and Federal Communications Commission projections [2], and may in fact be conservative, based upon past experience with similar projections.

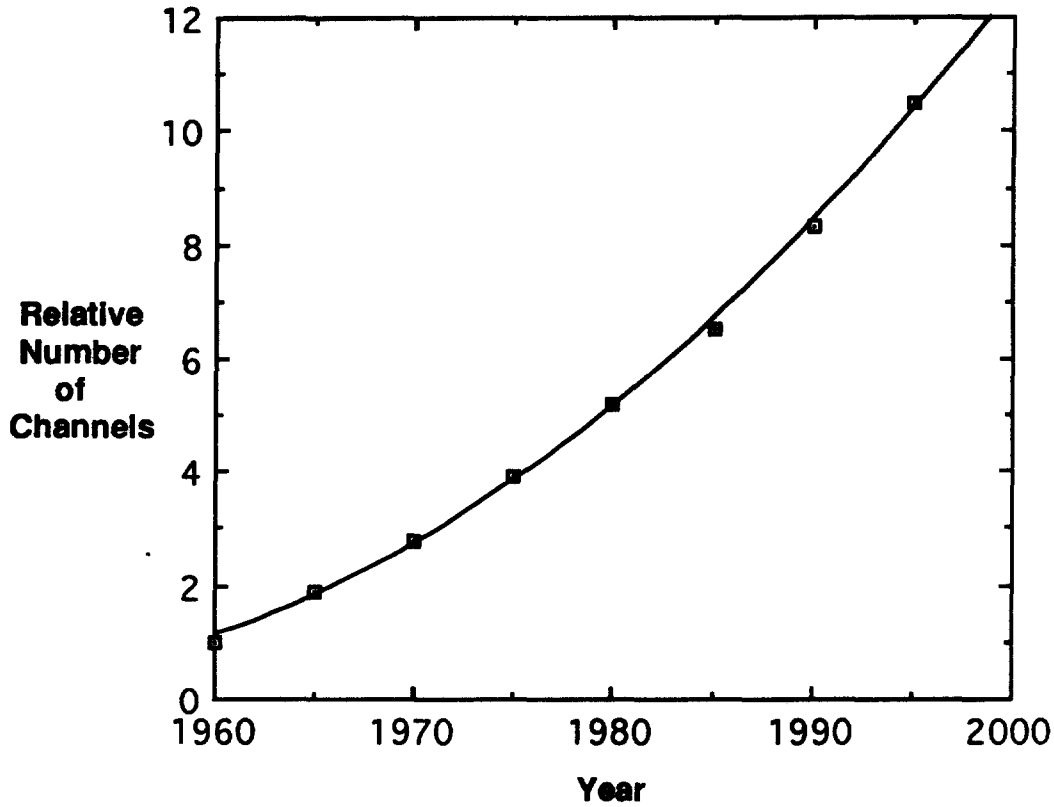

Figure 1: Spectrum Demand Trend

As shown, land mobile demand has increased steadily, and at a quickening pace, and is currently about ten times what it was in 1960. As described in Appendix A, advances in semiconductor technology have played a large part in keeping up with this demand. However, sound spectrum management has also played a large part in the form of periodic additional spectrum allocations. Table 2 shows a brief history of how the current land mobile spectrum bands evolved. All major spectrum allocations are shown, along with some technological advancements which have served to increase the amount of channels available to the land mobile user.

Year	Comment	Channels	Total	Rel.
1956	Total Existing Allocations	614	614	1
1956-early '70's	150-174 MHz: 60 to 30 kHz BW 150-174 MHz: 30 to 15 kHz Assignments 450-470 MHz: 100 to 50 kHz BW 450-470 MHz: 50 to 25 kHz BW 450-470 MHz: 12.5 kHz Low Power Assignments	1203	1817	2.9
1969-70	470-512 MHz: UHF-TV Sharing	216	2033	3.3
1976-83	800 MHz Allocations	600	2633	4.3
1986	800/900 MHz Allocations	399	3032	4.9
1986	800 MHz Public Safety Allocation	230	3262	5.3

Table 2 - Land Mobile Spectrum Allocation History

As shown, by 1956, 614 land mobile channels had been allocated in the 24-50, 150-174, and 450-470 MHz bands. Over the course of the next 14 years, equipment and system technology improvements increased the number of channels by about a factor of three. During this period, higher stability frequency references brought about narrower channel bandwidths, and low power offset channels were created in the 450-470 MHz band, on a secondary basis. In 1969-70, the FCC, recognizing the need for more land mobile spectrum, allowed spectrum sharing of two lightly used UHF-TV channels at 470-512 MHz. As demand rose still further during the 1970's and 1980's, additional spectrum allocations were made in the 800 and 900 MHz bands. Recognizing that demand was skyrocketing, the FCC instituted loading requirements on these 800 MHz channels to insure that they would be used in an efficient manner. Technology advances such as trunking were developed during this period, allowing more users on each new channel, further increasing spectrum efficiency and allowing the steadily increasing demand to be met. The last major spectrum allocations came in 1986, with new spectrum being opened up at 800/900 MHz. Again loading requirements were instituted, and technology improvements once again allowed a channel bandwidth reduction, this time to 12.5 kHz. Trunking technology has also helped optimize the use of this spectrum.

New technology advances are presently expected to increase capacity in the existing spectrum even further to keep up with today's increasing demand. New systems incorporating trunking, low bit rate speech coding, highly efficient digital modulation and TDMA technology are being introduced which have the potential to increase spectral efficiency by a factor of five to six [3]. In the near future, the process of replacing existing trunked systems in the 800 and 900 MHz bands

with these newer, more efficient systems will begin taking place. This process has been termed spectrum refarming, and is designed to meet the rising spectrum demand into the 1990's.

Figure 2 shows the land mobile spectrum allocations described above plotted against the demand curve shown in Figure 1.

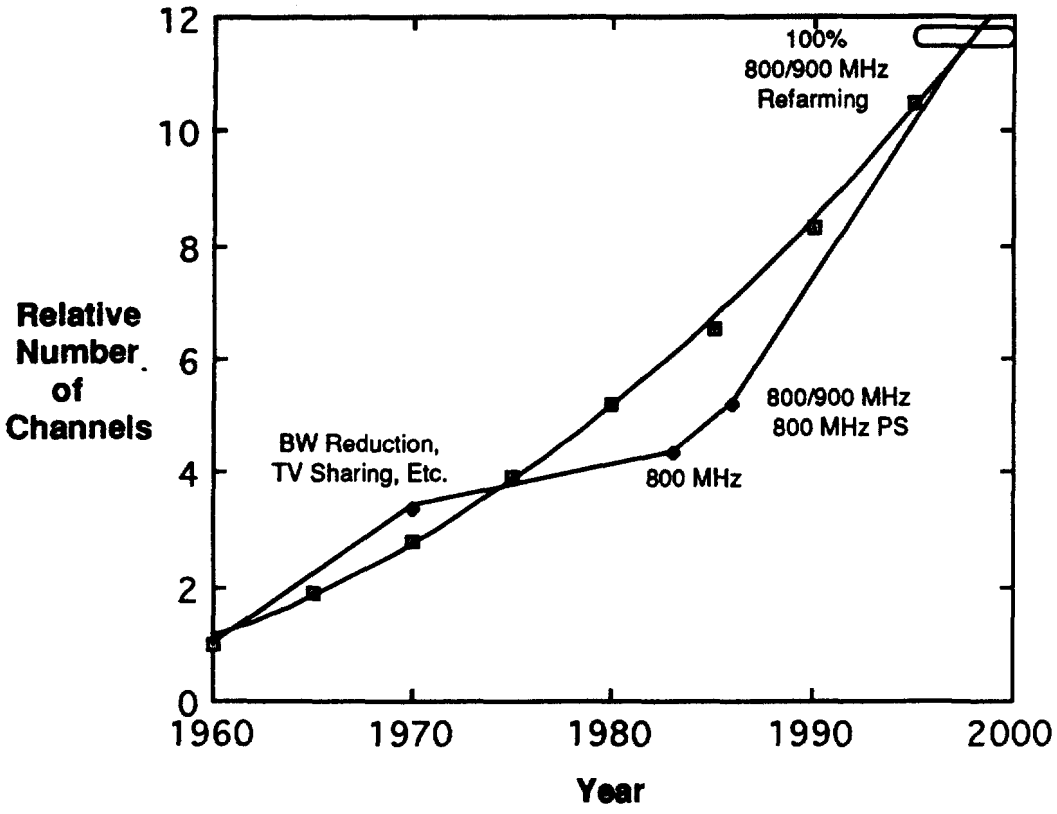

Figure 2: Spectrum Demand vs. Allocations

As shown, spectrum allocations and technology advances have paced the demand curve in the past. However, as the year 2000 approaches, new technologies must be relied upon to satisfy the rising demand in the absence of additional spectrum allocations. One solution which has been widely advanced is refarming. However, as shown in Figure 2, even total refarming of all 800 MHz and 800/900 MHz channels with 6:1 spectrally efficient replacement systems will only just meet the rising demand in the late 1990's.

It is crucial to note that the analysis given above is based upon providing traditional voice and data services. It does not take into account the emergence of new, advanced land mobile services like fax, imaging, video or the probable increased use of interconnect. These new services will drastically increase

spectrum demand as they become available in the 1995-2000 timeframe. Appendix C describes some of these services in detail, and a forecast is given for spectrum needs as the year 2000 approaches.

CONCLUSION

In the past, advances in land mobile equipment and system technology have spawned trunking, narrower channel bandwidths, efficient low bit rate voice coding, and the implementation of highly efficient digital modulation techniques. These technologies have served to increase the efficiency with which spectrum is used, and hand-in-hand with prudent spectrum management, have succeeded in meeting the rapidly increasing land mobile demand. However, other new technologies, such as low bit rate source compression technology, have made possible the introduction of more data intensive advanced services, like facsimile, imaging and video. It has been shown (see Appendix C) that the total user demand, including these emerging technologies, will increase faster than the technology itself can provide capacity for, given the current spectrum allocations. As a result, spectrum management policies which are responsive to these technologies are clearly called for. Specifically, new emerging technology spectrum allocations for these land mobile radio services are warranted.

REFERENCES

[1] Kenneth Crisler and Allen Davidson, "Impact of 90's Technology on Spectrum Management", *IEEE 1990 International Symposium on Electromagnetic Compatibility Symposium Record*, pp. 401-405, August 21-23, 1990.

[2] Planning Staff, FCC Private Radio Bureau, Future Private Land Mobile Telecommunications Requirements, Final Report, pp. 6-5, August, 1983.

[3] Mark A. Birchler and Steven C. Jasper, "A 64 KBPS Digital Land Mobile Radio System Employing M-16QAM," *Proceedings of the IEEE International Conference on Selected Topics in Wireless Communications,* pp. 158-162, June 25, 1992.

APPENDIX C

ABSTRACT

As the 21st century approaches, key advances in digital signal processing (DSP) enabling technologies are bringing about a paradigm shift in private land mobile radio. Digital information compression, made viable by advances in semiconductor integration and microprocessor speed, is providing the bandwidth reduction necessary to bring advanced communication services like fax, image and video to the land mobile marketplace. The emergence of these advanced technologies will be fueled, to a large extent, by the availability of adequate radio spectrum. In this Appendix, several emerging communication services are described, and the anticipated spectrum usage for each service is examined.

INTRODUCTION

The private land mobile radio market, driven by the constant need for the private sector to improve productivity and service, has historically provided the opportunity to explore and develop advanced communication services long before these opportunities exist in the public sector. As the 1990's progress, advances in semiconductor technology, including overall reduced cost and power consumption, increased memory integration and speed, and increased microprocessor speed, are making advanced digital signal processing (DSP) applications viable. In particular, DSP-based information compression technologies are providing the bandwidth reduction necessary to bring advanced communication services like fax, image and video to the private land mobile user.

At the same time, users of private land mobile radio are beginning to recognize the vast potential of these emerging services. In a recent speech [1], FBI director William Sessions reviewed several ways in which visual communications could be used to improve the investigative process in law enforcement. Remote video security monitoring, "real time" database retrieval of fingerprints and mug shots, transmission of stolen property or contraband descriptions, and image based automatic document processing were all mentioned as areas in which the FBI plans to use, or has implemented, visual communication services. In addition to law enforcement, these emerging visual communication technologies will be used by other private interests such as public safety agencies and utility companies, and shared system users such as the insurance and transportation industries.

As a result of the technical viability and market demand for these new communication services, private land mobile radio is poised to take a quantum leap forward in service, providing growth and increasing global competitiveness for its users. The speed at which these advanced services can be made available to the user will be determined, to a large extent, by the availability of adequate radio spectrum, the basic fuel for land mobile radio.

In this Appendix, several emerging communications technologies are described: decision processing/remote file access, facsimile, "snapshot" imaging, slow video, and full motion video. The objective of this analysis is to forecast the amount of spectrum necessary to provide these services in the 1995-2000 timeframe.

ADVANCED LAND MOBILE COMMUNICATION SERVICES: 1995-2000

In the 1995-2000 timeframe, a host of advanced communications services will be technologically viable for land mobile radio. These services can be divided into eight categories: dispatch, telephone access, transaction processing, facsimile, snapshot, decision processing/remote file access, slow video, and picture phone [2]. Among these, dispatch, telephone access, transaction processing and limited decision processing are offered on today's land mobile systems. This Appendix will deal primarily with several of the newer services: decision processing/remote file access, facsimile, snapshot, slow video, and full motion video. Before attempting to quantify the spectrum needs for these emerging services, it is instructive to consider a qualitative description of each.

• Decision Processing/Remote File Access - Decision processing is a data service distinguished from transaction processing in the amount and type of information handled. Decision processing generally involves significantly larger data transactions than occur in the transaction processing service and usually involves the explicit manipulation of the information by the end user. An example of such an application might be an insurance salesperson who would combine information provided at a remote location by a potential customer with statistical information drawn down from a database to provide analysis of the customer's requirements and supply a quotation for a policy. If the quote is accepted, the salesman could electronically "write" the policy, debit the customer's bank account, and thus place the policy in effect immediately. Implicitly included in this service is the ability to transfer files to and from remote filesystems. A user could directly use this capability to remotely access a home filesystem from a wireless laptop computer, enabling him or her to "extend the office" into the field.

• Facsimile - Facsimile service, as defined here, is a mobile version of the service prevalent today over the land line network. The information being transmitted is generally contained on single sheets of paper as a black-and-white image, and the primary content is alpha-numeric. The resolution and quality of the received information is modest. The user interface for reception could be either a printer or some type of display terminal. Landline usage has skyrocketed over the past five years and this trend will definitely evolve to the wireless world.

• Snapshot - The snapshot is a communications tool which goes beyond facsimile. It provides much higher resolution, gray scale and/or color, and could contain a much higher proportion of non alpha-numeric information. Examples of snapshot service would include the transmission of a photograph of a criminal suspect ("mug shot") to a police officer in the field or the transmission of a picture of a crime scene from the field to laboratory technicians. In this latter case, the input device could be some type of a video snapshot camera with a data interface to the communication

system. However, the snapshot service need not be purely visual. For example, the combination of sensor technology and powerful microcomputers could yield the "chemical snapshot" of a potentially hazardous material. This snapshot could be compared against a database of known materials to provide near instantaneous recommendations to field personnel concerning appropriate actions to take.

• Slow Video - This communications tool will provide high resolution color images at modest frame rates (i.e., approximately one frame per second). It is envisioned that this service would provide information for applications that require it on a real time basis or on a convenience store-and-forward basis. In the first case, emergency medical technicians could provide visual information of injuries to a patient to a doctor specializing in certain types of trauma. For this application, there is a requirement for both high resolution and color; however, a scan rate of approximately one frame per second is quite adequate. In the case of convenience store-and-forward applications, an insurance adjuster could provide a visual, voice annotated record of a disaster. Since the information is not required immediately but is required expeditiously, it could be packetized and forwarded through the system when there are lulls in the higher priority traffic. This would generally provide the information within tens of minutes rather than at the end of the day plus, relieving the insurance field personnel of the added burden to return to some location to transfer the information at the end of the day.

• Full Motion Video - This service is similar to slow video, but would support full motion frame rates of 30 frames per second (fps) or greater.

As stated earlier, advances in Digital Signal Processing technology, as well as in spectrally efficient wireless delivery, are achieving the bandwidth reduction needed to make these data intensive advanced services viable for land mobile radio. As a first step in estimating the spectrum needs, the raw information content associated with each service is calculated. Next, the advances in compression/source coding, channel coding, and spectral efficient wireless delivery technology are reviewed as relevant to each service. This information is then combined with a large metropolitan area usage model to forecast the spectrum needs for each service in the 1995-2000 period.

SOURCE REPRESENTATION: INFORMATION CONTENT AND DATA COMPRESSION

• Decision Processing/Remote File Access - The median file size that will be assumed for this service is 200 kilobytes (kbytes). Compression methods for binary data or ASCII text, commonly used for data storage today, would be suitable for this service. Although the amount of compression is highly dependent upon the source data files, a 2:1 compression ratio is assumed as average. Therefore the average compressed content to be handled in a single service access is 100 kbytes.

• Facsimile - Transmission of facsimile today is governed by two widely accepted international standards, CCITT's Group 3 and 4 [3,4]. These standards specify both horizontal and vertical resolution, which governs the "information" content, in bits, for

a typical 8.5 "x 11" page[1]. The Group 4 standard specifies a nominal resolution of 200 pixels per inch horizontally (300 and 400 pels per inch are also allowed) , and 100 lines per inch vertically (200, 300 and 400 lines per inch optional). Since the facsimile is a bitonal image, the nominal source content in bits, is:

8.5 in. x 200 pels/in. x 11 in. x 100 lines/in. x 1 bit/pel = 1.87 megabits (Mbits)
= 234 kilobytes (kbytes)

The CCITT Group 3 and 4 standards also specify compression algorithms to reduce the number of bits, and hence the bandwidth, needed to represent a typical page. These compression algorithms are content dependent, i.e. the amount of compression is dependent on the source material. The CCITT defines eight reference source pages to measure the effectiveness of the compression algorithms. The Group 4 compression scheme averages a compression ratio of roughly 10:1 over the eight reference source documents [5]. Thus, one page of fax, transmitted at nominal resolution, can be represented in approximately 23 kbytes.

The Group 4 fax standard compression algorithm is quite good; however, another standard, called JBIG, is in its final draft stages, and should be released soon. As a result, a modest 2:1 increase in source coding efficiency may be expected by the 1995-2000 timeframe. This information is summarized in Table 1.

• Snapshot - Unlike fax, snapshot images may contain full color or grayscale information, which greatly increases the amount of source data needed to represent an image. As stated earlier, the snapshot service may supply various resolutions and image sizes, according to the target market. For purposes of discussion, a 1024 x 800 pixel image will be assumed. For a full color image, three component colors must be coded per pixel, typically at 8 bits each for adequate color quantization. As a result, one 1024 by 800 pixel color snapshot image contains:

1024 pels x 800 pels x 8 bits/color x 3 colors = 19.66 Mbits
= 2.5 Mbytes

As with facsimile, a fairly well established standard compression algorithm exists. The JPEG (Joint Photographic Expert Group) standard [6,7], developed jointly by ISO/CCITT, has been developed to support a wide range of compression ratios for still color and grayscale images. The JPEG algorithm operates in two modes: a lossy and a lossless mode. The lossless mode provides modest amounts of compression with no degradation in image quality, while the lossy modes provide varying amounts of compression, which trades off directly for reconstructed image fidelity. It is generally accepted that the JPEG algorithm provides good quality image reconstruction at about 1 bit per pixel [7], or a 24:1 compression ratio, although this ratio is, like fax, source dependent. As a result of this compression technology, a snapshot image can be represented with good quality at about 820 kbits, or 102.5 kbytes. Of course, higher quality reconstruction may be obtained at the expense of added bits with the lossless mode, but this is a good estimate for high resolution and good image quality.

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[1]Note that "information" as used here refers to the uncompressed bit content, not the source entropy, as in a strict theoretical sense.

• Slow Video - Slow video is envisioned as a high resolution video service with very modest frame rates, approximately 1 per second. For purposes of discussion, the spatial resolution will be assumed to be somewhat less than the snapshot application, corresponding to a smaller display. A spatial resolution of 352 by 288 pixels will be assumed, for reasons which will soon become clear. With these resolution assumptions, the bit content of the video portion of the slow video source becomes:

352 pels x 288 pels x 3 colors/pel x 8 bits/color/pel x 1 frame/sec = 2.43 Mbps.

For the audio portion of the slow video signal, another 64 kbps must be added, bringing the total to roughly 2.5 Mbps.

There are two audio/video compression standards which have been steadily growing in popularity: MPEG-1 [8,9] and H-Series [10,11]. The ISO's MPEG (Motion Picture Expert Group) standard is designed as a single direction protocol providing audio/video compression, using various spatial and temporal resolutions, up to a rate of 1.92 Mbps. The CCITT's H-Series standard includes a two way protocol and is designed specifically for video communication services like teleconferencing, at a default resolution of 352 x 288 pixels per frame, and varying spatial resolutions from 1-30 fps. Both of these algorithms are designed to take advantage of temporal as well as spatial redundancies in the source material to achieve compression. Excellent results may be obtained at modest frame rates at about 0.5 bits per pixel [9,11], as opposed to the still image compression algorithm, JPEG, which requires roughly 1 bit per pixel for similar reconstructed fidelity. However, because slow video has such a low temporal resolution, the temporal redundancy of the source is low, and the compression ratio suffers. As a result, a 0.8 bit per pixel ratio is assumed, so that the compressed slow video may be represented in as little as 81 kbps. Adding another 16 kbps for compressed audio, and adding synchronization overhead brings the total slow video signal to about 100 kbps.

• Full Motion Video - Full motion video would most likely utilize either MPEG-x or H-Series standard protocols. As a result, the same spatial resolution is assumed as for slow video, but the frame rate is increased to 30 fps. As a result, the full motion video source is:

352 pels x 288 pels x 3 colors x 8 bits/color/pel x 30 frames/sec. = 73.0 Mbps

Again, another 64 kbps must be added for audio, but this is somewhat negligible compared to the video signal.

Either the H-Series or MPEG-x standards yield good quality video at 0.5 bits per pixel. Adding 16 kbps for compressed audio and allowing for overhead related to synchronization, the total full motion video bit rate comes to about 1.54 Mbps.

• Coding/Compression Advances in the 1995-2000 Timeframe - In the calculations above, compression ratios have been used which reflect the state of viable

technology as of today, in late 1992. As processing capability improves, higher complexity compression algorithms will become viable, increasing the compression ratios possible for these services. Semiconductor technology trends show that microprocessor computing speed increases by roughly an order of magnitude every 10 years (see Figure 1 and [12]). Special purpose DSP processors, which are more popular for the multiply-accumulate operations prevalent in compression, have demonstrated a similar trend. Thus, by the year 2000, compression schemes roughly ten times as complex as those of today should be viable for land mobile radio.

In Digital Pictures: Representation and Compression, Haskell and Netravali have quantified the compression efficiency versus complexity issue [13]. Figure 2, from [13], shows compression ratio in bits per Nyquist sample (pixel) in terms of relative complexity for monochrome video[2]. Both the MPEG and H-Series compression schemes utilize 2D transform coding with adaptive quantization and motion compensation. This scheme is similar to the point "2D: X + AQ" in Figure 1, however, motion compensation makes the scheme more complex, yet more efficient. Thus, today's compression schemes probably lie somewhat to the right of the 2D: X + AQ point in Figure 1. This is consistent with the earlier statement that good quality color video may be obtained with today's video compression schemes at about 0.5 bits per pixel.

As stated above, by the year 2000, an increase of roughly a factor of ten may be expected in complexity capability, due to advances in microprocessor speed. The trend in Figure 1 shows that with this complexity, improved compression ratios on the order of 0.1 bits per pixel should be possible. It is noted that the trend in Figure 1 cannot continue falling, but must be asymptotic to the video source entropy. Recognizing this fact, a conservative estimate of a 2:1 improvement over today's compression ratios, or roughly 0.25 bits/pel, should be achievable by the year 2000.

Table 1 summarizes the source content and compression capabilities of present day technology and expected gains in compression due to algorithmic advances and/or semiconductor technology gains. These processing advances would allow more complicated, more efficient compression algorithms. Table 2 further quantifies the four services according to type and service time. Each service has been classified as interactive or non-interactive. Interactive implies an "acceptable" real time interaction with the user. Clearly, a telephone interconnect-type service would fall into this category. Non-interactive implies that the service need not provide real time response. Note, this does not imply that response time is arbitrary. In addition, service time is shown, defined as the typical duration of time that a user would avail himself or herself of a particular type of service. This parameter is associated solely with interactive service types.

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[2] The authors state that roughly a 25% increase in compressed bit rate is needed for color.

Service	Source Content	Compressed Content	Compression Advances
Decision Processing/ Remote File Access	200 kbytes	100 kbytes	2:1
Fax	234 kbytes	23 kbytes	2:1
Snapshot	2.5 Mbytes	103 kbytes	2:1
Slow Video	2.5 Mbps	100 kbps	2:1
Full Motion Video	73.0 Mbps	1.54 Mbps	2:1

Table 1 - Source Content and Compression Ratios

Service	Type	Service Time
Decision Processing/ Remote File Access	Interactive	15 sec. per transfer
Fax	Non - Interactive	NA
Snapshot	Non - Interactive	NA
Slow Video	Interactive	180-300 sec.
Full Motion Video	Interactive	140-180 sec.

Table 2 - Service Type and Access Time

WIRELESS TECHNOLOGY: 1995-2000

Wireless technology is the enabler which gives the mobile worker the ability to utilize the services described in the previous section to more effectively perform their jobs. There are four segments of the technology which, when combined with frequency spectrum availability, determine the degree to which these services are enabled. Source encoding has been treated above; the other three are channel encoding, modulation, and infrastructure design. Each of these aspects will now be examined.

Channel encoding technologies employed for voice dispatch over the last ten years have consistently employed techniques which rely on various half rate coding techniques. The major improvements that have occurred were in implementation and sensitivity, rather than rate efficiency. This trend will continue through the year 2000 with the employment of channel encoders that are highly integrated with the modulation techniques (e.g., trellis coding). The sensitivity improvements will have direct impact on the infrastructure design, permitting the maximum geographic reuse of the frequency spectrum.

There is very little doubt that modulation technology will begin the evolution from analog constant envelope to linear digital techniques in the 1992 to 1994 timeframe. This evolution will initially be most viable in new spectrum allocations or where users are concentrated in single organized frequency bands. With the emphasis in the private and shared marketplace on user friendly interfaces, the modulation techniques introduced in that timeframe will be designed to operate effectively at approximately 3.5 bits per second per hertz, in harsh dispersive environments and without the need for equalizers, thus significantly reducing the battery current required by the demodulator. The trend as the year 2000 approaches will be to continue to improve power efficiency through packet technologies employed in the radio channel protocols. Additionally, frequency hopped spread spectrum may be employed to mitigate the effects of interference.

Infrastructure architecture as it relates to capacity will employ designs that allow for a gradual capital investment that parallels the addition of users. This will take the form of "traditional" wide area single site systems that can be migrated to multi-site "zone" systems and then to "cellular like" systems while utilizing the infrastructure equipment in a modular building block approach. By the year 2000 these systems will employ a combination of all three of these coverage techniques to provide optimized service. The reuse architecture will, in effect, be driven by the service requirements of the users and the infrastructure will emerge reflecting those requirements. The trend toward personal subscriber interfaces and the implicit requirement to provide reliable in-building service in large metropolitan areas where the density of buildings is nonhomogeneous will result in reuse factors of approximately 4:1 for the advanced visual services described herein.

Table 3 presents a summary of the channel encoding, modulation and geographic reuse technology expected by the 1995-2000 time period.

Service	Channel Code	Modulation	Reuse
Decision Processing/ Remote File Access	Half Rate	3.5 bits/sec/Hz	4:1
Facsimile	Half Rate	3.5 bits/sec/Hz	4:1
Snapshot	Half Rate	3.5 bits/sec/Hz	4:1
Slow Video	Half Rate	3.5 bits/sec/Hz	4:1
Full Motion Video	Half Rate	3.5 bits/sec/Hz	4:1

Table 3 - Wireless Technologies:1995-2000

At this point, the technological capabilities related to providing decision processing fax, snapshot, slow video and full motion video have been characterized. The spectrum needed to provide these services is dependent not only on these core

technologies, but also on the usage characteristics of the mobile workers who make up the end user population. This issue is now addressed.

METROPOLITAN AREA MODEL AND USAGE STATISTICS: 1995-2000

Census demographics show that in 1990, a typical large metropolitan area in the US, like New York, Los Angeles, or Chicago, has the following characteristics:

1. The population is approximately 14 million people.

2. The population of working adults is about 8.7 million or 62 percent of the total population.

3. Highly mobile workers (i.e., on the move more than 60 percent of the time) number approximately 1.9 million or 22 percent of the working population.

4. Moderately mobile workers (i.e., on the move from 30 to 60 percent of the time) number about 1 million or 12 percent of the working population.

As the year 2000 approaches, there does not seem to be any reason for these characteristics to change radically. The only likely change will be a population growth of about 2.25 percent per year, leading to the typical metropolitan area of 17.5 million people with 3.7 million moderately to highly mobile workers (For simplicity we will refer to this group as mobile workers for the remainder of this paper). Of these 3.7 million mobile workers, it is estimated that about 28%, or about 1.03 million workers will be private mobile radio users.

The needs of each of these mobile workers for the services in question must now be predicted. Service usage will be quantified in terms of the numbers of requests for service in the busy hour, the average duration (interactive service) or information content (non-interactive service) for the service, and the percent penetration of the population of private land mobile users that are forecast to use the service in the year 2000. The proposed usage model is shown in Table 4. Note that the use of traditional voice and data services as well as newer advanced services has been included. Also, while full motion video is expected to be viable in the 2000 timeframe, it is also expected to be quite expensive in terms of bandwidth and thus, cost to the user. Therefore, the usage model assumes only a very small number of full motion video users in the 1995-2000 timeframe.

Service	Request Rate	Ave. Duration/Content	Penetration*
Dispatch	1 per hour	40 sec.	25%
Telephone Interconnect	0.5 per hour	100 sec.	7%
Transaction Processing	2 per hour	1k byte	25%
Facsimile	0.5 per hour	23k bytes	12%
Snapshot	0.25 per hour	103k bytes	6%
Decision Processing/ Remote File Access	0.25 per hour	100k bytes/ 15 sec.	12%
Slow Video	0.125 per hour	210 sec.	2%
Full Motion Video	0.125 per hour	210 sec.	0.1%

* Percent of Private Land Mobile Users (Year 2000)

Table 4 - Advanced Service Usage Predictions

ADVANCED LAND MOBILE SERVICES SPECTRUM NEEDS: 1995-2000

The predicted mobile worker needs given above, coupled with the technological capabilities to meet these needs, described earlier, allow a calculation of the spectrum that will be required for advanced communication services as the year 2000 approaches. The results are presented in Table 5. An estimate of the spectrum needs for voice services is also included, based upon expected efficiency improvements in the current land mobile allocation, and the needs of advanced services users for traditional voice services. Some of the information listed earlier has been included for clarity. As previously stated, the calculations are based on a metropolitan area of approximately 17.5 million people with 1.03 million private mobile radio users. These spectrum requirements are expected to increase through the year 2010 as the penetration for these services increase and there is a greater dependence on multimedia information in the normal way in which business is conducted.

Service	Penetration*	Users	Spectrum
Voice Dispatch	25%	258,000	15 MHz
Telephone Interconnect	7%	72,000	5 MHz
Transaction Processing	25%	258,000	5 MHz
Facsimile	12%	124,000	19 MHz
Snapshot	6%	62,000	10 MHz
Decision Processing	12%	124,000	10 MHz
Slow Video	2%	21,000	6 MHz
Full Motion Video	0.1%	1,000	5 MHz
TOTAL			**75 MHz**

* Percent of PMR Users

Table 5 - Spectrum Requirements: 1995-2000

This vision of the future is a prediction and, like any other prediction, is subject to some debate. Although the details of the vision just described may unfold somewhat differently as time goes on (e.g. in the case of full motion video as a land mobile service), the general nature of the vision should be quite accurate and will advance most rapidly and successfully in the context of the private mobile radio community as implemented in private systems. The "details" of the vision will be driven by a combination of innovative technologies and innovative users from the PMR industry, user groups, and forward thinking regulatory agencies. Perhaps the largest factor influencing the speed at which these innovative technologies can be introduced will be the availability of adequate spectrum. Allocations as part of the Emerging Technologies Initiative would serve as a catalyst for this vision, and would serve to greatly improve the efficiency and/or competitiveness of the business and public safety users comprising the Private Land Mobile user community.

REFERENCES

[1] William S. Sessions, Armed Forces Communications and Electronics Association Convention, Washington, D. C., June 24, 1992.

[2] Comments of Motorola, Inc. to the FCC in the Matter of Redevelopment of Spectrum to Encourage Innovation in the Use of New Telecommunications Technologies, ET Docket 92-9, June 8, 1992.

[3] CCITT Recommendation T.4, "Standardization of Group 3 Facsimile Apparatus for Document Transmission," Red Book, ITU, Malaga-Torremolinos, 1984.

[4] CCITT Recommendation T.6, "Facsimile Coding Schemes and Coding Control Functions for Group 4 Facsimile Apparatus," Red Book, ITU, Malaga-Torremolinos, 1984.

[5] Advanced Micro Devices Am7970 Compression Expansion Processor Handbook, p.3-8, 1986.

[6] Digital Compression and Coding of Continuous-Tone Still Images, Part 1, Requirements and Guidelines, ISO/IEC JTC1 Committee Draft 10918, Feb. 1991.

[7] Gregory K. Wallace, "The JPEG Still Picture Compression Standard," *Communications of the ACM,* Vol. 34, no. 4, pp. 31-44, April 1991.

[8] Coding of Moving Pictures and Associated Audio, Committee Draft of Standard ISO11172: ISO/MPEG 90/176, December, 1990.

[9] Didier Le Gall, "MPEG: A Video Compression Standard for Multimedia Applications," *Communications of the ACM,* Vol. 34, no. 4, pp. 47-58, April 1991.

[10] Video Codec for Audio Visual Services at p x 64 kbps, CCITT Rec. H.261, CDM XV-R 37-E, ITU, August 1990.

[11] Ming Liou, "Overview of the p x 64 kbps Video Coding Standard," *Communications of the ACM,* Vol. 34, no. 4, pp. 47-58, April 1991.

[12] Patrick P. Gelsinger, Paolo A. Gargini, Gerhard H. Parker, and Albert Y.C. Yu, "Microprocessors circa 2000", *IEEE Spectrum*, pp. 43-47, October 1989.

[13] A. Netravali and B. Haskell, Digital Pictures: Representation and Compression, Plenum Press, New York, 1988.

APPENDIX D

ABSTRACT:
Based on historical and technological evidence, it is shown that the frequencies between 1.85 and 2.2 GHz are satisfactory for the operation of land mobile radio. Currently, systems are successfully operating in Japan at 1.5 GHz, and a recent MPT Committee there recommended that the next generation of digital systems operate in this 1.5 GHz band. Thus it is concluded that economically viable systems that increase the efficiency of mobile workers can be designed for the 2 GHz band.

INTRODUCTION:
In the past , when there was a need for additional spectrum for land mobile radio, a frequent solution was to look to higher frequencies. That trend continues with the present investigation of frequencies in the 2 GHz band for use in the next generation of systems. The propagation loss increases as a function of frequency, and the interaction of the mobile radio with the electromagnetic environment presents different challenges at higher bands. However, as the wavelength gets shorter, there are techniques such as space diversity that become physically realizable on the subscriber unit to mitigate against that increased loss.

It is the purpose of this Appendix to show that the frequencies in the 1.85 to 2.2 GHz band are satisfactory for use by the land mobile radio industry to satisfy the demands of the radio user for additional features and functions. We will investigate herein the key items that impact the use of 2 GHz for the next generation of land mobile systems, and give evidence that successful operation of those systems should be possible. The experience in Japan in the 1.5 GHz band will be used to illustrate that use of these higher frequencies is technically realistic for wide area coverage. Also, recent tests in Tokyo resulted in the recommendation that the next generation of digital trunked systems also be implemented in that band [1], further confirming that higher frequencies can successfully provide the features required by land mobile users

EXPERIENCE AT 1.5 GHz
In Japan one 1.5 GHz land mobile band of frequencies extends from 1465 to 1477 MHz paired with 1513-1525 MHz which is used for analog Multi-Channel Access (MCA). This is one of the bands which is used for analog trunking in Japan in addition to an 800 MHz band. When the band was opened up, it was questioned if the same services offered at the lower 800 MHz frequencies could be offered at these sub-microwave frequencies because of the larger propagation loss. The affirmative answer has been confirmed by considerable experience.

There are three levels of coverage for MCA that are defined by the Japanese MPT. They are identified in table D-1, and are the same for 800 and 1500 MHz. The field strengths are defined at the location where the level quoted is 3 dB

below the median measured value. For example, when a location is identified as 24 dBμV/m on coverage maps, the measured median field strength at that location is 27 dBμV/M. This provides 70 percent coverage of that area based on a log-normal standard deviation of 6 dB.

Table D-1 Voice Quality Definitions Used in Japan MCA Systems

Voice Quality Level	Description	Minimum Field Strength
4	Speech Easily Understandable	30 dBμV/m
3	Occasional Repetitions Needed	24 dBμV/m
2	Frequent Repetitions Needed	18 dBμV/m

Voice Quality Level 3 is virtually the same as circuit merit 3 [2] that is used in the land mobile industry in the U.S. for commercial service. Figure D-1(a) and (b) show the measured coverage that is obtained from 1500 and 800 MHz analog JSMR systems respectively that are operated from the Sunshine Building in downtown Tokyo. The height of the antennas on this site is approximately 895 feet, and the transmitter power used is of the order of 75 watts. The area which is green provides voice quality level 4 or better; the area which is yellow provides voice quality level 2 or 3, and the area that is white does not provide service from this site. The coverage for the two frequencies is obviously different, but the nominal range is approximately the same, and both systems are loaded with operating users.

The same can be said of the JSMR site at Tsukuba which is located about 65 km (40 miles) from Tokyo. Figure D-2(a) and (b) show the coverage from that site which has antennas located at a height of 1788 feet. Numerous other examples could be given, but the conclusion is the same, the coverage that is provided between 800 MHz and 1500 MHz systems is similar and subscribers find acceptable performance of their radio on either system.

PERFORMANCE AT 2 GHz

The experience gained at lower frequencies can be extended to the 2 GHz frequencies under consideration at the present time. The dominating characteristic of systems design at higher frequencies is the greater propagation loss. The propagation curves of Okumura [3] can be used to determine the magnitude of the additional loss, and Figure D-3 shows the loss as a function of frequency from a 1000 foot tower to a mobile or portable on the street 20 miles away in an urban environment. The additional loss above that experienced at 1.5 GHz is 4 dB.

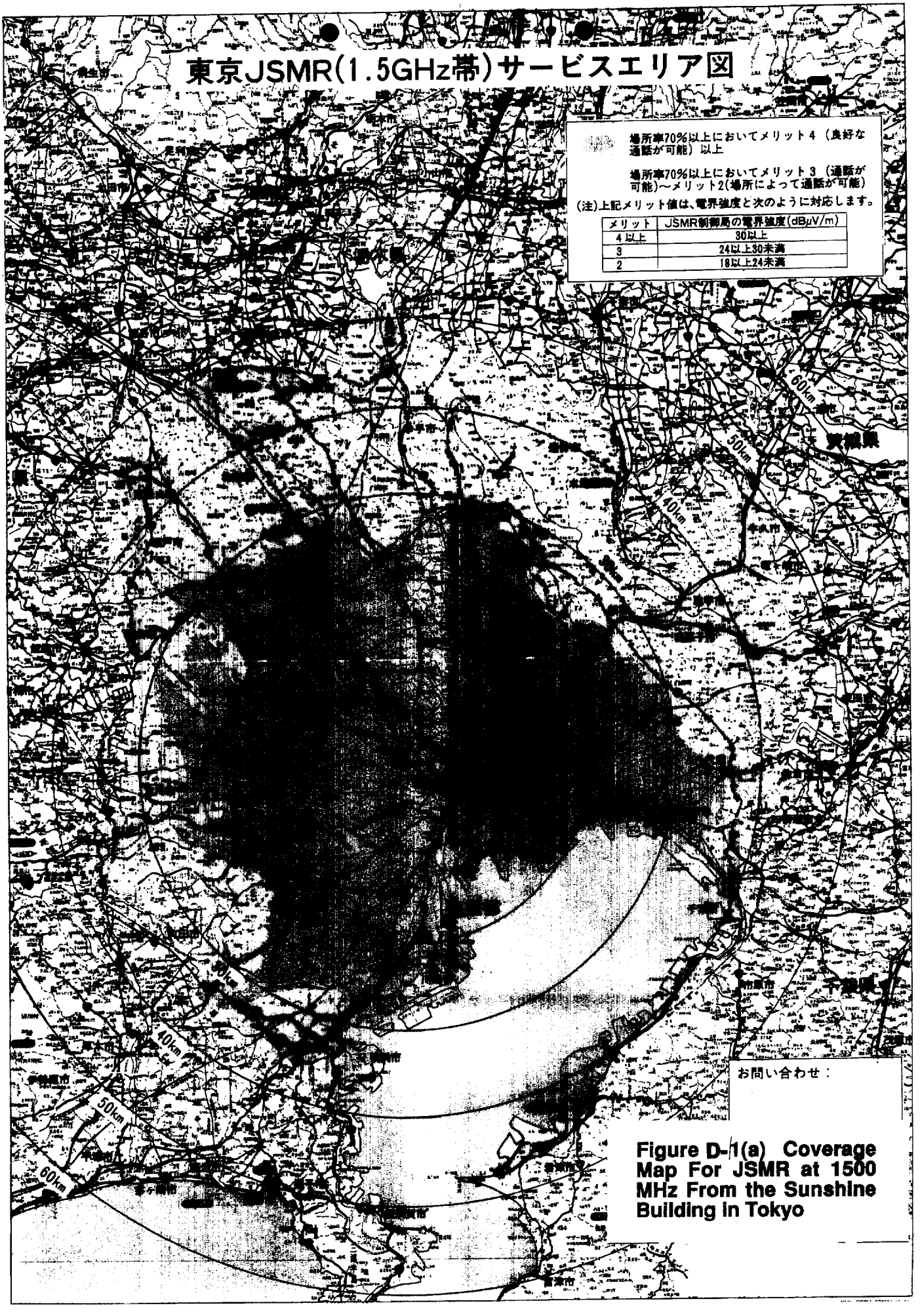

Figure D-1(a) Coverage Map For JSMR at 1500 MHz From the Sunshine Building in Tokyo

800 MHz

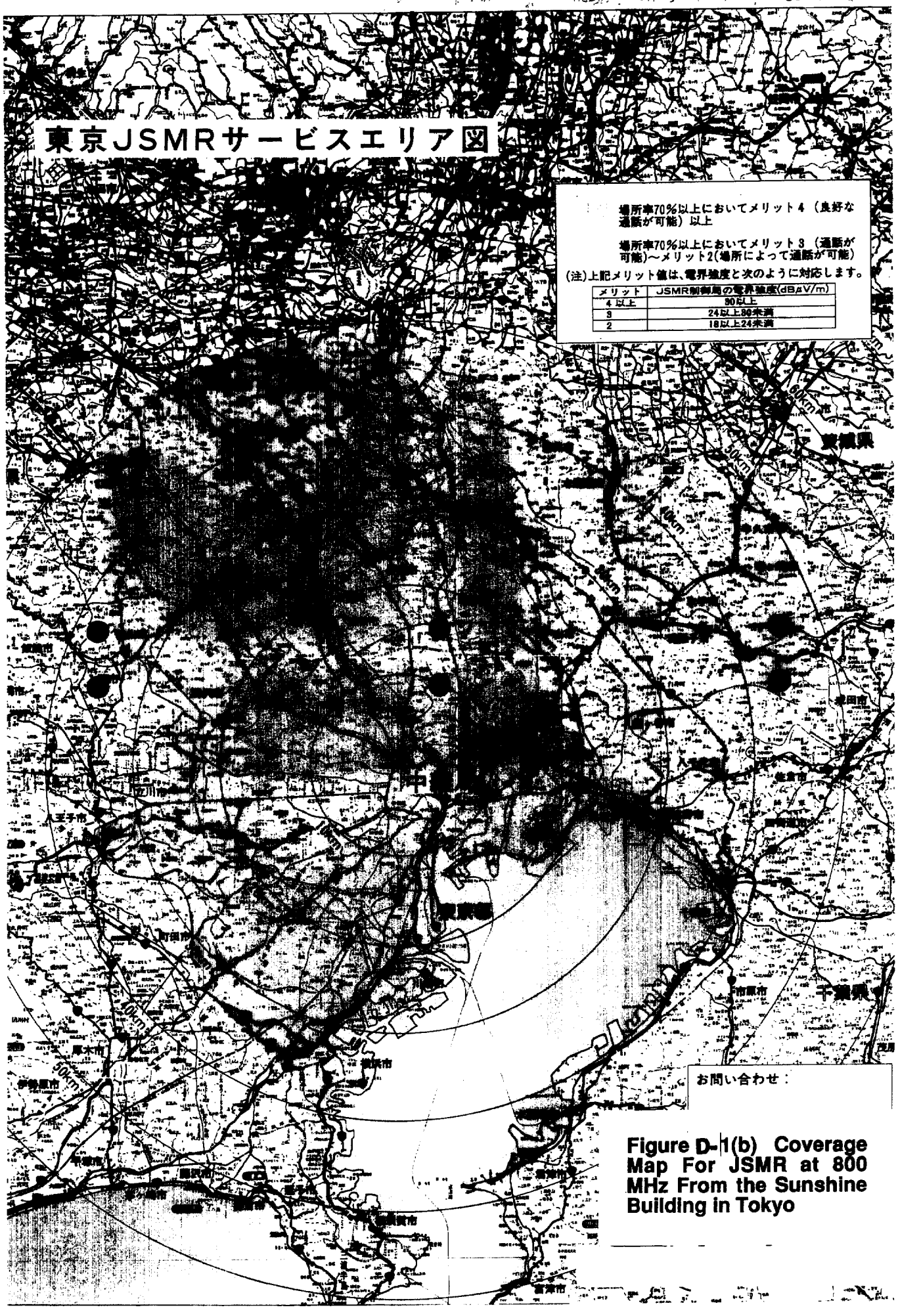

Figure D-1(b) Coverage Map For JSMR at 800 MHz From the Sunshine Building in Tokyo

つくばJSMR(1.5GHz帯)サービスエリア図

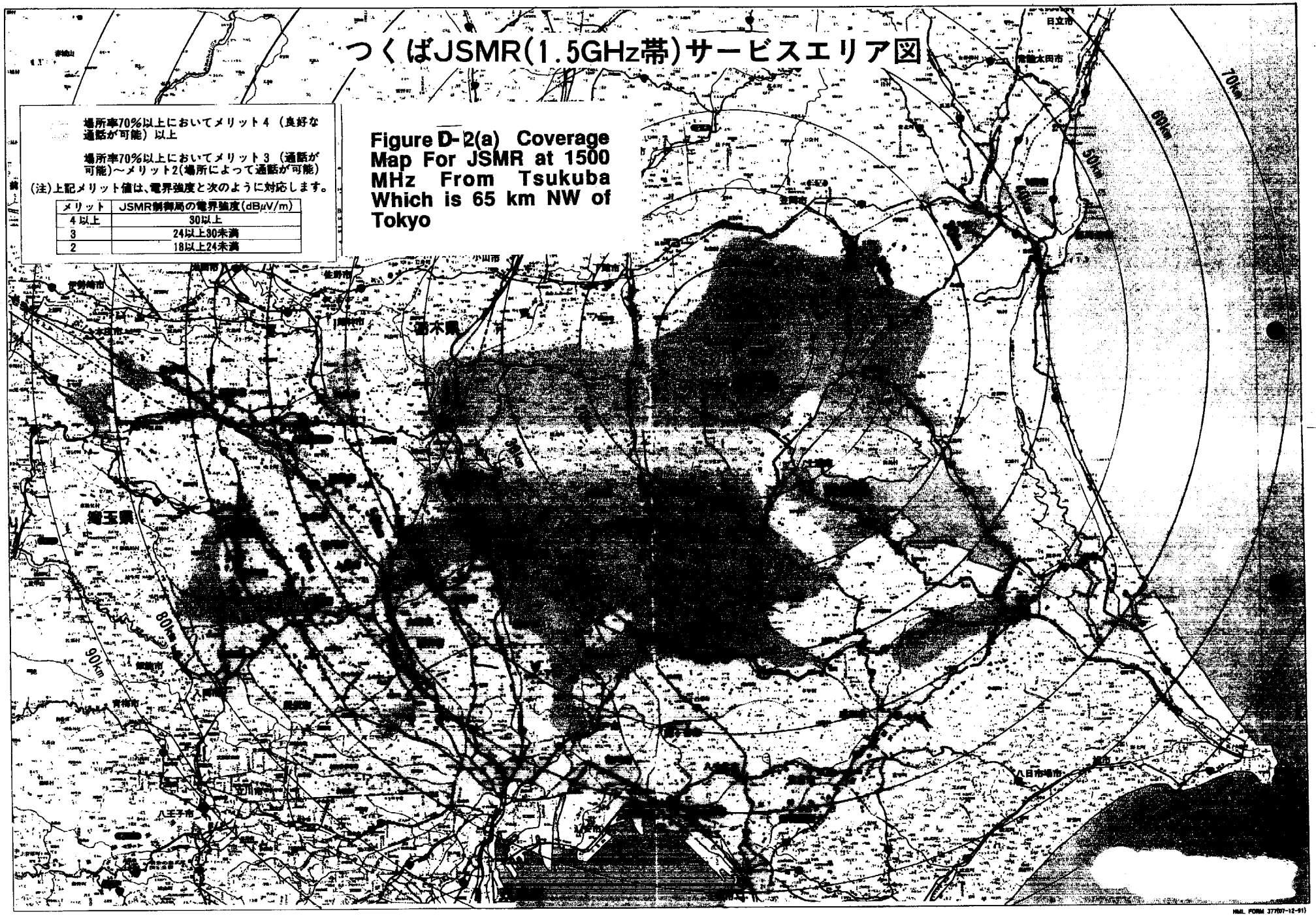

Figure D-2(a) Coverage Map For JSMR at 1500 MHz From Tsukuba Which is 65 km NW of Tokyo

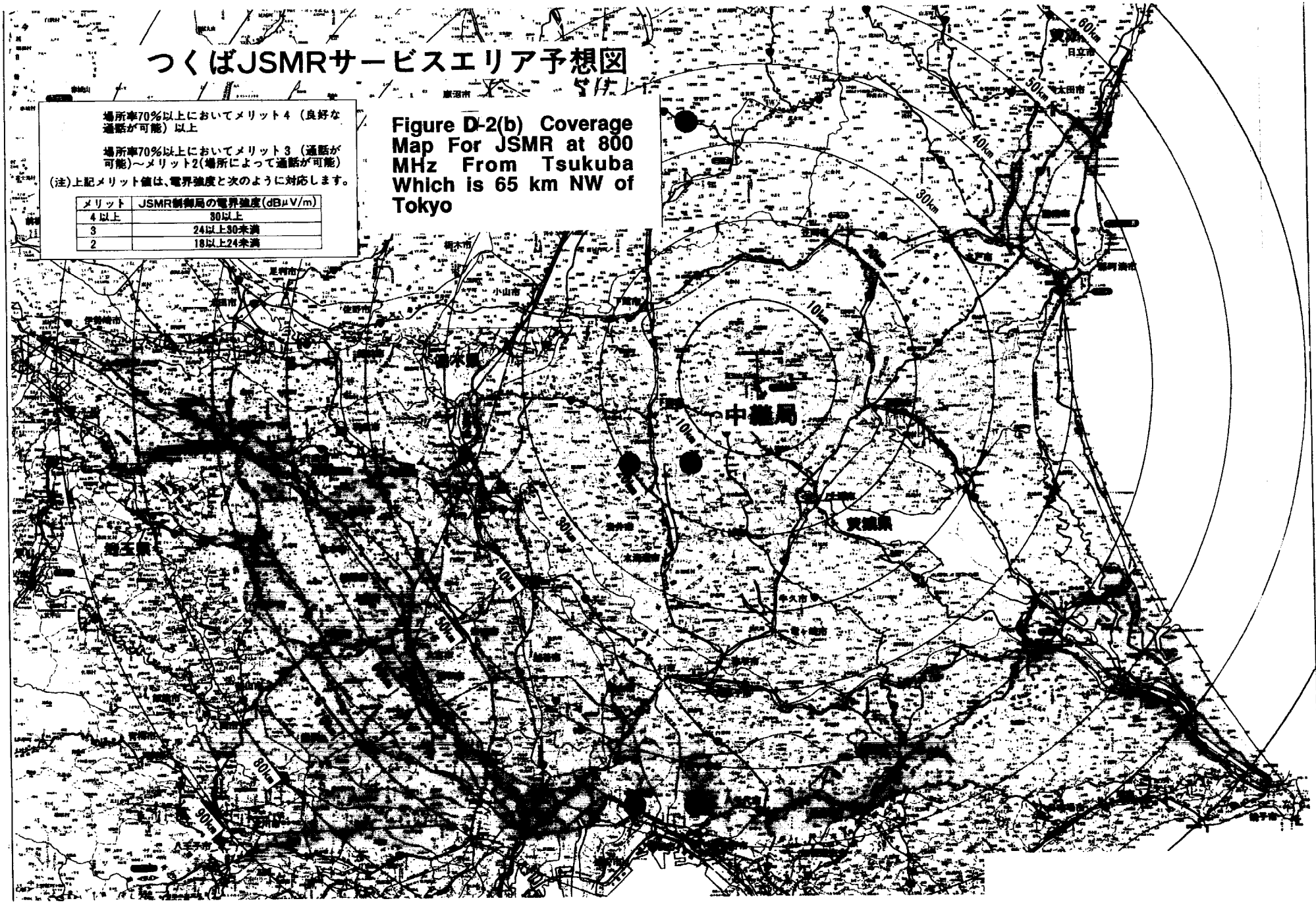

Figure D-2(b) Coverage Map For JSMR at 800 MHz From Tsukuba Which is 65 km NW of Tokyo

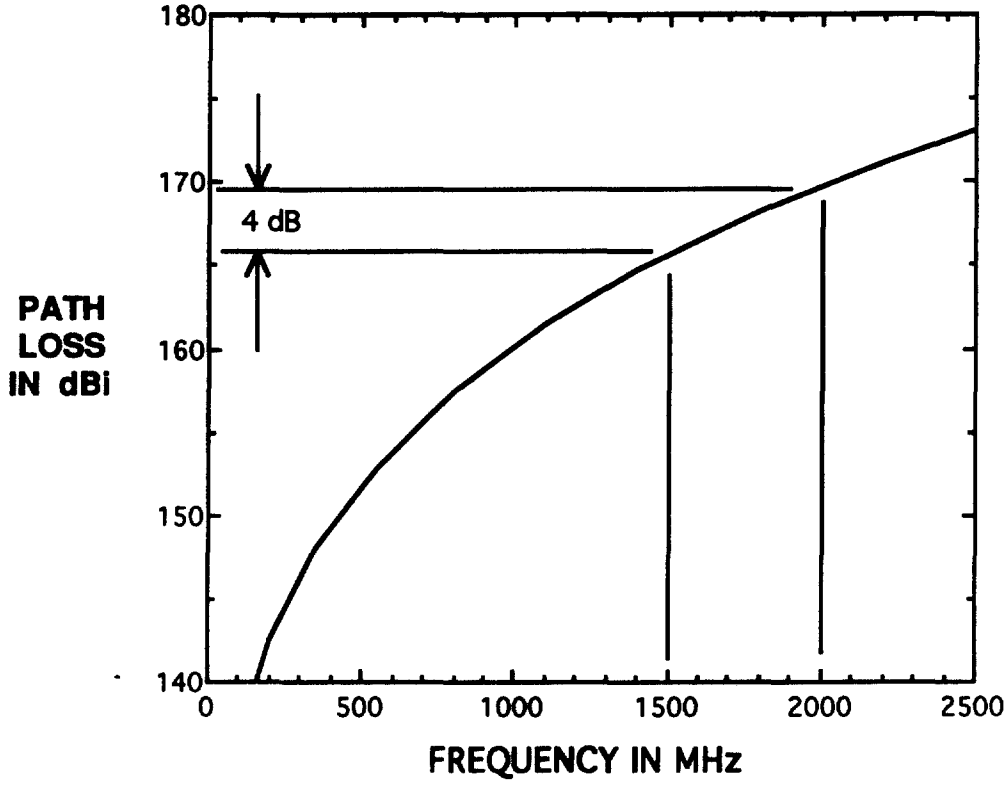

Figure D-3 Propagation Loss From a 1000 Foot Tower to a Mobile At a Range of 20 Miles

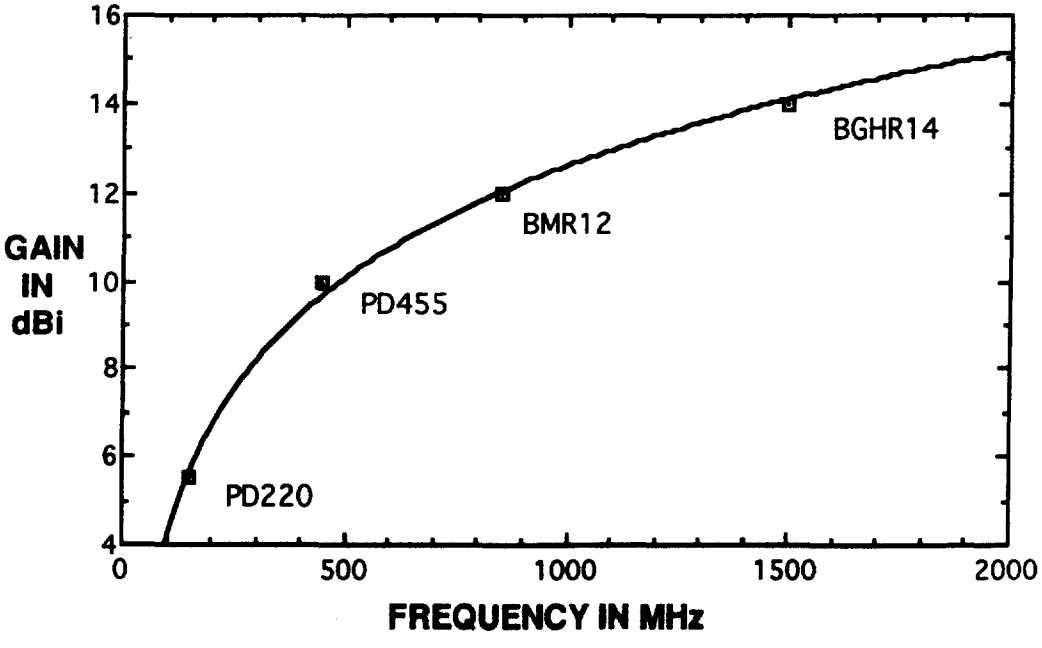

Figure D-4 Gain of 20 Foot Aperture Fiberglass Antennas

This additional propagation loss can be offset by several factors. The first is antenna gain which is shown for several omnidirectional base station antennas [4], as a function of frequency in Figure D-4. These antennas are all fiberglass enclosed with a radiating aperture of approximately 20 feet. It is evident that the gain is not continuing to increase as fast at higher frequencies, though theory says that the directive gain should increase 3 dB for every doubling in frequency. This is because of a practical implementation factor, the loss associated with the feed network. At higher frequencies the loss for the same length of line increases. However, it does appear that an additional 1 dB of gain could be expected at 2 GHz above that obtained at 1.5 GHz based on an extrapolation of the data in Figure D-4. A similar trend is seen for mobile and portable antennas.

An important factor in the design of systems for the future is the fact that portable radios are becoming more and more common. Portable radios are used in buildings, and therefore, the building penetration loss becomes important. The loss as a function of frequency for medium to large buildings[5-7] is shown in Figure D-5, and the trend is for the loss to decrease as the frequency increases. Thus, the coverage of portables in buildings should be slightly better at 2 GHz than at 1.5 GHz.

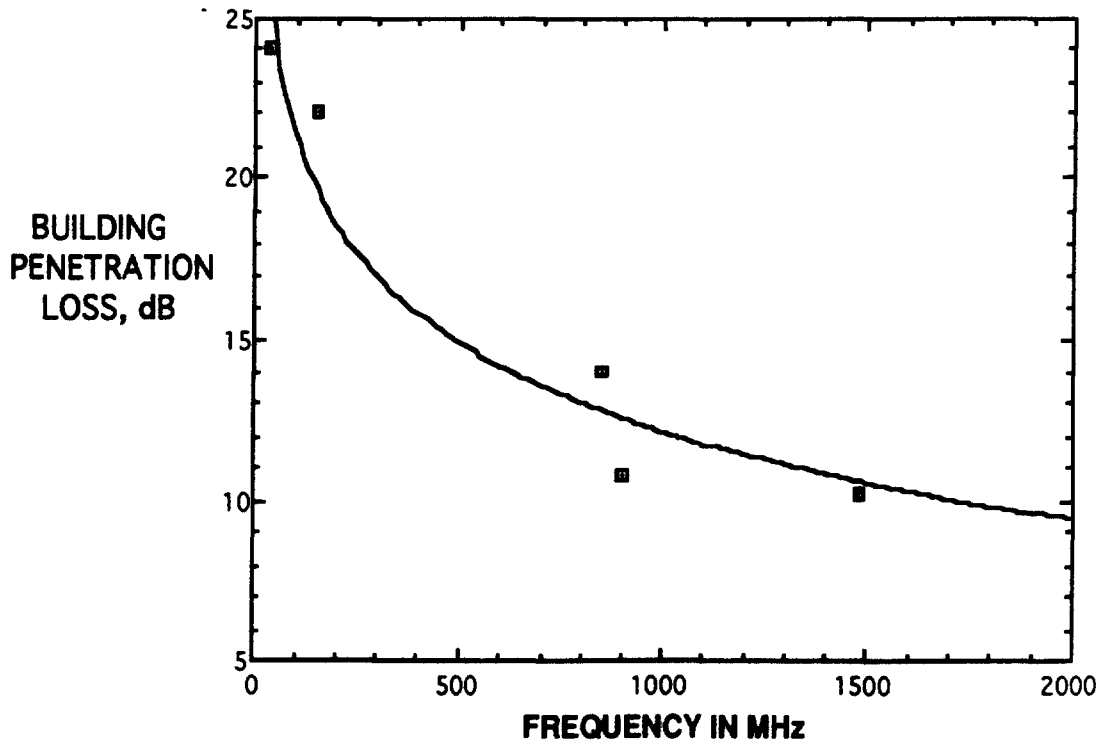

Figure D-5 Medium to Large Building Electromagnetic Penetration Loss

Additional factors that apply to the system design are the noise figure of the receivers, the ambient noise at the receiver, diversity techniques, and feed line losses. The noise figure of receivers is decreasing over time as better semiconductor devices are developed and lower loss preselector filter materials