REPORT ON THE ASSESSMENT OF MEANS TO INCREASE THE EFFICIENCY OF THE EXISTING SPECTRUM ASSIGNED FOR LAND MOBILE RADIO SERVICE USE

Wescom Communications
Research International Inc.

REPORT ON THE ASSESSMENT OF MEANS TO INCREASE THE EFFICIENCY OF THE EXISTING SPECTRUM ASSIGNED FOR LAND MOBILE RADIO SERVICE USE

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EXECUTIVE SUMMARY

Wescom Communications Research International was awarded a contract by DOC for a Study to Assess the Means to Increase the Capacity of the Existing Frequency Spectrum Assigned for the Use of Land Mobile Radio Service (LMRS). The study was divided into three tasks.

The first reviewed the situation in the U.S. through discussions with the FCC, users, operators and manufacturers, in order to compare it with that in Canada and to determine whether action being planned for the U.S. market would create any problems for the Canadian industry. The spectrum allocated to LMRS in Canada is in VHF 138-174 MHz, referred to as the 150 MHz Band, and in UHF 410-450 MHz, referred to as the 450 MHz Band.

The second task technically assessed the benefit that digital radio technology can provide in expanding the LMRS spectrum capacity, and if it can determine how to minimize any disruptive effect to current systems should it be introduced, and to develop a transition plan to introduce the new technology.

The third task identified the direction that long term spectrum planning should take and defined a course of action for DOC to consider in redeveloping the two LMRS bands to increase their capacity and efficiency.

Next Generation Trends

From discussions with the regulator, users, operators and manufacturers in the U.S., it was found that frequency congestion is concentrated in the large markets, as it is in Canada, and that the 150 and 450 bands are equally congested in the U.S. In addition, the allocations in the 800 and 900 MHz assigned for trunked systems are also congested.

A total of 10 large centres are reaching maximum capacity the U.S., including New York and Chicago. Those in border areas have a significant impact on Canada, where 90% of the market resides in areas within the transborder co-ordination band. Thus U.S. market development is important to Canadian industry and must be considered in developing any approach to be taken here.

Currently, the FCC does not plan on allocating additional spectrum for LMRS although they are under considerable pressure to do so. The introduction of standards and new technology when needed will result from action taken by the private sector. They are encouraging the use of trunked systems and expect that new technology, when introduced, will be digital.

Users in the U.S. as well as in Canada tend to stay with a single supplier and a form of "bonding" occurs that is carefully nourished by the manufacturer by providing full support and services in order to build a user base. As a result, the larger users are well satisfied and are not making any moves to change the relationship.

The U.S. market is dominated by three manufacturers; Motorola, E.F. Johnson and Ericcson G.E., who have almost equal shares. With market growth estimated at 30% per year they, and smaller manufacturers, are highly concerned with the exhaustion of spectrum resources.

As a result their emphasis in research and in manufacturing, is to increase the use of data transmission and trunking equipment by their users. This has resulted in potential expansion of the capacity of existing assignments by a factor of 6 or more, and since the majority of the large LMRS users have dispatch systems, the efficiency of these operations is significantly improved. National networks are also being developed for shared use to accommodate voice and data (Mobi-Tex by Ericcson G.E. to provide voice and data, Mobi-Data by Motorola for data only.)

All of the manufacturers are developing second generation equipment that is digital and uses narrow-band technology, which they propose to use for LMRS applications. Initially, channels will be split 3:1 and, within 10 years, they expect to increase this to 6:1 through the use of 5 KHz equivalent voice channels. The decision of TDMA or FDMA will be made later.

While the manufacturers expect that an LMRS standard will be developed, they will act to defer it as long as possible while they increase market share and complete new R & D, thus establishing *de facto* standards. Recent activity by the Association of Public Safety Communications Officers Inc. (APCO), the very large public safety user group, has initiated the development of a standard for LMRS. Their preference currently leans toward FDMA.

Trends identified include use of smaller, lighter digital terminals, with more features. Convergence of LMRS and LMTS (Cellular) systems is unlikely in the foreseeable future because the dispatch-type systems comprising the majority of the LMRS market in the U.S. are currently prohibited from using cellular systems.

In general, the market needs in the U.S. are similar to those in Canada and both Canadian and U.S. manufacturers view it as one market.

Technical Considerations:

As existing voice analogue technology is wasteful of spectrum second generation LMRS equipment will be digital. Dividing existing assignments into narrower 10 KHz channels is planned, and within 10 years this can be reduced to 5 KHz, resulting in considerable increase in spectrum capacity.

The choice of access technology is between TDMA and FDMA. Though research is continuing at Motorola and GE on a Code Division Multiple Access technology, there is insufficient information available to consider it at this time. In addition, the manufacturers were uncertain as to the probability of making it commercially feasible.

From analysis of NBTDMA and NBFDMA it was found that there are no significant technical differences between them and either could be used for second generation LMRS equipment.

Operationally, however, NBTDMA is the preferred candidate for shared trunked systems. It is both less costly and more flexible. In addition, technical evolution in the mobile radio field (cellular and personal communication services) is moving toward TDMA technology and its development for LMRS would be in harmony with R & D and the manufacturers of common equipment components.

Further study is required to confirm this preference and to determine how the Public Safety user requirements for a mobile-to-mobile feature can be provided. TDMA could not support this feature whereas it is possible using FDMA technology.

Thus from an evaluation of technical considerations it is recommended that the optimum capacity and efficiency of the 150 and 450 MHz Bands for LMRS use will be realized by re-developing the bands for shared trunked use and by the introduction of digital narrow band technology using 10 KHz, and in the future 5 KHz, equivalent voice channels.

An important consideration in the design of new equipment is that is has backward and forward compatibility.

This, then, is the recommended direction that longer range spectrum planning should take for LMRS.

Transition Considerations:

The proposed development and the introduction of new technology should be gradual since the spectrum is fully assigned, leaving no space to start, and most users require time to make any change.

Since spectrum re-development and new technology introduction are policy matters, it is recommended that a program be undertaken to define a new spectrum policy and develop a transition plan in a series of steps, each of which will require further study.

A policy to redevelop the spectrum for trunked use would include a plan to increase the annual licence costs and minimum channel loading requirements on a graduated basis starting a year prior to the availability of equipment and extending for a period of 5 to 7 years afterwards.

The mandated increase in licensing fees and channel requirements would result in releasing some frequencies to start the transition.

Subsequent increases would provide for continuing release for re-assignment until the target level of cost and channel loading met the increased objective of spectrum capacity and efficiency in the congested locations.

A preliminary study of the existing market and growth in the three major congested locations is required to provide input data for the development of the proposed transition program.

Wescom Communications Research International Inc., in association with Lapp-Hancock Associates Limited recommend the proposed LMRS redevelopment and transition program for DOC consideration.

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1.0 PURPOSE

This study was undertaken for the Department of Communications (DOC) by Wescom Telecommunications Research International Inc. in association with Lapp-Hancock Associates Limited. Its objective was to define and assess the means, (including the use of Narrow Band Digital Radio technology) of increasing the capacity of the existing frequency spectrum assigned for the use of Land Mobile Radio Service (LMRS) in order to accommodate growth, and to recommend the direction that long range spectrum planning should take. It was required that a recommended course of action be outlined to DOC for the provision of increased spectrum capacity.

1.1 Introduction

Land Mobile Radio Service (LMRS) is the term applied to mobile telecommunications systems that are dedicated to the private use of an organization(s) and do not require access to the Public Telephone Network (PTN) other than on an occasional, controlled basis. This is distinct from the Land Mobile Telecommunications Service (LMTS), which is also a mobile telecommunications service but is an extension to the PTN to permit its access from a any equipped vehicle. Each has its own frequency allocations. While this study is concerned with the LMRS, reference will be made the LMTS market, technology and spectrum assignments for comparison purposes.

LMRS systems have been in existence for nearly six decades. Between 1961 and the later 1970's, grew at a rate of 12%. Additional frequencies were made available for mobile services in the 800 and 900 MHz bands at the historic WARC meeting in 1979. Subsequently the growth increased to 15% by the mid 1980's and has continued to the point that now it is estimated as high as 30% per year.

The frequency spectrum allocated to Land Mobile Radio Services (LMRS) in Canada is in the 30-50 MHz, 150-170 MHz and the 410-470 MHz bands. The 30-50 MHz band is not widely used due to its inherent skip and interference characteristics. There is currently some congestion in the 47-50 MHz portion of the band but relief is not a priority because of the limited expansion of user demand.

The 150-170 MHz and 410-470 MHz bands are particularly suitable for LMRS use. They are very congested in the large urban centres and require relief.

The use of these bands has essentially reached capacity in Toronto, Montreal and Vancouver and are forecast to reach capacity in many other Canadian cities during the next 5 to 10 years unless relief is provided. Since spectrum is a finite resource that is increasingly in demand, means are required to increase the efficiency of existing assignments before giving consideration to the allocation of any more.

The congestion in the VHF and lower UHF bands in Canada has resulted to some degree from the rapid growth overtaking current frequency management planning. This planning permitted assignments on a first come-first served basis and the assignment of blocks of frequencies that were not efficiently used. Thus spectrum utilization was a major consideration when the 800 band was recently opened for trunking assignments only. The lower bands reached capacity use in the large centres before trunking allocations could be made.

The increasing interest in LMRS has been attributed to rapidly improving mobile radio technology, the lower equipment costs, improved capability to move data and to the rapidly increasing popularity and convenience of the "cellular phone" which has become both mobile and portable. The latter has generated a demand for small compact terminals with increased functional capability that can be used for LMRS. Another factor contributing to the frequency congestion is that many large centres in the US and Canada that are close to the border and must, by agreement, share available band allocations to limit interference.

Similar growth patterns exist in the USA where large metropolitan areas of New York, Chicago and Los Angeles have almost exhausted the available capacity for LMRS and several others will reach a similar condition in the near future.

The scope and size of the market in the US is of particular interest to the Canadian telecom industry that has established a world-wide reputation for its leadership in the development and manufacture of new technology. Examples include digital switching and transmission technologies and standards; the development of digital cellular telephony utilizing TDMA access technology; and the successful development of mobile data terminals (MDTs). These lead the market against increasing competition.

Thus it is important that spectrum planning for LMRS development take into account the fact that Canadian industry is required to serve both Canadian and the US markets.

As part of its development of a long term plan for spectrum allocation and management to serve Canadian needs, the Department of Communications has awarded Wescom Communications Research International Inc. this study contract to assess the means of increasing the capacity and efficiency of the existing spectrum allocations for LMRS.

1.2 Study Requirements

The study was divided into three tasks described as follows:

Task 1 was to determine the direction to be taken by radio systems manufacturers for the next generation land mobile equipment for LMRS in the US that would:

- include the views of an appropriate representation from regulators, TIA/EIA -TR 45.3, manufacturers, operators and R & D sources,
- outline LMRS spectrum problems in the US and compare them with those found in Canada,
- identify any Canadian problems resulting from being driven by solutions required to serve the larger US market,
- identify alternatives being considered - particularly by manufacturers and regulators.

Task 2 was to carry out an in-depth technical analysis to determine the benefits that digital radio technology can provide in expanding the capacity of the LMRS spectrum and its effectiveness and, if possible, the technical factors that must be considered for its introduction in order to minimize any disruptive effects on existing users. If it cannot provide for expansion effectively, define and assess alternatives.

In addition, an evaluation of new technology, including TDMA digital radio and whether it can play a role in long term spectrum planning was carried out. Further, this task required the development of a possible transition plan from existing systems to new ones. Finally, any impact on the development of standards and specifications and testing equipment by DOC was to be indicated.

Task 3 was to develop overall conclusions, based on the results of Tasks 1 and 2, regarding the direction that longer term planning should take to provide the necessary relief for LMRS, and to recommend a preferred course of action to DOC.

2.0 SCOPE

The scope of this study was limited by funding and its short time frame in the coverage of the large number of relevant organizations in the US and Canada. By association with Lapp-Hancock Associates Limited, Wescom was able to proide a significant representation of the market within the contract resources available.

It was noted during the course of this study that the rapid development of events in the US market would justify further indepth work, since there are large competitive forces developing independent strategies that could have a significant influence on future market development.

3.0 APPROACH AND CONSIDERATIONS

3.1 Approach

Since Tasks 1 and 2 were relatively independent of each other, they were carried out concurrently.

Task 1

In order to undertake Task 1, Wescom prepared the topics to be discussed with the firms and organizations in the US and in Canada in the form of a discussion guide. Section 2.0 above outlines the background discussion leading to the preparation of the discussion guide. A list of the organizations contacted is given in Appendix A.

Visits were made to the key manufacturers and the FCC in the US with the remainder of the interviews being made by telephone.

Consideration of the use of mail questionnaires was ruled out because their preparation, distribution and return could not be completed within the available contract time.

Task 2

For Task 2, Wescom first compared the available technologies and evaluated the effects on the LMRS should they be adopted, particularly with respect to any limitations that would be felt by users.

Task 3

Task 3 used the results of Tasks 1 and 2 as inputs to derive a course of action that DOC could consider.

The action proposed identifies a series of steps, including alternatives, to be taken over a period of time that will result in an optimum assignment of frequencies in the existing allocations. Where additional study is required in order to complete certain steps, this is identified.

3.2 Considerations

The increase in spectrum capacity required to serve the growing LMRS demand can be met in a number of ways, including the allocation of additional spectrum; the optimization of frequency assignments to obtain more extensive frequency reuse; and the introduction of new more spectrally efficient technology.

Allocating additional spectrum would be the simplest approach and, in the long term, may be inevitable. Currently the total spectrum available for LMRS use is approximately 80 MHz, and as far back as 1978, it was forecast that between 130 and 300 MHz of additional spectrum would be required by the year 2000, taking into account new developments anticipated at that time. Current forecasts run much higher, (up to 500 - 1000 MHz), though there are none which are accepted industry-wide. Spectrum capacity of this order may only be found by opening up the 1.7 GHz band. However consideration should not be given to this approach until optimum efficiency and capacity can be obtained from existing assignments by the introduction of new technology and more extensive frequency reuse.

During the last three years, frequency reuse has successfully contributed to the provision of spectrum relief required to serve the LMTS cellular growth. A frequency can be reused repeatedly providing adjacent and co-channel interference criteria can be met. The re-use distance depends on the choice of transmitter power, receiver sensitivity and the interference tolerance of the selected transmission scheme. Optimum capacity is defined by the location to be served, (downtown, urban or rural) its area, interference, and application (vehicle or pedestrian use).

The introduction of a new digital technology, for example, would be expected to utilize any components that have been developed to serve the second generation cellular LMTS. Cellular growth quickly outgrew its spectrum allocations which are inefficiently used by the current analogue systems and faced the same congestion now appearing in LMRS. The proposed digital equipment being developed for introduction in 1992 is expected to provide an improvement in spectral utilization by a factor of 3 and subsequently up to 6.

If similar results can be realized by the application of a new technology to LMRS, the channel assignments in the 150 - 170 MHz band, for example, would be increased from the current 666 to 2000 (for 3:1 split) and to 4000 when technology is available to split the existing 30 kHz channels into six channels of 5 khz.

An obvious question that arises from the above is whether the planned digital cellular technology could be adapted suitably for LMRS use whose characteristics are considerably different from those of LMTS.

A brief comparison shows the following:

	LMRS	LMTS
Speech Quality	Lower than LMTS	High
Messages	Interruptible	Must complete
Handoffs	not needed	needed
Average length of call	10 - 20 secs.	100 - 180 secs.
Mobile access	by contention with waiting	Random with P .01-.03 blocking
Offered traffic	i) majority from dispatcher to mobile	mobile to and from PTN network
	ii) asymmetric	symmetric
	iii) difficult to measure with accuracy.	measurable and predictable
Users/channel/unit area	LOW	very large
Operating Area	Most anchored to a designated area	local and roaming for access to PTN
Networking	must be adaptable to trunking and sharing schemes	tied to cellular network
Data and Voice	Must be adaptable to data only as well as capability for systems data	mostly voice usage, has voice and data

The contrast between the needs of LMRS and LMTS users indicates that even though they are both served by mobile technology, the design and configuration to serve one may not be appropriate for the other. Further, because of the large component of dispatch type needs that are best served by LMRS, any significant merging of the two requirements would appear unlikely at this time and two different architectures will be required.

US regulatory rules do not permit dispatch services to be served by a cellular system because of the use of automatic diallers. In Canada there is no prohibition, and while it is difficult to see any long term functional benefits for a user or an operator by migrating from LMRS to LMTS, Canadian cellular operators are discussing with large users that this possibility will be attractive when second generation equipment is available. In their view, the economic benefits of sharing an established infrastructure outweigh the investment in a dedicated one providing, of course, that the user obtains the service he needs. There are still a few technical problems to be resolved, however.

Since it has been agreed in Canada and the US that the second generation cellular equipment will use digital narrow band TDMA technology and be introduced by 1992, this project will include consideration of whether the technology could be modified to serve the needs of the LMRS market and, if so, whether the access method should be TDMA or FDMA.

Because of its importance to Canadian industry, the project calls for an assessment of the direction that manufacturers in the US propose to take since the US market is at least 20 times larger than the Canadian one. A similar frequency congestion has developed in the US and the direction that US suppliers take to increase the capacity of their allocations could have some impact on Canadian users and operators that may need to be taken into account in longer term spectrum planning by DOC.

4.0 SURVEY OF US MANUFACTURERS, REGULATORS, USERS AND OPERATORS

4.1 Introduction

The current analogue technology used for LMRS is obsolescent since it is capacity-limited due to the use of spectrally inefficient analogue transmission, and outdated modulation and access methods. All other forms of telecommunications are moving rapidly away from analogue to digital techniques and it is reasonable to assume that for the next generation of LMRS equipment, a new technology is required to increase existing spectrum capacity and that it will be digital.

Spectrum congestion in large centres is occurring in the US as it is in Canada. Since their market is 20 times the size of ours, it is important that an assessment be made of the direction being taken there to solve the problems since it will be of importance to the Canadian telecom industry and should be taken into account in spectrum planning.

The assessment by Wescom was based on interviews with the US regulatory body, the three largest manufacturers in the US and two in Canada, users in the US and in Canada, and operators in Canada. Contacts in the Canadian market were made to assess whether there are significant differences that would need to be considered in any recommendations.

Discussions with key representatives were based on a discussion guide prepared by Wescom. The contact list and discussion guide are given as Appendices A and B of this report.

4.2 Results of Interviews

4.2.1 The Regulator

Federal Communications Commission

In general, the current FCC approach is to encourage competitive forces in the marketplace to solve the frequency congestion problems and to develop new spectrally efficient technologies for LMRS services. FCC initiatives if taken, would involve lengthy and complex bureaucratic processes that tend to inhibit progress more than if the private sector originates the change in a submission. They recognize that the manufacturers are currently driving the market because of their ties to their users and therefore it is they who will need find means to improve the efficiency of the frequency assignments they have in order to increase their business and remain competitive. The FCC will continue to assign frequencies as long as spectrum is available in the current allocations.

Spectrum Planning

Allocations of spectrum are made by the FCC and assignments determined by frequency coordinators and consultants in the private sector, who are authorized by the FCC. Each industry association, for example, appoints a frequency coordinator who completes the applications, selects the frequency and provides the FCC with the necessary documentation for approval. The Code of Regulations defines the rules under which the coordinators and consultants are authorized, their responsibilities and how they are to undertake them.

In Canada the DOC performs the functions of the coordinators and consultants as well as the policy and regulatory role of the FCC.

Since the FCC prefers to encourage initiative rather than take it, one form of encouragement used is to waive or modify rules when dealing with submissions that will reflect the direction that FCC prefers to go and could even signal whether consideration is being given to making some rule changes. For example, consideration is being given by the FCC to re-thinking their approach to some of their licensing procedures and rules that will acknowledge their support for the industry trend toward providing new services and technology in Specialized Mobile Radio (SMR) systems that would result in more and better utilisation of currently assigned spectrum.

It is not expected that users will make any direct interventions to the FCC in order to initiate a change because of their ties to a manufacturer, who will sense the need first and take the necessary action in order to retain the customer and to stay competitive.

There are ten large metropolitan areas, referred to as markets, of which three have reached capacity and the remainder are approaching it. For these cases, the FCC is approving assignments in the reserve bands between the 800 and 900 MHz allocations. For the other bands allocated, the 30 - 50 MHz is not attractive to LMRS users. The 150 - 170 MHz and 400 MHz allocations are full and the FCC does not intend to force new technology on users of these frequencies until reserves are used up. While the 150 -170 MHz band is very attractive for LMRS use, the majority of it was randomly assigned to single frequency users who use it inefficiently. Now that it is fully assigned there is no simple way to open up a window to redevelop it without involving a large number of users. To date FCC studies have not produced an approach that could be approved.

This did not occur in the 800 and 900 bands which were allocated for trunking and shared use. Though they are fully allocated they are not all assigned. For example, frequency allocations have been made for Public Safety applications which have not all been used whereas allocations for Specialized Mobile Systems (SMR) have been fully subscribed for in some of the congested markets and new requests are being filled from the 800 and 900 reserve bands.

Recently the Private Mobile Group in the FCC has been considering licensing some 10 KHz channels in the 900 KHz band and some 5 KHz channels in the 220 - 222 MHz band for nation wide SMR systems.

US - Canada Coordination

Consistent with the mutual interest of Canadian and US firms in the LMRS market in Canada and the US, there is ongoing liaison between the FCC and the DOC that results in effective coordination of spectrum planning to serve the growing requirements of both countries.

Standards

Standards do not exist for LMRS and FCC expects that when they are required in the US, they will be developed and coordinated in the private sector, as was done for cellular standards by TIA/EIA organizations.

To date there has been limited interest registered to develop LMRS standards. Strong ties are maintained by the manufacturers with large users and operators based on their proprietary protocols that will not operate with equipment of another manufacture. Most users indicate that they are satisfied with this arrangement. (See Section Users)

A notable exception is the National Telecommunications and Information Agency (NTIA) in the US government which has developed a set of requirements for LMRS standards and submitted it to the Association of Public Safety Communications Officers Inc. (APCO) for consideration. APCO supports the development of a standard and has committed funds to undertake the necessary studies and coordination to meet this objective.
Thus some need for standards is starting to find expression.

Trends

Particular trends noted by FCC in addition to the rapid exhaustion of available spectrum for LMRS, is the growth in Special Mobile Radio (SMR) service organizations. All of these are tied to a manufacturer of their choice. In the case of Motorola, the company has acquired substantial ownership in their SMRs and have linked them together into a network that covers most of the markets in the US.

The FCC expects that digital technology will be introduced to provide improved spectral efficiency and increased capacity in the existing frequency bands. Whether or not it would be accomplished through the introduction of narrow band or another technology was not decided. The 150 - 170 MHz band is not the target of any special attention by the FCC in the foreseeable future.

There is a growing use of data transmission on SMR's for dispatch systems with voice used only for occasional backup or particular functions and for data only trunked systems.

Special Mobile Radio is a category of service that is similar to a Radio Common Carrier (RCC) but for which state law has been preempted by federal law to bring it under federal regulation. An SMR is considered a private carrier and is not obligated to provide service to any user as a common carrier would be required to do. On the other hand, FCC does not provide interference protection for the SMR users since it is a private operation.

There is no equivalent category of service in Canada, though there are RCC's.

Frequency licenses are granted to the SMR operator for 5 channels or more and an operator can hold more than one license by buying other SMR operations. Trunked systems constitute better than 80% of the SMR market and are tied to a manufacturer of choice.The majority of customers remain in a single market doing very little roaming. However, SMR operators are rapidly expanding by acquisition and a trend is to connect them together (by land lines) into a network to accommodate an increasing need for roaming.

Interconnection to the PSTN is permitted under the same terms as for a PBX (Part 90 of FCC Rules) and it is expected that SMR operators will expand the use of this feature because of the attractive revenue potential involved.

FCC rules prohibit the use of dispatch services on cellular systems but limited migration of some small LMRS users to cellular is expected. Large users, in addition to other reasons, do not want to put cellular telephones in the hands of their employees.

The FCC has noted publicly that they should re-think their rules and procedures applying to SMRs in order to lighten some of the restrictions and encourage their growth. Already they have waived some of these to approve specific applications in support of the public benefit to be obtained.

Of particular note is the 40 mile radius within which a SMR may not expand if the minimum 70 mobiles/channel has not been realized. Also one SMR may not acquire another one within a 40 mile radius if one party has not reached the minimum channel loading. This restriction has not favoured rural development and needs to be adjusted.

Another consideration is to assign some 10 KHz channels in the 900 band and some 5 KHz channels in the 220 - 222 MHz band for national SMR networks. The latter is shared with Government.

Summary

As in Canada, the LMRS bands are congested in the large markets in the US and the FCC will continue to assign frequencies as long as they can be found within the currently allocated bands.

The 800 and 900 bands are being assigned to serve trunking and shared systems and in congested markets reserve bands in the 800 and 900 MHz are being used. Assignments are determined by frequency coordinators and consultants authorized by the FCC who prepare the applications for FCC approval.

The introduction of new technology will result from action taken in the private sector resulting in appropriate submissions to the FCC for approval to make the necessary changes affecting the spectrum.

When a change is approved (i.e. to introduce narrow banding) the transition procedure used by the FCC is to advise the affected users of the proposed change and to provide them with interference protection in the use of their existing equipment for a period of 5 years. This provides reasonable opportunity to make the adjustment.

4.2.2 The Users

Introduction

US Users

Due to the size of the user population in the US, it was not possible within the resources of this study to make sufficient user contacts to obtain a reliable set of data from a representative survey. Thus available statistics from current literature confirmed by discussions with the manufacturers have been used.

For the Canadian market, it was possible to obtain representative data from users that confirmed observations made in the US and also supported the observation that the US and Canadian user needs are similar. Military users, though large have not been considered in this study.

The non military users of LMRS in the US may be classified into the following major categories:

- Public Safety
- Utilities
- Transportation
- State and Local Government
- Big Business

The contractors found that the US users were tied to the manufacturer that they had chosen and, from all available data found, are satisfied with that arrangement. Because of the lack of LMRS industry wide standards, each manufacturer has developed proprietary protocols for the operation of their equipment in trunked systems that are incompatible with another make. However, in a simple system not involving trunking, mobile sets can be intermixed.

Once involved with a user, the manufacturer works hard to maintain a continuing and supportive relationship in terms of maintenance, update of equipment, training and developing modifications to serve the users needs.

This has worked so well that in annual polls of users by category, made by COMMUNICATIONS magazine, it was found that the most important factor that influences users in all of the above categories for buying the equipment they do is Past Experience (with their supplier). The second most important factor was the on going Service Assistance (received from the supplier). The next two factors were Delivery Time and Price and these alternated between third and fourth place depending on the user category but with only a few percentage points difference. For the overall survey Price was slightly ahead of Delivery Time.

Standards for LMRS

Without industry wide Standards for LMRS, such as there are for cellular technology, competition is limited to those occasions when a large user decides to replace his equipment with a trunked system or is building one for the first time. For these, competitive bids in which all suppliers can participate are usual. Provisioning for subsequent changes and expansion is available only to the original supplier of the system. As a result of the limited competition, users cannot obtain the benefits of price, quality or have significant impact on the new technology development.

Despite this apparent disadvantage, it was found that the status quo was supported more than it was opposed. This is consistent with the surveys. The users felt that the large reputable manufacturers were sensitive to their needs and were able to anticipate and provide what was required in a timely manner. They also made the point that with a dedicated supplier, changes and additions could be made without having to resort to the tedious bidding process, and that budgets could be established more effectively.

The opposite view comes from the National Telecommunications and Information Agency who on behalf of the Federal Government as a user, has initiated action to develop standards for LMRS. They have submitted a description of their needs, supported by the results of studies made over the past three years, to the Association of Public Safety Communications Officers Inc. (APCO) who have committed up to $ 400,000 to undertake development of a standard. They are in a good position to encourage other user organizations to participate.

Apathy among users regarding standards is high because of the satisfaction with the current user-manufacturer relationship and the initiative taken by APCO should be able to translate apathy into action that could result in an approved standard being available within 3 to 4 years.

The current thinking by APCO leans toward a Digital Narrow Band FDMA standard and among their requirements is a "talk - in, talk - out" capability for communication between mobiles that is particularly useful to Public Safety organizations but could be used by some utilities and mass transportation sectors as well.

The contractor's view is that the development of standards for LMRS should be encouraged as one of the means to establish a new technology in the industry. It will also provide the user with increased opportunity to influence the long term development of the service.

A similar situation existed in the late 1970s when action was taken to deregulate telephone companies and allow competition. Many large users were reluctant to give up their convenient arrangement with their telephone company and it was only after they experienced the improved cost benefits and the new services, developed as a result of competition, that they became supporters. The same can be expected to happen in LMRS when standards are introduced and manufacturers have to compete on a continuing basis.

User Trends regarding Growth and Services.

Data transmission for dispatch applications is increasing rapidly because it permits the user to handle more traffic in a more efficient manner. A data message can be sent, received and understood 6 to 8 times faster than the same message using voice. Thus a taxi company using data transmission with voice backup will serve more vehicles, use fewer dispatchers and fewer frequencies than with a voice dispatched system.

Data transmission has been accelerated further by the improvements in Mobile Data Terminals over the last two years that have made them smaller, less expensive, more fully featured, and easier to use. Canadian development at MDI has made it a leader in this field. User surveys show an increasing rate of growth for these terminals in the Large Business, Police and Utilities categories.

Mobiles and portable units are shown as the prime area of terminal growth for all user categories and is consistent with the growth of SMRs and trunking networks for individual corporations.

Users are aware of the shortage of additional frequencies in the congested markets and are taking initiatives to increase the utilization of those that they have. In this respect they are getting assistance from their supplier in whose interest it is to help them. This has been one of the driving forces to introduce data dispatch systems and thus create more capacity on their existing assignments.

It has also motivated the manufactures to develop trunking systems that will permit many users to share the same infrastructure, without interference, and in order to provide an improved means to accommodate their user's growth and development.

Summary of U.S. Users Attitude to LMRS Development

Generally, the user in the US is currently delegating to the manufacturer any initiative to improve LMRS technology and to increase the spectrum capacity for growth.

With the exception of the APCO, there is no growing user pressure to develop LMRS standards. However, while the APCO initiative has just started, it represents a very powerful force to undertake the successful development and a time frame of about three years is currently being considered to meet the objective.

Users are satisfied with their association with a manufacturer and will likely continue to be as long as their needs can be met. The APCO process to develop LMRS standards is expected to obtain growing user support should studies now being undertaken by APCO produce favourable results.

Users are expanding their use of data transmission for dispatch operations to realize the cost benefits and the increased efficiency obtained in their operations. The trend also increases spectrum efficiency.

USERS IN CANADA

In general, Canadian users are facing the same problems of growth as those in the US and are dealing with them in a similar way but under somewhat different circumstances.

User - Manufacturer Relations

The same user-manufacturer relationship exists in Canada as in the US, and it was noted that US manufacturers are strengthening their marketing organizations in Canada whereas they are moving their manufacturing facilities back to the US for its consolidation there.

Data transmission

Taxi and courier companies are moving slowly into data dispatch primarily because of the initial capital costs involved and their interest in making change consistent with the amortization and replacement of mobile equipment. For this reason, suppliers have been reluctant to spend the marketing resources needed to accelerate the development of this market. It typically takes a minimum of a year to complete the initial sale that is usually small and acts as an experiment by the user in making the transition to data dispatch operation.

However police and large utilities are increasing their use of data transmission and the use of mobile data terminals, backed up by voice.

Trunking Systems

Trunking systems are being developed by large users to serve their own needs by consolidation and sharing. The Government of Ontario, for example, have installed a trunking system in south western Ontario and are experimenting with sharing it with a number of the government organizations, one of which is the ambulance service. It is too early to assess whether this will be successful.

BCE Mobile has established a subsidiary, National Mobile Radio Communications Inc. (NMRCI), as an LMRS operator to undertake the planning, development, installation and operation of LMRS trunking systems for large users. As such, they can contract to resell unused capacity where appropriate. In addition NMRCI plans to implement a national trunked network for shared use of clients.

CANTEL is also preparing to enter the trunked LMRS market with the Mobi-Tex data and voice operation system.

The RCMP is in the process of developing trunked, networks particularly in those provinces where they are responsible for provincial police duties. While they would prefer not to share their system outside the force, it may become necessary to include some provincial and municipal related activities.

SMRs are not developing in Canada, though consolidation of RCCs by manufacturers is increasing. One of the large SMR operators in the US, Johnson Communications Company (JCC), states that (to be successful), the minimum population of a target market for an SMR is 1 million. The limited number of such markets in Canada may be a deterrent at this time to their development.

Licensing

Unlike the US, users deal directly with the Regional offices of DOC in applying for frequency licenses since Canadian policy does permit coordinators or consultants to undertake this role.

Standards

Interest in the development of standards has been expressed by operators and by government organizations such as the Ministry of Government Services in Ontario and Federal government departments. However there is no one organization prepared to take an initiative similar to that of APCO in the US.

4.2.3 Manufacturers Views

Introduction

As a result of discussions with the regulator and users, it was observed that the main forces driving the development of the very large LMRS market are the manufacturers. It is their R and D resources that will provide improvements of the current technology, and develop the second generation of equipment in the US.

However, without agreed standards in place, these development programs are independently aimed at obtaining as much of the market as possible for each company. This is to not only increase current revenue and profit, but to increase the use of a given technology, through a large supportive user base, against the time when the inevitable development of a standard takes place. Thus the manufacturers will delay the development of a standard as long as possible or until one of them has a dominant share of the market.

However, with the current shortage of spectrum, and, with a burgeoning market to be served, time is running out and it appears essential that a standard be developed in the next 3 years.

Since there are a limited number of technical options available to provide spectrum relief, it was necessary to determine to what degree there was similarity in the approaches of each manufacturer in the development of new technology. In addition they were asked to indicate changes that could be made to current spectrum management that would assist the introduction of a new technology and their views on the development of LMRS industry -wide standards.

The views obtained came from:

- Motorola,
- Ericsson - G.E.,
- K.F.Johnson,
- M.D.I.
- NovaTel
- Glenayre Electronics

Cellular equipment manufacturers AT&T, Northern Telecom and Harris Communications indicated that they were not involved with LMRS equipment development or manufacture.

General Comments

All of the manufacturers are working to increase the capacity of the existing available spectrum in order to obtain as much of the growing market as possible. They are promoting the use of data transmission and the development of trunking and shared systems since available frequency assignments are only for that purpose. They agree that the next generation of equipment will be digital and most expect that it will be narrow band. None will acknowledge a preference for TDMA or FDMA on the premise that the decision will not be made for a while.

Another point of agreement is that they will not support the development of LMRS standards.

Motorola, Ericsson - G.E. and K.F.Johnson have the largest market share in the US and contributed the most to this study in terms of information and views. MDI is directing its efforts to the development of data trunking systems that will use its Mobile Data Terminal. NovaTel is focussing primarily on cellular equipment development and manufacture, but serves the LMRS market for mobile and portable terminals.

The manufacturers are closely associated with the growth and development of SMRs and trunking networks for large users. The supply and servicing of RCCs, is mainly carried out by equipment distributors and operators. This confirms the user survey results of Communications Magazine.

The growth experienced by distributors and operators was estimated to be in the range of 7 - 9 % annually. K.F Johnson said that their revenue projections were $125 million in 1989 to over $400 million in 1993. The majority of this increase being from trunking systems for large individual users and not from SMRs. Thus there is no doubt from the manufacturers viewpoint that the market is large.

In addition to the above general points the following individual views of the three largest manufacturers were obtained.

Motorola

Half of Motorola's business is in the mobile market and the other half is the manufacture of semi-conductors. This point was made to indicate their dedication to the mobile market and the fact that they are in the total mobile market, rather than just the segment.

For LMRS they monitor the assignment of spectrum very carefully. Motorola has developed a model into which they feed spectrum assignment data, short and long term requirements of their users, economic and pricing data, manufacturing costs and as complete data as is possible on the changing market. With the model they have developed forecasts that show the frequency capacity that will be required in the short and long term. It also permits them to assess the impact of new technology. Their most recent data indicates that to accommodate the growth of LMRS by the year 2000, between 500 and 1000 MHz of additional spectrum will be required, even taking into account anticipated technological innovation. This is considerably higher than the 120 - 300 MHz requirement forecast in 1978. Japan has forecast a requirement of up to 800 MHz additional for their country.

While the quantitative result is incredible the consultants suggest that it does indicate that the growth requirements projected in 1978 are now forecast to be

2 to 3 times larger and that the capacity of the 80 MHz currently assigned will need to be increased by between 3 and 6 times.

Motorola is developing digital narrow band equipment that will provide 3 to 1 division within 5 years and as much as 10 to 1 over the 10 year period. They have research underway in TDMA, FDMA and even CDMA. The latter is being undertaken as a joint research venture with a Regional Bell Operating Company (REBOC) that they would not name until an announcement is made in the near future. Motorola has serious doubts that the price and performance can be can be made acceptable but a field trial is planned in California this year. They have not decided between the other two.

Motorola's market focus is on SMRs and they have purchased over 700 systems to link together in a network. Their prime concern in the introduction of new technology is to find sufficient available spectrum to start.

They stated that they are preparing a submission to the FCC requesting consideration of the 220 to 222 MHz, 901-942 MHz and 900-941 MHz, or 894-896 MHz and 859-861 MHz as possibilities to create space for introducing second generation technology.

Because of their large market base in Canada, they recognize the Canadian need to increase the capacity of the existing spectrum and are encouraging the development of shared and trunked systems among their users.

Ericsson - G.E. Mobile Inc.

Ericsson and GE entered into a joint venture to serve the LMRS market in North America, primarily Canada and the United States. Ericsson owns 60% and GE the remainder. The prime thrust of the venture is the development of the market for the Mobi-Tex data and voice trunking system but they are active in developing the total market as well. The GE contribution is their large share of the market for terminals and existing trunking systems.

The results to date are that contracts for Mobi-Tex have been signed with Ramm Mobile Data, a large US operator setting up a national data and voice network, and with CANTEL that intends to undertake a similar venture in Canada.

The joint venture is committed to both the cellular and LMRS markets, and in Ericsson's global approach they have recently established their Technical Assistance Centre (TAC) in Montreal, for global cellular operations. At the centre the software development and technical support is coordinated for all countries. It resulted in a move of 60 people to Canada from Dallas. Ericsson is also heavily involved in personal communications development, in particular the Digital European Cordless (DEC) system.

GE's activities and programs have not significantly changed and they are carrying out the R & D for LMRS technology in the US and Canada. The combined organization is continuing to enlarge its user base and, unlike Motorola, does not acquire ownership in SMRs but relies on the manufacturer - user bonding.

Ericsson - GE (E/GE) research is directed to the development of a second generation digital narrow band system. They have not yet decided on an access technology but are currently leaning toward FDMA and channels as narrow as 3 KHz. Quadrature modulation using pi/4 offset QDPSK appears preferable to serve either FDMA or TDMA. GE is still looking at CDMA though they are not confident that it can be competitive.

GE expressed concern for the frequency congestion in Canada in the large markets because it is slowing down their ability to serve demand. GE is encouraging their user base towards trunked and shared systems.

In their view new spectrum allocations should only be made for shared or trunked use and consideration should be given to limiting any re - assignment of existing frequencies to shared use.

The trend is that large users will be served by trunked systems and small users may be served by RCC operators.

There were no suggestions for transition planning at this time until the development of the second generation equipment was more advanced.

E.F Johnson (EFJ)

In terms of total LMRS market share, EFJ is either just a little ahead or a little behind Motorola in the race for first place depending on who one talks to. EFJ's focus is on the large user for whom they provide trunking systems. As noted previously their revenue target is $ 400 million in 4 years and they are currently on track at $ 125 for 1989.

EFJ is developing digital narrow band technology but cannot say whether TDMA or FDMA is preferred. While they would object to establishing standards at this time the requirements that APCO is considering are diverging from the market EFJ is serving.It could be presumed that this means FDMA as well.

While they would make no comment on spectrum management, their objective is to encourage the development of trunked and shared systems. One feature that is in growing demand is for interconnection to the PSTN. Also some of their large users are leasing time on an SMR with overlapping frequencies as a back up in case their private network should fail.

Summary of Manufacturers Views

The manufacturers are the driving force in the development of the market in the US and recognize their position and consequent responsibility to maintain user satisfaction.

The potential market is large and while there is little agreement on its size, each manufacturer has set targets that are large and achievable if they can manage to obtain the frequencies needed. Most of those available are in the 800 - 900 bands and are allocated for trunking system use. Thus they are developing SMRs and large user trunked networks that can be shared and are promoting the increased use of data transmission with or without voice. This is consistent with the FCC objective to increase the efficiency of the existing spectrum.

None were focusing on providing relief to the VHF and lower UHF but indicated that the systems they are developing are not frequency sensitive and could be introduced wherever space is found. Motorola is taking some initiative with the FCC designed to make some additional frequencies available in the VHF and UHF bands to permit new technology to be introduced.

All of the manufacturers consider that the LMRS market in Canada and the US is homogeneous and that new technological developments will serve them both.

They are developing second generation equipment that will be digital narrow band but are keeping their options open regarding TDMA or FDMA. Narrow banding can be provided with a minimum split of 3 to 1 within 5 years and 6 to 1 within 10 years. GE and Motorola both referred to their research in Code Division Multiple Access (CDMA) but none expressed serious optimism about its success.

The Manufacturers will object to the development of LMRS standards.

4.3 Conclusions

The following conclusions were drawn regarding the trends of the next generation of LMRS:

- From the views expressed by the regulator, by users and by the manufacturers, LMRS frequency congestion in the US and in Canada is concentrated in the heavily populated area.

- Standards for LMRS are required so that equipment of all manufacturers will be compatible with any system. As it is now the manufacturers are driving the development of the market in the US and Canada instead of the user because of the manufacturer - user bonding that occurs, and which is carefully nourished by the manufacturer. As a result the user is unable to obtain competitive bids for expansion or change. Also, without standards, manufacturers are proceeding independently without user or government direction in their research towards the development of second generation equipment.

- APCO is developing an LMRS standard on behalf of its user membership. The target for completion is 3 years or earlier. There is no equivalent organization in Canada. APCO's initial position favours FDMA.

- While the Canadian market will be driven by the solutions developed to solve the US problems, the direction being taken at this time does not create serious problems for Canada. Manufacturers are focusing on the development of trunking systems and data transmission and there were no alternatives seriously identified.

  Mobi-Tex and Mobi-Data are nation wide systems are being developed in the US and will be introduced here by CANTEL and BCE National Mobile. It is expected that connection between US and Canadian systems will be requested.

- The manufacturers are developing second generation narrow band digital LMRS equipment and are prepared to go with either TDMA or FDMA. They would not say which they preferred and are unlikely to do so until a standard is introduced. The equipment of individual suppliers is currently incompatible with that of any other supplier because of the proprietary protocols used.

- Digital transmission is growing among users in order to make more efficient use of their frequency assignments but more importantly they find that digital technology opens up important ways to improve the efficiency of their dispatch operations.

5.0 OPERATIONAL AND TECHNICAL ISSUES IN THE APPLICATION OF NEW TECHNOLOGY TO LAND MOBILE RADIO SYSTEMS (LMRS)

In order to consider means to provide relief to the existing LMRS frequency bands it is necessary to examine the technical options available and the means to implement them in order to determine a preferred approach.

5.1 User Conditions

The users of LMRS systems may be classified into the following major categories:

- Public Safety
- Utilities
- Transportation
- State and local Government
- Big business

The majority of the users in these categories have dispatch operations and are served by LMRS systems employing FM analogue technology on 25 and 30 KHz channels in the VHF and UHF frequency bands. Voice is the predominant means of communications.

The accelerating annual growth, estimated to be over 30% , has caused the capacity limits of the available frequency allocations to be approached in 10 of the largest markets in the US and 3 in Canada. This has put pressure on the spectrum regulators to make more spectrum available. However, with the growing demands from other forms of radio communications, including cellular and the coming Personal Communication systems, it cannot be easily done and the regulators have had to insist on better utilization of the existing allocations.

This shortage has resulted in a trend by users to employ digital transmission, either with or without voice for backup, in order to meet growth requirements. The additional benefits realized include a significant increase in message throughput, increased efficiency of the dispatch operation and a reduction in dispatch staff.

Voice transmission has been the traditional mode of communicating in LMRS but with the reduction in cost and size of mobile and portable terminals over the past few years, users are finding ways to use the service that were previously uneconomical.

The variety of applications is increasing, as are the value added features such as security, privacy, the use of mobile data terminals and even hard copy for those who need access to a data base to complete a transaction. Features that have become common place with the telephone network are expected to be available in the mobile terminal to the extent that they can be useful. These features and services can be provided with digital encoding, including voice.

However, for public safety requirements there is a need for an inter-mobile mode to permit police, fire, and ambulance units at the scene of a disaster to communicate with each other without losing control from their respective base stations. While this appears mainly as another feature to the user, it is more complex because it involves both equipment and network design considerations.

Thus in the long term planning to increase spectrum efficiency consideration must be given not only to the increasing number of users but, more importantly, to the provision for an extensive array of new features and value added services.

5.2 TECHNICAL CONSIDERATIONS IN EVALUATION OF NEW TECHNOLOGY FOR LMRS

5.2.1 Compatibility

New technology for LMRS must have backward as well as forward (growth) compatibility and should be tested against several important criteria including cost effectiveness, introduction with minimum of disruption, and maximum attainable spectral efficiency.

Backward compatibility is the ability of a new system to integrate with existing systems with the least amount of change to system parameters such as transmission power and frequency. To meet this need, the spectral efficiency of the existing systems may need to be increased by reducing the radius of the coverage area (by lowering the antennae height and reducing power) to permit frequency reuse when introducing the new system.

Forward compatibility implies that specifications of the new digital equipment allow minimum of changes when future developments take place. This will help to retain harmony with the evolving technology.

5.2.2 The Question of Cellular (LMTS) Technology

In any discussion of narrow band technology for LMRS the question arises of using cellular technology developed for the second generation systems.

As was shown in the comparison table in the introductory section to this report the two applications of mobile technology are distinctively different.

Public LMTS is an extension to the Public Switched Telephone Network (PSTN) with the mobile terminal behaving in approximately the same way as a regular telephone. Voice is the prime mode of communication and the average message length is considered to be 180 secs. Thus the handoff feature is required to maintain a conversation while moving in and out of adjacent cells.

LMRS on the other hand is a closed mobile radio communications system available to only those on the system. Average message lengths are 20 secs. and there is no requirement for handoff. When a mobile moves out of the range of the base station into that of a repeater, a call can be restarted or repeated with little or no penalty.

It is technically possible to use the cellular system for some LMRS purposes in Canada but the slow access time even with an autodialler would limit operational efficiency. In the US, dispatch applications are not allowed on cellular systems but there is no similar restriction in Canada.

While the two Canadian cellular companies are discussing the possibility of cellular system use LMRS with some of the large users, they advised that it is not economically feasible in congested markets such as Toronto and Montreal. However it could have application in areas of lower density.

5.2.3 Digital Voice Encoding

While voice has been the traditional mode of communicating over LMRS, it is no longer required for dispatch systems. When used it wastes spectrum compared to that needed to transmit the same amount of information as a data message.

For example, a voice message containing 67 characters sent to a cab driver will take about 12 seconds of the channel time. The same information in a data message sent at a transmission rate of 4800 bits/sec and including a 50% overhead to combat channel impairments, will require only 2 seconds. The channel time is thus reduced and channel capacity increased by a factor of 6. A further capacity improvement results if the response from the mobile is digital. Access by contention is also made easier.

Thus for dispatch systems that do not require recognition of the sender's voice the information can be assembled and sent as a data message for display on the receiving mobile terminal in a fraction of the time required by an equivalent voice transmission. The result not only improves the analogue channel utilization but allows it to accommodate much more traffic. Further, system operating efficiency is improved since the data message is easily understood without the distraction of voice and pronunciation impediments.

However some applications require the use of voice as a backup to accommodate specific functions. In this case, the voice transmission can be encoded digitally and transmitted as data. For some applications in the Public Safety domain, sender identity is important and can be provided either in data form or in the less spectrally inefficient alternate voice mode.

Research in digital encoding of voice is an area of active research. During the past five years a number of low bit rate voice encoders have emerged out of which Regular pulse Excited Linear Predictive coding (RELP), and Code Excited Linear Predictive (CELP) coding are of considerable importance for mobile radio applications.

For a fixed data rate the transmission bandwidth can be reduced by smoothing out the phase trajectory of the signal. The continuous phase and constant envelope class of modulation format produces a compact spectrum, so that high transmission rates are possible over narrower channels. However, using smooth phase changes to reduce bandwidth results in considerable degradation of performance and an expensive receiver design becomes necessary to overcome this.

Constant envelope format using a class C amplifier improves transmitter power efficiency but in the past eliminated the use of more spectrally efficient modulation schemes, such as QPSK and its derivatives, due to battery power limitations. Recent advances in linearization technology now permit QPSK and OQPSK modulation schemes to be used.

Thus the transmission of encoded data and voice over the current 25 and 30 kHz channels significantly increases the capacity and spectral efficiency of an LMRS system.

5.2.4 ACCESS METHODS - NBTDMA, NBFDMA and CDMA

By digitally encoding the message content the spectrum requirements for an equivalent voice channel become less. Thus the available spectrum resource (25 or 30 kHz channels) can be split into smaller channels each of which can be assigned to a user thereby increasing the capacity of the spectrum resource as well as its efficiency. To split and utilize the resulting narrow bands requires an access technique to be employed.

The three technologies that can be used to access the smaller channels are Narrow Band Time Division Multiple Access (NBTDMA), Narrow Band Frequency Division Multiple Access (NBFDMA) and Code Division Multiple Access (CDMA) - of which there are two varieties Frequency Hopped and Direct Sequenced.

The available spectrum resource may be considered to be a space composed of time and frequency components that may be divided into time and frequency ranges. The division of the spectrum resource into a number of smaller frequency channels or slots is the basis for NBFDMA technology. The division of time of transmission into a number of time slots across the whole frequency band is the basis of NBTDMA technology.

A third method is to divide the spectrum resource into time and frequency slots - diagrammatically resembling a checkerboard of small time/frequency squares. This is the basis for Code Division Multiple Access technology. A subscriber channel is created by assigning an appropriate number of these squares throughout the resource spectrum according to a code, unique to the subscriber, (frequency hopped) or by means of a unique sequence spread across the spectrum (direct sequenced).

CDMA has been used extensively for military applications but there is insufficient evidence from experience in the market or from research completed to date to show the technology to be economically or operationally suitable for commercial application.

CDMA is often considered because of the high degree of security it provides and its resistance to interference and multipath fading. However its spectral efficiency is highly controversial varying in separate opinions from a low of 17% to a high of more than 67%. Very long spreading sequences are necessary to achieve high spectral efficiency.

In a recent publication in the Communication Magazine it is claimed that CDMA could provide higher spectral efficiency than either FDMA or TDMA. The assumptions regarding TASI and the frequency reuse pattern considered seem to have been deliberately chosen to favour CDMA and when similar assumptions are made for TDMA or FDMA the reported high efficiency advantage of CDMA is lost.

Research is continuing to develop this technology for commercial use but until satisfactory performance and cost objectives can be met it should not be considered as a candidate for second generation LMRS systems.

Thus only NBTDMA and NBFDMA will be compared for consideration in LMRS systems.

With FDMA system, the 30 kHz VHF channel may be split into three 10 kHz wide channels initially and subsequently into 6 channels of 5 kHz width when the technology is available. Similarly 25 kHz UHF channels may be split into two channels of 12.5 kHz and five 5 kHz channels later.

Using TDMA, the transmission time is divided into a number of time slots each of which represents a TDMA message channel. As was done in the development of the second generation cellular plan, a total of 6 slots can be provided ultimately on a 30 kHz channel.

Thus with both narrow band TDMA or FDMA access technology the channel capacity can be increased up to 6 times. The choice must therefore be made based on the requirements of LMRS

The following outlines the characteristics of the two technologies and identifies criteria for choice for use with second generation digital LMRS systems.

5.2.5 Spectral Efficiency

As noted above the channel resource may be considered to be space composed of time and frequency. If this space (time and frequency) is divided into N new smaller spaces each of which has the capacity equivalent to the original channel, then the spectral efficiency is improved by a factor of N.

For FDMA, the old channel bandwidth, B, is divided into N new channels each with a bandwidth B/N . The newly created channels can be used individually or in a trunking group.

For TDMA, the channel bandwidth of the old channel is retained but the time of transmission is divided into N time slots and the data from these slots transmitted in a cyclic order.

Under ideal conditions the use of TDMA or FDMA should deliver identical spectral efficiency by creating more channels.

In practice, both systems suffer some loss of capacity due to existence of non-ideal conditions and implementation dissimilarities, but not sufficient to favour one more than the other.

In FDMA the loss is mainly due to frequency guardbands that limit the impact of adjacent channel interference whereas with TDMA provision of guard times in the frame structure is the principal cause of capacity loss. Moreover, some performance loss must also be expected due to a specific receiver architecture (detection and decision) design, transmission format, error control overhead and resources allocation for system access.

5.2.6 Capacity and Utilization Considerations:

Capacity is the most important issue facing the LMRS. Division of a frequency channel into a number of narrow band channels creates additional capacity. The number of new channels which can be created from a single old channel depends on information type and its bandwidth. At present, the LMRS is predominantly analogue and it is expected after a few years information transmission will be digital. However, use of voice can not be ruled out. As mentioned earlier, some users prefer to retain voice as a back up facility. Thus we suggest that both voice and data should be considered for LMRS.

The number of voice channels available from one 30 or 25 kHz channel depend on the bandwidth of voice encoding rate. At present, a 6.7 Kbits/sec CELP coder delivering toll quality voice is already available. The error protection needed to mitigate the effects of channel fading will increase the data rate to in excess of 13 kbits/sec. Spectrally efficient modulation schemes such as OQPSK or GMSK, allow transmission of 1.6 bits/Hz. Thus a 10 kHz channel is sufficient for the transmission of voice. Thus the spectral efficiency of a 30 kHz voice channel can be increased by at least three times.

Experts in the field of voice encoding agree that 4 kbits/sec toll quality speech encoders will be available in the next 5 to 10 years to create 5 kHz channels. Spectral improvement would be further augmented by combining these into trunked systems.

Trunking is equally applicable to both FDMA or TDMA. With similar trunking groups the improvement in the spectral efficiency is expected to be identical for both TDMA and FDMA access.

The transmission rate of at least 1.6 bits/Hz is fundamental to the use of 10 and 5 kHz channels and requires considerable compactness in the transmission spectrum. The constant envelope and continuous phase modulation class is a possible candidate. Another possibility is linear modulation such as OQPSK.

In the constant envelope and continuous phase modulation the signal phase is allowed to vary gradually and deviations in the phase changes are eliminated resulting in a compact spectrum. This class of modulation does not have any amplitude fluctuation and a class C amplifier can usually be used to conserve power. Good examples of this class are MSK, GMSK, Duobinary and TFM. In a fading environment, however, they suffer considerable performance degradation resulting from the unreliable performance of phase acquisition circuits in presence of channel fading.

Phase shaping is frequently used to control the transmission spectrum. Transmission efficiency of more than 1 bit/sec/Hz can be obtained by transmission of a signal using two carriers in quadrature. QPSK has been preferred as the modulation technique since it provides maximum channel utilization with minimum power consumption. Its disadvantage is that the QPSK modulated waveform goes through zero amplitude when the input changes from say 00 to 11, and therefore is not very suitable for mobile environment. A modification in the form of Offset QPSK is preferred for mobile use because it reduces the amplitude variations to around 1 dB.

On the receiver side several types of detection methods are possible. These include synchronous, differential and discriminator detection. Differential detection is preferred over synchronous detection because phase recovery problems are not encountered. A basic assumption of differential detection is that the channel does not change appreciably between two successive symbols, and that contribution to phase error due to channel fading is negligible. A Discriminator will also be needed when backward compatibility with the existing receivers is required.

The need for a linear power amplifier to limit intermodulation interference is perhaps the biggest disadvantage of ODQPSK. Recent research indicates that linearization of power amplifiers can be achieved with the available technology. From the point of view of performance, ODQPSK requires at least 3 dB higher transmission power than for binary transmission to achieve the same error rate. Within a given bandwidth it can deliver a data rate double that of binary modulation schemes.

5.2.7 Frequency Stability Requirement

With the reduction of channel bandwidth to 10 or even 5 kHz, frequency stability for FDMA technology becomes more critical than for TDMA to avoid severe degradation in the performance of the narrower channel. For example at 450 MHz, a stability of 2 ppm could result up to 1800 Hz frequency offset between the transmitter and the receiver. This is 18% and 36% of the total bandwidth.

To offset this performance degradation, transmitters and receivers with very high frequency stability will be required. Stable but more expensive transmitters are available for base stations where the environment is easily controlled. Since base transmitters and receivers are relatively few, the expense could be justified.

However, it is difficult to maintain the frequency stability in the mobile unit because the environment cannot be well controlled, and more expensive sets with good stability would not be attractive economically.

Thus the use of FDMA will require higher cost and more complex equipment design to compensate for increases in frequency instability as the channels become narrower.

In addition to stability, FDMA is susceptible to adjacent and co-channel interference. Sharp cutoff filters in the receivers and the transmitters are necessary to curtail adjacent channel interference. The impulse response of a sharp filter cutoff is of (sinx)/x form, lasting for a very long time. A long impulse response produces high inter symbol interference. The multipath channel selectivity (another reason for ISI) combined with a filter for ISI will degrade performance considerably and the use of adaptive equalization becomes necessary.

Narrow Band TDMA access technology retains the bandwidth of the original channel and thus frequency stability is not as critical as in case of FDMA because the tolerance to relative frequency offset is approximately one sixth of that for FDMA when six channels are considered. Thus additional compensation is not required. Also since 30 kHz mobile systems are already in use and provide satisfactory performance, this issue is not considered to have any serious consequences in the use of TDMA.

5.2.8 Operational and Equipment Considerations

Each channel in a narrow band FDMA system can be used independently as a link if desired. This permits the user to have complete control over the management of available channels and system resources. Such a capability is of particular interest for applications that need the talk-in and talk-out feature.

The talk-in provision allows two or more mobiles located near each other to communicate without going through the repeaters or central control.

However, high costs can be expected due to the requirement for tighter filters, a very large number of receivers, high stability transmitters and receivers and receiver adaptive equalization. These could be offset to some degree with the use of baseband signal processing and application specific integrated circuits (ASICS).

Spectrum planning for frequency assignment is more complex for FDMA in order to compensate for its susceptibility to adjacent channel interference.

With the use of TDMA the basic channel bandwidth (25 or 30 kHz) is retained since the three narrow band channels are derived by time division and cannot be separated. Thus current frequency planning would not be disrupted by its introduction.

The TDMA approach is particularly suited to LNRS trunking applications and because the time divided channels must be kept together the result is a mini-trunking system of three or six logical channels that adds to the overall trunking gain.

The provision of the talk-in, talk-out feature may be very difficult, if not impossible, to implement. It would require the permanent assignment of some slots for the purpose or the introduction of a concept of slot reuse. This is discussed later in this report.

5.2.8.1 Equipment Considerations

Recently, NBTDMA was adopted for the second generation cellular systems and it is expected that VLSI technology will be used extensively for the design of an all digital mobile terminal.

If the NBTDMA technology is selected for the second generation LMRS, further cost savings should be achievable by the elimination of design features such as handoff and vehicle location protocol and the use of simplex or half duplex sets rather than full duplex needed for cellular.

5.2.9 Interference and Trunking Efficiency Considerations:

Carrier to interference ratio (C/I) must be specified for a given system to obtain required speech quality and data integrity. Carrier to interference ratio determines frequency reuse plans and system capacity. Therefore, evaluation of new technology must include studies on its susceptibility to interference.

Digital transmission systems are more resistant to co-channel and adjacent channel interference than analogue systems, requiring around 13 dB C/I (4 dB lower than 17 dB required for present day FM) to deliver toll quality voice. It has been suggested that for some applications, lower voice quality may be acceptable, but for some Public Safety situations, confirmed in discussions with the RCMP, voice quality is a high priority in order to be able to recognize the speaker.

With digital systems a lower figure for C/I for digital means a reduction in the frequency reuse distance. This will lead to a further increase in the spectral utilization. It is estimated that if optimum frequency allocation proposed by Delfour is followed, the primary cell size can be reduced from 0.95x0.95 km to 0.8x0.8 km resulting in many more elementary cells available for frequency reuse.

Trunking efficiency has similar implications in both the access methods and are therefore are discussed together. The differences in the traffic and mode of operations are the two important considerations in the evaluation of trunking gains for the two systems. It is suggested that there are insufficient differences between the two to prefer the use of use of one, more than the other, for the LMRS.

It is assumed that a 30 kHz channel is divided into 3 narrowband message channels. The other overheads are assumed to be identical for the two systems. The erlang C formula is used to estimate improvement to the capacity of the system, since the calls are queued and under heavy traffic conditions delays in serving the call are expected.

The probability of delay in processing the call, $C(c,\alpha)$ is given by:

$$C(c,\alpha) = p(0) \frac{(\alpha/\mu)^c}{c!} \left(\frac{c}{c-a}\right) \qquad (1)$$

where α is arrival time , $1/\mu$ is mean holding time, c is number of channels and p(0) is given by:

$$p(0) = \left(\sum_{n=0}^{c-1} \frac{(\alpha/\mu)^n}{n!} + \frac{(\alpha/\mu)^c}{c!} \cdot \frac{c}{c\mu-\alpha}\right)^{-1} \qquad (2)$$

The probability of delay of 0.75 and 0.5 are used for non-public and public dispatch systems.

(a) Channel Capacity under prevailing conditions (c=1):

For Non-public Applications: The use of Equations (1) and (2) gives a capacity of 0.75 Erlangs, when the probability of delay is chosen to be 0.75.

For Public applications: The probability of delay is chosen to be 0.5 which gives the channel throughput of 0.5.

(b) Channel capacity when an old channel is split into three new channels:

For Non-public Applications: The use of Equations (1) and (2) result in a capacity of 2.585 Erlangs.

For Public Applications: The probability of delay is chosen to be 0.5 and the use of three channels results in a total capacity of 2.115 Erlangs.

It is seen from the above calculations that the capacity has improved by 347% and 425% for non-public and public applications respectively. It is also observed that trunking gain is higher for a higher grade of service.

5.2.10 DELAY SPREAD

The signals transmitted in an environment consisting of several types of terrain experience diffractions and multi-path reflections before reaching the receiver. Thus the received signal includes several replicas of the transmitted signal, each with some differential delay.

When the transmitted signal is digital, the delays contribute to inter symbol interference (ISI) and thus affect system performance. The delay spread of a channel is defined as the length of time during which signal replicas are received. Thus delay spread is an important parameter in system design.

Experimental measurements demonstrate that delay spreads of up to 100 u/secs can be expected. When the channel bandwidth is narrow and tight filters are used to contain adjacent interference, the problem of delay spread can become worse. The total delay spread (due to channel and filters) is directly proportional to the tightness of the filter characteristic. In some instances the filter delay spread may over-ride the channel delay spread.

Specifically, for a data transmission rate of 4800 bits/sec, a channel delay spread of 100 u/sec amounts to about half a bit period (1/4 of a symbol period for OQPSK). However, the filter impulse response can last for several bit periods. The delay spread problem becomes worse for narrowband FDMA when the channel bandwidth is reduced to 5 kHz. In this case the control of adjacent channel interference is a major consideration and filters as tight as possible must be used.

Adaptive equalization is the major weapon used against ISI, but increases the complexity of the system and its cost.

5.2.1.1 Synchronization

Synchronization and timing recovery are important parameters in evaluating modulation schemes to be used. Phase recovery is very difficult in a fading environment requiring a narrow loop filter. Deep fades however result in large frequency deviations which cause the phase recovery circuit to unlock. To restore the locking a wider band width filter is needed, in conflict with the requirement for phase locking.

Because of this difficulty, coherent modulation schemes are not recommended for use in a mobile environment.

Robust timing recovery is critical for the good performance of a digital communications system. In the mobile environment the timing recovery circuit has the added responsibility to recover very quickly following a deep fade when the signal is usually not available.

Thus the timing recovery circuit should not only provide reliability in restoring phase synchronization but also to recover quickly after the signal suffers a deep fade.

5.2.1.2 Co-location of Transmitters

In some cases the same antenna site and the same mast is used by several operators using different frequencies. This increases the risk of intermodulation interference. In the case of NBTDMA the problem is of little consequence since adjacent channels are rarely used for present analogue systems. Thus no new combiners are required.

Where the practice exists the channel by channel replacement with NBTDMA may be undertaken without any increased exposure to intermodulation interference.

In the case of NBFDMA several transmitters may be collocated only after frequency assignments are rearranged to satisfy the interference criteria. Thus for NBFDMA, new frequency assignments have to be made that can affect the whole channel group, thus new combiners (multicouplers) may be needed.

5.2.13 Other Considerations

With digital technology privacy and security requirements for users can be met easily. This is essential when encouraging users in competitive or similar types of business, or public safety users to share the channels Privacy and security can be provided with either access methodology.

5.3 TECHNICAL CONSIDERATIONS FOR A TRANSITION TO A NEW TECHNOLOGY

The objective of new LMRS technology is to increase the capacity and the efficiency of the current spectrum allocations, thus deferring the need for further spectrum allocations.

From the preceding parts of this report it is clear that new technology will be available shortly that can achieve the objectives. There remains the consideration of a transition plan for its introduction and use. The focus of a transition plan would be on the 138-174 MHz and 410-470 MHz bands in the VHF and UHF spectrum.

The optimum results will be obtained when the two bands are used exclusively for trunked systems employing second generation digital narrow band technology. The new technology will provide for splitting VHF 30 kHz channels into three equivalent voice channels and 25 kHz UHF channels into two thereby increasing the capacity of the 88 MHz allocated in the two bands by a combined factor of 2.3 times. This will provide a total of 7550 equivalent voice channels compared to the present total of 3350. When subsequent advances in technology permit the use of a 5 kHz equivalent voice channel, the capacity could be increased further to an estimated 12600 channels.

The transition problem in the congested markets is that the bands are fully assigned and most of the equipment is user owned. Thus in order to obtain a release of frequencies to get started and to continue with the conversion, appropriate policy support will be needed that will encourage users and operators to move to the new technology. It is expected that the transition plan would extend over a period of time in order to minimize the investment required by the user to make the change.

Support from the users may be obtained by some form of incentive or by the regulatory process to mandate the change to a new technology.

The incentive could be a reduction in annual licence fees or the opportunity to resell service from spare capacity or some other means to offset the capital cost of conversion. Because of the potential problems, including legal ones, a fair and equitable incentive program could be difficult to develop and there would be no certainty of its results. Thus it is not recommended.

The second possibility is a regulatory initiative whereby the users in the two bands will be required to change over to the new technology in a five to seven year period. The time frame is based on the average equipment replacement schedule in the public safety sector of the LMRS and coincides with a reasonable time frame to provide the additional capacity.

Coupled with the mandate could be a program, implemented in steps over the transition period, to increase the annual license fee and the minimum channel loading requirement to a point that would more equitably represent the increased value of a channel resource due to the introduction of the new technology. No distinction in the cost and channel loading increase should be made between the UHF and VHF assignments.

Users would then be encouraged to improve the utilization of their assigned frequencies or consider alternatives such as the early conversion to digital equipment or transfer to a shared trunked system thereby releasing their frequencies.

The frequencies retrieved by DOC from this approach could be the basis for re-assigning the band for trunked systems. This transition approach is preferred for consideration by DOC in their longer range spectrum planning.

5.3.1 Frequency Reassignment Considerations

A plan to reassign frequencies once they have been released will depend on which of the two access technologies is standardized.

If NBTDMA is standardized individual frequencies may not be assigned to each of the narrow channels and therefore they must be assigned for use in a trunked system.

If NBFDMA is used, each narrow channel can be licensed as a separate frequency and the licensee can only be encouraged to use a trunked system. Another factor in assigning FDMA channels is the susceptibility to adjacent channel interference that must be compensated by assignment planning.

In general, since frequencies will become available on a random basis as users independently decide to convert, initiating the transition in a selected frequency band may proceed by either creating blocks of frequencies for reassignment in the band or on a channel by channel reassignment as they become available.

Creating a block within the band may be more considerate of the users, particularly RCC's, because it gives them some incentive to convert in terms of additional channels. The success of this strategy will depend on how long it will take to accumulate a block of five or more frequencies in order to get started. There is considerable probability that this strategy will succeed.

The channel by channel approach can start as vacant channels appear and can be reassigned for new technology use.

Subsequently should some further reassignment be required in order to obtain optimum utilization, digital synthesizers in the new equipment will make the adjustment easier for a user to make.

5.4 Conclusions and Recommendations for Task 2

5.4.1 Conclusions

From the work carried out on this task, the following conclusions were arrived at:

- Current analogue voice systems used in the 138-174 and 450-470 MHz bands are spectrally inefficient and limit the capacity that could be realized if the information was transmitted in data format.

- The introduction of channel splitting (narrow band) and digital technology will provide the optimum increase in spectrum capacity in the near future. Available digital encoding technology permits toll grade voice transmission over 10 kHz channels. The majority of LMRS systems are used for dispatch applications whose efficiency is improved by the use of data messages rather than currently used voice, with voice required for occasional need including backup.

  The current 3350 channels available in the two bands could be increased 2.3 times to approximately 7550 effective voice channels by the use digital narrow band technology throughout. By assigning these exclusively for trunked systems, further capacity would be created. When 5 kHz channels can be used (within 10 years) spectrum capacity could be increased to a multiple of over 5.2 times the preset capability.

- There are two alternative technologies to provide the increased capacity i.e. Narrow Band TDMA and Narrow Band FDMA. A third method, Code Division Multiple Access (CDMA) is used for military applications but to date insufficient data is available to show that it is commercially feasible and eligible for consideration.

- The candidate technologies for private land mobile system have been compared and it is concluded that some preference emerges for NBTDMA but would need further in depth studies in order to decide.

5.4.2 Discussion

Technically there are insufficient differences to recommend either NBTDMA or NBFDMA as superior to the other.

Operationally TDMA is a good candidate for shared trunked systems and is well suited for dispatch systems where the base station remains in control.

LMRS requirements for TDMA technology are less complex than those proposed for cellular systems since handoff and vehicle location functions are not needed and simplex and half-duplex terminals can be used rather than full duplex. The resulting cost benefits of these modifications would augment those generated by the anticipated scale of cellular manufacture.

In addition as evolution occurs in the mobile field towards the development of Personal Communications and third generation LMTS, the proposed NBTDMA will be technically in harmony for the consideration of other options.

NBFDMA, on the other hand, requires high stability RF components in the transmitters and receivers and expensive compensating narrow band filters that increase the costs of a system. Both of these concerns are increased as the move to the narrower 5 kHz channels develops.

Spectrum management is also more flexible with NBTDMA than with NBFDMA.

If other options are not economically feasible to provide the talk-in and talk-out feature on LMRS, as required by public safety users, the NBFDMA is recommended since it is better suited for the purpose and because it would be very difficult to implement the feature with NBTDMA. However if the "talk around" option (i.e. the provision of two dedicated frequencies) or some other equivalent, can be used then NBTDMA should be preferred for its other advantages. (See Appendix C for analysis of means to provide for this feature.)

Discussions with the RCMP indicated that they are considering experimenting with alternatives, such as the use of cellular telephone, to provide the talk-in feature to complement their dispatch systems.

5.4.3 RECOMMENDATIONS

From analysis of the conclusions and from the discussions given in Section 5.4.2 above, it is recommended that:

- The introduction of digital narrow band technology will provide the most effective means to increase the capacity and the efficiency of the existing LMRS spectrum in the 138-174 and 450-470 MHz bands. Assignments in the bands should be made only for trunked systems, when that technology is available, in order to realize the additional capacity from shared use.

- Digital NBTDMA technology is preferred, based on the following considerations, but more in-depth study will be needed before a final conclusion can be made.

- Technically the differences between NBTDMA and NBFDMA are not sufficient to favour one more than the other to serve the second generation LMRS. However, if the talk-in feature becomes an important need for users, it is recommended that NBFDMA has the most technical capability to provide for it. To fully consider this issue and the alternatives, further study in depth is required in order to define the need and the most effective means of serving it.

- Operationally NBTDMA has the most capability to serve LMRS in terms of lower potential costs, less complex equipment and greater flexibility for spectrum management and its assignment. In addition, the technology is in harmony with that of developing radio systems for cellular and for Personal Communications (PCN) service and should realize potential benefits from research in those fields.

- The transition to a new chosen technology will require policy and regulatory action to encourage users to increase the efficient use of their current systems and release frequencies for reassignment in the bands. The reassignment can be frozen until a block of 5 or more is created for a trunked system or they can be reassigned on a channel by channel basis for use with new technology.

6.0 RECOMMENDATIONS FOR PREFERRED ACTION TO PRODUCE LMRS SPECTRUM RELIEF

6.1 Introduction

The purpose of this Task was to develop overall conclusions on the direction that longer term spectrum planning should take to provide spectrum relief for the two LMRS bands, 138-174 MHz and 410-470 MHz and to recommend a preferred course of action for DOC to consider, based on the results of Tasks 1 and 2.

6.2 Considerations

As a result of the review undertaken in this study, it was found that the congested LMRS bands in Canada are also in the same condition in the US, that the LMRS market is growing in both countries by as much as 30% annually, that the user needs are similar and that the only significant difference was size. It was also noted that all Canadian and US suppliers were active in both markets and were generally directing their research in a similar direction to provide the spectrum relief needed.

This study has also shown that the spectral efficiency and capacity of the two LMRS bands can be increased over 2.23 times by replacing voice transmission with data messages; by increasing the use of trunked systems shared by users; and by splitting the existing channels into narrower equivalent voice channels through the introduction of new digital narrow band technology. Manufacturers estimated that the technology would be available within 5 years.

The replacement of voice with data and the increased use of trunked systems is currently being recommended by some manufacturers to their users on an as-required random basis that is only marginally effective without an overall policy in place.

In the US a policy decision of this kind will not be made by the FCC without a coordinated recommendation from the private sector seeking approval. To date there is limited interest in the development of such a recommendation.

Thus there is a unique opportunity is available to Canada through the DOC to decide on a direction for LMRS planning to take over the next 5 to 10 years. This will serve as a guide to manufacturers, users and operators in Canada, and will influence those in the US to increase spectrum efficiency and capacity in a coordinated manner. The influence on US manufacturers will result from their operation in the Canadian market.

From the review and analysis in the previous sections of this study it was recommended that the direction that long range planning should take to increase spectrum capacity is to encourage the use of data message transmission, increase the use of trunked systems in the two bands by making assignments only for that purpose and support the introduction of digital narrow band technology when it becomes available.

To achieve this objective a course of action has been developed that provides for the development of a new policy approach regarding the utilization of the two LMRS bands and a transition plan consisting of a series of steps to achieve the objective.

Some priority is recommended since a greater percentage of the population in Canada is affected by the congestion problem, because of its proximity to the border, than is the case in the US and thus may be considered more essential to resolve.

6.3 Proposed Course of Action

The following series of steps is recommended to develop a long range program and plan:

i) Decide to undertake a program to increase the capacity of the LMRS spectrum in the 138-174 and 410-470 MHz bands.

ii) Market Study: To evaluate the potential capacity that can be realized from the current spectrum and to compare this with the projected demand in the three congested markets. An estimate of the net impact of the relief and how long it will last in the growing market can then be made. Current demand from existing users should then be developed from the survey including any applicants waiting for service.

Included in the study would be a summary of the services users in various categories will require over the next 5 years, their plans to serve growth, including the use of shared and trunked systems, and in particular the features that will be needed for their operations.

iii) Program Definition: The objective of the policy review program would be to determine the policy changes required and activities to be carried out for the re-development of the LMRS spectrum. Timing would be guided by the introduction of new technology, estimated by manufacturers for 1995.

Implementation would be focussed on the congested markets initially and later on others as they became congested.

6.3.1 Issues to be addressed

Prior to policy development decision, positions will be required on the following:

i) To displace voice analogue technology with digital when the technology is available and to encourage the transmission of data messages rather than voice in the meantime.

ii) The allocation of the spectrum exclusively for digital shared trunked systems

iii) Selection of access technology from the available candidates i.e. NBTDMA or NBFDMA

iv) To encourage the development of LMRS standards

v) To develop a proposed transition program for the introduction of the new technology

In the development of positions for i) and ii), studies will be required for which input data from the marketing study will be an important factor.

6.3.2 Voice Displaced by Data

In the study for i) representative information from users in the three congested markets will be required to assess the requirements for voice, in addition to the use of data, and to determine whether there are any special needs to take into account. Information on the normal equipment replacement cycles should be developed in order to assess the extent of any disruption when implementing the new policy and technology

6.3.3 Total Spectrum for Trunked Systems

For the ii) study, information from the marketing study should provide data on the extent that shared trunked systems are available in the three markets. Consideration for small users with only one or two frequency assignments may have to be given if they are unable to convert from their existing system until trunked system capacity is available.

6.3.4 Selection of Technology

The study associated with iii) will evaluate the candidate technologies in greater depth than was possible in this report, and will develop and compare a form of critical path for the introduction of each one. From this comparison it will be possible to assess the possible disruptive impact on current systems and decide on action to minimize it.

The output of this study will also provide the basis for a Canadian position on the choice of a new technology.

6.3.5 Standards

Regarding iv), industry-wide standards for second generation LMRS equipment will be developed by a similar participatory process that was used for cellular. An in-depth study of the various system parameters would have to be made including modulation, transmitter signal mask, maximum allowable effective radiated power, adjacent, co-channel and intermodulation criteria, protocols, sharing procedures, channelization, receiver sensitivity, filter characteristic etc.

The results of these studies would be considered in the procedures required by the DOC regulatory process.

6.4. Transition Planning for New Technology and Spectrum Redevelopment.

The purpose of a transition plan is to expedite the creation of new capacity in the two bands by coordinating the activities required to overcome the problems.

The problems involved in introducing the new LMRS technology and in converting the two bands to trunked use are:

- Both bands are fully assigned
- Most users own their equipment.

As recommended in Task 2, the choice in assigning available frequencies is between establishing a block in each band for reassignment to a trunked system operator waiting to expand, or to reassign frequencies as they become available for trunked system use to qualified applicants. Either approach or both will work.

However, since the bands are fully assigned and most users own their own equipment, they are unlikely to convert to a new technology voluntarily or transfer to a trunked group without some incentive.

Financial incentives are not recommended due to the complexities of arriving at fair and reasonable compensation, and the uncertainty that they would be effective.

Thus a regulatory mandate is recommended.

A policy statement, resulting from the steps outlined above, could be made to advise of the proposed redevelopment of the spectrum for trunked service use and the steps to be taken for implementation.

The proposed redevelopment would be in recognition of the increased value that the spectrum bands would have as a result of the introduction of the more spectrally efficient new technology.

Starting at an appropriate time, in advance of the availability of the new technology, a stepped schedule of increasing license fees and minimum per channel loading would be introduced. These would increase to a level that was relative to the increased value of the spectrum resource. This schedule would be derived from an economic study of the market demand, the available resources and the impact on the current users in the congested markets. The study would also outline in detail the transition steps required to complete the redevelopment of the spectrum and the time frame to be considered.

The implementation of the steps would be on an annual basis over a period long enough to permit existing users to make the necessary changes to their operations in a least disruptive manner, and to permit the development of appropriate alternatives from shared trunked operators.

In general, it is expected that the smaller users would migrate to shared trunked groups whereas the large users would establish their own trunked networks.

The increasing requirements for minimum channel loading would encourage users to increase the efficiency of their use of the spectrum they had or return those channels that could not qualify.

From the recommended transition study to decide on the graduated increases and with input from the marketing study in Step 2, reasonable estimates could be made of the anticipated frequencies that would be released and over what period of time to assist in the transition planning.

This series of four steps outlines a plan for the consideration of DOC to provide for the redevelopment of the LMRS spectrum, and to introduce new second generation technology to provide optimum capacity in the currently congested markets.

* * *

APPENDIX A

KEY CONTACTS IN THE U.S. AND CANADA

APPENDIX A

The key contacts made by the contractor to obtain input for this project are as follows:

In the U.S.:

Regulators

Federal Communications Commission

Manufacturers

Motorola
Ericsson - General Electric
E.F. Johnson
Bellcore
Harris Communications
A T & T
Northern Telecom
Telecommunications Industry Association (TIA)

Users

Association of Public Safety Communications Officers Inc. (APCO)
National Telecommunications and Information Agency (NTIA)
Johnson Communications Company
Some randomly selected users, including taxi companies in Chicago and Washington to confirm information supplied by manufacturers

In Canada:

Manufacturers

Glenayre Electronics Ltd, (Vancouver and Toronto)
NovaTel - Calgary
MDI (subsidiary of Motorola) in Burnaby
Motorola - Toronto
GE - Ericsson, Toronto and Montreal
Data Radio Inc. - Montreal
Gandalf Data Ltd.

Users and Operators

Government of Canada (RCMP)
Government of Ontario
Government of British Columbia
BCE Mobile
Cantel
Bell Cellular
Blue Line Taxi, Ottawa and Toronto
National Pagette
Hydro Electric Power Commission of Ontario
Quebec Hydro
Purolator Courier
Speedy Messenger Service
Federal Express

In addition, a number of contacts with some randomly selected smaller dispatch operating firms were contacted, whose views were similar to those obtained from the larger users.

* * *

APPENDIX B

DISCUSSION GUIDE

APPENDIX B

Discussion Guide

ASSESSMENT OF MEANS TO ENHANCE THE UTILIZATION OF LMRS SPECTRUM AND TO RELIEVE THE PRESENT CONGESTION

Lapp-Hancock Associates Limited, in association with Wescom International Inc., of Vancouver, B.C. is undertaking the above project in order to provide recommendations to the Department of Communications (DOC) on means to increase the efficient use of spectrum assigned for Land Mobile Radio Service and thereby provide relief to accommodate the forecast growth within the current allocations.

Frequencies in the 30-50, 150-170m 400 and 800 MHz Bands are becoming congested, particularly in Montreal, Toronto and Vancouver, and no additional frequencies can be assigned. The extensive growth forecast over the next ten years will need to be served by finding means to increase the capacity of the existing spectrum.

One of the essential tasks in the project is to reflect accurately the circumstances existing in the U.S. where similar frequency congestion exists, and to determine how it proposed to provide relief there. Because of the much larger market involved, the resolution decided in the U.S. will have a significant impact on what is done in Canada.

Since Glenayre is one of the large manufacturers of LMRS equipment serving the canadian and U.S. market, and also is a large Service Operator, we would appreciate your views in response to the following:

1. Since additional frequencies cannot be allocated, what changes to current spectrum policy would provide more opportunity for your firm as a manufacturer and a network operator to use existing frequency assignments more efficiently? Is there a preference for any particular VHF or UHF band?

2. What direction is being taken in the development of new technology for the market that will increase spectrum efficiency, and within what timeframe can it be expected to be available?

3. To what extent can the efficiency be increased and how will it be achieved?

4. What services and features will predominate in the market during the next 5 to 8 years? Of particular interest are trunking developments, digital technology, TDMA/FDMA, networking and transition methods.

5. Would the development and introduction of North American Standards for LMRS assist technical planning and development?

* * *

APPENDIX C

CONSIDERATIONS FOR THE PROVISION OF A DIRECT INTER-MOBILE TRANSMISSION MODE

APPENDIX C

CONSIDERATIONS FOR THE PROVISION OF A DIRECT INTER-MOBILE TRANSMISSION MODE

A direct inter-mobile transmission mode (talk-in talk-out) is an important requirement on LMRS for public safety users. It would allow mobile to mobile calling in emergency situations without going through the dispatch control. To exercise control and avoid interference, some LMR users prohibit mobile to mobile transmission.

Other potential users could include utilities and some state and local government users but there has been no indication of interest in th capability as a feature to be provided on LMRS.

Thus it should be considered as an optional requirement, and if included would require some additional functional controls to be added to a system.

Consider a system where a base or repeater is providing coverage to a certain area, in which several mobiles need inter-mobile transmission. Let it be assumed that they are all on the same shared trunked system. Thus if the need to intercommunicate among fire, police and ambulance services at an emergency location, then the base must be able to undertake the coordination.

A simple solution currently in place is at a large airport where sharing of the LMRS system by all of the public safety services, including fire, police and ambulance. The system can be flexibly coordinated as part of the total system installation, including inter-mobile transmission.

However to make this feature available throughout a large municipality or Metro area is a much more complex problem.

The Public Safety user groups are frequently not in favour of sharing a system by police, fire and ambulance and it may be some time before this will come about.

Therefore to consider the problem, a metro wide LMRS system serving one of the organizations, i.e. police, who are interested in the feature has been hypothesized as follows.

Mobile transmission frequency f_1, repeaters/base Rx
Repeater/base Tx frequency f_2, Mobile Rx

Scenario: Mobile "A" wants to attract the attention of the other mobiles in its vicinity. There are several scenarios:

A normal mobile to mobile call would proceeds as follows

A -> repeater ---> base controller ---> repeater ---> B
f_1 L.L. control L.L. f_2

A <-- repeater <--- base controller <--- repeater <-----B
f_2 L.L. L.L. f_1

The above assumes that a repeater is involved with the system. This is not always the case. It also assumes that all of the mobiles are under the control of the base station.

The feature required for public safety purposes is to let A and B communicate without going through repeaters or base controller and be able to shift to an alternate frequency mode in order to communicate on the same frequencies.

Some alternative strategies have been considered using FDMA and TDMA. All have disadvantages and while the two described below are the most feasible, more work is required to provide a practical solution to serve the Public Safety need. It will be made even more difficult should agreement not be reached by the fire, ambulance and police services to share a trunked network.

The two scenarios discussed are:

i) Modification of the mobile sets to permit one to talk to the others within short range creating a mini-base station. This includes consideration of feasibility if digital NBFDMA or NBTDMA is used.

ii) Provide two separate frequencies metro wide and modify the terminals to access these when required.

Scenario 1

If FDMA technology is used the following scenario is suggested:

Mobile A wants to talk - in. It selects push to talk with a special switch to reverse the frequencies. Now it transmits at f_2 instead of f_1 which becomes its new receive frequency, and it becomes a mini base station but transmitting at a much lower power than the base.

The mobiles in range can hear A and to reply, press their switch and transmit on f_2.

The base station keeps transmitting at f_2 and all other mobiles on the system are listening to base except those in the neighbourhood of A who can also hear A as well. Thus, the neighbours of A may get some interference from the base when receiving messages from A.

Thus a mini-cell is created with mobile A assuming the role of the mini base station. It is only cut off from base when it is transmitting to other mobiles. All mobiles essentially remain in contact with the base.

Advantages:

All mobiles can transmit. All are under the control of the base at times other than when actively transmitting to another mobile. Thus the network practically remains intact.
A mininet is established covering a small distance around the initiating mobile.

Disadvantages:

There is high probability of interference.

If TDMA Access is selected, the following scenario is suggested:

With TDMA a talk-in and talk-out strategy is difficult to implement.
TDMA requires transmission of messages precisely within assigned time slots. Thus, precise frame and slots timing must be available at the mobile. The difficulty lies in the operation of system where propagation time from each mobile to base is independent and can vary between practically zero to that required for round trip propagation from a mobile located at the edge of the coverage area.

For a coverage area radius of 30 kms, the round trip propagation time is 0.1 msec. requiring a slot guard time of approximately 0.1 msec. The danger of slot transmission overlap may be avoided if precise time reference is available at each mobile and if propagation delay, due to its location, can be compensated.

Such compensation requires that the mobiles must transmit a reference time pulse which is returned by the base to adjust to the time. Acquisition of time reference requires frequency contacts with the base. This will require transmission and reception of reference pulse in a specially designated slot. Frequent contacts with the base may only be done when the mobile is not active.

Even if the time referencing can be done, the other difficulty is the identification of users with a particular slot. A procedure would be required to obtain allocation of a slot and a means to implement it by the base or the switch.

While it can be considered theoretically, substantial modification to the system and its operation would be required without any assurance that the end result would serve the user's objective. Thus further consideration is required to derive a workable solution.

Inherently, NBTDMA technology would not appear to be as adaptable to providing the talk - in, talk - out feature as does NBFDMA technology.

One alternative option would be to provide a pair of dedicated frequencies in a municipality for this purpose which could be accessed by a switch on the transmitter. This would essentially be a "talk around" approach and some protocol would need to be developed to allow base to mobile transmissions to be heard.

Summary

The use of NBFDMA is the preferred technology to support the Talk -in, Talk - out feature. The explanation above assumes that all of the mobiles are under the control of one base station. This would be applicable to one of police, fire or ambulance services.

Scenario 2

If it was necessary to have all three share the feature at an emergency location, the coordination among the base stations involved would be much more complex than the allocation of a dedicated pair of frequencies for this purpose in a municipality to implement the "talk around" option.

Recommendation

Further study is required to decide on an approach for a broader application of this feature, since it may become a factor in the decision to adopt an access technology.

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