting client needs.

For those interviewees who worked with other communications laboratories, the Branch also compared reasonably favourably. In some cases, these other organizations were large national laboratories much better funded than the Branch, so in that respect clients noted that the comparison may not be fair. On average, clients rated the quality of Branch equipment and facilities, quality of personnel, and overall responsiveness to client needs slightly better than these comparable organizations.

4.7 Quality - Recommendations

4.7.1 Hiring and Retention of Qualified Staff

The Terrestrial Wireless Systems Branch should treat the hiring and retention of qualified professional staff as a priority. Hopefully, now that the overheated technology sector of the economy has returned to a more normal level, potential employees will consider working in the Branch more favourably. As a short-term measure, other avenues should be explored, such as working with university professors on sabbatical, secondments from other organizations, and increased use of graduate and post-graduate students.

The Broadcast Technologies Research Branch has had good success over the past year in finding qualified staff to fill a number of vacancies, and it may therefore be useful for the Radio Science Branch to consult with this Branch to determine its approach.

5.0 Alternatives

Issue 3: Are there alternatives to the present design and delivery of programs and services within the Terrestrial Wireless Services Branch that can better meet the needs of the public and private sector ?

This issue provides an opportunity to examine the present design and delivery approach being employed within the Terrestrial Wireless Systems Branch, at both the Branch and research group levels.

As for the other review issues, alternatives were addressed by examining a number of specific questions. One concerns the degree to which the Branch is in fact a cohesive unit, or a collection of parts, each with its own specific objective, clientele and stakeholders. Another is an examination of the mechanisms in place to ensure that programs and activities within the Branch are aligned with client and stakeholder needs. A third is the adequacy of resources to provide a balanced mix of research, development, testing and advice to meet client needs. The fourth and final question addressed under this issue is more general, and provides an opportunity to identify and address any areas where improvements which have not been covered previously under a specific research question can be identified.

The information to address the questions under this issue comes from a variety of sources, primarily client and staff interviews, Branch internal documents and expert interviews.

5.1 To what extent do managers and staff of the Terrestrial Wireless Systems Branch have a clear understanding of Branch objectives, strategy and their role in achieving them?

5.1.1 Context

Since the mid 1990s, proactive management of S&T programs has emerged as a new focus within the government of Canada. For example, the 1996 government review of S&T review identified the need for new approaches to governance and improved consultation with stakeholders. The Council of Science and Technology Advisors has also published several reports identifying the need for more active management of government S&T programs. As well, the Industry Portfolio has made a commitment to providing greater attention to the management of S&T. These government and portfolio level policy statements imply more proactive management, and a more integrated approach, with resource allocation and project selection decisions being tied more directly to planned outputs and outcomes, with a balance between bottom-up and top-down decision making and management. The Branch's current approach will be examined in light of this new environment.

In addressing this question, it is important to review the formation and development of the Branch, which was formed in April 1998, as part of a reorganization of CRC. During the reorganization, the CRC management structure was flattened, with one level of management

(directors) being removed, leaving a Branch Vice President and managers for each of the Branch research groups. Several existing research groups (Radio Communications Technology, Narrowband Wireless, Voice Systems and Technologies, and Integrated Electronics) were moved to TWS, and one new group (Broadband Wireless) was formed. Soon after the Branch was formed, an additional new group was formed, linked to the development of a Wireless and Internetworking Systems Experimentation Laboratory (WISELab). Since the formation of the Branch four years ago, Narrowband Wireless and Voice Systems and Technologies have been amalgamated within the Radio Communications Technology group due to the loss of research managers due to departure and retirement. Also, as discussed in Section 4.4, there has been a major turnover in Branch staff due to retirement and departures. In March, 2002, four years after its formation, the Branch remains in transition. This is important background context to the examination of this issue.

5.1.2 Detailed Findings

Staff Interviews

In terms of operational and strategic decision making, information gathered in staff interviews suggests that most responsibility is distributed to the four group managers and their senior scientific and engineering staff, who have significant freedom to operate within their own domain, in keeping with established broad guidelines. In reality, the four groups seem to be operating fairly independently at the present time.

The four group managers meet regularly with the Branch Vice-President to discuss delivery of Branch services. Staff reported that the Branch has an annual workshop, at which time all members of staff get together. Research groups discuss their research objectives and achievements, and identify future priorities.

Document Review

A review of recent TWS Annual Business Plans and reports also suggest that research groups operate largely independently, with differing approaches, cooperating where operationally useful. Clients and projects of the four groups are largely independent of one another, limiting the need for collaboration and interaction.

The presentation by the Branch Vice President for the review demonstrated that the Branch had thought carefully about its role in contributing to CRC objectives and those of Industry Canada. Each of the four research groups can be shown to be aligned with organizational and departmental objectives. As well, the presentation identified Branch level priorities and those research activities that were of lower priority.

The CRC 2001 Strategic Plan identified Remote Broadband Access as a major new initiative for the organization. TWS is well positioned to contribute to this initiative. This may become an opportunity to bring the capabilities and expertise from the various Branch research groups together to address a common objective.

5.1.3 Summary

Evidence available from staff interviews and document review suggests that group managers and staff are primarily interested and aware of the strategy and objectives of their own research group and their role in achieving them. Groups seem to operate largely independently, with differing approaches, co-operating where operationally useful. It was suggested that the clients and projects of the four groups are largely independent of one another, limiting the need for collaboration and interaction. The Branch Vice President and group managers do meet regularly to plan and co-ordinate their research. The new Remote Broadband Access initiative may provide an opportunity to develop an integrated Branch level approach to address a common objective.

5.2 What mechanisms are in place to ensure that Branch programs and activities are well aligned with the needs of clients and stakeholders?

5.2.1 Context

As discussed in Section 4.1, government is moving to a more formal and documented approach to the management of S&T programs. In many cases, major clients and stakeholders have formal mechanisms for identifying their needs to assist research organizations in aligning their research programs.

In many organizations, research groups demonstrate that their research programs are aligned with client and stakeholder needs through their Annual Business Plans. These Business Plans describe resource allocation, and new research initiatives in terms of their relationship to present or emerging stakeholder requirements.

The manner in which TWS identifies research priorities and demonstrates their alignment with clients needs will be examined.

5.2.2 Detailed Findings

Document Review

An examination of TWS Annual Business Plans and progress reports since the formation of the Branch shows that it is not the practice within the Branch to identify future plans, nor project progress in terms of stakeholder needs. This is consistent with the findings of previous reviews of Broadcast Technologies and Radio Science Branches within CRC. Based on the approach used by these three branches, it seems that CRC has not formalized the reporting of research initiatives in terms of client needs.

An examination of TWS resources as found in Table 1 shows that only 65% of salaries and 25% of operational funding is provided by A base funding, with the remainder provided by

clients, primarily DND, SITT and contract revenue. It is clear that a major fraction of Branch resources are provided by clients and stakeholders to conduct research and development to meet their needs. This is an effective mechanism to ensure that their needs are being met.

Staff Interviews

Interviews with staff revealed that all of the research projects performed on behalf of DND through Defence R&D Canada (DRDC) are funded by specific client groups to meet their specific, defined needs. This approach is used by DRDC for all their research to ensure that research is relevant to the needs of clients and that clients take responsibility for allocation of resources and definition of projects. Similarly, SITT identifies its research needs and funds specific projects with defined objectives. Other contract related resources are provided by clients for TWS to conduct specific contract research or testing.

Managers also stated that most A base funding is used to buy equipment and conduct the longer term research needed to build and maintain the technical capability and infrastructure to perform the applied projects.

5.2.3 Summary

Based on an analysis of documents and discussions with staff and clients, it is clear that the control of the allocation of resources and funding of projects by major clients such as DND and SITT is the primary formal mechanism to ensure that Branch programs are aligned with client needs. Similarly, contract research is by its nature defined by clients to address their specific needs.

5.3 To what extent does the Branch have adequate resources to meet client needs?

5.3.1 Context

This question has several dimensions. They include both the adequacy of A base resources and the willingness or ability of clients to contribute to meeting their needs.

The ability of Branch staff to meet client needs is another dimension. This question has been extensively examined in previous section and will not be dealt with further here. There is clear evidence that there is a problem with the adequacy of human resources to meet client needs, particularly at the intermediate and senior researcher levels. As shown in Section 4.4, there has been major loss of staff due to departure and retirement. A number of respondents to the client survey have stated that the loss of staff has reduced the capability of the Branch to meet their needs. In the most extreme example, the loss of a complete group of researchers working on NATO STANAG waveforms has severely compromised the ability of the Branch in this area of expertise. There are a number of other examples.

In this section, the adequacy of financial resources will be examined from four perspectives. They include:

- fair sharing of A-base resources among branches;
- the contribution of clients and collaborators towards research projects;
- the share of CRC A base resources received by the Branch compared to the needs of the Wireless Sector; and,
- potential sources of additional resources.

Evidence for the examination of these questions comes primarily from document review and staff interviews. CRC corporate managers were particularly helpful in providing information.

5.3.2 Detailed Findings

Sharing of CRC A Base Resources Among Branches

At the time of the reorganization of CRC, a detailed analysis was made of the appropriate allocation of operational funds among the Branches. After careful examination, there was no evidence found that any type of research warranted more or less funding. Consequently Branch allocations were made based on a minimum level of funding for each staff member to pay for training and conferences, etc, plus a larger amount as base budget for each researcher. The amount was $12,000.

This is clearly a very low level of research funding. However, it was the result of an earlier decision in the early 1990s by CRC management when faced with resource cuts. At that time, a decision was made to maintain as many staff positions as possible, and reduce the levels of operational funding disproportionately. These earlier decisions continue to have their effects at the present time. They effectively drive research managers to seek additional sources of funding to pay for the costs of conducting research.

Contribution of Clients and Collaborators Towards Their Research Projects

There are two major TWS client groups, SITT and DND. They will each be examined.

In the case of SITT and Spectrum Engineering, the amount of research funding available annually has dropped over the past decade from about $2 million, to $600K. In most cases, Spectrum Engineering funding covers only a portion of the costs of research projects. However, as the main mission of CRC is to provide "an independent source of advice for policy purposes", many in SITT believe that CRC's A base funds are to be used to meet their needs. In the case of the earlier reviews of Broadcast Technologies and Radio Science, this was clearly the case. As shown in Table 2 TWS does receive about $160K from Spectrum

Engineering, which is about 25% of the SITT funds available. The large majority of these funds are going to WISELab, to support specific projects and assist in building their expertise and capability.

DND provides funding for 12.5 FTE staff, which is over 25% of Branch staff, and an additional $970K in operational funding, which is 40% of Branch operational funds. Within the Branch, the Radio Communications Technology Group receives the lion's share of DND staff and operational funding, with the Integrated Electronics Group receiving a small portion.

In order to leverage resources, TWS has developed several international collaborations that have brought a significant level of revenue into the Branch, as well as additional human resources to work on research linked to Branch needs. These have been a mixed blessing. As mentioned previously, the Branch has had to reduce its level of support to traditional clients in order to make room for these new relationships and sources of revenue.

In order to get a sense of the level of O&M resources available to the Branch compared to other branches, the financial information from the previously reviewed branches, namely Broadcast Technologies and Radio Science, was compared to TWS. This analysis reveals that there is about twice as much O&M funding per TWS staff person as for the other two branches ($51K, compared to $26K). Much of the additional O&M funding for TWS comes from DND, which has had a policy of providing adequate operating resources to conduct research. It is also true that some of the operational costs of TWS Branch research groups are very high. For example, within the Integrated Electronics Group, a foundry run for MMIC devices typically costs $85 - $100K, and more than one run per year can be required. Often sufficient funds are not available.

Share of CRC A-Base Resources Coming to Terrestrial Wireless Services Branch Compared to the Needs of the Wireless Sector

There are a number of factors to be considered under this topic. The first is the level of effort devoted to the Wireless Sector. If the work tied to DND, which is directed to that specific client is excluded, there are a total of 34 FTEs and $ 1.4 million in O&M funds assigned to the support of the public and private sector needs linked to wireless telecommunications. This level has not changed since the formation of the Branch in April, 1998, even though the level of business activity in the Wireless Sector in Canada and internationally has exploded, with the opening of additional, higher frequency licence exempt bands.

There is some specific evidence that more resources are needed within the Branch. A number of respondents to the client survey, particularly those linked to Radio Communications Technology and Integrated Electronics stated that a weakness of the Branch was the lack of sufficient resources to meet their needs. It must be remembered that this survey was conducted following the loss of staff to the private sector during the past two or three years.

It is also true that the Wireless Sector is supported by research conducted in other CRC Branches as well as TWS. These include Radio Science, Space and Broadcast Technologies. Unfortunately, in most cases, research is carried out independently, and is not focused on achievement of a more holistic systems level solution.

Potential Sources of Additional Resources

There are some potential sources of additional resources for CRC, some of which could come to TWS for new wireless related projects. The major new research initiative in Remote Broadband Access identified in the CRC 2001 Strategic Plan may provide an opportunity for additional resources. As needs are analyzed and CRC plans are developed, it is likely that additional funds will flow into CRC to undertake specific initiatives, and the Branch is well placed to undertake needed research and testing.

There is also the possibility of reallocation of resources within CRC to provide a greater effort and focus on this priority initiative. As mentioned previously, an early review of the capabilities of the various Branches that are linked to the Remote Broadband initiative shows that TWS is well positioned to be a major participant and contributor to this initiative.

5.3.3 Summary

Based on an analysis of A base and total Branch resources, TWS research staff seems to be relatively well resourced compared to other branches. Much of the additional operational funding is provided by DND for their projects. Recently, some new projects which have been brought in to provide revenues have reduced the availability of support to previously existing clients.

The Branch has had difficulty responding to the recent increased needs for wireless related research by the public and private sector. There has been no increase in A-base funding since the Branch was formed in 1988, and to date, there have been no significant additional resources available from Canadian sources.

However, there are a number of new and potential wireless related initiatives within Industry Canada and the federal government that may provide the opportunity to significantly increase the level of resources available to TWS. The Branch will be required to aggressively seek out opportunities and demonstrate Branch relevance and capabilities in order to be successful.

The Remote Broadband Access initiative is the most obvious opportunity for TWS. WISELab is well positioned to provide systems related R&D, measurement and testing of various approaches to linking broadband wireline, satellite and wireless technologies to meet the needs of the community. Several other Branch capabilities are also relevant to potential research areas.

5.4 What lessons can be learned to improve the efficiency and effectiveness of the Terrestrial Wireless Systems Branch?

5.4.1 Context

During the course of this study, several items have been identified which did not fit within the specific research questions which were addressed. This question provides the opportunity to describe and discuss these issues.

All sources of information contributed to this question, as well as the integration and analysis phase, which pulled together the information from various sources.

5.4.2 Detailed Findings

Carrying out of Similar or Related Research in Different Branches

One general concern in conducting reviews of government programs is the possibility of branches acting as "stovepipes", looking primarily inward, and not being aware of other groups carrying out similar work, which could benefit from a partnership or collaboration. This may be the case in CRC.

Based on documents reviewed in undertaking this and the previous studies of Broadcast Technologies and Radio Science Branches, there are examples of research with similar titles being carried out in more than one group and more than one Branch. An examples is Multiple Input/Multiple Output transmission and receiving (MIMO), which is being investigated in Terrestrial Wireless Systems and Broadcast Technologies Branches. Another example is research associated with adaptive antennas.

On the surface at least, there is good reason to believe that research which is potentially complementary is being carried out within several CRC branches. It may be appropriate to determine to what extent the research is complementary, and, if so, develop mechanisms for collaboration.

Level of Acceptance and Utilization of WISELab within CRC

There were several reasons given originally for the development of WISELab. One was to provide a testing capability for private sector wireless telecommunications firms to measure the characteristics of new products and systems. The second was to encourage CRC researchers to move beyond individual prototypes and products to a more systems perspective.

To date, WISELab has had one project to test a CRC product or system, and that was with the Broadband Wireless Research Group to test a Wireless Ethernet Bridge for use at 5 GHz. This data, together with information gained in discussions with researchers from

other branches, shows that that other branches have their own measurement capabilities, and, at least until now, have not seen the benefit of utilizing the testing or research capabilities of WISELab. There has also been a drop off in planned collaboration with other Branches in the development and implementation of measurement capability.

Based on this evidence, it is clear that WISELab is still in the developmental phase, and is seeking a client base. WISELab is well positioned to contribute to the Remote Broadband Access initiative within CRC, which may encourage use of the facility by other CRC branches. Also, as the wireless telecommunications private sector grows and moves into new, higher frequency bands, there is potential for use of WISELab to test components and systems against SITT requirements.

Role of Business Office in Client Negotiations

Because of the additional compensation provided to researchers for revenue producing projects, there is always some concern about conflict of interest, especially when researchers are heavily involved in negotiations for private sector access to their own technology.

The survey of clients also revealed a few complaints by private sector clients about this issue. One respondent suggested that researchers should focus on what they do best, research, and leave the business negotiations to those who have training and experience in that area. One CRC interviewee also gave an example of a researcher not recognizing the commercial value of his own work, and negotiating a licence fee considerably less than its market value.

5.5 Summary

Based on evidence available, since the formation of the Branch in 1998, the four research groups within Terrestrial Wireless Systems Branch have operated largely independently. They each have their separate clients and research interests. The recent Remote Broadband Access initiative within CRC may provide an opportunity for the Branch to develop a more integrated research and delivery approach.

Based on a review of Branch business plans and progress reports, there is little evidence that the Branch has a formal mechanism for aligning research priorities to client needs. It seems that the primary mechanism for ensuring that client needs are met is the control by major clients (SITT and DND) of a large fraction of the total Branch resources. This ensures that the majority of Branch research programs are closely linked to their needs.

A review of Branch resource levels compared to other branches shows that the Terrestrial Wireless Systems Branch has more O&M funds than other branches. This is largely due to the DND funding received, which is reserved for projects of the Radio Communications Technology Research Group. The CRC Remote Broadband Access initiative and other related federal initiatives provide a major opportunity for the Branch to demonstrate its relevance and gain access to additional funding.

During the course of this extensive study, several issues arose which did not conveniently fit within the various research questions being addressed. These led to specific recommendations, which are shown below, to address the problem.

5.6 Recommendations

5.6.1 Develop mechanisms to encourage discussion among groups working in complementary areas

CRC should identify research areas of broad interest and develop mechanisms to encourage groups working in areas of potential complementarity to hold discussions and share information. Potential mechanisms include seminars and workshops. Having guest speakers from the stakeholder and potential user community is a possible approach. To maximize credibility and effectiveness, it is likely best if the initiative is led by researchers knowledgeable about the subject.

5.6.2 Support for awareness and utilization of WISELab measurement and testing capabilities

In order to encourage CRC Branches to learn more about the capabilities of WISELab and its potential role in meeting their needs, CRC senior management should proactively support the use of the facility by CRC researchers and external clients. Information about the recent use by the Broadband Wireless Research group to obtain valuable data on their WEB prototype device could be used as an example of the value of WISELab, and shared with other Branches.

5.6.3 Involvement of CRC Business Office in all client negotiations

In order to ensure that CRC and government interests are protected and to ensure that business negotiations are handled by those with capabilities and responsibilities in that area, it is recommended that the CRC Business Office be brought in early to all negotiations with private sector clients. This would also eliminate any possibility of complaints by clients about the self interest of researchers affecting negotiations.

ANNEX A - List of CRC Managers and Staff Interviewed

Name	Position
Mr. Gerry Turcotte	President, Communications Research Centre
Dr. Gerry Chan	Vice President, Terrestrial Wireless Systems Branch
Dr. John Sydor	Broadband Wireless Group Manager
Mr. Joe Schlesak	Radio Communications Technology Group Manager
Dr. Trish Willink	Radio Communications Technology Group
Dr. Valek Szwarc	Integrated Electronics Group Manager
Dr. Malcolm Stubbs	Integrated Electronics Group
Mr. Luc Boucher	WISELab Manager
Dr. Erle Jones	Director, Corporate Strategies and Issues

A number of the clients and collaborators who completed the telephone survey also provided input on the appropriate roles and strategic positioning for the Branch.

ANNEX B - Client Interview Questionnaire

CRC Terrestrial Wireless Systems Branch
Client / Partner Interview Guide

Contact name: _____

Organization: _____

Telephone #: _____

Introduce yourself and the study.

1. How many people does your organization employ on a regular full-time basis at this location?

   _____ **EMPLOYEES**

2. For how many years have you been dealing with the Terrestrial Wireless Systems Branch / CRC?

   _____ **YEARS Branch**

   _____ **YEARS CRC**

3. During those years, how many research projects have you had with the Branch?

   _____ **RESEARCH PROJECTS**

4. Which group(s) in the Branch have you worked with?

   _____

   _____

5. Why do you work with the Terrestrial Wireless Systems Branch? *Probe:* Any other reasons?

   _____

   _____

The letter you received from CRC identified a specific project *(read project information from list)*. I would like to ask you several questions about that specific project.

6. *If project is completed, read:* Overall, how successful was this project? Please use a scale of 1 for not at all to 10 for very successful.

1 2 3 4 5 6 7 8 9 10 DK

If project not completed, read: **Overall, how successful do you anticipate this project will be? Please use a scale of 1 for not at all to 10 for very successful.**

1 2 3 4 5 6 7 8 9 10 DK

7. Why do you say that? *Probe:* Any other reasons?

_____

_____

_____

8. Using a scale of 1 to 10, 1 being not at all important and 10 being very important, how important are each of the following, as it relates to this project?

1 2 3 4 5 6 7 8 9 10 DK

9. Also using a scale of 1 to 10, 1 being not at all satisfied and 10 being very satisfied, how satisfied are you with the Terrestrial Wireless Systems Branch on this for this project?

Feature	Q.7 – Importance		Q.8 – Satisfaction	
	Rating	DK / NA	Rating	DK / NA
Branch's understanding of your needs		X		X
Quality of Branch equipment and facilities		X		X
Availability of CRC facilities for your project		X		X
CRC's link to IRAP		X		X
Branch's link to other parts of CRC		X		X
Branch's link to other organizations		X		X
Overall, how important was the Branch to this project? / Overall, how satisfied are you with the Branch's contribution on this project?		X		X

10. If the Branch had not been available, would there have been a major, minor or no effect at all on this project?

MAJOR **1**

MINOR **2**

NO EFFECT ..... **3** *Skip to Q.12*
DON'T KNOW / TOO EARLY TO TELL ..... **X** *Skip to Q.13*

11. What would have happened? *Probe:* Anything else?

_____

_____

Skip to Q.13

12. Why do you say that? *Probe:* Any other reasons?

_____

13. Did the following occur as a result of this project?

14. *If not:* Do you anticipate that this will occur in the future as a result of this project?

15. *If yes to Q.13 or Q.14, ask:* To what extent is this due or will this be due to the involvement of the Terrestrial Wireless Systems Branch on the project? Please use a scale of 1 to 10, 1 being not at all and 10 being to a great extent.

Result	Q.13 – Occurred		Q.14 - Will occur		Q.15 - Due to Branch
	Yes	**No**	**Yes**	**No**	
Solution to technical problem	1	2	1	2	
New knowledge	1	2	1	2	
Increased scientific or technical expertise / capability	1	2	1	2	
Reduced development time	1	2	1	2	
New or improved products	1	2	1	2	
New or improved process	1	2	1	2	
Cost savings / more efficient operation	1	2	1	2	
Increased competitiveness	1	2	1	2	
Increased sales	1	2	1	2	
Others *(Please specify)*	1	2	1	2	
New or improved policies / regulations	1	2	1	2	

16. On a scale of 1 to 10 with 1 being not at all relevant and 10 being very relevant, please rate the relevancy of the Terrestrial Wireless Systems Branch capabilities to the needs of your organization.

1 2 3 4 5 6 7 8 9 10 DK

17. Overall, how satisfied are you with Branch staff on each of the following? Please use a scale of 1 to 10, 1 being not at all satisfied and 10 being very satisfied.

Feature	Not at all									Very
Scientific or technical competence	1	2	3	4	5	6	7	8	9	10
Responsiveness of Branch researchers	1	2	3	4	5	6	7	8	9	10
Ability to meet deadlines	1	2	3	4	5	6	7	8	9	10
Overall quality of Branch staff	1	2	3	4	5	6	7	8	9	10

18. Does the Terrestrial Wireless Systems Branch help keep your organization aware of emerging trends in broadcast technologies and systems?

YES 1

NO ..... **2** ☐ ***Skip to Q.21***

19. How important is it to your organization that the Branch keep you aware of emerging trends? Again, please use a scale of 1 to 10, with 1 being not at all important; and 10 being extremely important.

1 2 3 4 5 6 7 8 9 10

20. How well does the Branch keep your organization aware of emerging trends? Please use a scale of 1 to 10, with 1 being not well and 10 being extremely well.

1 2 3 4 5 6 7 8 9 10

21. What are the strengths of the CRC Terrestrial Wireless Systems Branch? *Probe:* Any others?

_____

_____

22. What are its weaknesses? *Probe:* Any others?

_____

_____

23. Have you worked with organizations, which are similar to the Branch?

YES 1

NO 2 Skip to Q.26

24. Can you identify some examples?

Name of organization: _____

Name of organization: _____

25. How does the Branch compare to this organization for each of the following? Please use a scale of 1 to 10, with 1 being the Branch is much poorer and 10 being the Branch is much better?

Feature	Much poorer									Much better
Quality of personnel	1	2	3	4	5	6	7	8	9	10

Quality of facilities and equipment	1	2	3	4	5	6	7	8	9	10
Responsiveness	1	2	3	4	5	6	7	8	9	10
Value for money	1	2	3	4	5	6	7	8	9	10
Overall	1	2	3	4	5	6	7	8	9	10

26. How important is the Terrestrial Wireless Systems Branch to your organization's success? Please use a scale of 1 to 10, where 1 is not at all important and 10 is very important.

1 2 3 4 5 6 7 8 9 10 DK

27. Why do you say that? *Probe:* Any other reasons?

_____

_____

28. What additional service or capabilities could the Branch provide that would better meet the needs of your organization? *Probe:* Any others?

_____

_____

29. Do you have any other suggestions for improvement or changes at the Branch? *Probe:* Any others?

_____

_____

Thank and Terminate

ANNEX C - Clients and Collaborators of the Terrestrial Wireless Systems Branch

Clients Name and Organization	Project Information	TWS Research Group	Completed Survey?
Canadian Government Departments			
Michel Cuhaci/Aldo Petosa, Radio Science, CRC	Antenna development for WEB/MILTON	BBW	Yes
Mario Caron/Pierre Tardif, Satellite Communications, CRC	Development of modem technology for WEB/MILTON	BBW	Yes
Doug Sward, SITT, Industry Canada	Policies for 5GHz unlicenced wireless systems, WEB/MILTON	BBW	Yes
Dick Ko, Ontario Ministry of Energy, Science and Technology	Development of proposal to deliver Broadband Multimedia Wireless to Northern Ontario	BBW	Yes
Dr. Dave Rogers Radio Science, CRC	Collaboration on propagation measurements and modelling for modem for IRIS combat net radio	RCT	
Michel Cuhacci Radio Science, CRC	Antenna design for MIMO fixed wireless system for Space Time Wireless	RCT	
Don Paskovitch SITT, Industry Canada	Transmitter identification and finding	RCT	Yes
William Taylor SITT, Industry Canada	Support to Canadian ITU activities	RCT	
Jean Claude Brien EMC, Industry Canada	Assess digital mobile radio link performance at 2 and 6 GHz	RCT	Yes
Lt. Cdr. Perry Dombowsky, Maritime Ship Support, DND	Development of advanced high data rate modem technology, Joint Warrior Interoperability Demonstration	RCT	
Cdr. Tony Cond, Science and Technology Maritime, DND	HF, VHF, NATO naval communications technologies	RCT	Yes
Lt. Mike Craig, former Maritime Ship Support, DND	HF adaptive antenna receiving technology (counter jamming and inteference)	RCT	
Lt. Col. James deRosenroll and Maj. Paul Fritz-nemeth, Land Requirements, DND	Development of high data rate modem for Army IRIS Combat network radiorct	RCT	Yes
L. Col. H.E.C. Smith, Telecommunications and Spectrum Engineering Support, DND	Development of high data rate, wideband HF communications	RCT	Yes
L.Col. Paul Poirier, DREO, DND	R&D in terrestrial wireless communications	RCT	
Dave Eaton, Diving R&D, DCIEM, DND	Collaboration on helium speech descrambler for naval diving	RCT	
Paul Devlin, CSE (former)	Development of PC software based secure telephone	RCT	Yes
Capt. D. Kirkland, Search and Rescue, DND	Testing of noise cancellation techniques to reduce audio noise in radio receivers in Search and Rescue	RCT	Yes
Michael Poole, Transportation Safety Board		RCT	

Clients Name and Organization	Project Information	TWS Research Group	Completed Survey?
Chun Loo Satcom Branch, CRC	Development of demultiplexer for Advanced Satcom project	IE	Yes
Dr. Guy Seguin CSA.	MMIC C band design and evaluation	IE	
Dr. Shen-en Qian CSA	Consultation on EMS implementation of computational engine	IE	Yes
Dr. Gilbert Morin DREO, DND	Miniaturization of EHF T/R modules for phased array antennas	IE	Yes
Dr. Ryan English DREO, DND	Artificial neural network based image classifier	IE	
Don Paskovitch SITT	Neural network based signal classification	IE	Yes
Sabah Towaij, Spectrum Projects, SITT	Several projects for measurement and testing of wireless broadcasting options	WISELab	Yes
John Sydor, Terrestrial Wireless Systems, CRC	Field trials, testing of WEB terminal	WISELab	Yes
Nur Serinken, Terrestrial Wireless Systems Branch, CRC	Provide support to other TWS groups – equipment	WISELab	
Keith Chang, Industry Canada	Develop overview and product description of Canadian wireless communications sector	WISELab	Yes
Dr. Pearce Leroy, Information Management, DND	Analysis of new wireless technologies and current trends - produce report	WISELab	Yes
Canadian Industry			
Keith Doucet, others, Redline Communications	Licencing of WEB, technology development and product development	BBW	Yes
Corey Pike, Nanowave	Development of licencing and collaborative agreements for WEB/MILTON	BBW	Yes
Paul Tosolini, TecNorth	Development of Broadband Multimedia Wireless Project	BBW	Yes
Herman Chang and Alex Oprea, Space Time Wireless (now Avendo Wireless)	Signal design/signal processing and channel measurements for MIMO	RCT	Yes
Parke Davis, Telus Mobility	Testing of secure Entrust Phone over MIKE cellular network	RCT	Yes
Trevor Moat, SOMA Networks	Investigation of vocoder options and digital voice technologies	RCT	
Geoff Hodgson, SED/Calian	Development and licensing of HF adaptive antenna receiving technology	RCT	Yes
Nick Massey, RACAL Canada (former)	Licensing of technologies	RCT	Yes
Dr. Gerard Nourry, IP Uniwired Inc.	Development of high data rate HF and VHF modem technologies for military communications applications	RCT	
Eldon Mellaney, MySkyWeb	Investigation of opportunities for collaborative work	RCT	

Clients Name and Organization	Project Information	TWS Research Group	Completed Survey?
Dr. Paul Witke, AstroCom Associates	Collaborator on SITT project-channel measurement of W-CDMA	RCT	
Hiroshi Kato JGKB Photonics	Testing and characterization of devices	IE	Yes
Dr. T.K. Kwasniewski PMC-Sierra	Testing and characterization of devices	IE	Yes
Dr. Alan Harrison Nortel	Exploratory MMIC esign	IE	Yes
Rick Power, Collaborative Network Technologies	Evaluate radiation ddangers of using wireless devices	WISELab	
Yvon Depratto, Hydro Québec	Simulations and analysis of converting microwave network to space diversity from frequency diversity	WISELab	Yes
Luc Bouchard, Newbridge	Contracts to conduct measurements (performed by Broadcast Technologies Branch)	WISELab	
Bill Taylor/Remi Chayer, RABC	Measurements/analysis for information, development of spectrum utilization recommendations	WISELab	Yes
Canadian Universities/Research Institutes			
Peter Stark, OCRI	Demonstration of WEB - high speed video distribution from OCRI to Glebe High School	BBW	Yes
Dr. David Falconer Carleton	Cosupervision of students	BBW	Yes
Dr. David Falconer, Carleton	Comparison of fixed MIMO systems to SDMA – graduate student supervision	RCT	
Dr. P. Brown, U. of Western Ontario.	Leonid Storm Shower measurements	RCT	Yes
Dr. R.A. Webster, U of Western Ontario	Research on multiple base line interferometric techniques for radio location of transmitters	RCT	Yes
Prof Roshdy Hafez, Carleton	Co supervision of CRC staff member – estimate performance of spread spectrum for future wideband mobile systems	RCT	
Dr. C. Charalambos, U. of Ottawa	Development of model to reflect nonstationary characteristics of mobile radio channels	RCT	
Dr. Jim Wight Carleton	Microwave and millimeter wave circuits/advanced packaging and interconnectivitry/student cosupervision	IE	Yes
Dr. Langis Roy Carleton	Microwave and millimeter wave circuits/advanced packaging and interconnectivitry/student cosupervision	IE	
Capt. S. Drouin RMC	Designof 20 GHz demodulator on MMIC with coplanar waveguide technology	IE	

Clients Name and Organization	Project Information	TWS Research Group	Completed Survey?
Dr. Dhamin Al-Khalili RMC	Communications devices and circuits	IE	
Dr. Stefan Kremer Guelph University	Collaboration on neural network based signal classification (university contract)	IE	
Dr. Gilles Delise Laval University	Coplanar waveguide techniques	IE	
Dr. Lot Shafai CITR	Design of MMICs for up/down converter @ 3.6/30.1 Ghz	IE	Yes
Dr. Tho LeNgoc CITR	Development of enabling technology for group demodulator	IE	
Robert Stevenson Canadian Microelectronic Corp'n	Development of virtual microwave test laboratory	IE	Yes
Prof Roshdy Hafez, Carleton	Research on Broadband Wireless Access, Wireless over Fibre Options	WISELab	
Foreign Government			
Dr. Paul Cannon; Qinetiq, U.K.	Partner in DAMSON – experimental measurements of high latitude HF channels	RCT	Yes
Nigel Davies, Qinetiq, U.K.	Development of robust waveform design and automatic radio control systems	RCT	
Dr. Vivianne Jodalen, Norwegian Defence Research Establishment	Partner in DAMSON & robust waveform design		
Captain Onder Tekbas, Turkish Army Academy	Transmitter identification from turn on characteristics	RCT	
Lt. Col. Osman Erogul, Gulhane Military Medical Academy, Turkey	Transmitter identification from turn on transients	RCT	
Jeet Hothi, for various individuals, Centre for Development of Telematics – India	Guidance in design of MMICs for use in C-DOT system – training of personnel	IE	Yes
	Development of VLSI macrocells for C-DOT	IE	
Dr. Joseph Hsu National Science Council, Taiwan	Investigation of circuits relevant to implementation of complex EHF MMICs	IE	
	Exchange of information on smart antenna systems	IE	
Dr.Masahiro Kiyokawa Communications Research Laboratory, Japan	Joint research on compact millimetre – wave phase-locked signal sources	IE	
Professor Chul Soon Park, Information and Communications University, South Korea	Advanced packaging and interconnectivity	IE	

Clients Name and Organization	Project Information	TWS Research Group	Completed Survey?
Foreign Universities			
Dr. G. Brossaard, Eindhoven University of Technology, Netherlands	Analysis of propagation data for mobile radio channel, cosp[ervision of students	RCT	
Prof. Faruk Ozek, Ankara University, Turkey	Techniques for identification of transmitter using turn on transients	RCT	
Foreign Industry			
Dr. Hans Denke and Mr. Jurgen Escher, Daimler Chrysler Aerospace, Germany	Licenced technology, contract to develop HF waveforms and modems	RCT	Yes
Bruno Seiferet, Daimler Chrysler Aerospace, Germany	Development of 800 bps vocoder for use in HF communications radios	RCT	
John Nieto, Harris Corporation, U.S.	Interoperability testing between Harris and CRC modems for STANAG 4359	RCT	Yes
International Organizations			
Heinz Lyklama, Vectrad (IEEE)	Inteference and coexistence issues, IEEE 802.16B	BBW	
Ken Pierce, Malibu Networks (IEEE)	Chair, Working Group for 802.16B	BBW	Yes
Brian Kiernan, Interdigital Group (IEEE)	Chair of IEEE Joint 802.16A/B development	BBW	
Dr. Roger Marks, NIST, USA (IEEE)	Arranged meeting to coordinate US/Canadian support for IEEE 802.16	WISELab	
Dr. Vladimir Minkin, Chairman ITU-R Study Group 9	Participation in International Working Party 9C HF fixed service	RCT	
Volker Neumann, Chairman NATO HF Radio Ad Hoc Working Group	Participation in Working Group, development of advanced HF communications STANAG standards	RCT	
John Collura, Chairman, NATO Ad Hoc Working Group on Narrow band Voice Coding	Participation in Working Group – investigation of measurement of coder delay options in a simulated environment	RCT	

CRC staff members are included in this list when a formal collaboration or contract exists.

ANNEX D - Case Studies

- Development of Wireless Internet Application Systems
- Development of NATO STANAG Waveforms
- Early Stage R&D Related to Miniaturization of EHF Transmit/ Receive Modules for Phased Array Antennas
- Development of Canadian 50 – 70 GHz Frequency Allocations

Development of Wireless Internet Application Systems for Use in the 5 GHz Unlicenced Bands

Development of High Speed Wireless Ethernet Bridge for 5GHz licence exempt use. Parallel, complementary contribution to development of industry standards and government regulations and policies needed to define and enable use of the frequency band for wireless broadband applications.

Project Overview

Beginning in 1998, the Broadband Wireless group has led the development of new technologies to deliver high data rate wireless LAN services in the unlicenced 5 GHz frequency bands. A Wireless Ethernet Bridge (WEB) has been developed along with a wireless LAN system to deliver high speed data services to individual clients in urban and rural areas (Microwave-Light Organized Network MILTON).

As well as developing the technology, the Broadband Wireless group also recognized the need to work through the Radio Advisory Board of Canada (RABC), the Industry Canada Spectrum Information Technology and Telecommunications Branch (SITT), the International Telecommunications Union - Radio group (ITU-R) and the International Electrical and Electronic Engineers Association (IEEE) to ensure that national and international policies and regulations and industry standards for use of the 5 GHz unlicenced bands for wireless LANs were open to the technologies being developed. The group was successful in having the WEB and MILTON technologies accepted for use in the 5 GHz licence exempt bands.

In 2000, after discussions with a number of firms, the WEB technology was licenced to a Canadian wireless communications startup firm. The Broadband Wireless group has continued the development and improvement of WEB, and has also continued the development of MILTON.

Profile of the Partners

The Radio Broadband Wireless Group within Terrestrial Wireless Systems Branch was created from the Satellite Mobile Terminal Development Group at the time of the formation of TWS in 1998. The group focuses on developing broadband wireless application systems. The present focus is on the 5 GHz licence exempt frequency band.

A number of other CRC groups supported various phases of the project..

The **Institute for Electrical and Electronic Engineers** (IEEE) is an international body that supports research and development of industry standards in many fields related to electronics, computers and telecommunications.

Industry Canada Spectrum, Information Technologies and Telecommunications Branch (SITT) is the federal agency responsible for the efficient and effective use of radiowave spectrum in Canada. SITT have a long standing, close relationship with CRC,

which has the responsibility to provide technical support and advice to the agency. The Spectrum Policy group within SITT is responsible for drafting new policies and regulations.

The **International Telecommunications Union** (ITU) is an international standards regulatory agency that sets international policies, standards and guidelines for a wide range of telecommunications technologies and applications.

Redline Communications Inc. is a Canadian telecommunications startup firm, active in the wireless communications sector.

Project Profile

In 1998, when TWS was formed, the Broadband Wireless group had already created a plan to develop new broadband wireless technologies to deliver bidirectional high data rate information using the 3 – 7 GHz unlicenced bands. To implement this plan, and ensure that industry standards and government spectrum utilization policies took account of the proposed approach, a number of tasks were undertaken.

Technology Development

In terms of development of the technology, work focussed on four main elements: antenna development, high speed modem development, experimental measurements of 5 GHz propagation characteristics and product development. These studies, which are discussed in the following sections, took place primarily between 1998 and 2000

The Advanced Antenna Group within Radio Science Branch collaborated on the development of a number of prototype antennas with the required design characteristics for use in the system.

A collaboration with the Mario Caron Group in the Satellite Branch within CRC took advantage of their expertise in high speed modem development to develop modems for use in the terrestrial broadband wireless environment, to be incorporated in the technology being developed.

The Broadband Wireless Group undertook a number of propagation and interference experiments and studies to understand the characteristics of high speed wireless data networks in the 5 GHz frequency range.

As one important component in the development of a complete system, the Broadband Wireless Group developed a high speed Wireless Ethernet Bridge (WEB), complete with receiver and transmitter, operating at 5 GHz, to provide an Ethernet data bridge capable of transmitting data over 10 Km. By the end of 1999, an operational prototype had been developed. Development continued, with successive prototypes incorporating additional features.

The TWS WISELab recently conducted tests on the most recent WEB prototype. The test results were very helpful in making adjustments to the product.

The Broadband Wireless Group has also developed a prototype version of a high data rate point to multipoint wireless LAN known as MILTON (Microwave Light Organized Network), to be deployed in the 5GHz licence exempt band.

Standards and Regulatory Support

The Broadband Wireless Group conducted experiments and provided the results to RABC to demonstrate that MILTON was compatible with other use of the 5GHz licence exempt bands. The group also provided advice to the Spectrum Policy Group within SITT with respect to the use of the 5Ghz band for licence exempt wireless local area networks in Canada, to ensure that the policy allowed for the use of a MILTON type system.

The group, in consultation with SITT, also made a presentation to ITU–R on the results of this project, including experimental measurements. This presentation was well received by this international regulatory body and resulted in ITU including the Canadian perspective in international regulations for broadband wireless licence exempt use of the 5 GHz band.

As well as working with national and international regulatory bodies, the Broadband Wireless Group made important contributions to the development of industry standards for broadband wireless LANS. In particular, important contributions to the development of IEEE standard 802.16 were made over the past two years. Once again, the result is that the standard accommodates the WEB and MILTON approach, thus ensuring that these technologies are compatible with the latest broadband wireless industry standards.

Commercialization and Utilization

In 1999, WEB technology was successfully demonstrated via a high speed wireless communications link between the OCRI Media Centre and Glebe High School in Ottawa. Industrial interest grew, as the WEB technology was shown to be viable. In 1999, there was considerable effort devoted to obtain Government of Ontario Technology Applications Program funding to develop a MILTON based wireless communications system in Northern Ontario. Although funding was approved, the project did not proceed due to issues related to intellectual property and licensing. Following discussions with a number of firms interested in applying the technology, a licencing agreement was signed with Redline Communications in late 2000 for transfer of the WEB technology. Since then, the Group has been working with Redline on further development of the technology.

Incrementality

The Broadband Wireless Group research manager has been responsible for conceptualization, design and development of this technology, as well as the initiatives to ensure that IEEE standards, national and international policies and regulations have

included the use of these technologies for 5GHz licence exempt wireless local area network applications. This development has occurred over the period 1998 to the present.

Impacts

National and International Policies and Regulations about Spectrum Utilization and Industrial Standards

The work of the Broadband Wireless research group has directly contributed to the development of Canadian and international policies and regulations for the use of the 5GHz unlicenced frequency bands. The industry standards recently developed for outdoor wireless LANS, which are embedded in IEEE 802.16 also allow these technologies to be used, as well as several others.

Commercial Impacts

Working with the Broadband Wireless group has given Redline access to highly skilled technical personnel to leverage their internal capabilities, and has increased their internal technical capabilities. Licencing of the technology incorporated in WEB has reduced product development time for Redline, and has given the firm the basis for a potential product which may help them establish a position in the 5 GHZ wireless LAN market and generate early revenues. It is expected that the technological approach contained in WEB will form an important foundation point for Redline's future product development strategy.

Potential Future Impacts

With the establishment of national and international standards and regulations, and industrial standards (IEEE 802.16) which permit the use of the technologies incorporated in WEB and MILTON, the way is clear for these technologies to be developed commercially, as alternatives to other competing approaches.

Several of those interviewed stated that in their opinion, WEB and MILTON had advantages over other available technologies in terms of both cost and efficient, effective delivery of high speed broadband wireless services over LANS.

CRC has recently created a high priority task force in response to the federal Broadband Initiative. The technological solutions contained in WEB and MILTON are candidates for use, particularly in rural LANS, with very low density use separated by up to 10 Km.

There is continuing commercial interest in WEB and the MILTON technology. It is likely that the concepts embodied in these technologies will have a significant impact on the development of products and applications for wireless LANS in the 5 GHz frequency bands, both in Canada and abroad.

Individuals Interviewed

John Sydor	Radio Broadband Wireless Group Research Manager, Terrestrial Wireless Systems Branch, CRC
Mario Caron	Project manager, Satellite Branch, CRC
Gerald Chouinard	Manager, Broadband Initiative, CRC
Doug Sward	Director, Terrestrial Engineering, Spectrum, Information Technologies and Telecommunications Branch, Industry Canada
Ken Pierce	Software developer, Malibu Networks, participant in development of IEEE 820.16
Keith Doucet	Vice President, Product Development, Redline Communications Inc.

Documents Reviewed

"A New Broadband Wireless Network for 5 GHz Licence Exempt Applications", by John Sydor, Alain Dugas and Jason Duggan, Communications Research Centre, presented to 20th Biennial Symposium on Communications, Kingston, Ontario, May 2001

ITU-R Document 8a9b/CAN4 19 October 2001 – "Qualitative Analysis of Inteference from Outdoor Operation of Wireless Access Systems into the Earth Exploration-Satellite Service (active) in the Band 5250 – 5350 MHz", by John Sydor and A. Brandao

IEEE 802.16 TG4 Standards Committee Document: 802.16 4c-01/15 – "Proposal for a 5.2/5.8 GHz Licence-Exempt (LE) Wireless HUMAN Network Standard based on a Modified IEEE 802.11a PHY and IEEE 802.16 MAC Standards", 2001/01/15 by John Sydor

"Spectrum Utilization Policy for Licence Exempt Wireless Local Area Networks in the 5GHz Range", Industry Canada SP – 5150 MHz, October 1999

"5.2 – 5.8 GHz Licence-exempt Terminal Technology for Wireless Ethernet Bridge Applications", CRC Infosheet.

Case Study – Development of Wireless Internet Application Systems for use in the 5GHz Unlicenced Bands

Project Incrementality (influence)	Direct User Impacts	Industry Sector / Public Sector Impacts	Economy / Societal Impacts
Major x project would not have been undertaken without Branch involvement x conducted some critical R&D that otherwise would not have been done **Minor** o Participated in project as one of a number of participants (contribution was helpful, but not essential) o increase in jobs	**Technical results** x new or improved product x new or improved process x advancement of knowledge x increased technical capabilities o improved quality control x new skills internally o increased efficiency / improved productivity x technology transfer **Policy/Legislative results** o policy behavioral changes o agreement / accord o legislative / regulation o acceptance of standards **Commercial results** p increased sales p increased market share o increased profitability o cost savings **Organizational effects** p increase in jobs o diversification p expansion o strategic alliances / partnerships o achievement awards / recognition	**Industry** o production process efficiencies x increased science and technology information p increased sales o cost savings p changes to industry structure o spin-off companies x training of technological problem-solvers o establishment of operational standards **Public Sector** o increased decision making capability	o reduced consumer costs o protection of environment o improved energy efficiency savings x improved public regulatory capability x effective use of radiowave spectrum x public access to latest communications technology o increased public security p increased employment

o has not occurred
x has occurred
p potential in future

Development of NATO STANAG Waveforms for High Capacity HF Communications

Project Overview

Beginning in the early 1990s, on behalf of DND, CRC researchers began working on increasing the data rate for HF battlefield communications. CRC participated in the development and testing of several specialized waveforms, including STANAG 5066. CRC researchers led the development of an additional waveform, designed for maritime application. Following a number of operational trials, it was realized that this waveform was applicable to a wide variety of applications, not just maritime, and it eventually became STANAG 4539. A U.S military version, 188-110B, based on the 4539, was also developed, based on the Canadian work.

Roles and Relationships Among the Participants

The Narrowband Wireless Research Group at CRC led this research initiative during the period 1994 – 1999. This group existed before TWS was created in April, 1998, and moved to the Branch during the CRC reorganization. In 1999, the research leaders left CRC to form a private company, and continue work on this technology. The remaining staff from the group were then amalgamated with the Radio Communications Technology Group. CRC has continued to access the expertise of this group through contracts.

The **NATO HF Radio AD Hoc Working Group** has led the development of a number of advanced HF communications standards over the past ten years or more. This committee was responsible for testing and measuring the performance of proposed standards to ensure that they met technical requirements before being accepted. CRC participated in this group on behalf of DND and Canada.

The **D**oppler **A**nd **M**ultipath **S**ounding **N**etwork (**DAMSON**) was an international research project to investigate high latitude HF communications. CRC (Canada), Defence Evaluation Research Association (UK), FFI (Norway), and FOA (Sweden) were members. While not directly involved, knowledge developed during this project assisted in the development and testing of NATO waveforms. DERA was able to develop a channel simulator as a standard HF testing protocol for testing the performance of STANAG 4539.

The U.S. Military Standard group developed US 188-110B based on the CRC waveform.

Harris, a major U.S. HF military communications manufacturer, participated in interoperability testing that examined the performance of their modem technology and that of CRC, both of which were based on STANAG 5066/Mil.Std-188-110B, which led to STANAG 4539.

Project Profile

During the 1990s, DND funded CRC to conduct research and development aimed at improving the reliability and speed of HF communications in battlefield conditions. Much of this work involved working within the NATO community to develop advanced **STAN**dard **AG**reement (STANAG) waveforms to meet new requirements. Development, testing and reaching agreement on these standards among the allies typically took several years. CRC began developing expertise during the early 1990s, participating in the development of STANAG 4444 in the 1992 –96 period, continuing with STANAG 4415 during 1994-97, and STANAG 5066 during 1995 – 98. CRC researchers had developed a specialized high data rate waveform, designed for maritime applications, which was originally to be included within 5066. Delays and IP difficulties led to the removal of all high data rate waveforms from 5066. However, the CRC waveform was attached to the standard as 5066 High data Rate Waveform Annex G. With this visibility and participation in number of operational tests (i.e. Joint Warrior Interoperability Demonstration '98), the waveform was quickly recognized as having broader applications. There was a competition between the Canadian waveform and others from France and Germany, which the Canadian waveform won handily, emerging as STANAG 4359.

Harris collaborated with CRC in conducting tests comparing the performance of their modem and that of CRC using the STANAG 4539 waveform, and participated in the NATO tests discussed above.

During the time of transition between ANNEX G and STANAG 4359 which took several years, the U.S. military recognized the advantages of the Canadian waveform and moved forward to implement their own version, 188-110B, based on the CRC waveform. The acceptance of STANAG 4539 ensured the interoperability between these new NATO and US standards.

Impacts

There are several levels of impacts related to the development of this waveform.

Military

At the NATO operational level, all NATO HF high data rate communication modems are or will soon be based on work in which CRC played a major role.

The influence of the CRC waveform development work is spreading into more military applications. STANAG 4539 is being implemented or considered for implementation in many other applications. These include NATO AWACs, Aurora Maritime Air Command, and the NATO BRASS (Broadcast and Ship to Shore) upgrade. The AUSCANNZUKUS military alliance is also discussing the appropriate implementation of the waveform.

At an operational level nationally, it is important for Canada that the U.S. and Canadian navies both have the type of telecommunications equipment that can support these waveforms, and the interoperability between 188-110B and STANAG 4359 contributes to

the ability to conduct joint operations between the navies of the two countries. As mentioned recently in the press, Canada is the only country that the U.S. will permit to participate in joint operations, and the interoperability between the telecommunications systems is a major reason for that decision. As an example, Canadian navy ships are currently part of a navy task force supporting the Afghanistan operations.

Even more importantly for Canada and DND, the great success of the waveform development work has given us a high degree of credibility in NATO and the U.S. in the area of HF communications. As one interviewee stated: "At the moment, Canada is viewed as the most important military high speed waveform developer in the world". It is however, recognized that, while this work was originally done at CRC, and CRC is still an important contributor, much of the expertise has now left, and is resident in those researchers now operating as IPUnwired.

Commercial Impacts

Commercially, Harris benefited from working with CRC and deciding to support the development of modems using the Canadian waveform. While Harris developed their own equalizer/modem technology based on the CRC waveform, the collaboration shortened their product development cycle and gave Harris a headstart on the competition. By participating in the competition and being on the winning team, Harris received credibility, visibility and early sales. Now, almost all significant U.S. military HF equipment manufacturers make products using these waveforms.

The knowledge and expertise developed at CRC during this period continues to be applied to commercial development of military HF equipment, through IPUnwired working with U.S. firms.

CRC modem equalizer technology associated with the waveform development has also been licenced to RACAL, now in the U.K. for potential use in the private sector commercial HF communications market and to Daimler Chrysler in Germany for military communications equipment applications. CRC received $140K in licencing fees.

Potential Future Impacts

There is every reason to believe that NATO, US, Canadian and related allied forces military use of the STANAG 4539 will continue to grow, and battlefield operational HF communications capabilities will be improved because of it.

CRC and DND are also planning to apply the knowledge gained during this research to further applications in the in the VHF/UHF. As there are Canadian firms with capability in VHF/UHF communications equipment systems integration, DND hopes that this new research focus will eventually provide both a military and an industrial benefit to Canada.

Individuals Interviewed

Joe Schlesak	Radio Communications Technology Group Research Manager, Terrestrial Wireless Systems Branch, CRC
Dr. Trish Willink	Project manager, Radio Communications Technology Branch, Terrestrial Wireless Systems Branch, CRC
Dr. Paul Cannon	Chief Scientist Radio Science and Propagation Group, DERA (now QinetiQ), Chair of DAMSON project
Lt. Cdr. Gerry Oulette	Maritime Policy and Project Development, Tactical Communications Systems, DND, member of NATO Maritime Working Group
Lt. Col. R.C. Johnston	(I'll get his coordinates) Canadian representative on NATO Communications Network Subcommittee, overseer of HF Radio Ad Hoc Working Committee activities
Thomas Kenney	Harris Corporation, Rochester, New York
John Nieto	Harris Corporation, Rochester, New York

Case Study – Development of NATO STANAG 4539 Antenna

Project Incrementality (influence)	Direct User Impacts	Industry Sector / Public Sector Impacts	Economy / Societal Impacts
Major x project would not have been undertaken without Branch involvement x conducted some critical R&D that otherwise would not have been done **Minor** o participated in project as one of a number of participants (contribution was helpful, but not essential)	**Technical results** x new or improved product o new or improved process x advancement of knowledge x increased technical capabilities x improved quality control o new skills internally o increased efficiency / improved productivity x technology transfer **Policy/Legislative results** o policy behavioral changes x agreement / accord x legislative / regulation o acceptance of standards **Commercial results** x increased sales x increased market share x increased profitability o cost savings **Organizational effects** o increase in jobs o diversification o expansion x strategic alliances / partnerships o achievement awards / recognition	**Industry** o production process efficiencies x increased science and technology information x increased sales o cost savings p changes to industry structure x spin-off companies x training of technological problem-solvers x establishment of operational standards **Public Sector** O increased decision making capability	o reduced consumer costs o protection of environment o improved energy efficiency savings o improved public regulatory capability x effective use of radiowave spectrum x public access to latest communications technology x increased public security o increased employment

o has not occurred
x has occurred
p potential in future

Early Stage R&D Related to Miniaturization of EHF Transmit/ Receive Modules for Phased Array Antennas

Research towards development of a highly integrated miniature transceiver module for future military phased array antenna applications

Project Overview

With financial assistance from DND, TWS researchers are conducting early stage developmental R&D on three related miniaturization microwave technologies with a view to combining them to produce a miniature EHF transreceiver module for military satellite applications. The project, which began in 1998, has seen considerable progress, however, a number of technical problems remain to be solved.

Roles and Relationships Between the Participants

Researchers from the Integrated Electronics Group in TWS lead the project, and have been responsible for conducting almost all the research and testing to date.

A scientist from the **Military Satellite Research Group in Defence Research Establishment Ottawa** is the project manager on behalf of DND, which cofunded the project.

A professor from **Carleton University** was involved in the early stages of the project in a preliminary investigation of micromachining of silicon.

ComDev, a Canadian telecommunications firm, has recently begun supporting the project by facilitating access to a micromachining facility in the U.S.

VTT, a Finnish contract research organization, has recently become involved in fabricating specialized ceramic packaging for the project.

Nanowave, a Canadian telecommunications firm, has kept a listening watch on the project, and is now involved in discussions on utilizing knowledge in advanced packaging and interconnections developed during the project.

Project Profile

DND has a need to develop new technologies related to EHF satellite communications. One of the major challenges is the development of mobile terminals utilizing phased array antennas. The ultimate goal that this project is supporting is the development of a miniaturized communications transceiver module for use in this application. The specific technical objective of this project is to explore the potential to produce an integrated miniature module through the combination of three technologies: Gallium Arsenide miniature microwave integrated circuits (MMIC), low temperature cofired ceramic interconnect packaging (LTCC) and miniaturized electromechanical switches (MEMS). This

project was cofunded by DND through their Technology Infrastructure Fund, which funds "forward looking, high risk, but potentially high payoff research". As the project manager said, "This is blue sky research", which has the hope, but not the certainty of early success. The project was funded approximately equally by DND and CRC. DND paid for 1.5 research staff and some $50 - $70 K in operating funds annually, with CRC A base providing the remaining funds.

At the start of this project, CRC researchers had extensive experience in developing MMICs for EHF applications, but little or no experience in LTCCs or MEMS. In the early stages, a Carleton University professor and student were involved in investigating MEMS, but this collaboration did not continue. Much of the progress in this project was only partially within the control of the CRC researchers, as they needed to have their devices fabricated at a commercial foundry. Each fabrication run costs approximately $100K, a major expense for a limited operations budget. Another problem is that there are no commercially available foundries with proven capabilities for EHF applications of LTCC and MEMs technologies.

Progress on this project has not been as great as planned for. There are a number of reasons for this. One was the loss of key staff, which caused a significant delay. Others were the inevitable result of technological difficulties. Progress to date has varied significantly for each of the three technologies. MMIC progress has been the greatest, with designs for direct up conversion and down conversion meeting the original requirements for operating successfully at 20/44 GHz. The original requirements for signal bandwidth of 10MHz have also been met, however research is continuing to meet more severe requirements for 100MHz bandwidth. Progress in low temperature cofired ceramic multilevel packaging and interconnectivity has been significant, however, current technology is limiting performance to frequencies up to the 20 GHz range. Success at higher frequencies is unlikely until there are improvements in fabrication capabilities at commercially available foundries. Progress on MEMS has been the slowest, due to the lack of access to an adequate fabrication capability. This technology is still in its infancy and highly competitive. Consequently firms with fabrication facilities have not made them available to outside users.

Although the original project funding was to end in April 2002, the project has been extended for another year, with some funding reprofiled into the coming year. A number of steps are being taken to move forward. To advance the LTCC development, CRC is beginning to work with VTT, a Finnish organization that has a multilayer LTCC prototype production facility. DND is assisting CRC to gain access to U.S. MEMS fabrication capability by working through COMDEV. Also, CRC researchers will be attending workshops to learn more about MEMS technology. These approaches, if successful, will support progress towards an intermediate level product, not fully integrated, but assembled from several discrete, miniaturized components.

Nanowave has also recently begun contributing by agreeing to design and build phase shifter circuits at no cost to the project.

Impacts

Scientific/Technical

As for many "blue sky" type R&D projects, many of the outcomes and impacts of this project to date are in the areas of the development of new knowledge, and increasing the expertise and capabilities of CRC researchers. There has been considerable development of the technologies associated with this project, particularly MMIC and LTCC. This knowledge is shared with the scientific community through collaborative projects with local universities and the numerous scientific papers published in the past three years involving MMIC and LTCC technology.

These technological advances can and are being applied to other requirements beyond this specific project. For example, EHF MMIC designs are being considered for SATCom and software radio applications being developed by other CRC groups.

Commercial Impacts

The project has not yet developed technologies or devices suitable for transfer to the private sector for commercialization. However, there is commercial interest in some of the technological development associated with this project. For example, Nanowave is exploring the possibility of developing LTCC production capability based on the transfer of technology from this CRC laboratory.

There has also been technology transfer to industry through the transfer of several Branch staff members to private industry and the training of graduate students in various aspects of MMIC, LTCC and MEMS technologies during the past three years.

Potential Future Impacts

As development of these technologies for EHF applications continues, there will be more and more opportunities for practical applications for military and civilian purposes. As discussed, there is evidence of early interest from Canadian firms in acquiring and applying the technical know how being developed in this project. In addition, this research program may have some direct relevance to the newly announced CRC Remote Broadband Access initiative.

Individuals Interviewed

Dr. Malcolm Stubbs	Project leader, Integrated Electronics Group, Terrestrial Wireless Systems Branch, CRC
Dr. Valek Szwarc	Group Manager, Integrated Electronics Group, Terrestrial Wireless Systems Branch, CRC
Dr. Giles Morin	Research Scientist, Military Satellite Research Group, Defence Research Establishment Ottawa, Defence Research and Development Canada

Documents Reviewed

DND Investment Fund Project Proposal – "Miniaturization of EHF T/R modules for Phased Arrays", by Dr. Gilbert Morin and Dr. Malcolm Stubbs

Case Study – Development of Miniaturized EHF T/R Module for Phased Array Antenna

Project Incrementality (influence)	Direct User Impacts	Industry Sector / Public Sector Impacts	Economy / Societal Impacts
Major x project would not have been undertaken without Branch involvement x conducted some critical R&D that otherwise would not have been done **Minor** o participated in project as one of a number of participants (contribution was helpful, but not essential)	**Technical results** p new or improved product x new or improved process x advancement of knowledge x increased technical capabilities o improved quality control x new skills internally o increased efficiency / improved productivity x technology transfer **Policy/Legislative results** o policy behavioral changes o agreement / accord o legislative / regulation o acceptance of standards **Commercial results** p increased sales o increased market share o increased profitability o cost savings **Organizational effects** o increase in jobs o diversification o expansion x strategic alliances / partnerships o achievement awards / recognition	**Industry** p production process efficiencies x increased science and technology information o increased sales p cost savings p changes to industry structure o spin-off companies x training of technological problem-solvers o establishment of operational standards **Public Sector** x increased decision making capability	o reduced consumer costs o protection of environment o improved energy efficiency savings o improved public regulatory capability p effective use of radiowave spectrum x public access to latest communications technology x increased public security o increased employment

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x has occurred
p potential in future

Development of Canadian 50 – 70 GHz Frequency Allocations

Project Overview

Beginning in 1998, on behalf of Industry Canada Spectrum, Information Technologies and Telecommunications Branch (SITT) and the Radio Advisory Board of Canada (RABC), WISELab undertook a multidimensional study of the 50 – 70 GHz radio spectrum band. This study consisted of a review of present and planned use of this spectrum by major countries (U.S., Australia and Europe), an analysis of existing research studies, and also a series of experiments to characterize this frequency band. In 1999, these results were presented to the RABC, which recommended that Canada develop a policy for spectrum utilization in this band consistent with the U.S. FCC approach, but customized to Canadian requirements. SITT proceeded to develop a draft policy for utilization of several bands in the 45 – 77 GHz range, some of which were based on the results of the WISELab study. These draft regulations are now about to become official Canadian government policies. .

Profile of the Partners

Industry Canada SITT is the federal agency responsible for the efficient and effective use of radiowave spectrum in Canada. They have a long standing and close relationship with CRC, which has the responsibility to provide technical support and advice to the agency. Two groups within SITT were involved in this project. The first is the Spectrum Research Funding Group, responsible for identifying research needs and sponsoring relevant research. The second is the Spectrum Policy group, responsible for drafting new policies and regulations.

The Radio Advisory Board of Canada (RABC) is an industry association responsible for representing the interests of private sector firms providing radio and related wireless services in Canada. The Fixed Wireless Communications Committee of the RABC is responsible for reviewing existing policies regarding radio spectrum usage, and examining the potential for use of newly available spectrum. The committee works closely with SITT to determine the best use of spectrum in Canada, and represents the interests of the members of RABC in providing advice to SITT about spectrum policies and regulations in Canada.

Harris, a large U.S. telecommunications firm, supported the project. They provided equipment for use by WISELab, which, although not directly applicable to the project, increased WISELab overall RF technical infrastructure.

Project Profile

As the existing radio frequency spectrum becomes more congested, it is important to assess the technical and economic potential of unused spectrum ranges to ease the congestion and satisfy the growing demands. By the late 1990s, the frequency bands above 50 GHz were becoming of interest internationally for use in short distance, wireless applications. In 1998, Canada had not yet investigated what policies would be appropriate for use of the 50-70GHz

band, although several other countries, including the U.S., were developing policies and standards for use in this frequency range.

In 1998, following discussions about the potential use of the newly formed WISELab capabilities, Industry Canada SITT and the Canadian wireless industry decided to sponsor a project with WISELab for a study of the 50 – 70 GHz frequency band which included:

- a survey of the present and planned worldwide frequency allocation and utilization in this frequency band;
- a review of related research results; and
- field measurements carried out by WISELab.

Based on the results, WISELab wrote technical reports on the use of the 50 – 70 GHz band, and presented those results to the Fixed Wireless Communications Committee of the Radio Advisory Board of Canada, and SITT.

A presentation of the results of the investigation was made to the RABC in December, 1999. The Committee agreed that the approach taken by the Federal Communications Commission (FCC) in the U.S. had created a favourable climate for industry to develop and implement wireless systems for application in this band. Based on the presentation, RABC asked the Industry Canada SITT to develop policies for use of the spectrum in the 57 – 64 GHz range. A similar presentation was made to Industry Canada SITT. Industry Canada proceeded to consult with industry about proposed policies and in December, 2000, presented for final comment a draft policy for spectrum utilization by licence exempt wireless devices in this band, as well as two other bands in the 45 – 80 GHz region.

Roles and Relationships

SITT was the sponsor and client of the study. As the government organization responsible for spectrum allocation, policy and regulation, they were aware that other nations were beginning to make use of the higher frequency band, over 50 GHz. SITT required background information and advice based on factual information and credible experimental data in this frequency range to make informed decisions on frequency usage.

The Terrestrial Wireless Systems Branch WISELab group was responsible for gathering information on other countries' present and planned use of this spectrum frequency band, especially the United States. WISELab also reviewed experimental data in the literature and conducted a number of measurements.

The Fixed Wireless Communications Committee of the RABC represented the interests of the private sector, and was in effect a secondary client of the study. They reviewed and discussed the WISELab report and made recommendations to SITT about the use of the 57 – 66 GHz band.

Impacts

The evidence contained in the WISELab study had major influence on two complementary outcomes. First, presentations to the RABC led to increased industrial awareness in the use by other countries of the higher frequency bands in the 50 – 70 GHz range, and the commercial potential for use of this band in Canada, following a similar approach to that of the U.S., customized to meet Canadian requirements. This awareness led to the RABC recommending to SITT that the band be opened up for commercial use in Canada. Based on the evidence in the WISELab study and the recommendation from the RABC, SITT developed a draft spectrum utilization policy for wireless devices in the 57 – 64 and 76 - 77 GHz bands. This draft policy has recently been finalized, after being presented for comment through the Canadian Gazetting process, and is now official.

As shown, the WISELab research effectively expedited the development of new spectrum policy and regulations for Canada.

Future Potential Impacts

Canada now has a policy governing the utilization of licence exempt devices in a number of frequency bands above 40 GHz. Based on past experience, opening this new region of the spectrum for commercial applications serves to satisfy the growing demands for licence exempt bands by industry. Setting policies and regulations for use early in the process, supports orderly implementation, and will stimulate the development and growth of specialized industries. It is expected that new products and services will be developed and made available to Canadians for use in this band. Both Canadian and international export sales and commercial opportunities will likely result from opening this spectrum. The following quote from Bell Mobility supports this conclusion:

> *Firstly, we commend the Department for its initiative in opening new spectrum above 40 GHz for use in Canada. The millimeter–wave spectrum above 40 GHz offers significant potential for development and introduction of new and innovative communication services. At the same time, it will foster the development and growth of new technology in the Canadian telecom industry, thus encouraging job creation.*

Individuals Interviewed

Luc Boucher	WISELab Research Manager, Terrestrial Wireless Systems Branch, CRC
Doug Sward	Director, Terrestrial Engineering, SITT, Industry Canada
Dr. Sabah Towaij	Director, New Wireless Services and Technologies,SITT, and Chair of the Spectrum Engineering Funding Group which allocates and manages funds for contract research with CRC
Guy Mitchel	Spectrum Policy, SITT, Industry Canada
Bill Taylor	Former Chairman of the Fixed Wireless Communications Committee, Radio Advisory Board of Canada

Documents Reviewed

Proposed Statement of Work for 50 – 70 GHz Studies, by Luc Boucher, WISELab, Terrestrial Wireless Systems Branch, CRC

Presentation entitled "Frequency Allocations and Emerging Applications in the 50 – 70 GHz bands – Part 1 Propagation, Part 2 United States and Part 3 All other Countries", by Luc Boucher to the Fixed Wireless Communications Committee, December 16, 1999

Memo entitled "Consideration of Regulation for 57 – 66 GHz band" from the Fixed Wireless Communications Committee, RABC, to Director Spectrum and Orbit Policy, SITT, Industry Canada

Spectrum Utilization Policy for Licence Exempt Wireless Devices in the Bands 46.7 – 46.9 GHz, 57 – 64 GHz and 76 – 77 GHz, Industry Canada SP –47 GHz, January 2001 (DGTP-001-01)

Response of Bell Mobility to proposed new spectrum utilization policy

Case Study – Development of Policy on Spectrum Usage in 50 – 70 GHz Range Antenna

Project Incrementality (influence)	Direct User Impacts	Industry Sector / Public Sector Impacts	Economy / Societal Impacts
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