Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Spectrum Policy:	)	
	)	
Solicitation of Public Comment by the Spectrum Policy Task Force	))	ET Docket No. 02-135
	)	
	)	
To: The Commission		

COMMENTS OF

Statewide Wireless Network

New York State Office for Technology

6C Executive Park Dr.

Albany, NY 12203-3716

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Appendix 5

Appendix C of the PSWAC Spectrum Requirements Subcommittee Final Report pp. 65 (671) - 79 (685)

APPENDIX C

PUBLIC SAFETY WIRELESS ADVISORY COMMITTEE MODEL FOR PREDICTION OF SPECTRUM NEED THROUGH THE YEAR 2010

A WHITE PAPER

MOTOROLA **DRAFT v1.1** **February 2, 1996**

EXECUTIVE SUMMARY

The present service requirements of the public safety community that relate to wireless communications have been identified and projected through the year 2010. Future service requirements have also been identified that are made possible by advances in semiconductor and computer technology that will add to the efficiency and safety of public safety officers as well as the communities which they serve. All of these service requirements include voice, data, image and video. For each of these, the average number, duration, and message load offered, as they relate to the use of wireless communications now and in the future, have been quantified.

The technological parameters that relate the service requirements to spectrum need include RF transmission rate, digital coding, channel occupancy, and error control. The historical rate of change in these have been determined, and then projections were made into the future. A geographical model of Los Angeles which contained 390 thousand public safety officers with advanced services radios was then identified as shown below. The spectrum need for each was also determined as shown, and this is the basis that shows that 84 MHz of RF spectral bandwidth should be provided for public safety applications through the year 2010.

Spectrum Requirements 1996 through 2010		
SERVICE	**THOUSANDS OF USERS**	**SPECTRUM BANDWIDTH MHZ**
VOICE	273	20
TRANSACTION PROCESSING	195	5
FACSIMILE	117	9
SNAPSHOT	156	19
DECISION PROCESSING/ REMOTE FILE TRANSFER	117	14
SLOW VIDEO	27	6
FULL MOTION VIDEO	3	9
COMPUTATION TOLERANCE	NA	2
TOTAL		84

I. INTRODUCTION

The goal of the Public Safety Wireless Advisory Committee is primarily to advise the FCC and NTIA on the "operational, technical, and spectrum requirements of federal, state, and local public safety entities through the year 2010."[1] The objective is to bring about significant enhancement to the effectiveness and efficiency of public safety communications. Wireless communications have been well used by public safety in the past, and with proper planning, even better use can be made in the future.

This paper will examine the implications of semiconductor advances on computing and telecommunications, and the wireless offering of related services that will impact the public safety community.[2] The present state of semiconductor technology is reviewed in Appendix A, and the cost impact on one market is illustrated. The operational requirements of public safety will be reviewed and projected through the year 2010.

It is the function of this paper to present the best intellectually supportable forecast for the spectrum needed by public safety by 2010. A model will be used that is based on a projection of the current state of digital compression and wireless radio delivery technologies that apply to public safety needs. From that, a forecast is made for the amount of spectrum which will be needed for specific advanced telecommunication services through the year 2010.

II. SPECTRUM PREDICTION MODEL

We are herein proposing an engineering methodology for projecting spectrum needs. We will show a methodical approach to projecting the trends of key technologies, and how that approach can be employed to predict future spectrum requirements. The relationships between need and required spectrum can be described in terms of technical parameters. Mathematical equations can then be used to project the bandwidth of spectrum required. This methodology has been previously employed in the COPE[3] petition, and we use this as a starting point. The steps to be used are:

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1 FCC/NTIA Report No WT 95-22, Wireless Telecom Action, September 8, 1995.

2 This paper draws heavily from a paper by Allen Davidson and Larry Marturano titled Impact of digital techniques on future LM spectrum requirements, IEEE Vehicular Technology Society News, May, 1993. New material given in this paper and some material deemed of importance will be referenced herein. The reader is referred to the predecessor paper for complete citations.

3 Coalition of Private Users of Emerging Multimedia Technologies (COPE), FCC Petition for Rule Making, Spectrum Allocations for Advanced Private Land Mobile Communications Services, filed 12/23/93. COPE represents many private users of land mobile radio, including public safety organizations such as the Association of Public Safety Communications Officials, International (APCO) and the Public Safety Communications Council (PSCC).

1) Identify the geographical area over which the model will be applied and the population of officers who will use the services to which the model applies. We will use the greater Los Angles area herein.

2) Identify the advanced services that will be used by the public safety community through the year 2010.

3) Identify a self consistent set of technical parameters that can relate the usage of the advanced services to the spectrum required in a spectrally efficient manner.

4) Quantify those technical parameters for each of the advanced services.

5) Compute the spectrum need for each of the advanced services and sum them to obtain the total spectral need for public safety through the year 2010.

Each of these will be discussed in turn in the sections to follow. The application of semiconductor technology to radio communications has resulted in certain technology trends that can be useful in these discussions. Several of these trends are presented in Appendix B.

A. Metropolitan Area and Population (POP)

Above we identified the greater metropolitan area of LA as the area which will be used for the computation.[4] The population of public safety users there has been evaluated by the Association of Public Safety Communications Officials (APCO).[5] They show that there were an estimated 78,000 mobile and portable radios in the Los Angeles area in the year 1985, and that this number was estimated to grow to 155,000 by the year 2000.

However, the actual growth in the number of licensed mobile and portable radios in the public safety service between 1985 and 1990 as published by the FCC was much greater than had been estimated in 1985. The actual growth rate by the year 1990, 11.6 percent, produced 135,000 mobiles and portables. Using a much more conservative growth rate of 6.0 percent from 1990 to 2000 and 5.0 percent from 2000 to 2010 they projected that the population of public safety units will be 390,000 by the year 2010.

We will use this estimate as the population for our computation herein; it will be abbreviated POP in the equations to follow. This number may appear to be somewhat large for the population of resident public safety officers in the greater metropolitan area of Los Angeles. However, when one considers the case of a large emergency, where virtually all of the normal activities continue, and there is a large influx of additional resources which must interpolate with the resident population, the number seems very reasonable.

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4 It would have been possible to use the areas around New York or Chicago as these are crowded users of the spectrum and would also have provided a valid result.

5 The impact of Advanced Technologies on Public Safety Spectrum Requirements, prepared by APC O Spectrum Needs Task Force, July 1994

B. Advanced Services

The advanced services which will be available to the public safety community by the year 2010 are:

Table 1
Advanced Services

- voice dispatch (to support other services)
- telephone interconnect
- transaction processing
- facsimile
- snapshot
- decision processing/remote file access
- slow video
- full motion video

Each of these are described in detail in Appendix C and will not be described further here. The land line services that are driving the need for these advanced services in the public safety environment are also described in Appendix C. Further, some examples are given there of the first steps being taken to bring them into the wireless world.

C. Technical Parameters

A set of parameters that apply to the model at hand are given below, and each of them will be described further in the paragraphs to follow.

Table 2
Parameters Used in Model

- penetration of each service into the target population (%)
- source content (kbytes or kbits/sec)
- expected coding improvement (factor)
- average duration of message (sec)
- calls per hour (number)
- RF transmission rate (bits/sec/Hz)
- error control (% of transmission)
- average busy hour channel loading factor (related to blocking, %)
- geographic reuse factor (factor)

1. Service Penetration Into Target Population (PEN)

The penetration of each of the services into the population of public safety users is represented by the shortened form PEN in the equations to follow. It is a dimensionless quantity that may be expressed as a percentage, and as the penetration into any service increases, the amount of spectrum needed will also increase.

Each of the above identified services will not be used by all of the population of 390 thousand users of the advanced services identified above. For example, transaction processing functions will probably be used frequently by a traffic officers as they request data on license numbers. But they will probably not use telephone interconnect in their regular duties. An officer on foot may frequently receive mug shots of individuals who are wanted for some reason. But they will not usually need to transmit or receive long files such as locations of gas lines or power lines such as a firefighter is interested in.

The estimation of the penetration should also take into account that out of the ordinary emergencies require services that may not be used on an every day basis. Thus, adequate penetration should provide for the unusual. The penetration that will be used in the sample computation to follow is given in Table 3.

Table 3
Penetration of Services Into the User Population

SERVICE	PENETRATION, %
Voice	50
Transaction Processing	50
FAX	30
Snapshot	40
Remote File Access	30
Slow Video	7
Full Motion Video	0.7

2. Source Content (SRC)

The content of the source message to be transmitted is represented by the shortened form SRS in the equations to follow. It is given in two forms, depending on the service being discussed. Those services which have a stringent latency requirement, which include voice, telephone interconnect, slow video, and full motion video, are expressed in bits per second.

The data services which include transaction processing, snapshot, facsimile and decision processing are given in kbytes. In order to determine the number of bits per second required of these services, we multiply by 8 to determine the number of bits, and then divide by the average duration of the message which is described in 5 below.

The magnitude of the source content is that content which is contained in the state of the art message today, including any coding improvement that has been done. Advances in coding are addressed in the next parameter. The content of the advanced features is discussed in Appendix C, and are summarized in Table 4.

3. Coding Improvement (COD)

The coding improvement is a dimensionless factor that describes the anticipated improvement in coding that will take place between the years 1996 and the year 2010. The shortened term

COD is used in the equations to follow. This too is described in Appendix C and in Table 4 below.

Table 4
Source Content, Compression Ratio, and Future Content

ADVANCED SERVICE	CONTENT	IMPROVEMENT	FUTURE SOURCE CONTENT
Decision Processing/ Remote File Transfer	200 kbyte	2 to 1	100 kbyte
4 Page FAX	92 kbyte	3 to 1	31 kbyte*
SNAPSHOT, including			
Fingerprint Inbound	3 kbyte	1 to 1	3 kbyte
Fingerprint Outbound	6.25 kbyte	1 to 1	6.25 kbyte
Mug Shot Outbound	2.5 kbyte	1 to 1	2.5 kbyte
EMS Picture	103 kbyte	2 to 1	51 kbyte
Slow Video	384 kbps	3 to 1	128 kbps
Full Motion Video	1.5 kbps	3 to 1	500 kbps

4. Duration of Message (DUR)

The needs of each mobile officer who uses the services in question will now be predicted. The length, or duration, of the messages on the RF link will be called the DUR in the equations to follow.

Table 5 summarizes the number of seconds that each transmission will take on average. In the case of voice dispatch, the length of the message on private trunked systems averages about 24 seconds and on community repeaters it averages about 17 seconds. [6] On public safety systems the length us frequently less because of the strict discipline enforced on those systems. Telephone interconnect calls are usually much longer, and in the public safety environment, where there may be a hostage situation, the length can become hours. However, the average call length for the composite voice application which is used in conjunction with the advanced services is taken as 24 seconds.

The length for the video applications is estimated based on the information that might be obtained from the periodic observation of a fire or a crowd. The estimated times for the data applications are taken from those applications in use on wire based computers today.

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6 Garry C. Hess, Land-Mobile Radio Sys tem Engineering, Artech House, Boston - London, 1993, pp.249-253.

Table 5 Length of Messages on Advanced Systems	
SERVICE	**AVERAGE MESSAGE LENGTH SEC.**
VOICE	24
TRANSACTION PROCESSING	1
FACSIMILE	15
SNAPSHOT	20
DECISION PROCESSING/ REMOTE FILE TRANSFER	15
SLOW VIDEO	210
FULL MOTION VIDEO	210

5. Messages Per Hour (MPH)

Service usage will be quantified in terms of the numbers of requests for service per user in the busy hour, and this parameter will be called MPH in the equations to follow. The proposed usage model is summarized in Table 6. These have been gleaned from many sources over time. Where possible, wireless data has been used, but where none is available, data from wireline use has been extrapolated The use of traditional voice and data services as well as newer advanced services have been included. Also, full motion video is expected to be viable by the 2000 time frame, and it is expected to find more use as it is placed in the hands of the users.

Table 6 Advanced Service Usage Rates Per Hour	
SERVICE	**AVERAGE REQUEST RATE PER HOUR**
VOICE	3
TRANSACTION PROCESSING	6
FACSIMILE	0.5
SNAPSHOT	1

Table 6
Advanced Service Usage Rates Per Hour

SERVICE	AVERAGE REQUEST RATE PER HOUR
DECISION PROCESSING/ REMOTE FILE TRANSFER	0.5
SLOW VIDEO	0.1
FULL MOTION VIDEO	0.4

6. RF Transmission Rate (RATE)

The word RATE will be used to designate the RF transmission rate in the equations to follow. The historical transmission rate is discussed in Appendix B. The leading edge technology in use was projected there to be 3.5 in the year 2000 and 5.0 in the year 2010. Assuming a 15 year life, the systems in use in the year 2010 will be the accumulation of systems sold starting with those purchased today and including those that will be sold in the year 2010. Those sold today include some which are at the level of about 2.5 b/s/Hz on Figure B2 and some that are less than 1.0 b/s/Hz. Those sold in the year 2010 will likewise have a range of values.

By using crude integration, we arrive at a values of 1.5 b/s/Hz that can provide all of the advanced features in a reasonable bandwidth for all applications except video. For slow and full motion video we use 3.5 b/s/Hz.

7. Error Control and Overhead (ERR)

In the equations to follow, we will use COD to represent the subject parameter, and it will be expressed in the average percent of transmitted bit rate that is dedicated to this function.

Coding of the information bits allows more and more compression to take place. However, each bit then becomes more important, and the error correcting function then becomes more important. In addition, over time, linear modulation schemes are being used with higher transmission rates. Because of the multipath propagation environment, it becomes necessary to provide synchronization and equalization functions that also use some capacity.

State of the art systems in operation today use up to 55 percent of their transmitted bit rate for error correction and overhead. Because increased emphasis will be given in the future, we will project that this parameter will only improve to 50 percent for all of the services by the year 2010.

8. Channel Loading (LOAD)

Channel loading is the portion of time the channel has RF transmitted over it expressed in percent of the total time the channel is available. It is represented by the term LOAD, and is a complex subject that is a function of many parameters. These parameters include the kind and urgency of the message, the number of users of the channel, how many servers are available for the channel, and the length of message and number of them per hour offered by the users.

An example of a situation where a lightly loaded channel is necessary is when a group of scattered police officers are waiting to simultaneously close in on a suspect with a hostage. They operate on a single channel, and It is imperative that when the word go is uttered they all move with the greatest of speed. The channel in use must be **very** lightly loaded, LOAD less than 5 percent, to assure that the short message will not be blocked.

An example of a situation where a heavily loaded channel can be used involves trunked systems that carry routine messages. Data requests for license plate checks can wait two or three seconds as the officer writes a ticket. A dispatcher request for present location usually takes a few seconds for a voice reply as the officer reaches for the radio to reply. That too will not suffer greatly if two or three seconds of blockage occur. LOAD can be 20 to 25 percent on a single channel system and as much as 70 to 80 percent on 20 channel trunked systems and meet this criteria.

Finally, there are messages that can wait for a few minutes before delivery to the intended party. These may include a FAX sent to an individual driving a car (we recommend that they keep their eyes on the road as opposed to reading a FAX), and E-Mail message, or a long file which is to be used at some time in the future. Single channel systems can be loaded up to 50 percent and 20 channel systems up to 95 percent and provide this service. Table 7 summarizes the estimated average channel loading that will be attained by the year 2010 for all of the public safety services being considered herein.

Table 7
Assumed Public Safety Channel Loading in the Year 2010

SERVICE	AVERAGE CHANNEL LOADING, %
VOICE	40
TRANSACTION PROCESSING	50
FACSIMILE	60
SNAPSHOT	60
DECISION PROCESSING/ REMOTE FILE TRANSFER	60

Table 7
Assumed Public Safety Channel Loading in the Year 2010

SERVICE	AVERAGE CHANNEL LOADING, %
SLOW VIDEO	50
FULL MOTION VIDEO	50

9. Geographic Reuse (REUS)

This parameter is a dimensionless factor which will be called REUS in the material to follow. There are three states for REUS, it may be greater than, equal to, or less than 1.0. We will look at each of these in turn.

"Talk around" is a function that is used on systems with two frequency repeaters with no additional infrastructure. Mobile or portable radios disable their repeater function and use their radio in a single frequency simplex mode, public safety unit direct to unit. They use the base talk out frequency, but because they are so close together, their signal dominates the signal received at the base. Many individuals can simultaneously use this function in the same geographic region, in addition to those using the repeater. Thus, the reuse factor is greater than 1.0. REUS can perhaps be as high as 5 or 10 depending on the number of officers simultaneously using this function.

A second way that REUS can be greater than 1.0 is by the use of a cellular like system. Here, the same channel is used more than once in the same geographic area. That channel traditionally used Frequency Division Multiple Access (FDMA), but Code Division Multiple Access (CDMA) has been implemented in the past few years. Cellular FDMA has demonstrated REUS factors of 4 to 6 in a given geographic area while CDMA proponents claim REUS equivalent factors of 10.[7] This technology is not yet been proven in fully loaded service, so it is premature to conclude what this technology is capable of at this time.

Two frequency repeaters with high base antennas which cover wide geographic areas are the technology that provides a REUS factor of 1.0. These can either be conventional or trunked repeaters; it makes no difference to the REUS factor.

Finally, REUS factors less than 1.0 are provided by simulcast systems that use multiple transmitters on the same RF frequency that broadcast the same message content. This also applies to multiple transmitters on different frequencies that broadcast the same message.

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7 When CDMA was new, advocates claimed REUS factors of 20 would be possible. However, at the December 13 PSWAC Technology Subcommittee meeting, rep resentatives of CUALCOMM, Inc. and Airtouch Cellular stated that a factor of 10 is possible. We note that the trend of claims is decreasing. It is probably necessary to wait until fully loaded systems are in place demonstrating this capability before REUS for CDMA will be known.

These frequently take the form of state wide systems. Because the frequency can not be reused in the next geographic area, REUS will be less than unity. The value of REUS will be the ratio of the area covered by one high site repeater to the area covered by the multisite system. So, if the system covers the area which two high repeater sites normally covers, REUS = 0.5. If it covers the area of four sites it will be 0.25, and so on.

The amount of reuse that can occur is dependent on the advanced service being considered because the area of needed coverage varies. The value of REUS that will be used in the analysis to follow is given in Table 8 for each service.

Table 8
Public Safety Spectrum Reuse Factor by 2010

SERVICE	AVERAGE REUSE FACTOR
VOICE	2
TRANSACTION PROCESSING	3
FACSIMILE	3
SNAPSHOT	3
DECISION PROCESSING/ REMOTE FILE TRANSFER	4
SLOW VIDEO	4
FULL MOTION VIDEO	1

D. Spectrum Computation

At this point, the technological capabilities related to providing voice, transaction processing, FAX, snapshot, decision processing and file transfer, slow and full motion video have been characterized. The parameters that relate to the use of them by the public safety community have also been quantified. The spectrum needed to provide these services through the year 2010 must now be determined.

1. Model Equations

The equation that relates all of the user service capabilities and technical parameters to spectrum need is given in (1), where FREQ is the frequency in MHz and K is a normalization parameter used to accommodate the units and the type of service being analyzed.

$$FREQ = K \frac{POP \times PEN \times SRC \times DUR \times MPH}{COD \times RATE \times LOAD \times REUS \times ERR} \qquad (1)$$

For two frequency repeater operation, there is a factor of 2 included in K because two bandwidths are used that are separated by the inbound and outbound frequency. We will assume that the slow and full motion video services are single frequency simplex, and therefore only transmitted one way. So the factor of 2 only applies to the other services

In order to express the answer in MHz, and with the units described above, the additional factor of 1/3600 must be used because the service requests are expressed in terms of number per hour, and all other parameters involve seconds.

Finally, the voice and video services source content were described in terms of kb/sec while the data related services were described in terms of kbytes. In order to quantify the spectral need, we will assume that the transmitted rate just meets the time required to get the message through. So, for the data related services there is an additional factor of 8/DUR required. The constant K is summarized in Table 9.

Table 9
Normalization Factor K for Each Service

SERVICE	K
VOICE	2/36.00
TRANSACTION PROCESSING	16/(36.00*DUR)
FACSIMILE	16/(36.00*DUR)
SNAPSHOT	16/(36.00*DUR)
DECISION PROCESSING/ REMOTE FILE TRANSFER	16/(36.00*DUR)
SLOW VIDEO	1/36
FULL MOTION VIDEO	1/36

2. Spectrum Needs: 1996-2010

The predicted public safety radio 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 10. 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. The number of users within the geographic area that need the spectrum are also listed. 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.

Table 10
Spectrum Requirements 1996 through 2010

SERVICE	THOUSANDS OF USERS	SPECTRUM BANDWIDTH, MHZ
VOICE	273	20
TRANSACTION PROCESSING	195	5
FACSIMILE	117	9
SNAPSHOT	156	19
DECISION PROCESSING/ REMOTE FILE TRANSFER	117	14
SLOW VIDEO	27	6
FULL MOTION VIDEO	3	9
TOTAL		82

3. Tolerances in Parameters Used and Result

The parameters that were used in the computation above all require judgment in their selection and in the levels to which they were quantified. Additional time could be used to reduce the tolerance in each of the parameters, however, with the limited time available they are the best that could be done. It is believed that the computation involved in each of the bandwidths required for each service in Table 10 can have a one standard deviation error of 30%. Assuming that the errors are normally distributed, the probable error in the total is the square root of the sum of the squares of the separate errors. The first standard deviation error in total is therefore 2 MHz. So, in order to accommodate this error, it is recommended that a total of 84 MHz be made available to the public safety community by the year 2010.

4. Prediction Reliability

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 nature of the vision should be accurate. The "details" of the vision will be driven by a combination of innovative technologies and innovative users.

This model and it's reliability represent a comprehensive and scientific approach that has been assembled through the cooperation of the wireless communications industry and public safety user experts. The resulting conclusions and forecasts provide the FCC and NTIA with a firm foundation for allocating adequate spectrum for public safety.

There is a need to revisit the prediction periodically because there are many factors which can hasten or delay the use of these advanced services. Perhaps the largest factor influencing the speed at which these innovative technologies can be introduced will be the availability of adequate spectrum. This prediction is made on the basis that some spectrum be allocated within the next year, and also that a plan be put in place for reaching the required bandwidth. It is recommended that the prediction be revisited at 5 year intervals to determine if changes have occurred that would call for a revision of the spectrum need. Historically, such predictions have fallen short in stating the need. With periodic reexamination of the need, the safety, effectiveness and efficiency of the public safety community can be maintained at the necessary level.

III. CONCLUSION

Advances in semiconductor technology are one of the major enablers for the introduction of advanced telecommunications and computing applications and services. The introduction of these services in the home or office environment tends to increase the demand for ubiquitous wireless access to these same services shortly thereafter. We have also seen how the same semiconductor technology which creates the demand for these services in the wireline environment provides solutions for wireless access, by making advanced spectrally efficient modulation and source encoding techniques economically viable for mass production. These advances have been utilized by public safety mobile radio equipment manufacturers and service providers to pace the past user demand for new wireless services.

However, due to expected proliferation of advanced digital services through the year 2010, it is expected that the increase in demand will overtake the additional capacity offered by technological improvements. In order for these advanced telecommunications services, like file transfer, fax, imaging and video, to be offered to the public safety community, it is necessary that adequate spectrum be provided to make up for the shortfall between the anticipated demand and the expected advances in efficiency of presently allocated spectrum. The total spectrum that should be provided for public safety through the year 2010 is 84 MHz.