4.3 Data

4.3.1 Distinguished from voice service described above, data is fundamentally all non-voice communication of anything representable in alphanumeric form. This service is newer than voice, and has grown along with advances in computer technology.

4.3.2 With the growth in the use of computers and associated reductions in the cost of computing equipment has come an increased demand for data communications capabilities. Many of us are familiar with this in our everyday lives. Computer modems and facsimile machines are now commonplace in the office. Similar data communications needs exist in the public safety radio services. Indeed, most public safety systems are using data radio systems based on technologies of at least two decades ago.

4.3.3 Many of the early public safety data communications systems used circuitry much like telephone modems to create a voice-like signal which could both carry the data and travel over the analog voice paths of the public safety radio communication systems. Such hybrid systems are still widely used today.

4.3.4 More recently, manufacturers have begun to provide radio systems that are fully digital and that can carry data directly on the radio channel. Transmitting high speed data reliably on mobile radio channels is an enormous engineering challenge as compared to transmitting via wire, cable, microwave, fiber optics or other similar carriers.

4.3.5 Key attributes of data communications systems include:

4.3.5.1 *Message / file size.* The quantity of data to be transmitted via data communication is the first order differentiation of the type of data. At one time, *short data or messages* was generally descriptive of anything that could be conveyed by an equivalent voice short-hand. Short data has grown in recent years to also include the quantity of data text or alphanumeric information typically containing 500 characters or less. *Files* are in excess of 500 characters in length and may include images or file attachments to shorter messages.

4.3.5.2 *Reliability.* Data is significantly different from voice services in many respects. The contrast is significant in terms of reliability. Voice is generally thought of as a real-time event while the speaker is talking. The service goal of speech is to convey the best reliability achievable in real-time. Data however, according to its non-voice definition, generally lacks the real-time constraint of voice. As such, the reliability goal for data is not to deliver as reliable a signal as possible in real time, but instead to deliver 100% error free data in as little time as possible. To this extent, data reliability generally refers to two separate attributes: (1) the percent of data that is not deliverable, and (2) the percent of data that is delivered with undiscovered error. The former may often be referred to as reliability while the later is often referred to as falsing.

4.3.5.3 *Error Control (ARQ).* Error control refers to the same numerical techniques of error correction and error detection as described for voice. Data networks often provide return receipts back to the originator when the data is successfully delivered, coupled with repeated transmissions from the originator as needed. These are generally referred to as Automatic repeat ReQuest, or ARQ.

4.3.5.4 *Encryption.* Encryption is applicable for data transmissions in the same manner as for voice. Although the numeric representation of data is not intended to be converted into meaningful speech, the goal of data encryption is to prevent the unintended reception from being converted back into the data's original form.

4.3.6 *Examples.* The public safety services have used data to varying extents for several decades, starting first with short data and more recently with file data. The increasing availability and falling costs of mobile data terminals (MDTs) and portable data terminals (PDTs) in recent years has resulted in a dramatic increase in their use in public safety wireless applications.

4.3.6.1 Short data often conveys voice short-hand such as the common 10 codes. A traditional application conveys officer status such as available, enroute, at-scene, or out-of-vehicle. Emergency medical, fire, and law enforcement agencies extensively use these officer/vehicle status systems, particularly for first responders.

4.3.6.2 File-type data includes what is commonly known as data dispatch in which information on assignments are directly conveyed between a dispatch computer and a data terminal in the vehicle; these terminals typically include the short data message capabilities as a subset. Again, emergency medical, fire, and law enforcement agencies all use such terminals to varying degrees, particularly in large metropolitan areas.

4.3.6.3 Other traditional file applications from data-terminal equipped users include direct access of .motor vehicle and driver information from state motor vehicle departments and wanted persons/property checks to state justice departments or to the FBI's National Crime Information Center (NCIC) by law enforcement agencies and the transmission of building plans and permit information to fire agencies.

4.4 Image

4.4.1 Images represent a special category of data that is a numeric representation of a picture. While voice has the natural duration of the speaker, and other data has the natural length of the message or file, an image has no such natural definition.

4.4.2 The rapid increase in use of "wire-line" based facsimile transmission and similar image technologies within the public safety services has paralleled that within the

broader economy. Recent developments such as the inexpensive digital storage camera will lead to a rapid expansion in the use of image services.

4.4.3 Key attributes of image communications systems include:

4.4.3.1 *Resolution*. An image must first be converted into a numeric format before a length or quantity of data attribute exists. The attribute of the conversion which determines this is referred to as the resolution. It is expressed as image dimensions in terms of pixels, which each represent one PIXture cELl or dot. Any given image can variably be represented in higher resolution by using more pixels, resulting in a larger digital representation. Conversely lower resolution using fewer pixels results in a smaller digital representation. When the image is captured by a camera, the resolution is typically expressed as the number of pixels across and down. When the image is captured from a printed image, the resolution is often expressed as the dots-per-inch or dpi of the scanning device, which coupled with the image dimensions can equivalently define the number of total pixels across and down.

4.4.3.2 *B/W vs color level*. A picture of a given resolution defines the number of pixels. Along with the resolution there is a second dimension of the quantity of data in a digital representation of an image. It is based upon how much data is used to represent each pixel. Simple black and white images use minimally 1 bit per pixel, while gray scale imaging may utilize multiple bits to define the intensity of each pixel. In color imaging each pixel may be further represented by multiple data words defining the intensity of each primary color component of each pixel (red, green, and blue). The total data size of a given resolution image varies by over an order of magnitude from 1 bit per pixel (normally referred to as line-art) to 24 bits per pixel (normally for digital representation of broadcast quality color).

4.4.3.3 *Compression*. Compression can be applied to any service, whether it is voice, data, or image. Because of the ease with which an image may be converted into large digital representations, there has been a special focus on image compression techniques. Pioneered by technology to speed FAX transmission, areas of like pixels are represented by short-hand representation. The more uniform an image area the smaller the resulting compressed image. Conversely the more complex an image the larger the resulting compressed image will be. Popular standard image formats have emerged from the computer industry for compressed images such as Graphic Image Format or GIF, or newer negotiated standards such as JPEG. Many other standard image formats exist. However, they were not designed for efficiency of representation and are thus less suited for transmission.

4.4.3.4 *Error Control*. Error control can be applied to image transmissions identically to other non-voice data. However (unlike textual or numeric data), the graphical nature of images may lend itself to less than 100% reliability. FAX transmission normally is useful even in the presence of a limited transmission corruption as each line is individually only a piece of the total image. In a similar

fashion, error control on image transmission may usefully provide an optional lesser reliability service.

4.4.4 *Examples*. The typical passport photo of 2 inch square black and white results in only 1 or 2 kilobytes, while a full-color still from a video camera may exceed a few hundred kilobytes, and a high-definition (several hundred dpi) scan of a color photo can easily reach several megabytes. Image translation can convert higher resolution into a smaller form for transmission, although the reverse is not generally achievable. A notable exception is the emerging technology known as fractal image coding. It promises highly compressed image formats which are rescalable without loss of quality by the destination.

4.4.4.1 Emergency medical providers desire the ability to transmit images of the injured from paramedic units back to trauma centers or hospitals to aid in diagnosis and pre-arrival treatment.

4.4.4.2 Fire agencies desire the ability to transmit building plans and copies of permit and other data for fire prevention and protection.

4.4.4.3 Law enforcement agencies need to quickly transmit fingerprints from field units back to local, state and federal databases; units need the capability to receive mugshots and drivers license photographs to aid in identifying people in the field. Indeed, millions of dollars have been spent by the Federal government to update the FBI's automated system to support fingerprints and mugshots for NCIC-2000.

4.5 Video

4.5.1 Video has a real-time length attribute based on how long a scene is viewed.

4.5.2 Wireless video systems have seen limited use in state/local public safety services to date primarily due to a lack of available public safety spectrum over which to implement these systems. In fact, only a single video channel is currently available for public safety use and it is shared with other radio services.

4.5.3 Key attributes of video communications systems include:

4.5.3.1 *Frame rate*. In addition to the duration, the next attribute defining the size of the video transmission is the frame rate, the number of frames represented in each second of video. Television typically refreshes half of the picture lines at a 60 times per second rate, which results in the whole picture being refreshed at 30 frames per second. Reduction of the frame rate to half this rate (15 frames per second) loses the continuity or smoothness of motion, resulting in a jerky, old-time movie effect. Low frame rate video is commonly employed today in software or CD playback of video on computers due to its obvious impact of reducing storage requirements in half, compared to more fluid 30 frames per second.

4.5.3.2 *Resolution and Color level.* Within each video frame, resolution and color level define the transmission size. Because of the transient nature of each frame or the fact that the focus of the viewer is on the motion between frames, lower resolutions and color levels are viable. This is typically done to limit data storage in software or CD playback on computers, as well as in minimizing transmission times for picture telephone. A great deal of public safety video imaging is done under low light level conditions in which color information is generally unavailable.

4.5.3.3 *Error control.* Unlike still images where the viewer can study the image, transient noise in a video transmission can detract from the viewer's perception. User's tolerance to noisy or distorted video is different than for still images. Current ARQ techniques are not usable in real-time applications. The role of error control within video is to minimize viewer distractions.

4.5.3.4 *Compression.* Image compression takes account of like pixels within a picture. Likewise standards for two-dimensional compression take into account 'likeness' between successive frames. In this area, standards such as MPEG have emerged.

4.5.4 *Examples.* Motion video images, like still images, can be ranked on an image quality continuum. Limited black and white slow scan surveillance is accomplished today in analog on a standard voice bandwidth channel. Animating a black & white image the size of a passport photo at 15 frames per second can be accomplished with as little as 10 kilobytes per second with good signal quality (where minimal error control is needed). At the other extreme, broadcast quality color requires several megabits per second bandwidth. High definition TV requirements are even greater. Public safety agencies have expressed varied operational requirements for video systems.

4.5.4.1 The fire service uses full motion video extensively in some areas, primarily to monitor wildland fire scenes from airborne platforms, providing real-time video back to emergency command centers. The lack of public safety spectrum has often required state/local fire agencies to enlist Amateur Radio Service licensees to provide this service on amateur frequencies.

4.5.4.2 Law enforcement agencies, particularly at the federal level which have spectrum available for video, have long used video for surveillance purposes. State/local agencies have only recently begun to implement similar systems for monitoring areas of high crime and drug use.

4.5.4.3 State/local transportation agencies have implemented wireless video systems to monitor traffic flow and detect collisions and hazards on roadways in congested metropolitan areas.

4.6 Location information/GIS/APL/AVL[4]

4.6.1 Public safety agencies have struggled with the problem of identifying the location of vehicles and personnel. A variety of techniques have been tried over the years. The federal government funded substantial research into such systems in the late 1960s and early 1970s. Today there are several ways to obtain such location information. Each alternative has its strengths and weaknesses. The systems are:

- satellite navigation systems,
- the LORAN C terrestrial navigation system,
- the FCC licensed LMS service,
- dead reckoning systems,
- signpost systems,
- inertial navigation systems, and
- systems deriving location information from commercial mobile radio services (CMRS).

4.6.2 *Satellite navigation systems.* The most widely known and most widely available of these location systems are the satellite navigation systems. The two best know satellite navigation systems are the Global Positioning Service (GPS), and the Global Navigation Satellite System (GLONASS). GPS is operated by the U.S. Department of Defense; the somewhat similar GLONASS system is operated by Russia. The discussion below focuses on GPS, but similar comments would apply to GLONASS in many instances.

4.6.3 The heart of the GPS system is a constellation of 24 satellites in medium earth orbit that continuously broadcast time and satellite location information. A system that receives a signal from four of these satellites can calculate its location to within about 100 meters. GPS receivers are now offered in the consumer market for less that $200. Differential GPS can provide location estimates that are accurate to within ten meters. GPS can provide a signal to a ship or to an airplane. It was not designed to provide a signal capable of penetrating a building, nor to operate optimally in urban canyons or heavily forested areas. There may be some applications where better reliability or better accuracy can be obtained by a terrestrial system that processes signals from both the GPS and GLONASS satellites.

Reference:
For more details on GPS, see the excellent and comprehensive volumes (1,400 pages) Global Positioning System: Theory and Applications, Volumes I and II, Edited by B. W. Parkinson and J. J. Spilker Jr, AIAA, 1996.

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[4] GIS=Geographic information system, APL=Automatic Personnel Location, and AVL=Automatic Vehicle Location.

4.6.4 *Loran C.* Loran C is a older radio navigation system. Its future maintenance is not certain.

4.6.5 *Location Monitoring Service.* In the 1970s, the FCC allocated spectrum for the automatic vehicle monitoring service (AVM), now known as the location and monitoring service (LMS). One firm, Teletrac, is providing commercial LMS service in several larger cities. The Teletrac system uses multiple sites to measure the time of arrival of wideband pulses from vehicles and then solves for the vehicle's location. The Teletrac technology provides better coverage in urban areas than does GPS. It does not require augmentation by dead reckoning or inertial navigation systems.

4.6.6 *Dead reckoning systems.* Dead reckoning systems provide another approach to deriving location information. A computer system in a vehicle can count the number of rotations of the tires and thus estimate how far it has gone. Vehicle turns can be detected by differences in the rotation of the left and right side wheels. Anti-lock braking systems already require wheel rotation sensors. Combining this information with compass headings and a map database will allow for reliable calculation of the vehicle location even if the vehicle has traveled a substantial distance. Ultimately, after a sufficiently long interval, dead reckoning systems do tend to lose track of the vehicle's location. Either the user can manually update the location (a user-unfriendly system element if ever there was one) or another technology can be used to update the system's location estimate. GPS is an excellent candidate for such updating. Dead reckoning can be used for a few blocks, then the vehicle drives into the open, reacquires the satellites, and updates its location. Lacking an odometer equivalent, there is no application to portable units.

4.6.7 *Signpost systems.* Signpost systems involve the use of low-power, short-range transmitters that transmit messages describing their own location. Vehicles passing these signposts receive updates of their location as they pass the signpost. This technology requires a substantial investment in infrastructure. Signpost systems can be used to complement dead reckoning technology.

4.6.8 *Inertial navigation systems.* Inertial navigation systems process data from acceleration sensors to estimate the path of the vehicle. Such systems are still expensive today and work like dead reckoning systems in that their location estimates must be reinitialized from time to time.

4.6.9 *Commercial mobile radio services.* Commercial mobile radio services (cellular, PCS, and SMRS) have the potential for providing location information of varying resolution. For example, cellular systems know which cell is serving the mobile or portable unit. Some PCS systems also calculate fairly accurate range estimates and can combine the information from range estimates and cell locations to give more precise location estimates. Technologies exist for using the CMRS transmissions to generate more accurate location information.

4.6.10 Most of the systems discussed above, with the exception of the FCC's LMS service and location services provided by CMRS, provide location information at the vehicle or portable. For such information to be used with computer-aided dispatch (CAD), it must be transmitted from the mobile unit to the control point. This requires a data communications capability in the mobile unit.

4.6.11 Location information may serve the mobile user as well as fixed dispatch facilities. Where location information is used by the fixed dispatch, the information must be available. Technologies which natively generate the location fix at the mobile user (including GPS, Loran, dead-reckoning, and signposts) can place a burden on the capacity of the public safety communication system to transport the location back to the fixed dispatch facilities.

4.6.12 To conclude. Location technology is changing rapidly. Satellite systems, most notably GPS, are affordable and will provide near-universal coverage. Integration of GPS with other systems offers near universal coverage in urban areas. It appears likely that public safety agencies will be able to choose from several different technologies for identifying the location of vehicles and personnel. Depending upon the systems used and the design, this may require a substantial amount of air time, and possibly a dedicated channel.

Reference:
Robert L. French, "Land Vehicle Navigation and Tracking," Chapter 10 of Global Positioning System: Theory and Applications, Volume II, Edited by B. W. Parkinson and J. J. Spilker Jr., AIAA, 1996. p. 275-301.

5.0 EXISTING PUBLIC SAFETY COMMUNICATIONS CAPABILITIES[5]

5.1 Background

5.1.1 This section briefly describes public safety communications capabilities as they exist today. It tries to give the reader perspective on both the systems currently operating today and on the system solutions that are on the market. We consider the various technologies in the same order as they were historically introduced.

5.2 Voice

5.2.1 Most public safety communications systems use analog FM technology operating in 25 or 30 kHz channels to carry their voice signals. This technology has the

[5] While we use the broad term "existing public safety communications capabilities," our focus in this chapter is primarily on mobile communications capabilities as they are used and implemented today. We also discuss briefly some of the backbone communications needed to support mobile communications. We do not consider other important issues in public safety communications such as administrative support, 911 and E-911, etc.

advantage of being both robust and affordable. Almost all public service officers use voice radio communications to communicate from the field with their dispatchers and to communicate with their co-workers in the field. Vehicles are equipped with radios and most staff are also equipped with portable units. Radio voice communications has an enormous payoff in improved responsiveness and effectiveness of public safety operations and in improved safety for officers in the field.

5.2.2 Public safety communications systems normally operate using a variant of one of two basic methods. The first method, found primarily in bands above 406.1 MHz where frequencies are commonly paired, is repeater operation. A typical repeatered system uses two frequencies — one for communications from the mobile units to the base station and another frequency for transmissions from the base station to the mobile units. Communications from a mobile unit are transmitted to the dispatcher on one frequency and then are repeated on another frequency for reception by other mobile units. Some systems do not repeat all mobile transmissions and only send communications from the dispatcher out on the base-to-mobile frequency. Repeatered operation is normally used for day to day operations, for dispatcher control of mobile units, and for communications over a wide area. The second method is simplex or half-duplex which is repeaterless and relies upon direct unit-to-unit communications. This method is most common on bands below 406 MHz where frequencies are not paired. While most commonly used by operations or tactical groups working in a small area and needing to coordinate one with another, there are a number of wide area and statewide systems which still use this method. Typical examples include units needing to coordinate their actions at a fire, hostage situation or hazardous materials release.

5.2.3 Larger public safety organizations often use trunked radio systems. These systems operate using a pool of frequencies and assign these frequencies to conversations one call at a time. While use of trunking technology is more complex and adds expense, these systems are generally significantly more efficient in their use of spectrum and of radio transmitter infrastructure.

5.2.4 While digital voice is a technological possibility, it is little used today in public safety communications. We expect that digital voice systems will be offered by several manufacturers in the public safety market in the next few years. These systems will offer improved voice security, combined support of data and voice communications needs in a single unit, and may offer improved spectrum efficiency.

5.2.5 Another approach to improved spectrum efficiency is the use of narrowband analog modulation. While such narrowband techniques have long been used in other applications, the engineering challenges of matching them to mobile communications channels have only recently been overcome in commercially available products.

5.3 Data

5.3.1 Today data communications capabilities are used in public safety for such purposes as digital dispatch and checking computer data bases for information associated with wanted persons/property and vehicle registration . The flow of information is asymmetric, with more data flowing to the patrol unit than is originated at the patrol unit. Typically, such communications are done today either with an analog modem which transmits data signals over the voice communications radio link or with a with separate radio in the vehicle. Patrol officers do not normally carry portable data terminals when they are outside the vehicle. Typical data transmission efficiencies lie in the range of 0.3 to 19.2 kbps (error protected) per second in a 25 kHz channel.

5.4 Image

5.4.1 Still images include snapshots such as accidents, and crime scenes, mug shots, fingerprints, and a wide variety of other images. Modern digital cameras can take a picture and generate a data file containing a digital description of the scene photographed. This file can then be transferred over existing communications pathways and displayed on computer monitors or printed out. Thus, public safety service providers have the option today of putting in place still image transfer capabilities.

5.4.2 Today, there is relatively little use of still image transmission to and from the field in public safety. Image transmission is a case where the description of existing capabilities is difficult. Public safety communications systems support the necessary communications and all the building blocks for still image transmission are available in the marketplace. But, such systems are not yet widely used. However, this situation is expected to change markedly in the next decade. Still image transmission to the field will allow the dispatcher to send pictures of missing children or of suspects to patrolling police officers or to send high-resolution diagrams of buildings and charts showing storage of hazardous materials to fire trucks as they approach the scene of an incident. Still image transmission from the field will allow police officers to transmit photographs and fingerprints of suspects back to the office for processing, inspection by other officers, and comparison with materials in data bases.

5.4.3 The essential improvements in imaging and display technology required for such technologies to become user friendly and affordable appear to have been made. We expect that such systems will be deployed in increasing numbers over the next decade and a half.

5.4.4 We expect that still images will usually be transmitted as data files using file transfer protocols similar to those used to transmit other types of files over data networks. In most situations one would expect that image communications could

tolerate some delay as long as that delay did not affect the minute-to-minute operations of the officer on patrol.

5.5 Video

5.5.1 Video is the fancy name for television or for the electronic communications of moving images. Video is used in public safety today primarily for surveillance of crime scenes and of highways. Video cameras are also used to record some arrests and activities at crime scenes. However, it is expected that the use of video will grow greatly as video camera technology continues to improve. One can foresee hand held portable mobile radio units with built in video cameras. Transmission of such images back to central locations could be quite helpful in the management of major incidents.

5.5.2 Today, video images are normally transmitted using analog modulation. Wideband channels (several megahertz) are normally used to carry full-motion, high-quality video. However, only very limited spectrum is available to state and local agencies. Slow-scan video technology permits television pictures to be sent over a narrow-band channel by sending a picture every few seconds. Slow-scan technology is not appropriate for situations involving rapid movement, but can be quite useful for monitoring traffic, weather, secured areas, etc.

5.5.3 In the future, we expect that most public safety video communications will be digital. Digital video permits the use of compression technology, so that the resulting compressed signal requires only about 1/4 to 1/10 of the bandwidth or channel capacity required by uncompressed video. Currently though, compression equipment is still expensive and standards are changing rapidly. Video compression technologies are have already become consumer products (e.g., DirectTV's digital satellite television service uses digital compressed video) and are used in many personal computer systems. Hence, the market availability of digital video options will continue to expand.

5.5.4 The coming of affordable digital video cameras and affordable digital compression can be expected to lead to substantial growth in the requirements for public safety video communications. While many video communication needs will be satisfied by the use of recorded video, the need for real time communication of video will expand, and with it the need for public safety access to radio spectrum.

Reference:
White Paper "Wireless Video Transmission in Public Safety Applications," March 1, 1996, Thomas W. Christ, Chairman, HDS, Inc.

6.0 SYSTEM BUILDING BLOCKS AND TOOLS: FUNDAMENTAL CONSTRAINTS AND LIKELY EVOLUTION.

6.1 Background

6.1.1 In this section, the advances in technology and some of the ramifications of those advances will be presented as they relate to the demand for wireless communications and the ability to fulfill those demands. Trend curves will be presented showing the history of these trends, and from them their future directions will be projected.

6.2 Digital Integrated Circuits

6.2.1 The fundamental technology thrust through the year 2010 will be, as it has been in the recent past, that of semiconductor technology. The impact that this has had on computer and communications needs and capabilities has created the demand for increased radio spectrum through the wireless demand for these services. The increase in semiconductor capability will permit the partial offset of the spectrum demand by improved information compression techniques as well as increasing the capability of communication channels. Communication system architecture and the associated spectrum management policies are also affected by semiconductor technology. In this section, we examine the impact of semiconductor technology on future public safety communications system requirements.

6.2.2 The improvements in semiconductor processing and materials have resulted in roughly an order of magnitude advance every five years. This trend is demonstrated in the histories of memory devices, microprocessors, and computer systems.

Figure 1 presents the chip density of Dynamic Random Access Memory (DRAM) in bits versus the year of original market introduction.[6] The clear trend, indicated here, shows that chip densities have increased by a factor of ten every four years. Although Figure 1 addresses only DRAM devices, similar trends with almost identical slopes are observed for other types of memory devices.

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[6] Four Japanese microchip makers develop 256 M-bit DRAMs, Journal of Electronic Engineering, Vol. 30, Issue 323, Nov. 1993, pp. 30-31.

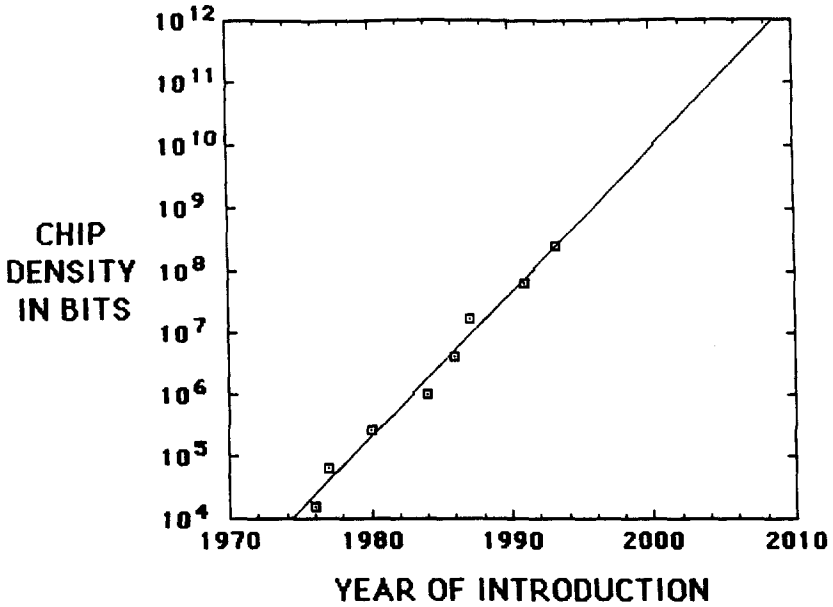

Figure 1 DRAM density trend over time

6.2.3 Rapid advancement is also observed in the progress of microprocessor technology over the last two decades. The increase in number of transistors per chip is displayed in Figure 2[7]. In this chart, each data point represents a new microprocessor plotted at its year of introduction, and it can be seen that the technology accomplishes an order of magnitude improvement about every 6 years.

6.2.4 The speed of microprocessors is also continuing to increase. The Semiconductor Industry Association predicts that on chip clocks will run at 1,100 MHz by the year 2010.[8] Their projection of the clock speed that will be resident on Microprocessors from the years 1995 through the year 2010 is shown in Figure 3.

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7 N. Ikumi et. al., A 300 MIPS, 300 MFLOPS four-issue CMOS superscalar microprocessor, 1994 IEEE International Solid-State Circuits Conference Digest, Feb. 16-18, 1994, pp. 204-205. See also footnote 2 in the body of this paper.

8 Solid State Technology 1996, IEEE Spectrum, January 1996, pp.51-55.

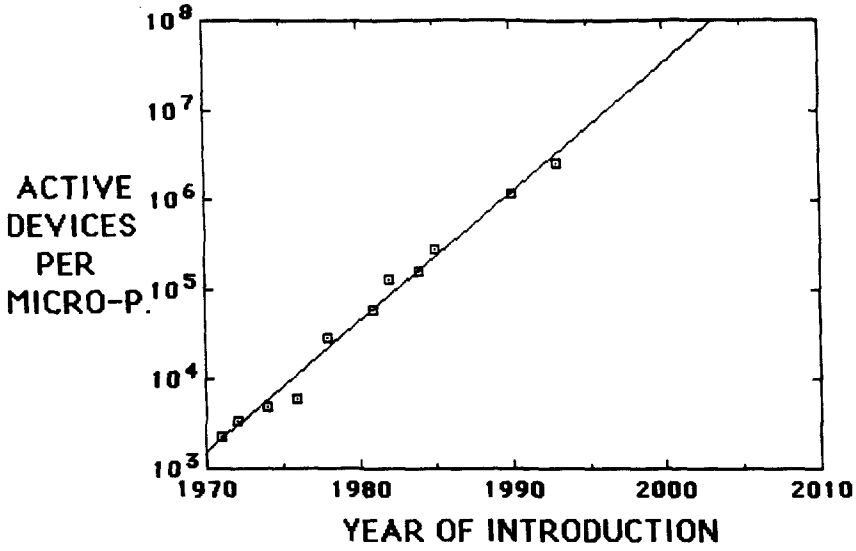

Figure 2 Microprocessor density trend over time.

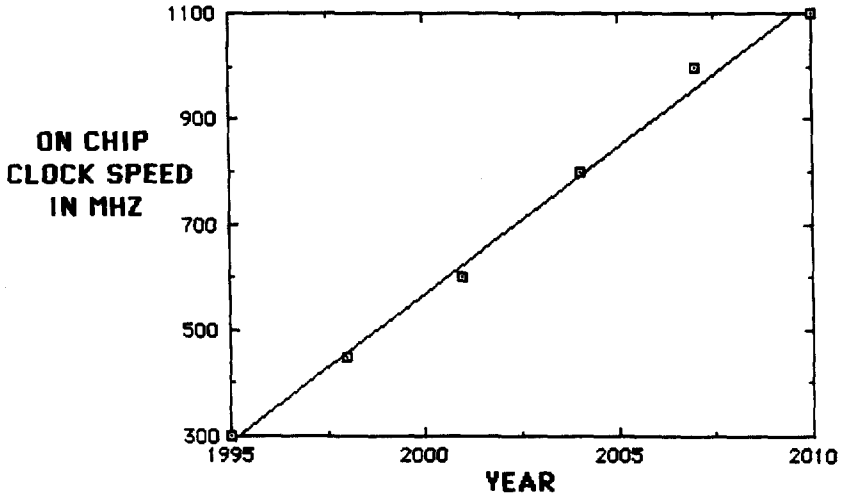

Figure 3 On chip clock speed projected to the year 2010

6.2.5 The result of these component level improvements has been that computer systems have advanced along similar trend lines. It has been observed that the performance of computer systems has advanced at approximately 35% per year.[9] Thus an order of magnitude improvement is seen every five years. In the case of computer systems, this is equivalent to a step of one platform tier. For example, the trend would predict that the current performance of a minicomputer will be available in

[9] D. L. Nelson and C. G. Bell, "The Evolution of Workstations," IEEE Circuits and Devices Magazine, Vol. 2, pp. 12-16, July 1986.

a workstation platform after seven years, and in a portable laptop computer by the year 2010.

6.3 RF Generation Devices

6.3.1 Batteries.

6.3.1.1 The batteries required to operate portable communications equipment are usually heavy, provide limited hours of operation, and can be expensive. A number of developments in battery technology are alleviating this situation. Some involve new technologies, such as nickel-metal-hydride and lithium-ion batteries. Another development is a zinc-air battery that draws oxygen from the atmosphere to extend its life. Power saving solutions that make more efficient use of battery power by communications equipment hold promise for extending battery life further; more power efficient amplifiers and more efficient sleep modes are examples of ways in which battery life may be increased.

Reference:
Office of Technology Assessment, "Wireless Technologies and the National Information Infrastructure," August 1995, page 16.

6.3.2 Oscillators.

6.3.2.1 Spectrum efficiency is improved if more communication channels can be placed within a given band of spectrum. In the past, the ability to decrease the channel size has been limited by both the transmission bandwidth and frequency stability concerns. Frequency stability in land mobile radio has also benefitted from improvements in semiconductors.

6.3.2.2 Figure 4 shows the trend of requirements on land mobile frequency stability. The trends for both base stations and mobiles track together until the mid-60's. Thereafter, the base station trend has continued toward tighter tolerances at a steeper slope than that of the mobile radio trend line. In both cases, the stability improvements were meet via two primary developments. These were the practical implementation of frequency synthesizers and the integration of temperature compensated oscillators.

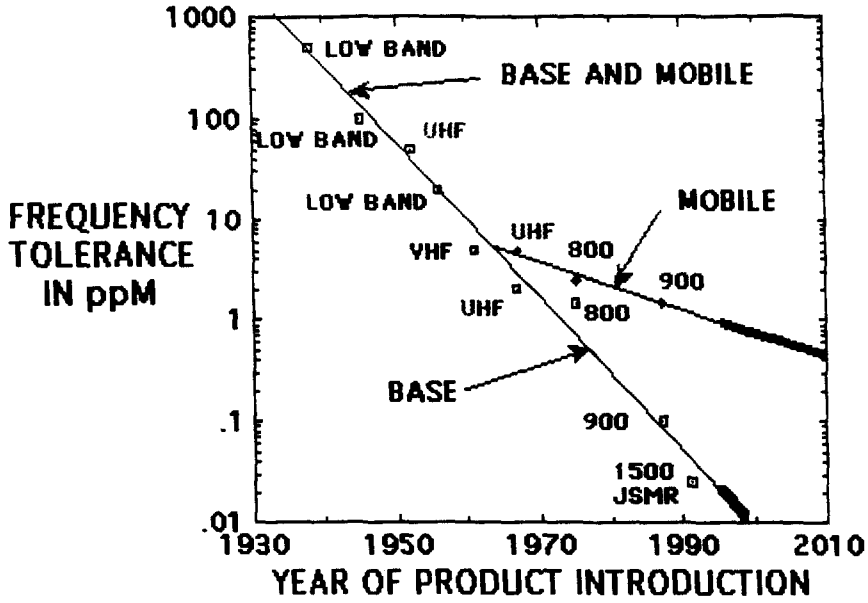

Figure 4 Trend of frequency stability over time.

6.3.2.3 Advances in semiconductors allowed the development of integrated temperature compensation circuits which could be packaged with the crystal. These compensation circuits dramatically reduce the variation in output frequency over the wide range of temperatures experienced, thus directly improving the frequency stability of the associated radio equipment.

6.3.2.4 The implementation of synthesized radio equipment was made practical by the integration of many complex functions into integrated circuits; among these are loop filters, phase detectors, and frequency dividers. The contribution of synthesizers to frequency stability was the standardization of the frequency source from which the signals were synthesized. This allowed effort to be focused on a small set of oscillator devices which drove the learning curve faster so the tolerance could be improved more rapidly.

6.3.2.5 Improvements in frequency stability can be used to enhance spectrum efficiency even when channel spacing is not reduced because the guard bands around the occupied bandwidth of each transmission can be reduced. The information content of the transmitted signal can be increased while maintaining acceptable adjacent channel splatter. This is important because reductions in guard bandwidth are limited by adjacent channel splatter considerations.

6.3.2.6 With the refarming report and order, the FCC has required that 6.25 kHz equivalent spectrum efficient technology be implemented for newly type accepted

equipment after the year 2005.[10] The required frequency stability has also been improved to 0.1 ppM for the mobile units. However, system considerations, such as not assigning adjacent channels in the same geographic area can make it unnecessary to provide close in splatter protection. In crowded urban areas where cellular type of coverage is required (such as for different precincts in a city) this does not impact spectral efficiency and can reduce the cost of equipment. The refarming Report and Order is the subject of several petitions for reconsideration, and it is not clear what the result will be at this time.

6.3.3 Antennas

6.3.3.1 *Smart antennas.* Smart antennas is a term applied to a family of technologies that generally integrate active antenna elements with microprocessor technology. One of these technologies, planar arrays, spreads the power over a large number of radiating elements in a flat plane in order to achieve, typically, a narrow beamwidth. By changing the current distribution of the array, the shape of the beam can be changed electronically in real-time. This can be used to increase gain and narrow beamwidth as necessary. The same techniques can be used to place a pattern null in the direction of an interfering signal, whether a strong multipath reflection, unintentional interference, an intentional jammer. The ability of the array to be flat allows for an installation that mechanically conforms to the antenna support.

6.3.3.2 In a transmitting situation, such antennas must split the input power several times in order to feed it to the multiple radiating elements. This multiple power splitting results in inevitable power losses which, in turn, limit the achievable antenna gain. (Similar concerns obtain in the reciprocal receiving situation.)

6.3.3.3 These techniques have been used for some time in military applications, but a re not widely used in commercial applications. This is likely to change with the attendant improvements in digital signal processing technology, which is necessary for economical implementation.

6.3.3.4 *Space diversity.* With land mobile radio communication, there is rarely a line-of-sight propagation path between the base and mobile station, and multiple signal paths exist. The signals from those paths combine both constructively and destructively at the receiver to produce multipath fading. For narrowband transmissions, the propagation delays associated with the various paths are extremely small compared to the inverse of the signal bandwidth. The channel can be considered as a Rayleigh fading channel with frequency flat fading. This fading results in both signal strength variation characterized by a Rayleigh distribution, and phase variation characterized by random FM noise.

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10 FCC Report and Order and Further Notice of Proposed Rule Making, commonly called the Refarming Notice, FCC 95-255, Adopted June 15, 1995, Released June 23, 1995.

6.3.3.5 Diversity is a commonly used technique for improving the quality of both digital and analog signals. When the new technique of single sideband is employed the use of multiple antennas becomes a virtual necessity, as when the vehicle is traveling at high speed, signal will become distorted due to phase shift. The most common form is space diversity, which is implemented using two appropriately spaced antennas. The advantages of this technique must be weighed against the disadvantages. There is some added cost for installation of the second antenna in a mobile vehicle, and a further cost for repairing or patching the hole when the vehicle is traded. Another concern is the difficulty in disguising the second antenna on unmarked or undercover vehicles.

6.3.3.6 For portable units, use of two antennas becomes even more of a problem, due to the limited space available. This concern for portables becomes even greater as agencies install infrastructures which provide portable coverage throughout the system and as portable units are used in vehicles in lieu of mobile units. There are at least two approaches to overcome this problem. One is the use of vehicle mounted adapter/chargers into which a portable unit can be inserted, which in turn connects to two space-diversity antennas on the vehicle. It should be noted that past use of such vehicular mounted devices has not been totally satisfactory due to the high incidence of wear and resultant equipment failure. Improved designs may overcome these former problems. Another method being researched is a one-piece diversity antenna system that uses two antenna elements, but performs the signal combining function in the antenna base and thus requires only one hole and one cable for mounting for either a mobile or a portable installation. In all instances, the difficulty of using two antennas is directly related to the frequency band used, with implementation becoming easier as the frequency increases.

6.3.3.7 Maximal ratio diversity combining is a third diversity technique which is used to combat fading. It is designed, as the name implies, to maximize the signal-to-noise ratio of the received signal. The performance of maximal ratio combining is theoretically the best of the three. In the past, the difficulties of practical implementation often rendered its performance relatively poor compared to the other two methods. However, with the advances in semiconductor technology, the implementations being made today reach the theoretical promise of this method.

6.4 Source Coding

6.4.1 Using today's systems, the additional traffic demands described above can only be met by increases in the available spectrum. However, the demands can, at least in part, be offset by utilizing semiconductor advances to make more efficient use of the limited spectrum resources. Information compression allows reduction in the amount of information which must be transmitted on the communications channel. Typically, this is done by removing redundant information, thereby reducing the overall information bandwidth. These improvements in voice coding technology must be couterbalanced with other factors. For example, it appears quite likely that

public safety users (like other users of communications systems) will demand higher quality speech as that option becomes available. We note that some cellular equipment suppliers have moved from 8 kbps vocoders to 13 kbps vocoders in order to improve speech quality.

6.4.2 Voice

6.4.2.1 Digital speech encoding has received significant attention of late. This means of transmitting speech leads naturally to encryption which is one very important aspect in many public safety communications scenarios.

6.4.2.2 Figure 5 shows trends in digital voice compression technology. The top line represents the speech bit rate reduction experienced for high or "toll" quality speech as used over telephone networks. The lower line shows rates necessary for "communications" quality coders. These coders produce slightly degraded but demonstrably useful speech for public safety applications. Since the mid-1970s, the federal government has had a digital voice standard operating at 2.4 kbps. However, this standard, valuable though it is, provides limited speech quality and does not always operate well in noisy environments. It did provide an early technology for digital secure voice.

Reference:
T.E. Tremain, "The government standard linear predictive coding algorithm: LPC-10," Speech Techno., vol 1, no. 2, pp. 40-49, Apr. 1982

6.4.2.3 In the past, these speech encoding systems have actually increased the occupied bandwidth due to relatively unsophisticated coding schemes, while noticeably degrading the audio quality. The 12 kb/s CVSD in Figure 5 is one example. More recently, advanced digital signal processors, made practical by improved IC technology, have contributed to the development of improved speech coding algorithms. For example, the 8.0 kbps VSELP shown in Figure 5 is used in Japan and US digital cellular and provides near toll quality audio with an information bandwidth comparable to analog speech.

6.4.2.4 Looking to the future, we can expect that increasingly powerful digital signal processing IC's will facilitate the introduction of more powerful and effective methods for reducing the amount of information that must be transmitted on the communication channel. Speech and image (facsimile) communications are two areas that should benefit greatly by these techniques. In 1995, the ITU started the process of producing a standard for a 4 kb/s speech coder for toll quality applications.[11] A closely related approach to improving spectrum efficiency is to use variable rate vocoders -- that is voice coding technology that outputs data at a variable rate reflecting the changes in speech patterns. Such vocoders are used

[11] ITU Study Group 15 Question Q.7/15 titled Subjective Qualification Test Plan for the ITU-T 4 kbit/s Speech coding Algorithm, November 9, 1995.

today in some land mobile radio systems and related technologies have long been used in telecommunications. Such techniques can improve spectrum efficiency by roughly a factor of two. Variable rate vocoders also offer another potential advantage to public safety systems. They allow capacity and quality to be traded off. For example, a public safety communications system shared with highway maintenance might could, in a time of emergency, borrow capacity from the highway maintenance radio communications capabilities by reducing the bit rate used to encode their calls. Such a reduction would free up capacity for public safety communications, but would allow the highway maintenance staff to maintain communications connectivity - albeit at reduced quality.

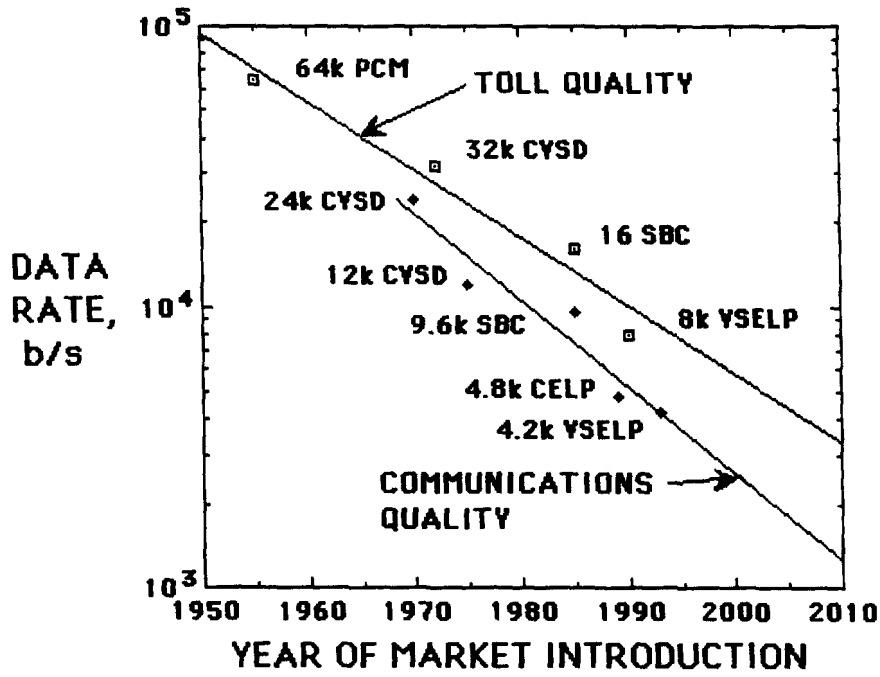

Figure 5 Trend of digital voice compression technology over time.

6.4.2.5 Of course, the mobile radio channel is subject to severe signal degradation due to shadowing and multipath fading. This degradation is more harmful to digital speech than analog, which tends to degrade gracefully in the presence of impairments. The recovery and regeneration of the source information from the compressed digital information is difficult due to the lack of redundancy. Thus, only with complex fading mitigation techniques such as error correction coding (which further increases the required bandwidth) and diversity can the compressed information be used effectively. Here again the digital signal processor IC will allow the implementation of the complex recovery techniques needed to realize usable communications in the mobile radio environment.

6.4.3 Image

6.4.3.1 *Facsimile*. Transmission of facsimile today is governed by two widely accepted international standards, ITU-T's Group 3 and 4. These standards specify both horizontal and vertical resolution, which governs the "information" content, in bits, for a typical 8.5 "x 11" page.[12] 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)

6.4.3.2 The ITU-T 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 ITU-T 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. Thus, one page of fax, transmitted at nominal resolution, can be represented in approximately 23 kbytes.

6.4.3.3 *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 particular imaging application. As examples, two public safety applications which have received considerable interest may be represented by the snapshot application: wireless transmission of criminal fingerprint and mug shot descriptions.

6.4.3.4 The NCIC 2000 system will provide nationwide wireline and wireless access for criminal justice agencies to the FBI's considerable data repositories. Current data repositories contain information fields on such things as stolen vehicles, stolen articles, stolen guns, stolen license plates, wanted persons, stolen securities, stolen boats, missing persons, unidentified persons, foreign fugitives, and violent felons. In addition, the NCIC 2000 system will provide information regarding probation/parole status, fingerprint searches, mugshot information, generic image information, on-line ad hoc inquiries, and on-line manuals. Use of mobile data terminals, laptops and other wireless technologies by criminal justice agencies have spurred an interest and necessity in immediate, responsive information transfer. Mobile units will be capable of capturing a fingerprint image and transmitting it over wireless communications systems. Likewise, data retrieved

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12 "Information" as used here refers to the uncompressed bit content, not the source entropy, as in a strict theoretical sense.

from the national level will contain mugshot images which will require relay through the wireless medium to mobile units. As use of these capabilities increases, the demand on law enforcement spectrum allocations will increase.

6.4.3.5 The NCIC requirement is that a 24 kb (or 3 Kbyte) file be provided for fingerprint identification purposes. If a record is on file (based on a fingerprint or demographic identifier search), a copy of the mugshot (from chin to top of head) will also be returned to the requesting officer. These files will be 20 kb (2.5 kbytes). These file sizes have been purposely limited to a size that will create the least impact on the wireless channels. However, due to the current loading on these channels, it is anticipated that many systems will require expanded bandwidth and additional spectrum.

6.4.3.6 Other snapshot applications may be envisioned which require much higher resolutions, such as medical imaging. As an illustration of such an application, 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

6.4.3.7 As with facsimile, a fairly well established standard compression algorithm exists. The JPEG (Joint Photographic Expert Group) standard, 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, 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.

6.4.3.8 It should be noted that a specific timeline for the implementation of the NCIC 2000 technology requirements has not yet been finalized. However, these technology requirements need to be considered for the purposes of this report.

6.4.4 Video

6.4.4.1 *Slow Video.* This is envisioned as a high resolution video service with very modest frame rates, approximately 1 per second. There are two audio/video compression standard suites which have seen widespread use: MPEG and H-Series.

The ISO's MPEG-2 (Motion Picture Expert Group) standard is designed as a single direction protocol providing audio/video compression, using various spatial and temporal resolutions, targeted at CD-ROM applications, using a compressed rate of roughly 1.5 Mbps for 352 by 240 pixel frame at 30 frames per second with associated audio. The ITU-T'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. The H.261 standard is optimized for coded bit rates of 384 kbps. Both of these algorithms are designed to take advantage of temporal as well as spatial redundancies in the source material to achieve compression. For current planning purposes, it can be assumed that the current implemented art uses H.261 at roughly 384 kbps for the video and associated audio channel.

6.4.4.2 *Full Motion Video*. For the full motion video application, it can be assumed that the same spatial resolution as the slow video application obtains, but that the frame rate is increased to 30 frames per second. For this type of application, the current state of the art is represented by MPEG-2, which as stated above requires roughly 1.5 Mbps for 352 by 240 pixels by 30 frames per second audio/video.

6.4.5 Source Coding Advances 1996-2000

6.4.5.1 As digital 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 3 and[13]. 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 2010, compression schemes more than ten times as complex as those of today should be viable for public safety radio.

6.4.5.2 New directions in compression are already under development to take advantage of this increased processing capability. In the fax arena, a more general standard, called JBIG, has recently been formalized.[14] Although JBIG is not yet widely used, as time progresses, it is likely that the higher compression ratios associated with JBIG will become increasingly attractive to wireless applications. Computed over the same corpus of eight typical fax documents, JBIG provides roughly a 2:1 increase in compression relative to the currently popular Group 3 and Group 4 methods. As a result, our assumption of a 3:1 increase in source coding efficiency for fax by 2010 seems reasonable.

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13 Patrick P. Gelsinger, Paolo A. Gargini, Gherhard H. Parker, and Albert Y.C. Yin, "Microprocessors circa 2000", IEEE Spectrum, pp. 43-47, October 1989.

14 ITU-T Recommendation T.82, "Coded representation of picture and audio information: progressive bi-level image compression," 1994.

6.4.5.3 Haskell and Netravali[15] have quantified the compression efficiency versus complexity issue, by examining compression ratio in bits per Nyquist sample (pixel) in terms of relative complexity for video signals. Drawing from them, with the expected increase of roughly a factor of ten in complexity capability due to advances in microprocessor speed, improved compression ratios on the order of 5:1 should result in compressed data of 0.2 bits per pixel. While this level of compression is exciting, a more conservative estimate is used here: a 2:1 improvement over today's compression ratios, or roughly 0.25 bits/pel, should be achievable by the year 2010.

6.4.5.4 For slow video, MPEG-4 is in its early stages of development.[16] MPEG-4 should provide improved quality over H.263 with additional features, at a coded bit rate of 128 kbps. Importantly, MPEG-4 is the first video coding scheme to explicitly address wireless concerns; the requirements include constant bit rate and error resiliency. A 3:1 increase in slow video coding efficiency is indicated when we assume that MPEG-4 will be implemented by 2010.

6.4.5.5 The source content and compression capabilities of present day technology and expected gains in compression due to algorithmic advances and/or semiconductor technology gains are summarized in Appendix C of this report. These processing advances will allow more complicated, more efficient compression algorithms.

6.5 Modulation

6.5.1 Another method of improving improved spectrum efficiency is to increase the amount of information that the communication channel can support. A communication unit moving through an urban environment encounters severe multipath fading. As a result, there are serious limitations to the data rates that are achievable when compared to those in stationary point-to-point communications.

6.5.2 Figure 6 shows the modulation efficiency of some representative digital systems that have been marketed for land mobile communications.

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

16 "MPEG-4 Call for Proposals," ISO/IEC JTC1/SC29/WG11 submission N0997, 28 July 1995.

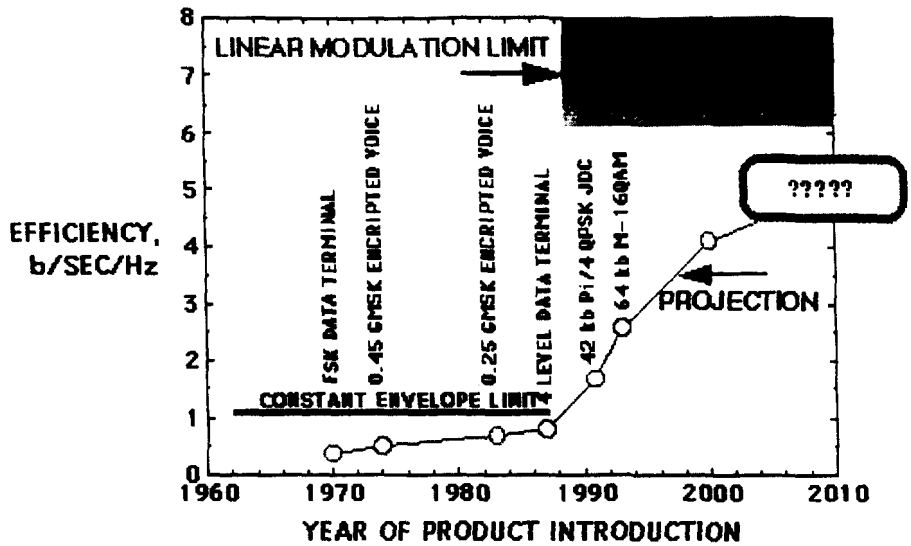

Figure 6 Modulation efficiency

6.5.3 Linear

6.5.3.1 Single sideband (SSB) modulation forms a basis for newer linear modulation techniques due to SSB's narrow-bandwidth properties; with standard SSB, the RF occupied bandwidth is identical to that of the information bandwidth. In addition to its spectrum efficient properties, SSB is a waveform preserving system, with the information waveform simply translated to an RF frequency, without the requirement for information source digitization and source coding. This makes SSB suitable for a wide range of information signals.

6.5.3.2 One common challenge of using SSB is its susceptibility to fading encountered in land mobile radio environments. Newly developed techniques are variations on traditional SSB that provide resistance to this fading. Many of these methods have been known for some time, but have only recently become economical to implement because of declining costs in digital signal processing technology.

6.5.3.3 Among the techniques used by current manufacturers of linear modulation technologies is Transparent Tone In Band (TTIB), which applies corrections to the received signal as necessary to produce known pilot tone characteristics, and thus correct the accompanying information signal. Fast Forward Signal Regeneration (FFSR) is also used for improving the performance of TTIB. A new TTIB linear modulation product now undergoing FCC type acceptance can send 14.4 kbps in a single 5 kHz channel, for a spectrum efficiency of 2.88 bits/sec/Hz. Tone Above Band (TAB) performs similarly, but with the pilot tone placed above the information signal instead of at its center.

6.5.3.4 A newly developed SSB technology is Real Zero Single Sideband (RZ SSB), which obtains information from zero crossings of the received signal, making